January 9, 1999

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judge Peter B. Bloch

In the Matter of	
HYDRO RESOURCES, INC.	
2929 Coors Road Suite 101 Albuquerque, NM 87120	Docket No. 40-8968-ML ASLBP No. 95-706-01-ML

WRITTEN TESTIMONY OF DR. WILLIAM P. STAUB

On behalf of Eastern Navajo Diné Against Uranium Mining ("ENDAUM") and Southwest Research and Information Center ("SRIC"), Dr. William P. Staub submits the following testimony regarding the amended application of Hydro Resources Inc. ("HRI") for a source materials license to conduct in situ leach ("ISL") uranium mining at three proposed sites in McKinley County, New Mexico.

Q.1. Please state your name and qualifications.

A.1. My name is William P. Staub. I completed a Ph .D. in geotechnical engineering at Iowa State University in 1969. I taught engineering geology and applied geophysics at the University of Tennessee from 1969 to 1977. After I left the University of Tennessee, I was with the Environmental Analysis and Assessment Section, Energy Division, of Oak Ridge National Laboratory from 1977 until I retired in 1996. My

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experiences included ground water impact analysis, liquid and solid waste management, and seismic hazard analysis. During my employment at Oak Ridge National Laboratory, I worked on many uranium mill tailings and uranium ISL mining projects under contract to the U.S. Nuclear Regulatory Commission ("NRC"). For instance, I co-authored, with Dr. John Nelson and his associates at Colorado State University, several NRC research reports (called "NUREGS") that addressed issues associated with the long-term stabilization of uranium mill tailings, including tailings dewatering, erosion control, and cover design for reduction of radon releases to the atmosphere. In this regard, I am the author of "Oversizing Riprap for Protection of Uranium Mill Tailings," published by the Association of Engineering Geologists in 1990.

Of particular relevance to uranium ISL mining in general and the HRI application specifically, I was the senior author of a report that remains one of a few in-depth evaluations of groundwater protection issues at uranium solution mines. This report, entitled "An Analysis of Excursions at In Situ Uranium Mines in Wyoming and Texas" (NUREG/CR-3967, July 1986), analyzed excursions at seven ISL mines in Wyoming and one in Texas during the late-1970s and early-1980s when much of uranium ISL mining was still in a demonstration phase. The general objectives of the study were to evaluate the hydrogeologic factors that control excursions and to develop hydrogeological evaluation guidelines that should be followed in order to achieve a thorough understanding of the hydrogeologic characteristics at current and future ISL mining sites. Many of the principles that my colleagues and I developed and discussed in that report

are still applicable today, and especially relevant to the HRI proposal.

In my capacity as an Oak Ridge scientist and consultant to NRC, I also participated in the preparation of environmental impact statements on the Wyoming Mineral Corporation Irigaray Project (1978), the Exxon Highland Project (1978), and the Bison Basin project (1981), all of which were proposed uranium solution mines. I also prepared and presented a paper on excursion control at uranium in situ leach mines at a waste management conference at Colorado State University in 1987.

My most recent experience in the uranium ISL field was in 1994 when I served on an Oak Ridge team that evaluated soil, vegetation, surface water, and groundwater impacts of land application of wastewater in preparation of an environmental assessment for the NRC of the proposed Reno Creek uranium solution mine in Wyoming. This work allowed me to become familiar with the concerns of the Wyoming Department of Environmental Quality ("WDEQ") about bioaccumulation and plant-animal uptake of selenium from land application of uranium ISL wastewater.

Further details of my education and experience are included in my resume, which is attached hereto as **Exhibit A**.

Q.2. What is the purpose of your testimony?

A.2. I have been retained by ENDAUM and SRIC as a technical expert in the field of uranium in situ leach mining in the matter of the licensing proceeding for HRI's application for a source and byproducts materials license for the Crownpoint Uranium Project ("CUP"). The purpose of this testimony is to set forth my professional opinion

on the adequacy of HRI's plans to protect and restore groundwater and drinking water supplies.

Summarized, my professional opinion is that HRI's license application ignores recent ISL excursion experience that has direct relevancy to HRI's plan to protect the high-quality ground water in the Westwater Canyon Aquifer, fails to consider factors that could lead to a loss of control of lixiviant in the mining zones, and ignores past and current restoration performance by asserting exaggerated and unsubstantiated restoration time frames. Given these deficiencies in the application, I do not believe there was an adequate basis for the NRC Staff's decision to issue Source Materials License SUA-1508 to HRI on January 5, 1998. Furthermore, based on my review of the HRI application, the NRC Staff's environmental and safety documents, excursion and restoration data for uranium ISL projects in Wyoming and Texas, and on the considerable experience I have in evaluating uranium solution mines, I conclude that HRI's proposed uranium mines will endanger the groundwater and drinking water supplies of Crownpoint and surrounding Navajo communities in northwestern New Mexico, and as such, threatens the public health and safety.

Q.3. What materials have you reviewed to prepare your testimony? Also, please indicate any activities you've undertaken to prepare this testimony.

A.3. I have reviewed the following documents:

COGEMA Mining, Inc., 1998. "Annual Report, WDEQ Permit to Mine No. 478, Irigaray and Christensen Ranch Projects, August 19, 1997 – August 18, 1998" (August 1998).

Deutsch, W.J., Martin, W.J., Eary, L.E., Serne, R.J., 1985. "Methods of Minimizing Groundwater Contamination From In Situ Leach Uranium Mining," Prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, NUREG/CR-3709 (March).

Dillinger, J.K., 1990. "Geologic and Structure Contour Maps of the Gallup 30° x 60° Quadrangle, McKinley County, New Mexico, U.S. Geological Survey Map I 2009.

Geraghty & Miller, Inc.,1993. "Analysis o odynamic Control, HRI, Inc. Crownpoint and Churchrock New Mexico Ur. .n Mines." Prepared for HRI, Inc., by Geraghty & Miller (Corpus Christi, Tex.) (October 7) (**ACN 9312160178**).

Harshman, E.N. "Distribution of Elements in Some Roll-type Uranium Deposits," International Atomic Energy Agency (Vienna, Austria), IAEA-SM-183/4, 169-183 (date unknown).

Hilpert, L.S., 1969. "Uranium Resources of Northwestern New Mexico," U.S. Geological Survey Professional Paper 603, U.S. Government Printing Office (Washington, DC).

HRI, 1993a. Church Rock Revised Environmental Report (March), transmitted by letter from M.S. Pelizza, HRI, to R. Hall, NRC (March 16) (**ACN 934130415**).

HRI, 1993b. Memorandum from M.S. Pelizza, HRI, to attached distribution list, transmitting "Replacement Pages to the Churchrock Project Revised Environmental Report, March 1993" (October 11) (**ACN 9312140083**).

HRI, 1996a. Letter from M. Pelizza, HRI, to J. Holonich, NRC (April 1), transmitting response to NRC Request for Additional Information #52, "Achievement of Restoration After Four Pore Volumes" (**ACN 9604030208**).

HRI, 1996b. Letter from M. Pelizza, HRI, to J. Holonich, NRC (April 1), transmitting HRI response to NRC Request for Additional Information #92, Cost/Benefit Analysis (**ACN 9604260063**).

HRI, 1997a. Letter from M.S. Pelizza, HRI, to J.D. Walker, USEPA Region IX Ground Water Office, concerning "Notice of Deficiency-Operating Area #1" and transmitting responses to EPA requests for additional information (February 4).

HRI, 1997b. "Crownpoint Uranium Project Consolidated Operations Plan, Revision 2.0," HRI, Inc. (Albuquerque, N.M.) (August 15) (**ACN 9708210179**).

HRI, 1998. Letter from M.S. Pelizza, HRI, to B. Carlson, NRC Staff, concerning "New Mexico Environmental Law Center Information Request" (October 16).

Kirk, A.R., and Condon, S.M., 1995. "Structural Control of Sedimentation Patterns and the Distribution of Uranium Deposits in the Westwater Canyon Member of the Morrison Formation, Northwestern New Mexico, A Subsurface Study," in *A Basin Analysis Case Study: The Morrison Formation, Grants Uranium Region, New Mexico*, edited by C.E. Turner-Peterson, E.S. Santos, and N.S. Fishman, published by Energy Minerals Division, American Association of Petroleum Geologists (Tulsa, Okla.), 105-143.

McCarn, D.W., 1997. "The Crownpoint and Churchrock Uranium Deposits, San Juan Basin, New Mexico: An ISL Mining Perspective," International Atomic Energy Agency (Vienna, Austria), Technical Committee Meeting on Recent Developments in Uranium Resources, Production and Demand — 1997 (June 10-13).

Peterson, R.J., 1979. "Geology of Pre-Dakota Uranium Geochemical Cell, Section 13, T16N, R17W, Church Rock Area, McKinley County," in *Geology and Mineral Technology of the Grants Uranium Region, 1979*, New Mexico Bureau of Mines and Mineral Resources (Socorro, N.M.) Memoir 38, 131-138.

Phelps, W.T., Zech, R.S., and Huffman, A.C., 1995. "Seismic Studies in the Church Rock Uranium District, Southwest San Juan Basin, New Mexico," in *A Basin Analysis Case Study: The Morrison Formation, Grants Uranium Region, New Mexico*, edited by C.E. Turner-Peterson, E.S. Santos, and N.S. Fishman, published by Energy Minerals Division, American Association of Petroleum Geologists (Tulsa, Okla.), 145-159.

Power Resources, Inc., 1991a. "Section 21, 20- and 30-Sand Mine Units Ground Water Restoration Plan," transmitted by letter from P.R. Hildenbrand, PRI, to R.E. Hall, NRC (February 6); NRC Docket No. 40-8857, License No. SUA-1511.

Power Resources, Inc., 1991b. Letter from B. Kearney, PRI, to B. Hogg, Land Quality Division, WDEQ (October 18); Wyoming Department of Environmental Quality ("WDEQ") Permit to Mine No. 603.

Power Resources, Inc., 1994. Letter from W.F. Kearney, PRI, to B. Hogg, Land Quality Division, WDEQ (September 14); WDEQ Permit to Mine No. 603-A2.

Power Resources, Inc., 1996. Letter from P.R. Hildenbrand, PRI, to G. Cash, Land Quality Division, WDEQ (August 6), transmitting quarterly monitoring report for period ending June 30, 1996.

Power Resources, Inc., 1997. "WDEQ Annual Report for Permit 603, Highland Uranium Project," transmitted by letter from P.R. Hildenbrand, PRI, to G. Cash, Land Quality Division, WDEQ (September 12).

Power Resources, Inc., 1998. Letter from P.R. Hildenbrand, PRI, to G. Cash, Land Quality Division, WDEQ (October 14), transmitting monthly excursion report for September 1998.

Rio Algom Mining Corp., 1998. "Annual Report, Permit to Mine #633," for Smith Ranch facility, transmitted by letter from W.P. Goranson (Rio Algom) to R.A. Chancellor, Land Quality Division, WDEQ (June 17).

Robertson, J.F., 1986. "Geologic Map of the Crownpoint Quadrangle, McKinley County, New Mexico," U.S. Geological Survey Geologic Quadrangle Map GQ-1596, scale 1:24,000.

Staub, W.P., Hinkle, N.E., Williams, R.E., Anastasi, F., Osiensky, J., and Rogness, D., 1986. "An Analysis of Excursions at Selected In Situ Uranium Mines in Wyoming and Texas," Oak Ridge National Laboratory (Oak Ridge, Tenn.), prepared for U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, NUREG/CR-3967 (July).

TNRCC, 1998. Table of Excursion Experience at Uranium ISL Mines in Texas, prepared by J. Santos, Texas Natural Resource Conservation Commission, Underground Injection Control Program (Austin, Tex.) (December 10).

URI, Inc., 1992. Letter from L.A. Canales,URI, Inc., to D. Kohler, Texas Water Commission, concerning "Excursion on monitor well 18" (April 3).

URI, Inc., 1998. Letter from M.S. Pelizza, URI, Inc., to J. Santos, Texas Natural Resource Conservation Commission, concerning "MW-49a & MW-172 Status Report" (September 18).

U.S. Nuclear Regulatory Commission, 1978. "Final Environmental Statement Related to Operation of Highland Uranium Solution Mining Project, Exxon Minerals Company," U.S. Nuclear Regulatory Commission, NUREG-0489.

U.S. Nuclear Regulatory Commission, 1988. "Environmental Assessment by the Uranium Recovery Field Office in Consideration of the Release of Source Material License No. SUA-1479 for Mobil Oil Corporation, Crownpoint, Section 9, In Situ Pilot Test Project, McKinley County, New Mexico," NRC, Docket No. 40-8911 (February 4)

(**ACN 8802230437**).

U.S. Nuclear Regulatory Commission, 1994. "Draft Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico," NRC, NUREG-1508 (October).

U.S. Nuclear Regulatory Commission, 1997a. "Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico," NRC, NUREG-1508 (February) (**ACN 9703200270**).

U.S. Nuclear Regulatory Commission, 1997b. Letter from J. Holonich, NRC, to R. Clement, HRI, transmitting Request for Additional Information No. 99 and NRC Staff comments on HRI responses to previous RAIs, including RAI No. 98, Effect of Mine Tunnels at Church Rock site (April 1) (**ACN 9704040271**).

U.S. Nuclear Regulatory Commission, 1997c. "Draft Standard Review Plan for *In Situ* Leach Uranium Extraction License Applications," NUREG-1569 (October).

U.S. Nuclear Regulatory Commission, 1997d. "Safety Evaluation Report, Hydro Resources, Incorporated, License Application for Crownpoint Uranium Solution Mining Project, McKinley County, New Mexico," NRC Docket No. 40-8968 (December) (**ACN 9712310298**).

U.S. Nuclear Regulatory Commission, 1998a. Letter from J.J. Holonich, NRC Staff, to R.F. Clement, HRI (January 5), transmitting copy of NRC Source Materials License No. SUA-1508 (**ACN 9801160066**).

U.S. Nuclear Regulatory Commission, 1998b. "Environmental Assessment for Renewal of Source Material License No. SUA-1341, Cogema Mining, Inc., Irigaray and Christensen Ranch Projects, Campbell and Johnson Counties, Wyoming," NRC Docket No. 40-8502 (June), transmitted by letter from J.J. Holonich, NRC, to D.L. Wichers, Cogema (June 30) (**ACN 9807100178**).

U.S. Nuclear Regulatory Commission, 1998c. Letter from M.A. Young, NRC Counsel, to J. Matanich, ENDAUM-SRIC Counsel (November 13), transmitting responses to ENDAUM-SRIC request for additional documents related to groundwater issues in the HRI license application.

Wallace, M.G. Affidavits dated January 13, 1998; March 4, 1998; September 1, 1998; and December 19, 1998, in support of pleadings of Intervenors ENDAUM and SRIC in ASLBP No. 95-706-01-ML.

HRI's license "application" is voluminous, consisting of tens of thousands of pages of environmental and technical reports, and revisions thereto, dating back some 10 years. I have reviewed many of its major components, including HRI's 1997 Consolidated Operations Plan (Revision 2.0), the NRC's draft and final Environmental Impact Statements ("DEIS" [1994] and "FEIS" [1997], respectively) and Safety Evaluation Report (1997), the hydrologic sections of the applicant's Church Rock, Unit 1 and Crownpoint environmental reports, and several of HRI's responses to the NRC Staff's requests for additional information on water resource issues. I have also reviewed ENDAUM's and SRIC's previous pleadings on water issues, including the affidavits of Dr. Richard Abitz and Mr. Michael Wallace given on behalf of ENDAUM and SRIC, and had numerous conversations in person and by telephone with Dr. Abitz and Mr. Wallace.

Finally, in advance of preparing this testimony, I visited the proposed HRI mining sites in New Mexico and the surrounding Navajo communities, traveled to Cheyenne, Wyoming, to review permit files for uranium ISL mines at the office of the Wyoming Department of Environmental Quality ("WDEQ"), and conducted about eight hours of interviews over several occasions with four WDEQ officials who are involved in regulating ISL mining in Wyoming: Roberta Hoy, Steve Ingle, Robert Licht, and Glen Mooney.

Q.4. Please summarize the early history of uranium ISL mining in the U.S., and particularly the findings of your 1986 report for the NRC.

A.4. Uranium solution mining was principally in a research and development phase

beginning in the mid-1970s and extending into the early 1980s. Most of the ISL projects I evaluated in my 1986 report for the NRC were demonstration or pilot-scale. My team examined documentation for seven projects in Wyoming and one in Texas, and wrote case histories for each. We summarized major characteristics of these projects, including the lixiviants used and the number of wells reported on excursion. Those data appeared in Table A.1. of the report (at A-5); I have attached a copy of that table, and other relevant portions of my report, as **Exhibit B** to this testimony.

Based on the case studies, we summarized hydrologic issues common to the projects reviewed. Those issues included hydrogeologic settings, aquifer properties, aquifer testing and modeling, and limitations observed in characterizing the groundwater regimes at the sites; history of horizontal and vertical excursions and their causes and consequences; shortcomings of methods used to detect excursions; and selection of excursion indicators. We noted that groundwater contamination was evident outside the mining zones at several pilot-scale and early commercial ISL operations, and warned that, without early detection and timely corrective action, "a large quantity of valuable production fluid may be irretrievably lost and serious contamination of adjacent groundwater resources may result." (Staub, et. al., 1986, at 27.) We concluded that horizontal excursions could be controlled with the then-current excursion detection mechanisms, proper wellfield management, and appropriate restoration. However, all of the sites studied were in remote areas where there were no nearby municipal water supplies at risk. Therefore, the thinking among the professionals who worked on the

study was that there would be sufficient time to rectify any mistakes that were made in excursion control. The team also concluded that aquifers contaminated through vertical excursions would pose the greatest restoration difficulties. And finally, while we concluded that some pilot-scale restoration efforts were successful, those efforts were at sites located in remote areas where public drinking water supplies were not at risk at any time in the foreseeable future. Of the eight sites we studied, none were completely analogous to the unique conditions present at Crownpoint, New Mexico.

Q.5. You indicated that you recently reviewed permitting and monitoring documentation for currently operating ISL mines in Wyoming and Texas. Please summarize your findings with respect to recent excursion experience and restoration performance at the mines you've reviewed.

A.5. I reviewed the most recent mine permit reports for three Wyoming ISL operations (COGEMA Mining, Inc., Christensen Ranch-Irigaray Project; Power Resources Inc. ["PRI"], Highland Project; and Rio Algom Mining, Inc., Bill Smith Ranch Project), including water quality monitoring data, and certain permit and monitoring records for two ISL operations in South Texas, Kingsville Dome and Rosita, both of which are operated by HRI's parent company, Uranium Resources, Inc. ("URI"). Based on that review, I have summarized recent excursion and restoration performance at certain of these operations in the following sections of this testimony.

a. Excursions are ongoing at several operating, commercial-scale uranium ISL mines in the U.S.

Our 1986 report for the NRC defined an excursion as "an uncontrolled migration

of lixiviant and its associated dissolution products and by-products away from controlled areas (production wellfields) of in situ mining ore zones." (Id.) Excursions of lixiviant, or mining solutions, are detected in monitor wells located outside of the mining zones, often at the perimeter of the mine permit area, when one or more "indicator" chemicals exceed their "upper control limits" in water in a well. A monitor well "on excursion," therefore, means that mining fluids have not only left the mining zone, but also may have reached a point at or close to the facility property boundary such that they threaten contamination of off-site groundwater.

That being the case, off-site groundwater is at increased risk of contamination because of ongoing excursions at several operating, commercial-scale uranium ISL projects in the U.S., including URI's Kingsville Dome facility, in Kleberg County, Texas. I have summarized current excursion experience at ISL sites in Wyoming and Texas in the following four tables. These lists of monitor wells on excursion do not represent the universe of ongoing excursions at ISL sites, only a sampling of the data available to me.

(i) Current excursion experience in Wyoming.

Seventeen wells are or recently were on excursion status at two operating commercial ISL sites in Wyoming. Table 1 provides a listing of monitoring wells currently or recently on excursion status at COGEMA Mining Inc.'s Irigaray and Christensen Ranch mines in Wyoming. These data are taken from COGEMA's most recent annual report to WDEQ (COGEMA, 1998), relevant portions of which are attached to this testimony as **Exhibit C.** According to data derived from the NRC's

recent environmental assessment for COGEMA's license renewal (USNRC, 1998b, at 58-64; attached in relevant part hereto as **Exhibit D**), some of the listed wells were on and off excursion status at various times in the late 1980s and early 1990s. Additionally, 20 other wells at the Irigaray and Christensen Ranch facilities were on and off excursion status at various intervals in the late 1980s to early 1990s. (Id.).

Table 1. Partial list of monitor wells recently or currently on excursion status at COGEMA Mining's Irigaray and Christensen Ranch ISL mines in Wyoming.

Site	Stage of Development	Well ID	Excursion Initiation	Excursion Termination
Irigaray Ranch	Restoration	SSM3 Unit 2	08/30/96	Ongoing
Irigaray	Restoration	SSM18 Unit 8	09/13/96	Ongoing
Irigaray	Restoration	SSM40 Unit 8	08/16/96	Ongoing
Irigaray	Restoration	SSM42 Unit 3	10/10/90	Ongoing
Irigaray	Restoration	SSM43 Unit 1	10/11/89	Ongoing
Irigaray	Restoration	DM10 Unit 6	02/02/94	Ongoing
Irigaray	Restoration	SSM41 Unit 4	09/12/97	03/04/98
Christensen R.	Production	MW89 Unit 2	08/07/98	Ongoing
Christensen	Production	MW46 Unit 6	03/02/98	04/01/98

Table 2 is a partial listing of monitoring wells currently or recently on excursion status at PRI's Highland Project in Wyoming. These data were compiled from PRI's 1997 annual report to WDEQ (PRI, 1997; attached hereto in relevant part as **Exhibit E**) and from PRI letters to WDEQ dated February 7, 1991; September 14, 1994; August 6, 1996; and October 14, 1998, all of which are attached to this testimony as **Exhibits F, G,**

H, and **I**.[1]

Table 2. Partial list of monitor wells recently or currently on excursion status at Power Resources Inc. Highland Uranium Project, Wyoming.

Stage	Well	Initiation	Termination
Restoration	M-8A	Before 10/96	??/98
Restoration	M-10A	01/25/95	Ongoing
Restoration	M-11	11/19/92	Ongoing
Restoration	B-56	11/22/96	Ongoing
Restoration	B-62	Before 10/96	Ongoing
Restoration	B-63	Before 10/96	??/98
Restoration	B-43	02/12/98	04/98
Production	CM-15	09/09/94	03/95

Tables 3 and 4 provide listings of monitoring wells currently or recently on excursion status at ISL mines in Texas. These listings were compiled from agency files and databases summarized and provided by geologist John Santos with the Underground Injection Control program of the Texas Natural Resource Conservation Commission ("TNRCC") in Austin. Mr. Santos's spreadsheets from which these data were taken are attached to this testimony as **Exhibit J**. Table 3 contains the excursion record summary for URI's Kingsville Dome mine and Table 4 contains the excursion record of other ISL projects in Texas.

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[1] PRI's excursion history file at WDEQ contains 16 volumes of excursion data that are too numerous to recount.

Table 3. List of monitoring wells currently (as of 12/10/98) or recently on excursion status at URI's Kingsville Dome mine, Kleberg County,Texas.

Company	Mine	Well	Initiation	Termination
URI	Kingsvl' Dome	A10	07/17/96	12/31/96
URI	Kingsvl' Dome	D2	07/12/96	08/31/96
URI	Kingsvl' Dome	D9	07/12/96	08/31/96
URI	Kingsvl' Dome	D15	08/24/88	09/08/88
URI	Kingsvl' Dome	D15	07/12/96	08/31/96
URI	Kingsvl' Dome	D16	08/24/88	05/03/89
URI	Kingsvl' Dome	D39	07/18/96	08/31/96
URI	Kingsvl' Dome	D45	10/14/96	10/28/96
URI	Kingsvl' Dome	D47	01/14/98	01/28/98
URI	Kingsvl' Dome	MW7	02/17/92	03/02/92
URI	Kingsvl' Dome	MW8	11/13/98	Ongoing
URI	Kingsvl' Dome	MW49A	05/01/98	Ongoing
URI	Kingsvl' Dome	MW172	07/22/98	Ongoing

Table 4. List of monitoring wells currently (as of 12/10/98) or recently on excursion status at various ISL sites in Texas.

Company	Mine	# of wells	Earliest	Most recent
Cogema	El Mesquite	9 (3 current)	06/30/94	07/10/98
Cogema	Holiday	3 (3 current)	08/31/94	02/17/98
Cogema	O'Hern	6 (1 current)	10/06/94	02/20/97
Cogema	West Cole	4 (2 current)	12/31/94	08/13/98
Everest	Tex-1	1 (0 current)	07/16/93 (on)	11/10/93 (off)
Intercontinental	Lamprecht	2 (0 current)	04/30/93 (on)	11/30/93 (off)
Intercontinental	Zamzow	6 (? Current)	11/18/92	05/03/94
USX	Burns "A"	3 (0 current)	05/16/96 (on)	06/18/96 (off)
USX	Burns "B"	1 (0 current)	05/12/96 (on)	08/03/96 (off)
USX	Clay West	2 (0 current)	03/31/96 (on)	05/01/97 (off)
USX	Moser "A"	4 (0 current)	04/30/96 (on)	10/01/98 (off)
USX	Moser "C"	3 (0 current)	04/30/93 (on)	01/22/97 (off)
USX	Pawlik	1 (0 current)	04/30/95 (on)	05/31/95 (off)

(ii) Causes and consequences of excursions.

The causes and consequences of some of these excursions are worth examining for the lessons they teach about the importance of understanding the subsurface environment *prior* to lixiviant injection.

For example, a vertical excursion into an underlying aquifer discovered in 1996 in A-Wellfield of PRI's Highland Uranium Project was caused by an undetected "hole in the intervening aquitard," according to PRI's 1997 annual report to WDEQ (PRI 1997 at 6-7) (see, also **Exhibit E**). The ancient buried stream channel that eroded through the aquitard separating two aquifers at the site was discovered soon after A-Wellfield went into production. The monitor well that went on excursion status was intended to monitor for horizontal excursions from a deeper wellfield that had not yet been placed in production. Eventually, PRI recognized the problem and began taking corrective action. By that time, a considerable amount of lixiviant had escaped into the underlying aquifer. Subsequent restoration efforts were complicated because pumping of groundwater sweep fluids from the lower mine zone contributed to drawing contaminated fluids from the upper mine zone through the aquitard hole. (Id., at 7.)

Also, PRI apparently did not anticipate drawing contaminated fluids from adjacent underground uranium mine workings into B-Wellfield during restoration. This "encroachment" of fluids from the abandoned mine workings "caused" three monitor wells "to reach excursion status" in early 1996 (Id., at 14.) Those three wells were still on excursion status in September 1998. (PRI, 1998, at 2-3; attached as **Exhibit I**.)

In Texas, two monitor wells on excursion at URI's Kingsville Dome facility as late as mid-October are located at the edge of PAA-2 ("Production Area Authorization"). (URI, 1998; attached in relevant part to this testimony as **Exhibit K**.) URI reported that the cause of mine solutions in those wells "is the close nature of the monitor wells to the injection wells. . ." (Id., at 2.)

b. Restoration is taking longer than originally estimated at several ISL sites in Wyoming and Texas.

Restoration performance at COGEMA's Christensen Ranch-Irigaray Project and PRI's Highland Project, both in Wyoming, are summarized in Table 5 below.

Uranium was produced from A-Wellfield and B-Wellfield at the Highland Project from January 1987 to July 1991. The ensuing restoration efforts were modeled after a successful pilot-scale restoration project that was completed in 1986. As shown in Table 5, PRI began restoration activities in both of these wellfields in July 1991. Restoration efforts were still ongoing at both wellfields through October 1998, or more than seven years after restoration had begun, and two full years behind PRI's revised projected restoration schedule filed with WDEQ in February 1991. (PRI 1991, Figure 2.2.1; attached hereto as **Exhibit F**.) PRI attributes slow restoration of the aquifer to the proximity of an abandoned underground mine operated in the 1970s by Exxon. (PRI, 1997, at 6, 1; attached as **Exhibit E**.) The large cone of depression in this wellfield has drawn contaminated water from the abandoned mine into B-Wellfield. In so doing, monitor wells, screened in the ore zone aquifer, have gone on excursion status.

Table 5. Restoration Performance at Selected Uranium ISL Mines in Wyoming

Project/ selected wellfields	Restoration period start-current status (yrs.)	Cum. pvs to date (method)	Conductivity (μmhos/cm) restor. goals	Conductivity (μmhos/cm) most recent sample
Christensen Ranch Mine				
Mine Unit 2	04/97-7/98* (1.3 yrs)	1.8-gws	≈700	3686
Mine Unit 3	11/96-7/98* (1.8 yrs)	1.84-gws	≈600	4015
Mine Unit 4	08/97-7/98* (1.0 yr)	1.93-gws	≈600	3401
Irigaray Mine:				
Units 1-3	unk.- "complete" 1993	unknown	unknown	unknown
Units 4-5	04/95-ongoing, 7/98 (3.3 yrs)	9.22-RO	≈750	816
Units 6-9	04/95-ongoing, 7/98 (3.3 yrs)	1.28-RO	≈750	1648
Highland:		thru 7/97:		
A-Wellfield	07/91-ongoing, 10/98 (7.3 yr)	21.0-RO	525	471
B-Wellfield	07/91-ongoing, 10/98 (7.3 yr)	3.6-RO	574	1365
C-Wellfield	07/97-10/98 trial (1.3 yr)	unknown	721	2343

gws = groundwater sweep
pvs = pore volumes
RO = reverse osmosis treatment-reinjection

*COGEMA Mining, Inc., the Christensen Ranch-Irigaray operator, reported that all groundwater sweep operations at Christensen Ranch were "terminated" in July 1998 "when COGEMA ceased all surface discharge activities. COGEMA's NPDES [National Pollutant Discharge Elimination System] permit for the discharge of restoration wastewater was reissued on July 31, 1998, with a new selenium limit of 0.05 mg/l. As COGEMA is not able to meet this limit through conventional water treatment methods, the discharge of restoration solutions stopped on July 31. . . .[T]he other wastewater disposal systems such as the disposal well and evaporation ponds are not capable of handling the additional volumes of groundwater sweep solutions. . ." (COGEMA 1998, at 7.) My interpretion of this statement is that COGEMA has suspended restoration until new disposal capacity is permitted and installed.

The principal consequence of the hydrologic difficulties at the Highland Project (i.e., the hole in the aquitard and the negative influence of the adjacent underground mine workings) has been that restoration of A-Wellfield and B-Wellfield is taking considerably longer than the original estimate of two years. (USNRC, 1978.) Restoration of C-Wellfield, which went into production in 1989, was expected to begin in late-1997 or early-1998. (PRI, 1997, at 19; attached as **Exhibit E**.) Accordingly, restoration schedules are beginning to stack up on one another.

At COGEMA's Irigaray Project, restoration of Units 4-5 and 6-9 is now in its fourth year. Restoration of three wellfields at COGEMA's Christensen Ranch mine had been going on for one to two years when restoration activities there were "terminated" on July 31, 1998, due to a lack of disposal capacity. (COGEMA, 1998, at 7-8; attached as **Exhibit C**.)

Achieving restoration goals at these wellfields also has proven difficult. As shown in Table 5, and in more detail in Table 3-1 of PRI's 1997 annual report to WDEQ (included in **Exhibit E**), A-Wellfield had been restored to or below baseline averages for sulfate, chloride, TDS and conductivity, but has yet to achieve baseline averages for bicarbonate, selenium, uranium and radium-226. As of July 1997, the average uranium concentration was still 60 times baseline and radium-226 was nearly two times baseline.

B-Wellfield at Highland is nowhere near final restoration. All eight "Guideline 8" parameters were considerably greater than their corresponding baseline values. For example, the July 1997 radium-226 concentration of 1,060 pCi/l was more than 3 times

its corresponding baseline level of 313 pCi/l, and the July 1997 uranium concentration of 17.5 mg/L was 250 times higher than its corresponding baseline value of 0.07 mg/l. (See, **Exhibit E**, Table 3-2.)

The Mobil Oil Section 9 pilot-scale ISL project conducted 5.5 miles west of Crownpoint in 1979-1980 required restoration efforts for nearly six years. (USNRC, 1988, at 1-2 and Table 1; attached hereto as **Exhibit L**.) Even then, restoration to baseline was not achieved for 19 of 29 contaminants analyzed. (FEIS, Table 4.13 at 4-38.) The average "restored" radium-226 concentration of 59.9 picoCuries per liter ("pCi/l") was 4.2 times project baseline, and "restored" uranium was 31 times its baseline value. (Id.) (I will discuss in more detail implications of the Mobil Section 9 pilot summary later in this testimony.)

c. Greater effort has been required for restoration than anticipated.

The baseline groundwater quality at the Wyoming ISL sites is usually suitable for drinking water, except in some locations where baseline radium concentrations may exceed the federal and state drinking water standard of 5 pCi/l.[2] As demonstrated by restoration experience at the Highland Project, one would expect that more pore volumes of clean water would be required from a reverse osmosis ("R.O.") unit to reach the higher standards required to meet drinking water standards then, say, livestock water standards.

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[2] A concentration of radium-226 exceeding the federal drinking water standard of 5 pCi/l does not preclude the use of the well or the aquifer which it taps as a source of drinking water because radium-226, and even uranium, is amenable to treatment by reverse osmosis and barium chloride ion exchange.

Indeed, PRI reported in September 1997 that the total volume of groundwater treated during restoration of the A-Wellfield alone was 302 acre-feet, or 21 pore volumes.

In summary, based on the documentation I have reviewed for the Highland and Christensen Ranch projects, it is apparent that none of the commercial wellfields at those facilities have been restored, even though restoration began in 1991 for two of those wellfields. The WDEQ officials I interviewed in preparing this testimony asserted that no commercial wellfield at any uranium ISL facility has been successfully restored.[3]

Although site-specific conditions and experiences may differ, restoration in Texas is not as challenging as it is in Wyoming, or as it will be at Crownpoint and Church Rock. In every Texas restoration case cited by HRI, the baseline water quality was poor (see, HRI 1996a, Response to RAI No. 52); hence, the primary goal of restoring the mine production area to "average baseline" is a much less stringent standard in Texas than it is in Wyoming or will be in New Mexico. In Texas, groundwater in the shallow coastal plain aquifers is moderately saline, or brackish (TDS ≈ 2,000 mg/l to 5,000 mg/l), and therefore, marginal for stock water and irrigation uses and unsuitable for human consumption. (See, Table 6 below for more data.) In Texas, recycled "clean" water from reverse osmosis treatment is likely to be much higher quality than groundwater under

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[3] I should note here that Cogema asserts that restoration of Irigaray wellfields 1, 2 and 3 is complete. The NRC Staff, however, has noted that "the success of these restoration efforts has been controversial because although COGEMA believes that best practicable technology principles were applied, there continue [sic] to be excursions at some of the shallow and deep monitor wells, even though the wellfields have undergone, or are still undergoing restoration." USNRC, 1998b, at 3 and 51. COGEMA, 1998, at 6; attached hereto as **Exhibit C**.

baseline conditions. Therefore, groundwater treatment with reverse osmosis would be expected to be more efficient in Texas than in Wyoming.

As stated above, Texas wellfields should be relatively easy to restore because of poor baseline water quality. Nevertheless, restoration in Texas has not been all that easy. Most mined-out commercial wellfields in Texas were originally permitted for 24 months of restoration, but in most cases, amended permits exceeded that timeframe by several more years. According to summaries of Texas Natural Resource Conservation Commission permit documents (open-file data) that I reviewed, three wellfields at the Benavides Mine that were originally permitted in 1986[4] for restoration in 24 months were re-permitted for restoration ranging between 24 and 36 months in 1989.[5] Another 10 wellfields scheduled for restoration in 24 months actually required from 60 to 107 months for restoration.[6] In order to achieve restoration at these 10 sites, concentration limits for uranium were revised upward from a few tenths of a milligram per liter to between 3 mg/l and 5 mg/l. Other parameters were revised upward as well to facilitate restoration compliance. Four wellfields at URI's Rosita Mine had their restoration schedules revised downward from 15 months to 18 months in their original 1988 permits to six months

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[4] TNRCC Permits #UR-02312-011, -021, and -031 (1986).

[5] TNRCC 1989 Permits #UR-02312-011, -021, and 031 (1989).

[6] These facilities were: Longoria Mine, TNRCC Permit #s UR-02222-011 and 021 (1986); Zamzow Mine, TNRCC Permit #s UR-02108-011, -021, -031, and –041 (1978); and Lamprecht Mine, TNRCC Permit #s UR-01949-011, -021, -031, and –041 (1984).

Wellfield imbalances contributed to excursions at three pilot test sites in Wyoming in the late 1970's and early 1980's.[10] Two other Wyoming sites had unique situations that led to horizontal excursions. In one case, Nine-Mile Lake, the operator attempted to produce from and inject into two ore zones (one on top of the other) simultaneously. Although there was an overall bleed rate, the operator did not know how much lixiviant was being injected into each ore zone. The result was that one of the ore zones was overpressured while the other was underpressured. (Staub, et. al., 1986, at A-80.) In a second case (Collins Draw), the operator did not bleed the ore zone aquifer which led to significant excursions. (Id., at A-193.) In summary, an ore zone aquifer must be bled and a field-wide injection/production balance must be established to reduce the risk of excursions.

That HRI's hydrology consultants, Geraghty and Miller, assumed that the Westwater Canyon Aquifer has homogeneous, isotropic hydraulic properties (Geraghty & Miller, 1993, at 4-5) contradicts one of the principal findings of our 1986 analysis of excursions for the NRC — that "leaky" aquifer models should be used to interpret pump-test data and model groundwater flow when geologic heterogeneity is known or suspected. (Staub, et. al., 1986, at 21-22.) The heterogeneous characteristics of the Westwater in both the Church Rock and Crownpoint areas are well documented in the published literature. (See, e.g., Kirk and Condon, 1995; McCarn, 1997, Figure 8; and

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[10] These are documented in Staub et al (1986; at A-116, A-117 [for Highland Project]; at A-57, A-59 [for Bison Basin Project]; and A-31 [for Irigaray Mine]).

each in their final 1998 permits.[7] Amended restoration goals for these last four wellfields are not available.

Q.6. Please identify some of the key differences and similarities between the Wyoming and Texas mining sites and the proposed New Mexico sites.

A.6. There are several important differences and similarities between the Wyoming ISL mine sites and those proposed for solution mining by HRI in New Mexico. The baseline groundwater quality is one such difference, as I have shown in Table 6 below.

Table 6. Average baseline groundwater quality data[a] for selected uranium ISL mine sites in Texas, New Mexico, and Wyoming. (all concentrations in mg/l, except as noted)

Parameter	WMC-Bruni	URI-K'Dome	URI-Rosita	HRI-C'point	HRI-C'Rock	PRI Highland	WMC-Irigaray
	PA 1,2 1979	PAA2 2/13/90	PAA3 6/6/96	CP mws '90-'91	CR mws '88-'89	A-W.F. 7/91	WF-'E' 1980
Bicarbonate	175.0	297.0	161.0	203.0	246.0	215.0	90.0
Chloride	1090.0	224.0	952.0	15.8	6.0	4.0	12.0
Conductivity[b]		1662.0	4276.0	602.3	556.0	525.0	650.0
Sodium	413.0	323.0	751.0	127.7	130.0		120.0
Sulfate	142.0	224.0	496.0	62.2	37.0	91.0	
TDS	2312.0	1035.0	2524.0	394.0	370.0	330.0	
Radium[b]	129.0	92.0	87.3	58.7 (0.9[c])	10.0	675.0	
Uranium	0.300	1.890	0.586	0.005	1.800	0.050	0.030
Arsenic	0.020	0.006	0.068	0.000	0.003		
Selenium	0.050	0.008	0.120	0.000	0.001	<0.001	

[a]The data used to compile this table appear in **Exhibit M** attached hereto.
[b]Conductivity concentration in umhos/cm; radium concentration in pCi/l.
[c]This is the mean radium-226 value for all HRI Crownpoint monitor wells, except CP-2, which has water quality different from that in other Westwater Canyon wells.

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[7] TNRCC Permits UR-02880-011 (wellfields I and II), -031, and –041 (1998).

As demonstrated in Table 6, baseline groundwater quality at Crownpoint and Church Rock is similar to that at the Highland and Christensen Ranch facilities in Wyoming, with total dissolved solids ("TDS") concentrations ranging between 330 mg/l and 394 mg/L. In contrast, baseline water quality for total dissolved solids at the Texas sites is much poorer, ranging from 1,035 mg/l TDS to 2,524 mg/l TDS.

Radium-226 concentrations also differ considerably, ranging from 10 pCi/l at HRI's Church Rock site to 675 pCi/l at the Highland Project. The radium-226 concentration of 58.7 pCi/l at the Crownpoint mine site is based on anamolous data. As Dr. Abitz has indicated in his written testimony, the water quality in just one of eight Westwater Canyon monitor wells at the Crownpoint site is unlike that in any of the other Westwater wells. When the concentrations from that well, CP-2, are included in the database, the results are skewed upward. When data from that well are removed from the analysis, the mean radium-226 concentration becomes 0.9 pCi/l, or roughly that in the Town of Crownpoint's municipal water wells. (See, FEIS, Table 3.12 at 3-26.) This analysis indicates to me that the overall quality of the groundwater at the proposed New Nexico mining sites is better than the water quality at virtually any other ISL mine.

By comparison, baseline radium-226 concentrations in the aquifers in and around the Wyoming sites render the water unsafe for human consumption without treatment to reduce radium concentrations below the federal drinking water standard of 5 pCi/l. Another major difference is that the Crownpoint and Unit 1 projects are within 0.5 miles to 2.5 miles of a currently used municipal water supply that serves thousands of people in

Crownpoint and surrounding Navajo communities (FEIS at 3-22 through 3-31), and water quality in the Westwater Canyon Aquifer near the Church Rock site is suitable for domestic uses, including for drinking water supplies (FEIS at 3-31 through 3-40).

The size and scope of the operations, the hydrogeology, and the land uses (ranching in a semi-arid region) are similar. And like PRI's B-Wellfield, the proposed Church Rock mining area is adjacent to an abandoned underground mine, and, as Mr. Wallace's testimony demonstrates, is likely to experience some of the same lixiviant control and restoration problems now evident at the Highland Project.

Q.7. What is your evaluation of the risks to groundwater quality posed by excursions that may occur during HRI's project?

A.7. In my professional opinion, HRI's project poses an excessive risk to groundwater quality through excursion, in several respects.

a. Confinement of the Westwater from overlying and underlying aquifers has not been demonstrated adequately.

HRI and the NRC Staff have pointed to several factors that they believe demonstrate that the Westwater Canyon Member is confined from the overlying Dakota and underlying Cow Springs aquifers: Results of 1988 pump tests conducted in Section 8, water-level data indicating that the Dakota is overpressured relative to the Westwater, and results of groundwater modeling conducted by Geraghty and Miller for HRI in 1993. (See, e.g., FEIS at 3-35; HRI, 1993a, at 86-114, and Appendix E; Geraghty & Miller, 1993, at 4-5.) However, HRI and the NRC Staff do not appear to have addressed at least three other factors that suggest that confinement of the Westwater may be compromised,

thereby leading to an increased risk of excursions: (1) erosion channels and surfaces at the Dakota-Brushy Basin interface; (2) collapsed mine tunnels in the Dakota, Brushy Basin and Westwater formations; and (3) thinning of the underlying Recapture Shale under Section 8. Allow me to explain.

First, geologic maps of the Church Rock quadrangle (Dillinger, 1990) show that the Brushy Basin member of the Morrison Formation is completely eroded out within 5 miles of the proposed Church Rock site. Pre-Dakota river channels may have eroded down into the Westwater Canyon Member of the Morrison prior to deposition of the Dakota Sandstone — a condition called scouring that was identified in Staub, et. al. (at 22-24), as a common difficiency in the interpretation of geologic and hydrogeologic data at ISL sites. (See, also, **Exhibit B**.) Any contact of the Westwater with the Dakota, either through a "hole" or erosion surface in the intervening Brush Basin "B" Sand and "B" Clay, would provide a conduit for mining fluids to migrate out of the mine zones in the Westwater and into the overlying Dakota aquifer. (See, FEIS, Figure 3.7 at 3-19.) I do not believe that HRI has demonstrated adequately that relief on the Brushy Basin-Dakota erosion surface does not exceed the thickness of the relatively thin Brushy Basin member of the Morrison Formation.[8]

Second, HRI does not adequately address the effects of underground, abandoned mine tunnels in the upper part of the Westwater Canyon Formation or in the overlying

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[8] The Brushy Basin B Sand and B Clay are said to be only 13 feet to 28 feet and 16 feet to 32 feet thick, respectively, at the Church Rock site. (FEIS at 3-18.)

Brushy Basin sand unit and Dakota Sandstone in Section 17. Some of these tunnels may have collapsed, causing fractures to propogate through the overlying Brushy Basin member. Even though HRI knows the existence and extent of the mine tunnels in the Westwater, Brushy Basin and Dakota formations (see, HRI, 1993a, Figures 2.6-12 and 2.6-13, which are oversized maps of the underground mine workings in Section 17), HRI has not determined whether abandoned mine tunnels have collapsed in Section 17. The NRC Staff acknowledged in the FEIS (at 3-40) that "it is likely that many of the workings have collapsed because of the type of underground mining employed at the site . . ." As late as April 1997, after publication of the FEIS, the Staff was still expressing concern about the potential effects of the underground mine workings (see, USNRC 1997b, NRC Staff response to HRI response to RAI No. 98), but concurred with HRI's plan to closely monitor groundwater flows in the Brushy Basin and Dakota in order to detect fluid movement through the mine cavities in the two overlying formations. There are two "rules of thumb" about mine subsidence: (1) Strata that overlie collapsed tunnels may themselves collapse if they are located above the collapsed tunnel by less than six times the original thickness of the tunnel, and (2) fractures may extend upward a distance of 30 times the thickness of the collapsed tunnel. I do not believe that HRI or the NRC Staff has assessed the effect of mine tunnels against these rules.

Third, there is evidence that the underlying Recapture Shale intertongues with the underlying Cow Springs Sandstone such that the Westwater may be in contact with the Cow Springs under Section 8 at Church Rock. Hilpert (1969) discussed this

intertonguing relationship in the vicinity of the Church Rock site in a 1969 U.S. Geological Survey report for the old Atomic Energy Commission. His structural cross-section shows the Cow Springs Sandstone pinching out to the south against the Recapture siltstone. (Hilpert, 1969, at 79; attached in relevant part hereto as **Exhibit N**.) The Cow Springs thickens northward across T16N, R16W in the vicinity of what was the Old Church Rock Mine in Section 17 and what now is the HRI's proposed Section 17 and Section 8 ISL mines. As can be seen from Hilpert's cross-section through the Church Rock Mine site, a thin layer of mudstone lies between the tongue of Cow Springs and the overlying Westwater Canyon Member of the Morrison Formation. In at least one location Hilpert shows the intervening mudstone to be absent with the Westwater Canyon Member lying directly above the Cow Springs Sandstone with no intervening mudstone. This being the case, the tongue of the Cow Springs Sandstone should be monitored for vertical excursions at Church Rock.

b. Inadequacies of Groundwater Flow Modeling in HRI's Application.

HRI's application does not adequately explore all of the mechanisms that can lead to horizontal excursions at Church Rock, thereby creating additional risk of excursion. In particular, HRI appears to have overlooked a common cause of excursions at past and current ISL sites — unbalanced wellfield hydraulic conditions. Instead, HRI assumed that a 1 pecent production bleed rate would be maintained uniformly throughout each well field being mined. (See, e.g., FEIS at 2-7; Geraghty & Miller, 1993, at 4.) But bleed rates are, by definition, average rates of fluid withdrawal over the entire wellfield.

While it is theoretically possible that a bleed rate can be constant across the wellfield, it rarely has been accomplished in the commercial-scale uranium ISL mines with which I am familiar. As we noted in our 1986 excursion report,

> "[H]orizontal excursions can be expected because operating systems are occasionally upset, the ore zone aquifer is nonhomogeneous, and the ground-water system is subject to transient external influences. Thus, local imbalances in injection and production rates will occur despite the implementation of a field-wide bleed."

(Staub, et.al., 1986, at 29.)

The reasons for this are fairly simple. Injection and production rates are bound to vary over a wellfield covering dozens of acres and having hundreds of wells, as is the case with the HRI proposal. At this magnitude, the probability increases that some of those wells will experience pump failures, plugging of well screens from scale buildup, or other mechanical problems that will preclude optimum performance. When this happens, the hydrodynamic control of that portion of the wellfield is compromised, the negative pressure gradient (i.e., "cone of depression") is lost, and an excursion occurs. The chance of a wellfield imbalance also increases in geologically diverse formations having sand channels, stacked stratigraphy and other heterogeneous properties, which is the case with each of the proposed HRI mining sites.[9]

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[9] Some operators have learned the importance of maintaining wellfield hydraulic balance. "In order to balance flows and prevent migration of leaching fluids between. . .groups of [injection-production] patterns, pumping wells have to be operated in every pattern group." (PRI, 1997, at 14; attached as **Exhibit E**.)

Phelps, et. al., 1995; copies of which are attached hereto as **Exhibit O, Exhibit P,** and **Exhibit Q,** respectively). As such, Geraghty and Miller's homogeneity assumption was not conservative. Mr. Wallace's use of the Modified Hantush Method in his January 13, 1998, affidavit to analyze HRI's Crownpoint pump test data was appropriate given the site-specific hydrogeologic information and the proximity of the Crownpoint municipal water supply to the proposed Crownpoint ISL wellfields.

Q.8 What is your evaluation of HRI's proposed mining sequence at the Church Rock site?

A.8 HRI's proposed mining and restoration sequence does not make hydrologic sense and is likely to complicate restoration at the Church Rock site. Allow me explain.

First, let's examine Figure 1.4-8 in COP Revision 2.0 (HRI 1997b, at 22), which is a diagram of the mine plan for the Church Rock site that I have copied and attached to this testimony as **Exhibit R.** This diagram shows the Church Rock site having six wellfields, four located in Section 8 and two in Section 17. Mining and restoration would proceed sequentially, beginning first in Wellfield 1 in Section 8 and continuing northward through Wellfield 4 in Section 8. Mining and restoration would then follow in Wellfields 5 and 6 in Section 17, in that order. This mining sequence also is shown in bar-chart timelines in the COP Revision 2.0 (Figures 1.4-6 and 1.4-7, at 20-21), and I have included those timelines in **Exhibit R.**

Now, let's look at Figure 3.1-6 of HRI's Church Rock Revised Environmental Report (HRI 1993b), which is a 1993 version of the Church Rock mine plan that I have

copied and attached to this testimony as **Exhibit S**. This map clearly shows that Wellfield 1 and part of Wellfield 2 are located in Section 17 and that Wellfields 3, 4 and 5 are located progressively northward into Section 8. In this, the 1993 version of the mine plan, there is no Wellfield 6 as there is in the diagram in Revision 2.0 of the COP.[11] The consecutive numbering of the wellfields in the 1993 diagram indicates that mining would proceed sequentially from south to north, from Section 17 into Section 8.

The most recent version of the mine plan does not make hydrologic sense. The groundwater gradient, or direction of groundwater flow, at the site is from the south-southwest to the north-northeast. (See FEIS, Figure 3.11 at 3-37.) That means that Wellfield 6, located in Section 17 in the current mine plan, is hydrologically "up-gradient" of all of the other wellfields, yet it would be mined and restored *last* in the sequence proposed by HRI.

The potential consequence of this mining sequence is that a horizontal excursion in an up-gradient wellfield may contaminate an already restored down-gradient wellfield. For instance, HRI's current timeline has production scheduled in up-gradient Wellfield 6 at the same time that restoration is being done in adjacent and down-gradient Wellfield 5. (HRI 1997b, at 21; **Exhibit R**.) Some of the lixiviant being injected into Wellfield 6 would be captured by an ongoing groundwater sweep in Wellfield 5. According to

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[11] It's worth noting here that the first two versions of HRI's Consolidated Operations Plan, dated September 30, 1996 (Revision 0.0), and May 12, 1997 (Revision 1.0), have the same mine plan configuration as shown in COP Revision 2.0 (dated August 15, 1997). (See, COP Revision 0.0 at 19 [**ACN 9701160106**] and COP Revision 1.0 at 22 [**ACN 9705220214**].)

Figures 3.1-1 and 3.1-2 of COP Revision 2.0 (Id., at 45-46), the production bleed rate in Wellfield 6 would be 40 gallons per minute (gpm) at the same time that 200 gpm would be pumped for groundwater sweep from virtually the same part of the aquifer in Wellfield 5. The fluid volume of the restoration cone of depression in the down-gradient wellfield would be larger by a factor of five. Under these conditions lixiviant in the northern end of Wellfield 6 would be drawn toward Wellfield 5, which is concurrently being restored. Such an event is technically not an excursion because lixiviant is being transferred from one wellfield to another. However, the simultaneous restoration and production in adjacent wellfields are likely to be inefficient both in terms of mining and restoration, and potentially quite costly should excursions from an upgradient wellfield recontaminate a restored down-gradient wellfield.

Geraghty and Miller's 1993 groundwater modeling did not address this problem because the mining and restoration sequence that Geraghty and Miller modeled at that time[12] had mining beginning in the far up-gradient portion of the site in Section 17 and continuing down-dip through Section 8 — the same sequence set forth in the October 1993 mine plan. Indeed, it makes much more hydrologic sense to mine the wellfields from south to north (up-gradient to down-gradient) to reduce the potential for up-gradient excursions to enter restored wellfields that are down-gradient.[13]

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[12] See, Geraghty and Miller, 1993, Figures 22 through 27.

[13] Even then, there should be some physical separation between wellfields being restored and produced simultaneously.

It's worth noting here that the first two versions of HRI's Consolidated Operations Plan, dated September 30, 1996 (Revision 0.0), and May 12, 1997 (Revision 1.0), have the same Section 8-first mine plan configuration that's shown in COP Revision 2.0 (dated August 15, 1997).[14] The Section 17-first, south-to-north mining sequence was still in HRI's plan in late-1994 because it was depicted that way in Figure 2.1 of the DEIS (October 1994; at 2-4). This means that HRI reconfigured the Church Rock mine plan sometime between October 1994 when the DEIS was published and September 30, 1996, when COP Revision 0.0 was published. Exactly when this dramatic change in the mine plan was made is not clear from the documents I reviewed. However, when it occurred does not alter my professional opinion that the current mine plan increases the risk of excursions and will further compromise restoration efforts at the Church Rock site.

a. Reinjection of production bleed wastewater could jeopardize lixiviant control.

I am concerned that HRI's plan to reinject virtually all of its 40 gpm (or 1 percent) production bleed will negate the purpose of the bleed rate (i.e., to create a cone of depression in the mining zone) and thereby jeopardize lixiviant control. HRI's COP Revision 2.0 indicates quite clearly that 39 gpm of the 40 gpm bleed rate will be reinjected for "aquifer recharge" (HRI 1997, Figures 3.1-1 and 3.1-2 at 45-46). This same information is represented in Figure 2.5 of the FEIS (at 2-11), but the NRC Staff

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[14] See, COP Revision 0.0 at 19 (**ACN 9701160106**) and COP Revision 1.0 at 22 (**ACN 9705220214**).

gave no indication in the FEIS that it evaluated the effects of this reinjection on lixiviant control. Geraghty and Miller did not account for it in their groundwater modeling for HRI. And nowhere in the license application does HRI indicate where this production wastewater will be reinjected in relation to its property boundaries and production wellfields. However, in a February 1997 written response to questions raised by EPA Region IX about HRI's Unit 1 underground injection control application, HRI stated that the "product" water from the clean side of the R.O. unit "is returned to the formation outside of the wellfield pattern" and that "it does not matter if [this] recharge occurs inside or outside the monitor well ring . . ." (HRI 1997a, at 2; attached hereto as **Exhibit T**.) Depending on where this fluid is reinjected, it could interfere with nearby monitoring wells or have a synergistic effect on operations as a whole. If this 39 gpm is injected into the Westwater Canyon Aquifer on the upgradient side of the first wellfield to go into production, it could partially negate the proposed 40 gpm production bleed. HRI should have modeled the simultaneous effects of bleeding 40 gpm in the most likely production wellfield to be affected and injecting 39 gpm at the designated injection site. Such an analysis should have addressed the potential interference of the reinjection on injection and production activities as well as its potential effects on the nearest monitor wells.

b. HRI's Excursion detection criteria for the HRI project are inadequate and will allow excursions to persist undetected for long periods.

As the record of current ISL operations clearly indicates, it's not a matter of *if*

excursions will occur, but a matter of *how* they will be detected *when* they occur. Excursion detection is an especially important matter for the Crownpoint Uranium Project because of the need to protect the high quality of water in the Westwater Canyon Aquifer. Two aspects of the excursion detection program proposed for the CUP are inadequate for the hydrogeologic conditions present: the proposed 400-foot well spacing scheme and the lack of uranium as an indicator parameter.

The uniform 400-foot monitor well spacing scheme proposed for all three sites is not adequate for the heterogeneous conditions that exist in the subsurface geology at the Church Rock, Unit 1 and Crownpoint sites.[15] The evidence for this conclusion is in HRI's own documentation. First, the geometry of the ore zones at each site was described in HRI's cost benefit analysis and is summarized in Table 7 below. (See, HRI 1996b, table entitled "Hydrology and Geologic," appearing on page 7-1 of each cost scenario and attached hereto as **Exhibit V**.) These figures show that the ore zone width ranges from 126 feet at Crownpoint to 158 feet at Church Rock — or roughly a third of the proposed 400-foot width between monitor wells.

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[15] The NRC's Draft Standard Review Plan (1997) for uranium ISL mining applications states that "the NRC staff has commonly found the location of horizontal monitor wells to be acceptable if the wells are located 140 m (400 ft) from the edge of the production or injection wells with 140 m (140 ft) between each monitor well so that the angle formed by lines drawn from any production well to the two nearest monitor wells would not be greater than 75 degrees. (See, USNRC, 1997c, at 5-40; attached hereto in relevant part as **Exhibit U**.) Clearly, this guidance is based on *overall* experience at ISL mines and can and should be adjusted to fit site-specific conditions. As I discuss in the text above, the site-specific conditions at the CUP sites warrant a monitor well spacing that is consistent with the orebody dimensions, especially in the down-gradient direction.

Table 7. Geometry of Orebodies, Number of Production and Injection Wells at Crownpoint Uranium Project, New Nexico.

Site	Orebody Thickness	Orebody Width	Orebody Length	No. Wells Production/Injection	
Church Rock	11.5 ft.	158 ft.	33,100 ft.	868	834
Unit 1	9.2 ft.	139 ft.	25,629 ft.	305	302
Crownpoint	9.02 ft.	126 ft.	80,960 ft.	823	767

This geometry is indicative of ancient, buried streambeds — thin, narrow and long channels through which groundwater flow is speeded up, much as Mr. Wallace described in his January 13, 1998, affidavit. Plus, the large number of producing and injecting wells planned for each site — 1,702 for Church Rock, 505 for Unit 1, and 1,590 for Crownpoint — increases the chances that excursions will occur in the channels where flow is faster.

Second, a diagram published by McCarn (1997, Figure 8; attached hereto as **Exhibit P**) clearly shows a series of stacked, narrow, elongated channels criss-crossing the south one-half of the Crownpoint mining site (Section 24, Township 17 North, Range 13 West). Based on an examination of the scale accompanying the McCarn diagram, I estimated that the channels depicted in the figure range from 75 feet to about 325 feet wide. And third, HRI's depiction of the LB Sand channel (HRI 1996a, Figure 50-3; attached hereto as **Exhibit W**.) located in the southwest quarter of Section 24 at the Crownpoint site shows a snakelike channel ranging in width from about 80 feet to about 150 feet.

The need for a substantially narrower spacing between monitor wells is made all the more urgent at the Crownpoint and Unit 1 sites by the presence of the Crownpoint municipal water system. The production bleed rates for both sites (40 gpm) are not sufficient to overcome the drawdown caused by the pumping of up to 320 gpm from the five wells that make up the Crownpoint municipal system. The Navajo Tribal Utility Authority's decision to oppose the NRC Staff's requirement that HRI replace and relocate the current municipal wells means that their drawdown effects on the local hydrologic system will not be ameliorated.

Under these hydrogeologic and water-use conditions, a more stringent set of excursion rules should apply. A 200-foot spacing between horizontal excursion monitor wells on the down-gradient sides of the Unit 1 and Crownpoint sites seems to me to be a *maximum* spacing width; a closer spacing may be needed where the orebodies are housed in even narrower channels. At the Church Rock site, a spacing interval of up to 300 feet would be appropriate for the orebody geometry documented there.[16] For all three sites, trend wells should be placed between the wellfield and the monitor wells to provide early

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[16] A spacing narrower than 400 feet at Church Rock would not be without precedence. COGEMA is now spacing its horizontal excursion monitoring wells 300 feet apart on the down gradient side of one of its wellfields at the Christensen Ranch facility. (USNRC, 1998b, at 21; attached hereto in relevant part as **Exhibit D**.) As noted earlier in my testimony, the groundwater quality around the Christensen Ranch site is similar to that of the Church Rock site, except that the Church Rock groundwater has low uranium and radium concentrations such that it could be used for domestic purposes if developed.

warning of excursions.[17]

The second major deficiency in the excursion detection program for the CUP is the lack of uranium an indicator parameter. Uranium is an important indicator of excursions because it is highly mobile in oxidized environments. Escaping lixiviant may mobilize non-ore grade uranium still bound up in the rock matrix in the vicinity of a monitor well. Moreover, uranium is used as an excursion indicator at some ISL sites in Wyoming[18] and at most sites in Texas, including at URI's Kingsville Dome and Rosita projects. In fact, a URI monitor well the Rosita site in Texas were placed on excursion status based on concentrations of uranium exceeding its upper control limit.[19] (URI, 1992; attached hereto as **Exhibit Y**).

Q.9. What is your evaluation of HRI's restoration plans?

A.9. In my professional opinion, HRI's restoration plan seriously underestimates the time required for restoration, does not include enhanced restoration methods necessary for restoration, and does not demonstrate that water quality can be returned to its original, pre-mining conditions. As I stated earlier in this testimony, I am familiar with the pilot-

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[17] The NRC's Staff Technical Position Paper on Groundwater Monitoring at Uranium In Situ Solution Mines, #WM-8102 (December 1981) recommends that monitor wells be located in two tiers measuring 50 feet and 250 feet from the outermost injection wells. (USNRC 1981 at 10; attached in relevant part hereto as **Exhibit X**.) Wells spaced 50 feet from injectors are akin to the "trend wells" that I recommend here.

[18] Uranium also is an indicator parameter for PRI's Highland Project (PRI, 1998, at 1; PRI, 1997, at Figure 3-7).

[19] The upper control limit for uranium at that time was 6.2 mg/l. Uranium concentrations ranged up to 12.7 mg/l for two days in April 1992.

scale restoration efforts in Texas, Wyoming and New Mexico as well as commercial-scale restoration efforts in Texas and Wyoming. As a general matter, restoration has taken much longer than expected, required chemical treatment in problematical areas, and, in several cases, failed to achieve target water quality goals. HRI's application gives me no comfort that these same problems will not be averted at the Crownpoint Uranium Project.

To assess the adequacy of HRI's restoration plan further, I examined documentation on Mobil Oil Corporation's Section 9 pilot ISL operation conducted 5.5 miles west of Crownpoint between 1979 and 1986. (USNRC, 1988; relevant portions of which are attached hereto as **Exhibit L**.) The Mobil Section 9 pilot is not comparable with the commercial operations proposed by HRI at Church Rock, Unit 1 and Crownpoint simply because the operational scales are different by orders of magnitude. However, results of the Mobil pilot project are *relevant* to the HRI proposal simply because leaching was conducted in the same aquifer in which HRI plans its operations.

Let's examine some of those results by looking first at the Mobil restoration data summarized in Table 4.13 of the FEIS (at 4-38). Even after 16.7 pore volumes of flushing, Mobil did not achieve restoration to *baseline*, the primary restoration goal established for the HRI project (see NRC License SUA-1508, License Condition 10.21(a)), for 19 of 29 parameters analyzed. "Restored" concentrations of radium, uranium, molybdenumn, aluminum, and arsenic were 4.2, 32, 6.5, 40.4 and 35 times their respective baseline concentrations. Restoration satisfied the most of the parameter-

specific standards selected for the project, but most of those standards have no relationship to primary and secondary drinking water standards that form the "secondary goal" for the HRI project. (See, LC 10.21(a), SUA-1508, at 7.) For example, the radium restoration standard of 97.2 pCi/l was more than *19 times* the federal drinking water standard of 5.0 pCi/l. The restored radium value of 59.9 pCi/l was not only 4.2 times site-specific baseline, but nearly 12 times the federal drinking water standard of 5 pCi/l and more than 100 times the average radium concentration in the town of Crownpoint water wells. (FEIS, Table 3.12 at 3-26.) Restoration of this nature would not be acceptable at any of the proposed HRI sites, but especially at Unit 1 and Crownpoint because of their proximity to the Crownpoint water system.

Although the molybdenum concentration in the mine-zone groundwater was reduced from 7 mg/l during mining to 1.118 mg/L at the end of restoration, the restoration goal of 1 mg/l was not achieved. The NRC Staff concluded that further reduction of molybdenum concentration was not practical, and therefore, waived compliance with the molybdenum standard. (USNRC 1988, at 20-21; attached hereto as **Exhibit L**.)

Other facets of the Mobil experience also are relevant. In scale, the Mobil Section 9 pilot project was a typical small-scale, field-level restoration demonstration test that consisted of 9 injection wells and 4 production wells uniformly spaced over a 1-acre site. Only 15 percent of the extractable uranium was mined before restoration began. But restoration activities were conducted for nearly five years (1980-1985), and in its later

stages, restoration required several months of treatment with a chemical reductant (hydrogen sulfide).[20] Mobil's efforts consisted of 15 stages involving various experiments, groundwater sweeps, reverse osmosis circulation, and down time stretched over five years and following only about 12 months of lixiviant circulation in between November 1979 and October 1980.

This was a tremendous amount of work for a pilot-scale operation when compared with a typical commercial scale restoration program that consists of three stages: 1) groundwater sweep, 2) RO circulation, and 3) the use of a reductant in problematic areas. A typical commercial-sized wellfield may contain several hundred wells uniformly spaced over perhaps 50 to 100 acres, wherein 80 percent or more of the uranium would be extracted.[21] Commercial scale in situ mining is two to three orders of magnitude (100 to 1000 times) more intense than pilot scale mining. A commercial well field is expected to have higher variability and concentrations of contaminants, and therefore, is expected to be more difficult to restore.

The difficulties Mobil had restoring the Section 9 pilot site will be compounded by orders of magnitude for the HRI project. Given recent ISL experience at Mobil and at commercial-scale operations in Wyoming and Texas, there simply is no basis to believe HRI's estimate that restoration at the Church Rock wellfields will take only 14 months

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[20] In fact, molybdenum concentrations were not reduced to a level approaching the restoration standard of 1.0 mg/l until hydrogen sulfide reduction was introduced in 1984-1985. (USNRC, 1988, at 17; attached as **Exhibit L**.)

[21] Indeed, as shown in Table 7 of my testimony, HRI's proposal envisions anywhere from 500 to 1,700 wells at each of the three sites, or about 150 to 500 wells per wellfield.

each. (See, **Exhibit R**, Figure 1.4-7.). Furthermore, there is no experience in the ISL industry for restoration to the low levels of uranium and radium in the groundwaters at Church Rock, Unit 1 and Crownpoint. If anything, the Mobil Section 9 test demonstrated the difficulty HRI will face in reducing uranium and radium concentrations to the very low baseline levels existing at and around these sites.

HRI's application does not adequately accommodate the necessary requirements of a rational restoration period. Substantial acreage is needed for evaporation ponds and/or irrigation plots if deep well injection is not used for disposal of restoration wastewater generated by groundwater sweep and reverse osmosis reinjection. Yet, HRI has deferred its decision about a disposal method or methods of choice. Enhanced restoration efforts have been necessary to achieve restoration at several other sites, including at the Highland Project where PRI is adding hydrogen sulfide in high concentrations (about 200 parts per million) to reverse osmosis permeate to facilitate restoration in its A and C wellfields. (See, **Exhibit E**, at 8, 20.) Yet HRI makes no provision for use of chemical reductants in its CUP restoration plan.

Against this background, my professional opinion is that HRI has grossly underestimated the time restoration will take at the proposed mining sites and the difficulty inherent in returning concentrations of key contaminants to their extremely low baseline values. Furthermore, given that HRI and its parent firm, URI, have no experience restoring groundwater to the high quality indigenous to the New Mexico sites, I have serious doubts that HRI will be able to comply with the primary and secondary

restoration goals required in its NRC license. As such, ISL mining at Crownpoint, Unit 1 and Church Rock will pose an unnecessary risk to the groundwater for years to come.

Q.10. Does this conclude your testimony?

A.10. Yes.

AFFIRMATION

I declare on this 9th day of ~~December, 1998~~ January, 1999, at Knoxville, Tennessee, under penalty of perjury that the foregoing is true and correct to the best of my knowledge, and the opinions expressed herein are based on my best professional judgment.

William P. Staub

William P. Staub

Sworn and subscribed before me, the undersigned, a Notary Public in and for the State of Tennessee, on this 9th day of ~~December, 1998,~~ January 1999 at Knoxville, Tennessee.

My Commission expires on July 23, 2002.

Heather Critchfield

Notary Public

Exhibit A

RESUME: WILLIAM P. STAUB

Work and Home Address:

6025 Nottingham Rd.
Knoxville, TN 37918
(423) 687-1480 or 687-9948

Technical Specialties:

Geotechnical Engineering
Geohydrology
Seismic Hazard Analysis
Environmental Impact Analysis

Work Experience:

12-1-97 to Present — Personal services contract to Oak Ridge National Laboratory through the University of Tennessee

1976-1996 (Retired 9-30-96) — OAK RIDGE NATIONAL LABORATORY, Tennessee

Environmental impacts of construction and operation of facilities requiring either federal funds or government regulation: surface water, ground water and land use impact analysis during construction, normal operations and upset conditions.

Environmental impacts of external accidents on operating facilities: slope stability, seismic and volcanic hazard analyses.

Environmental impact mitigation: erosion and sedimentation control plans; spill prevention, containment, and control plans; ground water monitoring; remediation of ground water contamination; mill tailings management; waste management.

Regulatory issues related to federal (Department of Energy, Environmental Protection Agency, Federal Energy Regulatory Commission, Nuclear Regulatory Commission) and state agencies.

Facilities: uranium mill tailings; insitu uranium mines; low level radioactive waste facilities; nuclear power plants; nuclear defense plants; coal-fired, geothermal, and hydro-electric power plants; mines; and demilitarization of chemical munitions.

1969–1976 THE UNIVERSITY OF TENNESSEE, Knoxville

Professor of Geological Sciences
Courses taught: introductory physical geology, introductory geology for engineers, Quaternary geology for engineers, introductory geophysics, physics of the earth, petrophysics, ground water geology, structural geology
Chairman: Graduate Admissions and Assistantship Committees.
Chairman: five thesis committees and one dissertation committee.

1968–1969 COLLEGE OF ST. THOMAS, St. Paul, Minnesota

Professor of Geology
Courses taught: introductory physical geology, mineralogy, ore deposits, structural geology.

1964–1968 IOWA STATE UNIVERSITY, Ames

Instructor of Geology
Courses taught: introductory physical geology, geology for engineers.

1956–1964 CHEVRON OIL COMPANY, Houston, Texas

Exploration Geophysicist
Seismic interpretation and preparation of structure contour maps in Louisiana, California, North Dakota, and the Rocky Mountain states; seismograph crew leader in western Canada.

Education:

1969	Ph.D., Geotechnical Engineering, Iowa State University, Ames, Iowa. Dissertation: Seismic Refraction Survey of the Ames Anticline
1961	M.S., Geology, Washington University, St. Louis, Missouri. Thesis: Gravity Survey of Southeast Missouri
1956	B.S., Geological Engineering, Washington University, St. Louis, Missouri.

Professional/Academic Honors:

Sigma Xi National Science Honorary

Professional Activities:

American Association of Petroleum Geologists
American Geophysical Union
Association of Engineering Geologists
Geothermal Resources Council
National Water Well Association
Society of Exploration Geophysicists

Community Service:

President (two years), Sterchi Elementary School PTA
Guest science lecturer, fifth and sixth grades, Sterchi Elementary School
Chairman (eight years), basketball committee, Fountain City Youth Recreation League
Baseball coach (four years), Sandy Koufax and Mickey Mantle youth leagues
Basketball coach (six years), Fountain City Recreation Commission
Assistant soccer coach (three years, AYSO)
Fund raiser for disadvantaged youth (eight years), Fountain City Recreation Commission
Judge, National Science Fair, Knoxville, Tennessee

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Exhibit B

NUREG/CR-3967
ORNL/TM-9956

An Analysis of Excursions at Selected In Situ Uranium Mines in Wyoming and Texas

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Prepared for
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these deposits can extend into the lagoon and seaward into the nearshore zone. Transition between deposits of the lagoon and barrier and channel-delta deposits occurs in the overlapping subenvironments of the back-barrier tidal flats, marsh, washover fans and flood-tidal deltas.

According to Klein (1980), uranium occurrences in sandstones usually are limited to sandstones that are interbedded with mudstones; precipitation of uranium from solution is believed to have been accelerated by impedence to ground-water flow at sandstone-mudstone intertongues, or by interbedded organic rich layers. Good examples of the barrier sandstone-type uranium deposits occur in the Texas Coastal Plain in the Jackson Group (Dickinson, 1976; Dickinson and Sullivan, 1976; Fisher et al, 1970). Uranium most commonly occurs in sandstones where they are in contact with mudstones and organic rich beds; uranium concentrations typically are highest on the updip side of barrier sands (Fisher et al, 1970), presumably because the updip sides of such systems tongue into lagoonal muds and marshes.

Interbedded sandstones and mudstones are common to tidal flats, particularly where intertidal channels are filled with sand (Klein, 1980). Supratidal environments potentially are conducive to uranium precipitation, if a source is present; organic matter in salt marshes may serve potentially as a precipitant for uranium in solution (Klein, 1980).

2.2 HYDROGEOLOGIC TESTING OF IN SITU URANIUM MINE SITES

Delineation of stratigraphic units and evaluation of hydrogeologic properties at in situ uranium mine sites are essential aspects of site characterization. Variations in subsurface hydraulic conductivity can significantly affect the movement of lixiviant by providing preferential pathways for the movement of lixiviant (excursions) beyond the production area of the in situ mine. Failure to collect comprehensive data during exploration and testing programs will result in an inadequate understanding of the hydrogeology and an inadequate monitoring system (Williams and Osiensky, 1983, Osiensky et al, 1984).

Questions that must be asked about proposed in situ mine sites include:

1. Can the hydrogeology be defined adequately to ascertain whether or not an excursion will develop?

2. Where will the lixiviant migrate?

3. What measures may be taken to prevent excursions?

4. Can excursions be controlled?

Upon completion of exploration and testing programs, the mining company and regulatory agency must decide what risks are acceptable.

Standard methods for delineating hydrostratigraphy include analysis of borehole logs such as drill cuttings and core samples. Hydraulic properties are estimated by a variety of field and/or laboratory methods. Laboratory methods and some field methods provide point values of the basic hydrogeologic characteristics; laboratory tests are performed on small samples that may not be representative of the entire area of interest or may have been disturbed during handling. Field methods of aquifer testing are more acceptable because they provide estimates of hydrogeologic parameters that are measured in situ. These estimates are representative of a volume of porous media surrounding pumping and injection wells. Single-well tests provide values representative of a small volume of porous media in the immediate vicinity of the well. Multiple-well field tests provide measurements that are averaged over a larger aquifer volume.

2.2.1 Borehole Logs

Exploration boreholes usually are drilled throughout the mine areas to evaluate the extent and quality of the ore zones. Some of these wells are logged throughout while many are logged only in specific ore zones. Once a uranium ore zone has been detected, boreholes typically are drilled at spacings from 5 to 15 m (20 to 50 ft). This grid of boreholes extends across the plan area of the ore zone. Natural gamma geophysical logs generally are recorded in closely spaced exploration boreholes primarily to locate the uranium-bearing zone(s). Additional geophysical logs (such as single point resistance, spontaneous potential, neutron epithermal neutron, sonic and caliper logs) are rarely recorded.

Data from boreholes drilled at in situ uranium mine sites are typically not obtained or fully utilized for the purpose of delineating stratigraphic units and sedimentary facies. Continuous cores or extracted samples and geophysical logs throughout the length of each borehole would enhance the ability to interpret stratigraphy and its associated ground-water regime. It is difficult to predict the nature of the ground-water regime without the ability to map sedimentary facies in the subsurface. However, collection and interpretation of these data are arduous tasks and the results of such efforts are not always satisfactory because of the stratigraphic and structural complexities involved. Even subtle changes in lithology can produce large changes in permeability as exemplified by the concretionary and silty sandstone facies of the Wasatch Formation.

Geophysical borehole logging requires considerable care. It is best to record all geophysical logs in open boreholes. Electric logs cannot be recorded properly in cased holes. However, uncased holes have a tendency to collapse below the water table. Service companies are reluctant to log uncased holes in unconsolidated sediments for fear of inability to recover instruments from a collapsed hole. Radiation logs can be recorded in uncased or cased boreholes. They generally require a maximum logging speed of 4.6 m (15 ft) per minute in order to give an adequate degree of detail. A constant hole diameter should be maintained to keep the radius of investigation constant and to eliminate the difficulties of interpreting logs from multidiameter holes. Caliper logs are necessary in all open holes when radiation logs are to be interpreted because the response of radiation

logs is sensitive to borehole diameter. The reader is referred to Keys and MacCary (1971), Pirson (1970), and Visher (1965) for detailed discussions of geophysical logs and their interpretation.

2.2.2 Aquifer Testing

Aquifer tests are used to delineate and characterize the stratigraphic units at in situ uranium mine sites. Carefully designed, conducted, and analyzed aquifer tests can be used to evaluate many hydrogeologic characteristics of importance. The characteristics include:

1. degree of hydraulic separation between the ore zone and adjacent overlying and underlying aquifers,

2. hydraulic continuity in the ore-bearing unit,

3. identification of boundaries and concomitant variations in hydraulic conductivity,

4. hydraulic conductivity of the ore zone and vertical hydraulic conductivity of the aquitards overlying and underlying the ore zone, and

5. velocity of ground-water flow through individual stratigraphic horizons.

Multiple-well and single-well pumping/injection tests are the most common aquifer testing methods used at in situ uranium mine sites. Values of hydraulic conductivity, transmissivity, and storativity should be estimated for the ore zone aquifer from data for each well completed in the aquifer. Vertical hydraulic conductivity of the confining bed(s) should be estimated by an appropriate methodology. Aquifer test data also should be analyzed for boundary and leakage conditions. ☆

Water levels often are measured in observation wells completed in aquifers overlying and underlying the pumped aquifer to evaluate possible leaky conditions. Such observations provide the most direct evidence of hydraulic communication between aquifers. In the most serious cases (broken casings, improperly plugged and abandoned holes, a discontinuous aquitard) of potential excursion pathways, observation wells may respond within a few hours of the initiation of pumping. For sluggish pathways of excursion, the response time may be excessive. In sluggish ground-water regimes, drawdown in observation wells may also be masked by other factors, such as antecedent water level trends, barometric pressure changes, interference pumping, and consolidation (the Noordbergum effect) (Verruijt, 1969). Antecedent water level changes and barometric pressure changes have not been measured during most aquifer tests conducted at in situ uranium mine sites; therefore, it is occasionally difficult to interpret the data collected from wells completed in the overlying and underlying aquifers. Where the results of the above observations are inconclusive, other methods of analysis to detect leakage and differentiate between causes of leakage will be required.

The Theis (1935) nonequilibrium method and the Cooper and Jacob (1946) straight line method are used extensively to estimate the transmissivity and storativity of the pumped aquifer from an analysis of pumping test data. These methods of analysis give valid results when a sufficient amount of drawdown data is available and when the following assumptions are approximated closely:

1. The aquifer is homogeneous and isotropic.

2. The aquifer has infinite areal extent (its boundaries are well beyond the effects of pumpage).

3. The pumping well fully penetrates the aquifer.

4. The well has a small diameter (of no practical significance for periods of pumping more than a few minutes).

5. Water is released from storage in the aquifer instantaneously with decline in head.

Modifications to these methods exist and must be applied if geologic and hydrologic conditions do not approximate the assumptions. Such modifications must be applied for changing water table conditions, leakage, partial aquifer penetration, boundary conditions, variable pumping rates, barometric pressure changes, tidal effects, or multiple confined aquifers.

One of the most common methods of analysis used for leaky aquifer conditions is the Hantush and Jacob (1955) leaky artesian method. This method allows the estimation of values of hydraulic conductivity and storativity of the pumped aquifer and the vertical hydraulic conductivity of the overlying confining bed. The calculated values of vertical hydraulic conductivity constitute highest estimates when water is leaking through both confining beds. The Hantush and Jacob (1955) method has limited applicability because it does not account for head changes in overlying and/or underlying aquifers, or water released from storage in the confining layers. The method of Hantush and Jacob (1955) is best suited for long pumping periods and where the leaky confining bed is noncompressible or thin so that water released from storage in the confining bed is significant.

The Hantush (1960) modified leaky artesian method, which allows estimation of the transmissivity and storativity of the pumped aquifer, takes into account water released from storage in the confining beds. Vertical hydraulic conductivity of a single confining bed can be estimated if the specific storage is known, and if the vertical hydraulic conductivity and specific storage of the other confining bed are known. The Hantush (1960) method is best suited for situations where the leaky confining units are thick and compressible so that water derived from storage in the confining beds is predominant.

Values of vertical hydraulic conductivity estimated in Appendix A using the Hantush (1960) method constitute highest (most conservative)

estimates for a single (overlying) confining bed because the vertical hydraulic conductivity (K") of the underlying aquitard is assumed (for the purpose of the calculations only) to be zero. Lowest (least conservative) estimates of vertical hydraulic conductivity occur when the vertical hydraulic conductivities of the two confining beds are equal. The resulting lowest estimates are less than an order of magnitude smaller than the highest estimates. It is assumed also that the specific storage of the upper and lower confining beds (S_s' and S_s'', respectively) is two orders of magnitude larger than that calculated for the corresponding aquifer; these values of specific storage correspond reasonably well with representative values calculated using the values of compressibility for clay cited in Freeze and Cherry (1979). The values of vertical hydraulic conductivity estimated using the Hantush (1960) method must be considered as approximations because of the assumptions described above. Leaky aquifers will receive water from storage in the confining bed(s) during early periods of pumping whereas water derived from overlying and/or underlying aquifers will reach the pumped aquifer by movement through the confining layers during later periods of time (assuming there is no "short circuit" such as a broken well casing, improperly abandoned borehole, or discontinuous confining layer in the vicinity). These time periods are a function of aquitard thickness and vertical hydraulic conductivity.

The "ratio method" developed by Neuman and Witherspoon (1972) is the most sophisticated pumping test method currently available for estimating the aquifer characteristics of multiple aquifer-aquitard systems. The vertical hydraulic conductivity of the individual confining layers can be estimated as well as the hydraulic properties of the aquifer being pumped. Because the ratio method does not provide an estimate of specific storage for the confining layers, these values must be measured independently. The method relies on early drawdown data, so the pumping test can be of relatively short duration. Prior knowledge of the aquitard thickness is not required. In addition, the ratio method is simple to use, and does not involve graphical curve-matching procedures.

Injection tests of zones isolated by hydraulic packers often are used to estimate the saturated horizontal hydraulic conductivity of selected intervals of boreholes. Saturated horizontal hydraulic conductivity using a packer assembly can be calculated from the following relationship (DOI, 1974):

$$K = \frac{Q}{2\pi LH} \ln \frac{L}{r}$$

where:

K = hydraulic conductivity,

Q = constant rate of flow into the hole,

L = length of the portion of the hole tested,

H = differential head of water, and

r = radius of the hole tested.

This equation is valid for L>10r. Relative rather than absolute values of hydraulic conductivity are best described when conducting injection tests using packers. Causes for common errors include (Cedergren, 1977):

1. leakage along casing and around packers,
2. clogging due to sloughing of sediment in the test water,
3. air locking due to gas bubbles in soil or water, and
4. flow of water into cracks that are opened by excessive head in test holes in soft rocks.

The hydrogeologic characterization of existing or potential in situ mine sites is a difficult task given the sedimentary environments at these locations. The NRC (1982) lists the following factors of primary importance in the measurement of hydraulic conductivity:

1. selection of a method compatible with the hydrogeologic conditions,
2. recognition of the limitations and assumptions of the method used,
3. testing only the proper hydrostratigraphic unit as defined before the test, and
4. have the test conducted and analyzed by someone thoroughly familiar with the test, the hydrogeology, and the applicability of the test to the hydrogeologic environment in question.

2.3 SUMMARY OF LIMITATIONS IN CHARACTERIZING GROUND-WATER REGIMES

Conventional exploration methods as described above seldom provide enough detail to determine whether an ore zone aquifer is sufficiently isolated from other aquifers. The complex stratigraphy of alluvial sediments is a serious obstacle to projection of lithologic units between boreholes even at short distances. Figure 2.8 presents several interpretations of the same data. In the absence of proof of the contrary, stratigraphic units are often projected as continuous layers between boreholes (refer to case histories in Appendix A) which may lead to a false sense of security with respect to aquifer isolation. Furthermore, two-dimensional cross-sections do not necessarily portray accurate relationships between aquifers in three dimensions. Thus, an aquitard may be continuous in one direction and discontinuous in another.

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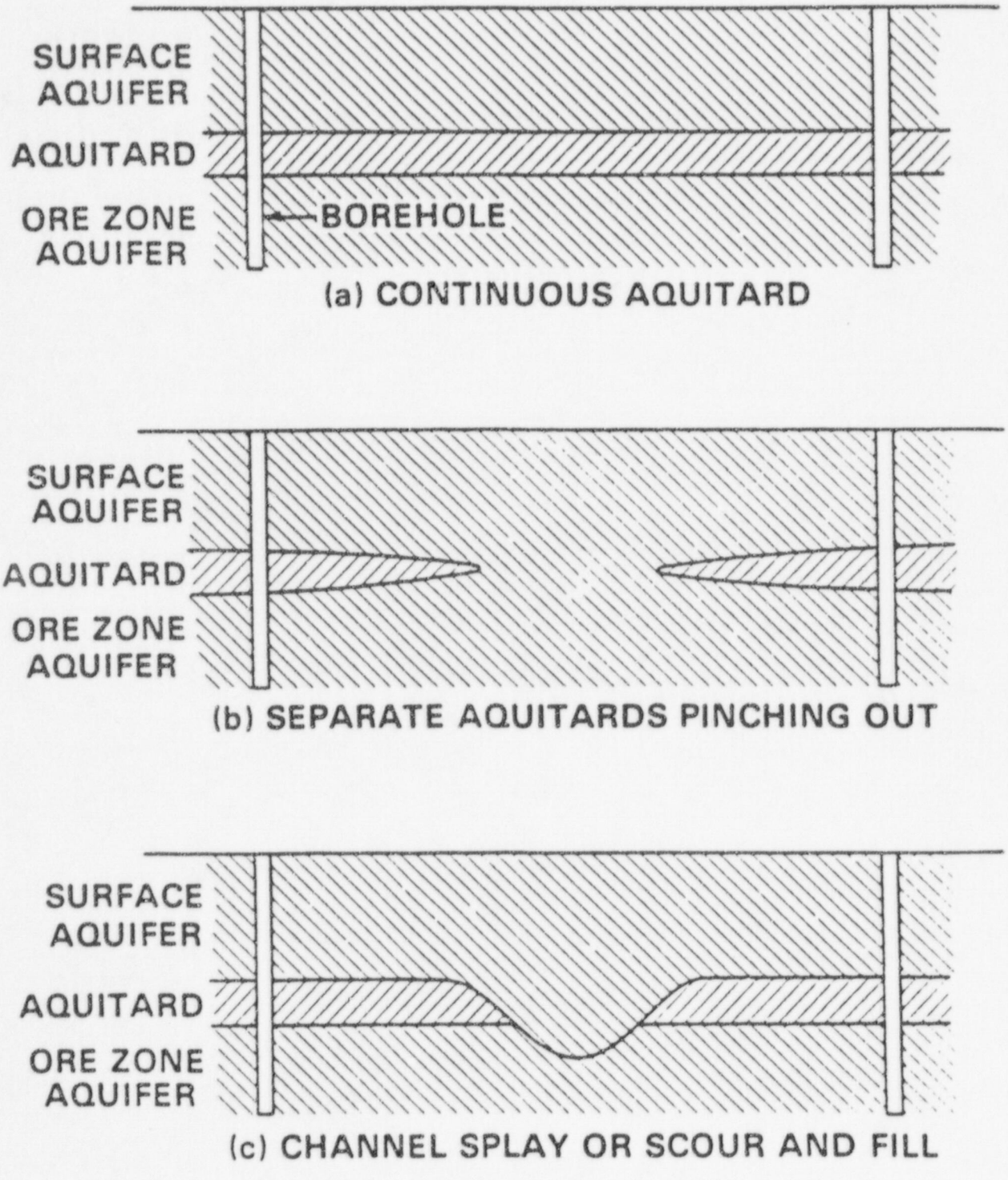

Fig. 2.8. Alternate interpretations of the same borehole data.

It is recognized that there are limits to the amount of data that can be collected and analyzed. Furthermore, subtle changes in lithology may remain undetected despite rigorous data collection and analysis. Subtle changes in lithology (slight variations in silt, clay or carbonate cementing agents) have the potential to profoundly influence hydraulic conductivity.

Potential in situ mine sites also have an uncertain prior drilling history. Older exploration holes in search of fossil fuels and uranium are difficult, if not impossible, to locate and many of them were improperly plugged and abandoned.

To counter the above uncertainties, aquifer tests are used to provide proof of aquifer isolation. To date, aquifer tests have not provided consistently definitive results. There are several reasons for this:

1. Ore zone aquifers yield only a few gallons of water per minute compared to the larger and more robust systems for which aquifer tests were originally designed.

2. The duration of aquifer tests is often too short to determine the aquifer properties that they were designed to measure.

3. Proper choice of testing methodologies and analyses depends on the level of understanding of the ground-water regime.

It is important to keep the above limitations in perspective in examining the case histories of Appendix A. These case histories were compiled from NRC docket files. A licensee's interpretation of stratigraphic information in these files is often oversimplified and fails to address the uncertainties involved. The reader is advised to consider the uncertainties. For example, the continuity of a thin aquitard in three dimensions is highly uncertain relative to that of a thick aquitard. On the other hand, even a thick aquitard may be truncated by an unmapped fault or by channel scour and fill. Finally, failure to identify the presence of poorly plugged or abandoned holes does not imply their absence.

3. EXCURSIONS

An excursion is an uncontrolled migration of lixiviant and its associated dissolution products and by-products away from controlled areas (production well fields) of in situ mining ore zones. Early detection of an excursion is a necessary prelude to the implementation of timely corrective action to return escaping fluid to the well field. Without timely corrective action, a large quantity of valuable production fluid may be irretrievably lost and serious contamination of adjacent ground-water resources may result.

Analysis of excursions at the 8 in situ mines in this study is complicated by the diverse methodologies used to identify excursions. Methodologies differed mainly in the selection of excursion indicators, the determination of their upper control limits (UCLs), and in the definition of a legal excursion.

Some reported excursions were probably false alarms. There are a variety of reasons for these false alarms. Most false alarms were caused by setting unrealistically low UCLs for trace elements or poor selection of indicators. Others were caused by placing monitor wells too close to the ore zone perimeter. At most mine sites close-in observation wells would be considered as trend wells rather than monitor wells.

Despite inconsistencies in identifying excursions it is evident that many excursions did occur. Most horizontal excursions were brought under control quickly. However, wells used to monitor for vertical excursions were on excursion status repeatedly and for excessively long periods of time. In many cases restoration procedures were eventually required. It is particularly important to recognize vertical excursions at an early stage in order to avoid costly and time consuming restoration.

Sections 3.1 through 3.3 summarize the causes, consequences, and control methodologies for horizontal and vertical excursions. Sections 3.4 and 3.5 summarize methods for recognizing the potential for excursions at in situ mining prospects and methods for recognizing excursions when they occur, respectively.

3.1 HORIZONTAL EXCURSIONS

The only serious horizontal excursions at sites in this study occurred during the early history of in situ uranium mining. At the Highland site several intense and long-term excursions took place during experimental pilot tests in the early- to mid-1970's (predating the Nuclear Regulatory Commission). These excursions were attributed to numerous breakdowns in pumping equipment and failure to adjust injection-production rates. Between March, 1972 and October, 1974 the total volume of fluid injected exceeded the amount produced at Highland, a practice which is now recognized by the industry as a fundamental cause of horizontal excursions. At Bruni, Texas 15 horizontal excursions were reported between Sept., 1976 and

Dec., 1977 in a commercial operation containing over 1700 production and injection wells. However, during the next four years of mining no more horizontal excursions were reported. The same company (Wyoming Mineral Company) performed commercial scale mining (over 250 production and injection wells) at Irigaray, Wyoming from Nov., 1978 to Dec., 1981 with only one brief (3 months) and unequivocal horizontal excursion. Evidently, WMC has developed an effective methodology for controlling the horizontal movement of lixiviant within the ore zone and its immediate surroundings.

There is direct evidence that poor control of injection and production rates is the fundamental cause of horizontal excursions. Early excursions at Highland occurred when malfunctioning production wells were shutdown for repairs without taking any compensating measures. At Bison Basin, excursions occurred in several monitor wells adjacent to a row of injection wells without any production wells between them. At Nine Mile Lake, lixiviant was simultaneously injected into two ore zones without control over the rates of injection into each zone. All of the horizontal excursions at Nine Mile Lake occurred in the upper ore zone, suggesting that the majority of lixiviant was discharged through the upper, rather than the lower, screened interval of each injection well. A number of horizontal excursions occurred at Collins Draw where no storage space was available for excess production fluid. Therefore, injection rates were (out of necessity) equal to or greater than production rates.

The natural ground-water gradient and external influences on the gradient contribute to the incidence of horizontal excursions. Well-field design should take these factors into consideration. This was not done at Bison Basin where the natural gradient was parallel to single rows of production and injection wells without any production wells on the downgradient side of the field. A monitor well on the southeast (downgradient) side of the well-field remained on excursion status for over a year beyond the end of the pilot test, presumably because the escaping lixiviant could not be drawn back into the field. Underground conventional mine dewatering contributed to horizontal excursions during expanded pilot tests at Highland. Nearly all of these excursions took place on the downgradient side of the well-field and toward the underground mine. However, production wells were located downgradient from the nearest injection well and these excursions were all brought under control within 2 to 5 months by adjusting production and injection rates.

Excursion control remedial actions provide indirect evidence that poor control of injection and production rates was responsible for initiating an excursion. Most excursions were brought under control within a few weeks or months simply by adjusting injection rates downward and production rates upward in wells adjacent to the effected areas. The implication is that excursions can be turned on and off, simply by manipulating local or field-wide injection and production rates. The most persistent horizontal excursions occurred at Collins Draw because excess production fluid could not be stored. Hence, unbalanced injection and production rates could not be corrected in one part of the field at Collins Draw without throwing them out-of-balance elsewhere.

A few of the relatively persistent horizontal excursions required more intense remedial action measures for their control. All of these measures, however, are variations involving the adjustment of injection and production rates. In some cases natural ground water was injected without refortifying it with lixiviant, while increasing the production rate. In other cases injection wells were shutdown completely while production continued. At Nine Mile Lake (where lixiviant had been simulatenously injected into upper and lower ore zones) the upper zone was sealed off while production continued from both ore zones. All of the above methodologies were effective in bringing horizontal excursions under control and all, in one way or another, involved the adjustment of injection and production rates.

In summary, the industry has demonstrated both the abiiity to reduce the frequency of horizontal excursions and to control them when they do occur. Excursions are reduced by controlling the field-wide production rate at a few percent greater than the injection rate (known as "bleeding" the ore zone aquifer) and storing the excess fluid in a secure surface impoundment for eventual evaporation. The size of the bleed will necessarily be limited by the size of the impoundment and evaporation rate. In no case should in situ mining of uranium take place without storage space for excess production fluid. In any event, infrequent horizontal excursions can be expected because operating systems are occasionally upset, the ore zone aquifer is nonhomogeneous, and the ground-water system is subject to transient external influences. Thus, local imbalances in injection and production rates will occur despite the implementation of a field-wide bleed. The frequency and intensity of localized horizontal excursions are inverse functions of the bleed rate. Nevertheless, horizontal excursions can be controlled by either local or field-wide manipulations of injection and production rates ranging from slightly reduced injection to complete injection well shut-down while continuing to produce from the ore zone aquifer. The options available will depend on the size of the impoundment for storage of excess production fluid.

3.2 VERTICAL EXCURSIONS

Serious vertical excursions persisted through the end of 1981 when commercial scale in situ mining was suspended in response to the declining uranium market. At Bruni, 12 shallow aquifer monitor wells were on excursion status one or more times during the same time interval (1978-81) that no horizontal excursions were reported. The duration and current status of these excursions is unknown. About half of the wells on excursion status at Bruni may have received contaminated water from a leaking evaporation pond, but other monitor wells appear to be beyond the influence of the evaporation pond. At Irigaray 8 shallow monitor wells were on excursion status one or more times for durations ranging from 2 months to 3.5 years. Although the causes of most vertical excursions are well known, attempts to control them have not been very successful.

The preponderance of evidence suggests that most vertical excursions are caused in the upper aquifer by improperly plugged and abandoned exploration holes and by poorly completed field wells. Among in situ mining

sites where both upper and lower aquifer monitor wells were present, all but one of the reported excursions took place in the upper aquifer. Thirteen of 30 monitor wells completed in the upper aquifer were reported on excursion on one or more occasions (some for extended periods of time) whereas only 1 of 14 wells completed in the lower aquifer was placed on excursion status (twice, for 1 and 6 weeks). It is likely, however, that this lone well experienced false alarms. It was placed on excursion status when a single trace element (uranium) exceeded its unrealistically low UCL (12 ppb) by only 5 ppb. No common anions were ever reported above their UCLs for any lower aquifer monitor well at the 8 in situ mine sites in this study. The good statistical correlation between the number of holes that penetrate the upper and lower aquifers and the number of excursions suggests the obvious: that somehow vertical excursions are directly related to the intensity of drilling activity. Exploration holes and wells that penetrate the upper aquifer outnumber those that penetrate the lower aquifer by perhaps two orders of magnitude. Furthermore, wells that penetrate the lower aquifer are seldom (if ever) used to transport lixiviant.

When a vertical excursion occurs standard practice is to locate abandoned open boreholes and pressure test completed wells in a search for defective or broken casings. Improperly plugged exploration holes are sealed and damaged wells are either recompleted or abandoned and sealed. The effectiveness of these procedures in controlling vertical excursions depends on the ability to locate all the abandoned holes. Older holes are most likely to be unplugged. However, they are difficult to locate because of the lack of records, the scattering and covering of well cuttings by erosion and vegetation, respectively, and the collapse of exposed surface casing, if indeed permanent casings were ever installed.

Approximately 15 monitor wells were placed in the upper aquifer at Irigaray during pilot tests and commercial scale mining. Eight of these wells were placed on excursion status for periods ranging from one month to more than 3 years. Three excursions were confirmed casing failure incidents. A total of 52 field wells were repaired or plugged and abandoned to shutoff the flow of lixiviant to the upper aquifer. Field well repairs in combination with increased production from nearby ore zone wells and direct pumping from monitor wells brought two of these excursions temporarily under control within 5 months. Although these corrective actions were beneficial, they were not completely effective. One well remained on excursion status continuously for over 3 years and the other 2 wells experienced later excursions that lasted 2 and 5 months. Three other excursions were evidently caused by open exploration holes. As in the casing failure excursions previously described, open bore holes were sealed, monitor wells were pumped, and production rates were increased in the vicinity of the excursions. Again the corrective actions were partially effective.

Possible causes of renewed excursions at the above sites are speculative. It is reasonable to assume that some open exploratory holes were never found. On the other hand, the confining bed overlying the ore zone aquifer is relatively thin (1.5 to 3 m) at Irigaray and may even be absent

in some places. Most upper aquifer monitor wells were screened in a thin coal unit to provide for an early warning of an excursion. Thus, the possibility exists that vertical excursions are taking place through a leaky confining layer as well as through undiscovered open boreholes.

Nevertheless a leaky aquifer does not appear to be the main cause of vertical excursions at Irigaray. Otherwise, adjusting injection and production rates should have been more effective in controlling these excursions. Furthermore, there should have been some leakage through the lower confining layer as well. In contrast to the upper aquifer where a number of prolonged and difficult to control excursions were reported, none of the 6 monitor wells in the lower aquifer was ever placed on excursion status. The lower confining bed is about 4.5 to 18 m thick, about twice as thick as the upper confining bed. Therefore, the lower bed should be only fractionally less leaky than the upper bed and at least a few excursions of brief duration might have been expected.

At Bruni, 45 of approximately 120 upper aquifer monitor wells were placed on excursion status; many for extended periods of time. As at Irigaray, broken casings and open boreholes are believed to be the main pathways of excursion. At Bruni, however, a number of vertical excursions were also caused by the rupture of an evaporation pond liner. Leakage is unlikely through confining strata because they are thick (15 to 18 m), dense claystones.

Corrective actions at Bruni were apparently ineffective. The licensee attempted to halt the spread of contaminants in the shallow aquifer by injecting fresh water around the perimeter of the affected areas while withdrawing contaminated water from the interior. A number of monitor wells remained on excursion status for several years.

Three other mine sites reported a total of 5 minor vertical excursions. Only one of these excursions was of any consequence. It was caused by a ruptured casing in an injection well. A new well was drilled within 3 meters of the damaged well to clean-up and monitor the affected aquifer. The clean-up well remained on excursion status for approximately 4 months.

3.3 SUMMARY OF EXCURSIONS, THEIR CONSEQUENCES, CAUSES, AND CONTROL

Horizontal excursions are not of serious concern in in situ uranium mining. First, the manipulation of injection and production rates is adequate for controlling horizontal excursions. Second, eventual restoration of an ore zone aquifer is an extension of horizontal excursion control. During aquifer restoration the bleed rate would be increased and natural or treated (rather than lixiviant rich) ground water would be injected. Natural ground water would also be swept through the ring of monitor wells and toward producing field wells. Thus aquifer restoration methodology is similar to, but more intensive than, horizontal excursion control. Any areas remaining on excursion status at the end of mining would automatically be brought under control during the restoration process.

On the other hand, the in situ mining industry has yet to demonstrate an effective method for controlling vertical excursions. Vertical excursions in this study generally lasted from several months to several years. A number of excursions that appeared to have been brought under control eventually recurred. Although notable improvements have been made in pressure testing field wells after their completion, the ability to locate and seal all open exploration holes is still questionable.

There is serious concern for vertical excursions for several reasons. First, shallow aquifers are likely to be suitable for livestock and domestic use. Second, existing technology does not appear to be adequate for vertical excursion control. Finally, eventual ore zone aquifer restoration has no effect upon an overlying aquifer after excursion pathways have been sealed-off. Therefore, excursion control of an overlying aquifer may require the installation of a separate set of field wells and a level of effort similar to that used for the restoration of the ore zone aquifer, itself.

The following sections discuss: 1) procedures for identifying excursion prone areas before mining begins, and 2) methodologies for early detection of excursions in an active mining area. The prevention and control of vertical excursions is emphasized.

3.4 AQUIFER TESTS

Aquifer testing is an accepted methodology for developing a well-field design at an in situ mine. Hydraulic properties of the ore zone aquifer are determined from these tests and they are used to determine distances between injection and production wells and their design flow rates.

Ore zone aquifers having suitable hydraulic properties for in situ mining also have the potential for horizontal excursions. Areas having low hydraulic conductivities and transmissivities would be unlikely candidates for either horizontal excursions or in situ mining. On the other hand, some areas might have such high natural ground-water gradients and transmissivities that the risk of horizontal excursions is unacceptably high. However, none of the 8 mine sites in this study experienced horizontal excursions that could not have been controlled through good management practices such as those described in previous sections.

Present aquifer testing procedures are adequate for measuring hydraulic properties in areas where the risk of horizontal excursions might be unacceptable. However, neither the upper limit for transmissivity (this limit being functionaly related to the ground-water gradient) nor the unacceptable risk has ever been defined. These limits will only become known when state-of-the-art technology fails to control a horizontal excursion.

In contrast to their use in appraising the potential for horizontal excursions, present aquifer testing procedures have had more limited success in determining the potential for vertical excursions. The limited

Table A.1. Summary of major characteristics at seven in situ uranium mines in Wyoming and one mine in Texas.

Mine Operator and Name	Lixiviant	Geologic Setting	Ore Zone	Number of Monitor Wells Reported on Excursion[a]
Wyoming Mineral Corporation, Irigaray	NH_4HCO_3 and $NaHCO_3$	SW Powder River Basin. No faults or folds.	Sandstone in Wasatch Formation (Eocene).	10
Ogle Petroleum, Inc., Bison Basin	$NaCO_3/HCO_3$	Bison Basin. Folding and several normal faults.	Sandstone in Green River Formation (Eocene).	10
Rocky Mountain Energy Company, Nine Mile Lake	H_2SO_4 and $NaCO_3/HCO_3$	SW Powder River Basin. Folding; no faults.	Sandstone in Mesa Verde Formation (Cretaceous).	5
Exxon Minerals Company, Highland	$NaCO_3/HCO_3$	S. Powder River Basin. No faults or folds.	Sandstone in Fort Union Formation (Paleocene).	11
Teton Exploration Drilling Company, Leuenberger	$NaCO_3/HCO_3$	S. Powder River Basin. No faults or folds.	Two sandstones in Fort Union Formation (Paleocene).	0
Rocky Mountain Energy Company, Reno Creek	H_2SO_4 $NaCO_3/HCO_3$	SE Powder River Basin. No faults or folds.	Sandstone in Wasatch Formation (Eocene).	0
Cleveland Cliffs Iron Company, Collins Draw	NH_4CO_3	S. Powder River Basin. No faults or folds.	Sandstone in Wasatch Formation (Eocene).	5
Wyoming Mineral Company, Bruni	NH_4CO_3/HCO_3	Texas Coastal Plain. No faults or folds.	Clayey Sandstone in Catahoula Formation (Miocene).	>60

[a]Individual wells may have been placed on excursion status more than once.

Exhibit C

COGEMA Mining, Inc.

ANNUAL REPORT
WDEQ PERMIT TO MINE NO. 478

IRIGARAY AND CHRISTENSEN RANCH PROJECTS

August 19, 1997 - August 18, 1998

August, 1998

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August 19, 1991 - July 31, 1992	239,723
August 1, 1992 - June 30, 1993	168,967
July 1, 1993 - June 30, 1994	323,726
July 1, 1994 - June 30, 1995	417,237
July 1, 1995 - June 30, 1996	713,238
July 1, 1996 - June 30, 1997	650,197
July 1, 1997 - June 30, 1998	523,237

f) All major construction during this reporting period occurred at the Christensen Ranch Project, and is described as follows:

- Development activities in Mine Unit 7, consisting of baseline well installation, delineation drilling, and well installation continued throughout this annual reporting period.
- A 50' x 100' construction building was installed at the Christensen laydown area.
- Injection and recovery trunklines were extended from Unit 6, Module 6-5, to Module 6-6 and southward to Unit 7.
- An access road was constructed to Unit 6, Module 6-5 from the main road in Unit 6.

Locations of all noted areas are shown on the Christensen Project General Location map provided in Appendix F.

g) Twenty-four reportable spills occurred during this reporting period, six at the Christensen Ranch Mine and eighteen at the Irigaray Mine. Of the twenty-four reportable spills, 50 percent were below the 420 gallon reporting limit as specified in the Land Quality Division's January 29, 1997 policy on spills at in-situ mines. These spills were reported to the Cheyenne, WDEQ, Water Quality Division and the WDEQ District III Land Quality Division offices only because a small portion of the spill entered into a dry draw. The remainder of the spills exceeded the 420 gallon reporting limit. A verbal and written report of each spill are issued to the WDEQ subsequent to each occurrence. The status of each will therefore not be repeated in this report.

No revegetation problems were experienced during this reporting period.

4. RECLAMATION

a) Status of Restoration and Reclamation Activities

Groundwater Restoration Progress Report - Irigaray

Groundwater restoration activities at the Irigaray site continued during this reporting period. A summary of the status of each restoration area is provided below. A map of the Irigaray restoration

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wellfields is provided in Appendix A of this report.

- Production Units 1-3: Restoration was completed in these wellfields in 1993. No further actions have been taken in these wellfields pending submittal of the final restoration package for Production Units 1 through 5. All of Units 1 through 5 were mined with ammonium bicarbonate lixiviant, and COGEMA feels it is best to present the restoration results of all Units 1 through 5 together. The submittal will be made at the end of Units 4 and 5 restoration completion.

- Production Units 4-5: At the time of the last Annual Report submittal, reverse osmosis operations were continuing in Units 4 and 5. The reverse osmosis phase of restoration was completed in Unit 4 at the end of October, 1997. At this time, all reverse osmosis operations were concentrated in Unit 5. Reverse osmosis operations continued in Unit 5 until the end of December, when severely cold weather caused the wellfield lines to freeze and operations were temporarily discontinued. Some flow was restored to the wellfield in January and February, 1998, with the resumption of full reverse osmosis operations in Unit 5 during March. By May, 1998, the goal of pre-mining concentrations of conductivity (indicative of TDS) was reached in Unit 5. However, work was then concentrated in several small patterns within the wellfield that had exhibited conductivity levels higher than baseline. For this reason, a slight increase in the average recovery conductivity was seen during the following two months of June and July, 1998.

  Data tables and graphs depicting the restoration progress in terms of gallons produced, cumulative pore volume displacements (PVD) removed and resultant water quality are provided in Appendix A of this report. The graphical presentation of the data indicates that the goal of restoration has been achieved in Units 4 and 5 with a total of 9.2 pore volumes of reverse osmosis treatment. There are no plans at this time to use a chemical reductant in these units as uranium is well below drinking water standards, and the addition of the reductant will cause TDS concentrations to increase. Plans are to begin the final recirculation of the two wellfields in August.

- Production Units 6-9: Minimal activity occurred in Units 6 through 9 during the reporting period as all efforts were concentrated in Units 4 and 5. Groundwater sweep continued in Unit 6, close to the border of Unit 5, so that solutions from Unit 6 were not pulled into Unit 5 while reverse osmosis activity was ongoing. Data tables and graphs depicting the restoration progress in terms of gallons produced, cumulative pore volume displacements (PVD) removed and resultant water quality are provided in Appendix A of this report. The water quality data presented shows that the Unit 6 conductivity concentrations are currently quite low, indicative that some cleansing action from Unit 5 is occurring.

  Plans are to commence reverse osmosis operations in Production Unit 9 during October, 1998. This schedule is dependent upon the time necessary to dismantle and move the two reverse osmosis (RO) units, currently located in the Units 1-5 Wellfield Building, over to the main plant. This is necessary as the trunklines servicing Units 7, 8 and 9 run directly from those units to the main plant, and do not connect with the Units 1-5 Wellfield Building. The

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RO units could not be moved to the main plant until treatment was completed in Unit 5. COGEMA will start reverse osmosis treatment in Unit 9 first, to take advantage of the local groundwater gradient, which is towards the northwest (pull in clean water from the south of Unit 9). The operations will then move north towards Units 8, then Unit 7, with Unit 6 as the last unit to receive reverse osmosis treatment.

Groundwater Restoration Progress Report - Christensen Ranch

Groundwater sweep activities continued in Mine Units 2, 3 and 4 during this reporting period. A map showing the locations of these units is provided in Appendix F of this report. A restoration status summary of each wellfield is provided following:

- Mine Unit 3: Groundwater sweep was first initiated in Mine Unit 3 in November, 1996. As of November, 1997, the goal of one PVD of groundwater sweep had been met (see data tables and graphs depicting the restoration progress in terms of gallons produced, cumulative pore volume displacements (PVD) removed and resultant water quality contained in Appendix A of this report). Groundwater sweep from Mine Unit 3 continued, however, primarily withdrawing groundwater from areas within the wellfield that exhibited higher conductivity and uranium concentrations.

  All groundwater sweep activities were terminated within Mine Unit 3 at the end of July, 1998, when COGEMA ceased all surface discharge activities. COGEMA's NPDES permit for the discharge of restoration wastewater was reissued on July 31, 1998 with a new selenium limit of 0.05 mg/l. As COGEMA is not able to meet this limit through conventional water treatment methods, the discharge of restoration solutions stopped on July 31. Because the other wastewater disposal systems such as the disposal well and evaporation ponds are not capable of handling the additional volumes of groundwater sweep solutions, and surface discharge is no longer an option, restoration in all wellfields at Christensen Ranch was terminated at the end of July.

  At the end of July, 1998, a total of 1.844 PVD had been removed from Mine Unit 3 through groundwater sweep. During the almost two year period of pumping the 1.844 PVD, conductivity concentrations declined somewhat, but not significantly. This is not unexpected, as the groundwater sweep phase is intended to simply move all solutions to within the wellfield where further treatment can occur. Significant improvements in the water quality levels are not anticipated until reverse osmosis treatment begins.

  Plans are to resume restoration activities in Mine Unit 3 as soon as more wastewater disposal capacity is available, tentatively scheduled during the fourth quarter of 1998. COGEMA has been aware of the wastewater disposal problem for several years now, primarily after injection into the existing disposal well has essentially failed. In September, 1997, COGEMA filed an application with DEQ, Water Quality Division (WQD), to permit a new injection interval within the existing well. In October, WQD issued a draft permit approving the new interval and no comments were received during the 30-day public comment period. EPA, however, objected to issuing the aquifer exemption for the new interval due to total

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dissolved solids concentrations being less than 3,000 mg/l. After further deliberations and data submittals to EPA, both EPA Region 8 and EPA Headquarters have recently concurred that the aquifer exemption should be issued as a significant revision to Wyoming's UIC program. COGEMA now expects to receive the WQD permit for the new interval in October, 1998, after another 30-day public comment period. Immediately after receiving the permit, the new interval will be completed in the existing disposal well. If all goes according to schedule, the well could be in operation during November or December, 1998, at a rate capable of sustaining continued restoration activities.

- Mine Unit 2: Groundwater sweep in Mine Unit 2 was initiated in May, 1997. One PVD of groundwater sweep was reached in this wellfield by the end of October, 1997. Although the goal of 1 PVD of groundwater sweep had been reached, sweep operations continued through the end of July, 1998, when all restoration activities at Christensen were terminated. At this point, a total of 1.797 PVD had been removed. Data tables and graphs depicting the restoration progress in terms of gallons produced, cumulative pore volume displacements (PVD) removed and resultant water quality are provided in Appendix A of this report.

  During the one year, two month period that the 1.797 PVD were removed, water quality in Mine Unit 2 improved only slightly. This is expected during the groundwater sweep phase. The significant improvements in water quality come during the reverse osmosis phase of restoration treatment.

  As stated above, Mine Unit 3 at Christensen will be the first unit to undergo reverse osmosis treatment, at the rate of 500 gpm. The schedule then calls for reverse osmosis to begin in Mine Unit 2 following completion of Mine Unit 3. In the interim period while Mine Unit 3 undergoes treatment, a limited bleed for excursion control will be maintained in Mine Unit 2 on an as-needed basis.

- Mine Unit 4: Groundwater sweep was initiated in Mine Unit 4 during August, 1997. One PVD of groundwater sweep was removed by the end of the year. Groundwater sweep continued through July, 1998, when all restoration activity was terminated. At the time of groundwater sweep termination, a total of 1.926 PVD had been removed from Mine Unit 4. Data tables and graphs depicting the restoration progress in terms of gallons produced, cumulative pore volume displacements (PVD) removed and resultant water quality are provided in Appendix A of this report.

  During the past eleven month period that the almost 2 PVD were removed, water quality in Mine Unit 4 improved slightly. This is expected during the groundwater sweep phase. The significant improvements in water quality come during the reverse osmosis phase of restoration treatment. Some of the increases seen in conductivity concentrations during the last few months of operation were caused by the pumping of selective areas within Mine Unit 4 that exhibited higher uranium and conductivity concentrations.

  The schedule for beginning reverse osmosis in Mine Unit 4 is dependent upon the schedule for start-up and completion of reverse osmosis treatment in Mine Units 3 and 2. In the

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6. 1998 - 1999 RECLAMATION PLAN

a) Surface Reclamation

IR: No surface reclamation is anticipated in the fall of 1999 at the Irigaray mine.

CR: Interim reclamation is planned for disturbed areas of the Mine Unit 7, Modules 7-1, 7-2, and 7-3. It is planned to conduct the seeding during the spring of 1998. Fall reclamation will be scheduled in 1998 if needed.

b) Aquifer Restoration

IR: As previously stated in Section 4 of this report, plans are to complete the final recirculation phase of restoration in Production Units 4 and 5 by September, 1998, then commence stability monitoring. The final restoration completion report will then be submitted to the regulatory agencies. If agency approval is received in time, wellfield decommissioning and well abandonment will begin in these units during 1999.

Reverse osmosis treatment is scheduled to begin in Production Unit 9 in October, 1998. This should continue for the remainder of 1998 and 1999.

CR: Pending the re-completion of the existing disposal well, reverse osmosis treatment should begin in Mine Unit 3 during the fourth quarter of 1998. This will continue through the remainder of 1999. Mine Units 2 and 4 will remain in standby (between groundwater sweep and the reverse osmosis phases of restoration) until the completion of reverse osmosis work in Mine Unit 3 .

A possibility exists that limited groundwater sweep may commence in Mine Unit 5 after the completion of mining and if wastewater disposal capacity exists.

7. MONITORING ACTIVITIES

a) Groundwater Monitoring

- Groundwater quality at both the IR and CR wellfields is continuously monitored through the sampling of environmental trend and monitor wells. Analytical results and associated water level data obtained from the sampling of the environmental wells for January 1, 1998 through June 30, 1998 are contained in Appendix B of this report. A computer disk containing the same information is included with this report. The locations of the environmental wells cited may be found on the Irigaray and Christensen Ranch General Location Maps or Piezometric maps located in Appendix F of this report.

Excursion Status Report - Seven monitor wells remained on excursion status during this reporting period. Six are located at the Irigaray site within restored wellfields, or within a

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wellfield undergoing restoration. These monitor wells are SSM3, SSM18, SSM40, SSM42, SSM43, and DM10. One well, MW-89, is located in Unit 2 of the Christensen Mine. Three wells were taken off excursion status during this reporting period, one at Irigaray and one at the Christensen Ranch site: SSM42 (Irigaray), and 6MW46 (Christensen). Monitor well MW89 was removed from excursion status on December 23, 1997 and was placed back excursion status on August 7, 1998. A listing of the wells is provided below. Monthly and quarterly excursion status reports are issued to the WDEQ and NRC, respectively. The status of each will therefore not be repeated in this report.

Irigaray

Interior Shallow Sand Monitor Well SSM3: Irigaray Production Unit 2.
Date of Initial Excursion: August 30,1996

Interior Shallow Sand Monitor Well SSM18: Irigaray Production Unit 8.
Date of Initial Excursion: September 13, 1996

Interior Shallow Sand Monitor Well SSM40: Irigaray Production Unit 8.
Date of Initial Excursion: August 16, 1996

Interior Shallow Sand Monitor Well SSM42: Irigaray Production Unit 3.
Date of Initial Excursion: October 10, 1990

Interior Shallow Sand Monitor Well SSM43: Irigaray Production Unit 1.
Date of Initial Excursion: October 11, 1989

Interior Shallow Sand Monitor Well DM10: Irigaray Production Unit 6.
Date of Initial Excursion: February 2, 1994

Perimeter Ore Zone Monitor Well MW89: Christensen Production Unit 2.
Date of Initial Excursion: August 7, 1998

Perimeter Ore Zone Monitor Well 6MW46: Christensen Production Unit 6.
Date of Initial Excursion: March 2, 1998
Date of Excursion Termination: April 1, 1998

Interior Shallow Sand Monitor Well SSM41: Irigaray Production Unit 4.
Date of Initial Excursion: September 12, 1997
Date of Excursion Termination: March 4, 1998

b) Surface Water Monitoring

Willow Creek is the only source of surface water present within and adjacent to the permit boundary of both the Irigaray and Christensen Ranch mines. Willow Creek is sampled at the Irigaray site on a quarterly basis at three stations, IR-9 (downstream from the mine at the confluence with the Powder River, IR-14 (upstream from the mine), and IR-17 (located

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Irigaray Units 4-5
Restoration Summary

Date	Conductivity	Monthly KGallons	Cumulative KGallons	Monthly PVD	Cumulative PVD
	Average umhos/cm			1PVD = 10,500 kgal	
Jan-95		0			0
Feb-95		0			0
Mar-95		0			0
Apr-95		0	Begin Restoration	0.000	0
May-95		120	120	0.0114	0.011
Jun-95		282	402	0.0269	0.038
Jul-95		282	684	0.0269	0.065
Aug-95		282	966	0.0269	0.092
Sep-95		898	1864	0.0855	0.178
Oct-95	3800	2184	4048	0.2080	0.386
Nov-95	1704	2347	6395	0.2235	0.609
Dec-95	1647	4069	10464	0.3875	0.997
Jan-96	1473	3590	14054	0.3419	1.338
Feb-96	1770	3733	17787	0.3555	1.694
Mar-96	1323	5113	22900	0.4870	2.181
Apr-96	1172	4259	27159	0.4056	2.587
May-96	1143	1126	28285	0.1072	2.694
Jun-96	1479	992	29277	0.0945	2.788
Jul-96	1264	730	30007	0.0695	2.858
Aug-96	1293	789	30796	0.0751	2.933
Sep-96	1286	988	31784	0.0941	3.027
Oct-96	1276	908	32692	0.0865	3.114
Nov-96	1252	3075	35767	0.2929	3.406
Dec-96	1230	1719	37486	0.1637	3.570
Jan-97	1230	0	37486	0	3.570
Feb-97	1230	0	37486	0	3.570
Mar-97	1230	0	37486	0	3.570
Apr-97	1230	0	37486	0	3.570
May-97	1330	3390	40876	0.3229	3.893
Jun-97	1212	6404	47280	0.6099	4.503
Jul-97	1057	6911	54191	0.6582	5.161
Aug-97	1019	7686	61877	0.7320	5.893
Sep-97	982	6636	68513	0.6320	6.525
Oct-97	893	2051	70564	0.1953	6.720
Nov-97	984	5055	75619	0.4814	7.202
Dec-97	910	3502	79121	0.3335	7.535
Jan-98	1031	245	79366	0.0233	7.559
Feb-98	868	1885	81251	0.1795	7.738
Mar-98	860	4934	86185	0.4699	8.208
Apr-98	798	2484	88669	0.2366	8.445
May-98	766	3750	92419	0.3571	8.802
Jun-98	820	2701	95120	0.2572	9.059
Jul-98	816	1721	96841	0.1639	9.223

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Irigaray Units 6-9
Restoration Summary

Date	Conductivity	Monthly KGallons	Cumulative KGallons	Monthly PVD	Cumulative PVD
	Average umhos/cm			1 PVD = 39500 kgal	
Jan-95		5972		0.151	0
Feb-95		1549		0.039	0
Mar-95		1703		0.043	0
Apr-95	4261	3025	Begin Restoration	0.077	0
May-95	3895	3318	6343	0.084	0.161
Jun-95	3697	2774	9117	0.070	0.231
Jul-95	3538	2454	11571	0.062	0.293
Aug-95	3582	3097	14668	0.078	0.371
Sep-95	3668	2468	17136	0.062	0.434
Oct-95	3395	3077	20213	0.078	0.512
Nov-95	3440	1232	21445	0.031	0.543
Dec-95	3346	1537	22982	0.039	0.582
Jan-96	3033	2278	25260	0.058	0.639
Feb-96	2831	2375	27635	0.060	0.700
Mar-96	2785	1436	29071	0.036	0.736
Apr-96	3121	2935	32006	0.074	0.810
May-96	3744	927	32933	0.023	0.834
Jun-96	3995	917	33850	0.023	0.857
Jul-96	3578	714	34564	0.018	0.875
Aug-96	3633	825	35389	0.021	0.896
Sep-96	3852	943	36332	0.024	0.920
Oct-96	3375	412	36744	0.010	0.930
Nov-96	3231	397	37141	0.010	0.940
Dec-96	3107	335	37476	0.008	0.949
Jan-97	3107	0	37476	0	0.949
Feb-97	3107	0	37476	0	0.949
Mar-97	3107	0	37476	0	0.949
Apr-97	3107	0	37476	0	0.949
May-97	3880	454	37930	0.011	0.960
Jun-97	3798	1099	39029	0.028	0.988
Jul-97	3799	939	39968	0.024	1.012
Aug-97	3820	1138	41106	0.029	1.041
Sep-97	3773	808	41914	0.020	1.061
Oct-97	3763	55	41969	0.001	1.063
Nov-97	2028	1454	43423	0.037	1.099
Dec-97	1640	1247	44670	0.032	1.131
Jan-98	1518	1160	45830	0.029	1.160
Feb-98	1531	331	46161	0.008	1.169
Mar-98	1518	862	47023	0.022	1.190
Apr-98	1570	774	47797	0.020	1.210
May-98	1529	1123	48920	0.028	1.238
Jun-98	1617	924	49844	0.023	1.262
Jul-98	1648	697	50541	0.018	1.280

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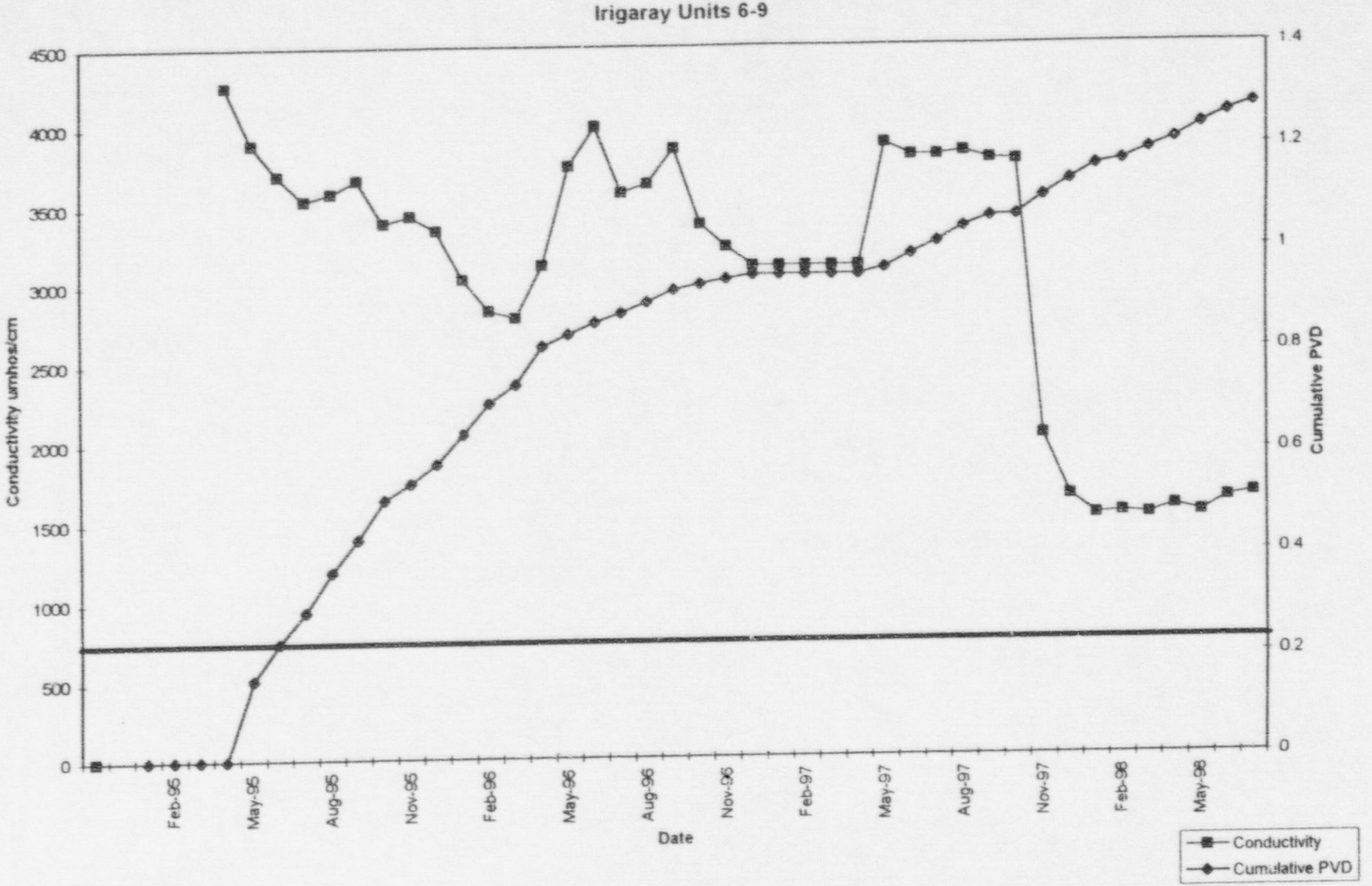

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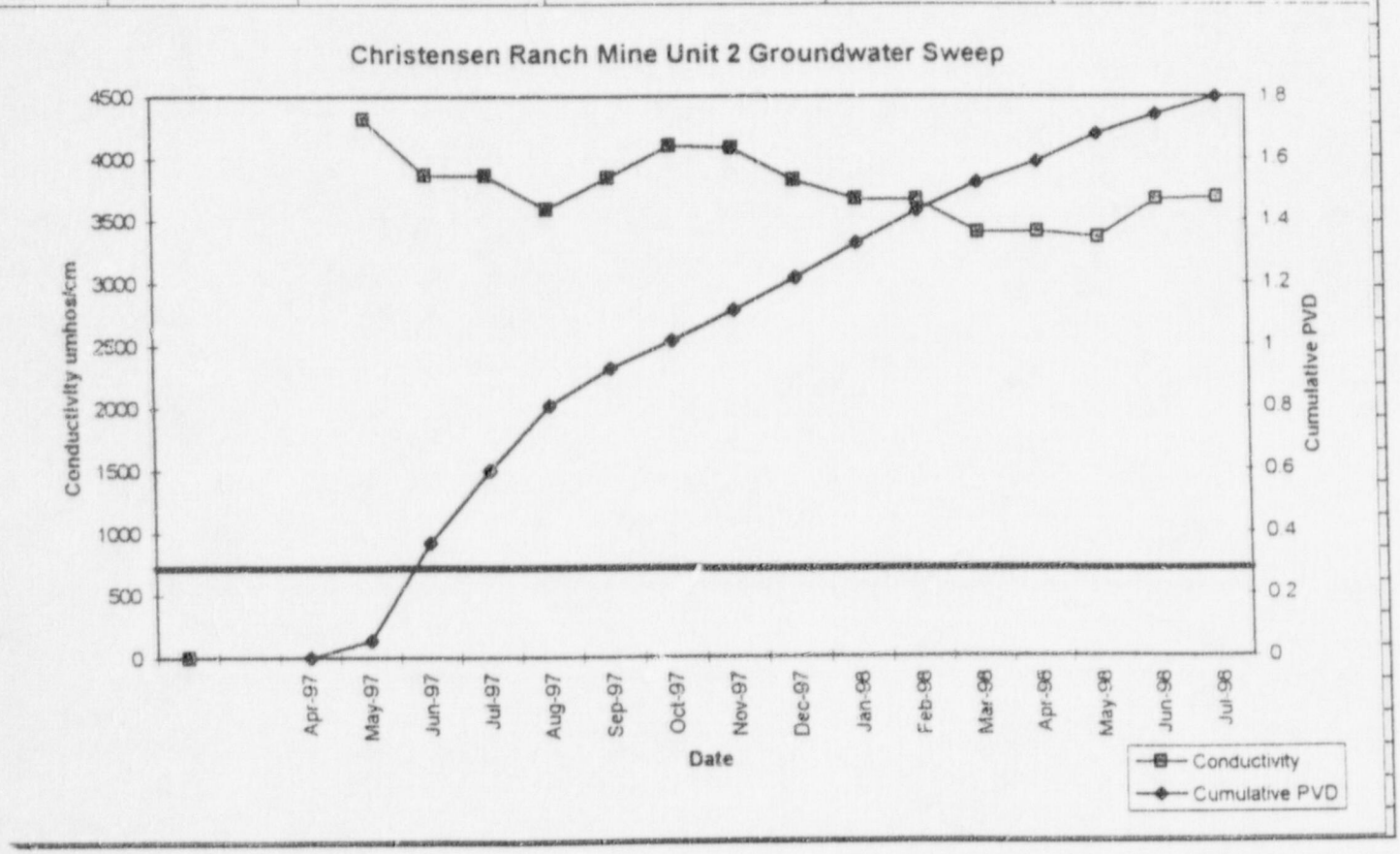
Christensen Ranch Mine Unit 2
Restoration Summary

Date	Conductivity	Monthly KGallons	Cumulative KGallons	Monthly PVD	Cumulative PVD
	Average umhos/cm			1PVD = 27417 kgal	
Apr-97		0	0	0.000	0.000
May-97	4324	1480	Begin restoration	0.054	0.054
Jun-97	3870	8649	10129	0.315	0.369
Jul-97	3869	6314	16443	0.230	0.600
Aug-97	3591	5656	22099	0.206	0.806
Sep-97	3848	3310	25409	0.121	0.927
Oct-97	4103	2406	27815	0.088	1.015
Nov-97	4083	2711	30526	0.099	1.113
Dec-97	3826	2845	33371	0.104	1.217
Jan-98	3673	3041	36412	0.111	1.328
Feb-98	3671	2850	39262	0.104	1.432
Mar-98	3407	2488	41750	0.091	1.523
Apr-98	3413	1828	43578	0.067	1.589
May-98	3363	2460	46038	0.090	1.679
Jun-98	3671	1694	47732	0.062	1.741
Jul-98	3686	1544	49276	0.056	1.797



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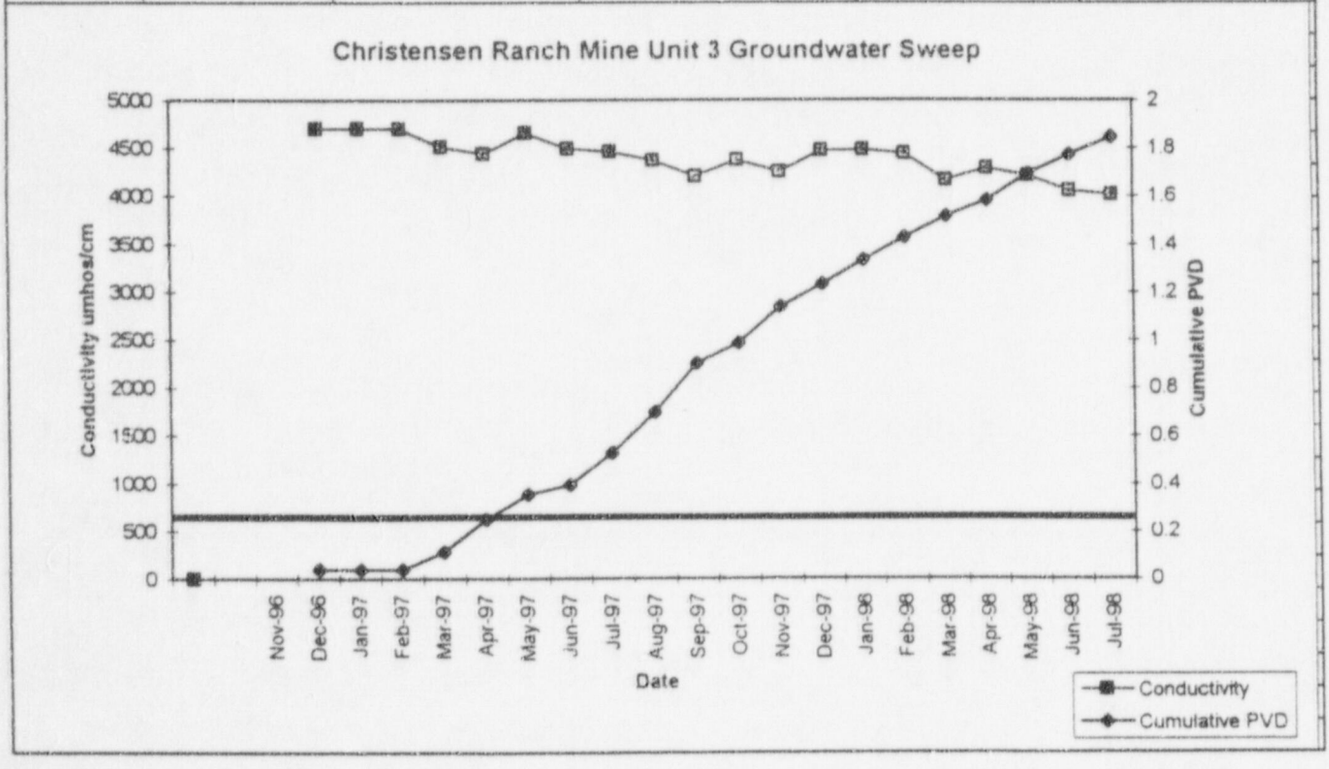
Christensen Ranch Mine Unit 3
Restoration Summary

Date	Conductivity	Monthly KGallons	Cumulative KGallons	Monthly PVD	Cumulative PVD
	Average umhos/cm			1PVD = 21968 kgal	
Nov-96		Begin Restoration			
Dec-96	4703	866	866	0.039	0.039
Jan-97	4703	0	866	0.000	0.039
Feb-97	4703	0	866	0.000	0.039
Mar-97	4514	1607	2473	0.073	0.112
Apr-97	4442	2987	5460	0.136	0.248
May-97	4662	2353	7813	0.107	0.355
Jun-97	4494	870	8683	0.040	0.395
Jul-97	4463	2888	11571	0.132	0.527
Aug-97	4369	3764	15335	0.171	0.698
Sep-97	4206	4510	19845	0.205	0.903
Oct-97	4375	1834	21679	0.084	0.987
Nov-97	4255	3366	25045	0.153	1.140
Dec-97	4473	2037	27082	0.093	1.233
Jan-98	4481	2224	29306	0.101	1.334
Feb-98	4443	2079	31385	0.095	1.429
Mar-98	4166	1937	33322	0.088	1.517
Apr-98	4289	1454	34776	0.066	1.583
May-98	4213	2412	37188	0.110	1.693
Jun-98	4056	1743	38931	0.079	1.773
Jul-98	4015	1579	40510	0.072	1.844



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Christensen Ranch Mine Unit 4
Restoration Summary

Date	Conductivity	Monthly KGallons	Cumulative KGallons	Monthly PVD	Cumulative PVD
	Average umhos/cm			1PVD = 19568 kgal	
Aug-97	4290	1346	Begin restoration	0.069	0.069
Sep-97	3848	2462	3808	0.126	0.195
Oct-97	4103	7524	11332	0.385	0.579
Nov-97	4083	5249	16581	0.268	0.848
Dec-97	3826	3676	20257	0.188	1.035
Jan-98	3334	2725	22982	0.139	1.175
Feb-98	3439	2921	25903	0.149	1.324
Mar-98	3037	2568	28471	0.131	1.455
Apr-98	2937	1086	29557	0.055	1.511
May-98	3366	3651	33208	0.187	1.697
Jun-98	3720	2697	35905	0.138	1.835
Jul-98	3401	1776	37681	0.091	1.926

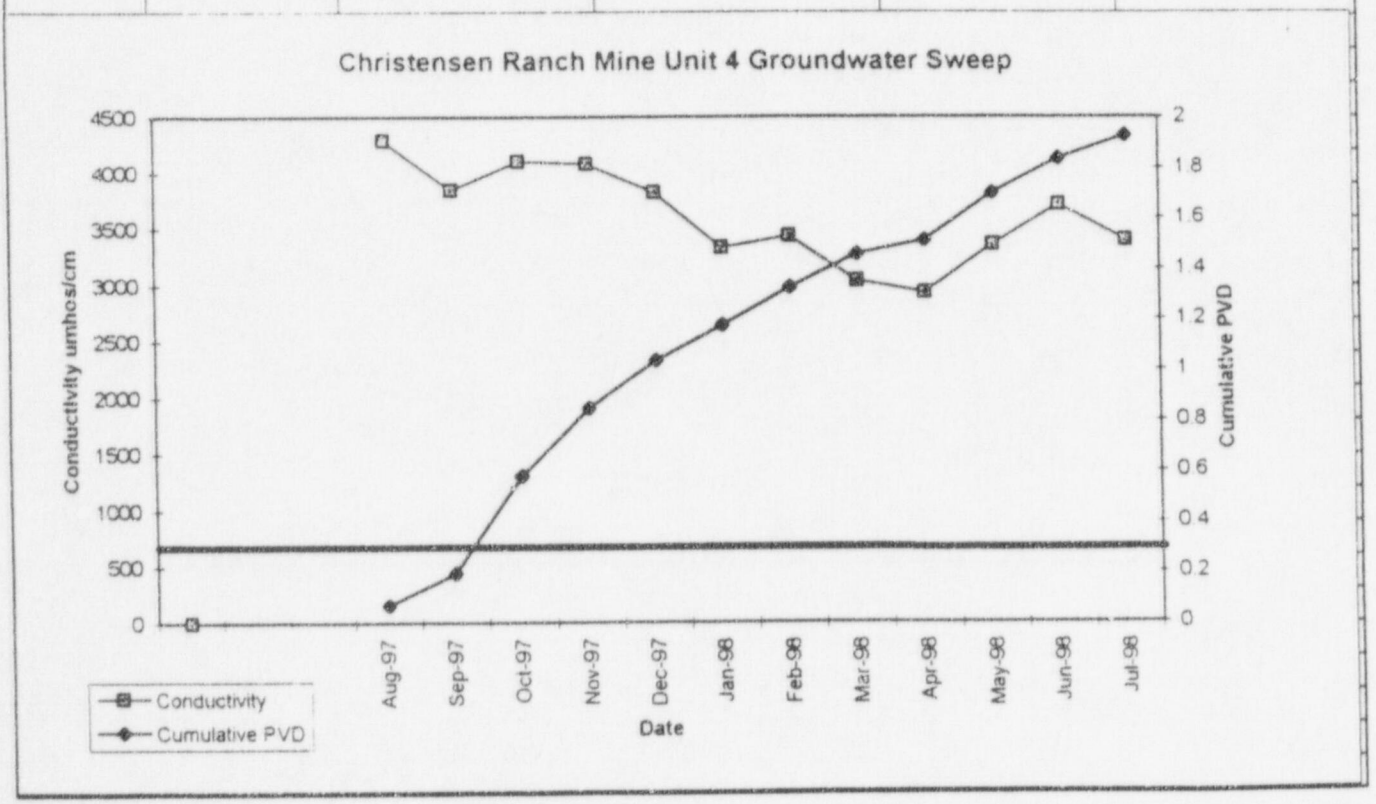

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Exhibit D

40-8502

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 30, 1998

COGEMA Mining, Inc.
ATTN: Donna L. Wichers, Manager
ISL Environmental and Regulatory Services
935 Pendell Boulevard
P.O. Box 730
Mills, WY 82644

SUBJECT: RENEWAL OF SOURCE MATERIAL LICENSE SUA -1341 FOR THE IRIGARAY/CHRISTENSEN RANCH ISL FACILITY

Dear Ms. Wichers:

The U.S. Nuclear Regulatory Commission (NRC) staff has completed its review of COGEMA Mining, Inc.'s (COGEMA) license renewal application for Source Material License SUA-1341, as submitted by letter dated January 5, 1996. Additional supplements and revisions to the renewal application were provided by letters dated December 13, 1996, and September 3, 1997.

The NRC staff determined, in accordance with 10 CFR 51.25, that preparation of an environmental assessment (EA) was necessary to document its review. The NRC staff issued an EA (Enclosure 1) to the public document file on June 18, 1998. Based on its analysis, the NRC staff concluded that the environmental impacts associated with the proposed license action (i.e., renewal of SUA-1341) were not significant and that the proposed action was acceptable. A final finding of no significant impact (FONSI) was prepared in accordance with 10 CFR 51.32, and, on June 26, 1998, published in the Federal Register (Enclosure 2), providing notice of: (1) the NRC's intent to issue the proposed license amendment, (2) the availability of the EA to the public, and (3) an opportunity for hearing for affected individuals.

The NRC staff also reviewed COGEMA's license renewal application for compliance with the requirements under 10 CFR Parts 20 and 40 and prepared a Safety Evaluation Report (SER) to document its review. A copy of the SER is provided as Enclosure 3. Upon completion of the safety review, the NRC staff concludes that the continuation of commercial operations at the Irigaray and Christensen Ranch facilities, in accordance with specified license conditions, is protective of the public health and safety and fulfills the requirements of 10 CFR Parts 20 and 40.

Therefore, pursuant to 10 CFR Part 40, Source Material License SUA-1341, is hereby issued for the continued commercial operations at the Irigaray and Christensen Ranch Uranium ISL Facility. The renewal license is provided as Enclosure 4. With this licensing action, the NRC staff will be authorizing continued operations under the Performance-Based License Condition format. The license has been renewed for a 10-year term

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In preparing the renewed license, NRC has also considered and addressed several additional issues and requests for amendments that COGEMA has made since the renewal request was submitted. Thus, in response to those communications, NRC has simplified and standardized the spill and incident reporting requirements that were in the existing license; has approved the general restoration plan, which resolves questions COGEMA has had about the appropriateness of proceeding with early restoration activities; and has reflected acceptance of COGEMA's efforts to use a new injection zone, the Lance formation for the two deep disposal wells, as part of the larger renewal action.

If you have any questions regarding this letter or the enclosures, please contact Janet Lambert at (301) 415-6710.

Sincerely,

[D. Gillen for]

Joseph J. Holonich, Chief
Uranium Recovery Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Docket No. 40-8502
License No. SUA-1341
Cases Closed: L51221, L51444
L51476, L51581, L52597

Enclosures: As stated (4)

cc: w/o enclosures:
G. Cash, WDEQ-LQD
G. Mooney, WDEQ-LQD
R. Poyser, COGEMA

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NAME	JLambert/eb/cc		DGillen		JHolonich				
DATE	6/30/98	H	6/30/98	H	6/30/98				

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ENVIRONMENTAL ASSESSMENT FOR RENEWAL OF SOURCE MATERIAL LICENSE NO. SUA-1341

COGEMA MINING, INC.
IRIGARAY AND CHRISTENSEN RANCH PROJECTS
CAMPBELL AND JOHNSON COUNTIES, WYOMING

JUNE 1998

DOCKET NO. 40-8502

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Waste Management

technology where 70% of the water that is withdrawn is reinjected into the aquifer. COGEMA's proposed restoration program has increased the number of PVD's of RO treatment, which reduces water consumption. At the same time, it has also decreased the number of PVD's of groundwater sweep.

5.4.3 Groundwater Quality

Potential groundwater quality impacts from operations at Irigaray and Christensen Ranch are associated with (1) uncontrolled excursions, (2) liner failures in evaporation ponds, (3) accidental leaks or spills of process solutions, and (4) improper or incomplete groundwater restoration.

5.4.3.1 History of Excursions

While it is common to degrade the water quality within the mineralized zone during uranium recovery activities, migration of lixiviant from wellfields (excursions) occurs occasionally due to varying aquifer properties and fluctuations in wellfield pumping rates. Monitoring programs as described in Section 3.7 are implemented to provide early detection of these excursions and to trigger the implementation of corrective action programs to assure that lixiviant does not does not migrate a significant distance from the production zone, and that impacts to the environment will be minimized.

Commercial operations at Irigaray and Christensen Ranch have demonstrated that monitoring is effective in detecting excursions, and that excursions can be controlled at those locations. Horizontal excursions, or those within the ore zone have typically been identified by COGEMA and controlled within a several week period (and sometimes days) by adjusting injection/recovery flow rates within the wellfield, at both Irigaray and Chnstensen.

At Irigaray vertical excursions to the upper or shallow aquifer have proven more difficult to draw back to original baseline. It is believed that this difficulty is due to the fact that excursions into the upper aquifer have been caused by improperly abandoned boreholes and faulty injection well casings from mining operations in the 1970's and 1980's when such processes were not regulated. These holes have since been plugged, and casings have been repaired. Thus, the excursions cannot be withdrawn through the same pathway from which they originated. As of May, 1998, six wells at Irigaray remain on excursion status. Though several parameters exceed baseline values in these wells, chloride, total alkalinity, and conductivity, they are still within class-of-use standards.

At Christensen Ranch, excursions to the ore zone have occurred and have been controlled. Likewise, several vertical excursions have also been controlled and returned to baseline.

In addressing excursions, COGEMA's corrective actions have included:

- Notifying NRC as required by license conditions
- Discontinuing injections of ISL solutions into nearby injection wells
- Reviewing well completion records and mechanical integrity test results for the wells surrounding the excursion well, reviewing historic water levels, and increasing the sampling frequency

- o Implementing groundwater remediation efforts, as needed, and
- o Providing monthly excursion reports to NRC, as required by license condition

A history of the excursions at both the Irigaray and Christensen Ranch sites since 1987 (last permit renewal) is provided as follows.

1987
DM-20 [deep monitor well, Irigaray (IR) Unit 3] was confirmed to exceed the UCLs for all excursion parameters on November 24, 1987. The excursion was determined to be caused by poor cement bond in the annulus of the monitor well. DM-20 was abandoned and replaced with DM-20C. Sampling of DM-20C began on December 21, 1987. No further problems were encountered with the well.

1988
No wells were reported on excursion status during this period.

1989
M-7 and M-18 (perimeter ore zone monitor wells, IR Unit 1) were placed on excursion status on January 27, 1989, and April 21, 1989, respectively. Both wells exhibited elevated sulfate concentrations which directly influence conductivity. The elevated sulfates were thought to be caused by the well being located in the Willow Creek flood plain rather than in the Irigaray wellfield. In March and April 1989, COGEMA requested that the Wyoming Land Quality Division approve a redefinition of the excursion criteria that would alleviate the problem with M-7 and M-18. As a result, M-7 and M-18 were both reported off excursion status in November 1989.

SSM-34 (shallow monitor well, IR Unit 9) was reported in excursion status on February 2, 1989. The well exceeded the UCLs for chloride and alkalinity. Corrective action consisted of re-entering and cementing an improperly plugged exploration hole adjacent to SSM-34. SSM-34 remained stable after replugging the adjacent exploration well. SSM-34 was reported off excursion status on October 19, 1989.

SSM-18 (shallow monitor well, IR Unit 8) was reported in excursion status on July 5, 1989. The well exceeded the UCLs for chloride and alkalinity. Corrective action consisted of over-recovery in the area. SSM-18 was reported off excursion on April 19, 1991.

DM-10 (deep monitor well, IR Unit 6) was reported in excursion status on July 5, 1989. Corrective action consisted of pumping wells adjacent to DM-10 and over-recovery in the area. DM-10 was reported off excursion on December 21, 1992.

SSM-43 (shallow monitor well, IR Unit 1) was reported in excursion status on October 13, 1989. The well exceeded two of three UCLs. Initially, over-recovery in the area was utilized in an attempt to correct the situation until over-recovery was ceased with permission of WDEQ. SSM-43 remains on excursion status.

1990
SSM-39 (shallow monitor well, IR Unit 1) was reported in excursion status in December 1990. The well exceeded the UCLs for chloride and alkalinity. Restoration of Units 1 through 5 was in progress at this time. SSM-39 was reported off excursion status on June 1, 1992.

SSM-42 (shallow monitor well, IR Unit 3) was reported in excursion status on October 10, 1990. The well exceeded the UCLs for chloride and conductivity. Restoration of Units 1 through 5 was in progress when the well was reported on excursion. SSM-42 remains on excursion.

MW19 (ore zone monitor well, CR Unit 3) was reported in excursion status on January 5, 1990. The well exceeded the UCLs for chloride and alkalinity. Corrective action consisted of over-recovery in the area. MW19 was reported off excursion on April 2, 1990.

1991

M-2 (ore zone monitor, IR Unit 2) was reported in excursion status in January 1991. The well exceeded the UCLs for chloride and conductivity. Corrective action consisted of pumping trend wells in the surrounding area. M-2 was reported off excursion status on March 8, 1993.

MW48S (shallow monitor well, CR Unit 3) was reported in excursion status on December 3, 1991. The well exceeded the UCLs for chloride and alkalinity. Integrity failure of injection well 3R27-1 was determined to be the cause of the excursion. MW48S was reported off excursion status on January 2, 1992.

MW19 (ore zone monitor well, CR Unit 3) was reported in excursion status on November 19, 1991. The well exceeded the UCLs for chloride and conductivity. Corrective action consisted of over-recovery in the area. MW19 was reported off excursion status on February 8, 1993.

1992

MW48S (shallow monitor well, CR Unit 3) was reported in exc ursion status on March 27, 1992, and again on June 19, 1992. The well exceeded the UCLs for chloride and alkalinity. Various corrective actions have been used to control this well. MW48S was reported off excursion status on August 29, 1995.

4E6-1 (ore zone monitor well, CR Unit 3) was reported in excursion status on September 10, 1992. The well had exceeded all three excursion parameters. 4E6-1 was reported off excursion status on April 30, 1993.

1993

MW46S (shallow monitor well, CR Unit 3) was reported in excursion status on March 10, 1993. The well had exceeded the UCLs for chloride and alkalinity. Corrective action consisted of over-recovery in the area. MW46S was reported off excursion status on August 29, 1995.

1994

DM-10 (deep monitor well, IR Unit 6) was reported in excursion status on February 2, 1994. The well had exceeded all three UCLs. Corrective action has consisted of pumping recovery wells HI-53 and HP-22, and active restoration in MU 6. DM-10 remains on excursion status, although the well is very close to meeting limits.

SSM-39 (shallow monitor well, IR Unit 7) was reported in excursion status on March 15, 1994. The well had exceeded the UCLs for conductivity and alkalinity. The exceedances were not identified at the time of the excursion and were later reported as a self-identified deviation from permit requirements. This well is no longer in exc_rsion status.

SSM-40 (shallow monitor well, IR Unit 8) was reported in excursion status on March 6, 1994. The well exceeded the UCLs for chloride and conductivity. Corrective action consisted of shutting

down various injection wells in the area. SSM-40 remains in excursion status.

1995

SSM-3 (shallow monitor well, IR Unit 2) was reported in excursion status on June 14, 1995. The well exceeded the UCLs for chloride and conductivity. The well is located in a restored wellfield. SSM-3 was reported off excursion status on August 29, 1995.

SSM-18 (shallow monitor well, IR Unit 8) was reported in excursion status on June 14, 1995. The well exceeded the UCLs for chloride and conductivity. A groundwater sweep was occurring when the well was reported to be on excursion. Corrective action consisted of pumping well KI-78. SSM-18 was reported off excursion status on August 29, 1995.

M-2 (ore zone monitor well, IR Unit 2) was reported in excursion status on June 14, 1995. The well exceeded all three UCLs. Corrective action consisted of pumping trend wells T-10 and T-11. M-2 was reported off excursion status on August 29, 1995.

MW108 [ore zone monitor well, Christensen Ranch (CR) Unit 2] was reported in excursion status on January 9, 1995. The well had exceeded the UCLs for chloride and alkalinity. Corrective action consisted of over-recovery in the area. MW108 was declared off excursion status on February 9, 1995.

4MW15 (ore zone monitor well, CR Unit 4) was reported in excursion status on June 8, 1995. The well exceeded the UCLs for chloride and alkalinity. Corrective action consisted of shutting off numerous injection wells and over-recovery in the area. 4MW15 was taken off excursion status effective December 5, 1995.

1996

SSM-3 (shallow monitor well, IR Unit 2): has been on excursion status on and off for the past 16 years, with little change. The well was off excursion status for the first half of 1996, then both chloride and conductivity exceeded Upper Control Limit (UCL) values during the second half of 1996 (total alkalinity remains normal). Unit 2 has been restored. The highest chloride and conductivity concentrations observed during 1996 for SSM-3 were 44.4 mg/l (38.5 mg/1 UCL) and 1936 µmhos/cm (1451 µmhos/cm UCL), respectively.

SSM-18 (shallow monitor well, IR Unit 8): returned to excursion status during the first two weeks of 1996, with chloride and total alkalinity barely exceeding the UCL values. The well then returned to normal status from the end of February through August, with only total alkalinity exceeding the UCL. The well returned on excursion status in August 1996, when chloride rose above the UCL. The highest chloride and total alkalinity concentrations seen during 1996 in SSM-18 were 17.2 mg/l (14.7 mg/l UCL and 145 mg/l (119.4 mg/l UCL) respectively. Conductivity did not exceed the UCL values at any time during 1996. Unit 8 is in the restoration phase of operations.

SSM-40 (shallow monitor well, IR Unit 8): continued on and off excursion status during the entire year of 1996, with both chloride and total alkalinity exceeding UCLs. The well would periodically only exceed one UCL, but due to fluctuating values, COGEMA did not report the well as off excursion. The highest chloride and total alkalinity concentrations seen during 1996, in SSM-40 were 16.4 mg/l (13.6 mg/l UCL) and 124.3 mg/l (109.2 mg/l UCL), respectively. Conductivity did not exceed the UCL values at any time during 1996. Unit 8 is in the restoration phase of operations.

SSM-42 (shallow monitor well, IR Unit 3): continued on excursion status throughout 1996, with little change in chloride and conductivity values, which both exceed UCLs. The highest chloride and conductivity concentrations observed during 1996 were 39.6 mg/l (23.3 mg/l UCL) and 2191 µmhos/cm (1571 µmhos/cm UCL), respectively. Unit 3 has been restored.

SSM-43 (shallow monitor well, IR Unit 1): continued on excursion status throughout 1996, with little change in chloride and conductivity values, which both exceed UCLs. The highest chloride and conductivity concentrations observed during 1996 were 36.9 mg/l (25.6 mg/l UCL) and 1779 µmhos/cm (1456 µmhos/cm UCL), respectively. Unit 1 has been restored.

DM-10 (deep monitor well, IR Unit 6): continued on excursion status throughout 1996. All three excursion indicators were exceeded. The highest chloride, conductivity and total alkalinity values observed during 1996 were 37.0 mg/l (16.4 mg/l UCL), 976 µmhos/cm (606 µmhos/cm UCL) and 266.4 mg/l (107.5 mg/l UCL) respectively. Ground water sweep operations were conducted in Unit 6 during this time period.

M-2 (ore zone monitor well, IR Unit 2): remained on excursion status throughout 1996, with chloride and conductivity exceeding UCLs. Pumping of nearby trend wells appeared to be having some positive impact on the well at the year's end. The highest chloride and conductivity values observed during 1996 were 33.2 mg/l (18 mg/l UCL) and 1082 µmhos/cm (685 µmhos/cm UCL). Unit 2 has been restored.

MW46S (shallow monitor well, CR Unit 3): this Chnstensen shallow monitor well was on excursion status through the first week in February, with both chloride and conductivity over UCL values. For the remainder of the year, the well was on normal status, exceeding only one UCL (conductivity). The highest chloride and conductivity values observed during 1996 were 15.0 mg/l (13.5 mg/l UCL) and 1799 µmhos/cm (1087 µmhos/cm UCL).

At the end of 1996, seven wells remained on excursion status, all located at the Irigaray project.

1997

SSM-3 (shallow monitor well, IR Unit 2): remained on excursion status throughout 1997, with chloride and conductivity exceeding UCL values. The highest chloride and conductivity concentrations observed during 1997 were 48.0 mg/l (38.5 mg/l UCL) and 1695 µmhos/cm (1451 µmhos/cm UCL), respectively. Unit 2 has been restored.

SSM-18 (shallow monitor well, IR Unit 8): continued off and on excursion status during 1997, with exceedances of the chloride and total alkalinity UCL. Little change has occurred in this well over time. The highest chloride and total alkalinity concentrations observed during 1997 were 18.4 mg/l (14.7 mg/l UCL) and 163.7 mg/l (119.4 mg/l UCL), respectively.

SSM-40 (shallow monitor well, IR Unit 8): continued on and off excursion status during the entire year of 1997, with both chloride and total alkalinity exceeding UCLs. The well would periodically only exceed one UCL, but due to fluctuating values, COGEMA did not report the well as off excursion. The highest chloride and total alkalinity concentrations seen during 1997 in SSM-40 were 15.0 mg/l (13.6 mg/l UCL) and 123.3 mg/l (109.2 mg/l UCL), respectively. Conductivity did not exceed the UCL values at any time during 1997. Unit 8 is in the restoration phase of operations.

SSM-42 (shallow monitor well, IR Unit 3): continued on excursion status throughout 1997, with little change in chloride and conductivity concentrations, which both exceed UCL values. The highest chloride and conductivity concentrations observed during 1997 were 47.0 mg/l (23.3 mg/l UCL) and 2263 µmhos/cm (1571 µmhos/cm UCL), respectively. Unit 3 has been restored.

SSM-43 (shallow monitor well, IR Unit 1): continued on excursion status throughout 1997, with little change in chloride and conductivity values, which both exceed UCLs. The highest chloride and conductivity concentrations observed during 1997 were 37.0 mg/l (25.6 mg/l UCL) and 1740 µmhos/cm (1456 µmhos/cm UCL), respectively. Unit 1 has been restored.

DM-10 (deep monitor well, IR Unit 6): continued on excursion status throughout 1997. All three excursion indicators were exceeded. The highest chloride, conductivity and total alkalinity values observed during 1996 were 36.5 mg/l (16.4 mg/l UCL), 1028 µmhos/cm (606 µmhos/cm UCL) and 278.7 mg/l (107.5 mg/l UCL) respectively. Ground water sweep and a small amount of permeate injection were conducted in Unit 6 during this time period.

M-2 (ore zone monitor well, IR Unit 2): was reported off excursion status during January of 1997, and continued off excursion status for the remainder of 1997. Unit 2 has been restored.

5MW16 (ore zone monitor well, CR Unit 5): was briefly on excursion status for a three week period in March 1997. All three UCLs for chloride, conductivity and total alkalinity were exceeded for this period. Corrective actions of over recovery quickly brought the well back to normal conditions, where it stayed for the remainder of the year.

5MW52 (ore zone monitor well, CR Unit 5): was on excursion status for only one week during 1997. The well exceeded all three UCLs during the first week of January 1997. Corrective action of over recovery immediately brought the well back to normal status, where it remained for the rest of the year.

MW64 (or zone monitor well, CR Unit 3): was briefly on excursion status from the week of May 13 through the week of June 2, 1997. Corrective action of increased over recovery (Unit 3 was in the ground water sweep phase of restoration) was successful in remediating the problem. The well was on normal status for the remainder of the year.

MW89 (ore zone monitor well, CR Unit 2): was on and off excursion status several different times during 1997. The well was affected by ground water sweep operations ongoing in Units 2 and 3 during 1997. The well was last reported off excursion status in December 1997, and continues in the normal status.

Eleven wells were reported on excursion status during 1997, with only six of those remaining on excursion status at the end of the year (all located at the Ingaray project)

1998

Six wells remain on excursion status as of May 1998, all located at the Ingaray site. Each well is listed below along with its respective analytical data from the end of April 1998

SSM-3 exceeds chloride and conductivity UCLs. Chloride 47.0 mg/l (UCL 38.5 mg/l), conductivity 1685 µmhos/cm (UCL 1451 µmhos/cm) and total alkalinity 162.4 mg/l (UCL 219.1 mg/l)

SSM-18: exceeds chloride and total alkalinity UCLs. Chloride 18.4 mg/l (UCL 14.7 mg/l), conductivity 1697 µmhos/cm (UCL 1849 µmhos/cm), and total alkalinity 162.4 (UCL 119.4 mg/l).

SSM-40: barely exceeds chloride and total alkalinity UCLs. Chloride 13.7 mg/l (UCL 13.6 mg/l), conductivity 1454 µmhos/cm (UCL 1672 µmhos/cm), and total alkalinity 119.1 mg/l (UCL 109.2 mg/l).

SSM-42: exceeds chloride and conductivity UCLs. Chloride 43.6 mg/l (UCL 23.3), conductivity 2231 µmhos/cm (UCL 1571 µmhos/cm) and total alkalinity 123.8 mg/l (213.2 mg/l).

SSM-43: exceeds chloride and conductivity UCLs. Chloride 33.7 mg/l (UCL 25.6 mg/l), conductivity 1702 µmhos/cm (UCL 1456 µmhos/cm) and total alkalinity 145.6 mg/l (UCL 170.4 mg/l).

DM-10: exceeds chloride, conductivity and total alkalinity UCLs; the last sample of DM-10 only exceeded conductivity and total alkalinity UCLs. Chloride 15.8 mg/l (UCL 16.4 mg/l), conductivity 691 µmhos/cm (UCL 606 µmhos/cm), and total alkalinity 154.3 mg/l (UCL 107.5 mg/l).

In summary, the wells that remain on excursion status as of May, 1998, are all located at the Ingaray site, and include five shallow monitor wells (SSM-3, SSM-18, and SSM-40, SSM-42, SSM-43) and one deep monitor well (DM-10).

COGEMA is required by license condition to monitor for excursions and take corrective actions. COGEMA typically monitors more frequently than required and is very proactive about taking corrective action to prevent or mitigate the effects of excursions. In addition, COGEMA has developed a well casing integrity testing program and a process of sealing exploration holes within wellfields which should preclude a repetition of the problem with vertical excursions like those previously experienced at Ingaray. In future mining at Ingaray or Christensen. This, along with the degree of excursion monitoring and corrective action being implemented is sufficient that future excursions should result in minimal environmental impacts. Additionally, COGEMA has provided sufficient financial surety to ensure that any excursions are properly mitigated prior to site decommissioning.

5.4.3.2 Waste Disposal Ponds Spills and Seepage

Spills from the evaporation ponds resulting from dike failure or overtopping the ponds could result in unacceptable contamination to surface waters and groundwater. The likelihood of dike failure is considered to be minimal because the evaporation pond embankments have been designed in accordance with NRC Regulatory Guidance. Requirements in the license for maintaining specific freeboard for each of the ponds are intended to prevent overtopping of the berms around the ponds by wave action, in addition to allowing for transfer of the contents of one leaking pond to the others.

The leak detection system installed under the ponds and frequent monitoring of those systems ensures that any failure in the liner will be detected before solutions migrate form the pond areas. Dry strata beneath the ponds at both sites mean the impact of any pond leak should be small. Since the last license renewal, only one evaporation pond leak has been detected. In 1992 a

Exhibit E

POWER
RESOURCES

September 12, 1997

Ms. Georgia Cash, District I Supervisor
Land Quality Division
Wyoming Department of Environmental Quality
Herschler Building
Cheyenne, Wyoming 82002

RE: Permit to Mine No. 603
1997 Annual Report

Dear Ms. Cash:

Enclosed please find two (2) copies of Power Resources, Inc.'s (PRI) 1997 Annual Report for the Highland Uranium Project. The report addresses applicable reporting requirements contained within the approved permit application, the WDEQ Annual Report Form, and W.S. 35-11-411.

Appendix 2 of the report contains the proposed 1997-1998 Reclamation Surety Estimate Revision. The proposed Surety Estimate revision results in an amount of $14,780,400 which is $1,254,943 over the existing amount of $13,525,457. The increase in this proposed surety estimate primarily results from expanded production operations and associated ground water restoration activities in the F-Wellfield, plugging of monitoring wells to be installed in the proposed H-Wellfield, the abandonment and decommissioning of an additional waste disposal well planned for installation in 1998 and the additional costs associated with installing and plugging approximately 100 wells proposed for use during ground water restoration. It should be noted that because the "flare factor" questions have not yet been resolved with your staff, this estimate utilizes the 2.94 interim "flare factor" estimate agreed upon by the WDEQ and PRI for the 1996-1997 Surety Estimate update.

Please call should you or your staff have any questions.

Sincerely,

Paul R. Hildenbrand
Manager of Environmental and
Regulatory Affairs

PRH/drc

cc: Crew Schmitt w/o att
Mark Wittrup w/o att
L.C. McGonagle w/o att
File 4.3.3.1
W. F. Kearney
M. Kelly w/o att
R.L. Thurman w/o att

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PERMIT 603

WDEQ ANNUAL REPORT

FOR

PERMIT 603

HIGHLAND URANIUM PROJECT

SEPTEMBER 1997

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PERMIT 603

1.4 Minerals Mined:

Uranium (U_3O_8)

1.5 State Leases and Federal Claims Inside the Permit Area:

State Lease Numbers

0-40077	0-27211	0-40211
0-27233B	0-27233C	

Federal Claims

Federal Claims within the permit area are shown on the location map (Map 2) within Volume 1, Appendix A of the approved permit application.

1.6 Reporting Period:

July 1, 1996 through June 30, 1997.

2.0 MINING ACTIVITIES

Plates 1A through 1D - "Affected Areas Map and Environmental Monitoring Locations" show the locations of existing facilities at the Highland Uranium Project and areas of planned operation during the next report period.

2.1 A and B-Wellfields and Satellite No. 1

Ground water restoration activities (ground water sweep pumping and reverse osmosis treatment) continued at the A and B-Wellfields throughout the report period. These activities are discussed in Section 3.0.

2.2 Satellite No. 2

Satellite No. 2 processes production fluid from the C, D, E-Wellfields and eastern portions of the F-Wellfield. Satellite No. 2 commenced operation on July 20, 1989 when production activities commenced in the C-Wellfield. During the period June 1, 1996 to May 31, 1997, 3,729.4 AF (1.22E9 gal) of production fluids were pumped through Satellite No. 2 and 3,652.9 AF (1.19E9 gal) of injection fluids were pumped from Satellite No. 2 to the C, D, E and F-Wellfields. Injection fluid was withdrawn as "bleed" from the production zone aquifers. A production bleed is maintained by treating a portion of the injection fluid and disposing of it at PSR-2/Irrigator No. 2. The total bleed during this period was 76.5 AF (2.49E7 gal) which represents 2.1% of the total production fluid volume.

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2.3 Satellite No. 3

Satellite No. 3 began operation on June 4, 1996 and processes production fluid from the western part of the F-Wellfield. During the period June 1, 1996 to May 31, 1997 3,980.7 AF (1.30E9 gal) of production fluids were pumped through Satellite No. 3 and 3,929.8 AF (1.28E9 gal) of injection fluids were pumped from Satellite No. 3 to the western portions of the F-Wellfield. A production bleed is maintained by treating a portion of the injection fluid and disposing of it at PSR-2/Irrigator No. 2. The total bleed during this period was 50.9 AF (1.66E7 gal) which represents 1.3% of the total production fluid volume.

The purge from Satellite No. 3 was pumped to Satellite No. 2 where it was treated for removal of uranium and Ra-226 and pumped to PSR-2 and Irrigator No. 2. To accommodate the additional flow of purge fluid from Satellite No. 3, the treatment system at Satellite No. 2 was upgraded. The process for Ra-226 removal was changed from a batch operation to a flow through operation. An additional filter press was also installed. The system's instrumentation and control were automated. Another consideration of the process upgrade was the increased restoration fluids that will result when ground water restoration begins in C-North in the third quarter of 1997.

2.4 C-Wellfield

Production activities continued at the southern porton of the C-Wellfield during the report period. A total of 201 patterns exist in the C-Wellfield. As of May 31, 1997, approximately 78.7% of the estimated uranium reserve in this area has been recovered.

2.5 D-Wellfield

Production activities continued throughout the report period in the D-Wellfield. A total of 43 production patterns exist in the D-Wellfield. As of May 31, 1997, approximately 82.1% of the estimated uranium reserve in this area had been recovered. The D-Wellfield will continue to operate through the next report period.

2.6 E-Wellfield

Production activities commenced in the northern portion of the E-Wellfield on November 22, 1991. A total of 153 production patterns exist in the E-Wellfield. As of May 31, 1997, approximately 100.8% of the estimated uranium reserve in this area has been recovered. The E-Wellfield will continue to operate through the next report period.

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2.7 F-Wellfield

Wellfield development and production activities continued during the report period in the F-Wellfield. As of May 31, 1997, a total of 299 production patterns (62% of the total planned F-Ring patterns) were in operation, including areas F-1 through F-9 and F-11 through F-29. The locations of all wells installed in the F-Wellfield are shown on Plates 5A and 5B. As of May 31, 1997, 51% of the uranium reserve has been recovered from the areas currently in production on that date. The F-Wellfield will continue to operate through the next report period.

2.8 Topsoil Stockpiling

Tabulated topsoil stockpile volumes and dates of stockpiling are summarized in Table 2-1.

The location of topsoil stockpiles are shown on Plate 1. Topsoil stockpiles associated with wellfield roads in the C, D, and E-Wellfields are shown on Plates 2A and 2B.

2.9 Affected Areas

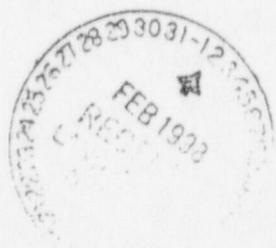
Tabulated acreage disturbed as of May 31, 1997 is summarized by year in Table 2-2. In order that a more accurate estimate of the amount of areas affected by mining activities could be determined, PRI contracted with Horizon's Inc. for aerial photographs of the affected areas at the Highland Uranium Project. The aerial photographs were taken in August 1997. The tabulated acreages in Table 2-2 were generated, and/or revised from earlier reports, from the aerial photographs. No areas affected by PRI activities have been permanently reclaimed.

2.10 Uranium Production

Tabulated uranium production (net eluted pounds) as of June 30, 1997 is shown in the following tabulation:

URANIUM PRODUCTION BY YEAR

Year	Pounds Uranium Eluted
1/7/88 - 6/30/88	412,177
7/1/88 - 5/10/89	621,000
5/11/89 - 4/30/90	886,097
5/1/90 - 6/30/91	1,396,298
7/1/91 - 5/31/92	1,026,676
6/1/92 - 5/31/93	847,082
6/1/93 - 5/31/94	833,542



6/1/94 - 5/31/95	693,804
6/1/95 - 6/30/96	969,023
7/1/96 - 6/30/97	1,373,658

Total pounds uranium produced (drummed) as of June 30, 1997:

9,182,040

3.0 GROUND WATER RESTORATION

General

The time period covered by this Annual Report is from July 1, 1996 to June 30, 1997. In order to allow sufficient time for analytical results to be returned from the laboratories and reviewed, the ground water restoration section of the Report usually includes sample data only up to May 31 of each year. Therefore, the Report period and the ground water restoration data collection period are typically out of phase by one month. When the submission of the Annual Report is delayed, as is the case with this report, then additional data will continue to be incorporated into the report wherever possible. Therefore, use of the term "current reporting period" in this report implies coincident report and data collection periods.

3.1 A-Wellfield Restoration Activities

Ground Water Sweep

Ground water restoration activities commenced in the A-Wellfield on July 16, 1991 when injection of lixiviant was discontinued and ground water sweep was started in the A1-A2 group of patterns in accordance with Section RP 4.3.2 of the approved permit application. From July 16, 1991 to the present time, ground water has been continuously pumped from the A-Wellfield. During the reporting period from June 1, 1996 to May 31, 1997, the pumping rate was maintained at approximately 15 gpm. The ground water sweep fluids are processed at Satellite No.1 to remove dissolved residual uranium and radium prior to pumping to the radium settling basins. From the radium settling basins, the treated water is pumped to the Satellite No.1 Purge Storage Reservoir where it is stored for periodic disposal at the Satellite No.1 Wastewater Land Application (Irrigation) Area.

During the current reporting period, a volume of approximately 16 AF of ground water sweep fluid was pumped from the A wellfield. Most of this water was pumped from wells AR-1, AR-2 and AR-3 to control excursions in monitor wells M-10A and M-11. These monitor wells are located near the hole in the aquitard between the 20-sand and 30-sand aquifers, the existence of which was described to the WDEQ in a letter dated May 13, 1996. The cumulative total volume of ground water sweep fluids pumped from the A-Wellfield since the beginning of ground water restoration

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activities, up to May 31, 1997, amounted to 76 AF. This represents 5.3 pore volumes (PV) removed and treated using the revised pore volume estimate of 14.3 AF/PV. A proportion of this fluid volume was extracted from an area of the aquifer outside of the patterns which has been impacted by fluids migrating from the 30-sand. Therefore, the number of cumulative pore volumes withdrawn from the A-Wellfield patterns cannot be determined exactly, but it is smaller than 5.3 PV and is probably less than 3 PV. The pumping of ground water sweep fluids from the 20-sand aquifer between 1991 and 1994 was a contributing factor in drawing 30-sand fluids through the aquitard hole.

Reverse Osmosis

The Satellite No. 1 Reverse Osmosis (RO) unit (#1) was put into service on June 8, 1994 and has been operated in accordance with section RP 4.3.3 of the approved permit application. This RO unit treats approximately 100 gpm of feed water with the production of approximately 75 gpm of permeate. All of the RO permeate produced to date has been reinjected into the 20-sand inside the A-Wellfield where it circulates through the formation and is drawn towards the pumping wells. The increase in hydrostatic pressure from injection of permeate allows for increased pumping flow rates, while the introduction of the very clean water replaces and dilutes the impacted ground water and restores it at a faster rate than ground water sweep. Injection of RO permeate was started inside the mining patterns using well configurations comprised of arrays of three or four patterns ("megapatterns"). Wells located centrally inside the megapatterns were used for injection, while peripheral wells were used for pumping. Other internal megapattern wells not required for injection were used for sampling to monitor restoration progress.

During the current reporting period, the focus of circulation of RO permeate in the 20-sand aquifer was progressively moved away from the A1-A2 mining patterns to the A3 patterns and towards the aquitard hole so that the zone impacted by fluids migrating from the 30-sand could be restored. This followed a plan which was outlined in correspondence to the WDEQ dated May 13, 1996, and was achieved using additional AR wells which had been installed to assist with restoration activities. A volume of approximately 122 AF (8.5 PV's) of affected A-Wellfield ground water was removed and treated by RO during the current reporting period, bringing the total volume of ground water treated from the A-Wellfield by RO to 302 AF (21 PV's). A similar quantity (117 AF) of treated RO permeate was reinjected. The difference between the two totals is due the bleed taken by the RO which is included with the ground water sweep total noted in the previous paragraph. The effect of circulation of RO permeate on the quality of the ground water is discussed below.

Additional Restoration Wells

During the reporting period from June 1, 1996 to May 31, 1997, 3 new restoration wells (AR-11 to AR-13) were installed inside the A-Wellfield monitor ring to assist

with circulation of RO permeate through the area of 20-sand aquifer impacted by 30-sand mining fluid. These wells are in addition to the 10 AR wells installed during the previous reporting period and referred to in the letter and report to the WDEQ dated May 13, 1996. The locations of all the AR wells are shown on a map of the A-Wellfield in Figure 3-1. Pilot hole drilling for well AR-12 revealed that the 20-sand thins to 5 feet or less in a zone between the A1 and A3 pattern areas and its location had to be moved closer to well AR-13.

Injection of Hydrogen Sulfide Reductant

During the current reporting period, the hydrogen sulfide (H_2S) tank trailer and associated injection equipment was moved from its location at the C1 wellfield experimental injection site to the A-Wellfield for use in final remediation of the 20-sand aquifer. This is in accordance with Section RP 4.3.4 of the approved permit application. Due to the possibility of H_2S returning to Satellite 1 with feed water being pumped to the RO unit, an extensive system of sensors, alarms and shut-off valves had to be designed, installed and tested. A delay of several months was incurred as problems with calibration of the sensors and other equipment were progressively resolved. Injection of H_2S gas into the 20-sand aquifer dissolved in the RO permeate stream at a concentration of 200 ppm was begun on May 20, 1997, with the reductant being directed to selected wells in the A1 pattern group and some of the AR wells near the aquitard hole. At the present time, loss of injectivity due to well screen plugging has not been experienced to the same degree in the A-Wellfield as it was in the C1 wellfield. No indications of reductant breakthrough have been noted yet at the recovery wells and it is assumed that all of the injected H_2S is being consumed in the formation.

A-Wellfield Water Levels

Water levels are measured in selected perimeter M wells and internal (injection) wells in the A-Wellfield (20-sand) semi-monthly (every 2 weeks). Additionally, water levels are measured every week in M wells on excursion status. All of these data are included in the Quarterly Reports. At least once a year, water levels are also measured in a selected number of injection or production wells throughout the wellfield on a date which coincides with one of the semi-monthly measurements of the monitor well water levels. These data are used to compile a contour map representing the potentiometric surface for the wellfield on that date. Figure 3-1 of this report is a contoured potentiometric surface map of the A-Wellfield measured on June 10, 1997. It is not generally possible to accurately depict the shape of the potentiometric surface from a limited set of water level measurements while injection and pumping is taking place at a number of wells in close proximity. In the case of the A-Wellfield, the measured water levels show a gradient towards the northwest part of the wellfield, consistent with the focus of the ground water sweep pumping from wells AR-1, AR-2, and AR-3. This activity has been represented on Figure 3-1 by a water level minimum located around the A1 line drive patterns. A second, smaller, water level

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minimum has been added at the A3 patterns to represent the net withdrawal of ground water taking place there. As with all computer generated contour maps, extrapolation of the contour lines to the map boundaries where there is no data is an artifact of the contouring program and should be ignored.

Ground Water Quality in the 20-Sand

Bi-Monthly MP Well Sampling

Ground water quality in the A-wellfield is monitored at perimeter M wells, overlying (MO) wells, underlying (MU) wells and wells in the production pattern areas (MP wells) every two months to help assess the progress of restoration activities. The samples are analyzed for uranium, chloride, bicarbonate and conductivity. Monitor wells on excursion are also sampled on a weekly basis. These water quality data are included in the Quarterly Reports. The MP wells are completed in the production zone and were sampled prior to leaching to establish baseline water quality conditions and target restoration values. Appendix 3A contains the bimonthly water quality data collected through May 31, 1997 for wells MP-1 through MP-5. Figure 3-2 contains graphs for the same wells which show the changing concentration of chloride, conductivity and uranium since restoration began in July 1991, with water level elevations and bicarbonate concentrations added from July 1992.

A review of the tabulated data and time-concentration graphs for the A-wellfield MP wells shows the impact of the first two stages of restoration of the ground water in the 20-sand aquifer since July 1991. The graphs are best considered in reverse order. The graph for well MP-5, located near the southern end of the main A1-A2 pattern group, is a good illustration of the effect of progressive ground water sweep. From July 1991 until the fall of 1995, unaffected formation water was drawn towards the mining patterns, resulting in gradual dilution of leaching fluids and a decrease in concentration of all parameters. The slow change in ground water quality was a consequence of the limited pumping rate that was possible from the 20-sand aquifer. Late in 1995, injection of RO permeate was directed to the southernmost wells surrounding well MP-5. Subsequent sample data shows a rapid decline in the residual concentrations of chloride, bicarbonate and uranium to values of 3, 322 and 0.5 mg/l respectively, with chloride being below baseline. This response is noticeable as curve inflections on the graph for well MP-5. Injection of permeate to this area was discontinued during the current reporting period and no deterioration of water quality has since been noted.

The effectiveness of injection of RO permeate is more evident in wells MP-4 and MP-3, which were located inside the first megapatterns to be operated. Prior to permeate injection, water sample data from well MP-4 showed only minimal decline in concentration of the measured parameters, while data from well MP-3 showed no decline at all. Both wells even registered a steady increase in uranium concentration. This condition is now interpreted to be caused by a continuing supply of leaching

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fluids migrating from the 30-sand aquifer through the aquitard hole. Circulation of RO permeate past these MP wells from June 1994 until July 1995 was very effective in flushing the formation, which quickly reduced major ionic species to concentrations close to baseline. The RO permeate was also effective in reducing uranium to concentrations of 1-2 mg/l.

Most of the improvement in water quality at wells MP-4 and MP-3 occurred during the first two months of permeate injection. It appears that little benefit resulted from the extended circulation time. After injection of RO permeate was moved to other patterns, water sample data from both of these MP wells showed a small rebound in bicarbonate concentration and conductivity levels, but the values declined again during the current reporting period. The temporary rebound of dissolved bicarbonate, together with calcium, is interpreted to be caused by solution of small amounts of calcite from the 20-sand formation. When these wells were last sampled, on May 27, 1997, well MP-4 showed 6 mg/l of chloride, 5.8 mg/l of uranium and 264 mg/l of bicarbonate. Equivalent concentrations for well MP-3 were 2, 0.7, and 161 mg/l, respectively, of which only uranium is slightly above baseline.

The time-concentration plots for wells MP-2 and MP-1 exhibit patterns similar to that for well MP-5, namely, a long, slow improvement in water quality from ground water sweep, followed by a more rapid change during the current reporting period as RO permeate was circulated past these wells. The curves show some fluctuation in values, however, as the efficiency of sweep along the staggered line drive is not as effective as with conventional 5-spot patterns. When sampled on May 27, 1997, both MP wells exhibited similar concentrations of measured parameters; 3-5 mg/l chloride, 272-275 mg/l bicarbonate and 4.1 mg/l uranium.

Circulation of RO permeate through that part of the A-Wellfield impacted by migration of leaching fluids from the 30-sand aquifer has been achieved by using peripheral injection wells at the mining patterns and the AR remediation wells which were installed during the previous and current reporting periods. Restoration progress was expected to be slower in this area due to the wider spacing between wells, but significant improvements in water quality have been noted at the recovery wells. As an example, a time-concentration plot for the routine weekly sample parameters (conductivity and uranium) for well AR-7 has been included with this report (Figure 3-3). The graph shows a steady decline in both parameters during the 12 month period from July 1996 to July 1997. When last measured on July 7, 1997, the conductivity level was 668 µmhos/cm and the uranium concentration was 1.7 mg/l.

One characteristic feature of RO permeate circulation in this area of impacted ground water beyond the mining patterns is the tendency of the bicarbonate concentration to stabilize at approximately 400-430 mg/l, while the chloride concentration continues to decline. This is interpreted to be caused by dissolution of calcite from the 20-sand formation by the permeate, which may also be dissolving trace quantities (often less

than 1 mg/l) of reduced iron. Re-precipitation of dissolved iron has been causing problems in Satellite 1 with plugging of filtration systems by flocculated iron oxy-hydroxides. Buffering by the formation may reduce the elevated bicarbonate concentrations over a period of several months if the trend observed inside the mining patterns is repeated in the impacted area outside.

In addition to time-concentration plots for individual wells, and in accordance with Section RP 4.5 of the approved permit application, the progress of ground water restoration can also be demonstrated by means of contoured iso-concentration maps. Figures 3-4 through 3-7 contain contoured A-Wellfield iso-concentration maps for chloride, bicarbonate, conductivity and uranium, respectively. The data used to construct these maps is collected from different wells at different times and each data set may represent sampling in a time window of 2-3 months. However, the maps incorporate only the most recent values for wells which are sampled several times during that period and these are posted below the well symbols. Labeled wells without posted values represent injection wells. To facilitate contouring, these have been assigned values based upon analyses of RO permeate samples collected in the Satellite. Lower contour intervals of 600 µmhos/cm conductivity, 10 mg/l chloride, 250 mg/l bicarbonate and 3 mg/l uranium have been selected to reliably depict the zones of impacted ground water.

It can be readily seen from the chloride map of the A-Wellfield (Figure 3-4) that the most significant remaining area where concentrations are elevated above baseline is at the location of the hole in the aquitard. Elimination of this final "bubble" of impacted water will not be achieved until the source of leaching fluids in the 30-sand aquifer near the aquitard hole is treated by RO permeate injection. A second, smaller zone of slightly elevated chloride concentration can be seen at the A3 patterns. As the time-concentration plots for recovery wells in the A3 patterns show little evidence of improvement in water quality, it is possible that this area is also being affected by leaching fluids from 30-sand patterns in the B-Wellfield above.

The bicarbonate map (Figure 3-5) shows a similar pattern to the chloride map except that small zones of elevated concentrations remain around the pumping wells, probably due to dissolution of formation calcite, as noted above. The conductivity map (Figure 3-6) has a very similar appearance to the bicarbonate map because the two parameters are directly correlated when chloride concentrations are low. The uranium map (Figure 3-7) shows that there has been a small rebound of this parameter within some of the mining patterns to concentrations of 6-8 mg/l. Concentrations up to 9.8 mg/l exist near the location of the aquitard hole and the latest samples from the A3 pumping wells had a maximum concentration of 16.43 mg/l. While injection of RO permeate can be very effective in lowering uranium to concentrations of only a few mg/l, its final removal has to be completed with injection of chemical reductant.

Injection into the A-Wellfield of hydrogen sulfide dissolved in RO permeate has only taken place in the last two weeks of the current reporting period. Consequently, there

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has been no noticeable affect so far on ground water quality from the addition of this reductant.

Annual Guideline-8 Sampling

Section RP4 of the approved permit application commits PRI to sample the MP wells for the Guideline-8 (Table 1) parameters at the end of "each year's active restoration period". In previous years this sampling was done in July since ground water restoration activity has been continuous since it began in July 1991. This sample schedule did not correspond with the June 30 date when the WDEQ Annual Reports were due, and, as a consequence, discussions of the changes in ground water quality for that year were based upon sample results that were 12 months old. In the previous reporting period (June 1, 1995 to May 31, 1996), this schedule was changed and the sample dates brought forward so that the results could be included in the current year's report. Sampling of MP wells for Guideline-8 parameters in this reporting period was conducted between May 27-29, 1997. The results are included with this report as Appendix 3B. Table 3-1 of this report summarizes the mean water quality characteristics for selected Guideline-8 parameters from the A-Wellfield MP wells for data collected annually from 1991 to 1997. Baseline and "Class of Use" concentrations for each of these parameters are also shown in the table. Changes in concentration of these parameters are discussed below.

A review of Table 3-1 shows that sulfate, chloride and TDS concentrations, as well as conductivity levels, continued to decline during the period from June 1996 to May 1997. All of these parameters lie within a narrow range and are below their respective baseline concentrations. This improvement in ground water quality is the result of restoration by injection of RO permeate and these data duplicate the trends shown by the bimonthly MP well sampling. Data from other pumping wells in the A-Wellfield patterns show similar improvements and confirm that the ground water restoration process has been extended throughout the wellfield area. As an example, time-concentration plots for 4 selected A-Wellfield wells are shown on Figure 3-8.

The average selenium concentration is 0.36mg/l in a range of 0.069-0.64 mg/l, while the average uranium concentration is 3.03 mg/l within a range of 0.46-5.8 mg/l. The statistics for both of these parameters are similar to those observed at the end of the previous reporting period and both remain above baseline. Finally, the average radium concentration is 1057 pCi/l in a range of 566-2474 pCi/l, lower than in the previous reporting period, but still above the baseline concentration of 675 pCi/l. It should be noted, however, that the average baseline radium concentration at wells MP-1 to MP-5 is over 100 times the limit for drinking water. It is also well documented that migration of radium in the ground water is naturally attenuated by the formation to a significant extent.

3.1.1 Monitor Well Excursions

At the beginning of the current reporting period, three wells in the A-Wellfield, M-8A, M-10A and M-11, were on excursion status. These wells are all located on the west side A-Wellfield monitor well ring. The activities undertaken to mitigate these excursions are discussed elsewhere in this report and in the Monthly Excursion Reports which have been submitted to the LQD. Individual well data are included in these Monthly Reports and the Quarterly Monitor Well Data Reports. By the end of the current reporting period, only well M-11 remained on excursion status. As the cause of this excursion is linked to the aquitard hole between the 20-sand and 30-sand aquifers, it is unlikely that this monitor well will be taken off excursion status until further quantities of RO permeate have been circulated through the 30-sand in the vicinity of the hole.

3.1.2 Ground Water Restoration Plans for 1997-1998

Restoration of the ground water to baseline quality in the A-Wellfield is at an advanced stage. Two small areas of partially treated leaching fluids remain around the aquitard hole and at the A3 patterns. These will be treated during the next reporting period in conjunction with RO permeate injection into the overlying 30-sand aquifer. Residual concentrations of dissolved uranium and selenium, located mainly inside the mining patterns, will be treated by continued injection of H_2S reductant into the 20-sand formation. For operational and safety reasons, the H_2S will be injected into only a few patterns at one time. Periodically, the injection system will be relocated to different groups of patterns until the entire wellfield has been treated. Changes will be made to the injection and recovery headers to allow permeate to be replaced as the gas carrier by water recirculated from the pumping wells without further treatment by RO. The permeate capacity made available can then be used more effectively in the B-Wellfield for reducing the concentration of major solutes. After injection of the H_2S reductant has been completed, probably at the end of 1997, the A-Wellfield will begin a 6 month stability monitoring period.

3.2 B-Wellfield Restoration Activities

Ground Water Sweep

Ground water restoration activities commenced in the B-Wellfield on July 16, 1991 when injection of lixiviant was discontinued and ground water sweep was started in several selected groups of mining patterns in accordance with Section RP 4.3.2 of the approved permit application. From July 16, 1991 to the present time, ground water has been continuously pumped from the B-Wellfield. During the period from June 1, 1996 to May 31, 1997, the pumping rate was maintained at approximately 30 gpm. The ground water sweep fluids from the B-Wellfield combine with those from the A-Wellfield and flow through Satellite No. 1 to remove dissolved residual uranium and radium and then to the radium settling basins. From the radium settling basins, the

treated water is pumped to the Satellite No.1 Purge Storage Reservoir where it is stored for periodic disposal at the Satellite No.1 Wastewater Land Application (Irrigation) Area.

During the same reporting period, a volume of approximately 40 AF of ground water sweep fluid was pumped from the B wellfield, bringing the cumulative total of withdrawn fluid by May 31, 1997, to 357 AF. Using the revised B-Wellfield pore volume estimate of 98.3 AF, this represents 3.6 PV displacements. Most of the ground water sweep fluid was pumped from the B4, B12, B13 and B17 pattern groups, with some intermittent pumping from the B16 pattern group. Pumping wells in B4 and B17 were operated with the objective of maintaining a lower hydrostatic head in the 30-sand aquifer around the aquitard hole which connects it to the underlying 20-sand aquifer. While the ground water gradient created by this activity may have restricted further migration of 30-sand leaching fluids to the 20-sand through the hole, unfortunately it also contributed to the encroachment into the B-Wellfield of fluids from the Exxon underground workings. This caused monitor wells M-56, M-62 and M-63 wells to reach excursion status.

The pumping of a well in B13 is a continuation of a practice that has been maintained since ground water restoration activities began in the B-Wellfield. The objective was to prevent any migration of leaching fluids in the direction of the Exxon open pit where ground water gradients become steeper. During the current reporting period, investigations made in preparation for injection of RO permeate into the 30-sand aquifer demonstrated that this strategy had been effective. Unfortunately, it was also discovered that pumping from wells in B13 had caused the southward migration of leaching fluids from the B12 pattern group into the space between B12 and B13. At the present time, ground water sweep fluids are being recovered from a single, new restoration well (BR-5), when RO unit #2 is not in operation. Continued pumping of ground water sweep fluids from a well in B13 is no longer seen as being of any benefit.

From the previous two examples, it is becoming increasingly apparent that in areas of wellfields where there are discrete groups of patterns, extended periods of ground water sweep, as outlined in Section RP 4.3.1 of the approved permit application, may not be as beneficial as originally thought. In order to balance flows and prevent migration of leaching fluids between these groups of patterns, pumping wells have to be operated in every pattern group. This requires the withdrawal, treatment and disposal of larger volumes of ground water. It might be preferable to keep ground water sweep activities to a minimum, especially where natural ground water gradients are relatively flat. Pumping of ground water sweep fluids should occur from selected wells with specific ground water control objectives and it would be more effective to begin RO treatment at an earlier stage.

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Reverse Osmosis

During the current reporting period, two areas of the B-Wellfield have been prepared for injection of RO permeate, the B11/B12/B13/B14 and B4/B17 pattern groups (Figure 3-9). In the former area, a second, trailer mounted, RO unit (#2) has been constructed and linked to the B13-14 header house. Trial operation of this RO unit, which has a maximum permeate capacity of 125 gpm, began in May 1997. Some final design modifications are being made and routine operation will start in August 1997.

In the B4/B17 pattern group areas, reconstruction of most wellheads and two of the header houses was required. This work was delayed during the spring of 1997 by frequent snow storms. Construction work began in June 1997 and injection of RO permeate started in July 1997. The permeate is supplied from RO unit #1 in the Satellite 1 building and is being injected into selected B4 wells near the aquitard hole. Further permeate injection capacity will be diverted to these pattern groups as the A-Wellfield is progressively converted to an operating mode which involves recirculation of ground water in the header-houses without treatment in the satellite. There has not been sufficient injection time in either of these two B-Wellfield areas for weekly sample data to show any reportable change in ground water quality.

Additional Restoration Wells

The intention of installing up to 43 additional BR wells to assist with accelerated restoration of the B-Wellfield was discussed in the 1996 Annual Report to the WDEQ. During the current reporting period, a total of 13 new restoration wells (BR2 to BR14) were installed in the 30-sand aquifer between the B12 and B13 pattern groups when it was discovered that leaching fluids had migrated there after five years of ground water sweep pumping from wells in B13-B14. The BR wells will be used for both pumping and RO permeate injection.

30-Sand Water Levels

Water levels are measured in all excursion monitor wells and MP wells in the B-Wellfield every 2 months. Additionally, water level data is measured every 2 weeks in MP wells on excursion status. All of these data are included in the Quarterly Reports. Once a year, water levels are also measured in a selected number of injection or production wells throughout the wellfield on a date which coincides with one of the bimonthly measurements of the monitor well water levels. These data are used to compile a contour map representing the potentiometric surface for the wellfield on that date and Figure 3-9 of this report is a contoured potentiometric surface map for the B-Wellfield measured on June 10, 1997. A well defined cone of depression is shown surrounding the three wells pumping ground water sweep fluids from the B4/B17 pattern groups. It represents the situation in this part of the B-Wellfield prior to the start of injection of RO permeate in July 1997. The gradient

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from this cone extends to the northwest as far as the Exxon underground workings, in which monitor well M-80 is completed.

No cone of depression existed in the southern half of the wellfield at the time the water level survey was completed. This is because the routine pumping of ground water sweep fluids from the B12 and B13 pattern groups had been temporarily discontinued to enable the header houses and pipelines to be converted for circulation of RO permeate. At the present time, a single well, BR-5, is operated as a ground water sweep well on those days when RO Unit #2 is not undergoing operational trials. When RO Unit #2 is operating, the injection and pumping wells complicate the potentiometric surface and a well defined cone of depression if difficult to measure. However, a net wellfield bleed is maintained by the RO Unit at all times.

As with all computer generated contour maps, extrapolation of the contour lines to the map boundaries on Figure 3-9, where there is no data is an artifact of the contouring program and should be ignored.

Ground Water Quality in the 30-Sand

Bi-Monthly MP Well Sampling

Ground water quality in the B-wellfield is monitored at excursion monitor wells and MP wells every two months. Monitor wells on excursion are also sampled on a weekly basis. These water quality data are included in the Quarterly Reports. The MP wells are completed in the production zone and were sampled prior to leaching to establish baseline water quality conditions and target restoration values. Appendix 3C contains the bimonthly water quality data collected through May 31, 1997 for the wells MP-11 through MP-31. Figures 3-10 through 3-13 contain graphs for these wells which shows the changing concentration of chloride, conductivity and uranium since restoration began in July 1991, with water level elevations and bicarbonate concentrations added from July 1992.

A review of the tabulated average values for the B-wellfield MP wells for the current reporting period shows no significant changes from the previous year. A slow, but progressive, decline in the measured parameters has occurred at most MP wells since the pumping of ground water sweep fluids began in July 1991. However, dramatic improvements in water quality are not generally expected at MP wells which are centrally located within pattern groups during this phase of restoration, particularly when the MP wells are used as pumping wells. The time-concentration graphs show that the changes in ground water quality at individual MP wells can be variable as volumes of water with different characteristics are sampled each year. During the current reporting period, some of the MP wells, notably MP-15 and MP-20, registered temporary increases in the measured parameters which subsequently disappeared. In other MP-wells, such as MP-19 and MP-28, an increase in these parameters was beginning to develop in May 1997. Significant improvements in

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ground water quality are expected to be observed at wells MP-11, MP-25, MP-26, MP-27 and MP-29 in the next reporting period as RO permeate is injected in the B4/B17 and B11/B12/B13/B14 pattern groups.

Preparation of iso-concentration maps for the B-Wellfield, in accordance with Section RP 4.5 of the approved permit application, has not been attempted for previous Annual Reports because of the limited sample data available. Such maps would have been very generalized and subjective, with little practical value. During the current reporting period, sampling of the 13 new BR wells, together with a number of injection and production wells, has generated a data set which has been used to produce a series of iso-concentration maps for the southern part of the B-Wellfield in the B12/B13/B14 areas (Figures 3-14 through 3-17). Lower contour intervals of 600 µmhos/cm conductivity, 10 mg/l chloride, 250 mg/l bicarbonate and 3 mg/l uranium have been selected to reliably depict the zones of impacted ground water.

A review of these maps clearly shows two important effects of the enhanced wellfield bleed withdrawn from the B13-B14 pattern group, during both production and restoration periods. Firstly, the ground water quality at the southern-most patterns is very close to baseline values, with the exception of uranium, which is at 5 mg/l. This illustrates the success of the production bleed and ground water sweep pumping in preventing the migration of leaching fluids towards the Exxon open pit. Sufficient native ground water has been drawn into the wellfield from the south to dilute the leaching fluids and confine this water to the pattern area. The second effect is not so beneficial, as leaching fluids from the B11 and B12 pattern groups have been caused to migrate southwestwards into an area of the B-Wellfield lying between the B12 and B13 patterns. The volume of impacted ground water now located there probably contributed to the prolonged excursion at monitor well M42.

In the center of this impacted wellfield area, conductivity levels up to 2560 µmhos/cm, bicarbonate concentrations over 1000 mg/l, and chloride concentrations over 260 mg/l have been measured from wells BR-9 and BR-12. The uranium concentrations at these wells, possibly showing some natural attenuation by redox reactions in the 30-sand formation, do not exceed 24 mg/l. The installation of the 13 BR wells will assist with the injection of RO permeate and the restoration of ground water in this part of the wellfield.

Annual Guideline-8 Sampling

Section RP4 of the approved permit application commits PRI to sample the MP wells for the Guideline-8 (Table 1) parameters at the end of "each year's active restoration period". As described in the equivalent section for the A-Wellfield, these samples have been collected earlier in the reporting period so that current data can be

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reviewed in the Annual Report. Sampling of MP wells in the B-Wellfield for Guideline-8 parameters in this reporting period was conducted between May 27-29, 1997. The results are included with this report as Appendix 3D. Table 3-2 summarizes the mean water quality characteristics for selected Guideline-8 parameters from the B-Wellfield MP wells for data collected annually from 1991 to 1997. Baseline and "Class of Use" concentrations for each of these parameters are also shown in the table.

A review of the Guideline-8 water quality data confirms that there has been no significant change in the measured parameters during the current reporting period, as indicated by the bi-monthly sampling data. There is only a limited variation between the 1996 and 1997 results for the major ions, although some of the trace elements, particularly selenium and radium, show more fluctuation. A similar variability and absence of trend for selenium and radium is evident in the mean annual values for all of the years from 1991 to 1997.

3.2.1 Monitor Well Excursions

During the current reporting period, three B-Wellfield excursion monitor wells were on excursion status with the WDEQ. All three wells are located in the northwest corner of the monitor well ring, close to the Exxon underground mine workings. Wells M-62 and M-63 were on excursion status at the start of the reporting period and remained on excursion throughout the period. Well M-56 went on excursion status on November 22, 1996. As discussed in correspondence to the WDEQ dated November 27, 1996, these wells are being affected by ground water being drawn from the abandoned underground mine as a consequence of the enhanced potentiometric gradient of the 30-sand aquifer towards the B-Wellfield. The steeper gradient is a result of the pumping of ground water sweep fluids from the wellfield, and in particular, from the B4, B17 and B18 pattern groups.

PRI has requested that the Upper Control Limits (UCL's) for these wells be revised to account for the change in water quality which is not a result of PRI's in situ mining activities. Individual well data are included in the Monthly and Quarterly Reports.

3.2.2 Ground Water Restoration Plans for 1997-1998

Restoration of the ground water in the B-Wellfield will be accelerated during the next reporting period by operation of both RO units for permeate injection into the 30-sand aquifer, as previously discussed. Another group of BR restoration wells will be installed between the B9/B15 and B6/B10 pattern blocks where it is suspected that past ground water sweep activities may have caused the migration of leaching fluids away from the patterns. If the ground water quality in that part of the wellfield being treated by permeate from RO unit #2 (B12/B13/B14) improves to a sufficient extent, this RO unit will be relocated to the central area to operate in conjunction with the next group of BR wells. At that time, the H_2S injection system will probably be

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moved to the B12/B13/B14 area for final immobilization of residual concentrations of dissolved uranium and selenium. Wells pumping ground water sweep fluids at a combined flow rate of 15-20 gpm will be operated in the B1/B2, B6 and B19 pattern groups.

3.3 C-Wellfield Restoration Activities

General

Production began from the 50-sand aquifer in the north of the C-Wellfield in 1989. At the present time, there are no operating wells in the northern half of the C-Wellfield, but a number of wells still remain in production in the southern half. Preparation for restoration of the ground water in the northern half of the C-Wellfield began towards the end of the current reporting period, with the objective of starting the restoration in August 1997. This preparation consisted of renovation and sampling of the 20 CMP wells and installation of an electrical power supply and other surface facilities. Two pumping wells which had been maintaining a wellfield bleed where shut off and the pumps moved to more appropriate wells to begin ground water sweep.

It should be noted that the naming convention for wells was changed in the C-Wellfield, when the wellfield letter started to be used as a prefix. Thus, in the C-Wellfield, individual production and injection wells are labeled "CP-" and "CI-", pattern areas are labeled "C1", "C2" etc., and monitor wells are labeled "CM-", "CMP-", "CMO-" and "CMU-".

No perimeter monitor (CM) wells are on excursion status in the C-Wellfield.

Ground Water Sweep

Two pumping wells were in operation during the current reporting period, withdrawing a combined bleed of 10 gpm from the C12 pattern group. This bleed was sufficient to maintain a cone of depression in the 50-sand aquifer in the northern half of the wellfield. In preparation for the beginning of ground water restoration, the pumps were moved to different wells in the C8 and C3 pattern groups towards the end of the current reporting period. This was to prevent undesirable migration of leaching fluids beyond the pattern areas at the increased flow rates and to also pump undiluted production fluids.

Reverse Osmosis

RO Unit #3 is planned to be constructed in late 1997 for operation early in 1998. In Section 3.1, the effectiveness of RO permeate circulation in improving ground water quality in the A-Wellfield was discussed. The impact of the same activity in the B-Wellfield will be closely monitored and, if the same response is observed, PRI will

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propose a revision to the approved permit application so that injection of RO permeate can begin in the C-Wellfield at an earlier stage. Only minimal pumping of ground water sweep fluids will be recommended to maintain control of potentiometric surface gradients.

Additional Restoration Wells

During the current reporting period, a total of 10 new trial CR wells were installed which will be used to define the extent of the impacted ground water and to assist with its restoration in the 50-sand aquifer. The location of these wells is shown on Figure 3-18. The wells will be used for both pumping and injection of RO permeate in conjunction with the existing pattern wells.

Hydrogen Sulfide Reductant Injection Test

During 1995 and 1996, an experimental pre-restoration reductant injection test was conducted at the northern end of the C-Wellfield. One objective of this test was to develop equipment and safety procedures for routine operation of the H_2S injection facility. Another objective was to observe the reaction of injected H_2S with undiluted production fluids prior to any ground water restoration treatment and the effect, if any, on residual dissolved uranium and selenium concentrations. The experiment involved closed-loop circulation of ground water containing dissolved H_2S gas in the C1 pattern area using five patterns at a time. Approximately 20,500 lbs of H_2S was injected into a total of 10 patterns over a period of 10 months, although most of this reductant was injected into patterns CP-1 to CP-5. Fluid containing dissolved reductant was injected into the corner injection wells and pumped from the central production wells, in the same configuration as used during wellfield production. Samples were collected from the pumping wells at regular intervals during the experiment and on several occasions since the injection of H_2S was discontinued. Some of these samples were collected during the current reporting period. The samples were for analyzed for selected parameters which may have indicated changes in redox potential or breakthrough of reductant.

The sample data from wells CP-1 through CP-5 have provided the most consistent results from the experiment. As an example, a graph (Figure 3-19) of the measured parameters from one of the pumping wells, CP-5, has been included with this report. Graphs for wells CP-1 through CP-4 show similar features. It can be seen that the uranium concentration at well CP-5 was reduced from nearly 40 mg/l to 13 mg/l during the injection phase of the experiment. A further reduction to below 2 mg/l occurred several months after injection was discontinued, then the concentration increased again to nearly 6 mg/l. It cannot be concluded unequivocally that all of the reduction in uranium concentration was a result of the injection of reductant. Some of the changes may have been a consequence of recirculation of the ground water.

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Of the remaining curves on Figure 3-19, only the oxidation-reduction potential (ORP) readings show a declining trend which matches that of the uranium. There was no evidence of reductant breakthrough from the sulfate, pH or selenium data, although selenium concentrations were low at this well before the experiment began. Selenium curves for some of the other recovery wells do show evidence of decreasing concentrations, despite the complications caused by "noise" from the analytical error. Well CP-5 is also well CMP-9 and was sampled recently and analyzed for Guideline-8 parameters. The uranium and selenium concentrations in these results were essentially unchanged at 3.3 and 0.006 mg/l respectively.

From an operational standpoint, the experiment suffered from persistent screen plugging of the injection wells. This is now thought to have been caused by formation of pyrite solids when the H_2S gas reacted with dissolved iron and particulate iron oxy-hydroxides which were probably contained in fluid flowing from the pumping wells. The consumption of reductant by the undiluted leaching fluids was also thought to be excessive and probably contributed to the absence of breakthrough at the pumping wells. The experiment is not yet complete, however, because trace elements may precipitate in the reduced formation within the C1 area as fluids are drawn through it during normal ground water restoration activities. Sampling for the same parameters will continue when restoration begins.

50-Sand Water Levels

Water levels will be measured in all peripheral monitor wells and MP wells in the C-Wellfield every 2 months, starting in August 1997. Once a year, water levels are also measured in a selected number of injection or production wells throughout the wellfield on a date which coincides with one of the bimonthly measurements of the monitor well water levels. These data are used to compile a contour map representing the potentiometric surface for the wellfield on that date. Figure 3-20 of this report is a contoured potentiometric surface map of the C-Wellfield measured on August 4, 1997, after the relocation of the two ground water sweep pumping wells. The data has been supplemented by water level measurements taken in the nearest E-Wellfield perimeter monitor wells to indicate the continuity of the potentiometric surface. The contours indicate that a cone of depression exists around these pumping wells. It is connected to a shallower trough of depression which extends through the southern half of the C-Wellfield and into the E-Wellfield, which is contiguous and is permitted in the same aquifer.

Ground Water Quality in the 50-Sand

Bi-Monthly MP Well Sampling

MP wells are completed in the production zone and were sampled prior to leaching to establish baseline water quality conditions and target restoration values. Sampling of MP wells is suspended while wellfields are in production and then resumed once

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ground water restoration begins. Routine sampling of the CMP wells will start in August 1997, two months after the first post-mining Guideline-8 samples were collected. These water quality data will be included in future Quarterly Reports. Contoured iso-concentration maps will be prepared for sections of the wellfield from these and other data throughout the next reporting period and included with the 1998 Annual Report.

Annual Guideline-8 Sampling

Section RP4 of the approved permit application commits PRI to sample MP wells for the Guideline-8 parameters to characterize an "end of injection" water quality average and thereafter at the end of "each year's active restoration period". The "end of injection" samples were collected from the CMP wells during a period from June 10 to June 26, 1997. The results are included with this report as Appendix 3E, with averaged selected parameters summarized on Table 3-3. Data for only 17 of the 20 CMP wells are included, as the wellheads of wells CMP-3, CMP-5 and CMP-13 have been damaged and require repair before they can be sampled. The absence of data for these three wells is unlikely to make any significant difference to the 1997 averages for the selected water quality parameters or to the conclusions derived therefrom. The averages summarized in Table 3-3 will be updated with the missing data after the wells have been sampled and the revised values reported in the next Annual Report to the WDEQ.

A review of Table 3-3 shows that the ground water quality in the C-Wellfield pattern areas is typical of undiluted wellfield leaching fluids. When compared to the "end of injection" averages for major ions from the A- and B-Wellfields, the sulfate and TDS concentrations are a little higher, but the chloride, and bicarbonate concentrations, and the conductivity levels are slightly lower. Among the trace element averages, uranium is similar to the B-Wellfield but lower than the A-Wellfield, while radium is higher than the B-Wellfield and lower than the A-Wellfield. The average concentration of selenium in the C-Wellfield is significantly higher than both but is biased by the single sample at the high end of the concentration range, which is from 0.006 to 14.4 mg/l. The latter value is from a suspect sample and a duplicate will be taken to confirm it.

Underground Mine Workings

During 1991 it was determined that production fluids from the 50-sand aquifer within the C-Wellfield had entered the abandoned underground workings below. This was not unexpected, as the workings and the C-Wellfield production zone are connected by raises and fan drilling at several locations. The workings also extend to the 40-sand production zone in the D-Wellfield. In November 1992, the WDEQ approved a permit revision to include the workings in the C-Wellfield production zone.

Additional wells were installed to monitor the potential movement of production fluids within and surrounding the workings. As described in Section RP 4 of the approved permit application, this group of 11 monitor wells (CMU-1, CMU-2, CMU-3, CMU-12, CMU-13, CRMW-1 through CRMW-6) are to be sampled during the restoration and stability periods to assess the progress of ground water restoration in the underground workings. Sampling of these wells will begin in August 1997 and the results will be included in the Quarterly Reports.

3.3.1 Ground Water Restoration Plans for 1997-1998

Ground water sweep pumping will continue throughout the next reporting period. During the second half of 1997 additional ground water sweep wells will operated in the northern half of the C-Wellfield in areas with the highest conductivity water. The combined bleed rate is unlikely to exceed 30 gpm. Construction of RO Unit #3 will begin in September 1997, when RO Unit #2 is completely operational and all the recent design changes have been finalized. The capacity of this unit will be 125 gpm of permeate. Repair and upgrading of wellfield surface facilities and electrical power will continue throughout the remainder of 1997 and the early part of 1998. Minor modifications will also be made to the pipelines to Satellite 2 to enable the restorations flows to be treated in conjunction with the production stream.

Injection of permeate from RO Unit #3 is expected to begin in the Spring of 1998, probably starting with the C1/C2/C3/C5 pattern groups and using the CR wells to help treat leaching fluids beyond the pattern area. Injection and pumping wells will be configured in "megapatterns", i.e. multiples of regular mining patterns. Installation of additional CR wells may be required to assist with the ground water restoration activities and a number of existing pattern wells may also require recompletion of screened intervals to improve flow rates.

4.0 RECLAMATION ACTIVITIES

4.1 Seeding of Disturbed Areas

Reclamation activities during the report period consisted of seeding approximately 36 acres within the F-Wellfield during the Spring of 1997. Plates 1C and 1D show the areas in the F-Wellfield which were seeded. Approximately 11,800 linear feet (4.1 acres) of decommissioned wellfield access roads in the C, D, E and F - Wellfields were also seeded during the Spring of 1997. Thirty-eight (38) topsoil stockpiles, most of which were associated with wellfield access road construction, were also seeded at the same time. All seeding activities used the approved permanent seed mix, as follows:

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TABLE 3-1

A-WELLFIELD
SELECTED MEAN WATER QUALITY CHARACTERISTICS AT
WELLS MP-1 THROUGH MP-5
(mg/l unless noted)

Year	HCO_3	SO_4	Cl	TDS	COND (µmhos/cm)	Se	U_3O_8	Ra(pCi/l)
July 1991	720	381	213	1507	2390	1.00	47	3286
July 1992	817	341	209	1564	1926	0.84	53	2550
July 1993	782	265	182	1399	1997	0.66	50	2877
July 1994	487	100	65	687	1077	0.46	22	2235
July 1995	407	92	43	570	879	0.51	21	1678
July 1996 (MP2-MP5)	394	50	7	358	556	0.33	4	1439
July 1997	259	41	4	319	471	0.36	3	1057
Baseline	215	91	4	330	525	<0.001	.05	675
Class of Use Domestic	NA	250	250	500	NA	.05	5	5
Class of Use Livestock	NA	3000	2000	5000	NA	.05	5	5

TABLE 3-2

B-WELLFIELD
SELECTED MEAN WATER QUALITY CHARACTERISTICS AT
WELLS MP-11 THROUGH MP-31
(mg/l unless noted)

Year	HCO_3	SO_4	Cl	TDS	COND (µmhos/cm)	Se	U_3O_8	Ra(pCi/l)
July 1991	824	402	232	1672	2580	0.81	26	1478
July 1992	802	346	201	1559	2010	0.48	37	1571
July 1993	720	270	165	1331	1901	0.79	29	1203
July 1994	633	292	146	1212	1773	1.17	22	1515
July 1995	595	229	109	1035	1602	.58	19	1222
July 1996	534	215	91	941	1388	.69	19	951
July 1997	561	208	94	981	1365	0.37	17.5	1060
Baseline	210	117	5	355	574	<0.001	.07	313
Class of Use Domestic	NA	250	250	500	NA	.05	5	5
Class of Use Livestock	NA	3000	2000	5000	NA	.05	5	5

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TABLE 3-3

C-WELLFIELD
SELECTED MEAN WATER QUALITY CHARACTERISTICS AT
WELLS CMP-1 THROUGH CMP-20
(mg/l unless noted)

Year	HCO_3	SO_4	Cl	TDS	Cond (µmhos/cm)	Se	U_3O_8	Ra(pCi/l)
July 1997	628	627	199	1995	2343	2.56	25	2261
Baseline (CMP1-CMP32)	203	210	5	492	721	.02	2.16	703
Class of Use (Domestic)	NA	250	250	500	NA	.05	5	5
Class of Use (Livestock)	NA	3000	2000	5000	NA	.05	5	5

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Exhibit F

POWER RESOURCES

February 6, 1991

RE: Docket No. 40-8857
SUA-1511

Mr. R.E. Hall, Director
Uranium Recovery Field Office
U.S. Nuclear Regulatory Commission
P.O. Box 25325
Denver, Colorado 80225

Dear Mr. Hall:

In accordance with License Condition No. 45 of SUA-1511, please find attached for your review and approval, three copies of Power Resources, Inc.'s (PRI) ground water restoration plan for our Section 21, 20 and 30-Sand Mine Units. The details given in this plan are consistent with the general restoration plan outlined in the original license application. These two mine units commenced production in January 1987. It is anticipated that active ground water restoration will commence in July or August 1991.

Please call should you have any questions.

Sincerely,

Paul R. Hildenbrand
Manager of Environmental and
Regulatory Affairs

PRH/ksj

attachment

cc: S.P. Morzenti
M.R. Lueders
W.F. Kearney
File 4.6.4.1

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Highland Uranium Project
Post Office Box 1210
Glenrock, Wyoming 82637

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POWER RESOURCES, INC.
HIGHLAND URANIUM PROJECT

SECTION 21, 20 AND 30-SAND MINE UNITS GROUND WATER RESTORATION PLAN

FEBRUARY 1991

US NRC Docket No. 40-8857
SUA-1511

TABLE 2.1.1

SECTION 21, 20-SAND MINE UNIT

Average Premining Ground Water quality Based on Baseline Sampling of Wells MP-1 through MP-5*

Parameter	Det. Limit & Range	Average Concentration
Ca	0.05	44.7
Mg	0.01	9
Na	0.05	55
K	0.10	8
CO_3	0.10	<0.1
HCO_3	0.10	215
SO_4	0.50	91
Cl	0.10	4.2
NH_4 (N)	0.05	0.1
NO_2 (N)	0.01	<0.01
NO_3 (N)	0.01	<0.01
F	0.10	0.2
SiO_2	1.00	16
TDS @ 180 C	1.0	330
Cond (umho/cm)	1.0	525
Alk-$CaCO_3$	0.1	177
pH (units)	1-14	8
Al	0.10	<0.1
As	0.001	<0.001
Ba	0.10	<0.1
B	0.10	<0.1
Cd	0.01	<0.01
Cr	0.05	<0.05
Cu	0.01	<0.01
Fe	0.05	<0.05
Pb	0.05	<0.05
Mn	0.01	0.03
Hg	0.001	<0.001
Mo	0.10	<0.1
Ni	0.05	<0.05
Se	0.001	<0.001
V	0.10	<0.1
Zn	0.01	<0.01
U - Total	0.0003	0.041
Ra-226 - Total (pCi/l)	0.20	675

* mg/l unless specified otherwise

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TABLE 2.1.2

SECTION 21, 30-SAND MINE UNIT

Average Pre-Injection Ground Water Quality Based on Baseline Sampling of Wells MP-11 through MP-31

Parameter	Det. Limit & Range	Average Concentration
Ca	0.05	47
Mg	0.01	10
Na	0.05	57
K	0.10	8
CO_3	0.10	0.11
HCO_3	0.10	207
SO_4	0.50	117
Cl	0.10	5.4
NH_4 (N)	0.05	2
NO_2 (N)	0.01	<0.01
NO_3 (N)	0.01	0.09
F	0.10	0.23
SiO_2	1.00	16
TDS @ 180 C	1.0	355
Cond (umho/cm)	1.0	574
Alk-$CaCO_3$	0.1	168
pH (units)	1-14	8
Al	0.10	<0.1
As	0.001	<0.001
Ba	0.10	<0.1
B	0.10	<0.1
Cd	0.01	<0.01
Cr	0.05	<0.05
Cu	0.01	<0.01
Fe	0.05	0.04
Pb	0.05	<0.05
Mn	0.01	0.02
Hg	0.001	<0.001
Mo	0.10	<0.1
Ni	0.05	<0.05
Se	0.001	<0.001
V	0.10	<0.1
Zn	0.01	<0.01
U - Total	0.0003	0.06
Ra-226 - Total (pCi/l)	0.20	313

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TABLE 2.1.3

SECTION 21, 20 AND 30 SAND MINE UNITS

Production Zone Typical Water Quality at Start of Restoration

Parameter*		Det. Limit & Range
Ca	300-400	0.05
Mg	50-100	0.01
Na	90-100	0.05
K	15-30	0.10
CO_3	<0.10	0.10
HCO_3	500-1200	0.10
SO_4	300-500	0.50
Cl	200-400	0.10
NH_4 (N)	0.3-0.4	0.05
NO_2 (N)	<0.1	0.01
NO_3 (N)	0.01-0.03	0.01
F	0.10-0.25	0.10
SiO_2	20-40	1.00
TDS @ 180 C	1400-1600	1.0
Cond (umho/cm)	1900-2600	1.0
Alk-$CaCO_3$	500-900	0.1
pH (units)	6.5-7.5	1-14
Al	0.1-1	0.10
As	<0.001	0.001
Ba	0.1-0.2	0.10
B	<0.1-0.1	0.10
Cd	<0.01	0.01
Cr	<0.05	0.05
Cu	0.01-0.04	0.01
Fe	<0.05-0.1	0.05
Pb	<0.05	0.05
Mn	0.1-1	0.01
Hg	<0.001	0.001
Mo	<0.1	0.10
Ni	0.05-0.15	0.05
Se	2.5-3.5	0.001
V	<0.1-0.1	0.10
Zn	<0.01-0.2	0.01
U - Total	3-50	0.0003
Ra-226 - Total (pCi/l)	2500-5000	0.20

* mg/l unless specified otherwise

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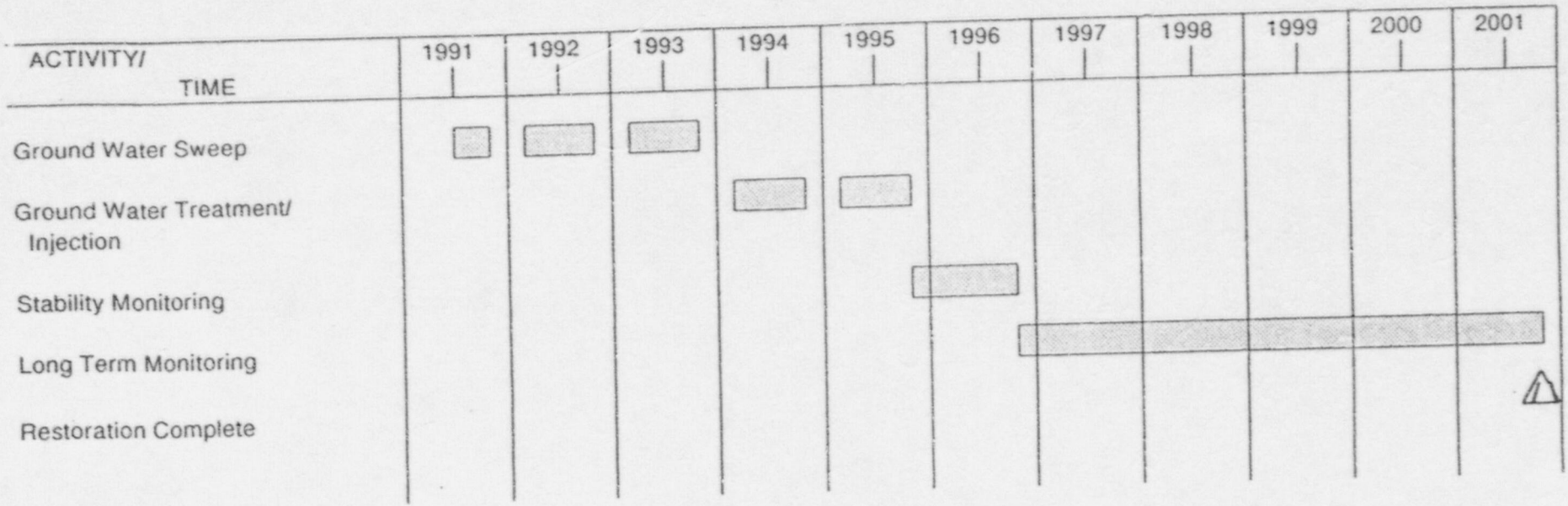
FIGURE 2.2.1

SECTION 21, 20 AND 30 SAND MINE UNITS (A&B WELLFIELDS)
ESTIMATED GROUND WATER RESTORATION SCHEDULE



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PRH:FIG221

Exhibit G

WCH
GAC

POWER
RESOURCES

Steve I SI
Georgia GAC
Ramona ___

VIA FAX

September 14, 1994

RE: Permit to Mine No. 603-A2
Well CM-15 Excursion

Mr. Bill Hogg, District I Supervisor
Land Quality Division
Wyoming Department of Environmental Quality
Herschler Building
Cheyenne, Wyoming 82002

Dear Mr. Hogg,

In accordance with Section 8.4 of the Operations Plan, Power Resources, Inc. (PRI) herein provides written notification that well CM-15, located in the C-Wellfield at the Highland Uranium Project, went on excursion status on September 9, 1994. Consistent with the requirements of Section 8.4 of the Operations Plan, I notified you of this excursion by telephone on September 9, 1994. The NRC (Mr. Mike Layton) was also notified of this excursion by telephone on September 9, 1994.

WENT OFF EXCURSION STATUS ~~JULY~~ 9: MARCH
CONFIRMED JULY 9:

Well CM-15 monitors the 50-Sand production zone, lateral to the southern portion of the C-Wellfield (pattern area C-17). A review of the attached data sheet shows that both bicarbonate and conductivity exceed the respective Upper Control Limits (UCL's) while chloride remains below it's UCL. Uranium concentrations are at, or very near, the detection limit of 0.1 mg/l U_3O_8.

PRI has been aware of increasing conductivity levels at well CM-15 since late 1993. Because of the increase in conductivity, an increased bleed has been taken since that time near well CM-15 (pattern areas C-17 and C-19) to return any production fluids to the production areas, thereby preventing an excursion at well CM-15. Unfortunately, these activities did not prevent well CM-15 from reaching excursion status.

Because the increased bleed in the area did not reduce conductivity levels, and there is only a marginal increase in chloride and bicarbonate concentrations, PRI is investigating the possibility that well CM-15 is being influenced by water emanating from the abandoned TVA underground mine which is located only about 400 feet away. Over the next two weeks PRI will continue our investigation by pumping various wells to determine the best way to mitigate this situation.

Highland Uranium Project
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Wells M-8A, M-10A, M-11 located in the A-Wellfield, and wells M-62 and M-63 located in the B-Wellfield, remained on excursion status during the report period. Conditions at wells on excursion are discussed in the Monthly Excursion Reports. The most recent report was for June 1996 which was submitted to the WDEQ-LQD under cover dated July 22, 1996.

Wells M-16, M-40, M-42, M-45 and MU-11 showed chloride concentrations which were at, or just above the UCL. Bicarbonate concentrations and conductivity levels remained below the respective UCL's at these wells. A review of the data for wells M-50, M-56, M-61 and M-64 show that these wells, similar to wells M-62 and M-63, are being affected by ground water from the abandoned underground mine located upgradient, and to the west, of the B-Wellfield.

C-Wellfield

Production operations continued in the C-Wellfield during the report period. A review of the water quality data for well CM-15 shows that bicarbonate and conductivity remain elevated slightly above baseline conditions and below the respective UCL's. Chloride concentrations have remained at baseline. A review of the water quality data for well CMO-4 indicates that chloride was slightly above the UCL of 14 mg/l during the report period, while bicarbonate and conductivity remained well below the respective UCL's. The water quality data for wells CMO-9 and CMO-10 indicate that chloride concentrations were elevated slightly above the UCL of 14 mg/l for the report period, while bicarbonate and conductivity remained well below the respective UCL's. Also, the water quality data for well CMO-13 shows that conductivity levels remained above the respective UCL during the report period, while chloride and bicarbonate concentrations remained well below the respective UCL's. It appears that the quality of water within well CMO-13 is being impacted by the very low yield of the well.

D-Wellfield

Production activities continued in the D-Wellfield during the report period. A review of the water quality data shows no anomalous conditions, except at well DM-16 where all excursion parameters have shown some increase. Modifications to production areas adjacent to well DM-16 have been made. Conditions at well DM-16 will continue to be assessed.

E-Wellfield

Production activities continued in the E-Wellfield during the report period. A review of the water quality data shows no anomalous conditions, except at well EM-11 which shows anomalous chloride and bicarbonate concentrations for the June 14, 1996 sampling event. Well EM-11 was resampled on June 17, 1996 and that data, and subsequent data colleted in July 1996, show no anomalous changes in water quality actually occurred.

PRI intends to keep your office informed of the conditions at well CM-15 in the Monthly Excursion Reports" which are currently submitted for wells M-11 and M-63.

If you have any questions, please call.

Sincerely,

Bill Kearney

W.F. Kearney
Environmental Director

WFK/ksj

attachment

cc: S.P. Morzenti w/atta
L.C. McGonagle
P.R. Hildenbrand
R.W. Nehl
File 4.3.3.1

Exhibit H

(ENCLOSURE OMITTED)

POWER RESOURCES

August 6, 1996

RE: Permit to Mine No. 603-A2
Quarterly Report
Period Ending June 30, 1996

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LAND QUALITY
DIVISION

Ms. Georgia Cash, District I Supervisor
Land Quality Division
Wyoming Department of Environmental Quality
Herschler Building
Cheyenne, Wyoming 82002

Dear Ms. Cash:

Please find enclosed the Highland Uranium Project excursion monitor well analytical data and data for additional wells in the A and B-Wellfields for the quarter ended June 30, 1996. During the report period, well mechanical integrity tests (MIT's) were conducted at 110 new wells constructed at the F-Wellfield. All of these wells passed the MIT. MIT's were also conducted at four new restoration wells in the A-Wellfield (AR-7A, AR-8, AR-9 and AR-10). All of these wells passed the MIT.

The monitoring well data are also included on the enclosed floppy disk in ASCII format. The floppy disk contains the data from January 1996 through June 30, 1996.

A review of the water level and water quality data, by wellfield, follows:

A/B-Wellfield (M, MO, MU, MP, and I-Wells)

See as marked Groundwater Restoration and Monitoring Data

Ground water sweep activities continued throughout the report period at the A and B-Wellfields. The operation of the Reverse Osmosis (RO) Unit and injection of RO permeate continued in the A-Wellfield.

A review of the water level data for the MP, I, and M-wells shows that the water levels continue to be depressed as a result of ground water sweep activities and the reject stream from the RO. Fluctuating water levels at the A-Wellfield reflects the operation of the RO Unit.

A review of the water quality data for the MP wells in the A-Wellfield (MP-1 through MP-5) indicates that the improving trend has continued at all wells. Well MP-1 was not monitored during June 1996 as it was, and continues to be used for the injection of RO permeate. Chloride concentrations and conductivity levels are near, or below, baseline at wells MP-2, MP-3 and MP-4. RO activities will continue in the A-Wellfield. A review of the data for the MP wells in the B-Wellfield shows that in general, the overall trend in ground water quality continues at most wells.

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Fax 307•358•4533
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-Wellfield

Production activities continued in the F-Wellfield during the report period. A review of the water quality data shows no anomalous conditions.

As detailed in the previous report, consistent with the WDEQ's approval of the monitoring plan for the entire F-Wellfield (Change No. 19, dated March 1, 1994) PRI started monitoring the entire F-Wellfield monitoring ring in June 1996 to accommodate production operations at the F-8 production area. Production operations commenced at the F-8 production area on July 9, 1996.

Please call me if you have any questions or require further information.

Sincerely,

P.R. Hildenbrand by W.F. Kearney

Paul R. Hildenbrand
Manager of Environmental
and Regulatory Affairs

PRH/WFK/ksj

enclosure

cc: File 4.3.3.2
W.F. Kearney w/o att
L.C. McGonagle w/o att

Exhibit I

JH
Ramona File
PC
RAC

POWER RESOURCES

Highland Uranium Project
P. O. Box 1210
Glenrock, Wyoming USA 82637
Casper: 307-235-1628
Douglas: 307-358-6541
Fax: 307-358-4533

October 14, 1998

See Vol. Marked "Weekly Excursion Status Reports" for A + B Wellfields

OCT 1998
Received
Land Quality Division

Ms. Georgia Cash, District I Supervisor
Land Quality Division
Wyoming Department of Environmental Quality
Herschler Building
122 W. 25th Street
Cheyenne, Wyoming 82002

RE: Permit to Mine 603-A2
September 1998 Excursion Report

Dear Ms. Cash:

Enclosed please find excursion water quality data collected during September 1998 for wells M-10A, M-11, M-43, M-56, and M-62. A detailed explanation of the origin of the excursions at the A-Wellfield, together with a description of the corrective action plan now in progress, was provided to you in correspondence dated May 13, 1996. That correspondence also identified additional wells that have been installed to assist with restoration of the 20-Sand inside the A-Wellfield monitor well ring and the strategy of progressive circulation of reverse osmosis permeate towards the hole in the aquitard. Also enclosed is certain data related to the seepage at PSR-1 as requested by the WDEQ/LQD.

M-11 Monitor Well

As previously discussed in correspondence dated May 13, 1996, PRI attributes the excursion at Well M-11 to 30-Sand mining fluids moving downwards through a hole in the aquitard. Mitigative action taken to control the excursion at Well M-11 consisted of installing and operating the additional pumping Wells AR-1 and AR-3. No significant improvement in the ground water quality at Well M-11 was expected until circulation of RO permeate had been advanced to the site of this aquitard hole. Final remediation of this excursion started in July 1997 with injection of RO permeate into the 30-Sand from two wells in the B4 group of patterns

After the sudden increase in all parameters in the first week of September, caused by the resumption of ground water sweep pumping from Well AR-1 in late August, no further deterioration in water quality at Well M-11 was observed during the remainder of the month. The concentrations of chloride and bicarbonate were 31-32 and 334-337 mg/L respectively. The conductivity level was 813-814 µmhos/cm and the uranium concentration was 0.4 mg/L. It was intended that ground water treated by RO in the 30-Sand would be drawn past Well M-11, possibly leading to a gradual

OCT 1998
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decrease in the concentration of the elevated parameters in this well. The water quality at Well M-11 did begin to show a slight improvement in the last week of September and the well will be closely monitored during the next month to determine if this trend continues.

The conductivity level and the concentrations of chloride and bicarbonate at Well M-10A returned to normal again during September after ground water sweep pumping from Well AR-2 was stopped on August 25. It was presumed that pumping from Well AR-2 had been drawing water from the 30-Sand in the B17 patterns. The immediate change in water quality at Well M-10A in response to this action confirms the connection between the two aquifers. By the end of September, the conductivity level had decreased from 711 to 612 µmhos/cm and the concentrations of chloride and bicarbonate had decreased from 30 to 6 mg/L and 290 to 260 mg/L, respectively. Uranium continued to be undetectable in this well. The proximity of Wells M-10A and M-11 to the hole in the aquitard between the 20-Sand and 30-Sand aquifers means that they are very sensitive to slight changes in ground water flow direction caused by adjustments of pumping and injection rates. This sensitivity is particularly noticeable in the final stages of remediation as RO permeate is injected close to the aquitard hole and the wells themselves.

Monitor Well M-43 went on excursion status during the month of February 1998. As explained in correspondence dated February 12, 1998, this well is located at a deep reentrant in the B-Wellfield monitor well ring and impacted fluids were being drawn towards it in response to the cone of depression created by the wellfield bleed associated with RO Unit #2. Action taken during February and March 1998 succeeded in reversing the brief excursion at this well. The water quality continued to improve during April and early May to near baseline conditions. In late May, the chloride concentration and conductivity levels increased slightly, and remained marginally elevated throughout June and July, but decreased again in August. During September the chloride and bicarbonate concentrations were unchanged at 7-8 mg/L and 197-200 mg/L, respectively. The conductivity level ranged from 642-653 µmhos/cm and uranium was undetectable in water samples from this well.

As discussed in the correspondence dated February 13, 1996, the "excursion" conditions at Well M-62, which is located in the northwest area of the B-Wellfield, result from the movement of ground water from the abandoned Exxon underground mine into the northwestern portion of the B-Wellfield monitoring ring. A review of the September 1998 water quality data for Well M-62 shows bicarbonate concentration remaining at approximately 309 mg/L. Slight fluctuations in conductivity levels within the range of 822-835 µmhos/cm were noted during the month. The chloride concentration has remained near baseline at 9 mg/L. Uranium remained less than the detection limit of 0.1 mg/L.

Well M-56, located in the northwest area of the B-Wellfield, went on excursion status on November 22, 1996. As discussed in correspondence dated November 27, 1996, the B-Wellfield has been in active ground water restoration since July 1991. Similar to conditions at Well M-62, which is located to the west and is also on excursion status, the change in ground water quality causing the excursion at Well M-56 is attributed to accelerated movement of ground water from the abandoned

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Land Quality Division

Exxon underground mine area into the northwestern portion of the B-Wellfield monitoring ring as a result of ground water restoration activities.

A review of the September 1998 water quality data for Well M-56 shows bicarbonate concentration lessened to approximately 232 mg/L. Conductivity remains within the range of 1124 to 1162 µmhos/cm. Chloride concentration has remained near baseline at 10 mg/L. Uranium remained at, or below, the detection limit of 0.1 mg/L.

The continual drawdown in the 30-Sand since ground water sweep operations began in July 1991 has maintained a ground water gradient from the underground mine area into the northwestern portion of the B-Wellfield. Water level data collected from B-Wellfield wells indicates that the direction of ground water flow continues to be from the abandoned mine area into the northwest portion of the B-Wellfield.

The observed change in ground water quality at Well M-56 and water level gradient data for the wellfield area supports the position that the ground water quality at Well M-56 is being affected by a source outside the monitor well ring and may be related to the abandoned Buffalo Shaft, or other areas associated with the abandoned Exxon underground mine. In accordance with Section 4.1 of the approved Reclamation Plan, PRI submitted a request to the WDEQ-LQD, dated January 29, 1996, to modify the UCL's at those B-Wellfield monitoring wells which are currently, and potentially could be, affected by ground water from the abandoned underground mine. PRI met with LQD personnel on January 9, 1998 to more fully describe conditions associated with the northwest area of the B-Wellfield and the abandoned Exxon underground mine. Consistent with discussions at the meeting, PRI submitted an additional request to modify the UCL's in correspondence dated March 18, 1998. In response to further LQD questions, PRI submitted additional information in correspondence dated September 21, 1998 to modify the UCL's which will result in these wells no longer meeting excursion criteria.

ACTIVITIES AT SATELLITE NO. 1

The following information concerning activities at Satellite No. 1 for the month are included:

• Storage Capacity of Sat. No. 1 Purge Storage Reservoir on September 28, 1998	34VAF (5.9 vertical ft)
• Irrigation Application Rate at Sat. No. 1 Land Application Facility	54.8 gpm (204 hr @ 200 gpm)
• Average Ground Water Sweep Pumping Rate at the A and B-Wellfields	20 gpm
• RO Reject Rate (RO-1 and RO-2)	38 gpm

As part of the Corrective Action Plan for the Satellite No. 1 Purge Storage Reservoir, PRI performs weekly inspections and measures water levels at the six monitoring wells located adjacent to the reservoir. The monitoring well data included in Table 1 show that water levels in shallow wells H3A and H4 are continuing to fall as the water level in the reservoir decreases. Data collected at the wells

completed in the deeper zone (wells H10D, H11D and H12D) show minor variations in water level of approximately one to two feet.

During September 1998, the Interceptor Trench pumped back approximately 133,878 gallons (3.32 gpm) of subsurface flow. The trench remains very effective at eliminating the surface seeps south of PSR-1, as all seeps have remained dry. During September 1998 the East Pumpback Sump pumped back 608 gallons (<0.02 gpm) to PSR-1.

PRI will continue to keep your office informed on the status of wells M-10A, M-11, M-56 and M-62 and conditions at the Satellite No. 1 Purge Storage Reservoir. Please call if you have any questions or need additional information.

Sincerely,

WFK for PR Hildenbrand

P.R. Hildenbrand
Manager of Environmental
& Regulatory Affairs

WFK/PRH/ksj

cc: File 4.3.3.1
L.C. McGonagle
W.F. Kearney
File HL 7
M.S. Chalmers
M.B. Wittrup
J. Hunter

OCT 1998
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Exhibit J

TABLE OF EXCURSIONS AT TEXAS URANIUM ISL MINES FROM TNRCC FILES AND DATABASES, 1998.

Thursday, December 10, 1998 ANSWER

COMPANY NAME	MINE NAME	PAA	WELL NUMBER	DOCUMENT TYPE	DATE REPORT DUE	COMMENTS
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-262	Excursion Status **	10/31/1994	Well went off excursion status
MALAPAI RESOURCES COMPA	Holiday	UR-02156-051	UI-2046	Excursion Status **	3/31/1993	Well went off excursion status
MALAPAI RESOURCES COMPA	Holiday	UR-02156-071	UI-2752	Excursion Status *	5/31/1993	Well went on excursion status
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	118	Excursion Status *	1/31/1994	Company to attempt demonstration soon that excursion not due to mining activity
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	118	Excursion Status **	10/31/1994	Company removing well from active excursion list (letter dated October 20, 1994)
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	702	Excursion Status **	1/31/1995	Well went off excursion status
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	704	Excursion Status **	1/31/1995	Well went off excursion status
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	705	Excursion Status **	1/31/1995	Well went off excursion status
RIO GRANDE RESOURCES CO	Palangana	UR-02051-011	706	Excursion Status **	1/31/1995	Well went off excursion status
URI	Kingsville Dome	UR-02827-011	A10	Excursion Status *	8/31/1996	Well went on excursion status 7/17/96: EC, Cl
URI	Kingsville Dome	UR-02827-011	A10	Excursion Status **	12/31/1996	Well had damaged casing and was plugged, replaced with new well
URI	Kingsville Dome	UR-02827-011	D 2	Excursion Status *	8/31/1996	Well went on excursion status 7/12/96: Cl
URI	Kingsville Dome	UR-02827-011	D 2	Excursion Status **	8/31/1996	Well went off excursion status 8/96
URI	Kingsville Dome	UR-02827-011	D 9	Excursion Status *	8/31/1996	Well went on excursion status 7/12/96: Cl
URI	Kingsville Dome	UR-02827-011	D 9	Excursion Status **	8/31/1996	Well went off excursion status 8/96
URI	Kingsville Dome	UR-02827-011	D15	Excursion Status *	8/31/1996	Well went on excursion status 7/12/96: Cl
URI	Kingsville Dome	UR-02827-011	D15	Excursion Status **	8/31/1996	Well went off excursion status 8/96
URI	Kingsville Dome	UR-02827-011	MW8	Excursion Status *	11/13/1998	Well went on excursion status 11/13/98: cond.
URI	Kingsville Dome	UR-02827-021	D39	Excursion Status *	8/31/1996	Well went on excursion status 7/18/96: Cl
URI	Kingsville Dome	UR-02827-021	D39	Excursion Status **	8/31/1996	Well went off excursion status 8/96
URI	Kingsville Dome	UR-02827-021	D45	Excursion Status *	11/30/1996	Well went on excursion status 10/14/96
URI	Kingsville Dome	UR-02827-021	D45	Excursion Status **	11/30/1996	Well went off excursion status 10/28/96
URI	Kingsville Dome	UR-02827-021	D47	Excursion Status *	1/31/1998	Well went on excursion status 1/14/98: Cl
URI	Kingsville Dome	UR-02827-021	D47	Excursion Status **	1/28/1998	Well went off excursion status 1/28/98: Cl
URI	Kingsville Dome	UR-02827-021	MW-172	Excursion Status *	7/31/1998	Well went on excursion status 7/22/98: Cl, Cond.
URI	Kingsville Dome	UR-02827-021	MW49a	Excursion Status *	3/31/1998	Well went on excursion status 5/98: Cl, Cond.
USX	Burns " A " Zone	UR-01890-021	120-MS	Excursion Status *	5/31/1996	Well went on excursion status 5/27/96 conductivity
USX	Burns " A " Zone	UR-01890-021	120-MS	Excursion Status **	6/30/1996	Well went off excursion status 6/18/96
USX	Burns " A " Zone	UR-01890-021	23-MD	Excursion Status *	5/31/1996	Well went on excursion status 5/16/96 conductivity
USX	Burns " A " Zone	UR-01890-021	23-MD	Excursion Status **	5/31/1996	Well went off excursion status 5/27/96
USX	Burns " A " Zone	UR-01890-021	24-MD	Excursion Status *	5/31/1996	Well went on excursion status 5/16/96 conductivity
USX	Burns " A " Zone	UR-01890-021	24-MD	Excursion Status **	5/31/1996	Well went off excursion status 5/27/96
USX	Burns " B " Zone	UR-01890-031	118-MS	Excursion Status *	5/31/1996	Well went on excursion status 5/12/96 sulfate
USX	Burns " B " Zone	UR-01890-031	118-MS	Excursion Status **	8/31/1996	Well went off excursion status 8/3/96
USX	Clay West	UR-02130-011	769-MSC	Excursion Status *	3/31/1996	Well went on excursion status 3/31/96 conductivity
USX	Clay West	UR-02130-011	769-MSC	Excursion Status *	2/28/1997	
USX	Clay West	UR-02130-011	769-MSC	Excursion Status **	6/30/1996	Well went off excursion status 6/19/96
USX	Clay West	UR-02130-011	MD-730	Excursion Status *	1/31/1997	Well went on excursion status 1/18/97 sulfate
USX	Clay West	UR-02130-011	MD-730	Excursion Status **	5/31/1997	off excursion 5/1/97
USX	Moser " A " Zone	UR-01890-011	766-MS	Excursion Status *	1/31/1995	Well went on excursion status
USX	Moser " A " Zone	UR-01890-011	766-MS	Excursion Status **	8/31/1994	Well went off excursion status
USX	Moser " A " Zone	UR-01890-011	769-MS	Excursion Status *	4/30/1996	Well went on excursion status 4/11/96 sulfate
USX	Moser " A " Zone	UR-01890-011	769-MS	Excursion Status *	2/28/1997	Well went on excursion status 2/3/97 sulfate
USX	Moser " A " Zone	UR-01890-011	769-MS	Excursion Status **	7/31/1996	Well went off excursion status 7/8/96
USX	Moser " A " Zone	UR-01890-011	770-MS	Excursion Status **	10/31/1998	Off Excursion 10/1/98
USX	Moser " A " Zone	UR-01890-011	917-MS	Excursion Status *	9/30/1998	On Excursion 9/21/98 sulfate
USX	Moser " A " Zone	UR-01890-011	917-MS	Excursion Status **	10/31/1998	Off Excursion 10/1/98
USX	Moser " C " Zone	UR-01890-041	904-MD	Excursion Status *	2/28/1997	Well went on excursion status 2/13/97, conductivity
USX	Moser " C " Zone	UR-01890-041	904-MD	Excursion Status **	1/31/1997	Well went on excursion status 1/14/97
USX	Moser " C " Zone	UR-01890-041	909-MD	Excursion Status *	10/31/1996	Well went on excursion status

SOURCE: Table of excursion records for Texas uranium ISL mines prepared and provided by John Santos, geologist, Texas Natural Resource Conservation Commission, from TNRCC/Underground Injection Control files and databases (December 10, 1998).

* well on excursion
** well off excursion

(wpr/121298)

TABLE OF EXCURSIONS AT TEXAS URANIUM ISL MINES FROM TNRCC FILES AND DATABASES (cont'd)

Thursday, December 10, 1998

ANSWER

COMPANY NAME	MINE NAME	PAA	WELL NUMBER	DOCUMENT TYPE	DATE REPORT DUE	COMMENTS
COGEMA MINING, INC	El Mesquite	UR-02155-021	UI-708C	Excursion Status *	6/30/1994	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-114	Excursion Status *	7/31/1998	Well went on excursion status 7/10/98 Cl
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-515	Excursion Status *	4/30/1995	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-515	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-522	Excursion Status *	8/31/1994	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-522	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-523	Excursion Status *	7/31/1998	Well went on excursion status 7/10/98 Cl
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-524	Excursion Status *	8/31/1994	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-524	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-572	Excursion Status *	4/30/1995	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-572	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-573	Excursion Status *	6/30/1994	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-573	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-588	Excursion Status *	12/31/1994	Well went on excursion status
COGEMA MINING, INC	El Mesquite	UR-02155-031	UI-588	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	Holiday	UR-02156-011	UI-5352	Excursion Status *	2/29/1996	Well went on excursion status
COGEMA MINING, INC	Holiday	UR-02156-041	UI-2402	Excursion Status *	8/31/1994	Well went on excursion status, Chloride
COGEMA MINING, INC	Holiday	UR-02156-071	UI-1906	Excursion Status *	2/28/1998	Well went on excursion status 2/17/98 Cl
COGEMA MINING, INC	O'Hern	UR-01941-011	UI- 26	Excursion Status *	1/31/1995	Well went on excursion status
COGEMA MINING, INC	O'Hern	UR-01941-011	UI-1031	Excursion Status *	5/31/1995	Well went on excursion status
COGEMA MINING, INC	O'Hern	UR-01941-011	UI-1031	Excursion Status **	10/31/1995	Well went off excursion status
COGEMA MINING, INC	O'Hern	UR-01941-011	UI-26	Excursion Status **	5/31/1996	Well went off excursion status 4/29/96 per TNRCC letter
COGEMA MINING, INC	O'Hern	UR-01941-011	UI-43	Excursion Status *	10/31/1996	Well went on excursion 11/3/96, Cond
COGEMA MINING, INC	O'Hern	UR-01941-011	UI-43	Excursion Status **	5/31/1997	Well went off excursion status 5/7/97 per TNRCC letter
COGEMA MINING, INC	O'Hern	UR-01941-041	UI- 92	Excursion Status *	10/31/1994	Well went on excursion status 10/6/94, Cond., Sulfate
COGEMA MINING, INC	O'Hern	UR-01941-041	UI- 92	Excursion Status **	9/18/1997	Well went off excursion status 9/18/971, outside contamination
COGEMA MINING, INC	O'Hern	UR-01941-041	UI-187R	Excursion Status **	8/31/1997	off excursion 8/97
COGEMA MINING, INC	O'Hern	UR-01941-041	UI-194	Excursion Status *	2/28/1997	Well went on excursion status 2/20/97, Uranium
COGEMA MINING, INC	West Cole	UR-02463-021	M-21	Excursion Status *	12/31/1994	Well should have gone to excursion status in December 1994 - co. admits mistake
COGEMA MINING, INC	West Cole	UR-02463-021	M-21	Excursion Status *	2/29/1996	Well went on excursion status, Chloride
COGEMA MINING, INC	West Cole	UR-02463-021	M-21	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	West Cole	UR-02463-021	M-21	Excursion Status **	2/28/1998	Well went off excursion status 2/9/98
COGEMA MINING, INC	West Cole	UR-02463-021	M-25	Excursion Status *	6/30/1996	Well went on excursion status 6/18/96 - Cl
COGEMA MINING, INC	West Cole	UR-02463-021	M-25	Excursion Status **	9/30/1995	Well went off excursion status
COGEMA MINING, INC	West Cole	UR-02463-021	M-29	Excursion Status *	8/31/1998	Well went on excursion status 8/13/98 Cl, cond
COGEMA MINING, INC	West Cole	UR-02463-021	SM-13	Excursion Status *	9/30/1995	Well went on excursion status
EVEREST EXPLORATION	Tex - 1	UR-02493-011	MA-3	Excursion Status *	7/31/1993	Well went on excursion status (July 16, 1993)
EVEREST EXPLORATION	Tex - 1	UR-02493-011	MA-3	Excursion Status **	11/10/1993	Well went off excursion status (per TNRCC letter of November 10, 1993)
INTERCONTINENTAL ENERGY	Lamprecht	UR-01949-011	L-33	Excursion Status *	4/30/1993	Well went on excursion status
INTERCONTINENTAL ENERGY	Lamprecht	UR-01949-011	L-33	Excursion Status **	11/30/1993	Well went off excursion status
INTERCONTINENTAL ENERGY	Lamprecht	UR-01949-011	L-34	Excursion Status *	4/30/1993	Well went on excursion status
INTERCONTINENTAL ENERGY	Lamprecht	UR-01949-011	L-34	Excursion Status **	9/30/1993	Well went off excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-222	Excursion Status *	5/31/1994	Well went on excursion status 5/3/94
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-222	Excursion Status **	2/28/1993	Well went off excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-236	Excursion Status *	12/31/1994	Well went on excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-240	Excursion Status **	2/28/1995	Well went off excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-242	Excursion Status *	1/31/1995	Well went on excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-242	Excursion Status **	9/30/1995	Well went off excursion status
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-249	Excursion Status *	11/30/1992	Well went on excursion status 11/18/92
INTERCONTINENTAL ENERGY	Zamzow	UR-02108-011	ZMW-262	Excursion Status *	8/31/1994	Well went on excursion status

TABLE OF EXCURSIONS AT TEXAS URANIUM ISL MINES FROM TNRCC FILES AND DATABASES (cont'd)

Thursday, December 10, 1998 ANSWER

COMPANY NAME	MINE NAME	PAA	WELL NUMBER	DOCUMENT TYPE	DATE REPORT DUE	COMMENTS
USX	Moser " C " Zone	UR-01890-041	909-MD	Excursion Status **	9/30/1996	Well went off excursion status 8/29/96
USX	Moser " C " Zone	UR-01890-041	909-MD	Excursion Status **	1/31/1997	Well went off excursion status 1/22/97
USX	Moser " C " Zone	UR-01890-041	910-MD	Excursion Status *	4/30/1993	Well went on excursion status
USX	Moser " C " Zone	UR-01890-041	910-MD	Excursion Status **	10/31/1993	Well went off excursion status
USX	Pawlik	UR-02368-011	501-MD	Excursion Status *	4/30/1995	Well went on excursion status
USX	Pawlik	UR-02368-011	501-MD	Excursion Status **	5/31/1995	Well went off excursion status

Exhibit K

URI-27

URI, INC.

(A Subsidiary of Uranium Resources, Inc.)

Rosita Project
HC01, Box 50
San Diego, Texas 78384
Telephone: (512) 279-3307
Fax: (512) 279-2260

12750 Merit Drive
Suite 1020, LB 12
Dallas, Texas 75251
Telephone: (972) 387-7777
Fax: (972) 387-7779

Kingsville Dome Project
Route 1, Box 425
Kingsville, Texas 78363
Telephone: (512) 595-5731
Fax: (512) 595-0403

September 18, 1998

Mr. John Santos
Uranium Team Geologist
UIC, Uranium, and Radioactive Waste Section
Industrial and Hazardous Waste Division
Texas Natural Resources Conservation Commission
PO Box 13087
Austin, TX 78711-3087

RE: Kingsville Dome Project
Permit No. UR02827
MW - 49a & MW - 172 Status Report

Dear Mr. Santos:

Please find attached the MW – 49a & MW - 172 Remedial Action Report August 18 through September 14, 1998.

Please feel free to contact me with further questions pertaining to this matter.

Sincerely,

Mark S. Pelizza
Vice President
Health, Safety and Environmental Affairs

Cc: Mike Maxson
Rick VanHorn

RECEIVED
SEP 28 1998
UIC AND
RADIOACTIVE WASTE

URI Kingsville Dome Project
MW – 49a & MW – 172 Remedial Action Report August 18 through September 14, 1998

1) Explanation of actions taken since the verifying analysis was taken.

Sampling of MW – 49a & MW – 172 continued during the report period. Additionally the offset well to MW – 49a, MW – 49b, that was drilled approximately 25 feet south toward the production wellfield, was sampled during the report period (See Figure 1 for location). Analysis for control parameters and other ions have been performed by URI's laboratory (See Tables 1, 2 & 3).

During the report period URI continued to overproduce the ore zone expected of excursion into adjacent MW – 49a, MW – 49b & MW – 172 by pumping wells 6185, 6186 & 6364 (See Figure 1) at a cumulative rate of ~ 82 gpm (See Table 4).

Calcium, Bicarbonate, Sulfate, Chloride, Conductivity, pH and Uranium analysis starting from the time the excursions were reported, are listed on Tables 1, 2 & 3, for wells MW – 49a, MW – 49b & MW – 172 respectively, and plotted on Figures 2 through 13. These analyses show that MW – 49a conductivity and chloride are below the UCL's. Although showing a declining trend, MW – 49b & MW – 172 conductivity and chloride are currently above the UCL's. Uranium values in all monitor wells are below UCL's.

2) Actions that are to be taken during the next report period.

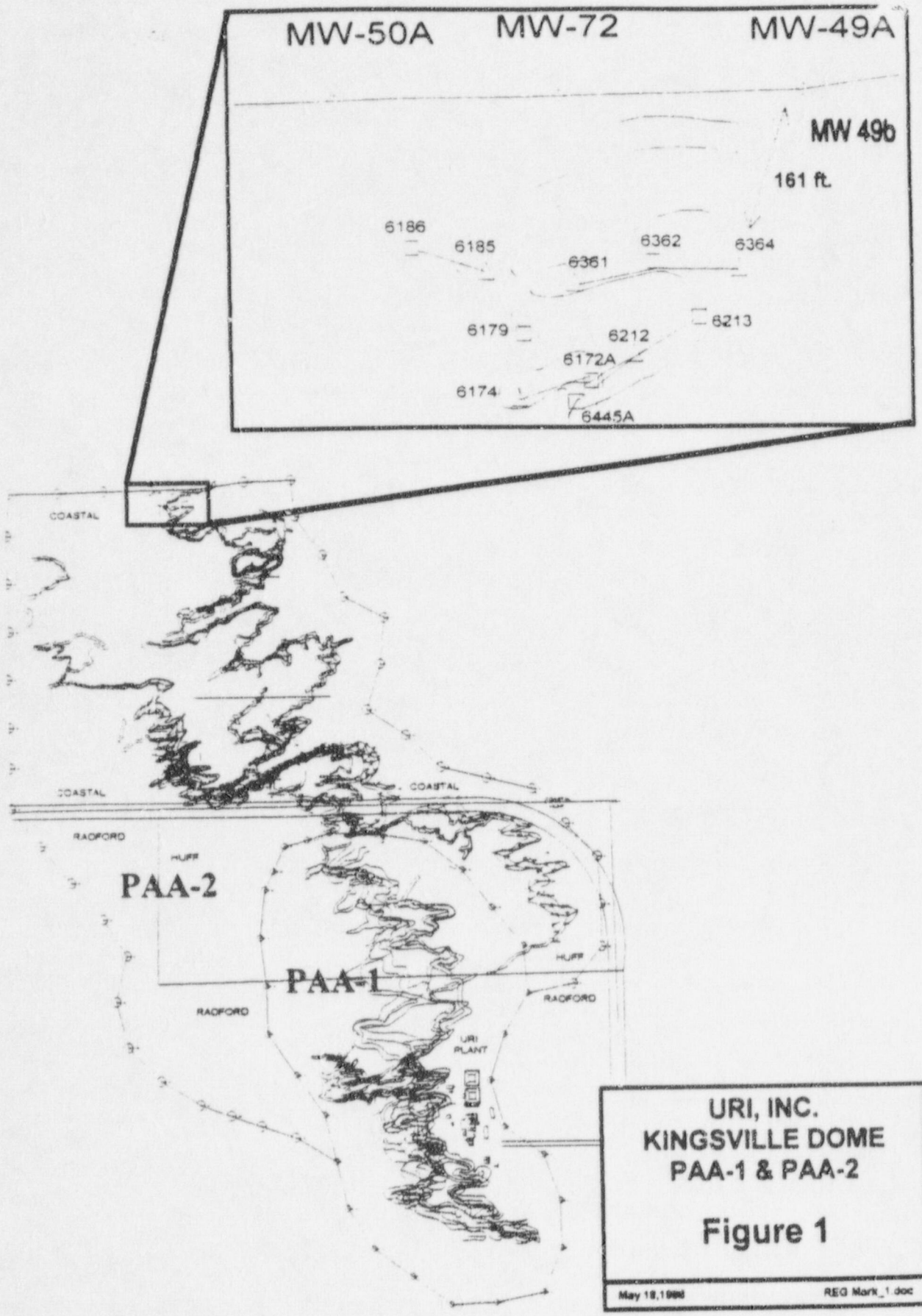
During the next report period, URI will continue to over produce wells adjacent MW – 49a, MW – 49b & MW – 172 by pumping wells 6185, 6186 & 6364 at a cumulative rate of ~ 80 gpm. This will result in net overproduction of both ore zones adjacent to the affected monitor wells. Sampling of MW – 49a, MW – 49b & MW – 172 will be conducted on a bi-weekly basis. Analysis for control parameters and other ions will be performed by URI's in house laboratory.

3) Sample analysis results for control parameters.

UCL results for conductivity and chloride are shown on Table 1, 2, & 3 and Figures 2, 3, 6, 7, 10 &11 for MW – 49a, MW – 49b & MW – 172. Uranium values are plotted on Figure 4, 8 &12. Uranium has been reduced to below UCL's in all observation wells. Conductivity and chloride are currently in decline in MW – 49a, MW – 49b & MW – 172.

4) Efforts to define the extent of the probable cause of mine solutions in MW – 49a.

URI believes that the cause of mine solutions in MW – 49a & MW – 172 is the close nature of the monitor wells to the injection wells in the wellfield pattern which resulted in the monitor wells intercepting production fluid flow pathlines (See Figure 1 for details). This has been demonstrated by the analysis results of water from the offset well MW - 49b.



URI, INC.
KINGSVILLE DOME
PAA-1 & PAA-2

Figure 1

May 18,1998 REG Mark_1.doc

URI Kingsville Dome Project

MW-49a Conductivity - URI LAB

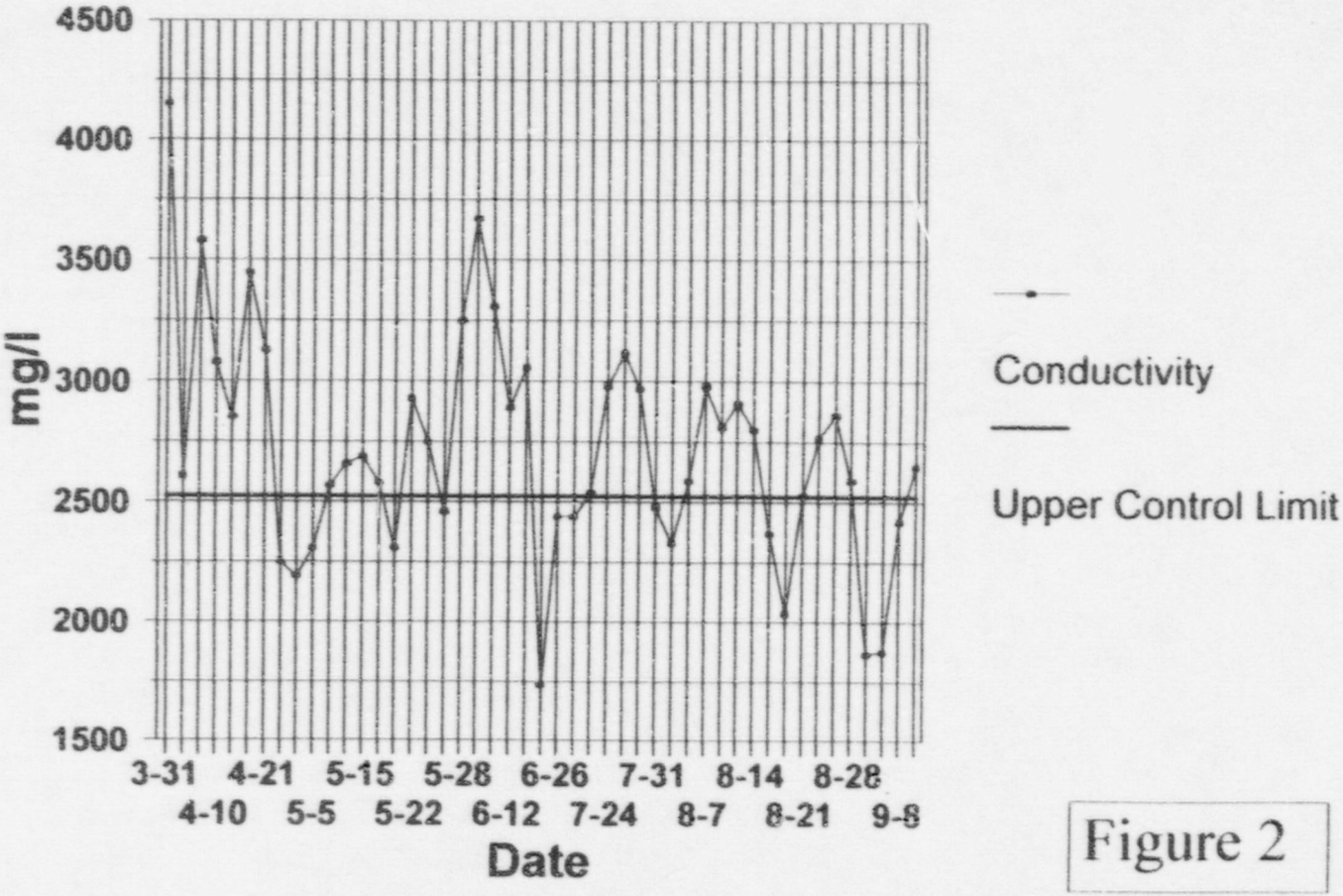


Figure 2

URI Kingsville Dome Project

MW-49a Chloride- URI LAB

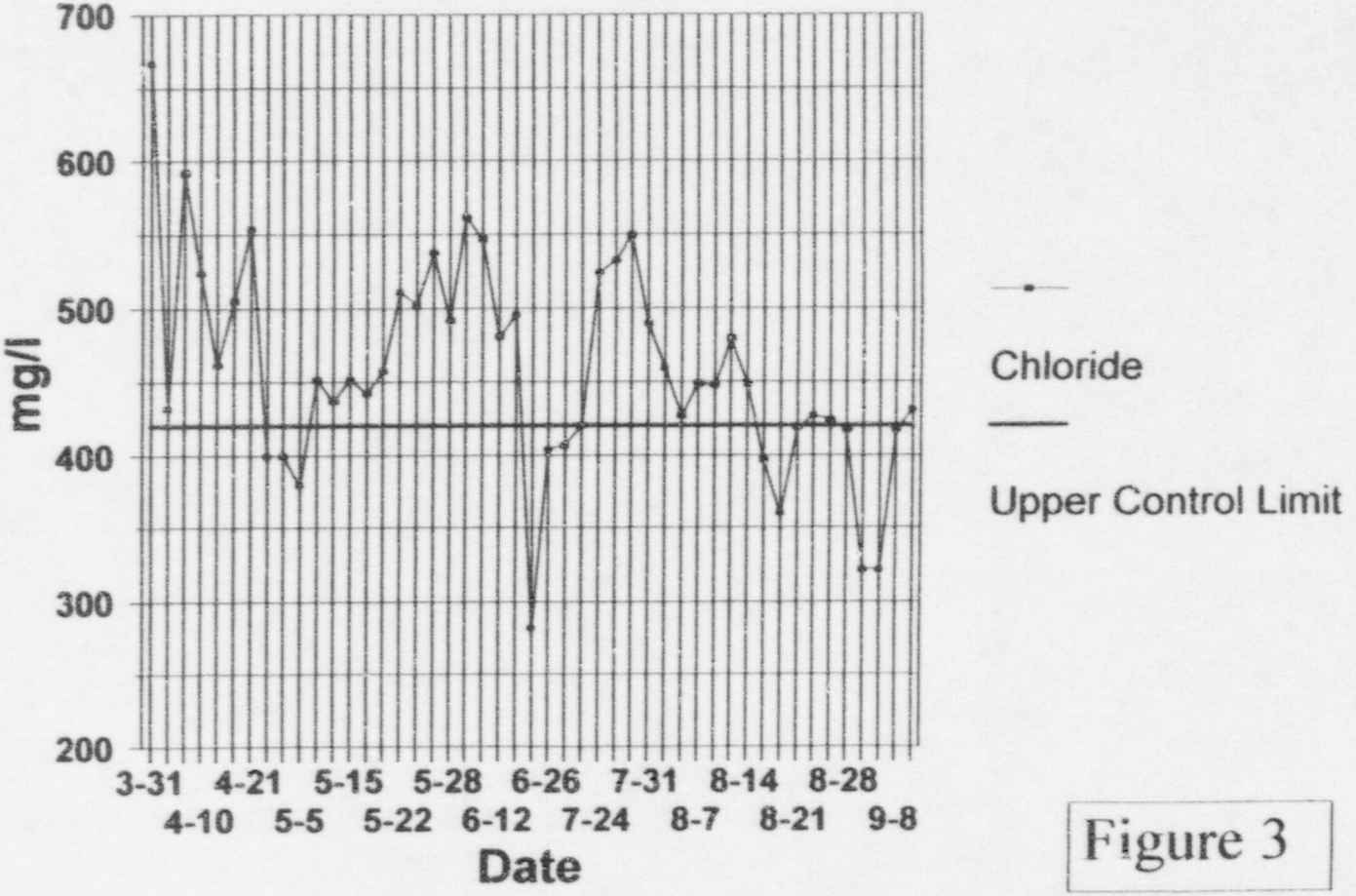


Figure 3

URI Kingsville Dome Project

MW-49a Uranium - URI LAB

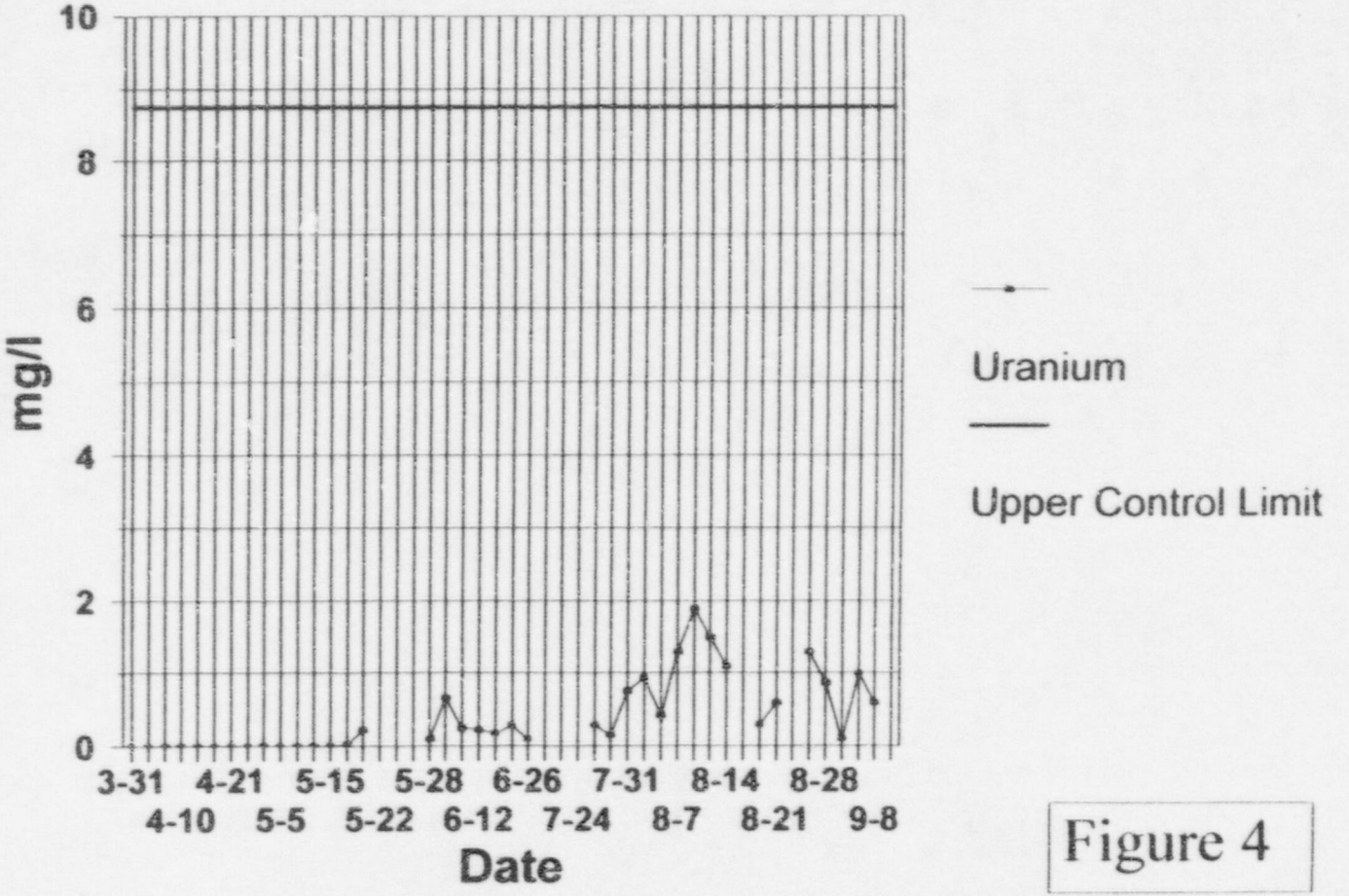


Figure 4

URI Kingsville Dome Project

MW-49a Common Ions - URI Lab

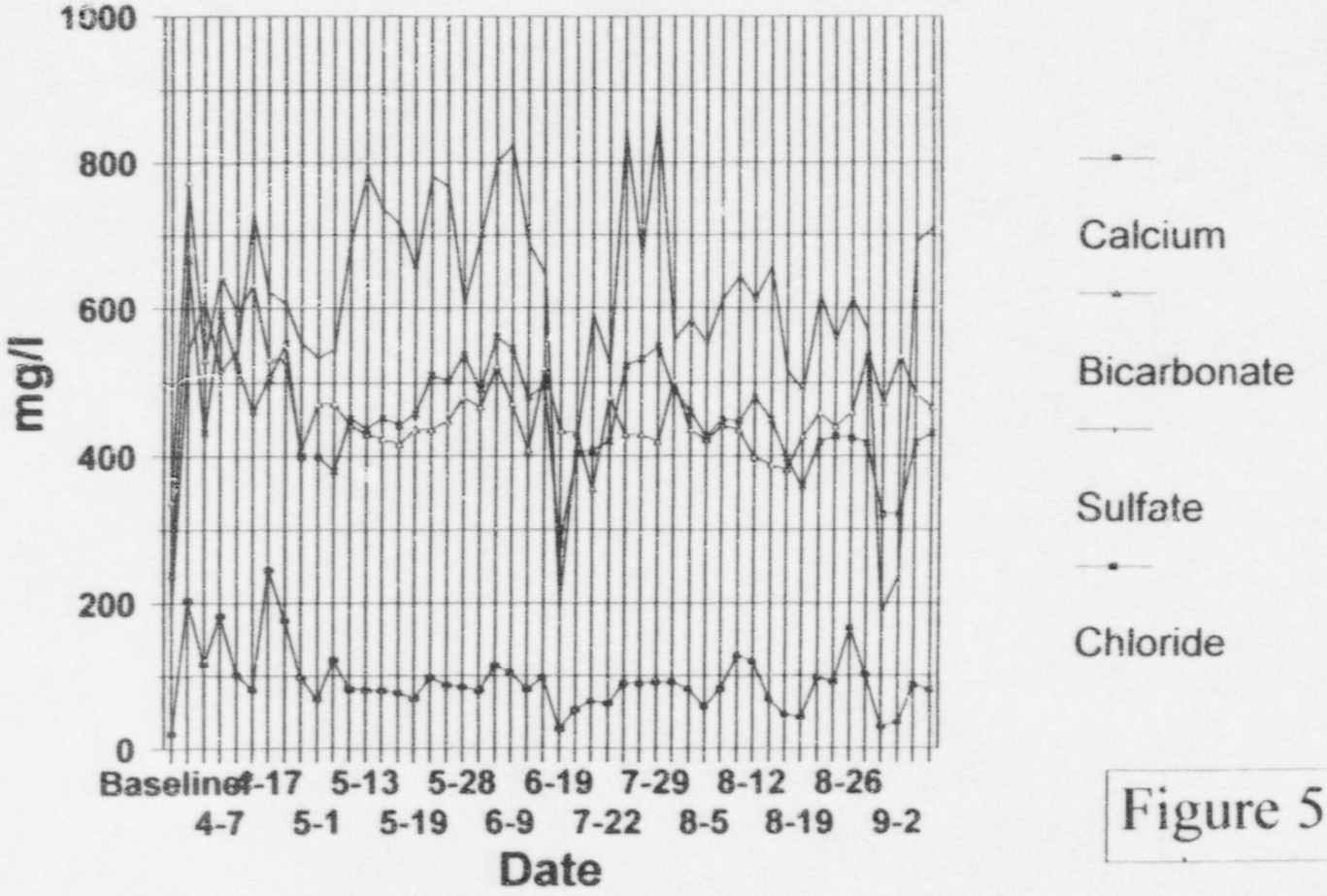


Figure 5

URI Kingsville Dome Project

MW-49b Conductivity - URI LAB

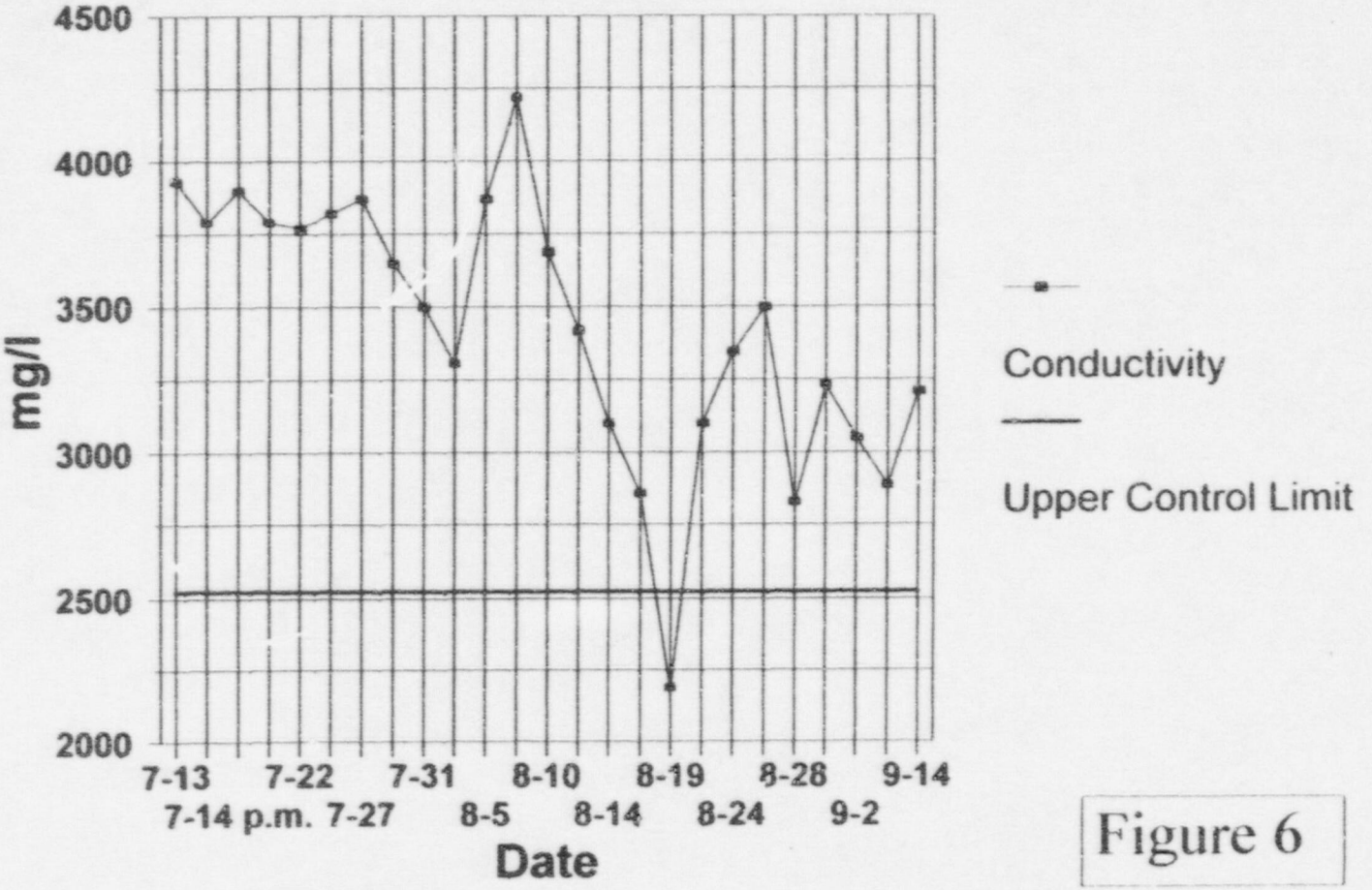


Figure 6

URI Kingsville Dome Project

MW-49b Chloride- URI LAB

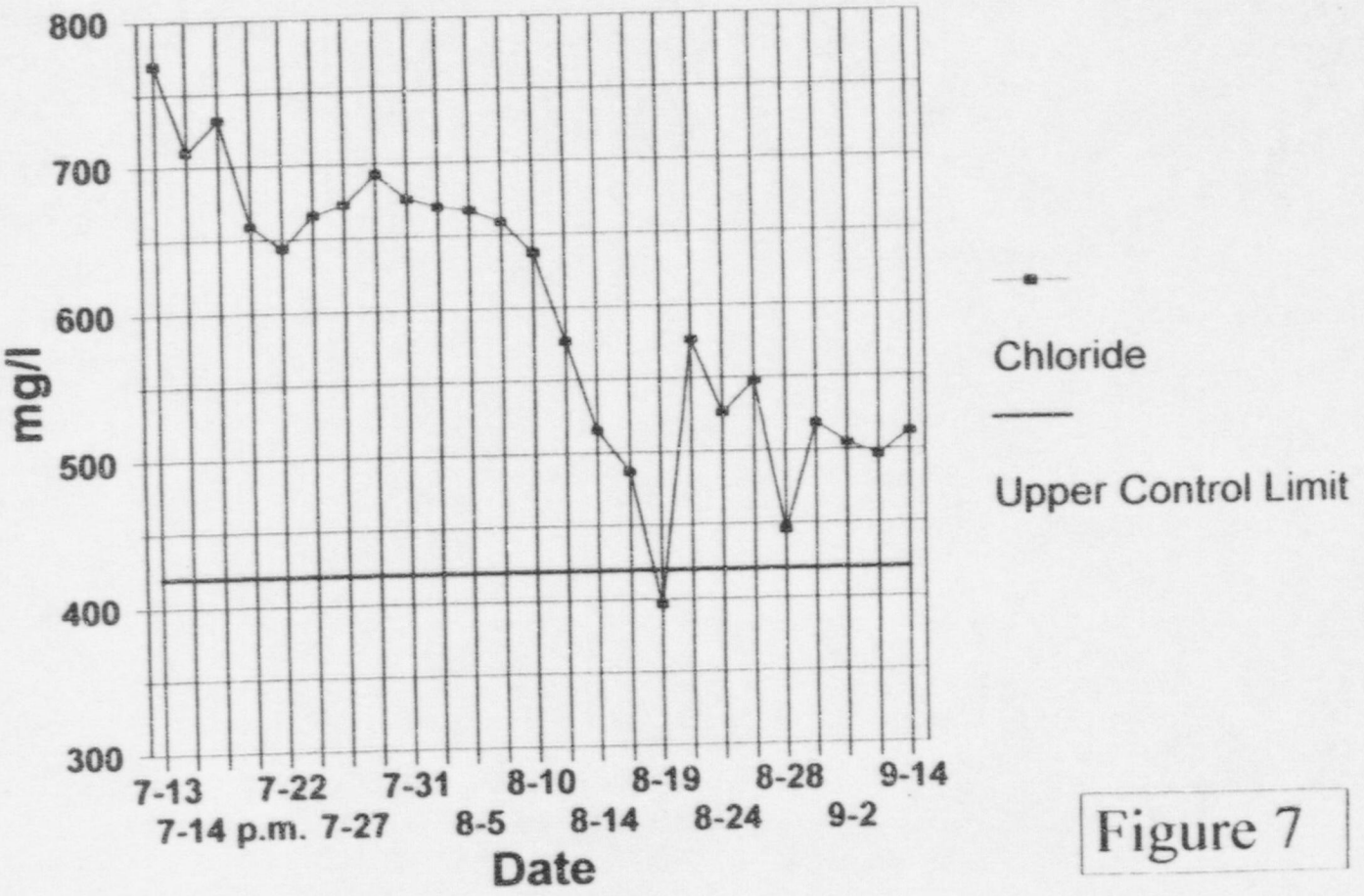


Figure 7

URI Kingsville Dome Project

MW-49b Uranium - URI Lab

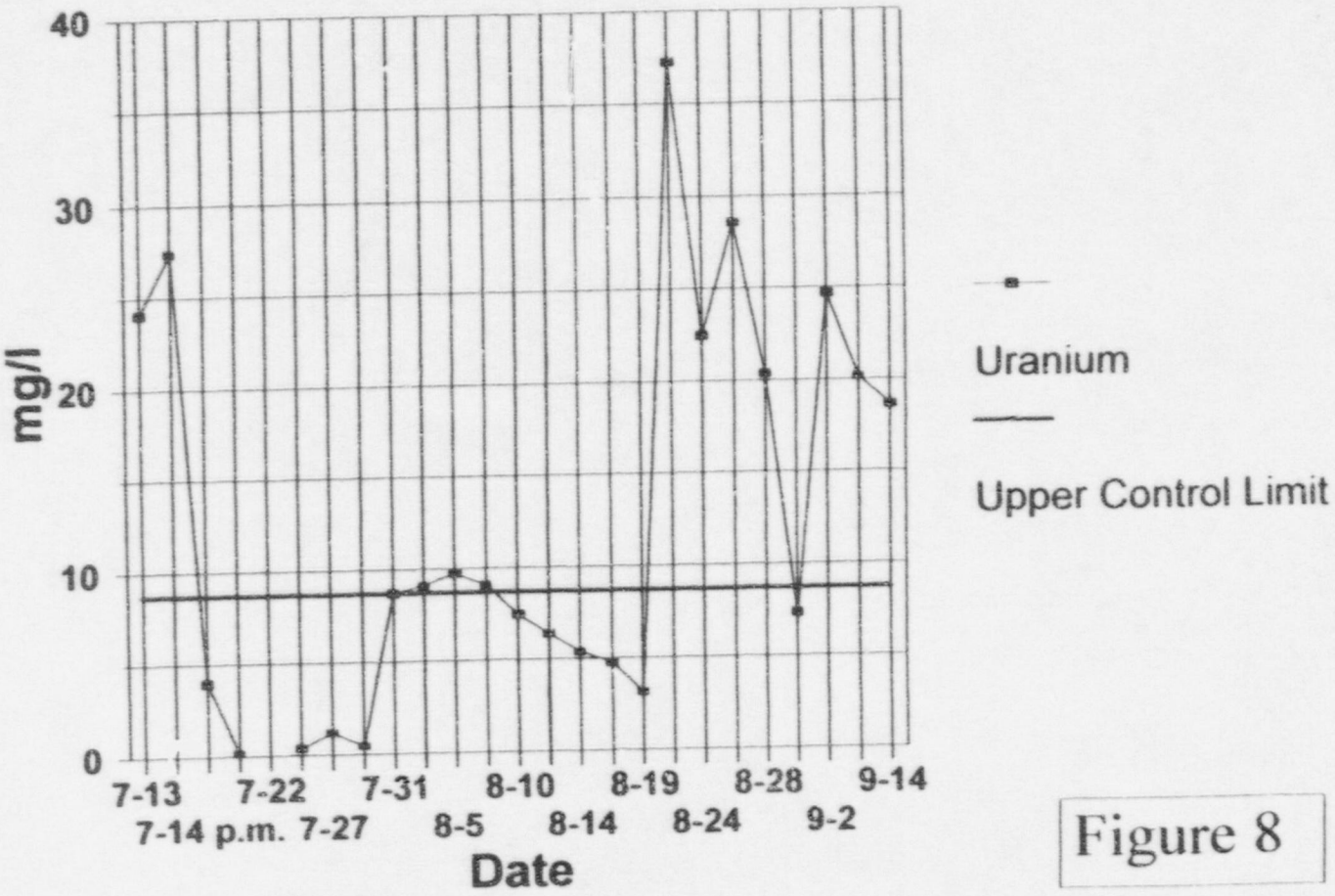


Figure 8

URI Kingsville Dome Project

MW-49b Common Ions - URI Lab

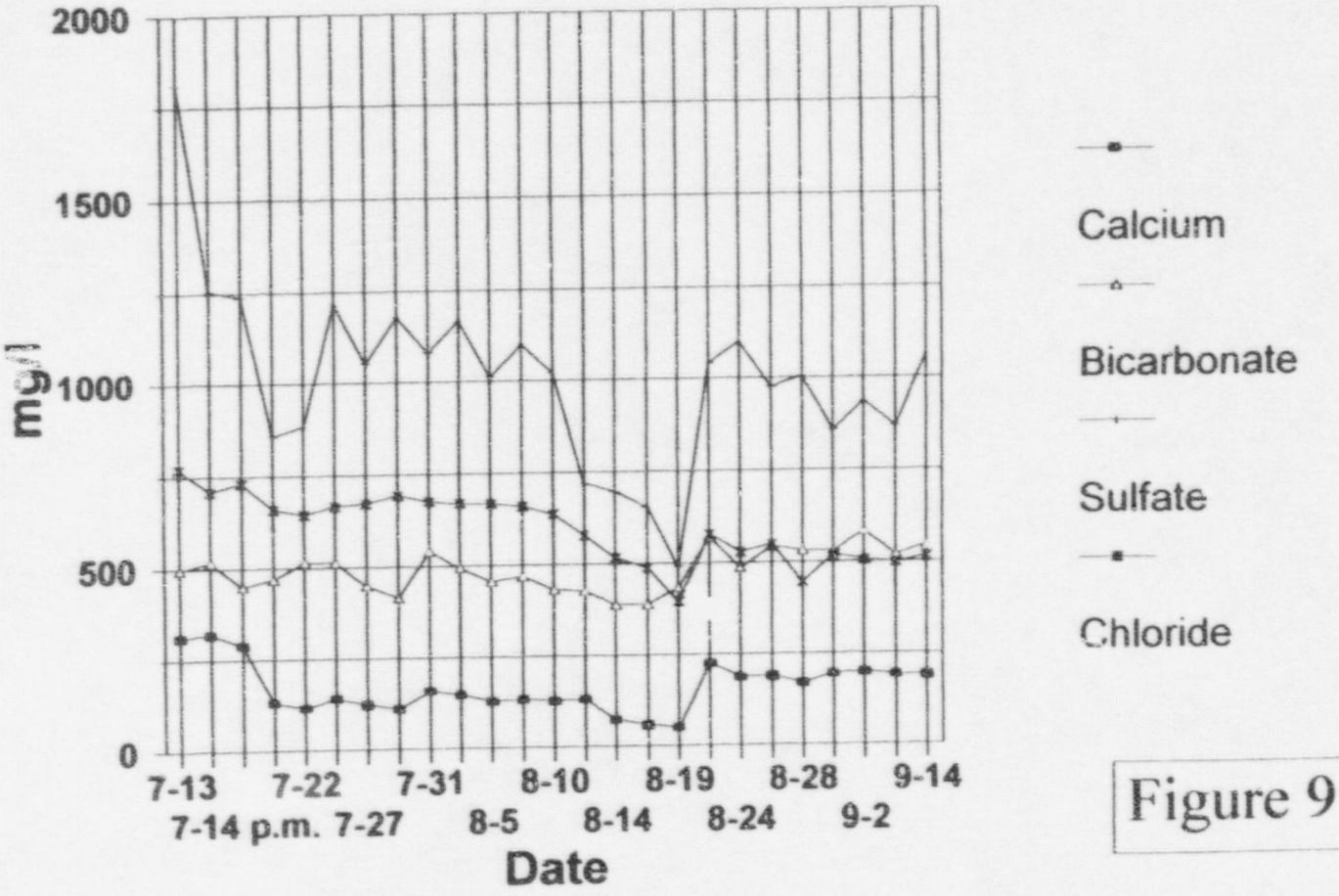


Figure 9

URI Kingsville Dome Project

MW-172 Conductivity - URI LAB

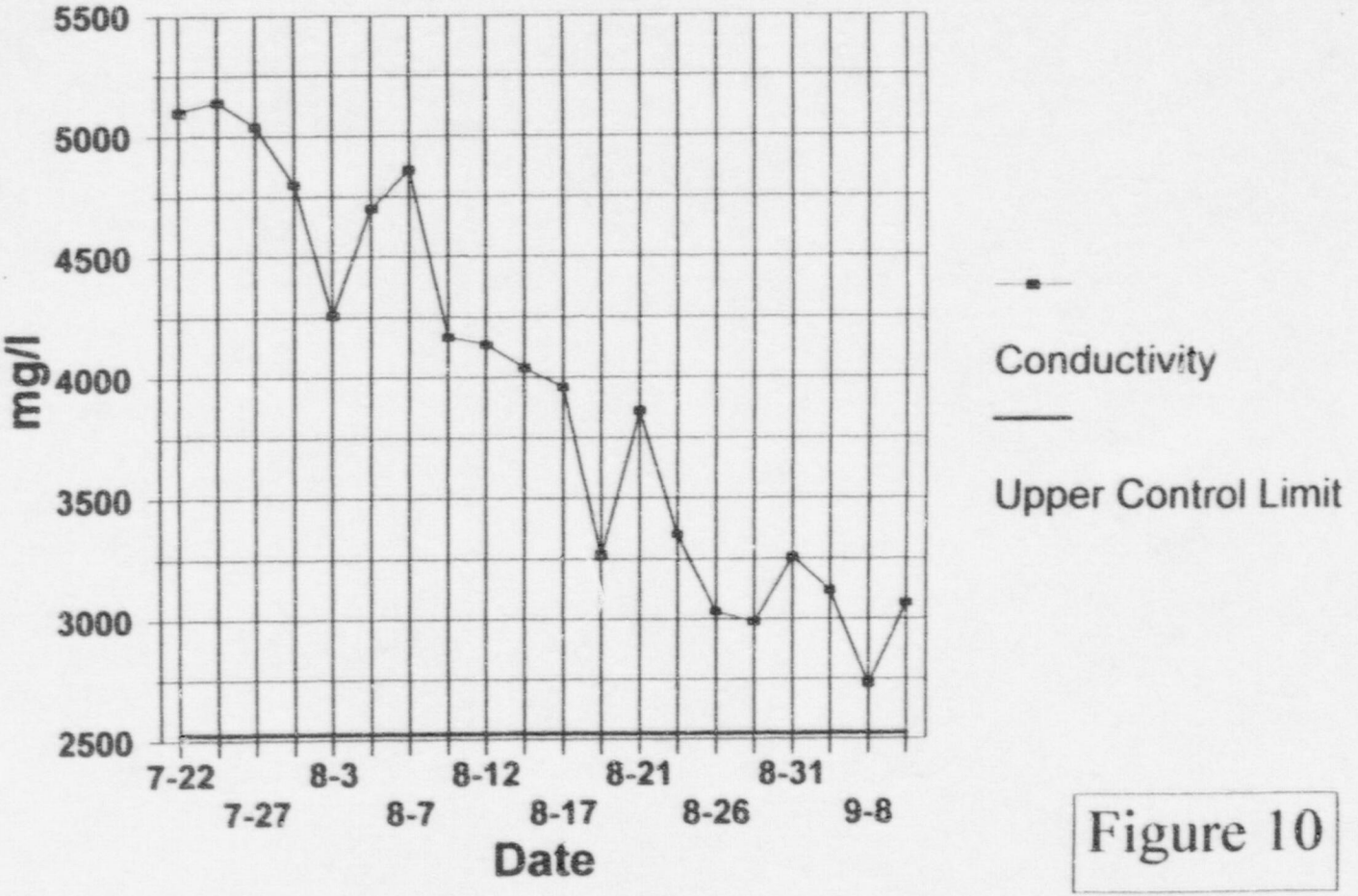


Figure 10

URI Kingsville Dome Project

MW-172 Chloride- URI LAB

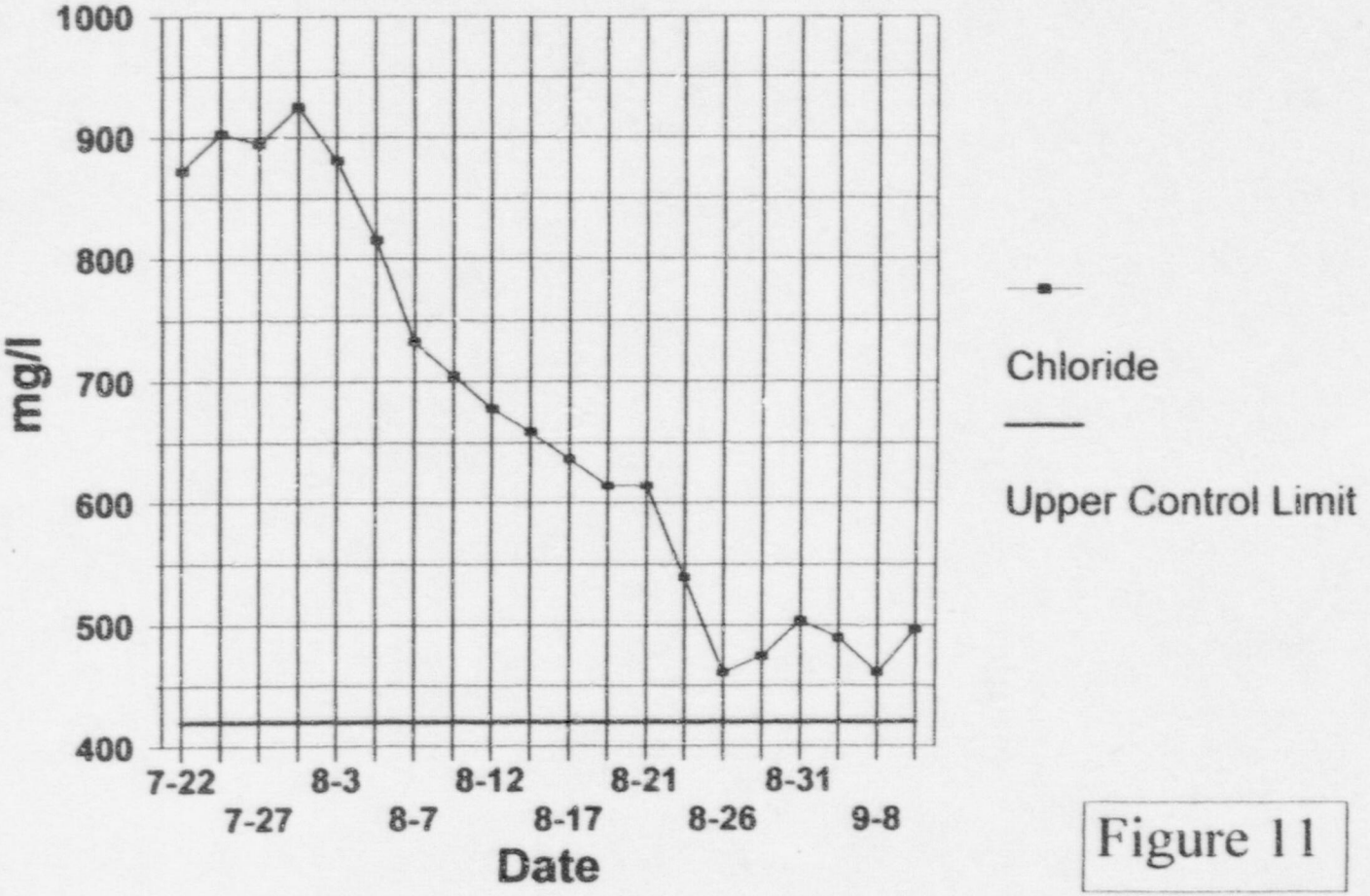


Figure 11

URI Kingsville Dome Project

MW-172 Uranium - URI Lab

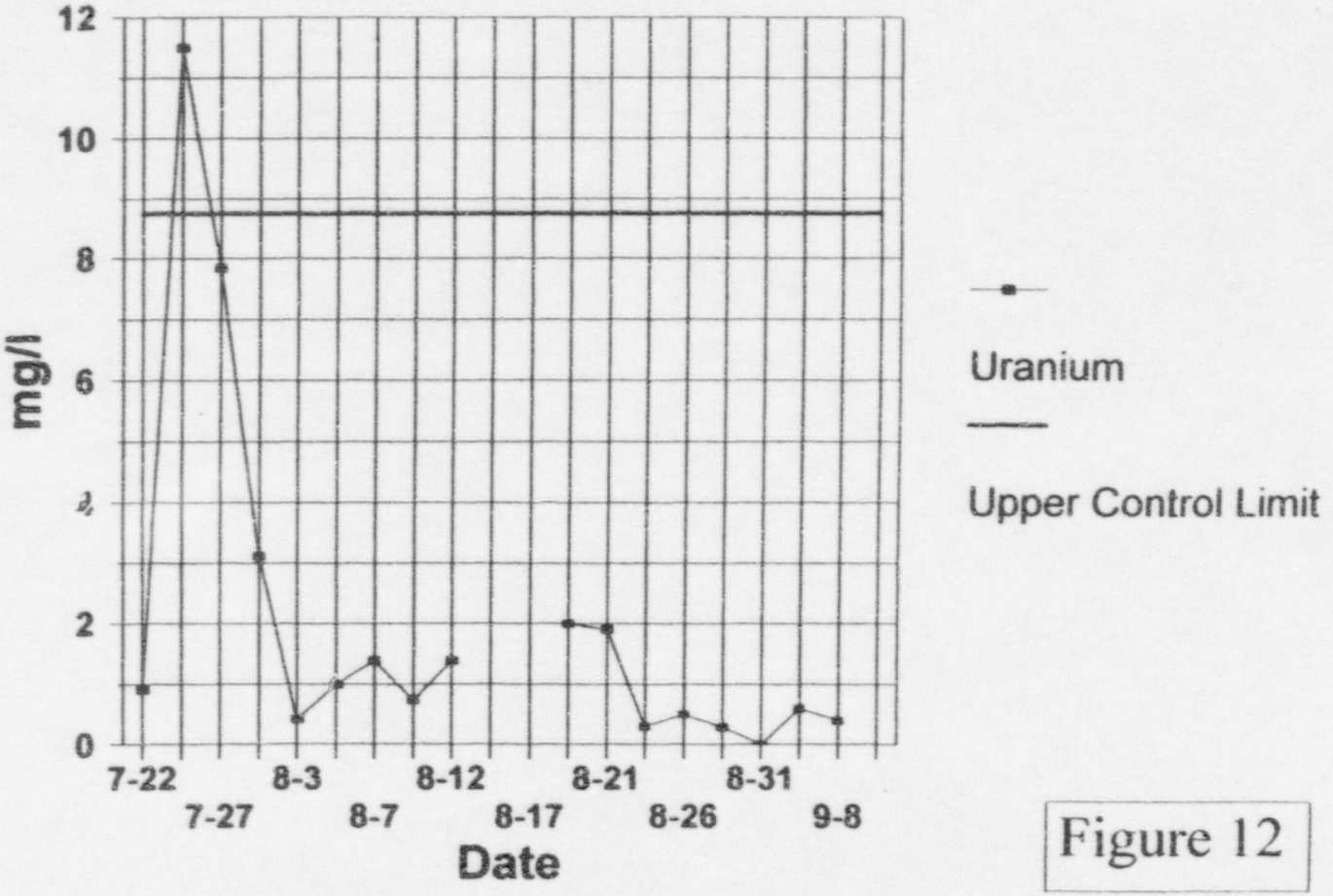


Figure 12

URI Kingsville Dome Project

MW-172 Common Ions - URI Lab

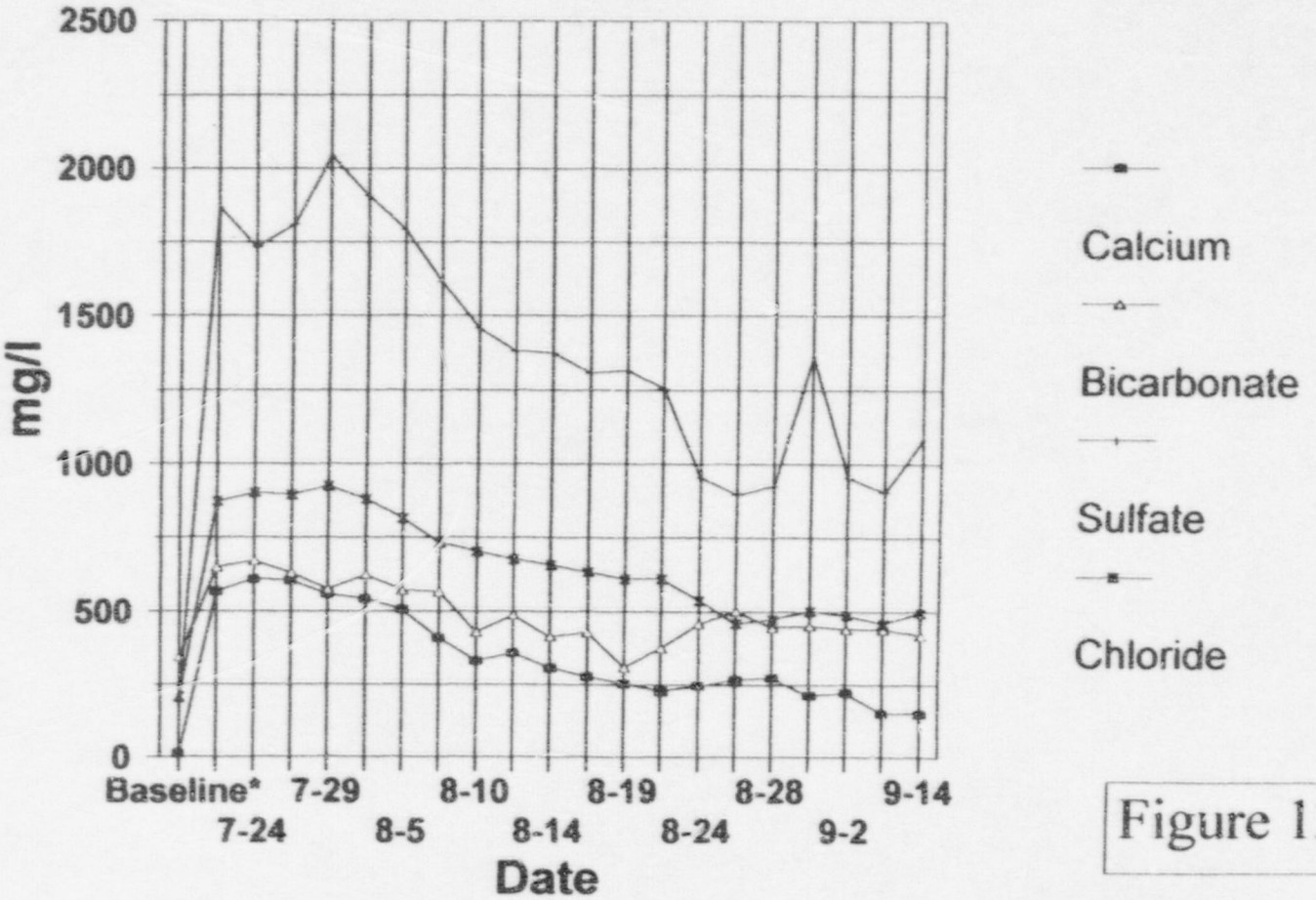


Figure 13

Exhibit L

DISTRIBUTION

Docket File 40-8911
PDR/DCS
DBangart, RIV
TOlsen
MBrown, RCPD, NM
LLO Branch, LLWM
URFO r/f

40-8911/TTO/88/01/28/0

URFO:TTO
Docket No. 40-8911

Jim Cullen, Manager
Technical Services
Mobil Oil Corporation
P.O. Box 17772
Denver, Colorado 80217

Dear Mr. Cullen:

The Uranium Recovery Field Office (URFO) has completed review of all pertinent information involving the Mobil Oil Corporation, Crownpoint, Section 9, In Situ Pilot Test Project, ground-water restoration and reclamation program. An Environmental Assessment (EA) has been written and based on the EA, a draft finding of no significant impact (FONSI) is being forwarded for publication in the Federal Register. The comment period for the draft FONSI will be extended to 60 days to allow all interested parties adequate time to respond. A final FONSI will not be published until we are convinced that all outstanding issues have been adequately addressed. A copy of the EA and the draft FONSI are enclosed.

As I understand it, we have tentatively scheduled two meetings for March 8, 1988. At this phase of the process, it would be beneficial to all concerned to meet for informative sessions. The two scheduled meetings are to assure that all parties are aware of the status of the project and the responsibilities of each party. One meeting will be with the Navajo Tribe Officials at Gallup, New Mexico, at 1:30 p.m., and another with local interested citizens at Crownpoint, that evening. At this time, I anticipate that NRC may have three to seven representatives at the meetings. Please let me know if there are changes to the scheduled meetings.

In terms of agendas for the meetings, I suggest that Mobil start off with a brief history of the project, followed by discussions by each agency on their role, responsibilities and future actions. We should probably try to keep the meetings rather informal with plenty of time for discussion and questions. I also suggest that Jim Malla lead the meetings for us.

OFC :
NAME :
DATE :88/02/03

8802230430 880204
PDR ADOCK 04008911
PDR

If you have any questions or comments, please feel free to contact me or Mr. Tom Olsen of my staff at (303) 236-2805.

Sincerely,

/S/

Edward F. Hawkins, Chief
Licensing Branch 1
Uranium Recovery Field Office
Region IV

Enclosures: As stated

OFC	URFO	URFO
NAME	TOlsen/lv	EHawkins
DATE	88/02/03	2/3/88

U.S. NUCLEAR REGULATORY COMMISSION

DOCKET NO. 40-8911

MOBIL OIL CORPORATION

DRAFT FINDING OF NO SIGNIFICANT IMPACT REGARDING A TERMINATION OF THE SOURCE AND BYPRODUCT MATERIAL LICENSE FOR OPERATION OF MOBIL OIL CORPORATION'S CROWNPOINT, SECTION 9, IN SITU PILOT TEST PROJECT, MCKINLEY COUNTY, NEW MEXICO.

AGENCY: U.S. Nuclear Regulatory Commission

ACTION: Notice of Draft Finding of No Significant Impact

1. Proposed Action

The proposed administrative action is to terminate the source and byproduct material license authorizing Mobil Oil Corporation to operate the Crownpoint, Section 9, In Situ Pilot Test Project facility located in McKinley County, New Mexico.

2. Reasons for Draft Finding of No Significant Impact

An environmental assessment was prepared by the staff at the U.S. Nuclear Regulatory Commission (NRC) and issued by the Commission's Uranium Recovery Field Office, Region IV. The environmental assessment performed by the Commission's staff evaluated potential impacts onsite and offsite due to radiological releases that may have occurred during the course of the operation. Additionally, an impact assessment was conducted on ground-water restoration efforts at the site. The assessment indicates that ground-water quality at the site was restored to required levels, with the exception of slightly elevated molybdenum concentrations. Documents used in preparing the assessment included the following:

- Environmental and operational information submitted by the licensee to the NRC during the period of October 1, 1986 through November 15, 1987;
- Discussions and written correspondence with the State of New Mexico;
- Site visit by NRC staff on May 11-12, 1987;
- Permit information from the New Mexico Environmental Improvement Division that was transferred to NRC at the time of NRC reassertion of authority over New Mexico licensees in 1986;
- Information derived from professional papers, journals and textbooks; U.S. NRC regulations and regulatory guides; Federal, State and local agencies; and independent consultants; and

- Mobil Oil Corporation's Irrigation Evaluation Report in Support of the Withdrawal of Discharge Plan DP-26, January 1988.

Based on the review of these documents, the Commission has determined that no significant impact will result from the proposed action.

The following statements support the draft finding of no significant impact and summarize the conclusions resulting from the environmental assessment.

A. The site reclamation and decontamination program proposed by Mobil Oil Corporation is sufficient to meet all requirements as specified in 10 CFR Part 40.

B. The ground-water quality at the site has been restored to required concentrations, with the exception of slightly elevated molybdenum concentrations. The elevated molybdenum concentrations are not considered significant due to the very small volume of affected ground water, the natural restoration that will continue to occur over time, and the low probability of use due to the depth to the aquifer and the availability of other, more easily accessible water. Further, it is highly unlikely that additional restoration will provide any more reduction in molybdenum concentration at the Mobil site.

In accordance with 10 CFR Part 51.33(a), the Director, Uranium Recovery Field Office, made the determination to issue a draft finding of no significant impact and to accept comments on the draft finding for a period of 60 days after issuance in the Federal Register.

This finding, together with the environmental assessment setting forth the basis for the finding, is available for public inspection and copying at the Commission's Uranium Recovery Field Office at 730 Simms Street, Golden, Colorado, and at the Commission's Public Document Room at 1717 H Street, Washington, D.C.

Dated at Denver, Colorado, this 4th day of February, 1988.

FOR THE NUCLEAR REGULATORY COMMISSION

Edward L. Hawkins

Edward F. Hawkins, Chief
Licensing Branch 1
Uranium Recovery Field Office
Region IV

UNITED STATES NUCLEAR REGULATORY COMMISSION
ENVIRONMENTAL ASSESSMENT

BY THE

URANIUM RECOVERY FIELD OFFICE

IN CONSIDERATION OF THE RELEASE OF
SOURCE MATERIAL LICENSE SUA-1479

FOR

MOBIL OIL CORPORATION
CROWN POINT, SECTION 9, IN SITU PILOT TEST PROJECT
McKINLEY COUNTY, NEW MEXICO

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1.0 INTRODUCTION

1.1 Background

Mobil Oil Corporation (Mobil) began uranium exploration in 1972 and commenced research and development activities for in-situ leaching (ISL) of uranium at a site known as Crownpoint, Section 9, In Situ Pilot Test Project, in 1978. This research was initially conducted under the State of New Mexico, Environmental Improvement Division (EID), Permit No. MM-M08-UL-RI-01. Mobil presently has a USNRC Source Material License No. SUA-1479, as the authority for uranium licensing was transferred to USNRC from New Mexico in 1986, upon the State relinquishing the licensing program. Mobil had two other licenses for in-situ leaching in the same general area, but no leaching was ever performed at either site. These licenses were subsequently terminated. During the period of November 1979, through October 1980, test patterns which utilized sodium bicarbonate lixiviants were operated at the Crownpoint, Section 9 site.

Since October of 1980, Mobil has been actively conducting aquifer restoration at this research and development (R&D) test site. Since that time, several concerns have arisen regarding the adequacy of restoration and the environmental impacts of the contamination of the ground water. The remaining major concern of the NRC is the presence of somewhat elevated concentrations of molybdenum in water samples from wells throughout the site. Mobil's original license with New Mexico established a molybdenum ground-water standard at 1 mg/l concentration. This standard is based on an irrigation criteria for the State of New Mexico. When comparing present Mobil site ground-water concentrations with baseline concentrations, it is evident that molybdenum at the Mobil site is somewhat elevated, but is not considered excessive in concentration.

In addition to ground-water restoration, Mobil will be required to complete surface reclamation and decontamination of their facility. The surface reclamation will be implemented through the State of New Mexico Environmental Improvement Division and decontamination will be completed in accordance with Code of Federal Regulations, Part 40, Appendix A, Criterion 6.

The purpose of an ISL R&D facility is to ensure that all phases of a mining operation and subsequent restoration can be accomplished as a prototype to a larger full-scale mining effort. In all cases, the ISL R&D must be operated in a safe manner and restoration must show that ground water is restored to an acceptable quality. The small scale of an ISL R&D ensures that if ground-water restoration is not

successful, the subsurface contamination is not extensive and is usually confined to a very small area.

1.2 Basis of NRC Review

An impact appraisal for the termination of Source Material License SUA-1479 has been performed by Region IV, Uranium Recovery Field Office (URFO) of the U.S. Nucelar Regulatory Commission (NRC). This report documents that appraisal. The staff performed the appraisal of environmental impacts in accordance with Title 10, Code of Federal Regulations (10 CFR Part 51, Licensing and Regulatory Policy and Procedures for Environmental Protection). In conducting this appraisal, the staff considered the following sources:

- Environmental and operational information submitted by the licensee to the NRC during the period of October 1, 1986, through November 15, 1987;
- Discussions and written correspondence with the State of New Mexico, EID;
- Site visit by NRC staff on May 11-12, 1987;
- Permit information from the New Mexico EID that was transferred to NRC at the time of NRC reassertion of authority over New Mexico licenses in 1986.
- Information derived from professional papers, journals and textbooks; U.S. NRC Regulations and Regulatory Guides; Federal, State and local agencies; and independent consultants.

The purpose of this environmental assessment is to evaluate the nature of any remaining contamination, its statistical significance with respect to baseline variability, and its overall impact on the potential uses of the aquifer.

The analysis has been extremely difficult due to the hydrogeology of the site, complexities imposed by operational difficulties encountered during leaching and restoration, a high degree of natural variability and the small area of previous mining activity. Due to the high degree of uncertainty in the analysis of the ground-water quality data, no value of concentration or statistical function of concentration is used as a rigid criterion on which to base decisions.

2.0 SITE DESCRIPTION

This section describes the natural environment of the mining area and surrounding region. Data have been compiled through literature search, other projects in the vicinity and programs initiated by Mobil. More complete descriptions can be found in appendices and text of the Mobil license application (Mobil, 1978), Mobil restoration reports (Mobil, 1980-1987) and in Muck (1982).

2.1 Site Location and Topography

The Crownpoint, Section 9, In Situ Pilot Test Project (Figure 1) is located in McKinley County, New Mexico, approximately 6 miles west of Crownpoint, New Mexico. It consists of about 5 acres and is part of a single Navajo allotted lease of 160 acres.

The Crownpoint area lies within the Colorado Plateau Physiographic Province as defined by Fenneman (1931). This section is characterized by old plateaus, up-lifts, basins, dams and synclinal structures. In the vicinity of the ISL site, relief is not great as elevations in the area generally range between 5500 feet and 7000 feet. The landsurface near the site dips gently to north and arroyos are in evidence throughout the area. The site elevation is approximately 6700 feet MSL.

In the project area, surface runoff generally is confined to numerous small, closed basins. These basins are characterized by poorly defined drainage networks where runoff is carried to lowland depressions. Due to the seasonal nature of runoff and to high evaporation rates, these depressions are frequently dry.

2.2 Geology

2.2.1 Regional Geology

The project site lies along the southwestern side of the San Juan Basin, a major structural basin covering most of northwestern New Mexico. The basin is a circular structure that also trends into Southwestern Colorado.

The San Juan Basin (see Figure 2) is composed of several thousand feet of Paleozoic, Mesozoic and sedimentary rocks which dip toward the center of the basin. Along the margins of the basin, synclinal and dome structures are present.

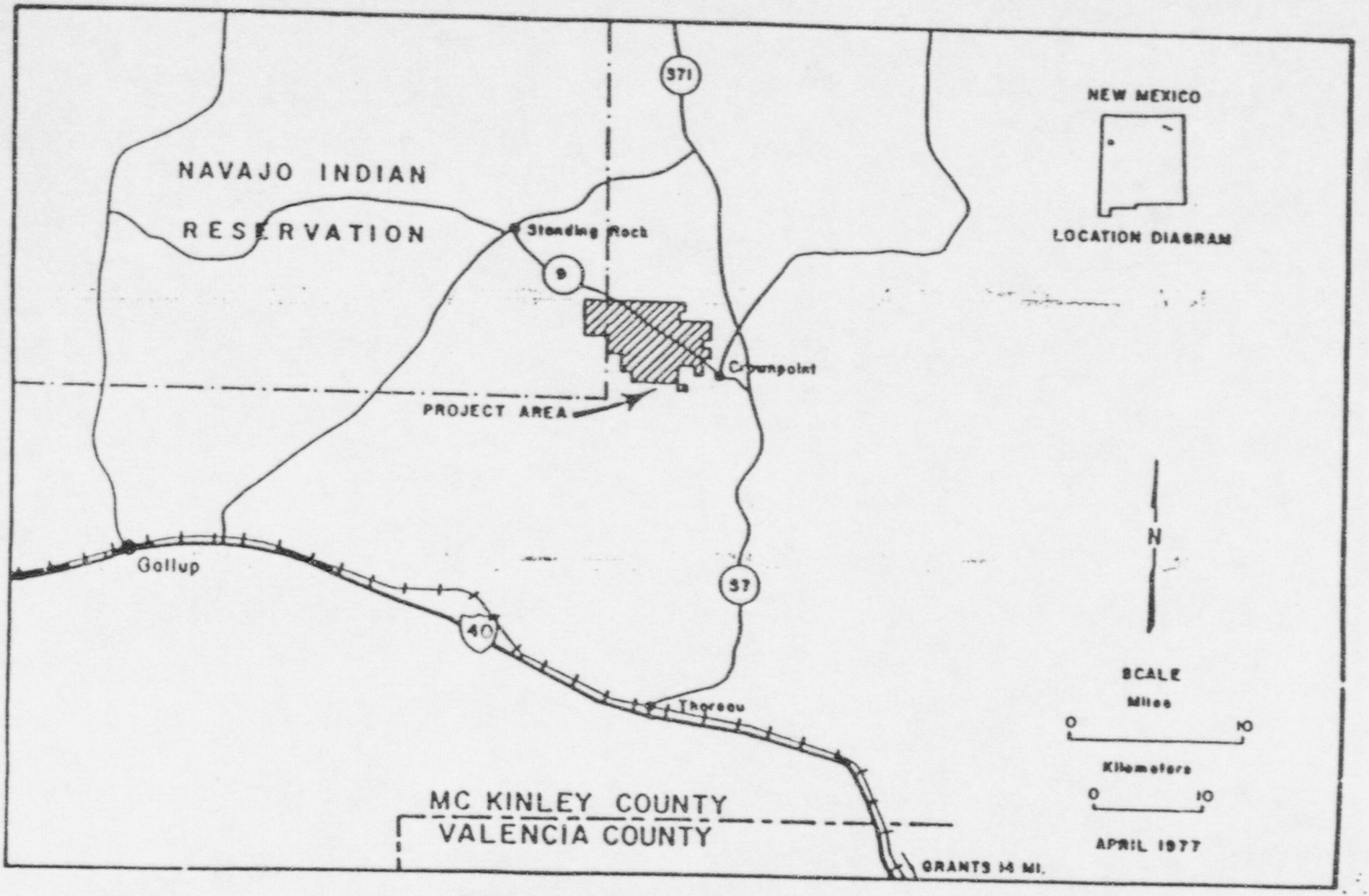
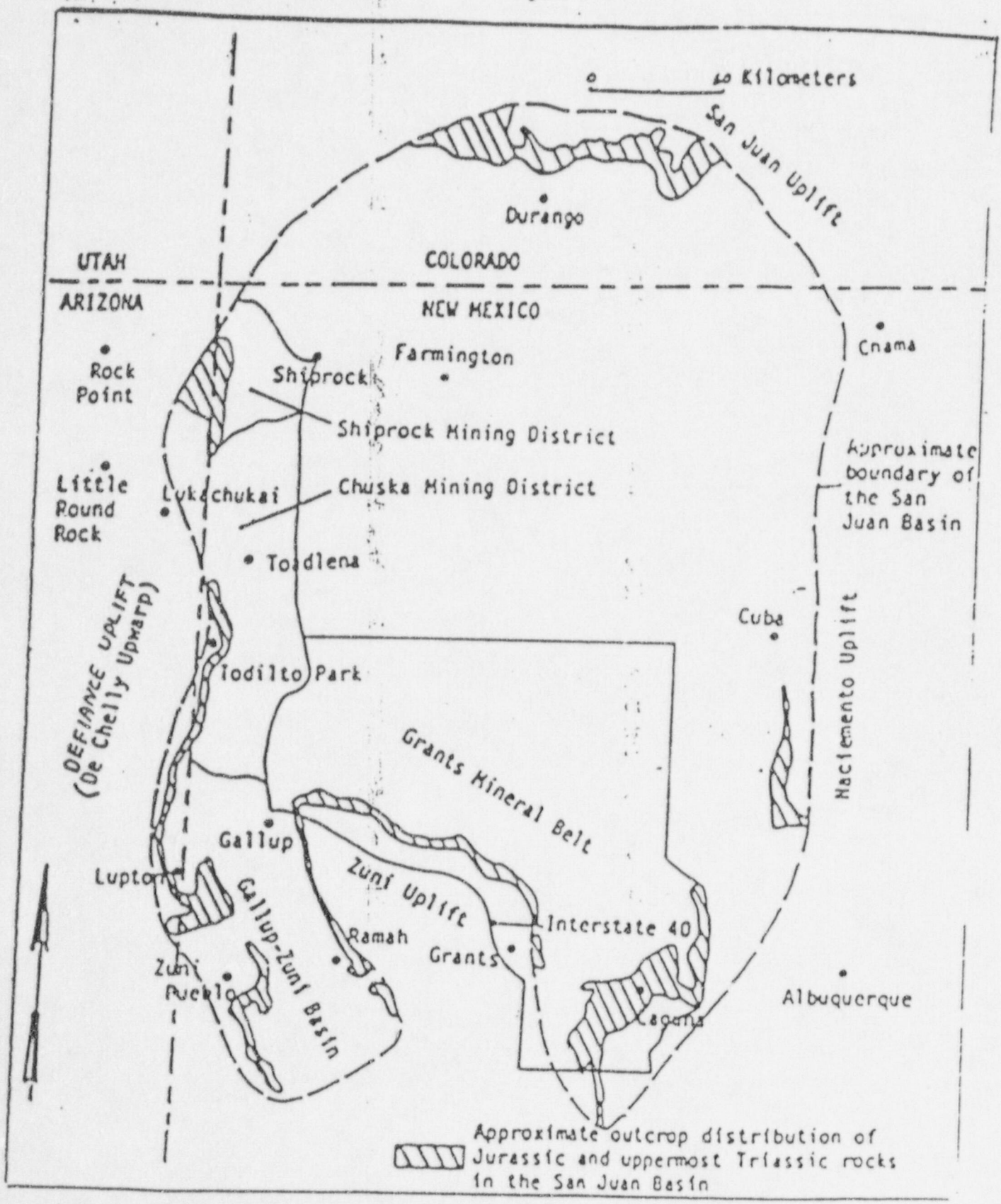


Figure 1. Crownpoint Project Area

Figure 2



Index map of the San Juan Basin and adjacent areas showing major tectonic features, outcropping uppermost Triassic and Jurassic sedimentary rocks (lined), and uranium mining areas.

Location Map of the Grants Mineral Belt.

(after Pierson and Green, 1977).

Figure 3 presents a generalized description of the formations outcropping on the southwestern side of the San Juan Basin, including the project site.

2.2.2 Site Geology

Formations exposed on the project site and immediate vicinity are mapped on Figure 4. The Westwater Canyon Member of the Middle Jurassic Morrison Formation contains the orebody in which in-situ R&D operations were conducted.

The Westwater Canyon Member consists of interbedded fluvial, red, tan and light gray arkosic sandstone, claystone and mudstone. The Westwater Canyon Member is approximately 50 feet thick near the ISL site. The Westwater Canyon Member is characterized by sandstone containing cross-bedding, pebbles and silicified logs, and is a water bearing unit throughout the San Juan Basin. At the project site, uranium occurs in coarse-grained, poorly-sorted sandstone units.

The Recapture Creek Member, the lower member of the Morrison Formation, underlies the Westwater Canyon (refer to Figure 3). This formation consists primarily of thin beds of siltstone and sandstone. No uranium deposits of any significance occur in the Recapture Member.

The Brushy Basin Member, the upper member of the Morrison Formation, overlies the Westwater Canyon (refer to Figure 3). The Brushy Basin contains mudstone and sandstone and intertongues with the Westwater. The Brushy Basin is approximately 150 feet thick at the ISL site, and contains no uranium deposits of any significance.

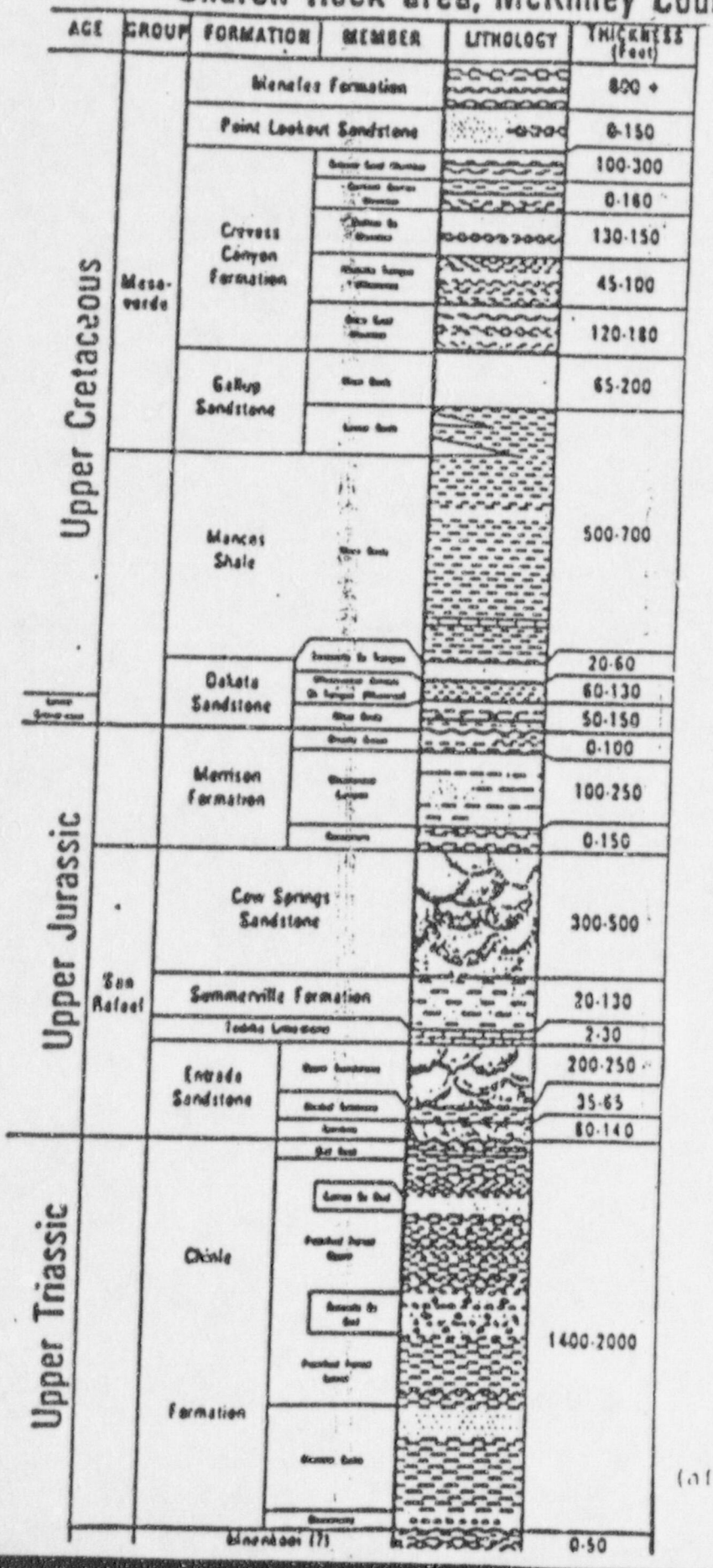
2.2.3 Uranium Mineralization

Typically, uranium mineralization is deposited by reduction and subsequent precipitation in a "roll front," which is C-shaped in vertical section with the leading edge pointing downdip. The Crownpoint deposit is a typical "roll front" deposit with discernible oxidation-reduction boundaries in the host rock. The principal uranium mineral has been identified as uranite (UO_2). Most of the uranium ore has been identified in a sandstone strata approximately 30 feet in thickness.

The uranium ore commonly occurs as lenticular, tabular or coalescing masses in the Crownpoint vicinity. The ore bodies are usually oriented parallel to the paleo-channel trends.

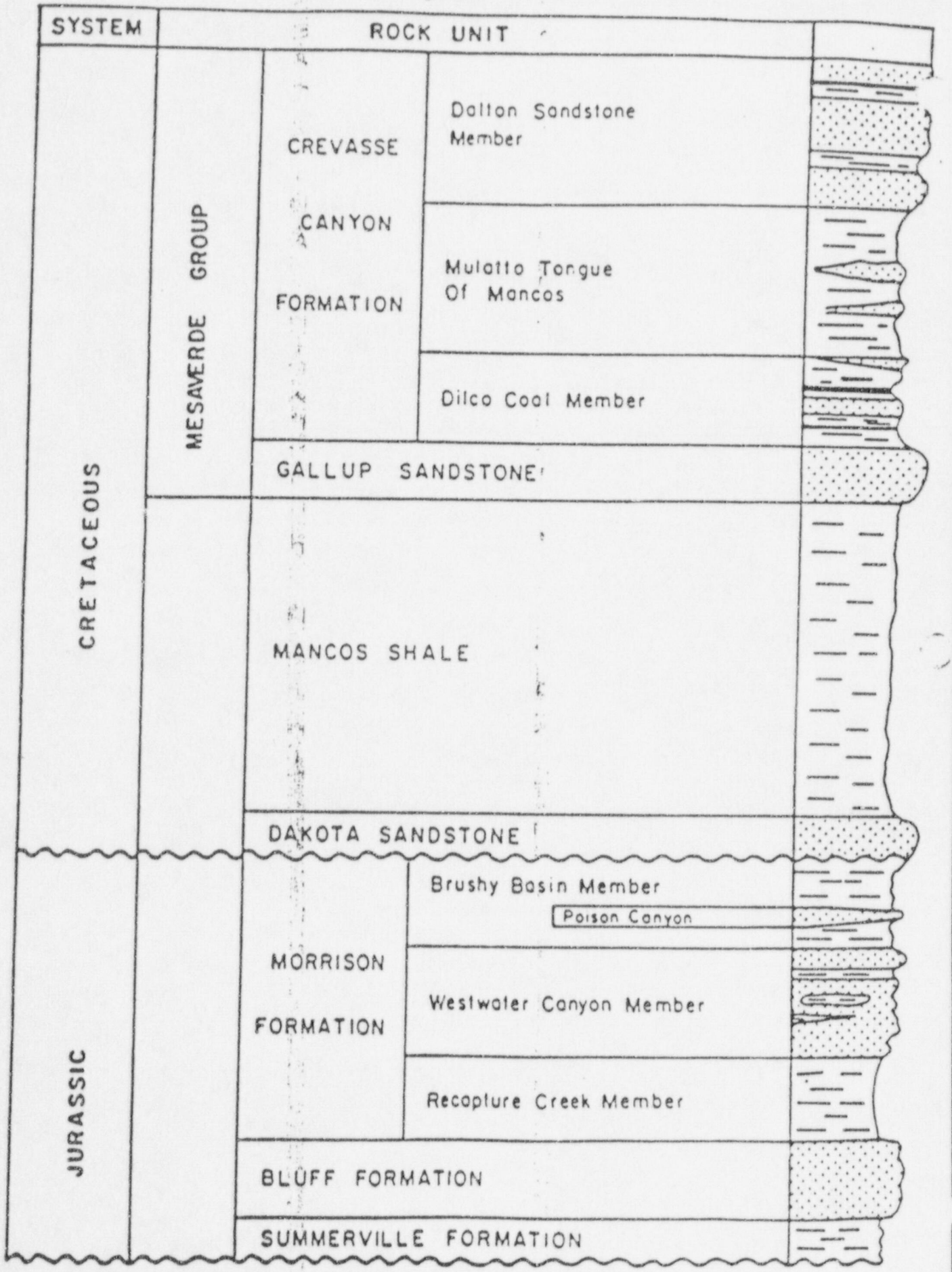
Figure 3

Stratigraphic section, Church Rock area, McKinley County, New Mexico



(after Chenoweth and Holen, 196

Figure 4



STRATIGRAPHIC COLUMN
SEDIMENTARY UNITS PRESENT IN SEC. 9-T. 17 N.-R. 13 W.

either northwest-southeast or west-east. The ore may occur in channel thicks as well as near shale-sand contacts of intervening mudstones. On a smaller scale, ore may be localized along bedding planes, clay gall horizons, fossil log jams, cross-bedding or other primary sedimentary structures.

Migrating uranyl dicarbonate complexes, (possibly $UO_2(CO_3)_3^{-4}$,) in the ground-water system were adsorbed by the organic matter. The UO_2^{+2} was captured by an ion exchange or chelation process, and the organically bound uranium was readily reduced and internally distributed. Some organic matter would be oxidized, but much more would be freed to adsorb uranium complexes. Leventhal (1979) notes organic matter may concentrate uranium 10,000 times from water.

The width of the orebody is extremely variable. Average depth is approximately 2,000 feet to the mineralized zone, but can be as much as 2,100 feet in a downdip direction.

2.3 Ground-Water Hydrology

2.3.1 Regional Flow System

Ground water in the region occurs both in unconsolidated sediments and in bedrock aquifers. Except for alluvial deposits in valley areas, unconsolidated deposits have not been developed as sources of ground water. The occurrence of ground water in bedrock aquifers is largely dictated by structure and stratigraphy associated with the San Juan Basin. Flow in these aquifers generally is downdip.

2.3.1.1 Bedrock Aquifer System

Regional aquifers have been grouped into "multiple aquifer" systems in northwestern New Mexico on the basis of hydrologic interrelationships. One of these regional systems underlies the Crownpoint Project and includes the Morrison Formation and the Dakota Sandstone.

The Dakota Sandstone is overlain by the Mancos Shale, a thick aquiclude. The Mancos Shale underlies and intertongues with the Mesaverde Group, which includes several aquifers of regional significance: the Gallup Sandstone, the Crevasse Canyon Formation, the Point Lookout Sandstone and the Menefee Formation (refer to Figure 2), all of which are utilized as water sources in McKinley County.

Regional water movement is northward, generally downdip. movement of ground water in the Mesaverde Group is impeded by low permeabilities (generally less than 10 gpd/ft^2), by facies changes and by thinning of the aquifers downdip.

Recharge to the aquifers is by precipitation and by runoff in ephemeral stream channels in the outcrop areas. The Jurassic and Cretaceous rocks crop out in narrow bands on the south and west sides of the San Juan Basin divide.

Ground-water discharge is believed to occur to the San Juan River. Some discharge to springs occurs within the region, where fractures provide avenues for upward movement, but no such springs are known within the project area vicinity.

Alluvial deposits are used as aquifers in places within the region, but they are generally limited and are mostly less than 50 feet thick. The permeability of alluvial deposits is higher than that of older materials, allowing rapid infiltration of storm runoff and snowmelt.

2.3.2 Site Hydrogeology

Detailed information on the ground-water hydrology of the site was obtained by conducting several multiple well aquifer tests. The tests were made to determine drawdown, capacity, direction of flow, and establish control boundaries.

2.3.2.1 Aquifers

In the vicinity of the Crownpoint Project area, the Westwater Canyon Member of the Morrison Formation is the principal aquifer, in that potential yield of good-quality water is greater than for other aquifers in the area. It is also the host rock for most of the uranium ore. Most wells in the vicinity of the Crownpoint Project, however, are in the Mesaverde Group, of which the most commonly used aquifer is the Gallup Sandstone.

The basal unit of the Morrison Formation is the Recapture Creek Member and it consists of of siltstone, shale and fine-grained sandstone, which does not yield significant amounts of water.

The Westwater Canyon Member overlies and in places intertongues with the Recapture Creek Member and consists of poorly sorted, fine- to coarse-grained sandstone

containing claystone and mudstone. At the Crownpoint Project, the formation is about 260 feet thick. Dip of the formation is northward at about 100 ft/mi.

The Brushy Basin Member of the Morrison Formation overlies and intertongues with the Westwater Canyon Member. It consists of 150 feet of gypsiferous and bentonitic mudstone containing lenses of coarse sandstone and a few thin beds of limestone. It has been shown from testing to be a confining layer for water in the underlying Westwater Canyon Member.

2.3.2.2 Aquifer Test Results

An aquifer pump test in the Westwater Canyon Member of the Morrison Fromation was made on the proposed pilot ISL site (see Appendix A) in February, 1978.

Seven observation wells (see Appendix A), Wells 9U-208, 9U-210, 9U-218, 9U-220, 9U-221, 9U-222 and 9U-224, were drilled and equipped to monitor the water level in the Westwater aquifer during pumping operations. Wells 9U-208, 9U-210, 9U-218 and 9U-220 were also designed to be used as injection wells in the pilot test. The pumped well, Well 9U-214, was located at the center of the injection-recovery well array for the ISL pilot testing. An eighth well, Well 9U-207, was constructed specifically to determine if the Dakota and Westwater Canyon members are in direct pressure communication in the area affecting the pilot project. They are separated by the Brushy Basin Member.

The pump test was comprised of a 72-hour constant yield (79 gpm) test followed by a 72-hour recovery period. Water level measurements in the observation wells were obtained with water level recorders.

The pump test results also indicated that the net sandstone contributing to flow on a regional basis can vary as a result of the interbedding of the shale and sandstone members of the Westwater Canyon aquifer. Transmissivity was found to vary from 1100 gallons per day per foot (gal/d/ft) to 2200 gal/d/ft, for an average of 1400 gal/d/ft. This change is due to both thickness and permeability changes in the area tested during pumping operations. A pressure decline of approximately 0.5 feet was noted in the Dakota Sandstone well during the pumping

operation. The results of the aquifer test are presented in Appendix A of this report.

A 13-day constant yield test was made in the Westwater Canyon sandstone in Section 16, approximately 2 miles southeast of the pilot leach area on Mobil property in March-April, 1977. A transmissivity of about 2000 gal/d/ft and a storage coefficient of $1X10^{-4}$ were indicated.

There was not any indication of geological boundaries (i.e., faults, fractures) being encountered in either of the two pump tests. The time length of the tests suggests the area of influence in each test overlapped. The order of magnitude of the hydrologic properties indicated are similar and support the contention that the Westwater is a very large regional aquifer.

2.3.3 Baseline Ground-Water Quality

2.3.3.1 Regional

Chemical analyses of ground water in the region indicate that sodium sulfate is the predominant type of water. The absence of calcareous rocks in the Upper Cretaceous and Tertiary rock has resulted in the lower concentrations of calcium and bicarbonate. In general, ground water is of low quality by drinking water standards. Much of the ground water is not suitable for irrigation because of its high salinity.

2.3.3.2 Mining Area

Chemical and radiochemical composition of ground water from the mining area is typical of the ground-water quality in the region. The water contains sodium sulfate, with calcium and bicarbonate as secondary constituents. Total dissolved solids (TDS) range between 250 and 10,000 mg/l. Sulfate concentrations range between 40 and 1,800 mg.l, while chlorides range from 5 to 1,100 mg/l. Radioactive constituents in the orebody are not pronounced, with radium-226 ranging up to 500 pCi/l. the present ground water in much of the orebody is of fair quality and is, in most cases, suitable for a variety of uses.

2.3.3.3 ISL Site

Baseline chemical and radiochemical analyses of ground water from wells in the Crownpoint ISL R&D site are summarized in Appendix B. Ground water from the site is typical of regional waters in that it is fair quality sodium sulfate water. As indicated in Appendix B, chemical composition is moderately variable with TDS concentrations ranging from 200 to 400 mg/l, sulfate concentrations ranging from 40 to 100 mg/l, and chloride concentrations ranging from 50 to 100 mg/l.

3.0 HISTORY OF OPERATIONS

3.1 Description of the In Situ Leaching Process

If hydrogeologic conditions are favorable, in situ leaching of uranium is presently the foremost technical and cost effective mining method in use today. There are many advantages to this method, and the environmental impacts from in situ leaching are much less severe than the impacts from conventional mining methods. The potential for the greatest impact of the in situ method is the contamination of ground water in the host aquifer. In most cases, the ground water can be restored to baseline quality or premining use category. The in situ leaching method also will permit economical recovery of deep, low-grade roll-front deposits that are not economically recoverable with conventional methods. The extent to which in situ techniques are effective is limited by the hydrologic and mineralogic characteristics of the ore zone.

Basically, the in situ leaching method involves: (1) the injection of a leach solution (called the lixiviant) into a permeable uranium ore body via injection wells to mobilize the uranium; (2) the recovery of the pregnant solution via recovery wells; and (3) the separation of the uranium from the leach solution by ion exchange. The mobilization of uranium in the ore zone involves oxidation of tetravalent uranium to hexavalent uranium and subsequent anionic complexing of the hexavalent uranium. In a carbonate lixiviant, uranium is oxidized by oxygen and complexed with carbonate ions to form mobile complexes of uranyl dicarbonate and uranyl tricarbonate. The leaching process also introduces other chemical reactions in the ore body, causing mobilization of some ions and precipitation of others. After the leaching phase is completed, the aquifer must be restored so that the ground-water quality is within baseline variability or at least within the premining use category. To achieve this objective, residual lixiviant must be removed from the host aquifer. This can be accomplished by pumping the residual lixiviant out of the aquifer and discharging the solution to the

surface (commonly called ground-water sweep) or by pumping residual lixiviant out of the aquifer and injecting the solution back into the aquifer after treatment (recirculation). Water discharged to the surface during a ground-water sweep must either be discharged to an evaporation pond or treated to meet water quality standards before releasing to surface waters. Reverse osmosis and electrodialysis are commonly used water treatment procedures.

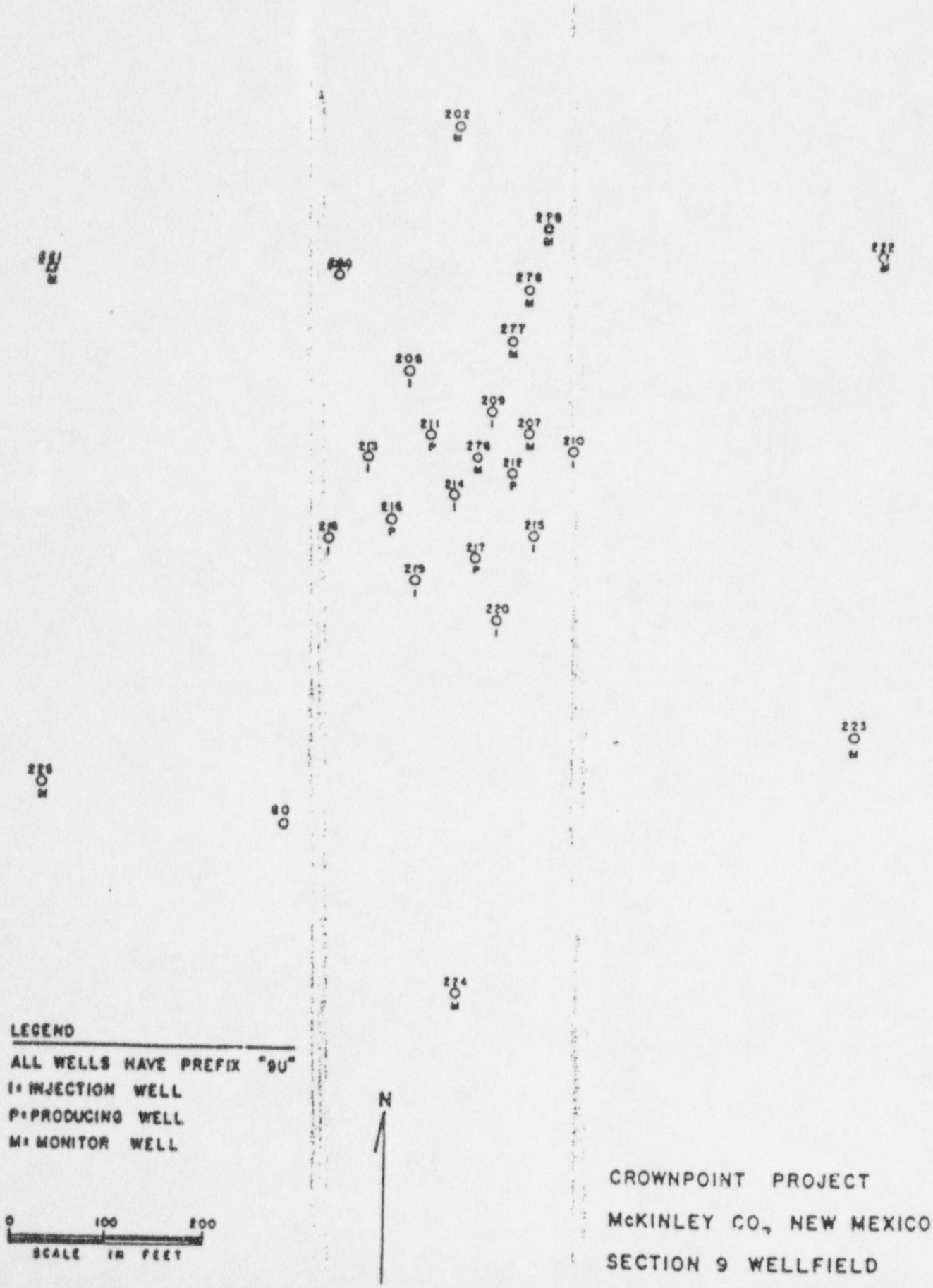
There are many geochemical processes that complicate restoration procedures. One process is the adsorption of undesirable ions on formation clays during leaching and the slow release of these ions into the ground water during restoration and stability phases of operation. To remove these contaminating ions from the clays during restoration, solutions containing high concentrations of exchangeable ions are often injected into the aquifer. Another process which complicates restoration is the slow release of contaminants that have precipitated or co-precipitated during leaching or previous restoration activity. One problem associated with the Crownpoint ISL site is the release and solubility of molybdenum during the leaching process. References providing more complete descriptions of the geochemical and mass transport mechanisms associated with aquifer restoration include Guilinger and others (1979), Kidwell and Humenick (1981), Markos and Bush (1981), Runnels and others (1983), and Thompson and others (1978).

3.2 Well Field Design and Operation at the Crownpoint ISL Site

The site is comprised of one in situ leach well pattern consisting of 9 injection wells and 4 production (recovery) wells; numerous monitoring wells; a pilot plant; and two evaporation ponds. Figure 5 illustrates the locations of wells pertinent to the analysis. The purpose of this section is to provide an account of the operational history of all well patterns at the site.

Chemical injection at the Crownpoint site began on November 6, 1979. The initial injection rate was 73 gpm and was gradually reduced to 55 gpm. Uranium production, after a 3-month period, reached 100 ppm and remained at this level throughout the life of the project. Concurrent with uranium production, molybdenum was liberated in the well field. Its concentrations were very near that of uranium. Due to this, a separation circuit was divised to remove the molybdenum from the production stream, thereby maintaining the uranium production and the ion exchange (IX) resin beads at an optimum performance level.

Figure 5



CROWNPOINT PROJECT

McKINLEY CO., NEW MEXICO

SECTION 9 WELLFIELD

The R&D well field leaching was terminated on October 1, 1980. At this time, it was concluded that approximately 15 percent of the uranium had been recovered from the mining zone. Water quality data at this point in time, indicated that most of the parameters sampled in the well field had been elevated.

Following the mining period, Mobil initiated a restoration effort consisting of fifteen stages. The restoration work began in October of 1980, and ended in October of 1986.

Stage 1 involved well field recirculation without the injection of lixiviant. During this 1-month period, well field water was circulated through the ion exchange columns to remove uranium. As a consequence of this action and the molybdenum strip circuit, molybdenum was also reduced. Waste waters were routed to the evaporation ponds.

Stage 2 lasted from the first week of December until December 24, 1980. During this time period, a lime water softener was utilized to reduce water hardness. This process prepared the well field water for reverse osmosis treatment.

Stage 3 involved six days of ground-water sweep at a rate of 260 gpm. Approximately 2.2 million gallons of water were swept through the well field and discharged to the waste evaporation ponds.

Stage 4, which took place from December 30, 1980, until the end of January, 1981, did not directly involve the well field. During this restoration phase, waste pond water was run through the water softener and back to the pond to reduce hardness.

Stage 5 involved the utilization of reverse osmosis. The unit was installed in late January, 1981, and operated until July, 1981. Water from the well field was run through the unit at approximately 70 gpm. It was at this time in the restoration process that molybdenum was targeted as a problem parameter.

Stage 6 lasted from July, 1981, until May, 1982. During this period, lime was added to the reverse osmosis permeate to reduce dissolved molybdenum. This process resulted in a molybdenum reduction from 32 mg/l to 9.7 mg/l.

Stage 7 utilized the ion exchange columns in combination with a ground-water sweep operation. From May, 1982, to November, 1982, the well field was pumped at 40 gpm, routed through the ion exchange columns for the removal of uranium and molybdenum and pumped back into the well field. At this point in the restoration process, all

major cations and anions were below restoration values. However, molybdenum remained above agreed to restoration values.

Stage 8 began on November 8, 1982, and continued until April 15, 1983. During this time period, sodium sulfide was added to the water coming from the IX columns. The object of this process was to eliminate dissolved oxygan from the well field water and re-establish the reducing environment which would make molybdenum unavailable for dissolution into the well field waters.

Stage 9 began on April 15, 1983, and terminated on July 14, 1983. During this period, the well field was allowed to "sit-and-soak." This phase allowed an equilibrium to establish itself throughout the well field due to the prior addition of sodium sulfide.

Stage 10 was a ground-water sweep. The well field was pumped, beginning on July 14, 1983, until January 18, 1984, at rates varying from 20 to 40 gpm. During the initial 10 weeks of this time period, the well field was pumped and the evaporation ponds filled with approximately 1 million gallons of water. During the remainder of the time, the ground-water sweep program maintained a 1 gpm bleed to the evaporation ponds. During this 5-month period, molybdenum concentrations did not change significantly and remained to be the single elevated parameter above restoration target values in the well field.

Stage 11 began on January 18, 1984, and ended on May 1, 1984. During this period, the well field ground water was pumped at a rate of 34 gpm and routed through a reverse osmosis unit. Twenty-nine gpm was reinjected to the well field, while the remaining 9 gpm was discharged to the evaporation ponds.

Stage 12 began on May 1, 1984, and extended until March 18, 1985. During this period, hydrogen sulfide gas (reducing agent) was injected into the well field. This was another attempt at reducing the well field environment and thereby taking molybdenum out of the solution. At the conclusion of this stage of restoration, six wells showed lower concentrations of molybdenum, three wells remained constant and four wells rose slightly.

Stage 13 involved a "sit-and-soak" period. During the period of March 18, 1985, until April 15, 1986, the well field was allowed to equilibrate with the hydrogen sulfide injection. Laboratory data indicated that ten wells showed a decrease in molybdenum concentrations and three wells showed a slight rise.

Stage 14 began on April 15, 1986, and ended on May 20, 1986. During this period, ground water in the well field was recirculated to

ensure flushing of any well cleaning fluids and equal dispersion of the residual hydrogen sulfide.

Stage 15 began on May 20, 1986, and ended November 10, 1986. During this period, the well field was left idle.

The restoration process utilized at the Crownpoint site involved many stages. It was apparent by Stage 5 that the dissolved salts in the well field waters were responding to the restoration efforts and that molybdenum would be a restoration problem. As an overview of the restoration progress, Table 1 shows water quality based upon annual average of values for the well field.

On November 20, 1986, stability monitoring began and continued until July 20, 1987. The stability period has shown through monthly sampling that the well field is stable, with the exception of a slightly elevated molybdenum species.

4.0 IMPACTS OF ISL OPERATIONS ON GROUND-WATER QUALITY

4.1 Water Quality and Geochemistry

Although influenced by precipitation-dissolution reactions and ion exchange phenomena, concentrations of major cations and anions are useful indicators of the presence of residual lixiviant. Due to their high mobilities relative to trace metals and radionuclides, major ions are removed most easily during restoration. Reactions that do occur are usually predictable and provide insight into the more complex reactions involving trace elements. In addition, concentrations of major ions in individual wells tend to be more representative of spatial variation in the aquifer than concentrations of trace elements.

Concentrations of trace elements and radionuclides are important to analyses of environmental impacts, but are usually much more difficult to interpret than concentrations of major ions. Mobilities are highly dependent on solution Eh, pH, and ionic strength, and are governed by complex adsorption, ion exchange, oxidation-reduction, coprecipitation, and solid-solution reactions. Concentrations in wells may reflect very localized conditions not representative of the aquifer (e.g., localized mineralization, contaminated well screens, etc.).

Elevated concentrations of molybdenum have been observed in a number of wells throughout the site. To reduce concentrations of trace elements (specifically molybdenum) from prerestoration levels to restoration target levels, trace elements often must be diluted to a

Table 1. - Historical Water Quality Data for the Crownpoint Insitu Leach Site

Chemical Constituent	New Mexico Standard mg/liter	Restoration Standard mg/liter	1981 Average of Values	1982 Average of Values	1983 Average of Values	1984 Average of Values	1985 Average of Values	1986 Average of Values
Aluminum, dissolved	5.0	5.0	0.500	0.700	0.550	0.500	0.500	0.808
Arsenic	0.1	0.1	0.086	0.073	0.069	0.057	0.032	0.014
Barium	1.0	1.0	0.227	0.200	0.325	0.262	0.215	0.277
Boron	0.75	0.75	0.191	0.155	0.088	0.108	0.215	0.238
Cadmium	0.01	0.036	0.005	0.005	0.005	0.005	0.007	0.006
Chloride	250.0	250.0	127.273	156.000	372.500	115.5	111.5	54.538
Chromium	0.05	0.074	0.004	0.005	0.005	0.007	0.011	0.005
Cobalt, dissolved	0.05	0.05	0.016	0.020	0.020	0.020	0.026	0.021
Copper, dissolved	1.0	1.0	0.007	0.005	0.005	0.005	0.012	0.008
Cyanide	0.2	0.780	0.005	0.005	0.005	0.005	0.009	<0.005
Fluoride	1.6	1.6	0.336	0.309	0.413	0.500	0.508	<0.5
Iron, dissolved	1.0	5.50	0.130	0.018	0.015	0.065	0.372	0.146
Lead, dissolved	0.05	0.063	0.005	0.022	0.009	0.005	0.006	0.016
Manganese, dissolved	0.2	0.456	0.217	0.053	0.142	0.048	0.096	0.035
Molybdenum, dissolved	1.0	1.0	27.667	9.076	13.250	8.231	4.803	1.118
Mercury, total	0.002	0.002	0.0002	0.0019	0.0001	0.0001	0.0001	0.0003
Nickel, dissolved	0.2	0.2	0.030	0.020	0.070	0.021	0.021	0.022
Nitrate (as N)	10.0	10.0	0.050	0.075	0.050	0.941	0.050	0.556
PH	6 to 9	6 to 9	6.665	8.402	*	8.438	8.446	9.062
Phenols	0.005	0.047	0.005	0.012	0.003	0.002	0.004	0.008
Combined Ra-225 & 228	30.0	97.2	*	30.525	*	22.077	48.677	59.939
Selenium, dissolved	0.05	0.05	0.017	0.149	0.067	0.017	0.032	0.006
Silver, dissolved	0.05	0.05	0.007	0.005	0.005	0.005	0.006	<0.005
Sulfate (as SO4)	600.0	600.0	131.091	44.182	46.500	81.538	80.846	47.615
TDS (at 180 C)	1000.0	1000.0	623.182	529.727	785.000	479.231	556.923	356.154
Uranium (as U)	5.0	5.0	*	0.166	0.370	0.590	0.303	0.319
Zinc, dissolved	10.0	10.0	0.014	0.031	0.014	0.027	0.027	0.039

NOTE:
* Data not available.

Source: Mobil Mining and Minerals Company, November 14, 1986

much higher degree than major ions. However, the effectiveness of trace element removal is reduced further by the limitations of water treatment procedures at low concentrations, the dissolution of precipitates found during leaching, desorption and ion exchange processes and oxidation and mobilization of redox-sensitive species (Bell and others, 1983).

5.0 EVALUATION OF ALTERNATIVES

5.1 Introduction

As part of this report, alternatives have been evaluated. At this stage, there are two alternatives which are addressed, and they will be discussed below.

5.2 No Further Remedial Action

This alternative would result in Mobil initiating decommissioning of the plant and well field and reclamation of the site in accordance with 10 CFR Part 40. It is considered that the concentration of the redox-sensitive trace element (molybdenum) would gradually approach baseline as natural conditions are eventually established within the aquifer.

5.3 Additional Aquifer Restoration

The use of additional restoration methods has been evaluated, and these are described in the following text. The additional restoration synopsis would probably involve the utilization of one or more of the described methodologies.

1. Traditional methods of aquifer restoration, such as ground-water sweep and recirculation. These would probably result in little improvement in the overall ground-water quality at the site. Concentrations of redox-sensitive species may actually increase due to a re-establishment of oxidizing conditions in the aquifer.

2. Injection of reductants. Although this is a potentially viable method for lowering concentrations of redox-sensitive species, the technique does not always give entirely satisfactory results in the field. This is evident from past restoration programs implemented at the Irigaray and Exxon mines in Wyoming and the Ferret mine in Nebraska. The above mentioned facilities were similar in circumstance to the Mobil site and a parallel can be drawn here.

3. Restoration of trace elements through natural processes. Due to the unknowns and the risks involved, this appears to be the preferable method for restoration of molybdenum. It has been shown at the Irigaray and Exxon facilities that natural flushing is a viable alternative.

It is apparent from past restoration efforts (described in the Mobil November 1986 Restoration Report), that molybdenum levels were reduced to their concentrations by a combination of restoration methods (ground-water sweep and reductant treatment).

It is highly unlikely, as indicated by the Mobil monitoring data, that additional ground-water sweep and reductant treatment will provide any more reduction in molybdenum concentration at the Mobil site. Natural restoration processes such as mineral precipitation and adsorption that occur between the residual lixiviant and the aquifer sediment will eventually reduce the concentration of molybdenum from solution. Reducing conditions exist downgradient from the ore zone and under these conditions, the redox-sensitive trace element molybdenum will form a relatively insoluble compound. As a consequence, molybdenum solution concentration will be lowered, perhaps to the restoration level or lower, after a period of contact with the aquifer sediment adjacent to the leached ore zone. The transport of the trace element molybdenum at its present level would be very slow at best. Calculations for transport indicate that ground water in the Westwater Canyon Formation moves at a rate which is approximately 15 feet per year in a North-Northwesterly direction. Accordingly, it would take ground water on the order of hundreds of years to move 1 mile. This, together with the fact that over time the trace element molybdenum will undergo dilution, would indicate that any problems associated with elevated concentrations of molybdenum at present are minimal and temporary. The limited extent of contamination, together with the slow movement of ground water in the Westwater Canyon Formation, suggest that the most realistic approach is to allow natural conditions to restore water quality at the Mobil site. The potential for agricultural use of this water also appears to be very small, as evidenced by Mobil's evaluation of ground-water use (Mobil, 1988).

6.0 PROPOSED NRC ACTION

Due to the extreme depth of the affected zone, the potential for human use of the ground water, the limited areal extent of mining and the cost and limited success of additional restoration, the NRC has determined that further remedial action would result in minimal improvement to the ground water in the aquifer. Therefore, the proposed administrative action is to terminate Mobil Oil Corporation's Source Material License

SUA-1479 after successful decommissioning of the Crownpoint ISL R&D site in accordance with 10 CFR Part 40.

Thomas T. Olsen

Thomas T. Olsen, Project Manager
Licensing Branch 1
Uranium Recovery Field Office
Region IV

Approved by: Edward F. Hawkins

Edward F. Hawkins, Chief
Licensing Branch 1
Uranium Recovery Field Office, Region IV

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Exhibit M

DATA FOR TABLE 6, AVERAGE BASELINE GROUNDWATER QUALITY FOR SELECTED URANIUM ISL MINE SITES IN TEXAS, WYOMING AND NEW MEXICO.

Bruni -- Texas
Kingsville Dome -- Texas
Rosita -- Texas
Crownpoint -- New Mexico
Church Rock -- New Mexico
Highland -- Wyoming
Irigaray -- Wyoming

Table A.53. Average baseline water quality[a] for the Bruni mine.

Parameter	Production Zone Average Baseline[b]	Shallow Gravel Average Baseline[b]
Calcium	267	799
Magnesium	68	297
Sodium	413	879
Bicarbonate	175	164
Sulfate	142	588
Chloride	1090	2696
Nitrate	2.2	10.5
TDS	2312	5682
Ammonia	1	<0.64
Arsenic	0.02	<0.006
Barium	0.15	0.134
Cadmium	0.007	<0.007
Chromium	0.002	0.009
Copper	0.007	<0.021
Iron	1.2	1.95
Lead	0.052	<0.023
Manganese	0.086	0.14
Mercury	0.001	<0.0004
Molybdenum	0.42	<0.05
Nickel	0.34	<0.01
Selenium	0.05	<0.021
Zinc	0.42	0.13
Boron	1.2	4.35
Vanadium	0.05	<0.07
Uranium	0.33	<0.05
Radium-226 (pCi/L)	129	3.3
pH (units)	7.5	7.31

[a]Units are mg/L except as noted.

[b]Average baseline values obtained from Production Areas 1 and 2.

Source: WMC, 1979a.

BRUNI BASELINE WATER QUALITY from Staub et. al. (1986) at A-212.

ATTACHMENT G

Company: URI, Inc.
Mine Name: Kingsville Dome
Mine Area: #2
Date Summarized: 2-13-90

GROUND WATER ANALYSIS REPORT SUMMARY And BASELINE WATER QUALITY -- In Situ Mining

	PARAMETER	UNIT		NON PRODUCTION ZONE**			PRODUCTION ZONE						WELL I.D. BY AREA*		
							MINE AREA**			PRODUCTION AREA			NON PROD. ZONE	PROD. ZONE	
				Low	Average	High	Low	Average	High	Low	Average	High		Mine	Product
1	Calcium	mg/l		2.5	10.2	41	8.4	25.3	74	12	22	35	D-17 through D-51	MW-31 through MW-71	BL 542
2	Magnesium	mg/l		.2	3.0	8.8	3.3	5.5	10	3.9	5.1	6.2			BL 1047
3	Sodium	mg/l		321	363	406	296	318	352	315	323	338			BL 1248
4	Potassium	mg/l		3.1	7.9	28	5.1	6.7	9	6.3	8.2	9.6			BL 1265
5	Carbonate	mg/l		0	25	72	0	7	23	0	4	16			BL 1491
6	Bicarbonate	mg/l		243	383	500	253	327	505	246	297	333			
7	Sulfate	mg/l		3	96	280	13	183	227	206	224	239			
8	Chloride	mg/l		217	270	325	198	231	336	209	224	239			
9	Fluoride	mg/l		.57	1.05	2.20	.55	.65	1.10	.57	.61	.65			
10	Nitrate - N	mg/l		< .01	.11	1.8	.01	.89	5.8	.09	.50	1.2			
11	Silica	mg/l		18	42	160	18	22	30	22	27	34			
12	pH	Std. unit		7.98	8.71	9.20	7.37	8.33	8.94	8.15	8.34	8.66			
13	TDS	mg/l		895	1058	1250	914	1008	1230	976	1035	1070			
14	Conductivity	µmhos		1490	1761	1970	1490	1648	2020	1590	1662	1720			
15	Alkalinity	Std. unit		199	355	446	240	280	444	228	250	273			
16	Arsenic	mg/l		<.001	.002	.01	< .001	.004	.023	< .001	.006	.017			
17	Cadmium	mg/l		<.0001	.0001	.0005	< .0001	.0002	.0017	<.0001	.0001	.0001			
18	Iron	mg/l		< .01	.09	.82	.01	.03	.16	.02	.02	.03			
19	Lead	mg/l		<.001	.005	.065	< .001	.002	.014	< .001	.004	.017			
20	Manganese	mg/l		< .01	.01	.03	< .01	.02	.08	< .01	.01	.01			
21	Mercury	mg/l		<.0001	.0001	.0001	< .0001	< .0001	< .0001	< .0001	.0001	.0001			
22	Selenium	mg/l		< .001	.001	.004	< .001	.002	.006	.001	.008	.017			
23	Ammonia	mg/l		< .01	.13	1.50	.01	.08	.2	.08	.15	.23			
24	Uranium	mg/l		<.001	.006	.027	< .001	.019	.272	.252	1.89	3.75			
25	Molybdenum	mg/l		< .01	.01	.03	< .01	.03	.2	.05	.38	.84			
26	Radium 226	mg/l		.1	.42	2	.3	5.7	82	31	92	157			

* LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

KINGSVILLE DOME BASELINE WATER QUALITY from TNRCC permit #URO2827-021, June 28, 1990.

PERMIT NO. URO2827-021

ATTACHMENT G

BASELINE WATER QUALITY TABLE

GROUNDWATER ANALYSIS REPORT SUMMARY And
BASELINE WATER QUALITY TABLE - In Situ Uranium Mining

Company: URI, Inc.
Mine Name: Rosita
Mine Area: PAA 3
Date Summarized: 6/6/96

	PARAMETERS	UNITS	NON PRODUCTION ZONE**			PRODUCTION ZONE						WELL I.D. BY AREA*		
						MINE AREA**			PRODUCTION AREA			NON PROD. ZONE	PROD. ZONE	
			Low	Avg.	High	Low	Avg.	High	Low	Avg.	High		Mine	Prod.
1.	Calcium	mg/l				50	153	430	46	104	230		MW-122	BL-34
2.	Magnesium	mg/l				9.8	46	103	12	30	65		MW-122	BL-34
3.	Sodium	mg/l				355	550	913	375	751	988		MW-120	BL-28
4.	Potassium	mg/l				18	25	55	20	34	50		MW-119	BL-33
5.	Carbonate	mg/l				0	0	5	0	2	10		MW-119	BL-32
6.	Bicarbonate	mg/l				116	231	428	54	161	275		MW-120	BL-29
7.	Sulfate	mg/l				104	364	1450	163	496	750		MW-122	BL-28
8.	Chloride	mg/l				504	840	1230	667	952	1090		MW-120	BL-32
9.	Fluoride	mg/l				0.7	1.18	1.7	0.9	1.37	2		MW-126	BL-32
10.	Nitrate - N	mg/l				<0.01	0.97	4.3	<0.01	0.64	2.4		MW-138	BL-34
11.	Silica	mg/l				20	36	66	23	35	54		MW-133	BL-34
12.														
13.	pH	std. units				7.29	7.89	8.4	7.75	8.19	8.65		MW-119	BL-32
14.	TDS	mg/l				1390	2183	3640	1610	2524	3060		MW-123	BL-20
15.	Conductivity	µmhos				2520	3637	5310	2840	4276	5100		MW-120	BL-28
16.	Alkalinity	std. units				95	189	351	52	134	225		MW-120	BL-29
17.														
18.	Arsenic	mg/l				0.001	0.025	0.147	0.004	0.068	0.27		MW-116	BL-32
19.	Barium	mg/l				0.05	0.09	0.24	0.05	0.07	0.1		MW-110	BL-34
21.	Cadmium	mg/l				<0.001	0.002	0.007	<0.001	0.002	0.007		MW-123	BL-32
22.	Chromium	mg/l				<0.01	<0.01	0.02	<0.01	<0.01	<0.01		MW-112	
23.	Copper	mg/l				<0.01	0.01	0.11	<0.01	<0.01	0.01		MW-120	BP-28
24.	Iron	mg/l				<0.01	0.13	3.4	0.01	0.03	0.08		MW-110	BL-29
25.	Lead	mg/l				<0.001	0.003	0.027	<0.001	<0.001	<0.001		MW-120	
26.	Manganese	mg/l				<0.01	0.04	1.6	<0.01	<0.01	0.02		MW-110	BL-29
27.	Mercury	mg/l				<0.0001	<0.0001	0.0004	<0.0001	<0.000 1	<0.0001		MW-136	
28.	Nickel	mg/l				<0.01	<0.01	0.01	<0.01	<0.01	<0.01		MW-110	
29.	Selenium	mg/l				<0.001	0.034	0.27	<0.001	0.012	0.024		MW-122	BL-33
30.	Silver	mg/l				<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
31.	Zinc	mg/l				<0.01	0.25	3.1	<0.01	0.03	0.16		MW-119	BL-29
32.														
33.	Ammonia	mg/l				<0.01	0.16	1.1	<0.01	0.04	0.16		MW-119	BL-33
34.	Uranium	mg/l				0.004	0.125	0.725	0.136	0.586	1.53		MW-122	BL-28
35.	Molybdenum	mg/l				<0.01	0.4	3	0.05	2.56	8.2		MW-117	BL-32
36.	Vanadium	mg/l				<0.01	<0.01	0.05	<0.01	0.01	0.05		MW-133	BL-33
37	Radium 226	pci/l				2.2	14.76	57	35	87.29	235		MW-120	BL-28

*LIST THE IDENTIFICATION NUMBERS OF WELLS USED TO OBTAIN THE LOW, AVERAGE AND HIGH VALUES. **MONITOR WELLS

ROSITA BASELINE WATER QUALITY from TNRCC permit #UR02880-031
December 6, 1996

15. Page 3-27, Table 3.13: replace the existing table with the following (values in bold underline have been changed):

Revised Table 3.13. Crownpoint site water quality data,[a] Westwater Canyon aquifer

Parameter	Mean (mg/L)	Maximum (mg/L)	Minimum (mg/L)	EPA (and NNEPA) drinking water standard
	2.73	7.8	0.07	
Magnesium	**0.48**	2.5	0.00000	
Sodium	**127.7**	184.0	97.0	
Potassium	**13.0**	56.0	1.5	
Carbonate	**27.9**	127.0	0.00000	
Bicarbonate	**203.0**	260.0	54.0	
Sulfate	**62.2**	177.0	19.0	250.0
Chloride	**15.8**	54.0	1.8	250.0
Nitrate	0.05	0.26	0.00000	10.0
Fluoride	0.35	**0.62**	0.23	4.0 or 2.0
Silica	**16.3**	20.0	1.0	
TDS	**394.0**	666.0	**281.0**	500.0
Conductivity[b]	**602.3**	1040.0	**418.0**	
Alkalinity	**213.0**	256.0	**191.0**	
pH[c]	9.0	10.4	8.26	6.5-8.5
Arsenic	0.00000	**0.002**	0.00000	0.05
Barium	**0.13**	1.0	**0.01**	2.0
Cadmium	0.00000	0.0008	0.00000	0.01
Chromium	0.00000	0.00000	0.00000	0.05
Copper	0.00000	**0.02**	0.00000	1.0
Iron	**0.11**	**0.92**	0.00000	0.3
Lead	0.00000	**0.078**	0.00000	0.05
Manganese	**0.035**	0.029	0.00000	0.05
Mercury	0.00000	0.00000	0.00000	0.002
Molybdenum	0.00000	0.02	0.00000	
Nickel	0.00000	0.00000	0.00000	0.1
Selenium	0.00000	0.00000	0.00000	0.05
Silver	0.00000	0.00000	0.00000	0.1
Uranium	**0.005**	0.021	0.00000	
Vanadium	0.00000	0.00000	0.00000	
Zinc	0.00000	0.03	0.00000	5.0
Boron	**0.05**	0.11	0.00000	
Ammonia	**0.05**	0.31		
Radium-226[d]	**58.7**	806.0	0.1	5.0

[a]Values obtained from Wells CP-3, CP-5, CP-6, CP-7, CP-9, and well CP-2 (for parameters from arsenic to radium-226. (*Source:* HRI 1992b).
[b]µmhos/cm.
[c]Units.
[d]pCi/L.

CROWNPOINT BASELINE WATER QUALITY
1990 - 1992

Table 3.19. Church Rock site water quality data,[a] Westwater Canyon aquifer

Parameter	Mean (mg/L)	Maximum (mg/L)	Minimum (mg/L)	EPA (and NNEPA) drinking water standard
Calcium	2.775	5.8	1.5	
Magnesium	0.235	0.81	0.07	
Sodium	129.75	148.0	114.0	
Potassium	2.46	6.6	0.85	
Carbonate	28.75	80.0	0.0	
Bicarbonate	246.25	331.0	185.0	
Sulfate	37.0	46.0	32.0	250.0
Chloride	6.15	12.0	2.8	250.0
Nitrate	0.02	0.16	0.01	10.0
Fluoride	1.628	22.0	0.21	4.0 or 2.0
Silica	16.5	68.0	11.0	
TDS	369.75	435.0	322.0	500.0
Conductivity[b]	556.25	651.0	485.0	
Alkalinity	256.0	491.0	218.0	
pH[c]	8.923	9.67	8.15	6.5–8.5
Arsenic	0.0025	0.012	0.001	0.05
Barium	0.0675	0.12	0.02	2.0
Cadmium	0.00028	0.005	0.0001	0.01
Chromium	0.0125	0.07	0.01	0.05
Copper	0.0125	0.08	0.01	1.0
Iron	0.0375	0.29	0.01	0.3
Lead	0.001	0.003	0.001	0.05
Manganese	0.01	0.01	0.01	0.05
Mercury	0.0001	0.0001	0.0001	0.002
Molybdenum	0.01	0.04	0.01	
Nickel	0.01	0.01	0.01	0.1
Selenium	0.00125	0.01	0.001	0.05
Silver	0.01	0.01	0.01	0.1
Uranium	1 8	10.9	0.002	
Zinc	0.01	0.03	0.01	5.0
Boron	0.1	0.65	0.04	
Ammonia	0.0775	0.16	0.01	
Radium-226[d]	10.225	26.0	1.1	5.0

[a] *Source*: HRI 1996b.
[b] µmhos/cm.
[c] Units.
[d] pCi/L.

CHURCH ROCK BASELINE WATER QUALITY
1988 - 1989

TABLE 3-1

A-WELLFIELD
SELECTED MEAN WATER QUALITY CHARACTERISTICS AT
WELLS MP-1 THROUGH MP-5
(mg/l unless noted)

Year	HCO_3	SO_4	Cl	TDS	COND (µmhos/cm)	Se	U_3O_8	Ra(pCi/l)
July 1991	720	381	213	1507	2390	1.00	47	3286
July 1992	817	341	209	1564	1926	0.84	53	2550
July 1993	782	265	182	1399	1997	0.66	50	2877
July 1994	487	100	65	687	1077	0.46	22	2235
July 1995	407	92	43	570	879	0.51	21	1678
July 1996 (MP2-MP5)	394	50	7	358	556	0.33	4	1439
July 1997	259	41	4	319	471	0.36	3	1057
Baseline	215	91	4	330	525	<0.001	.05	675
Class of Use Domestic	NA	250	250	500	NA	.05	5	5
Class of Use Livestock	NA	3000	2000	5000	NA	.05	5	5

HIGHLAND BASELINE WATER QUALITY, from PRI 1977, Table 3-1.

Table A.6. Water quality[a] for the well field recovery solutions before, during, and after restoration at Well Field E of the Irigaray site.

Parameter	Wyoming or EPA Drinking Water Stds.	Preleaching Baseline[b]	Post Leaching/ Prerestoration[c] 3/11/80	During Restoration[c] 6/26/80	Termination of Restoration[c] 8/27/80	Post Restoration[c] 11/12/81
Chloride	250	12	210	116	98	39
Bicarbonate	500	90	1670	435	241	196
Sodium	200	120	787	230	200	177
Uranium (U_3O_8)	5.0	0.03	40	7.5	3.1	1.9
Conductivity (μmhos/cm)	--	650	3070	1148	1044	870

[a]Units are mg/L except as noted.

[b]Complete chemical analyses were not performed on the recovery solution samples.

[c]Average concentration from wells in Well Field E.

Source: WMC, 1981c.

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[c]Average concentration from wells in Well Field E.

Source: WMC, 1981c.

Exhibit N

Uranium Resources of Northwestern New Mexico

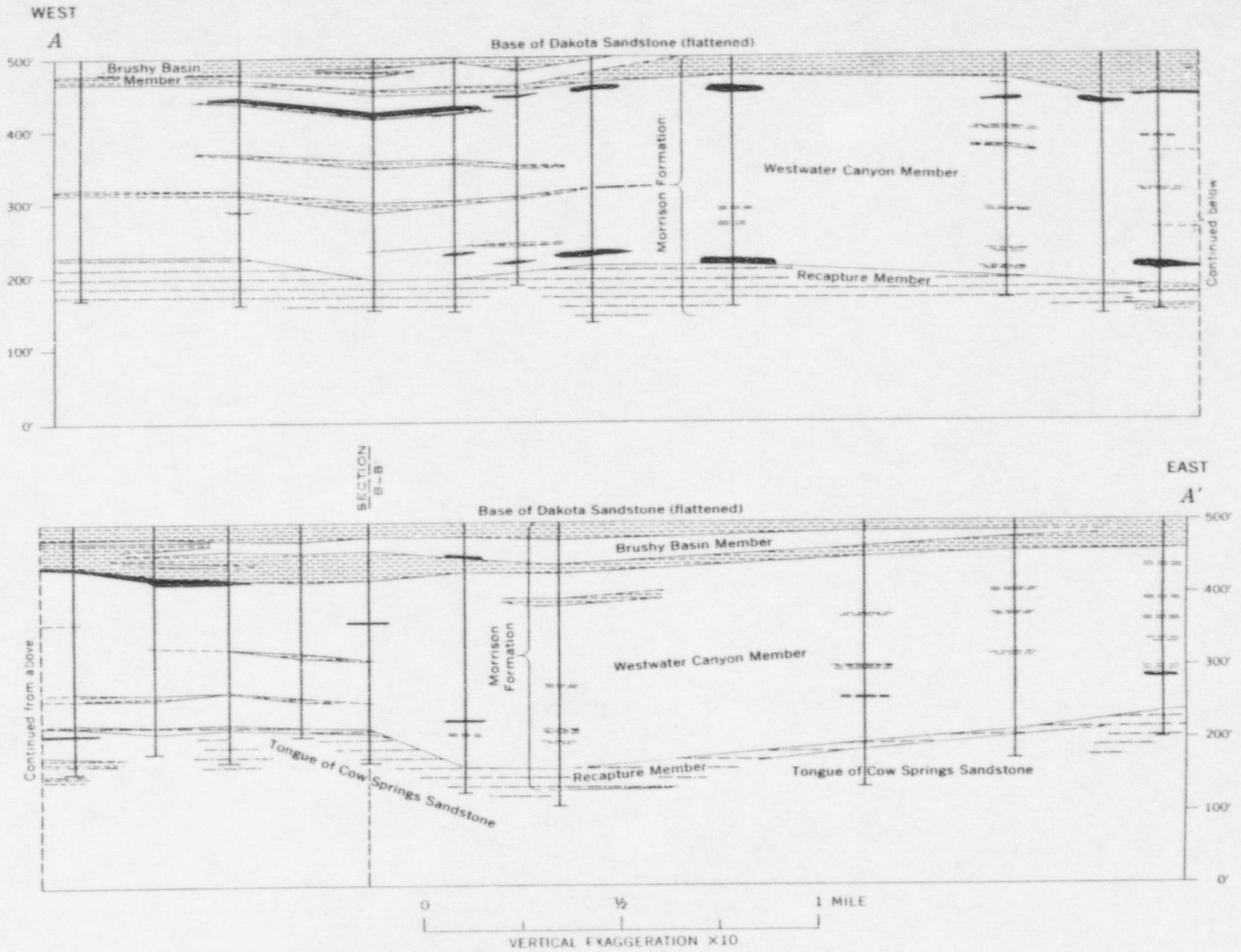
By LOWELL S. HILPERT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

Prepared on behalf of the U.S. Atomic Energy Commission

A description of the stratigraphic and structural relations of the various types of uranium deposits in one of the world's great uranium-producing regions

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969


WEST
A
Base of Dakota Sandstone (flattened)
500'
400'
300'
200'
100'
0'
Brushy Basin Member
Morrison Formation
Westwater Canyon Member
Recapture Member
Continued below
SECTION B–B
EAST
A'
Base of Dakota Sandstone (flattened)
Continued from above
Brushy Basin Member
Morrison Formation
Westwater Canyon Member
Tongue of Cow Springs Sandstone
Recapture Member
Tongue of Cow Springs Sandstone
0
½
1 MILE
VERTICAL EXAGGERATION ×10

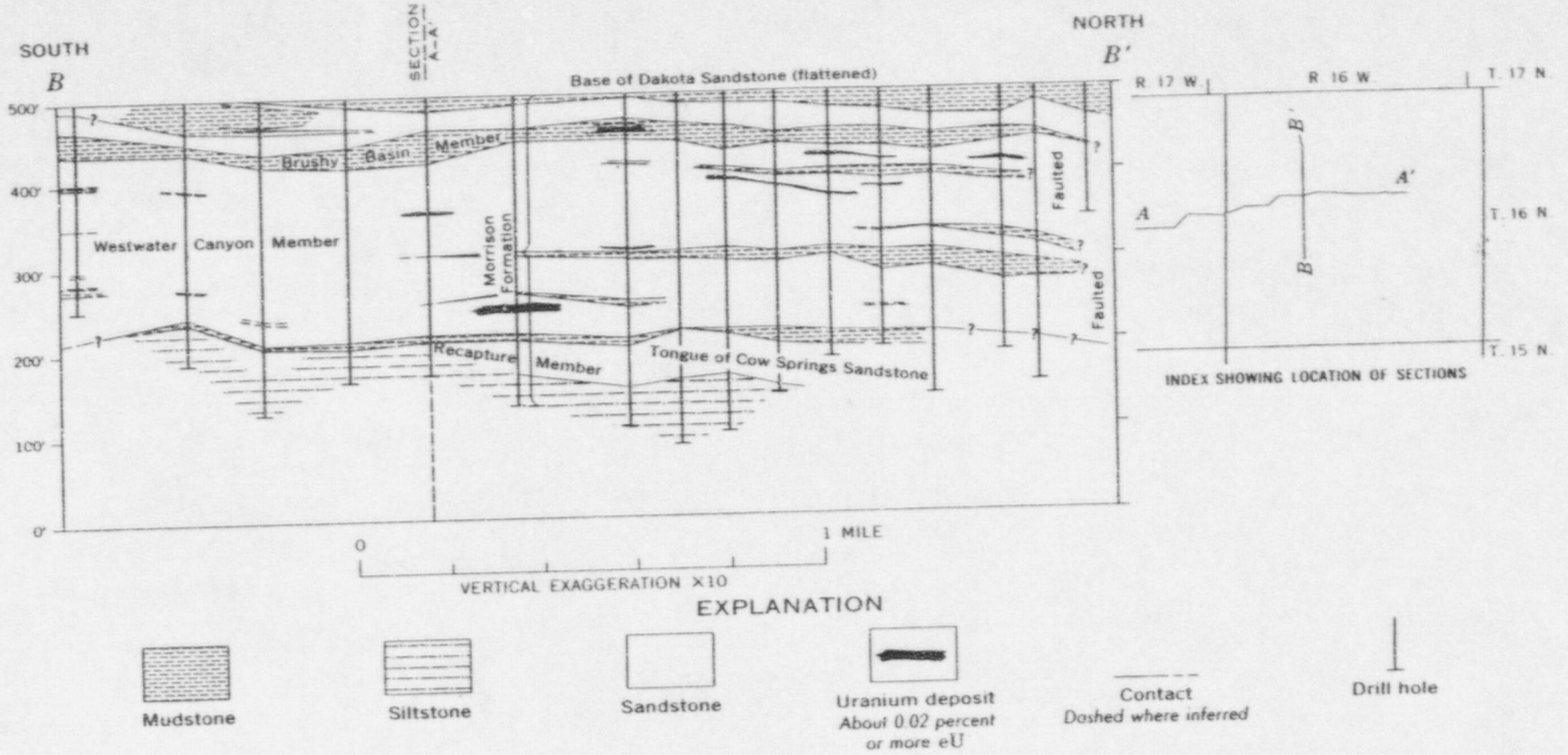


FIGURE 11.—Geologic sections in the western part of the Gallup district showing the stratigraphic relations of the uranium deposits to the members of the Morrison Formation and the Cow Springs Sandstone. Compiled from electric logs in 1957–59, provided by courtesy of Phillips Petroleum Co. and Tidewater Oil Co.

Exhibit O

attached:Kirk and Condon

A Basin Analysis Case Study: The Morrison Formation Grants Uranium Region New Mexico

Edited by

Christine E. Turner-Peterson
Elmer S. Santos
Neil S. Fishman

1995

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Structural Control of Sedimentation Patterns and the Distribution of Uranium Deposits in the Westwater Canyon Member of the Morrison Formation, Northwestern New Mexico—A Subsurface Study

Allan R. Kirk and Steven M. Condon
U.S. Geological Survey, Denver, Colorado

Approximately 1,800 geophysical logs and 100 measured sections provided data for several types of isopleth maps of the Westwater Canyon and Brushy Basin Members of the Upper Jurassic Morrison Formation in the southern San Juan basin, New Mexico. These types of maps include: isopach, sandstone:mudstone ratio, percent sandstone, net sandstone, and average number of mudstone interbeds per 100 ft (30 m) of section. We also constructed a paleotopographic map on the base of the Westwater Canyon and a structure contour map on the base of the Upper Cretaceous Dakota Sandstone.

These maps illustrate depositional unit geometry, sandstone depocenter distribution, and large-scale lithofacies variations within the units. The Westwater Canyon is thinner and less sandy over paleotopographic highs and is thicker and sandier along paleotopographic lows, which suggests active structural control of facies distribution during deposition. Sedimentation of the Brushy Basin Member was also affected by some of the same active structural elements. Detailed reflection seismic studies have defined basement faults that were periodically reactivated since the Precambrian. These faults exerted a significant influence on depositional patterns in the Morrison Formation.

Primary uranium ore in the Westwater Canyon Member is restricted to sandstone depocenters associated with east-southeast-trending isopach thicks. Remnant ore deposits are relict primary deposits that lie in oxidized ground updip from a regional oxidation-reduction (redox) interface. Sedimentologic controls seem to be similar to those for primary ore, and in general these deposits have been preserved from oxidation by stratigraphic variations and by structures. Redistributed ore deposits are also concentrated in the vicinity of isopach thicks, but in rocks with relatively low sandstone:mudstone ratios. However, the location of redistributed ore is much more closely related to the position of the regional redox interface. The geographic form of the interface was influenced regionally and locally by Laramide structures.

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Introduction

The Grants uranium region (Figure 1) is the largest uranium-producing area in the United States. It has accounted for more than 40% of the total U.S. production (Chenoweth, 1976), accounts for about 53% of the domestic reserves (Chenoweth and Holen, 1980), and was recently estimated to contain in excess of 2.6 million tons U_3O_8 in undiscovered endowment (McCammon et al., this volume). Most uranium production and reserves have come from sandstone deposits in the Westwater Canyon Member of the Morrison Formation (Adams and Saucier, 1981).

This report first presents background information on tectonic setting, stratigraphy, and ore deposits, and then presents the results of a subsurface study designed to examine the distribution of sedimentary facies in the Westwater Canyon and Brushy Basin Members of the Upper Jurassic Morrison Formation—work which was done by contouring drill-hole data of several stratigraphic parameters. The distribution of these parameters and sedimentary facies is shown to be structurally controlled and directly related to the distribution of various types of uranium deposits.

Tectonic Framework of the Region

The San Juan basin is a large structural downwarp that owes its present configuration to latest Cretaceous to mid-Tertiary Laramide tectonism. The basin is on the southeast side of the Colorado Plateau in northwestern New Mexico and southwestern Colorado (Figure 2; Kelley, 1951). It is bounded on the north in southwestern Colorado by the Uncompahgre uplift and the San Juan dome; on the east by the Archuleta arch, the Nacimiento uplift, and the Rio Grande trough; on the south by the Zuni uplift, which is flanked on the east by the Acoma sag and on the west by the Gallup sag (both large-scale northward-plunging synclines); and on the west by the Defiance uplift (Figure 2). The specific area of interest in this study is the southern part of the basin (Figure 1), an area that has been variously termed the Grants mineral belt (Kelley, 1963a), the San Juan mineral belt, or the Grants uranium region (Chenoweth and Holen, 1980). It is in a part of the structural element called the Chaco slope (Figure 2; Kelley, 1951). The Chaco slope is a northward-dipping homoclinal structure on the north flank of the Zuni uplift that dips gently (2°–10°) toward the central part of the San Juan basin.

Sedimentary rocks on the Chaco slope have been folded and faulted during several deformational events. Many of the major structural features of the slope (shown on Figure 2; and evident on the structure contour map of the study area, Plate A) can be related to recurrent movement of the Zuni uplift.

Thickening of units north of the Zuni uplift suggests active uplift in the ancestral Zuni Mountains area at least as early as the Pennsylvanian-Permian. The oldest rocks are Pennsylvanian(?)-Permian conglomerates (Goddard, 1966) that unconformably overlie Precambrian basement rocks of the Zuni uplift; Pennsylvanian strata are known to thicken away from the uplift (Kelley and Clinton, 1960; Jentgen, 1977). Arkosic red beds of the Permian Abo Formation (a lower Cutler Formation equivalent) also locally lie unconformably on Precambrian rocks and, along with the overlying Yeso, Glorieta, and San Andres Formations, thicken dramatically away from the Zuni uplift (Baars and Stevenson, 1977).

A later period of deformation is of Late Jurassic and Early Cretaceous age, although most of the deformation probably occurred in the Late Jurassic (Santos and Turner-Peterson, this volume). This deformation is indicated by the presence of pre-Dakota folds around Laguna, just east of the area discussed in this chapter, and is described by Hilpert and Moench (1960), Moench and Schlee (1967), and Hilpert (1969). In the Laguna area one prominent set of folds trends generally east-west, and a minor set of folds trends north-northwest. These folds were believed to have developed at the same time that Upper Jurassic rocks were deposited, and it was thought that the growing folds may have affected depositional patterns and processes. The folds are truncated by a pre-Dakota erosion surface and are therefore not detected by structure contouring of the base of the Dakota Sandstone. Hilpert and Corey (1957) and Hilpert and Moench (1960) proposed the extension of the east-west fold system westward into the Ambrosia Lake district in the east end of our study area (Plate B). Santos (1970), however, questioned whether these folds could be projected westward, and concluded that folds of the number and size as those described by Moench and Schlee (1967) did not extend into the Ambrosia Lake district.

Uplift during the Late Jurassic and Early Cretaceous is also indicated by depositional thinning, locally to a pinchout, of the members of the Morrison Formation onto the northern and eastern flanks of the ancestral Zuni uplift; and by tilting of Morrison and older units to the north, with subsequent erosional truncation from north to south of progressively older units beneath the latest Early Cretaceous, pre-Dakota unconformity (Harshbarger, Repenning, and Irwin, 1957; Maxwell, 1976).

The most significant deformational event in the San Juan basin area occurred during the Laramide orogeny in latest Cretaceous to middle early Tertiary. Movement associated with this deformation produced the uplifts, sags, and arches that defined the margins of the San Juan basin, deepened the central part of the basin, and produced the major folds, faults, and regional dip on the Chaco slope (Figure 2; Plate A).

Timing of the Laramide deformational events may be deduced from Tertiary sedimentation patterns, unconformities, and deformation. In the Paleocene, sediments (upper part of Animas Formation) spread southward from uplifted highlands in southwestern Colorado in the vicinity of the San Juan uplift, also known as the San Juan dome (Kelley, 1955; and Figure 2). Deepening and deformation of the basin are indicated by thick accumulations of Paleocene and lower Eocene sediments unconformably overlain by the Eocene San Jose Formation in the area of the Nacimiento uplift (Hunt, 1956; Hilpert, 1969). After the San Jose Formation was deposited, the southward part of the basin was tilted upward, which resulted in reversal of the earlier southward depositional dip of basal San Jose strata (Kelley, 1955; Hunt, 1956; Hilpert, 1969; Santos, 1970).

The last major period of uplift and deformation began in the Pliocene with broad continental arching in the Colorado Plateau area and with the beginning of crustal extension in the southwestern United States (Kelley, 1955; Hilpert, 1969). The major documenting events are the opening of the Rio Grande trough and formation of the Rio Puerco fault zone (Figure 2), and downfaulting and rapid deposition of sediments of the Miocene and Pliocene Santa Fe Group into the Rio Grande trough.

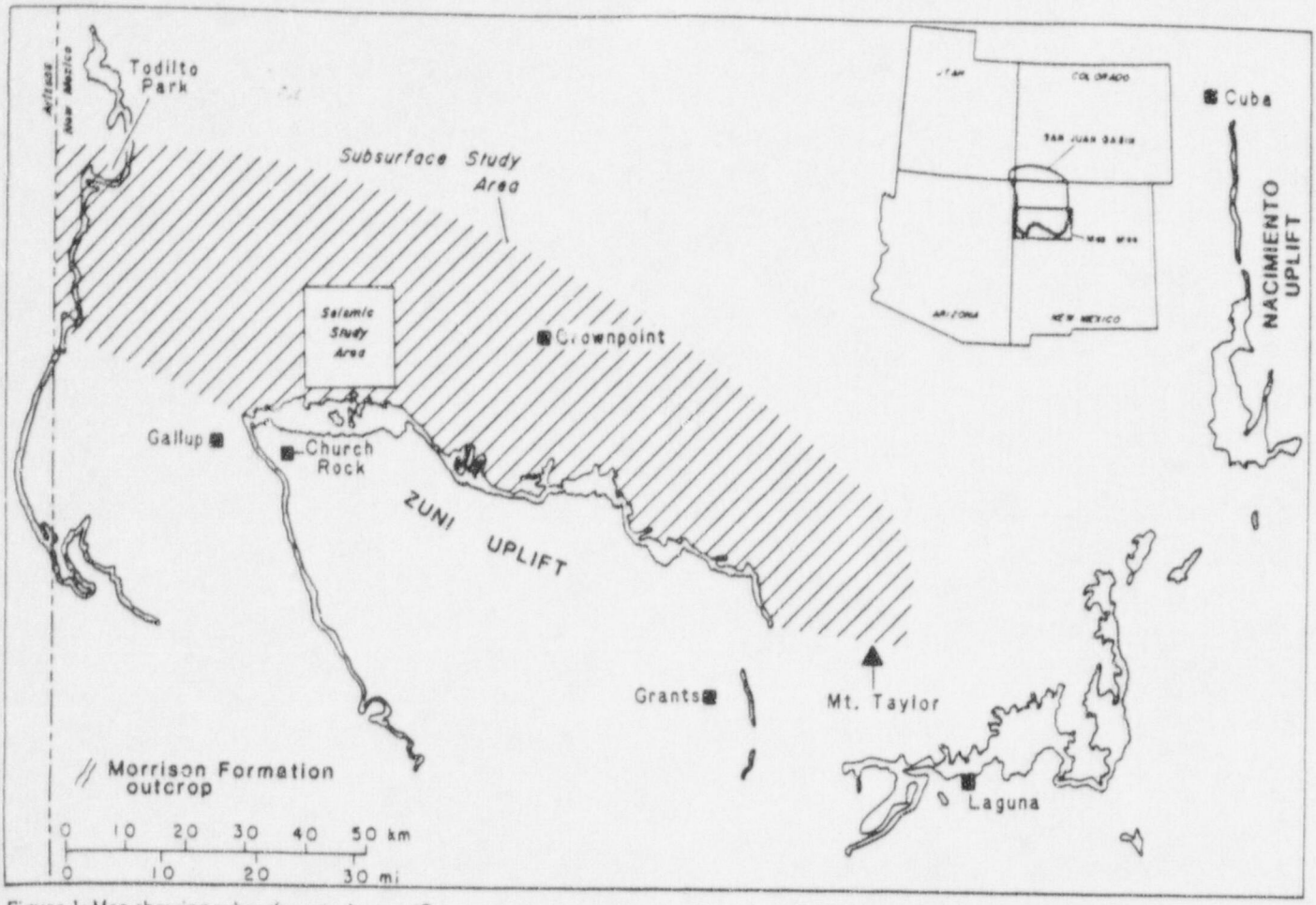

Figure 1: Map showing subsurface study area (Grants uranium region), seismic study area (Figures 7, 8), and outcrop of the Morrison Formation.

Some of the faults observed on the Chaco slope may have formed or become reactivated at this time (Hilpert, 1969; Santos, 1970). Crustal extension seems to have culminated with Pliocene and Pleistocene basaltic volcanic activity, such as that in the Mount Taylor area northeast of Grants, New Mexico (Bassett et al., 1963; Lipman and Mehnert, 1980; and Figure 1). Continued extension was accompanied by emplacement of volcanic plugs and basaltic flows, and by erosion, processes that have continued into the Holocene.

Existence of a major northwest-trending Precambrian tectonic grain on the Colorado Plateau has been emphasized by earlier workers (Kelley, 1955; Saucier, 1976). Major pre-Jurassic structural and sedimentologic patterns in the area between the reactivated Precambrian Mogollon highland in central and southwestern Arizona and southeastern California, and the Precambrian Uncompahgre-San Luis highland in southwestern Colorado reflect this trend. Further reactivation and continued uplift of these northwest-trending features may have controlled subsequent depositional patterns in the Morrison Formation (Saucier, 1976). The continued influence of these features into the Jurassic is supported by the presence of minor folds that trend northwest (Kelley, 1955; Hilpert and Moench, 1960) and by depositional patterns of Jurassic units as shown by isopach maps (Saucier, 1976; Galloway, 1980; Santos and Turner-Peterson, this volume). The northwest-trending tectonic grain appears to be the oldest and most prominent structural control of sedimentation, beginning in the Paleozoic and continuing through the Late Jurassic. Precambrian basement faults oriented west-northwest and northeast that were reactivated through time are the subject of a report by Phelps, Zech, and Huffman (this volume) and are discussed in detail herein.

During the Late Jurassic, the Uncompahgre-San Luis highland on the northeast side of the San Juan basin was apparently a minor structural element that became subdued by erosion, whereas an Andean-type magmatic arc and adjacent highland (Mogollon highland) in central and southwestern Arizona and southeastern California continued to rise (Burchfiel, 1979). This produced a northeast topographic gradient that became prominent in controlling Morrison sedimentation patterns (Craig et al., 1955; Moench and Schlee, 1967; Saucier, 1976). Thus, the magmatic arc and adjacent Mogollon highland were the major source for the mixed sedimentary, Mesozoic volcanic, and Precambrian igneous and metamorphic detritus of the Morrison Formation. Sediment transport by fluvial systems down the paleotopographic slope was mainly to the northeast and southeast (Turner-Peterson, this volume); the fluvial systems may have been deflected to the east and southeast by the older trough axis between the Mogollon and Uncompahgre-San Luis highlands and by active structures in the San Juan basin (Saucier, 1976). The Defiance uplift (Figure 2) was apparently a topographic low during Morrison deposition, because sediment was transported and deposited over this area. However, the

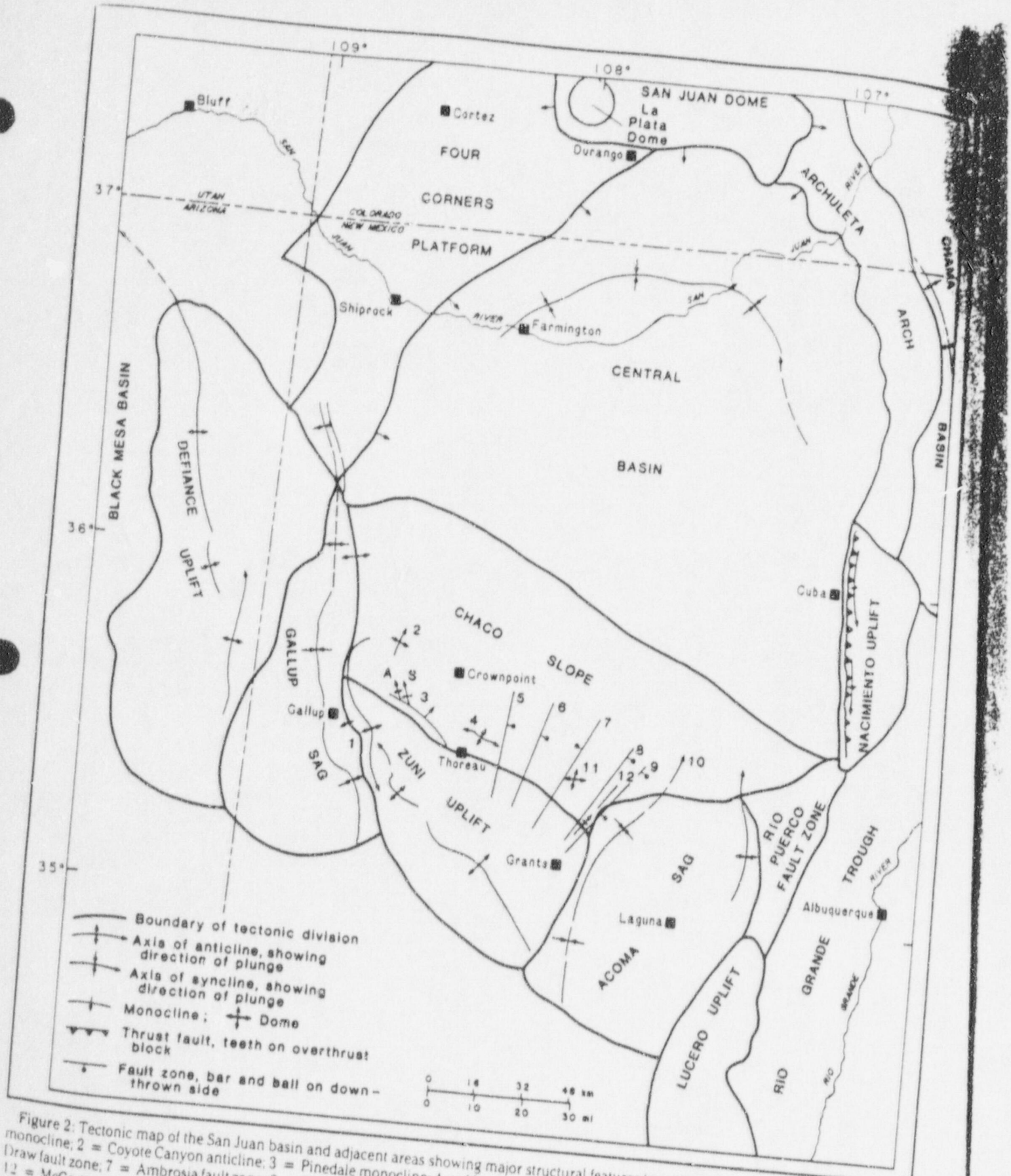

Figure 2: Tectonic map of the San Juan basin and adjacent areas showing major structural features (modified from Kelley, 1963b). 1 = Nutria monocline; 2 = Coyote Canyon anticline; 3 = Pinedale monocline; 4 = Mariano Lake-Ruby Wells anticline; 5 = Bluewater fault zone; 6 = Big Draw fault zone; 7 = Ambrosia fault zone; 8 = San Mateo fault zone; 9 = San Rafael fault zone; 10 = McCartys syncline; 11 = Ambrosia dome; 12 = McCartys arch; A = anticline; S = syncline.

ancestral Zuni uplift must have been an actively rising structure during deposition of the Morrison Formation. This is suggested by depositional thinning of the Recapture and Westwater Canyon Members of the Morrison Formation onto the north flank of the Zuni uplift, thinning to a depositional pinchout of the Recapture and Westwater Canyon Members, and thinning of the Brushy Basin Member on the southeast flank of the uplift about 7 mi (11 km) south of Grants (Figure 1; Hilpert, 1969; Santos, 1970; Maxwell, 1976).

Structure Contour Map on Base of Dakota Sandstone

A structure contour map of the study area (Plate A) was constructed on the base of the Upper Cretaceous Dakota Sandstone. The map shows the outcrop of the Dakota Sandstone, the distribution of ore deposits in the Morrison Formation, the regional redox interface in the Westwater Canyon Member of the Morrison (modified from Saucier, 1980), and the line of truncation of the underlying Brushy Basin Member of the Morrison Formation by the pre-Dakota unconformity. Major structural features, labeled on Figure 2, are also evident on Plate A. Data from about 4,000 geophysical logs and about 100 measured sections were used to construct this map. Much of the eastern part of the map area, around Ambrosia Lake, is only slightly modified from earlier contouring done in conjunction with geologic quadrangle mapping by U.S. Geological Survey personnel over a number of years. An extensive bibliography of contour data and maps has been compiled by Thaden and Zech (this volume).

Important Structures

Most of the important structures of the San Juan basin were formed by deformation during the Laramide orogeny. During that event the present San Juan basin was formed by uplift of areas marginal to the basin and by subsidence of the central part of the basin (Figure 2). It was also at that time that the gently dipping Chaco slope and the smaller-scale structures associated with it formed in response to local upwarping of the Zuni uplift (Plate A). The Zuni uplift has a northwest-trending axis about 20 mi (32 km) south of the Dakota Sandstone outcrop belt shown on Plate A.

The difference in structural style of deformation between the east and west halves of the Chaco slope (Figure 2; Plate A) is striking. The east half is intricately faulted, whereas the west half has only a few relatively insignificant faults, none of which has any large offset. The intense faulting in the east half of the slope might be related to the development of the McCartys syncline (Figure 2, no. 10), which extends southward to form the axis of the Acoma sag, a major structural element along the southeastern margin of the San Juan basin. Trends of fold axes and strikes of faults are more or less parallel to the axis of the syncline (Hilpert, 1969). Fault density and amounts of offset along faults decrease progressively westward away from the McCartys syncline.

Most of the major fault zones along the east half of the Chaco slope (Figure 2, no. 5, 6, 8, and 9; Plate A) are actually faulted monoclines, most of which are downthrown and downfolded to the east toward the McCartys syncline and Acoma sag. An exception to this is the Ambrosia fault zone (Figure 2, no. 7; Plate A), which is downthrown to the west and forms the west-bounding fault of a horst block bounded on the east by the San Mateo fault zone (Figure 2, no. 8; Plate A). This horst block includes most major deposits of the Ambrosia Lake district, and its bounding faults may have served to protect ore deposits from later oxidation and redistribution (Santos, 1970; Adams and Saucier, 1981). The strike of faults can also be seen to vary systematically from west to east across the study area, from nearly due north along the Bluewater fault zone on the west (Figure 2, no. 5; Plate A) to northeast along the San Mateo fault zone (Figure 2, no. 8; Plate A).

The San Rafael fault zone (Figure 2, no. 9), just east of the study area, also trends northeast, is downthrown to the east, and lies along the steep monoclinal west flank of the McCartys syncline. Thaden, Merrin, and Raup (1967) reported as much as 20,000 ft (6,100 m) of strike-slip movement along this fault, and Santos (1970) reported strike-slip movement on east-northeast-trending faults elsewhere in this area. A large north-plunging anticline, here called McCartys arch (Figure 2, no. 12; Plate A) is present west-northwest of McCartys syncline.

Ambrosia dome is north of Grants in the Ambrosia Lake area (Figure 2, no. 11; Plate A; Santos, 1963, 1970). The west end of the dome dips steeply into the Ambrosia fault zone and forms an asymmetrical dome-shaped fold with steep south and west flanks.

An east-west, elongated, doubly plunging anticline occurs near the Mariano Lake-Ruby Wells ore trend about 15 mi (24 km) north of the town of Thoreau, New Mexico (Figure 2, no. 4). The fold is about 7 mi (11 km) long and about 3 mi (4.8 km) wide; it has a closure of about 150 ft (46 m).

Northwest of Thoreau, along the Dakota outcrop, is a northwest-trending flexure called the Pinedale monocline (Figure 2, no. 3; Plate A). The monocline is folded down to the northeast and has about 700 ft (214 m) of structural relief.

Toward the northwest along the Dakota outcrop, the Pinedale monocline swings gradually from a northwest to a more west-northwest trend, parallel to regional dips on the Chaco slope, and then dies out into a series of northerly trending small anticlines and synclines (Plate A; Kirk and Zech, in press, a). One pair of these anticlines and synclines (labeled A and S on Figure 2), significantly larger than the other folds, has an amplitude of about 150 ft (46 m) and a wavelength of about 5 mi (8 km) (Kirk and Zech, in press, a). These folds are oriented north-northwest and extend from the Dakota outcrop northwest to the east end of the Church Rock orebodies, where they decrease in amplitude and merge into the regional dip of the Chaco slope.

Northwest of the Pinedale monocline is a small north-plunging anticline with local closure of about 50 ft (15 m) along the axis of the fold (Figure 2, no. 2; Plate A; Kirk and Zech, in press, b). This structure is referred to here as the Coyote Canyon anticline.

Near Gallup and north and south along the Dakota outcrop, the Nutria monocline (Figure 2, no. 1) forms the east flank of a large north-plunging syncline called the Gallup sag. About 4 mi (6.4 km) north of Gallup the monocline folds rocks down to the west a minimum of 3,000 ft (915 m). This large monocline probably is a result of draping of the sedimentary rocks over a basement fault zone. This fault zone may be one of the major bounding faults of the Zuni uplift (Edmonds, 1961).

Considerable evidence in the literature points to the existence of folds that were truncated by the pre-Dakota unconformity and that are therefore not apparent on the basal Dakota

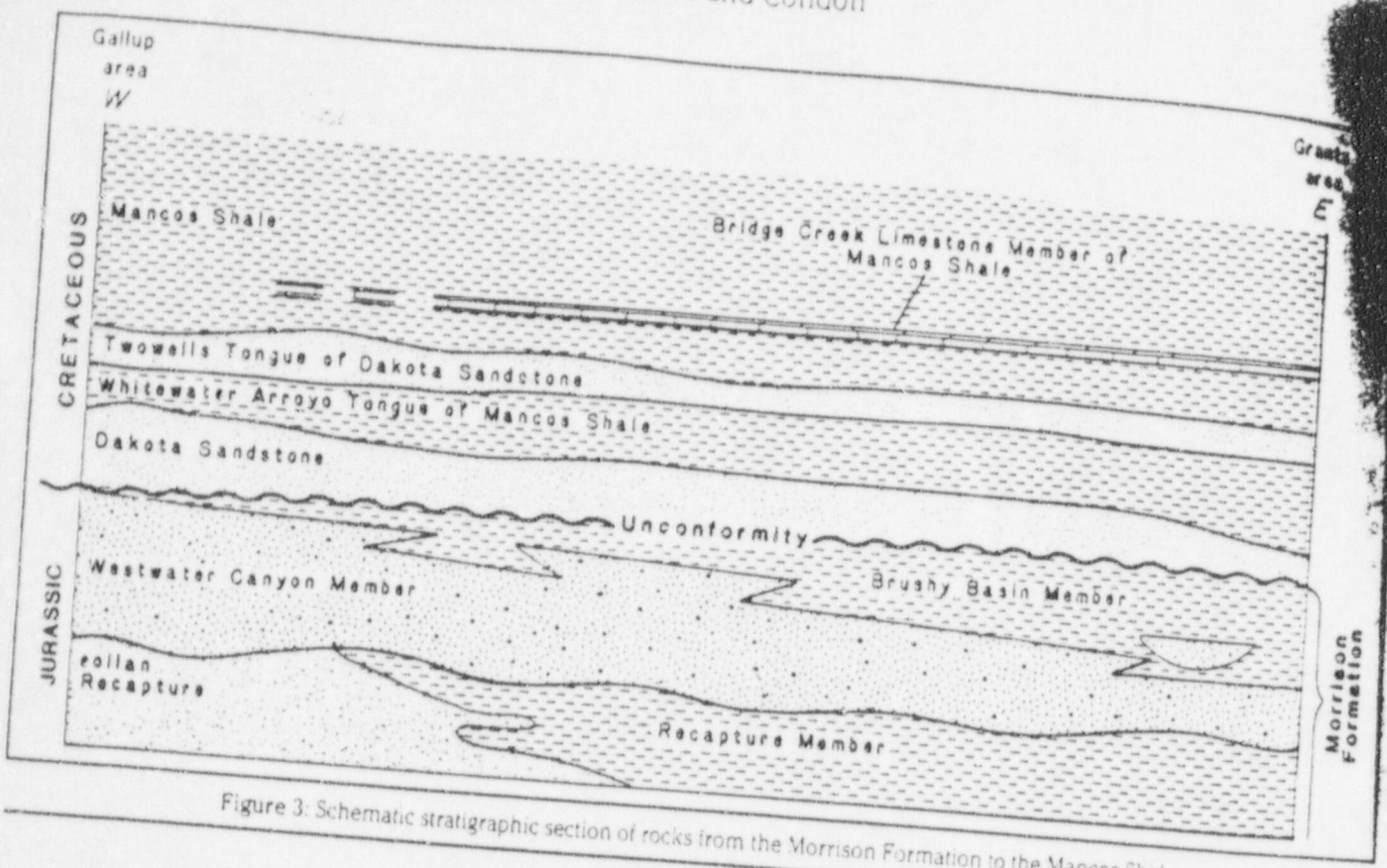

Figure 3. Schematic stratigraphic section of rocks from the Morrison Formation to the Mancos Shale.

structure contour map. We present evidence later to suggest that both pre-Dakota folds and faults do, in fact, exist and have been important in controlling Morrison depositional patterns. We also present evidence to show that some Laramide structures just discussed are reactivated older structures.

Additionally, some evidence suggests that deformation during the late Tertiary may have caused some local movement or readjustment along faults and may have been responsible for minor folding (Hilpert, 1969). The location of the Mount Taylor volcanic field along the zone of structural weakness associated with the San Rafael fault zone and the McCartys syncline suggests post-Laramide reactivation of Laramide structures.

Stratigraphy and Sedimentology

Within the San Juan basin, Pennsylvanian through Tertiary sedimentary units are exposed at the surface, and rocks of Cambrian, Devonian, and Mississippian age are known to exist in the subsurface (Hilpert, 1969). For the purposes of this subsurface study, only units of the Upper Jurassic Morrison Formation and the unconformably overlying lower part of the Upper Cretaceous Series were examined in detail.

General discussions of Upper Jurassic units may be found in papers by Craig et al. (1955), Harshbarger, Repenning, and Irwin (1957), Hilpert (1969), Santos (1970), O'Sullivan and Craig (1973), Green and Pierson (1977), Adams and Saucier (1981), and Condon and Peterson (this volume). Upper Cretaceous stratigraphy is summarized in reports by Sears, Hunt, and Hendricks (1941), Pike (1947), Beaumont, Dane, and Sears (1956), O'Sullivan et al. (1972), Peterson and Kirk (1977), and Molenaar (1977). These reports address some aspects of nomenclature, general stratigraphy, regional correlations, sedimentology, and environments of deposition. Stratigraphic units in and adjacent to the Morrison Formation and overlying Cretaceous units are depicted schematically on Figure 3 and are briefly discussed below.

Upper Jurassic Rocks

The Morrison Formation, named for exposures near Morrison, Colorado, consists of four formal members in the San Juan basin. The Recapture, Westwater Canyon, and Brushy Basin Members were named for exposures in southeastern Utah by Gregory (1938); subsequently, Rapaport, Hadfield, and Olson (1952) extended the terminology of these three members into the southern San Juan basin. The fourth and lowest member of the Morrison, the Salt Wash (Lupton, 1914; Gilluly and Reeside, 1928), was extended by Stokes (1944) into southeast Utah and was interpreted to be an equivalent of the lowermost Recapture beds in that area. The fluvial sandstone and mudstone beds of the Salt Wash Member crop out only in the north and northwestern part of the San Juan basin, and grade laterally into and intertongue with the Recapture Member as they thin to a depositional pinchout to the south (Craig et al., 1955; Harshbarger, Repenning, and Irwin, 1957; Condon and Peterson, this volume). The Salt Wash Member is not present at the outcrop or in the subsurface of the Chaco slope and is not discussed further. Two additional units are recognized in the Morrison Formation on the Chaco slope and are of interest because of their economic significance—the Jackpile sandstone, at the top of the Brushy Basin Member (Aubrey, this volume); and the Poison Canyon sandstone of economic usage, at the top of the Westwater Canyon Member (Turner-Peterson, this volume).

The Recapture Member (Figure 3) is the lowest member of the

Morrison Formation exposed at the outcrop and encountered in the subsurface of the study area. The Recapture predominantly comprises two facies, eolian and fluvial. The eolian facies consists of white, tan, and yellowish-gray, fine- to medium-grained, well-sorted, large-scale trough-crossbedded sandstone. It is best developed near Gallup, where it is about 300 ft (90 m) thick and intertongues with the fluvial facies of the Recapture. The eolian facies thins and pinches out in the subsurface a few miles northeast of Gallup (Kirk, Huffman, and Zech, this volume). This eolian sandstone unit has previously been called the Zuni, Cow Springs, and Bluff Sandstones. The origin, problems in nomenclature, and correlation of this unit are discussed by Condor and Peterson (this volume).

The fluvial facies of the Recapture Member consists of a complexly interbedded sequence of predominantly red and maroon (locally green, purple, and mottled red, green, and purple) mudstone interbedded with white, light-gray, and reddish-brown, fine- to medium-grained, moderately well sorted, lenticular, trough-crossbedded and ripple cross-laminated quartzose sandstone. Sediment transport directions have been reported as northeasterly (Craig et al., 1955; Saucier 1976). Much of the Recapture was deposited in a fluvial setting as fluvial channel-sandstone beds and abundant overbank mudstone. It is interbedded with eolian deposits of both dune and interdune playa origin and with minor thin, light-brown beds of lenticular lacustrine or playa limestone.

The Recapture has been recognized throughout all but the northeasternmost part of the San Juan basin and ranges in thickness from 0-500 ft (0-152 m) (Condon and Peterson, this volume). The fluvial facies of the Recapture thins to a depositional pinchout a few miles south of Grants (Hilpert, 1969; Santos, 1970; Maxwell, 1976). Around Laguna, just east of the study area, it is about 50 ft (15 m) thick, but it is locally absent where overlying channel sandstones of the Westwater Canyon have removed it by erosion (Moench and Schlee, 1967). Most of the drill holes used in this subsurface study bottom in the Recapture Member.

The contact between the Recapture and the overlying Westwater Canyon Member is commonly sharp: fluvial beds of the Westwater Canyon lie on scour surfaces cut into the Recapture Member, but the lithologies are often interbedded and have been mapped as intertonguing at the outcrop (Thaden, Santos, and Ostling, 1966; Thaden, Merrin, and Raup, 1967; Robertson, 1973, 1974; Green, 1976). These contact relationships show that, at least locally, the two members were deposited simultaneously, and no major erosional event is represented at the contact. Locally, in the southwestern part of the basin north of Gallup, the contact has been described as unconformable (Green and Jackson, 1975, 1976). Green (1980) has extended this unconformity eastward across the southern outcrop belt of the San Juan basin, but the unconformity could not be recognized on the geophysical logs used in this study.

The Westwater Canyon Member of the Morrison Formation (Figure 3) is a sequence of vertically stacked and laterally coalesced sandstone beds interbedded with thin, laterally discontinuous mudstone beds. Clay-clast conglomerate locally occurs along scours within the sandstone beds (Santos, 1970). The sandstone beds are pink to red, grayish green, and yellowish gray, fine to coarse grained, poorly sorted, feldspathic, and arkosic. In the southwestern part of the basin, Craig et al. (1955) recognized a conglomeratic facies in the Westwater Canyon. The sandstone beds are interbedded with minor to abundant red, green, or mottled (red, green, and purple) mudstone. Sedimentary structures in sandstone beds of the member include trough and tabular-planar crossbed sets, horizontal laminations, and ripple cross-stratification. Some beds are apparently structureless. Locally, the sandstone contains detrital plant debris. The Westwater Canyon Member was deposited by composite systems of moderate- to high-energy braided streams (Turner-Peterson, this volume). The braided character of the streams is recognized by the typical lack of fining-upward grain-size trends, by the types and sequence of sedimentary structures, by the tabular to lenticular geometry and stacking of sandstone beds, and by the minor amount of interbedded mudstone. Sediment transport directions in the Westwater Canyon Member in the southern part of the basin suggest multiple directions of transport; northeasterly directions of transport are most prominent in the lower part, and southeasterly components are more common in the middle and uppermost parts (Turner-Peterson et al., 1980). Further information on the Westwater Canyon may be found in papers by Adams and Saucier (1981) and Turner-Peterson (this volume).

The distribution of the Westwater Canyon Member has been delineated by Craig et al. (1955). It is present throughout most of the San Juan basin except in the area south and southwest of Gallup in the Gallup sag, where it has been removed by pre-Dakota erosion (Saucier, 1967; Condon, in press). The maximum thickness of the Westwater Canyon at the outcrop occurs about 30 mi (48 km) northwest of Gallup, near Todilto Park (Figure 1), where it is about 330 ft (100 m) thick and is conglomeratic (Craig et al., 1955; A. R. Kirk and A. C. Huffman, unpublished data, 1980; Turner-Peterson, this volume). However, thicknesses of more than 440 ft (134 m) occur in the subsurface about 17 mi (27 km) northeast of Gallup. The Westwater Canyon Member thins eastward to about 50 ft (15 m) and is locally absent near Laguna, just east of the study area. The Westwater Canyon has also been observed to thin to a depositional pinchout about 7 mi (11 km) south of Grants (Santos, 1970; Maxwell, 1976).

The Westwater Canyon Member is intertongued with the Brushy Basin Member on both a regional and a local scale. In this vertical zone of intertonguing, Brushy Basin mudstone beds that are interbedded with Westwater Canyon sandstone beds become thicker and have greater lateral continuity, making member contacts difficult to pick on geophysical logs in some areas.

The Poison Canyon sandstone of economic usage (Hilpert and Freeman, 1956) was an informal name given to the uppermost sandstone bed of the Westwater Canyon Member within the zone of intertonguing at the Poison Canyon mine (sec. 19, T. 13 N., R. 9 W.) in the Ambrosia Lake district. The name Poison Canyon sandstone, used indiscriminately by other workers rather than being restricted to the particular sandstone bed at the Poison Canyon mine, has also occasionally been used to denote any sandstone in the interfingering zone, or has been applied to the entire interval of intertonguing between the Westwater Canyon and Brushy Basin Members. Work by Santos (1970) showed that this particular sandstone bed at the Poison Canyon mine could not be correlated more than several miles from the mine itself. On the basis of numerous cross sections, our subsurface study indicates that individual sandstone beds in the zone of intertonguing are discontinuous and pinch

out laterally into mudstone or merge with the main body of the Westwater Canyon by eroding the intervening mudstone. We conclude that these sandstone beds cannot be correlated over significant distances with any degree of confidence—at least without data from extraordinarily dense drill-hole spacing. In fact, on a regional scale, with northeasterly thinning of the Westwater Canyon and concurrent thickening of the Brushy Basin Member, even the overall stratigraphic interval of this zone of intertonguing changes. Therefore, it is not correlative either stratigraphically or temporally with the zone of intertonguing elsewhere in the basin. Because our attempts to separate and correlate this zone of intertonguing as a distinct unit were unsuccessful, for this study we included sandstone beds in the zone of intertonguing with those of the underlying Westwater Canyon Member. Although we recognize that such a zone of intertonguing exists, we recommend that the use of the name Poison Canyon sandstone of economic usage be restricted to only the sandstone bed at the Poison Canyon mine.

The Brushy Basin Member of the Morrison Formation (Figure 3) consists predominantly of light-greenish-gray (locally mottled with red and purple), bentonitic and zeolitic claystone and mudstone; minor dark-green, fine-grained, well-sorted, silica-cemented, sheetlike sandstone beds; and white to tan and pinkish-gray, fine- to medium-grained, lenticular sandstone beds. The lenticular sandstone beds are locally conglomeratic and arkosic and commonly exhibit a fining-upward grain-size trend; they are poorly sorted to well sorted and generally contain small- to medium-scale trough-crossbeds. The Brushy Basin Member is interpreted to have been deposited in a fluvial and lacustrine-playa setting (Bell, this volume). The Brushy Basin is present throughout the San Juan basin in New Mexico except south of a line between Todilto Park and Gall[illegible]nd in another area south of Grants (Santos, 1970; Maxw[illegible]1976), where it was removed by erosion beneath the p[illegible]Dakota unconformity. The line of truncation near Gallup is s[illegible]on Plates A-M, to indicate that in the areas southwest of this [illegible]1) the Dakota Sandstone rests unconformably on the Westwater Canyon or Recapture Members and (2) the Westwater Canyon is incomplete. The computed rate of truncation, based on thinning of the Brushy Basin from northeast to southwest beneath the pre-Dakota unconformity, is about 10 ft/mi (1.8 m/km). The maximum thickness of the Brushy Basin in the San Juan basin is 372 ft (113 m) near Laguna (Freeman and Hilpert, 1956). Throughout the study area the Brushy Basin is unconformably overlain by the Dakota Sandstone; therefore, the total original thickness and the nature of the eroded upper part are unknown. The contact, then, between the Brushy Basin Member of the Morrison Formation and the overlying Upper Cretaceous Dakota Sandstone is a major regional unconformity with a considerable amount of local relief (as much as 120 ft or 36 m), produced by scour and removal of underlying material. In some areas a considerable amount of material was eroded beneath this surface, as Late Jurassic-Early Cretaceous deformation tilted the region to the northeast and pre-Dakota erosion cut down through successively older stratigraphic units southwestward across the San Juan basin.

East of the study area in the vicinity of Laguna, the Jackpile sandstone (Schlee and Moench, 1961; Moench and Schlee, 1967) occurs as a high-energy fluvial sandstone complex at the top of the Brushy Basin Member. The Jackpile has been preserved in the axis of a northeast-trending pre-Dakota syncline; it contains several large uranium deposits. This sandstone does not extend into the study area. The Jackpile is discussed extensively in papers by Hilpert (1969), Adams et al. (1978), Adams and Saucier (1981), and Aubrey (this volume).

Upper Cretaceous Rocks

Upper Cretaceous rocks were examined in this study in order to obtain stratigraphic control, to determine the nature of the pre-Dakota unconformity, and to provide a reliable datum for stratigraphic sections.

The main body of the Dakota Sandstone of early Late Cretaceous age (Figure 3) may be informally divided into lower and upper parts (Kirk, Huffman, and Zech, in press). The lower part is a nonmarine sequence of predominantly paludal shale and mudstone interbedded with white to light-gray, fine- to coarse-grained, locally conglomeratic fluvial sandstone beds and minor coal beds that were deposited in a delta-plain environment. Commonly, the lower contact with the Brushy Basin lies along a scour at the base of a Dakota fluvial sandstone bed, but locally the contact is shale on shale and is difficult to identify on geophysical logs. The upper part of the Dakota consists of a white to light-brown, fine- to coarse-grained, silica-cemented, coastal marine sandstone that locally contains stacked marginal-marine distributary channels. The contact with the overlying Whitewater Arroyo Tongue of the Mancos Shale is sharp but conformable.

The Twowells Tongue of the Dakota Sandstone (Figure 3) is a light-yellowish-brown, very-fine- to fine-grained, well-sorted calcareous sandstone that is locally fossiliferous at the top, where it contains the pelecypods *Pycnodonte newberryi* (Stanton) and *Exogyra* sp. The Twowells was deposited as an offshore marine sheet-sandstone bed. It has a sharp but conformable contact with the overlying Mancos Shale. Northeast of Thoreau (Figure 1), two additional offshore marine sandstone beds similar to the Twowells Tongue come into the section within the Whitewater Arroyo Tongue of the Mancos Shale (Landis, Dane, and Cobban, 1973). These were not examined in any detail in the subsurface and are not discussed further.

The Mancos Shale and the stratigraphically lower Whitewater Arroyo Tongue of the Mancos consist of dark-gray, interbedded claystone, mudstone, and very-fine-grained sandstone deposited in an offshore marine environment. The contact between the Whitewater Arroyo Tongue and the Twowells Tongue of the Dakota Sandstone is gradational and interbedded; grain size and bedding thickness gradually increase upward across the contact.

The Bridge Creek Limestone Member of the Mancos Shale (Hook, Cobban, and Landis, 1980; Hook and Cobban, 1981), formerly called the Greenhorn Limestone Member of the Mancos, consists of a series of interbedded thin limestones and limy shales in the lower part of the Mancos; the whole sequence was deposited in an offshore marine environment. It has been chosen for a datum because it approximates a time line throughout much of the San Juan basin; it contains fossils of the latest Cenomanian ammonite zone of *Sciponoceras gracile* (Shumard) and the earliest Turonian ammonite zone of *Neocardioceras juddii* (Hook and Cobban, 1981).

Younger Upper Cretaceous units were not studied in detail. The San Juan basin was the site of cyclic offshore marine, mar-

ginal marine, and nonmarine deposition during the remainder of the Late Cretaceous, when rocks of this age were deposited in response to several marine transgressive and regressive cycles of sedimentation in the epicontinental Western Interior seaway. Tertiary sediments, present elsewhere in the basin, have been removed by erosion within the study area.

Types of Uranium Ore Deposits

Uranium deposits in sandstone beds of the Morrison Formation can be divided into three basic types—primary ore, remnant ore, and redistributed ore. This subdivision is based on the geometry of the ore deposits, the genesis of the deposits or the ore-forming processes, and the position of the deposits with respect to a regional oxidation-reduction interface.

Discussions of mineralization may be found in reports by Hilpert and Moench (1960); Granger et al. (1961); Moench and Schlee (1967); Nash (1968); Hilpert (1969); Santos (1970); Squyres (1970); Adams et al. (1978); Turner-Peterson et al. (1980); Adams and Saucier (1981); Granger and Santos (this volume); Fishman and Reynolds (this volume); Turner-Peterson and Fishman (this volume); and Hansley (this volume). Descriptions of individual ore deposits are in two volumes published by the New Mexico Bureau of Mines and Mineral Resources (Kelley, 1963a; Rautman, 1980) and in reports by Adams et al. (1978); Granger and Santos (this volume); and Fishman and Reynolds (this volume).

Primary Ore

Primary ore deposits have been called prefault or trend-type deposits (Granger et al., 1961; Santos, 1970) and are considered to be the original form of ore deposition in the Grants uranium region. Primary deposits are elongate, tabular ore deposits that are aligned along a series of subparallel trends oriented about N70°–80°W (Santos, 1970). Mineralization trends such as those of the Ambrosia Lake area (Plate B) north of Grants range in width from 1,000-3,000 ft (305-915 m) and are as much as 9 mi (14 km) long (Adams and Saucier, 1981). Uranium mineralization is intimately associated with a pore-filling of organic-rich (kerogen or humate) cement in the host sandstones (Granger et al., 1961; Granger and Santos, this volume; Hatcher et al., this volume). Within ore trends, the humate-rich orebodies are laterally and vertically discontinuous and occur in various stacked ore horizons in the Westwater Canyon Member. In plan view (Plate B), individual stacked ore deposits are sinuous and cross one another within the overall trend.

Remnant Ore

Remnant ore deposits are relict parts of primary ore deposits that have been bypassed by a regional oxidation-reduction (redox) interface. They are now preserved as locally reduced sandstone orebodies updip from the redox interface in hematitically altered host rocks. Remnant deposits seem to owe their existence to some peculiar local property of the host rock or its geologic setting that enabled them to be preserved within surrounding oxidized rock. These peculiar aspects include (1) the relatively insoluble nature of the organic-rich ore associated with adjacent zones of high transmissivity that permitted bypassing of the oxidizing ground water (Smith and Peterson, 1980), (2) downdip stratigraphic pinchouts of the host sandstone that effectively lowered the transmissivity; (3) a stratigraphic pinchout of the host rock into mudstone in an updip direction before the host sandstone reaches the outcrop, thereby limiting the access of oxidizing ground water into the host sandstone; (4) effective blockage of oxidizing ground-water access by fault-bounded structures; or (5) the effect of cementation that locally reduced the transmissivity of the host sandstone and effectively isolated ore from oxidizing ground water.

In the case of the Mariano Lake-Ruby Wells remnant ore trend (Plate B), several of these characteristics exist, such as limited connection between the ore-bearing sandstone and main Westwater Canyon sandstone beds because of mudstone interbeds; pinchout of the host sandstone updip before reaching the outcrop, with no area of direct ground-water recharge; folding and faulting that may have slowed or deflected ground-water flow patterns; and local calcite cement associated with the ore.

Redistributed Ore

Redistributed ore deposits have been formed by modification of primary ore, mainly by oxidizing ground water that entered the host rock, dissolved the organic material, and redistributed the uranium down a hydrologic gradient. Two types of redistributed ore are recognized (Smith and Peterson, 1980)—redistributed fracture-controlled ore and redistributed geochemical-cell ore.

Redistributed fracture-controlled ore is the postfault or stack ore of Granger et al. (1961). In these deposits, the uranium-charged, oxidizing ground water moved down hydrologic gradients until it encountered clay-rich fracture systems or zones that altered the ground-water flow patterns and caused uranium precipitation along fracture zones as vertically stacked deposits lacking abundant organic material. Examples of this type of deposit are described by Granger et al. (1961), Gould et al. (1963), Smith and Peterson (1980), and Granger and Santos (this volume), from the Ambrosia Lake district north of Grants, and may be present in the Church Rock area northeast of Gallup (Adams and Saucier, 1981).

Redistributed geochemical-cell ore probably also results from the oxidation of primary orebodies, from which the uranium is redistributed by oxidizing ground water along a regional oxidation-reduction (redox) interface. An outline of the redox interface is shown on Plate B, and is reproduced for reference on Plate A and Plates C through M. The components of the regional redox interface consist of an area of hematitically altered sandstone (south of the southernmost boundary line, Plate B), an area of limonitically altered sandstone (between the north and south lines), and an area of regionally reduced sandstone north (downdip) of the northernmost line. The position of the redox interface is modified only slightly from Saucier (1980) and incorporates new data from A. E. Saucier (1982, written communication). Adams and Saucier (1981) have shown a large but weak tongue of limonitic alteration extending northward to encompass the Nose Rock deposits (Plate B). We have not included this change in our maps, because we have little subsurface data for that area. Hematitically oxidized and altered sandstone of the Westwater Canyon Member extends in a broad arcuate lobe northward downdip from the Morrison outcrop. This oxidation lobe extends northward from the outcrop about 17 mi (27 km) to a depth of about 2,600 ft (790 m) in the vicinity

of Standing Rock, New Mexico (Plate B). The position of the oxidation lobe is approximately symmetrical about the section of the Continental Divide that extends from northwest of Thoreau to just east of Crownpoint, New Mexico (Plate B; Saucier, 1980). The boundary between oxidized and reduced rock is not sharp in the subsurface, but is a zone of lateral and vertical intertonguing between hematitic, limonitic, and locally reduced sandstone (Saucier, 1980).

The Westwater Canyon Member north of the Zuni Mountains was exposed at the surface in the early Eocene, which enabled surface water to enter the rock and form an aquifer. Oxidizing ground-water recharge of this aquifer resulted in downdip or northward migration of the ground water toward a discharge area along the San Juan River. The hematitically altered sandstone zone is thought to have formed in the early Miocene to late Pliocene as a result of this downdip migration of oxidizing ground water (Saucier, 1980). The boundary between hematitic and limonitic sandstone probably represents the farthest downdip migration of the mid-Tertiary redox interface. This boundary is significant because the mid-Tertiary was the period when most of the primary ore deposits were remobilized. Also, most of the roll-type deposits are localized irregularly along the hematitic-limonitic boundary (Saucier, 1980). The limonitic alteration (probably late Pliocene to Holocene) postdates the hematitic alteration and resulted from modification of groundwater flow patterns that developed in topographically lower areas of Westwater Canyon discharge along the Rio Grande rift and southwest of Gallup along the Puerco River. Local structural control of the position of the redox interface is suggested by Saucier (1980) and is discussed below.

The geochemical-cell deposits have a C-shaped or roll-type geometry similar to that of Wyoming roll-type deposits (Harshman, 1972); the shape is determined by hydrologic flow patterns between confining shale layers. Saucier (1976, 1980) considered these deposits to be the result of destructive modification of primary-type ore by dissolving and dispersing preexisting deposits. In this regard they differ from Wyoming-type roll deposits, where the oxidation front is actively forming orebodies. In the Grants uranium region, uranium was being redistributed from primary deposits with a net loss of uranium from the geochemical system. That is, the deposits were not actively formed everywhere along the regional oxidation-reduction interface, but rather were reconstructed only downdip from preexisting primary deposits. Total transport of uranium was probably on the order of 1,000-3,000 ft (305–915 m) (Adams and Saucier, 1981).

Effect of Laramide Structure on Late Tertiary Oxidation and Localization of Redistributed Ore Deposits

Laramide structure was important in controlling both late Tertiary oxidation patterns within the Westwater Canyon Member and the localization of redistributed, geochemical-cell ore deposits. The location of the oxidation-reduction interface may be structurally controlled in a number of areas. Many of the large north- to northeast-trending fault zones apparently acted as zones of higher transmissivity. Oxidizing ground water was able to move farther downdip along these zones, to produce extended lobate tongues of oxidation along the leading edge of the oxidation front across the northern part of the study area (Plate A). These lobes are associated with the Bluewater, Big Draw, and San Mateo fault zones.

The Ambrosia fault zone has a similar lobate tongue at its north end, but it may have resulted from slightly different circumstances. The overall structure in the main Ambrosia Lake district is that of a horst block bounded on the west by the Ambrosia fault zone and on the east by the San Mateo fault zone (Santos, 1970). If recharge was in fact largely centered at the outcrop along the Continental Divide, ground water moving to the north and east may have encountered the Ambrosia fault zone, where its flow was slowed and largely diverted to the north. Limited recharge along the outcrop updip along this horst block and diverting effects of faults on ground-water flow patterns may be the reason for the limited penetration of the oxidizing ground water in the main Ambrosia Lake district (Plate B; Santos, 1970; Saucier, 1980). These factors may be largely responsible for preservation of primary deposits that have only been slightly modified and redistributed by oxidizing ground water.

The slight easterly skew to the lobate oxidation fronts associated with fault zones may be the result of very transmissive, thick, east-southeast-trending sandstone depocenters in the Westwater Canyon Member that acted as conduits for oxidizing ground water. Saucier (1980) suggested that ground-water flow along east-southeast-oriented transmissive zones may have destroyed uranium deposits between the Continental Divide and the Ambrosia Lake district and then transported uranium to enrich the primary ore deposits of the Ambrosia Lake district. He further suggested that, for this reason, ore grades of primary deposits in the Ambrosia Lake area may not be representative of primary deposits elsewhere in the basin.

Another example of structural control of the position of the redox interface is in the vicinity of the Church Rock deposits. Here, Saucier (1980) suggested that a fracture zone that trends northeast along the southeast side of the Church Rock deposits may have slowed the northwesterly flow of oxidizing ground water. It is the intersection of the Pipeline fracture zone with a northwesterly oriented set of fractures, he believed, that accounts for the northwesterly protruding lobe of oxidized sandstone along the northeast flank of the Church Rock orebodies. Although we have no serious argument with this hypothesis, we can suggest an alternative, namely that groundwater recharge south of the Church Rock area was restricted, and the flow was locally diverted to the northeast by the Pinedale monocline. This effectively limited the area and potential volume of recharge to the south and southwest of the Church Rock orebody. Furthermore, we think that downdip and to the north, the northwesterly flow of oxygenated ground water may have been controlled by the northwest-trending anticline-syncline pair (A and S, Figure 2) that split from the Pinedale monocline southeast of the Church Rock orebody. Farther to the northwest, ground-water flow may have continued to be directed north-northwest by the Coyote Canyon anticline at the northernmost end of the Church Rock orebody. Thus, ground-water recharge would be decreased to the south of the Church Rock orebody, and channeled flow of oxidizing ground water may have been diverted by structures to flow northwesterly east of the Church Rock Mine. The easternmost edge of the Church Rock orebody terminates along the eastdipping limb of the anticline, west of the northwest-trending syncline that we suggest channeled the ground-water flow (Plate A).

Another important control on the localization and form of the

regional redox interface is the position of the orebodies themselves. Saucier (1980) noted that the downdip migration of the interface is slowed in areas of preexisting ore, where organics and uranium deposits are oxidized before the interface migrates farther downdip. The result is that uranium deposits occur in reentrants along the regional redox interface (Plate B).

Preservation of remnant deposits in the Mariano Lake-Ruby Wells trend may have been affected by local structure. There, the east-southeast-trending doubly plunging anticline and syncline and an east-west-oriented fault in the synclinal axis southeast of the anticline (Plate A) may have slowed or diverted ground-water flow and protected the deposits (which are only locally altered by oxidation) from extensive alteration and destruction by regional oxidation processes. These deposits have been preserved by other factors as well, particularly by mudstone that encloses the sandstone that hosts the orebodies, and by the fact that they are in a sandstone tongue of Westwater Canyon that does not extend to the south far enough to reach the outcrop. This sandstone is, therefore, only connected with the main body of the Westwater Canyon to the north in the subsurface, where it scours out the intervening mudstone, and it has no direct connection to the surface for oxygenated groundwater recharge.

Regional Distribution of Ore Deposit Types

Because the formation of redistributed ore deposits and the preservation of remnant deposits are related to the alteration and modification of primary ore, many ore deposits exhibit characteristics of more than one type. However, in order to simplify our discussion of the relationships between facies distribution, stratigraphic parameters, and deposit types, we have shown the deposits as the three fundamental types—primary, remnant, and redistributed. These are shown in plan view on Plate B; sources for these data include Kelley (1963a), Hilpert (1969), Santos (1963), Rautman (1980), Adams and Saucier (1981), and various company mining and milling plans. Plan views of individual ore deposits differ in quality and accuracy. In general, we determined the type of deposit by its position with respect to the regional redox interface (Plate B). Redistributed deposits are inferred to occur along the regional redox interface; remnant deposits occur updip (south) of the interface; and primary deposits occur mainly downdip (north) of the interface. We recognize this as somewhat of an oversimplification in light of the mixed characteristics of ore deposits.

For example, the Crownpoint ore trend lies along the regional redox interface in an elongated trend parallel to the N70°–80°W orientation of ore deposits in the main Ambrosia Lake area. Ore from Crownpoint has been characterized as containing minor amounts of primary ore that has been extensively altered by oxidation (Wentworth, Porter, and Jensen, 1980); thus, Crownpoint ore represents a mixture of deposit types. Other mixed deposits have been described from the Ambrosia Lake district (Granger et al., 1961; Gould et al., 1963; Smith and Peterson, 1980) and the Mount Taylor area (Adams and Saucier, 1981). Thus, it is with caution that we present the simplified deposit-type map on Plate B.

The outlines of ore deposits are included on Plate A and Plates C through M; this overprinting lets the reader compare maps of various stratigraphic parameters with the distribution of ore. Specific property names and deposit type designations are shown by McCammon et al. (this volume).

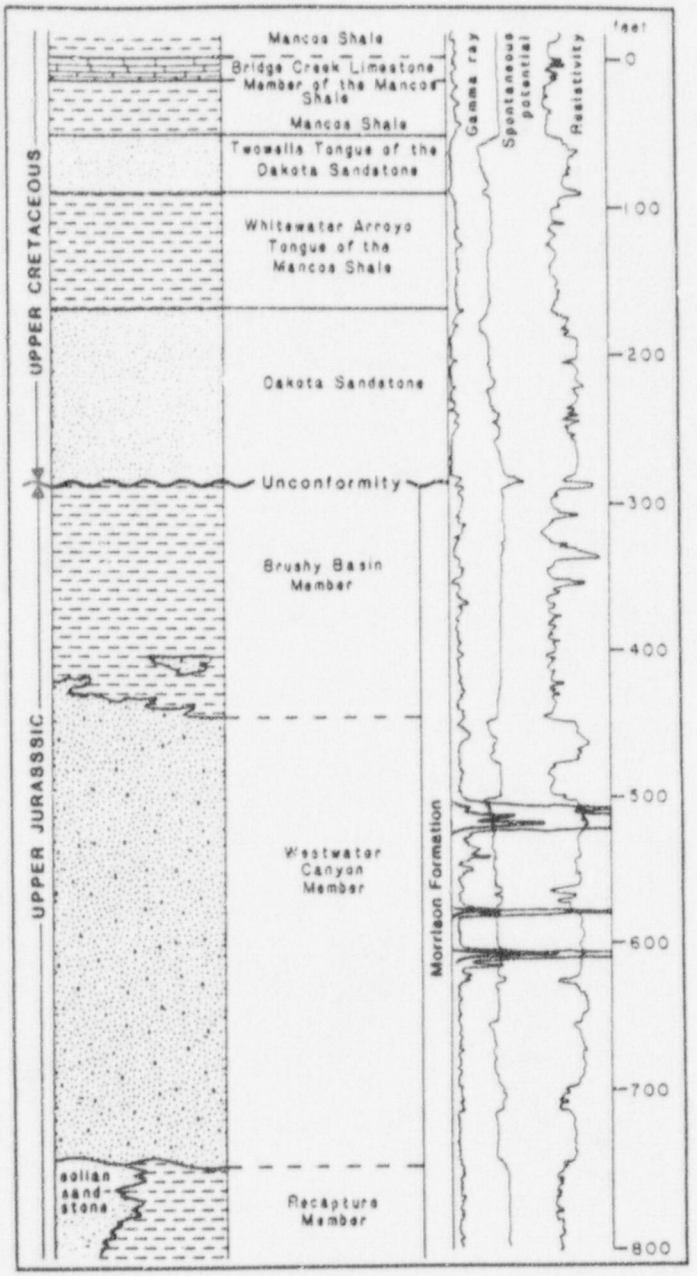

Figure 4: Representative geophysical log showing the stratigraphic interval from the Recapture Member of the Morrison Formation to the Mancos Shale, and mineralized zones (shown by high gamma-ray readings) in the Westwater Canyon Member.

Structural Control of Sedimentation Patterns and the Distribution of Ore Deposits

Data and Methods Used in Map Preparation

Data for this study came from approximately 1,800 geophysical logs of uranium and oil and gas exploration drill holes and from more than 100 measured sections, obtained mainly from the literature. The geophysical log files of 23 companies were examined and drill holes were selected for study. Geophysical logs for most holes consisted of four-track logs that included depth, natural gamma-ray, spontaneous potential, and single-point resistance logs. Figure 4 includes a typical geophysical log

showing our picks of formation and member contacts and also showing a mineralized part of the stratigraphic section. About 20% of the drill holes studied also had a lithologic log, and 12 cores were examined in detail both for lithology and correlation with geophysical-log responses. A few drill holes had a greater variety of geophysical logs; most of these were oil exploration drill holes and holes drilled by the U.S. Geological Survey that are discussed by Kirk, Huffman, and Zech (this volume).

Information collected from each drill hole consisted of general location data, types and quality of logs, surface elevation, depths to tops of formations and members, total hole depth, total amount of sandstone and total amount of mudstone for each member of the Morrison Formation, zones of mineralization, color of sandstone and mudstone beds in the Westwater Canyon Member, unusual mineralogy (pyrite, magnetite), and comments. Computer storage of data permitted easy computation of new variables from the data and allowed us to plot data points before hand contouring. These data form a major part of the data base used for a resource appraisal study of the Westwater Canyon Member (McCammon et al., this volume).

Data from each drill hole location were plotted by computer at a preselected scale and map projection. Data points were hand-contoured using a literal interpolation of contour spacing (each interval measured and plotted) between all adjacent points (Condon, 1980), and then connecting the contour data points into lines. No data points were violated in the contouring, and very little curve smoothing was needed to produce the contour maps presented here (Plates D-L). On each map a few data points had to be discarded because of unreasonable values that probably resulted from errors introduced during collection or encoding of the original data. Contour intervals were selected to give a reasonable line density on the final map.

Because much of the information is proprietary, company data and drill-hole locations cannot be reproduced here. However, contours of drill-hole density, shown on Plate C, give some estimate of degree of control. We determined drill-hole density by overlaying a 1 mi^2 (2.6 km^2) grid on a base map of drill-hole locations and summing the number of drill holes in all adjacent squares at the grid intersections; grid intersection values were then contoured. Note that the contour lines are drawn on half-values (.5, 2.5, 4.5, etc.). It was necessary to contour the grid intersections in this manner because large areas of the map have exactly the same number of drill holes. In effect, the contour lines separate areas of whole numbers that represent numbers of drill holes. For example, areas on the map between contour lines 2.5 and 4.5 contain either 3 or 4 drill holes.

Geophysical Log Characteristics of Stratigraphic Units and Geologic Contacts

The geophysical log shown as Figure 4 is useful in determining the lithology of stratigraphic units in the borehole. The natural gamma-ray log records gamma radiation from uranium- and thorium-series isotopes and radiation from potassium-40. In the Grants uranium region, this log responds to essentially two things, the relative clay content of the rock as reflected by changes in concentration of potassium-40 between units, and the presence of uranium-enriched zones. The effect of thorium-series isotopes is thought to be negligible (Scott, this volume). Thus, the gamma-ray log can also be used to estimate the thickness and grade of uranium mineralization.

The electric logs measure spontaneous potential and resistivity. Spontaneous potential is a measurement of the natural electric potential between a downhole probe and a surface ground electrode; resistivity is a measurement of the electrical resistance between the electrode on the probe and a surface ground electrode. These logs are related to lithologic properties of the rocks in the borehole, because they are sensitive to differences in porosity, permeability, and clay mineral content. For example, if the log of a clay-rich mudstone unit is compared with that of an adjacent sandstone unit, the mudstone shows decreased resistivity (owing to the large number of cations that aid conductivity), and spontaneous potential commonly becomes more positive. Gamma-ray logs should also become more positive, responding to higher potassium-40 values in the clays. These same effects can be noted in logs of sandstone bodies with increasing clay contents upward, for example, fining-upward grain-size trends. The electric log responses of the units examined in this subsurface study are briefly described here.

Recapture Member (Morrison Formation)

The eolian sandstone facies of the Recapture Member of the Morrison Formation typically shows very low natural gamma-ray values (very little clay content) and moderate spontaneous potential and resistivity values. No grain-size trend is apparent in the unit. The fluvial facies of the Recapture is predominantly thin sandstone beds and mudstone, and shows irregular but low gamma-ray values, relatively high spontaneous potential values, and low resistance values. Where sandstone beds are present in the fluvial facies, they are typically encased in mudstone, rest on a sharp lower contact (scour surface), are thin, and show fining-upward grain-size trends. As shown on Figure 4, the contact with the overlying Westwater Canyon Member is generally sharp, with sandstone of the Westwater Canyon resting on erosional surfaces that scour into the underlying Recapture.

Westwater Canyon Member (Morrison Formation)

The Westwater Canyon Member of the Morrison Formation typically has low gamma-ray values where unmineralized. Spontaneous potential and resistivity curves have a "blocky" shape, which indicates low clay content and high permeability. The beds locally show a coarsening-upward grain-size trend but generally show no distinctive grain-size trend. Sandstone beds are typically stacked one on top of the other and are separated by sharp (scour) bases. Locally, these sandstones are separated by thin mudstone or clay-clast conglomerate beds that resemble a typical shale in having moderate and irregular gamma-ray, high spontaneous-potential, and low resistivity responses.

Brushy Basin Member (Morrison Formation)

The Brushy Basin Member of the Morrison Formation is mostly mudstone with moderately high gamma-ray, moderately high spontaneous potential, and low resistivity log values. Beds of sandstone, where present, typically show sharp (scour) bases and fining-upward grain size. In the zone of intertonguing with the Westwater Canyon Member, mudstone units at the top of the Westwater Canyon may be fairly thick, and in places a distinct contact may be difficult to define on geophysical logs. However, in general, even in zones of intertonguing, Westwater Canyon sandstone beds maintain their distinctive geophysical log characteristics and are distinguishable from sandstone beds

in the Brushy Basin. Those in the Brushy Basin tend to have sharp bases, are suspended in mudstone, and exhibit fining-upward textural trends. Despite these distinctions, the contact in the zone of intertonguing had to be arbitrarily picked in some places.

Dakota Sandstone and Mancos Shale

The Dakota Sandstone rests unconformably on the Brushy Basin Member. Typically, the contact is sandstone on mudstone and is not difficult to pick. However, locally the contact is shale on mudstone, and errors in picking the contact were undoubtedly made where sample logs or cores were not available. Gamma-gamma density logs, which measure the apparent density of the rock, were useful in separating the carbonaceous shale and coal of the Dakota from the mudstone and claystone of the Brushy Basin, but these logs were not available for most holes (Kirk, Huffman, and Zech, in press). The lower part of the Dakota is typically interbedded sandstone, shale, and coal; the upper part is a thick sandstone sequence. On the geophysical log shown as Figure 4, the base of the Dakota Sandstone is picked below a coal bed showing high spontaneous potential, high resistivity, and moderate to low gamma-ray values.

Shale of the Whitewater Arroyo Tongue of the Mancos Shale, as well as the rest of the Mancos Shale, shows low to intermediate gamma-ray, high spontaneous potential, and low resistivity values.

The Twowells Tongue of the Dakota Sandstone has a gradational contact with the underlying Whitewater Arroyo Tongue of the Mancos Shale, a coarsening-upward textural trend, and a sharp upper contact with the overlying Mancos Shale. These characteristics are indicated on the geophysical logs by the inverted-bell shape of the spontaneous potential and resistance curves, and the decrease in gamma-ray values upward through the unit.

Thin interbedded limestone beds in the calcareous shale of the Bridge Creek Limestone Member of the Mancos Shale typically show three or four sharp resistivity and gamma-ray peaks.

Subsurface Parameters

Several subsurface stratigraphic parameters of the Westwater Canyon and Brushy Basin Members have been contoured from the drill-hole data. The maps constructed from these data show distinct patterns of lithofacies distribution of the members that can also be shown to correlate with areas that are favorable for the deposition of primary and redistributed ore deposits and the preservation of remnant ore deposits. Subsurface parameters measured or computed from measured values for the Westwater Canyon Member or Brushy Basin Member or both are as follows—structure contours, isopach, sandstone:mudstone ratio, percent sandstone, net sandstone, number of alternations between sandstone and mudstone per 100 ft (30 m) of section, total combined thickness of the Brushy Basin and Westwater Canyon Members, and paleotopographic reconstruction. An additional result of this study is the inference of actively rising Jurassic structures (Plate M). Each discussion of the following contour maps relates that particular parameter to Plate M, and the accumulated evidence for the actively rising structures is discussed below.

We have used the term actively rising structure to denote a sense of relative movement. Actually, we believe that the entire Morrison depositional area was subsiding, as seems apparent from its continued ability to accumulate sediments. However, some areas (to which we apply the term actively rising structures) were subsiding at a lower rate than adjacent areas that were actively downwarped.

The line shown on Plates A through M as the line of truncation of the Brushy Basin by pre-Dakota erosion is important. Southwest of this line, pre-Dakota erosion has removed part of the underlying Westwater Canyon Member, and values of all contoured parameters of the Westwater Canyon in that area should be considered only approximate because the Westwater Canyon section is incomplete.

Isopach Map of the Westwater Canyon Member

The isopach map of the Westwater Canyon Member (Plate D) was found to be most useful in understanding the overall depositional system. On this map the Westwater Canyon Member ranges in thickness from a maximum of 440 ft (134 m) about 17 mi (27 km) northeast of Gallup to less than 80 ft (24 m) northwest of Mount Taylor. An overall thinning can be observed from west to east across the map as the Westwater Canyon fluvial system changes from extensive, laterally coalesced and vertically stacked sandstone units in the west to isolated sandstone beds interbedded with more mudstone to the east. These relationships have been observed in outcrop studies by Campbell (1976) and Galloway (1980). Overall depositional thinning of the Westwater Canyon can also be observed from north to south across the map area. This depositional thinning of units onto the flanks of the Zuni uplift and thinning to a depositional pinchout about 7 mi (11 km) southeast of Grants strongly suggests a positive structure in the ancestral Zuni uplift area that resulted in the depositional pinchout of the Recapture and Westwater Canyon Members. This evidence of structural movement lends further support to the idea of a Late Jurassic deformational event that is suggested by pre-Dakota folds elsewhere on the Chaco slope. Episodic upwarping in the ancestral Zuni uplift may also explain the shifts in fluvial transport directions during deposition of the Westwater Canyon and Brushy Basin Members (Turner-Peterson, this volume).

Both Hilpert (1969) and Santos (1970) constructed geologic cross sections across McCartys arch and Ambrosia dome. These geologic sections and isopach maps show dramatic thinning of the Westwater Canyon over these structures. However, Santos (1970) showed that the thinning was due to intertonguing of a red mudstone unit with the base of the Westwater Canyon Member. He also showed on a geologic section, using the base of the Dakota Sandstone as a datum, that individual mudstone and sandstone beds were not folded over the dome before Dakota deposition and that this structure probably did not indicate a pre-Dakota fold. However, we now think that Westwater Canyon mudstone deposition over the dome (while thick sandstone deposits were accumulating in adjacent areas) and depositional thinning of the overlying Brushy Basin Member (Plate I) over the dome indicate that this structure was actively rising both during Westwater Canyon and Brushy Basin deposition. This structure may also have deflected major channel systems of the Westwater Canyon around the dome into depocenter axes and permitted only fine-grained overbank sediments to be deposited over the topographically elevated crest of the dome.

Over the entire map area (Plate D) there is a series of strongly oriented east-southeast-trending isopach thicks alternating

with east-southeast-trending isopach thins. This general orientation of isopachs was reported in more regional subsurface studies by Galloway (1980) and Saucier (1976). Because of the regional eastward and southward thinning of the Westwater Canyon, trends are defined by areas of relative isopach thickness compared with adjacent areas. For example, thick trends in the northwest part of the map area are considered to be greater than 320 ft (98 m) in thickness, whereas, in the southeast part of the map area, thick trends are only on the order of 200 ft (61 m) or more in thickness.

The thick isopach trends are here considered to be depocenter axes or axes along which relatively thick sections of Westwater Canyon sediments accumulated. We prefer the term depocenters to fluvial channels because without specific knowledge of subsurface sediment transport directions it cannot be assumed that these axes are thick individual or stacked channel sequences with flow in any particular direction (here, to the southeast). There could be a variety of other reasons for orientation of depocenter thicks that are not related to sediment transport directions, such as paleotopography, scour at the base of sandstone units, or structural control of depocenter axes (Peterson, 1984).

When compared with the other parameter maps of sandstone:mudstone ratio, net sandstone, and percent sandstone, a few areas on the map suggest consistently thick buildups of sand in the same geographic position oriented east-southeast for almost the entire period of Westwater Canyon deposition. These areas commonly show facies changes to the north and south to thinner and less sandy, laterally equivalent units. In these instances the facies distribution may indicate a stacking of channel sequences. Although many local examples of possible channel-stacking exist, the best examples may be the thick depocenter about 17 mi (27 km) north of Gallup, or the main depocenter axis through the Ambrosia Lake ore deposits in the southeastern part of the map area (Plate D). However, these relationships do not hold true for the entire map area, as might be expected with the complex stacking of sandstones in the braided stream systems of the Westwater Canyon. Having made note of some possible exceptions, we will continue to use the term depocenter axes for isopach thicks.

The location of depocenter axes suggests two prominent areas of sediment accumulation in the study area. One is in the vicinity of Todilto Park (Figure 1), where the Westwater Canyon is thicker (330 ft or 100 m) than anywhere else on the outcrop belt. There, the Westwater Canyon is also extremely conglomeratic; cobble-size clasts are common (Craig et al., 1955; A. R. Kirk and A. C. Huffman, unpublished data, 1980; Turner-Peterson, this volume). This depocenter axis probably passes through Todilto Park and continues south of the town of Tohatchi to join up with the isopach thick southeast of Tohatchi (Plate D). A second area of apparently large sediment accumulation is suggested by two depocenter axes north of Gallup (Plate D) near the north end of the Gallup sag (Figure 2). These areas of large volumes of sediment accumulation have been recognized by earlier workers from both surface (Craig et al., 1955; Saucier, 1976; and Turner-Peterson, this volume) and subsurface studies (Galloway, 1980). Crossbedding studies indicate that sediment input was from the west and southwest (A. R. Kirk and A. C. Huffman, unpublished data, 1980; Turner-Peterson, this volume), which suggests that these areas of thick sandstone accumulation were depocenters near the points of sediment input.

We should also point out here that regional distribution of subsurface parameters (Plates D-K) suggests that the Westwater Canyon Member at the outcrop is anomalous with respect to its characteristics in the subsurface. For example, on the isopach map (Plate D) the outcrop of the Westwater Canyon is delineated by the end of contours along the southern boundary of the map. As can be seen from the isopach values, the Westwater Canyon is anomalously thin along the outcrop belt.

Comparison of the paleostructure map (Plate M) with the Westwater Canyon isopach map (Plate D) shows that all areas of inferred actively rising structures are coincident with areas of anomalously thin deposits of the Westwater Canyon (Table 1). Isopach thicks are everywhere coincident with depocenter axes shown on Plate M. However, there are more depocenter axes than those defined by isopach thickness alone. Plate M shows that depocenter axes correlate well with the known distribution of all types of ore deposits.

The relationships of isopach thickness to the distribution of ore deposits can be seen on Plate D. In general, the distribution of primary and redistributed ore deposits occurs within or immediately adjacent to isopach thicks (Table 2). This is particularly obvious in the main Ambrosia Lake area, but it is also true elsewhere in the map area. Other workers have noted this relationship in isopach studies of individual mines (Wentworth, Porter, and Jensen, 1980; Fitch, 1980) and in more regional studies of larger areas (Santos, 1970; Galloway, 1980). Remnant deposits do not seem to be related to isopach thicks; however, remnant deposits in the Mariano Lake-Ruby Wells trend occur in an isolated upper sandstone tongue of the Westwater Canyon Member. This sandstone may need to be contoured independently to determine the local relationship between ore distribution and isopach thickness.

Sandstone:Mudstone Ratio Map of the Westwater Canyon Member

The sandstone:mudstone ratio map of the Westwater Canyon Member (Plate E) also shows many features of the overall Westwater Canyon depositional system. Sandstone:mudstone values ranged from about 1.6 to about 300 in the Westwater Canyon Member. Values larger than 30 (a large sandstone:mudstone ratio) were arbitrarily assigned a value of 30 for purposes of contouring. A zone of relatively low values of the ratio (≤ 4) crosses the central part of the western third of the map area (Plate E). This area coincides with a rather thick zone of the Westwater Canyon. Both the isopach thick and the relatively low sandstone:mudstone values result from addition of sandstones interbedded with mudstone at the top of the Westwater Canyon in the zone of intertonguing with the Brushy Basin.

The contoured sandstone:mudstone values exhibit a well-developed east-southeast trend. Many of the areas of high sandstone:mudstone values coincide with areas of isopach thicks—for example, in the areas of high sediment accumulation on the west side of the study area, southeast of Tohatchi and in the vicinity of the Gallup sag. In general, areas associated with inferred actively rising structures have low sandstone:mudstone values when compared with areas flanking these structures (Table 1).

Primary ore deposits are mainly associated with zones of high sandstone:mudstone values, but locally in the Ambrosia Lake area, sandstone:mudstone values are variable (Plate E; Table

Table 1: Relationship of inferred actively rising Jurassic structures to contoured subsurface parameters. [—, no correlation of contoured parameter to Jurassic structure]

	Westwater Canyon Member (Jmw)						Brushy Basin Member (Jmb)			
Positive Jurassic Structures	Paleoto-pography	Isopach	Sandstone: Mudstone Ratio	Net Sand-stone	Mudstone Interbeds per 100 ft (30 m)	Percent Sandstone	Isopach	Net Sand-stone	Total Thickness (Jmw + Jmb)	Laramide Structure
Church Rock	High	Thin	Mostly low (mixed)	Low	3-5	Mostly low	Thin	—	Thin	—
Dalton Pass	High	Thin	—	Low	3	Moderate	Moderate	Low	Thin	—
Bluewater	High	Thin	—	Low	2-3	Low	—	Low	Thin	Flat area
Borrego Pass	High	Thin	Low	Low	3-4	Low	Variable to thick	Low	Thin	Big Draw fault
West Largo	High	Thin	High	Moderate	3-4	Moderate	Variable to thick	Low	Thin	—
Ambrosia Dome	High	Thin	Low	Low	4-5	Low	Thin	—	Thin	Dome
Ambrosia North	High	Thin	Low	Low	4-5	Low to high	Variable	Low	Thin	—
McCarty Arch	High	Thin	Low	Low	6-7	—	Thick	High	Thin	Anticline

Table 2: Relationship of types of ore deposits to contoured subsurface parameters of the Westwater Canyon Member of the Morrison Formation
[—, no correlation of contoured parameter to ore.]

	Contoured Subsurface Parameters					
Ore Type	Isopach	Sandstone: Mudstone Ratio	Net Sandstone	Mudstone Interbeds per 100 ft (30 m)	Percent Sandstone	Depocenter
Primary	Thick	Mostly > 10	High	< 30	> 80	On thick axes
Remnant	—	Mostly > 10	Variable	< 3	> 85	On axes
Redistributed	Thick	Low but variable	Variable	Mostly < 3	Low but variable	On thick axes

2). Remnant ore deposits are clearly associated with zones of high sandstone:mudstone values (> 10) (Plate E). Redistributed ore seems to be generally associated with zones of lower sandstone:mudstone values (< 6), but the values are mixed. The Crownpoint ore trend appears to be, at least in part, a primary ore deposit that has been partly altered by Tertiary oxidation (Wentworth, Porter, and Jensen, 1980), which may explain the occurrence of ore in a zone of mixed values of sandstone:mudstone ratio.

The occurrence of primary ore in zones of both isopach thicks and high sandstone:mudstone values may be related to zones of high transmissivity, which may have played an important role in deposition of the organic-rich humate material that is intimately associated with primary ore. On the other hand, lower sandstone:mudstone values may indicate a reduction in the transmissivity of ground-water flow by the addition of mudstone to the stratigraphic section, so as to slow the advance of oxidizing ground-water tongues that are associated with redistributed ore deposits.

Percent Sandstone Map of the Westwater Canyon Member

The percent sandstone map of the Westwater Canyon Member (Plate F) provides a measure of sandstone content that is independent of total isopach thickness. This map shows the effect of overall depositional thinning from west to east, and aids in precise location of depocenter axes with high sandstone content. As on the other maps, axes of percent sandstone deposition exhibit an east-southeast orientation. The two areas of high sediment accumulation on the west side of the study area are also areas having a high percentage of sandstone. The inferred actively rising structures (Plate M), with the exception of Dalton Pass, West Largo and McCartys Arch, are all associated with low values of percent sandstone (Table 1), whereas depocenter axes tend to be associated with higher values of percent sandstone (Plate F).

Primary and remnant ore deposits are associated with high values of percent sandstone (> 80 %) (Table 2), which is again perhaps related to a necessity to have a thick sand conduit for the deposition of organic-rich humate bodies that are associated with these types of deposits. The main Ambrosia Lake district ore, the ore of the Mariano Lake-Ruby Wells trend, and the Crownpoint orebodies are all concentrated along depocenter axes that trend parallel to the ore deposits (Plate M). Santos (1970) compiled both an isopach and a percent sandstone map for the main Ambrosia Lake area; his results also indicate the association of primary ore with both isopach thicks (> 200 ft or 61 m) and high values of percent sandstone (> 80 %). Redistributed ore deposits tend to be in areas with lower percent sandstone values, and again this may be the result of their deposition in zones of decreased transmissivity that effectively retard the movement of oxidizing ground water.

Net Sandstone Map of the Westwater Canyon Member

The net sandstone map of the Westwater Canyon Member (Plate G) clearly shows the decrease in sandstone content in the Westwater Canyon from west to east. Values in the west tend to be on the order of greater than 280 ft (85 m) of sandstone and thin to values of less than 160 ft (49 m) at the east end of the study area. East-southeast-trending sandstone depocenters are also present on this map, and the two areas of high sediment accumulation on the west side of the study area are also areas with high net sandstone values. All of the inferred actively rising structures except West Largo are associated with low net sandstone values (Table 1), whereas many depocenter axes contain high net sandstone values.

Primary ore deposits in the main Ambrosia Lake area are associated with an east-southeast-trending net sandstone depocenter. However, other ore deposits seem to occur mainly in zones with variable net sandstone (Table 2).

Map Showing Number of Mudstone Interbeds per 100 Feet (30 Meters) in the Westwater Canyon Member

The number of alternations between sandstone and mudstone per 100 ft (30 m) of section in the Westwater Canyon Member (Plate H) is essentially a measure of the number of mudstone interbeds in the section. These data are useful when compared with the sandstone:mudstone ratio map. For example, if an area has a low sandstone:mudstone ratio, the number of mudstone interbeds reveals whether this low value is due to a large number of thin interbeds or to a few thick interbeds. This subsurface parameter should affect the transmissivity of the interval. In general, fewer mudstone interbeds occur in the northwestern part of the study area (Plate H); a greater number occur in the central and eastern parts. The strongly developed east-southeast trends, evident on other maps, are not obvious.

The areas of large volume of sediment accumulation along the west side of the study area show only a few mudstone interbeds. However, despite low sandstone:mudstone values over the inferred actively rising structures, the number of mudstone interbeds shows no consistent pattern with respect to the structures (Table 1). Major depocenter axes generally have very few mudstone interbeds.

Primary and remnant ore deposits are associated largely with areas having fewer than three mudstone interbeds per 100 ft (30 m) (Table 2), probably again related to major sand depocenter axes (Plate M). Many of the redistributed ore deposits are also associated with areas having fewer than three mudstone

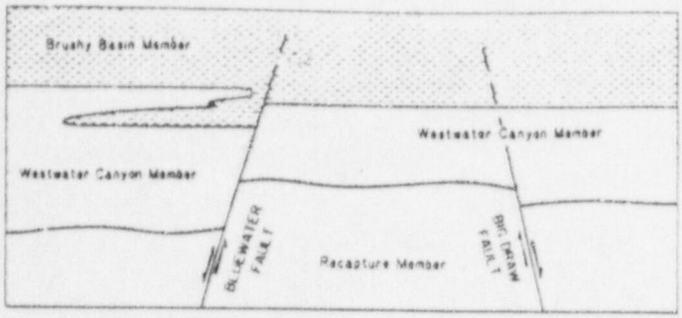

Figure 5: Diagrammatic sketch of possible fault movement during the Late Jurassic along the Bluewater and Big Draw fault zones. Faults dashed where inferred; arrows show direction of movement; no scale.

interbeds per 100 ft (30 m) (Table 2). The Church Rock and Dalton Pass ore deposits are exceptions, and the number of mudstone interbeds in these areas may be quite variable. This relationship of generally few mudstone interbeds locally associated with redistributed ore is somewhat surprising. We constructed this map to see if a large number of mudstone interbeds in the Westwater Canyon might produce an area of lower transmissivity and therefore slow the flow of oxidizing ground water and control localization of redistributed ore. This does not seem to be the case. Although most redistributed deposits are associated with low sandstone:mudstone values, these low values are apparently the result of a few thick mudstone interbeds.

Isopach Map of the Brushy Basin Member

The isopach map of the Brushy Basin Member (Plate I) shows (1) the effect of regional truncation of the member beneath the pre-Dakota erosion surface and (2) depositional thinning from north to south toward the Zuni uplift. We computed an approximate rate of truncation of the Brushy Basin beneath the pre-Dakota unconformity to be about 10 ft/mi (1.9 m/km), with truncation proceeding from the east-northeast toward the west-southwest. The line of truncation of the Brushy Basin is shown at the west end of the map area (Plate I). The irregular shape of the line of truncation, with a downdip lobe or arch north of Gallup in the vicinity of the present Nutria monocline (Figure 2; Plate A) and a slight reentrant in the Gallup sag area, is consistent with pre-Dakota downwarping in the Gallup sag and uplift along the Nutria monocline. However, this evidence is only circumstantial—conclusions about structural activity in this area are at best speculative.

The Brushy Basin Member is distinctly thinner over some of the inferred actively rising structures, such as the Ambrosia dome and the Church Rock structures (Table 1), but it is variable over many others. This lack of correlation may be the result of the effect of pre-Dakota truncation, resulting in an incomplete section of Brushy Basin being preserved under the unconformity, or it may suggest that some of the structures were inactive during Brushy Basin deposition. There is no apparent correlation between isopach values of the Brushy Basin Member and the distribution of ore deposits.

Net Sandstone Map of the Brushy Basin Member

The net sandstone map of the Brushy Basin Member (Plate J) shows only two distinctive trends. One is an essentially east-west sandstone thick just north of the outcrop in the central part of the map area, and the other is an almost due-north trend north of the town of Thoreau. This north-trending sandstone depocenter is interesting in that it is aligned almost exactly with the present position of the Bluewater fault zone (Plate A).

We examined the other stratigraphic parameter maps and found the following relationships in the area between the Bluewater and Big Draw fault zones: (1) a prominent isopach thick (Plate D) in the Westwater Canyon west of the Bluewater fault zone ends against this structure, and the unit is generally thinner to the east; (2) net sandstone values of the Westwater Canyon also decrease across this fault zone (Plate G); (3) percent sandstone (Plate F) and sandstone:mudstone ratios (Plate E) are relatively high, again suggesting a thinner but relatively sandy Westwater Canyon between the two fault zones; (4) the Brushy Basin isopach values (Plate I) increase significantly between these structures; (5) a distinct north-south-oriented net sandstone depocenter occurs in the Brushy Basin on the west side of the Bluewater fault zone (Plate J); (6) a paleotopographic low area lies west of the fault zone at the base of the Westwater Canyon Member (Plate L)—this was also seen on a structure contour map on the base of the Westwater Canyon Member (unpublished data); and (7) depocenter axes (Plate M) are difficult to trace eastward from the Bluewater fault zone, particularly in the northern part of the study area.

The above factors could be explained by movement, during Morrison deposition, along the ancestral Bluewater and Big Draw fault zones (as shown in Figure 5). Depositional patterns are also reasonably consistent with simple downfaulting to the west along the Bluewater fault zone only. In either case, movement would seem to have been down to the west along the Bluewater fault, and the movement must have been contemporaneous with deposition of both the Westwater Canyon and Brushy Basin to produce the observed facies changes. If this pre-Dakota fault existed and was downthrown to the west, it is interesting that movement on the fault was opposite from that of the reactivated fault during Laramide deformation (down to east, Figure 2, no. 5; Plate A).

All inferred actively rising structures are associated with areas of low net sandstone in the Brushy Basin Member (Table 1); however, there is no correlation between net sandstone in the Brushy Basin and the distribution of ore deposits, except in the Mariano Lake-Ruby Wells trends. There remnant ore deposits are in upper Westwater Canyon sandstone beds that intertongue with the overlying Brushy Basin, and it is noteworthy that Brushy Basin sandstone depocenters are aligned both with depocenter axes in the underlying Westwater Canyon and with ore deposits.

Total Thickness Map of the Westwater Canyon and Brushy Basin Members

A map of the combined thickness of the Westwater Canyon and Brushy Basin Members (Plate K) shows regional depositional thinning to the south across the study area and thinning to the southwest due to pre-Dakota truncation. East-southeast-oriented depocenter axes are also apparent on this map. Except over the east end of the Dalton Pass feature (Plate M), all combined thicknesses are anomalously thin over the inferred actively rising structures (Table 1). Any relationship between the trends of member thickness and distribution of ore deposits can probably be related more closely to thickness changes in the Westwater Canyon (Plate D) than to total thickness.

Paleotopographic Reconstruction

We constructed a paleotopographic map of the base of the Westwater Canyon in order to examine paleotopographic high and low areas for evidence (1) that preexisting topography might have been structurally controlled, (2) that the structural control continued during deposition of the Westwater Canyon and Brushy Basin Members, and (3) that structural control influenced facies distribution and thickness of these members.

The paleotopographic map (Plate L) was constructed in several stages. The isopach map of the interval comprising the combined thickness of the Westwater Canyon and Brushy Basin Members was constructed first (Plate K). An adjustment was then made (see Appendix) to remove irregularities on the upper surface of the isopach interval that were due to sedimentologic processes such as deep fluvial scours or paleovalleys at the base of the Dakota Sandstone. A correction for compaction was not made. The values for the combined Westwater Canyon and Brushy Basin isopach were then subtracted from the plane formed by the base of the Dakota Sandstone and those values were then contoured. The contours were renumbered so that they could be referred to an arbitrary datum surface rather than to the isopach interval.

The resulting map is a structure contour map (unpublished data) depicting the configuration of the base of the Westwater Canyon at the beginning of deposition of the Dakota Sandstone in the earliest Late Cretaceous. It is interpreted to show the approximate location of topographic and structural highs and lows at the beginning of deposition of the Westwater Canyon, based on the assumption that some topographic highs were coincident with structural highs. Possible structural tilt to the northeast and east-northeast that occurred during the latest Early Cretaceous is apparent on the structure contour map of the base of the Westwater Canyon (unpublished data) and amounts to about 1/4°. Another correction was made to rotate out this regional dip and to produce the paleotopographic map (Plate L). Local folding that may have occurred during the latest Jurassic through Early Cretaceous could not be determined, but it is thought to be minimal and not to have produced significant folds.

Another possible interpretation of the 1/4° slope to the east-northeast is that it was the result of a depositional slope or gradient. If this is the case, then these gradients reach a maximum of 22 ft/mile (4.2 m/km), on a regional scale, and average about 11 ft/mile (2 m/km). These gradients seem quite reasonable for braided stream systems (Schumm, 1977), and the slope direction is compatible with Recapture current-direction indicators (Craig et al., 1955) and with lowermost current directions in the Westwater Canyon Member according to Turner-Peterson et al. (1980).

We do not have the data to resolve the issue of whether this slope to the northeast developed as a depositional slope or formed postdepositionally by structural uplift. Perhaps both hypotheses are correct and both processes operated over time with changing depositional slopes and structural dips. In fact, a combination of these processes may account for the mixed southeasterly and northeasterly sediment transport directions reported in the Morrison Formation (Turner-Peterson, this volume).

The paleotopographic reconstruction (Plate L) shows several interesting features. There is a distinct east-southeast alignment of paleotopographic trends, including a large east-southeast paleotopographic low area extending through the center of the study area. The main Ambrosia Lake area is associated with a topographic low, as are the Church Rock deposits, and the two areas of high sediment accumulation along the west side of the study area, one southeast of Tohatchi and the other in the vicinity of the Gallup sag. Also, the two structures that led us to examine the relationship of paleotopographic features and active structures, Ambrosia dome and McCartys arch, were paleotopographic high areas.

Map of Inferred Actively Rising Structures and Depocenters

Examining the paleotopographic reconstruction, we reasoned that hills and valleys could be produced by several processes. For example, hills could either have been structurally controlled and have been actively rising structures (in which case, continued movement during sedimentation should have affected overlying sedimentary units) or they could simply have been paleotopographic hills produced by contemporaneous erosion (and should have become buried through time with continued deposition). In the latter case, the effect of the paleotopography should have decreased during late Westwater Canyon deposition and certainly should not have affected Brushy Basin deposition. Paleotopographic lows, on the other hand, could have been actively subsiding structures; or they could have been valleys produced by scours at the base of the Westwater Canyon Member that resulted from progradation of the high-energy fluvial system of the Westwater Canyon over the Recapture. We thought we had a better chance to explain the actively rising structures than to document the negative topographic features, and, therefore, we examined all the subsurface parameter maps for effects on sedimentation patterns over the positive paleotopographic areas.

The positive paleotopographic features (Plate M) can be shown to have affected the overlying units of the Brushy Basin and Westwater Canyon Members in the following ways (Table 1): isopach values are low over these structures relative to those of adjacent areas (Brushy Basin is locally variable); sandstone:mudstone, net sandstone, and percent sandstone values are low relative to those of adjacent areas; and the number of mudstone beds (alternations) per 100 ft (30 m) tends to be greater. In addition, the total thickness of the combined Westwater Canyon and Brushy Basin Members is low over all the inferred actively rising structures.

Sandstone depocenter axes, shown on Plate M, were defined by overlaying the various subsurface parameter maps and defining zones or trends in the Westwater Canyon Member that were consistently very thick and very sandy, with high values of net sandstone, percent sandstone, and sandstone:mudstone, and with very few mudstone interbeds. The coincidence of ore deposits with these depocenter axes is quite clear on Plate M.

Structural Control of Depocenter Axes as Indicated from Seismic Studies

Negative paleotopographic features at the base of the Westwater Canyon Member and localization of depocenter axes were difficult to evaluate because they could be produced by several mechanisms—they could reflect true paleotopography, the effect of which should become muted as the landscape is

eroded and buried with time; they could be the result of scour at the base of the Westwater Canyon Member as the high-energy fluvial system prograded over the unconsolidated Recapture Member; or they could be the result of actively subsiding structures.

A recent seismic study over the Church Rock ore deposits (Phelps, Zech, and Huffman, this volume) indicates that the position of the east-southeast-oriented Westwater Canyon depocenter there is controlled by a graben. Faults that bound the graben were active in the Precambrian but were reactivated during the deposition of the Westwater Canyon. Results of that study are briefly presented here; the location of the study area is shown on Figure 1. Figure 6 shows the location of seismic lines over the study area, the individual shot points on the seismic line, and a series of faults detected during the seismic study. The interpretation by Phelps, Zech, and Huffman (this volume) is that of a graben bounded by east-southeast-oriented faults that showed offset on the Precambrian basement on the order of 230 ft (70 m), and offset on the Middle Jurassic Todilto Limestone Member of the Wanakah Formation and basal part of the Westwater Canyon Member of the Morrison Formation on the order of 80 ft (24 m). Only one of the faults affected the overlying Upper Cretaceous rocks. The study documents Precambrian fault zones that are oriented east-southeast and that were reactivated several times, probably once in the Paleozoic; once again during deposition of the Morrison Formation; and at least one fault was reactivated again after deposition of the Dakota Sandstone. The coincidence of this graben with an east-southeast trend along a depocenter axis (Plate M) in the Westwater Canyon Member led us to examine the distribution of contoured stratigraphic parameters with respect to the graben. Figures 7 and 8 are small areas of Plates D and G that overlie the Church Rock ore deposits and that show a compelling spatial relationship between isopach thicks and anomalously high net sandstone values within the graben.

The cross section on Figure 9 uses the base of the Dakota Sandstone as a datum. It shows the faults located by the seismic study, the graben just discussed, and the lithologies in the underlying combined Brushy Basin and Westwater Canyon Members, as well as a paleotopographic profile from the same line of section. The cross section shows the effects of the graben on the combined Brushy Basin and Westwater Canyon isopach thickness, the relative amounts of sandstone and mudstone in the combined members, and the configuration of the paleotopographic profile. These relationships indicate that, at least in the Church Rock mine area, depocenter axes can be related to actively subsiding structures that controlled the orientation of the depocenter axes and the characteristics of the facies deposited along the axes. Because depositional patterns and sediment characteristics are similar along other depocenter axes, one can at least speculate that other depocenter axes were also structurally controlled.

Summary of Structural Control of Sedimentation and the Distribution of Ore Deposits

Evidence of structural control on sedimentation patterns of the Morrison Formation has been examined, using a paleotopographic reconstruction of the base of the Westwater Canyon Member, combined with the results of the seismic study by Phelps, Zech, and Huffman (this volume), to define areas of Late Jurassic structural activity.

Positive structures appear to be elongate domes or east-southeast-oriented, discontinuous, broad, low-amplitude, doubly plunging anticlinal folds that may have resulted from movement transmitted vertically through the overlying sedimentary rock sequence by upthrown edges or corners of fault-bounded basement blocks. Sediment distribution in the Morrison Formation over these actively rising structures shows isopach thins, low sandstone:mudstone ratios, low net sandstone values, and low percent sandstone in the Westwater Canyon Member; and low net sandstone and local isopach thins in the overlying Brushy Basin Member of the Morrison Formation. For the most part these actively rising structures did not affect overlying Upper Cretaceous rocks, and the structures are truncated along the pre-Dakota erosion surface. Ambrosia dome and McCartys arch are exceptions that apparently were reactivated during Laramide deformation and appear as anticlinal or domal structures on basal Dakota structure contour maps.

The various subsurface sedimentologic contour maps show many subparallel depocenter axes (Plate M) that are distinctly elongate along east-southeast trends. These depocenter trends may have developed (1) from downwarping or subsidence adjacent to active positive structures that were diverting the fluvial channels of the Westwater Canyon; (2) as a true fold system developing in a horizontal stress field; or, (3) as shown from seismic studies in the Church Rock area, as structurally controlled depositional features produced by reactivation of basement structures to produce east-southeast-oriented grabens that localized the depocenter axes.

All primary uranium ore deposits in the Westwater Canyon Member of the Morrison Formation in the Ambrosia Lake district are spatially related to these depocenter axes (Plate M), and ore trends of N70°–80°W are coincident with the orientation of depocenter axes and a prominent Precambrian structural trend (Kelley, 1955; Saucier, 1976). Additionally, remnant ore in the Mariano Lake-Ruby Wells trend and ore in the Crownpoint trend that is apparently extensively altered and remobilized primary ore are developed in or adjacent to the thickest part of the Westwater Canyon Member along depocenter axes that are probably structurally controlled. These ore deposits are spatially associated with organic-rich kerogen or humate bodies (although humate is only locally present at Crownpoint) that are frequently stacked vertically as elongate, locally sinuous deposits (Saucier, 1976) within depocenter axes. The association of ore with depocenter axes suggests that thick buildups of highly transmissive, clean sandstone with very little interbedded mudstone may be conducive to, and possibly a requirement for, primary ore deposition or preservation. Recent radiometric dating of deposits (Brookins, 1980; Ludwig, Simmons, and Webster, 1983) suggests that primary deposits formed shortly after deposition of the host sediments. This would be the optimum time for leaching of uranium from contemporaneously deposited or interbedded volcanic material, and for mobilizing humic material derived from degradation of organic material. It is also likely that the most efficient groundwater movement of these materials would occur along depocenter axes that were the most transmissive conduits in sandstone bodies already present in structurally low trends. Precipitation or flocculation of the humates might then occur

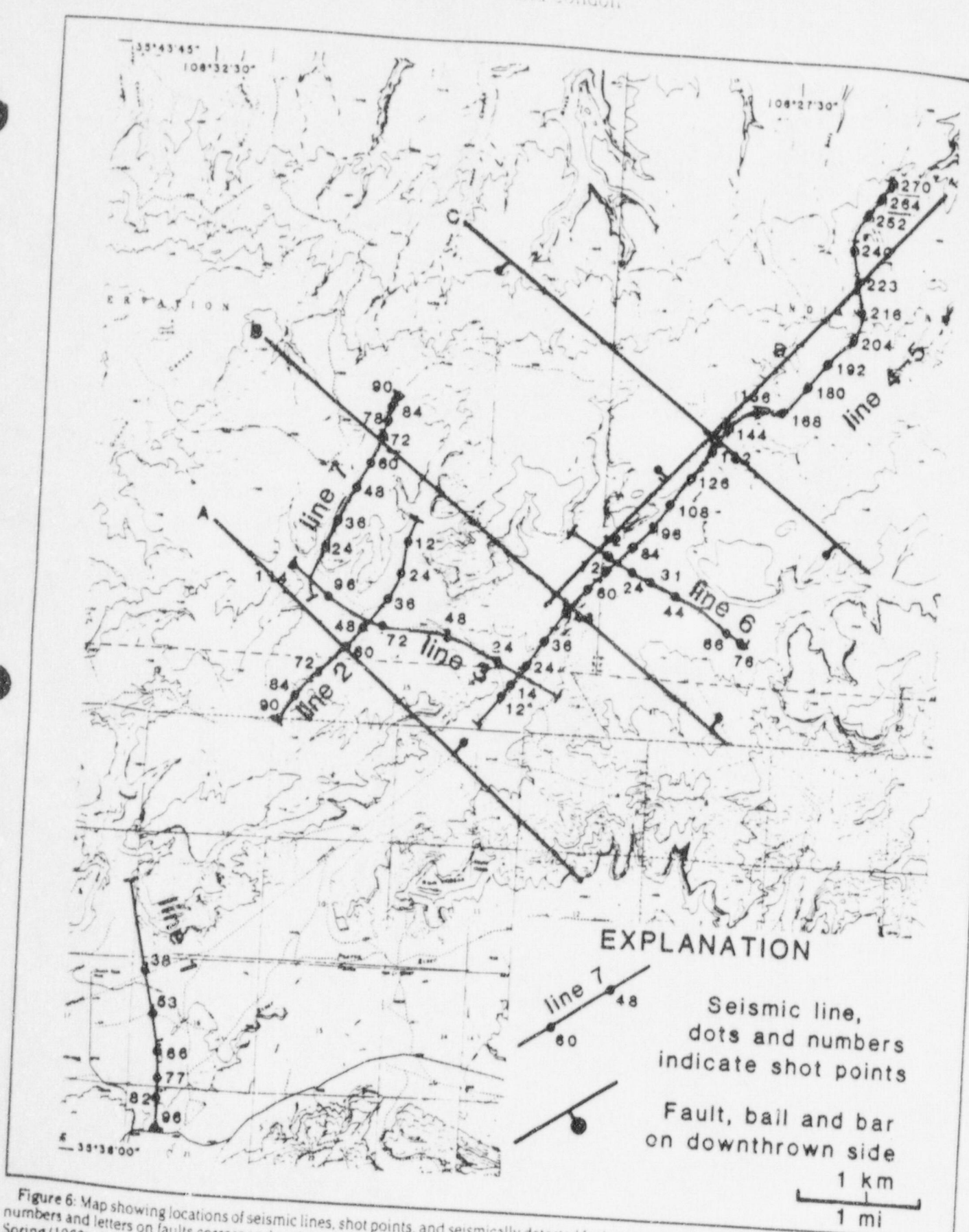

Figure 6: Map showing locations of seismic lines, shot points, and seismically detected faults in the vicinity of the Church Rock ore deposits. Line numbers and letters on faults correspond to those shown by Phelps, Zech, and Huffman (this volume). Base from Hard Ground Flats (1963), Oak Spring (1963), Church Rock (1963), and Pinedale (1963) 1:24,000 quadrangles.

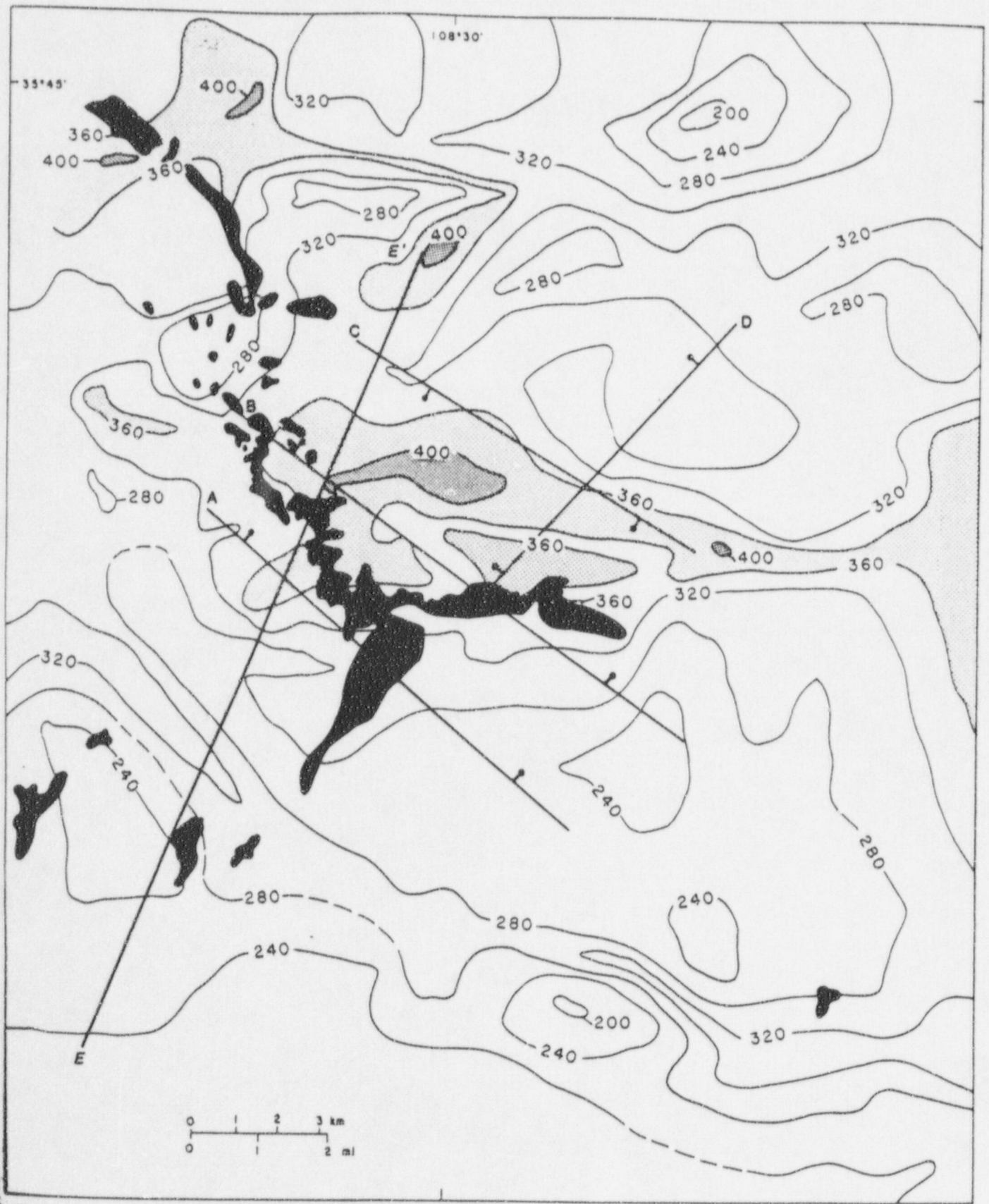

Figure 7: Seismically detected fault traces and Westwater Canyon isopach values (in feet) in the vicinity of the Church Rock ore deposits (ore shown in black). See Figure 1 for location of seismic study area. Contour interval 40 ft (12 m). Contours dashed where uncertain. Line E—E′ shown on Figure 9.

igure 8: Seismically detected fault traces and Westwater Canyon net sandstone values (in feet) in the vicinity of the Church Rock ore deposits shown in black). See Figure 1 for location of seismic study area. Contour interval 40 ft (12 m). Line E—E' shown on Figure 9.

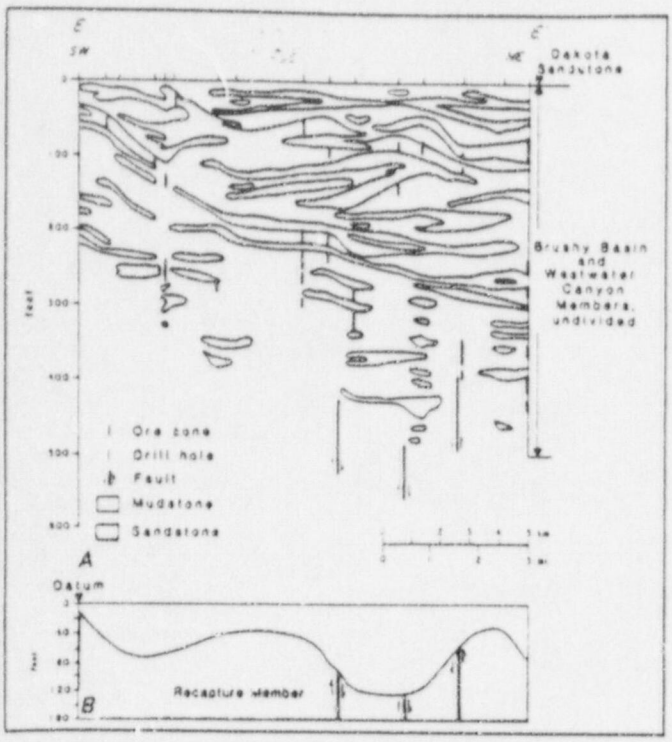

Figure 9: Cross section and paleotopographic profile, Church Rock mine area. See Plate B for location of Church Rock ore deposits. A. Cross section constructed from drill-hole data along line E—E' of Figures 7, 8, 8. Paleotopographic profile, base of Westwater Canyon Member (top of Recapture Member), constructed from data on Plate L. Graben referred to in text is shown on right side of profile.

with changes of salinity down the hydrologic flow paths (Galloway, 1980); or at a solution interface lower in the fluvial system, perhaps localized and controlled by alkaline ground water of the lacustrine-related ground-water tables of the Brushy Basin in the zone of intertonguing with the Westwater Canyon (Bell, this volume). The humates that flocculated and precipitated as tabular humate bodies then extracted and concentrated uranium from the ground water. Ground water continued to transport uranium through and past the humate bodies, enriching the deposits and possibly modifying their shape (Squyres, 1980) into the elongate tabular masses parallel to and within the depocenter axes.

Remnant deposits probably formed originally as primary deposits; they occur in areas with sedimentologic parameters similar to those of primary deposits. However, these deposits have been preserved in regionally oxidized ground as remnants behind the redox front by various processes or circumstances such as (1) intertonguing of sandstone with mudstone that isolates an individual ore-bearing sandstone bed from the main sandstone body, thereby limiting access for oxidizing ground-water recharge; (2) the position of the ore within sandstone beds that do not extend to the surface and therefore have no direct area of recharge for oxidizing ground water; (3) calcite cementing of host rocks, which reduces transmissivity and deflects the flow of oxidizing ground water around the orebodies; and (4) folding or faulting that deflects the flow around the ore deposit or slows the flow of oxidizing ground water across the orebody.

The distribution of redistributed uranium deposits seems to correspond to the distribution of subsurface stratigraphic parameters of large isopach thickness, low sandstone:mudstone ratios, and low percent sandstone. These attributes are characteristic of zones of low transmissivity that may slow downdip migration of oxidizing ground water and aid in the formation of a redistributed geochemical-cell deposit. However, a much greater control on localization of these redistributed ore deposits is the position of the regional oxidation-reduction interface itself (Plate B). The formation of this interface and its position have, in turn, been guided or controlled in large part by Laramide structures. The Laramide orogeny arched the ancestral Zuni uplift during the latest Cretaceous to early Tertiary, and subsequent erosion permitted ground-water recharge of the Westwater Canyon by oxidizing solutions. Laramide structures also controlled the local position of the oxidation-reduction interface by diverting and deflecting ground-water flow around folds and by facilitating fault-controlled channeling of oxidizing ground-water flow. Localization of the redox interface was also controlled by the ore deposits themselves. Because they are difficult to oxidize and move, they tend to trail behind the leading edge of the oxidation front as updip reentrants along the interface.

We have shown that syndepositional deformation in the Late Jurassic controlled, to a great extent, the distribution of sedimentary facies in the Westwater Canyon and Brushy Basin Members of the Morrison Formation and that, in turn, the distribution of these facies largely controlled the localization of primary ore deposits. Redistributed ore, although locally controlled by sedimentary facies, is largely controlled by Laramide structures and subsequent erosion that resulted in a middle to late Tertiary oxidation event, during which oxidized ground water entered the Westwater Canyon and redistributed uranium from preexisting primary deposits.

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Appendix

Correction Factor for Paleotopographic Map Reconstruction

Beginning with the structure contour map at the base of the Dakota Sandstone (Plate A), all the known Laramide structure

was removed from the erosion surface by unfolding and unfaulting the surface and then by rotating out the regional dip to produce a horizontal plane at the base of the Dakota. This was accomplished by assuming a constant fixed elevation for the base of the Dakota Sandstone. The combined thickness of the Westwater Canyon and Brushy Basin Members was then subtracted from this fixed elevation and the resultant elevations were contoured. This procedure effectively produced a structure contour map constructed on the base of the Westwater Canyon Member (unpublished data).

We recognized that, in the construction of the paleotopographic map at the base of the Westwater Canyon Member, some correction factor was needed to compensate for material removed along the pre-Dakota erosion surface. We therefore corrected by isopaching the thickness of the interval from the top of the Twowells Tongue of the Dakota Sandstone to the base of the main body of the Dakota Sandstone, making a minor correction for relatively constant southwesterly thinning of the intervening Whitewater Arroyo Tongue of the Mancos Shale. Once this isopach map was produced, we assumed that all differences in thickness of the interval between the top of the Twowells Tongue and the base of the Dakota were the result of relief on the pre-Dakota erosion surface. This assumption seems reasonable in that the top of the offshore marine bar environment of the Twowells Tongue is a relatively flat surface that maintains an almost constant stratigraphic distance from the overlying Bridge Creek Limestone Member of the Mancos Shale, which is known to be an approximate time line (Hook and Cobban, 1981). An arbitrary datum was then passed through the pre-Dakota erosion surface at the thinnest point on the isopached interval between the top of the Twowells Tongue and the base of the Dakota Sandstone. We assumed the thickness of material represented by Dakota Sandstone thickness below this new datum to represent material originally from the Brushy Basin Member that had been removed by pre-Dakota erosion. We observed local relief along this surface to be as much as 120 ft (36 m) within 1 mi (1.6 km), but values of about 30-50 ft (9-15 m) were much more common. We added this amount of material to the Brushy Basin isopach thickness and constructed a new structure contour map at the base of the Westwater Canyon Member (unpublished data).

This structure contour map indicated that the base of the Westwater Canyon, at the time of introduction of Westwater Canyon sediments into the basin, still had a slight regional slope to the northeast and east-northeast. Even this small amount of regional dip over the long map distances masked the effect of local relief on the dipping surface. We therefore rotated out this regional dip as well and contoured the map relative to an arbitrary datum to produce the paleotopographic reconstruction (Plate L). We recognize that, despite our attempts to correct for the effect of pre-Dakota erosion, we may not be as accurate as we would like to be. However, we also recognize that some correction was necessary and are certain that we have introduced no significant new errors in this graphical reconstruction. The actual values of most corrections were on the order of 20-30 ft (6-9 m); however, in some areas where there appeared to be significant erosion by northeast-trending pre-Dakota channels, the correction was on the order of 120 ft (36 m). Locally, on the structure contour map of the base of the Dakota Sandstone, these pre-Dakota channels appear to be folds. However, when compared with structure contours constructed on the top of the Twowells Tongue of the Dakota Sandstone, the same channeled areas show no apparent folding. This seeming paradox can only be explained by relief on the pre-Dakota erosion surface.

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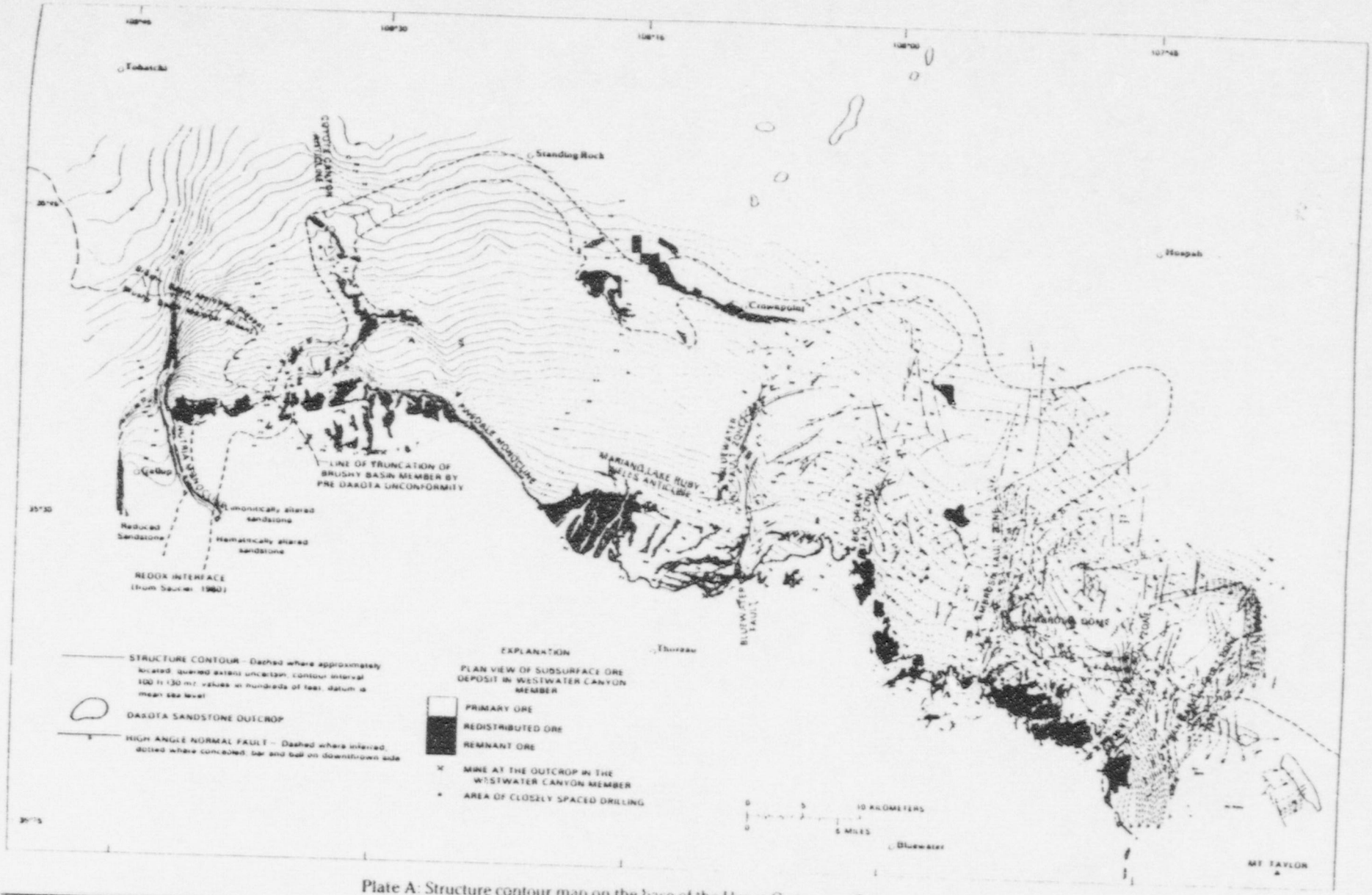

Plate A: Structure contour map on the base of the Upper Cretaceous Dakota Sandstone

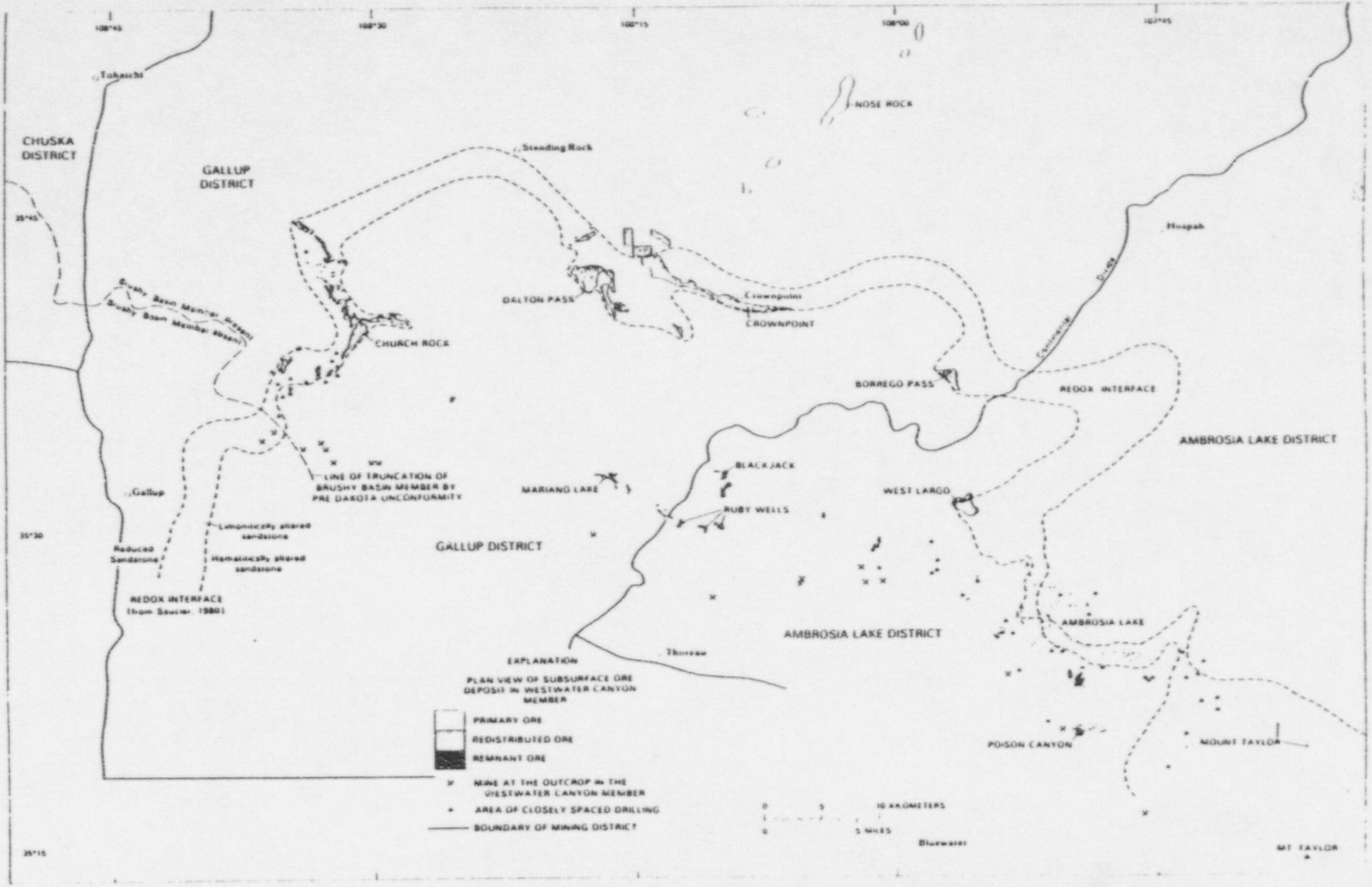

Plate B: Map showing groups of ore deposits and deposit types, mining districts, and the regional oxidation-reduction interface.

Plate C: Map of drill-hole density.

Kirk and Condon

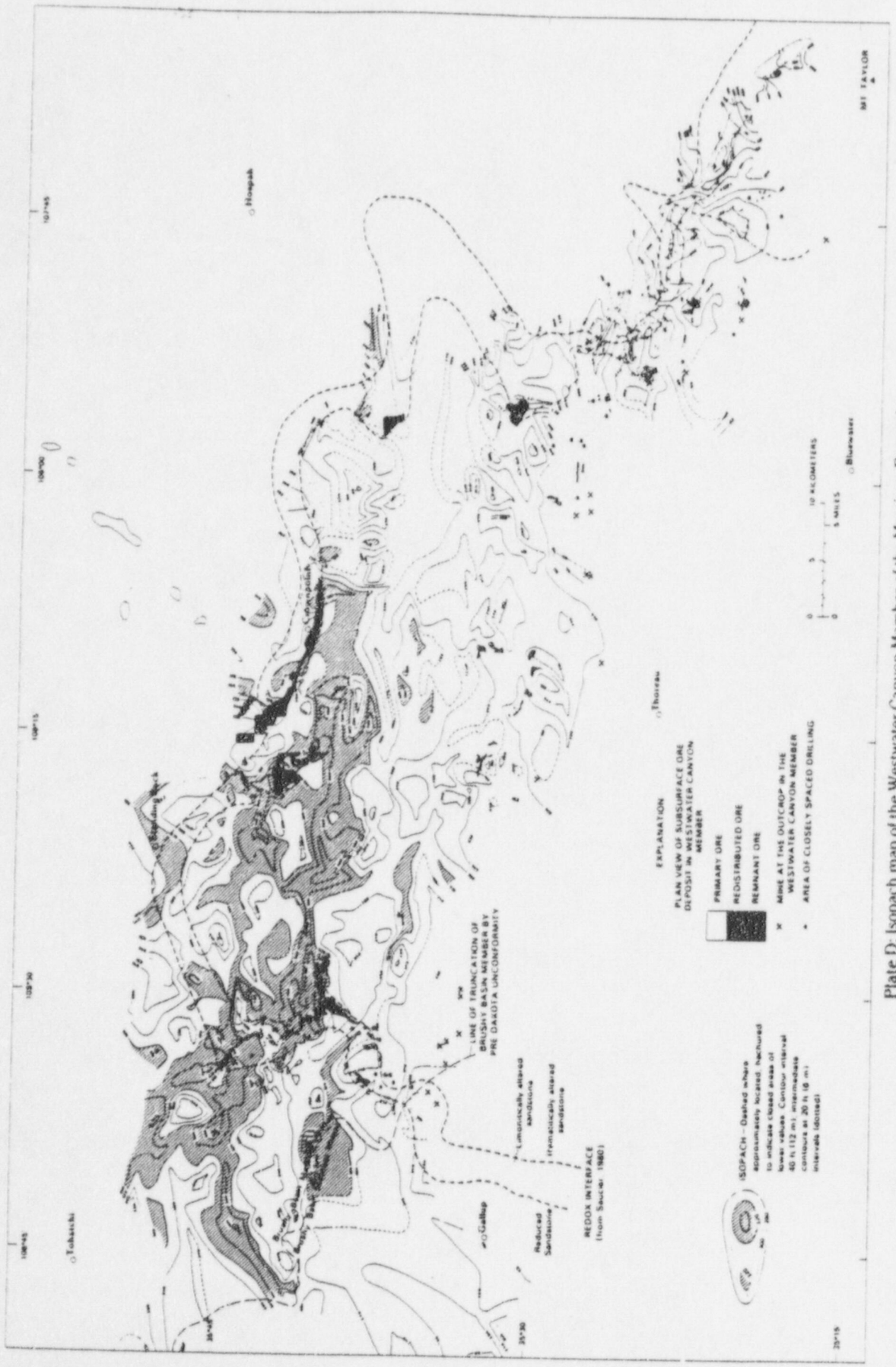

Plate D: Isopach map of the Westwater Canyon Member of the Morrison Formation.

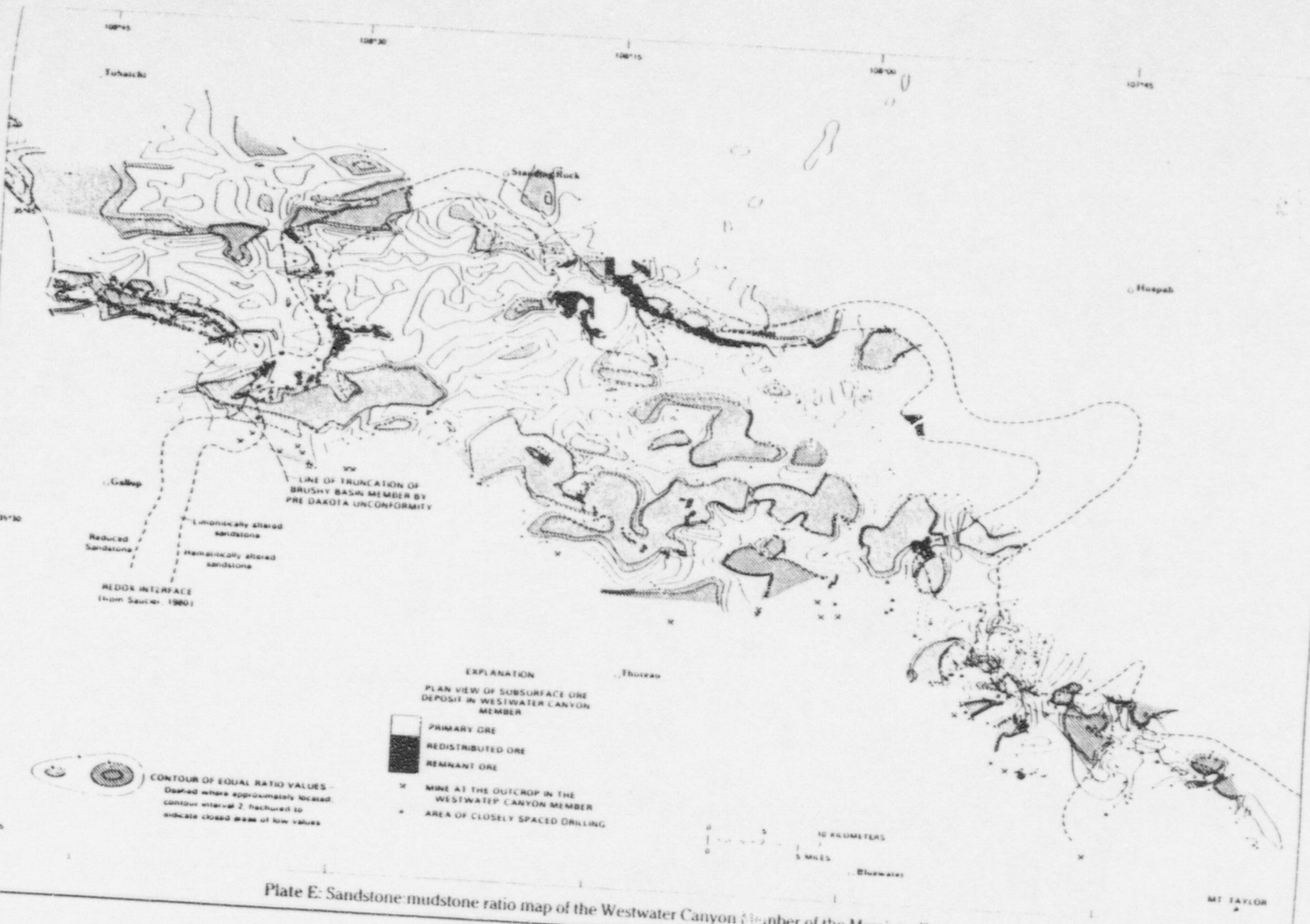

Plate E: Sandstone-mudstone ratio map of the Westwater Canyon Member of the Morrison Formation.

Kirk and Condon

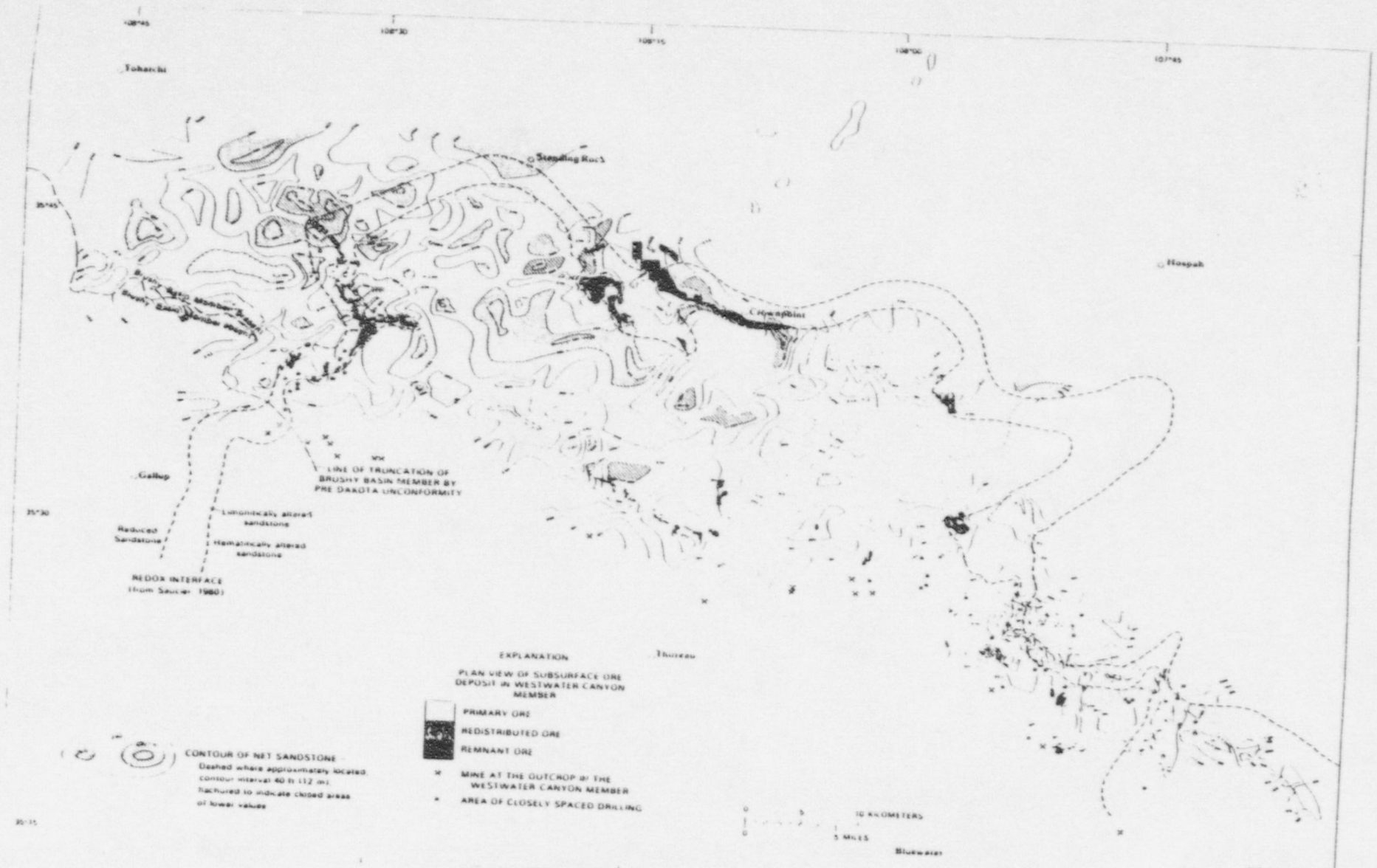

Plate G: Net sandstone map of the Westwater Canyon Member of the Morrison Formation.

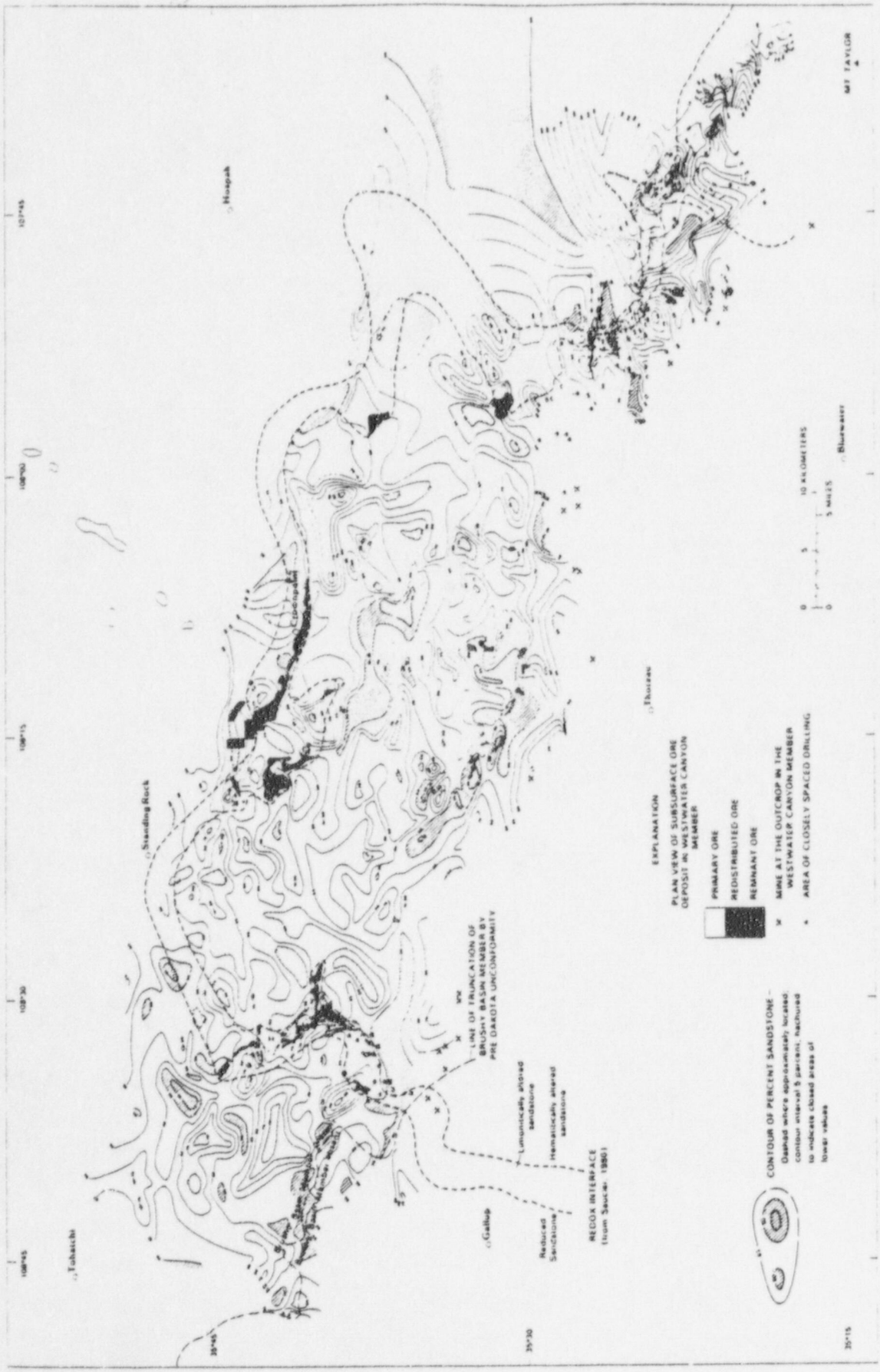

Plate F: Percent sandstone map of the Westwater Canyon Member of the Morrison Formation.

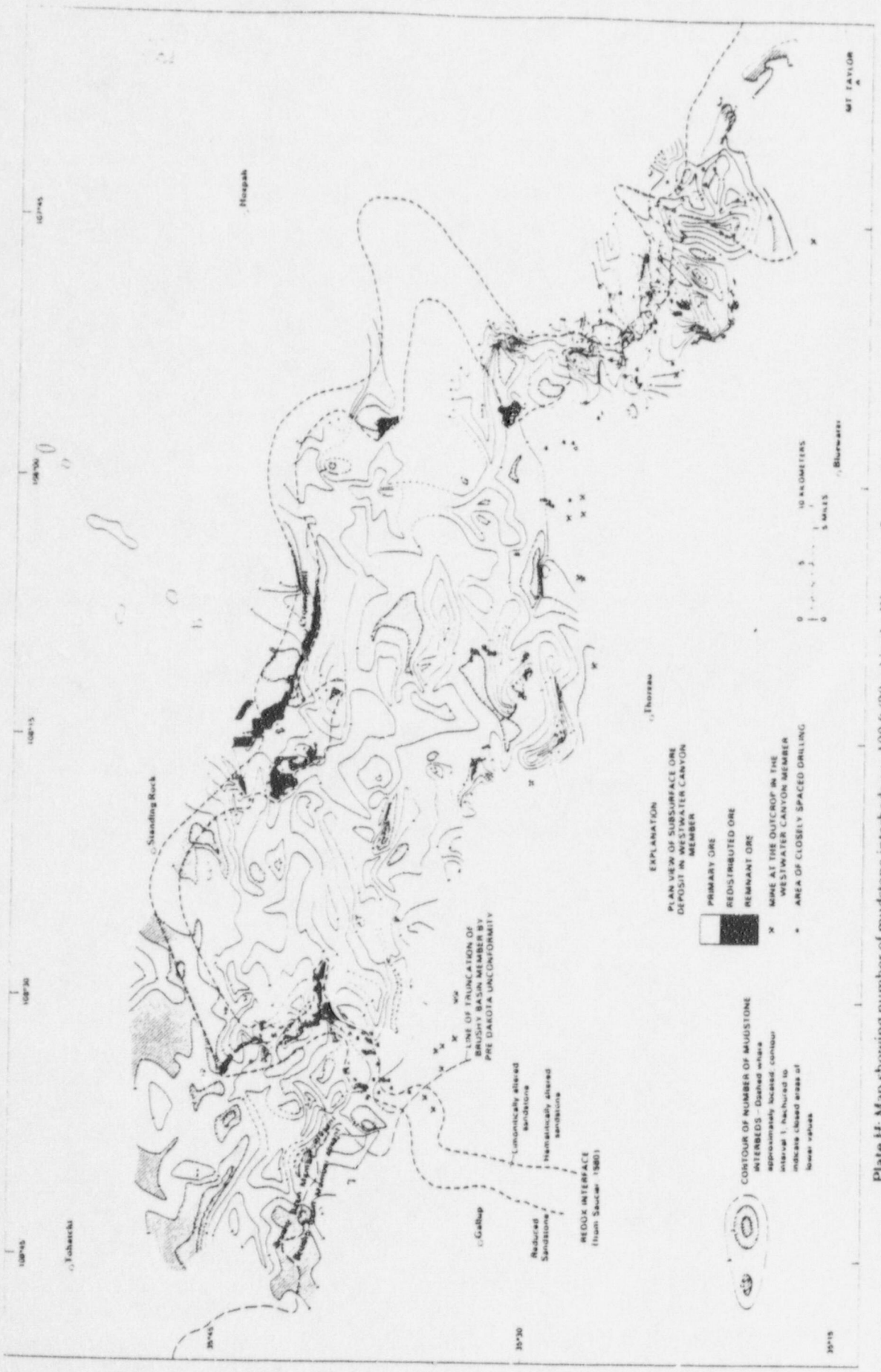

Plate H: Map showing number of mudstone interbeds per 100 ft (30 m) in the Westwater Canyon Member of the Morrison Formation

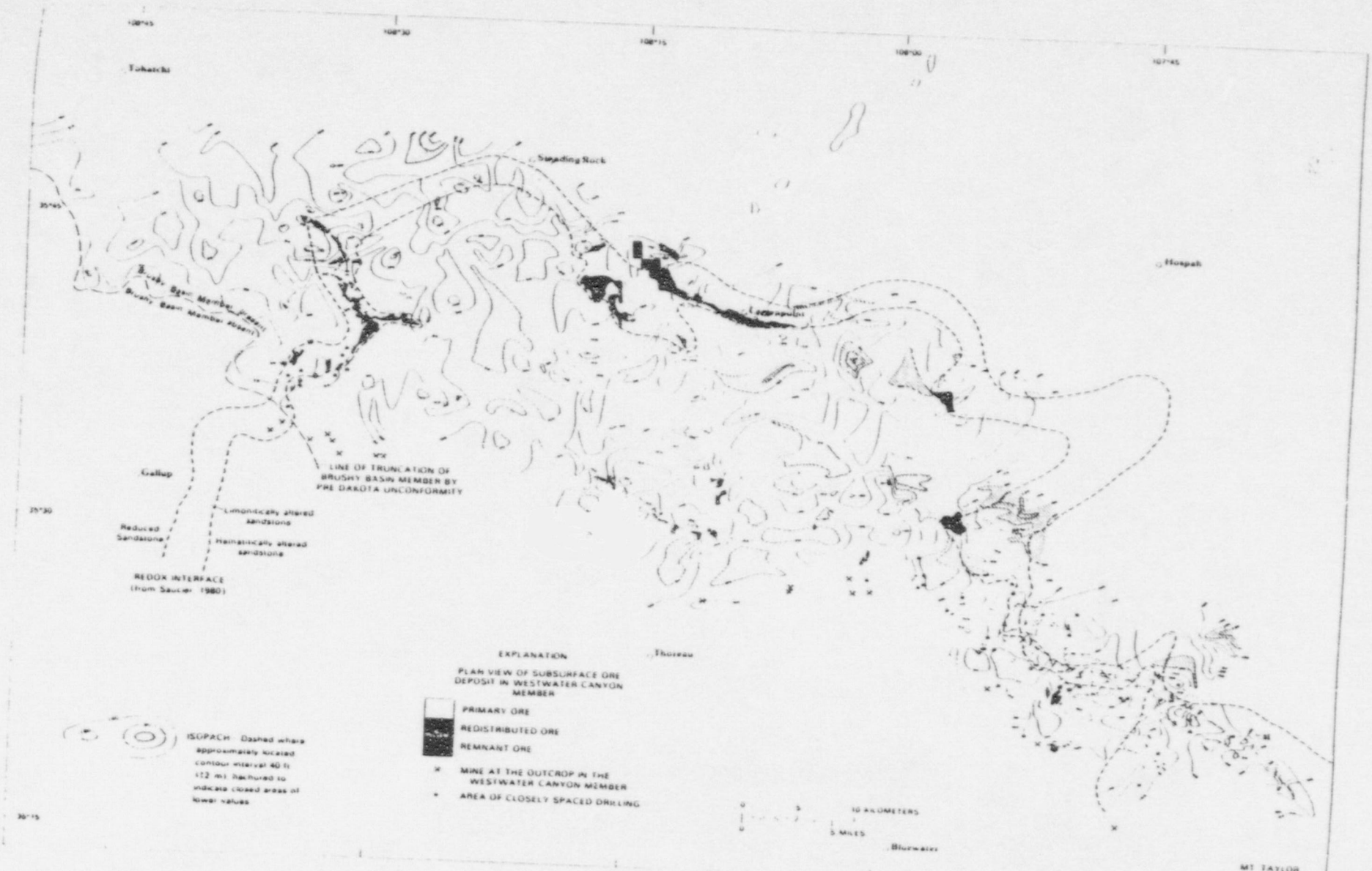

Plate I: Isopach map of the Brushy Basin Member of the Morrison Formation.

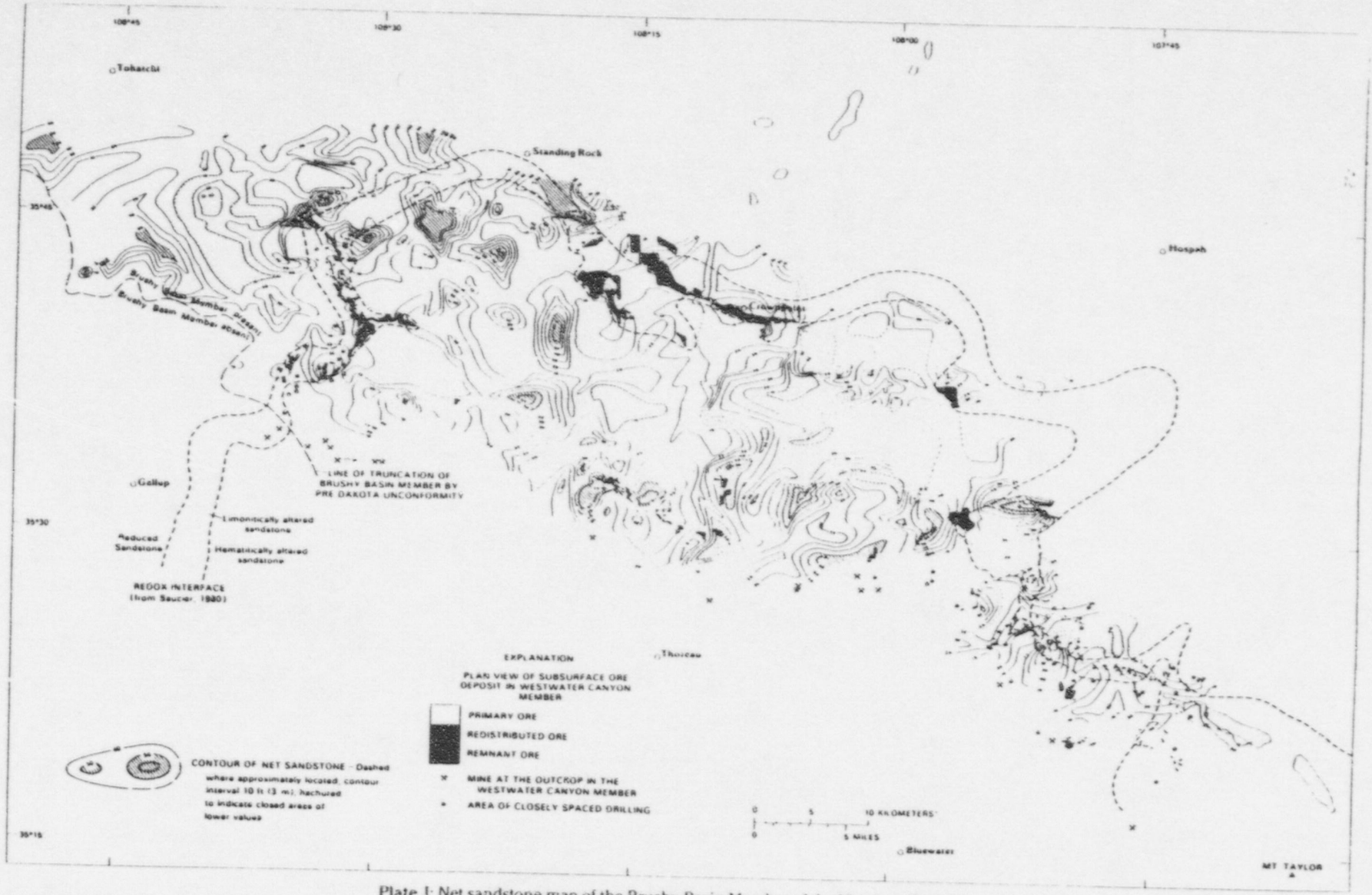

Plate J: Net sandstone map of the Brushy Basin Member of the Morrison Formation.

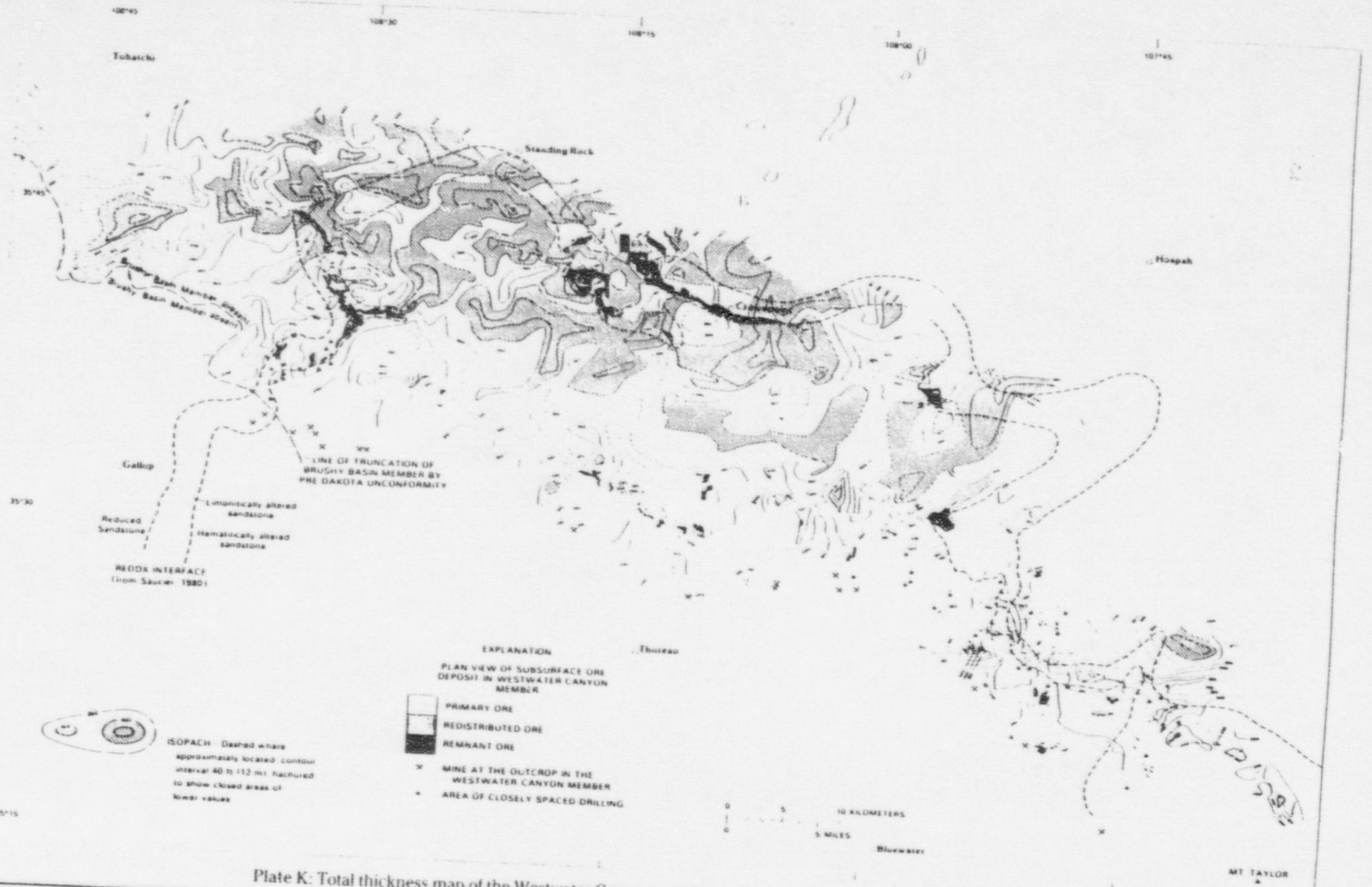

Plate K: Total thickness map of the Westwater Canyon and Brushy Basin Members of the Morrison Formation.

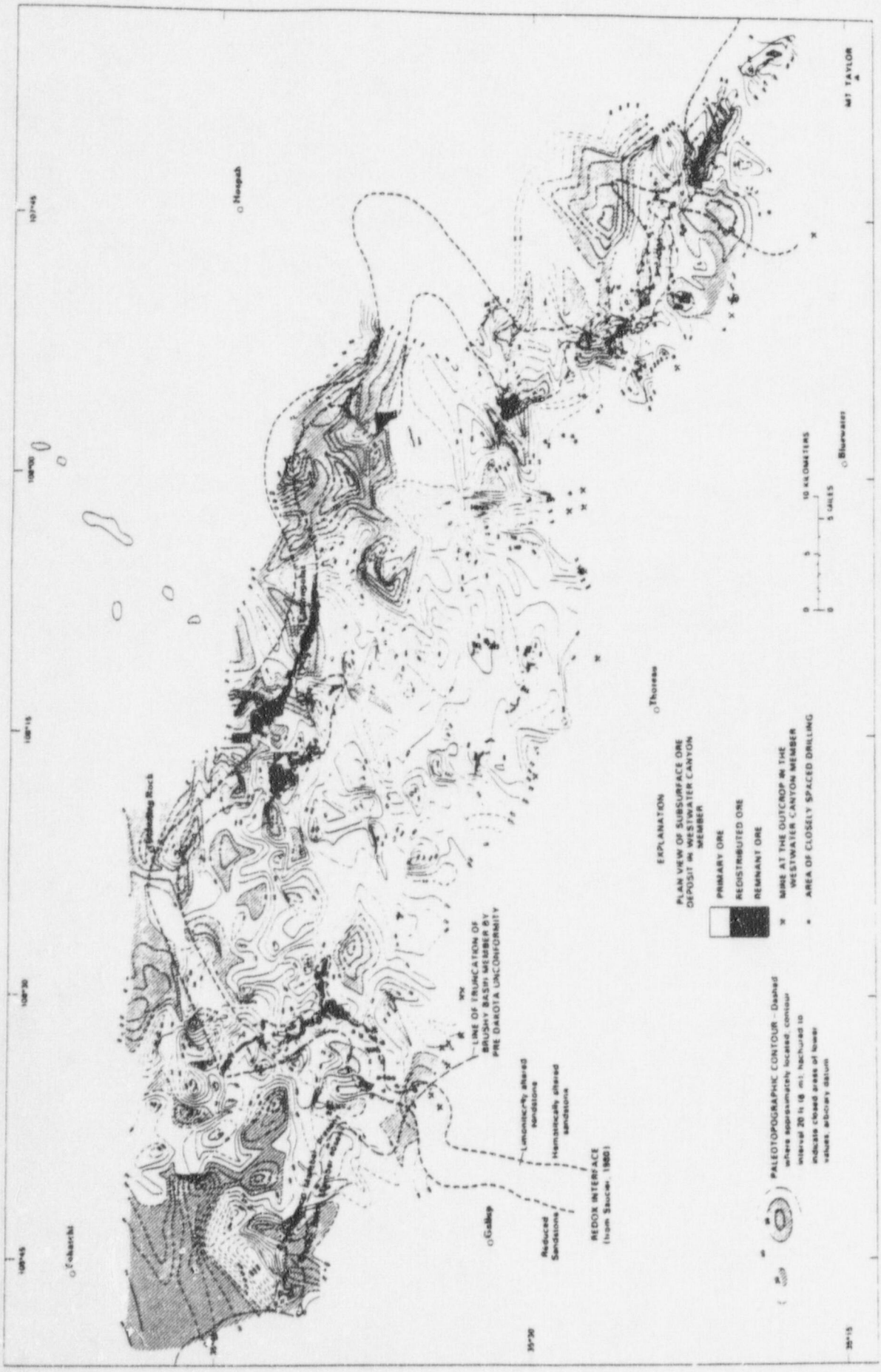

Plate L: Paleotopographic reconstruction of the base of the Westwater Canyon Member of the Morrison Formation.

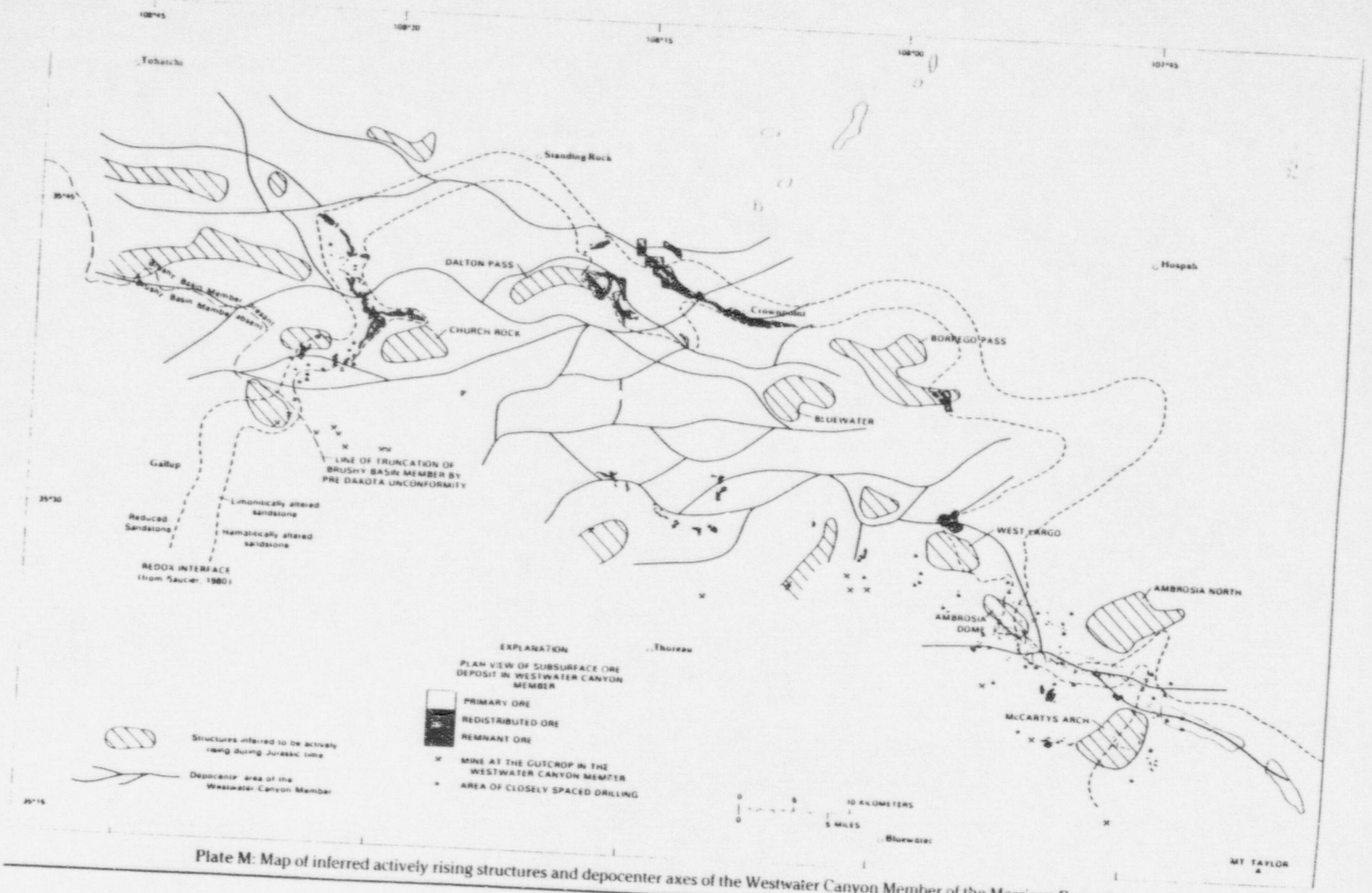

Plate M: Map of inferred actively rising structures and depocenter axes of the Westwater Canyon Member of the Morrison Formation.

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Exhibit P

INTERNATIONAL ATOMIC ENERGY AGENCY
in cooperation with the Nuclear Energy Agency of the OECD

Technical Committee Meeting on Recent Developments in Uranium Resources, Production and Demand — 1997

Vienna, 10–13 June 1997

The Crownpoint and Churchrock Uranium Deposits, San Juan Basin, New Mexico: An ISL Mining Perspective

D.W. McCARN

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THE CROWNPOINT AND CHURCHROCK URANIUM DEPOSITS, SAN JUAN BASIN, NEW MEXICO: AN ISL MINING PERSPECTIVE

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1. ABSTRACT

The Crownpoint and Churchrock uranium deposits, San Juan Basin, New Mexico are currently being developed by Uranium Resources, Inc. (URI) and its subsidiary Hydro Resources, Inc. (HRI) with an anticipated startup in 1998. Both deposits will be developed using advanced in situ leach (ISL) mining techniques. URI / HRI currently has about 14,583 tU (37.834 million pounds U_3O_8) of estimated recoverable reserves at Crownpoint and Churchrock at a cost less than $39 / kg U ($15 / lb U_3O_8). The uranium endowment of the San Juan Basin is the largest of any province in the United States.

In March, 1997, a Final Environmental Impact Statement (FEIS) for the Crownpoint and Churchrock sites was completed by the Nuclear Regulatory Commission which recommends the issuance of an operating license. The FEIS is the culmination of a 9 year effort to license and develop the deposits.

The Westwater Canyon Member of the Jurassic Morrison Formation is an arkosic, fine to coarse grained sandstone bounded by near basinwide confining clays deposited in a wet alluvial fan environment within the San Juan Basin. The primary, trend-ore deposits are hosted by the Westwater Canyon Member as humate-rich, syngenetic tabular deposits which were

subsequently remobilized into roll fronts. Since deposition in the Jurassic, two phases of remobilization have occurred in the basin causing the formation of in situ leach amenable monometallic uranium rolls free of organic debris.

Following in situ mining, ground water restoration of the Crownpoint and Churchrock mines is required to provide a water quality consistent with pre-mining baseline conditions.

The development of in situ mining offers an environmentally sound and cost-effective method for uranium extraction. URI / HRI anticipates a production of 385-1,156 Tonnes U / year (1-3 million pounds U_3O_8) from the New Mexico properties.

2. STRUCTURAL SETTING

The Crownpoint and Churchrock uranium deposits are located in northwestern New Mexico and are part of the Grants Uranium Region in the San Juan Basin (Fig. 1). The San Juan Basin, regionally part of the Colorado Plateau, is bounded on the north by the San Juan Uplift, to the west by the Defiance Uplift, to the south by the Zuni Uplift, and to the east by the Nacimiento Uplift and the Archuleta Arch. Fig. 2 presents an index map of the five mining districts within the region including the Churchrock, Crownpoint, Smith Lake, Ambrosia Lake, and Laguna districts as well as the locations of the three URI / HRI sites. Historically, the Grants Uranium Region represents the largest of all uranium-bearing provinces in the United States. Crownpoint is located in the central portion of the Chaco Slope and Churchrock is located 30 km to the west, also on the Chaco slope. The location of the three URI / HRI properties is also shown in Fig. 2 and are referred to as Churchrock, Crownpoint, and Unit 1.

3. DEPOSITIONAL FRAMEWORK

The Jurassic Morrison Formation is the single most important uranium producer in the United States and is the host for uranium deposits not only in the San Juan Basin, but also

throughout the Colorado Plateau which covers 500,000 km^2 (200,000 mi^2) including portions of Arizona, Colorado, New Mexico and Utah. The deposition of Morrison Formation occurred at a time in which large quantities of volcanic ash provided a source for uranium as the favorable sandstone hosts of the Westwater Canyon Member were being deposited. In the San Juan Basin, sub-aerial alluvial fans draining the Zuni Uplift to the south developed over Recapture Member clays. Following the basin-wide development of the Westwater Canyon Member sandstones, Brushy Basin Member bentonitic claystones and mudstones containing large quantities of volcanic ash were deposited. [1, 2, 3, 4, 5, 6].

Humate from the sediments was mobilized sygenetically [2, 3] and was reconcentrated into the Westwater Canyon Member sandstones. This provided a reductant for the large quantities of uranium in the Morrison system and gave rise to the humate-rich, tabular "trend-ores" throughout the San Juan Basin. The geometric mean of the total carbon content of the Ambrosia Lake "trend ores" is 0.60% [4]. Background concentrations at Ambrosia Lake is 0.14% [4].

Following deposition of the Morrison, transgressive Dakota seas enveloped much of the western United States depositing beach, barrier bar, and distributary deltaic sediments unconformably over the Morrison Formation. This was followed by deposition of the thick offshore sediments of the Mancos Shale.

Structural re-development of the San Juan Basin during Cretaceous and Tertiary times allowed for the redistribution of the tabular trend ores into the remobilized ores occurring at Crownpoint and Churchrock. This remobilization is responsible for the segregation of vanadium, selenium, and molybdenum from the remobilized ores such as Churchrock [4]. The total carbon is very low [4].

4. LOCATION

4.1. Crownpoint and Unit 1

The Crownpoint and Unit 1 sites covers 877 ha (2,192 acres) and is located on Sections 15, 16, 19, 21, 22, 24, and 25 of Township 17 North, Range 13 West and Section 29, Township 17 North, Range 12 West adjacent to the town limits of Crownpoint (Fig. 3). The Crownpoint Trend lies on the central portion of the Chaco Slope to the south of the interior part of the San Juan Basin near the regional redox front at a depth of about 700 m. The Crownpoint trend was discovered in the late 1970's by Conoco and Mobil. Conoco began engineering studies of for a major underground mine in the late 1970s and three deep shafts were completed in 1982.

Unit 1 is located 3.2 km west of the town Crownpoint and covers 512 ha (1,280 acres) in Sections 15, 16, 21, and 22 of Township 17 North, Range 13 West and has very similar geological characteristics to the Crownpoint site. The Unit 1 Site is shown in Fig. 3. This forms a portion of the area leased by Mobil which explored and discovered over 38,500 tU (100 million pounds U_3O_8) within their leases.

Because of the leachable nature of portions of the ore in the area, Mobil completed an in situ pilot operation near what HRI calls the Unit 1 area. This pilot demonstrated the economic viability for ISL production of the Crownpoint ores as well as demonstrating the ability for restoration.

4.2. Churchrock

The Churchrock site is located in the northwest corner of the Zuni Uplift near the boundary of the Chaco Slope and the depth to ore is approximately 250 m. The site is located in Sections 8 and 17 of Township 16 North and Range 16 West and covers an area, as shown in Fig. 4, of 145 ha (360 acres). HRI's mineral rights include 65 ha (160 acres) of patented claims

in Section 8, and 80 ha (200 acres) of leases on Section 17. A portion of the Churchrock site in the northeast corner of Section 17 was previously mined for uranium.

5. RESERVES AND PRODUCTION IN THE GRANTS URANIUM REGION

In the Grants Uranium Region, the estimated total endowment of the Westwater Canyon Member is 3.5×10^6 Tonnes U [6]. Cumulative production of uranium from the Grants Uranium Region by January 1, 1997 has been 131,450 tU (341.8 million pounds U_3O_8) [5, 7, 8, 9]. URI / HRI currently has about 14,583 tU (37.834 million pounds U_3O_8) of estimated recoverable reserves at Crownpoint and Churchrock. at a cost less than $39 / kg U ($15 / lb U_3O_8). About 40% of all uranium produced in the United States is from the Grants Mineral Belt [5].

6. REGIONAL GEOLOGY

The San Juan Basin has been a regional depocenter since the Paleozoic. Approximately 3,000 m of section are present and range in age from Precambrian to Holocene. Strata from Permian to upper Cretaceous are identified including the Jurassic Morrison formation which hosts most of the uranium deposits in the basin. Formation Of minor importance are the Cretaceous Dakota Sandstone and the Jurassic Todilto Limestone. Figure 5 is a cross-section between Gallup and Grants, New Mexico showing the regional relationships of the Jurassic Morrison [1].

6.1. Morrison Formation

The Morrison Formation consists of the Recapture, Westwater Canyon, and Brushy Basin Members and may attain a total thickness of about 225 m. A typical section in the Westwater Canyon Member along with a geophysical log is presented in Fig. 6 [1].

6.1.1. Recapture Member

The Recapture Member of the Morrison Formation is composed dominantly of two facies: aeolian and lacustrine. The eolian portion can be up 90 m thick and consists of white, tan, and yellowish-gray, fine- to medium-grained, well sorted, large-scale trough crossbedded sandstone [1]. The lacustrine facies is an interbedded sequences of alternating red and maroon mudstones and white, light-gray, and reddish-brown, fine- to medium-grained, moderately well sorted sandstone. It ranges in thickness in the San Juan Basin from 0 to 152 m [1].

6.1.2. Westwater Canyon Member

The Westwater Canyon Member is an artesian aquifer with a transmissivity of 3.676×10^{-4} to 3.880×10^{-4} m^2/s (2,556-2,698 gal/day/ft) [8] and is tightly confined by aquicludes of the overlying Brushy Basin clays and underlying Recapture Shale. As described by Kirk & Condon [1], the Westwater Canyon Member is a sequence of vertically stacked and laterally coalesced fine- to coarse-grained, arkosic to felspathic, poorly sorted, sandstone beds interbedded with thin, discontinuous mudstone beds. The color ranges from pink to red, grayish-green, and yellowish gray. The Westwater Canyon Member was deposited in a braided fluvial framework and ranges in thickness from 30 to over 125 m and deposited in a synclinal area between the Mogollon and Uncompahgre uplifts [3]. At Crownpoint, the Westwater Canyon Member ranges in thickness from 72 to 105 m. At Churchrock, the average thickness of the Westwater is 80 m. A shown in Fig. 2, the source of the sediment was from the southwest across the area of the Zuni Uplift.

6.1.3. Brushy Basin Member

The Westwater Canyon Member interfingers locally and regionally with the overlying Brushy Basin Member mudstones which also serve as a regional aquiclude. Locally, the Brushy Basin Member hosts braided fluvial sandstones sometimes referred to as "Poison Canyon". The

Brushy Basin Member is composed of light greenish-gray betonitic claystone and mudstone and ranges in thickness from 12 to 40 m [1, 8]. At Crownpoint, the Brushy Basin ranges from 20 to 35 m.

6.2. Dakota Sandstone

The Dakota Sanstone unconformably overlies the Morrison Formation and consists of two distinctive units. The lower portion is a paludal shale and mudstone overlying the Brushy Basin Member occasionally containing fluvial sandstone and locally coal. The upper portion of the Dakota is a well-developed white to light-brown, transgressive beach and barrier-bar marine sandstone unit occasionally containing distributary sandstone channels which are occasionally conglomeratic. These channels occasionally scour into the underlying Brushy Basin Member. [1]. The thickness of the Dakota Sandstone is up to 60 m.

6.3. Mancos Shale

The Mancos shale was deposited in a transgressive offshore marine environment and is a dark-gray claystone, mudstone and very-fine sandstone system and is up to 600 m thick [1, 8]. At the Churchrock Site, the Mancos Shale is present at the surface.

7. DEVELOPMENT OF URANIUM DEPOSITS IN THE WESTWATER CANYON MEMBER

Uranium was deposited in the Westwater Canyon Member penecontemporaneously with the deposition of volcanic ash in a humate rich environment. Syngentic concentration of humate and uranium within tabular sandstone masses created the tabular "trend-ore" deposits. Following structural changes in the basin during Cretaceous times, the trend-ore containing vanadium, molybdenum, and humate was redistributed into secondary "stacked" ore rolls virtually free of organics but containing some molybdenum. A later stage of basin development during Tertiary

further redistributed the uranium into monometallic stacked ores. Both Crownpoint and Churchrock are Tertiary stacked-ore deposits.

The Cretaceous and Tertiary remobilized uranium rolls are considered favorable for bicarbonate-oxygen ISL methods currently employed by URI's Kingsville Dome and Rosita plants.

7.1. Regional Ore Controls

Clear regional controls of the uranium deposits in the San Juan Basin are evidenced by the strong correlation between the regional redox fronts and the location of the ore deposits [1, 2, 3]. This regional redox front is presented in Fig. 7 [1]. The regional redox front is accompanied by discrete zones of hematitic and limonitic alteration within the basin, the hematitic zone being updip of the limonitic zone. Gray, reduced Westwater Canyon Member sandstones occur downdip of the regional redox front. The remobilized ore lies in the limonitic zone downdip of the more intensely oxidized zone of hematitic alteration.

Another important regional and local control for the concentration of uranium is the development of highly transmissive zones in the Westwater Canyon Member fan system which allowed large quantities of uranium bearing solutions to pass through regional redox fronts and be precipitated.

7.2. Local Ore Controls

Local ore controls for the individual rolls within the Westwater Canyon Member appear to be the thin, laterally discontinuous clays within the sandstone. As shown in Fig. 8 of the Crownpoint site, multiple, stacked ore bodies are present throughout the Westwater Canyon Member, each within an individual geochemical cell. Accurate interpretation and delineation of these ore rolls is required to design an effective well field.

8. ISL PROCESS

In order to develop the Crownpoint and Churchrock ore deposits, two distinct producing elements are necessary: the Well Field, and the Ion Exchange Plant. The plant consists of ion exchange columns containing resins with an affinity for uranyl carbonate ions. The flow of dilute solutions of uranyl carbonate (about 50-150 mg U / L) from the extraction wells is maintained at a rate of 10,000 - 20,000 L / m (2,500-5,000 gallons / m) through the plant. This yields between 230 kg U to 4,615 kg U per day (600 to 12,000 pounds of U3O8) for an annual production of 263 - 1,577 tU per year. Following extraction of uranium, oxygen and complexing agent such as sodium bicarbonate is added and the solution is reinjected. Of course, the true key to ISL development is the well field design.

8.1. Well Field Design

The well field is the mechanism by which the leaching solutions, or lixiviant, is circulated through the ore body (Fig. 9). Well field design for the in situ leach mines at Crownpoint and Churchrock will include up to 1,000-2,000 injection and extraction wells for each mine site located as close as possible to the ore. Because of the sinuosity of each individual roll front, wells as closely spaced as 10-50 meters will be used to extract the uranium. Each well field will be surrounded by a ring of monitoring wells not more than 120 m (400 ft) from the nearest production well and not farther than 120 m from each other. Leachate migration to the monitoring wells is called an excursion. Excursion controls consist primarily of the initial engineering design of the wellfield, balancing lixiviant flow in the wellfield, and maintaining a slight production bleed of 1% to create a cone of depression around the ore zone. URI has never had an excursion in its operating history.

9. LICENSING

URI / HRI is currently in the process of obtaining source material license as authorized by the Atomic Energy Act for the Crownpoint, Churchrock, and Unit 1 sites. With the issuance of the FEIS [8] in February, the lengthy re-evaluation by the U.S. Nuclear Regulatory Agency (NRC), the Bureau of Indian Affairs (BIA), and the U.S. Bureau of Land Management (BLM) was completed with a recommendation to issue a combined source and by-product material license from the NRC and minerals operating leases from the BLM and BIA. The FEIS recommended that the license and leases should be conditioned on the commitments made by HRI in the license application and related submittals as well as various recommendations made by the NRC [8]. The FEIS is the culmination of a 9 year effort by HRI to license and develop the deposits. The NRC license will be conditioned on a Safety Analysis Report (SAR) currently being prepared by the NRC and Consolidated Operating Plan (COP) which is currently undergoing review by the NRC.

Other required licenses and conferred rights include the Underground Injection Control (UIC) License, and Surface Discharge Permit, land disposal of treated waste water, and air quality licenses.

9.1. Underground Injection Control License

In addition to a source material license, URI / HRI has obtained a UIC license from the State of New Mexico Environmental Department. A UIC license allows for the injection of mining fluids into an aquifer for the purpose of extraction of uranium.

9.2. Land Application of Discharged Water

Surface application of treated discharge waters is licensed by the State of New Mexico Environmental Department or the U.S. Environmental Protection Agency depending on the land status.

9.3. Water Rights

Water rights in the State of New Mexico is administered through the New Mexico State Engineer. Applications for water rights are required to be published and are subject to a hearing if protested. Water rights may be approved subject to three conditions: That the application (1) not impair existing water rights, (2) not be contrary to the conservation of water within New Mexico, and (3) not be detrimental to the public welfare. URI / HRI is currently in the process of obtaining water rights for the anticipated projects.

9.4. Comparative Consumptive Water Use

Agricultural use of consumed water in McKinley County, New Mexico for 50 hectares (123.5 acres) is compared to the total consumptive water use for all three proposed ISL projects. As can be seen in Fig. 10, the consumed water use for to support 50 ha of all commercial agricultural products is greater than the average use for in situ uranium mining. By comparison, water use for the former Churchrock mines required at least 6 million m^3 (5,000 acre feet) per annum to dewater the mines or at least 36 times the ISL water requirements.

11. RESTORATION

Based on the experience gained in the industry, three strategies (Table I) are considered in ground water restoration including (a) groundwater sweep (GS); (b) reverse osmosis (RO); and (c) brine concentration (BC) depending on the water budget. Total water use is estimated to

be 13-29 million m^3 for groundwater sweep, 3.3-7.7 million m^3 for RO, and 0.03-0.07 million m^3 for BC. This represents the total water requirements for all currently foreseen projects.

12. RESOURCE & PRODUCTION BASE OF URI / HRI

12.1. Santa Fe Pacific Gold Corporation Agreement

URI / HRI recently signed an agreement with Santa Fe Pacific Gold Corporation in which certain mineral rights were acquired covering 200,000 ha (500,000 acres). These rights were obtained in exchange for 1.2 million shares of URI's common stock and a commitment for $200,000 per year in exploration expenditures for the next 10 years [11, 12]. URI estimates there is approximately 5,700 tU (14.7 million pounds U_3O_8) of proven in-place uranium reserves approximately 3,700 tU (9.6 million pounds U_3O_8) recoverable] that were drilled-out on the acquired land. The potential for further development is very large based on the USGS endowment study of the San Juan Basin completed in 1986 [6]. It is estimated from this study that the endowment at a cutoff grade of 0.10% of the Westwater Canyon Member is 1,392,000 tU (3,280 million pounds of U_3O_8) at ISL minable depths.

12.2. URI / HRI Operations and Production

URI and its subsidiary HRI currently has uranium production operations in South Texas in the Kingsville Dome and Rosita plants. Production in 1996 amounted to 524 tU (1.36 million pounds U_3O_8) making URI one of the largest domestic producer of uranium in the United States [11].

Based on the recent acquisition of Alta Mesa in Texas, the development of the Vasquez, Texas property, a favorable FEIS for three uranium properties in New Mexico, and recent agreements with Santa Fe Pacific Gold Corporation (SFPGC), the in-place uranium reserves of the company are 34,000 tU (88 million pounds U_3O_8) of which 22,000 tU (57 million pounds

U_3O_8) are recoverable [12]. URI / HRI has been extremely active in licensing the Alta Mesa, Texas and New Mexico deposits for production as early as 1998.

13. ACKNOWLEDGMENTS

The author gratefully acknowledges the generous support and technical review by Richard Clement, Craig Bartels, and Frank Lichnovsky of Hydro Resources, Inc. and Mark Pelizza of Uranium Resources, Inc. in the preparation of this paper.

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Fig. 1 Location & Structural Setting of the San Juan Basin

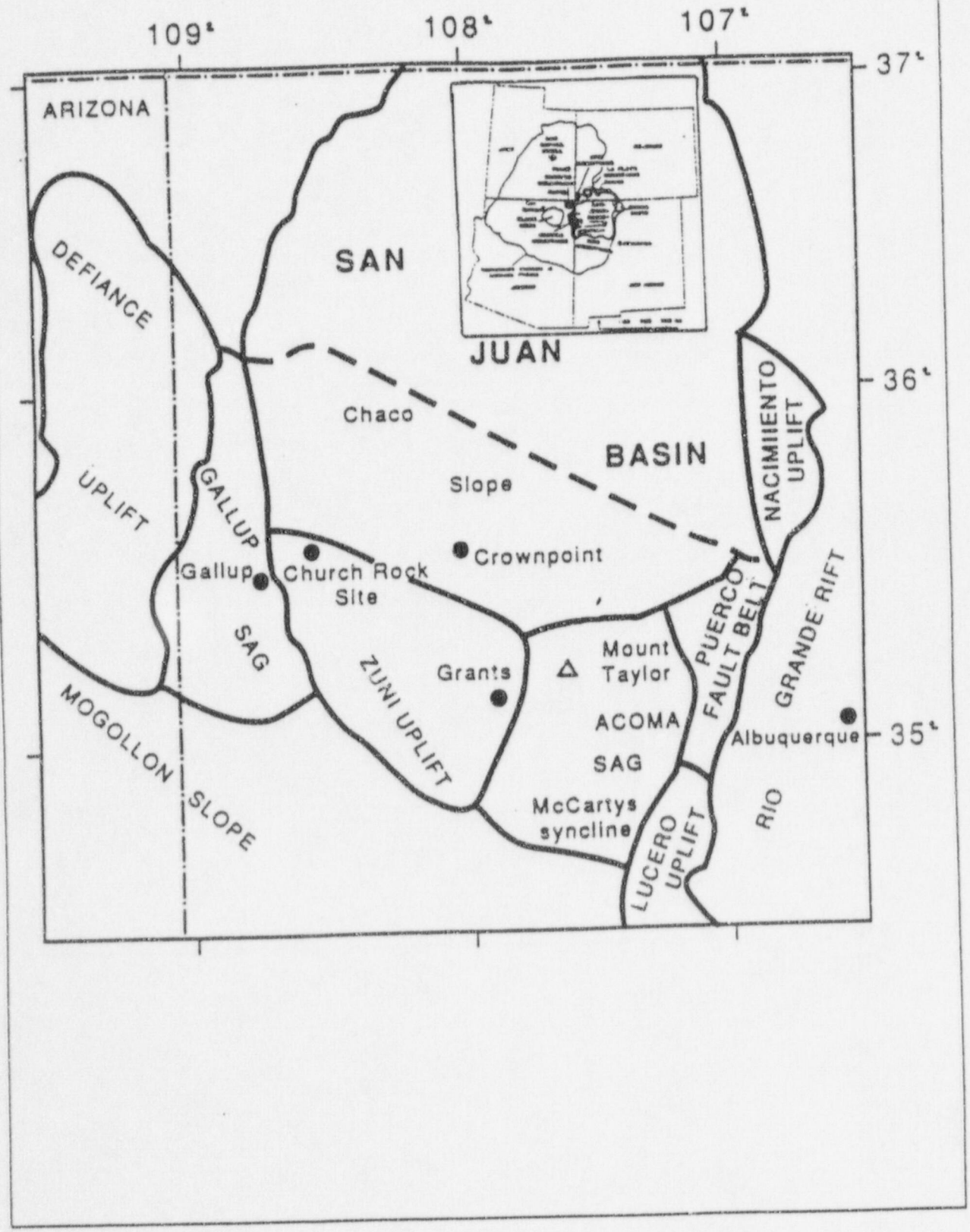
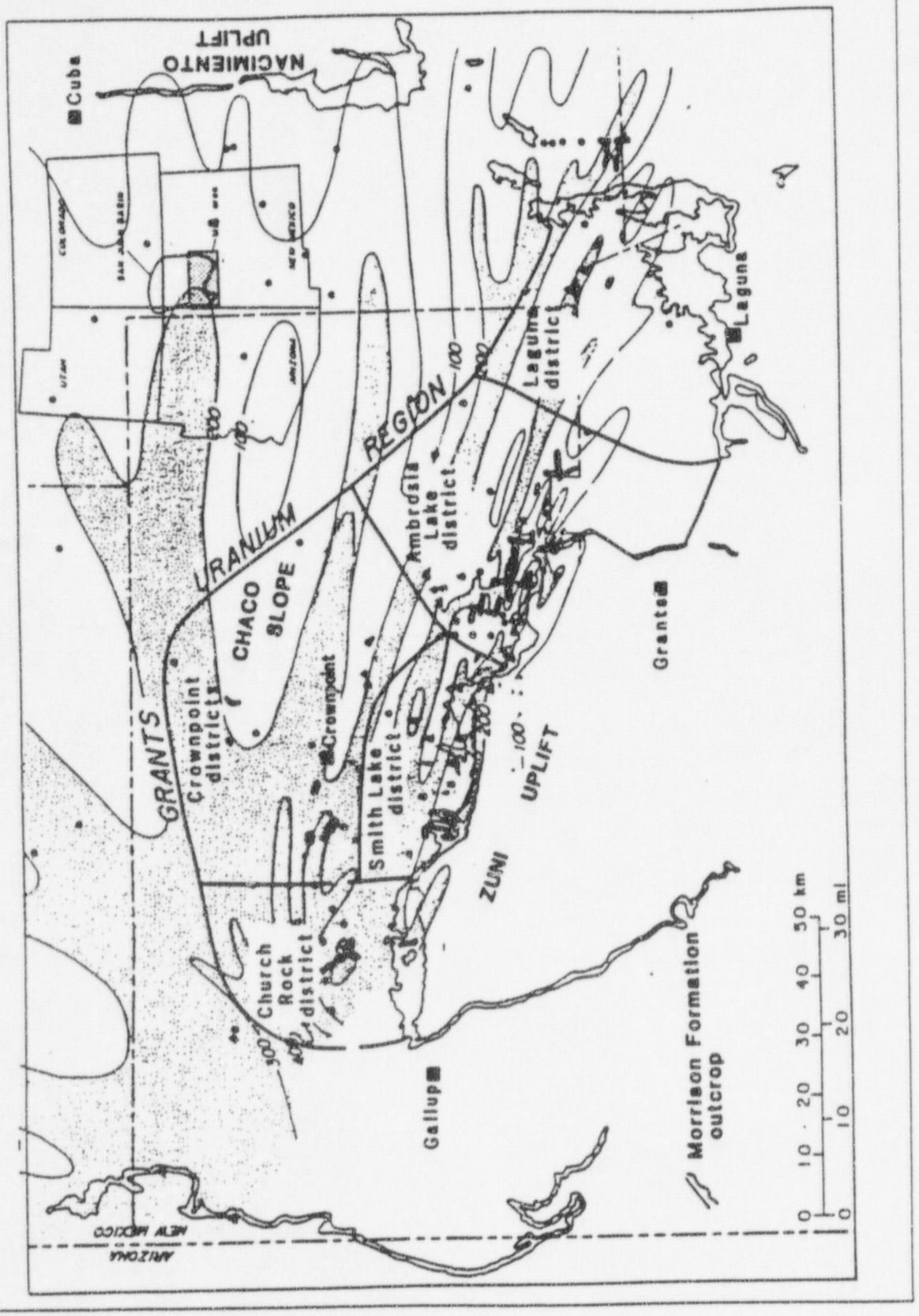


Fig. 2: Grants Uranium Region Depositional Framework of Westwater Canyon Member



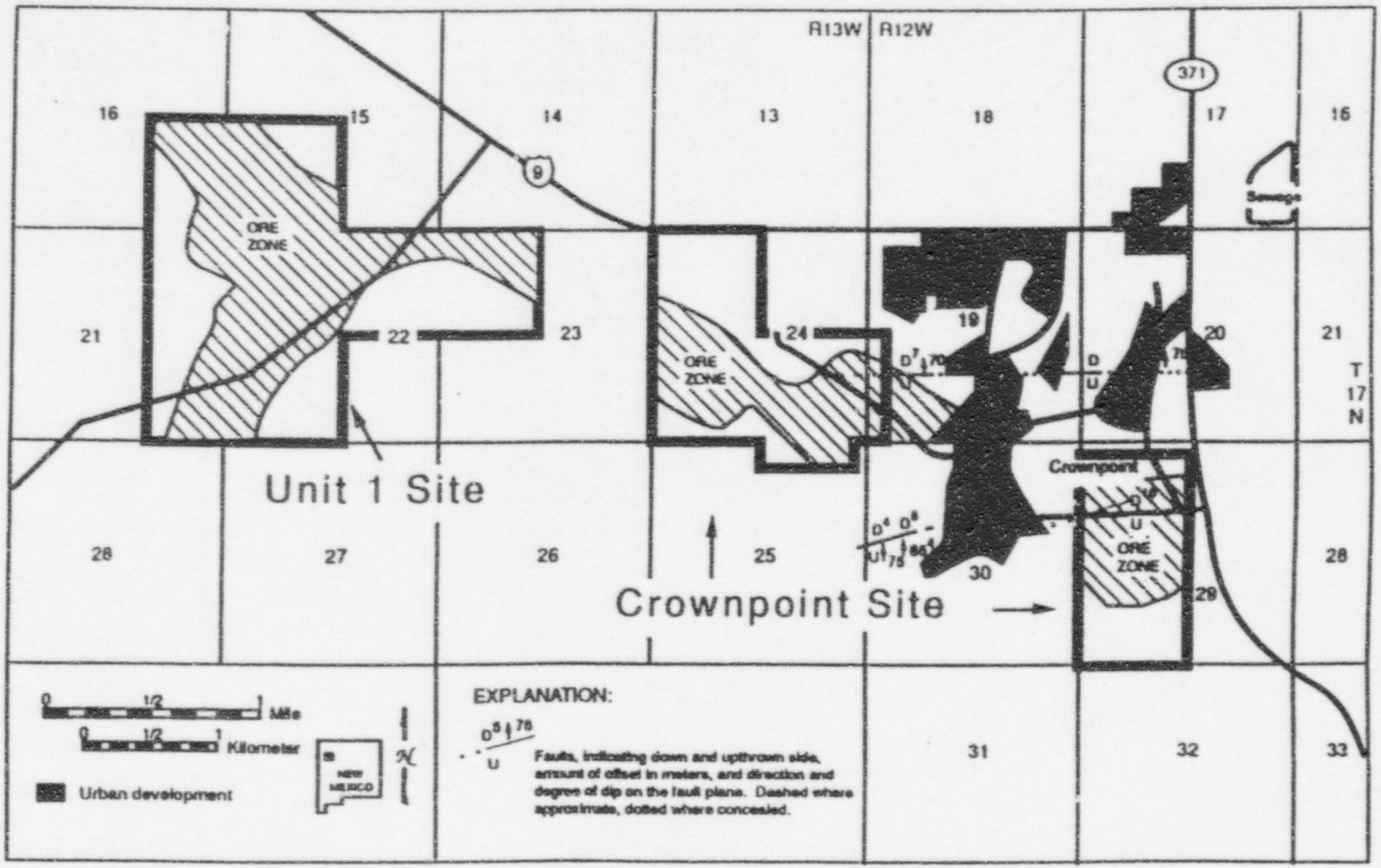


Fig. 3: Crownpoint and Unit 1 Site Map

Fig. 4: Churchrock Site Map

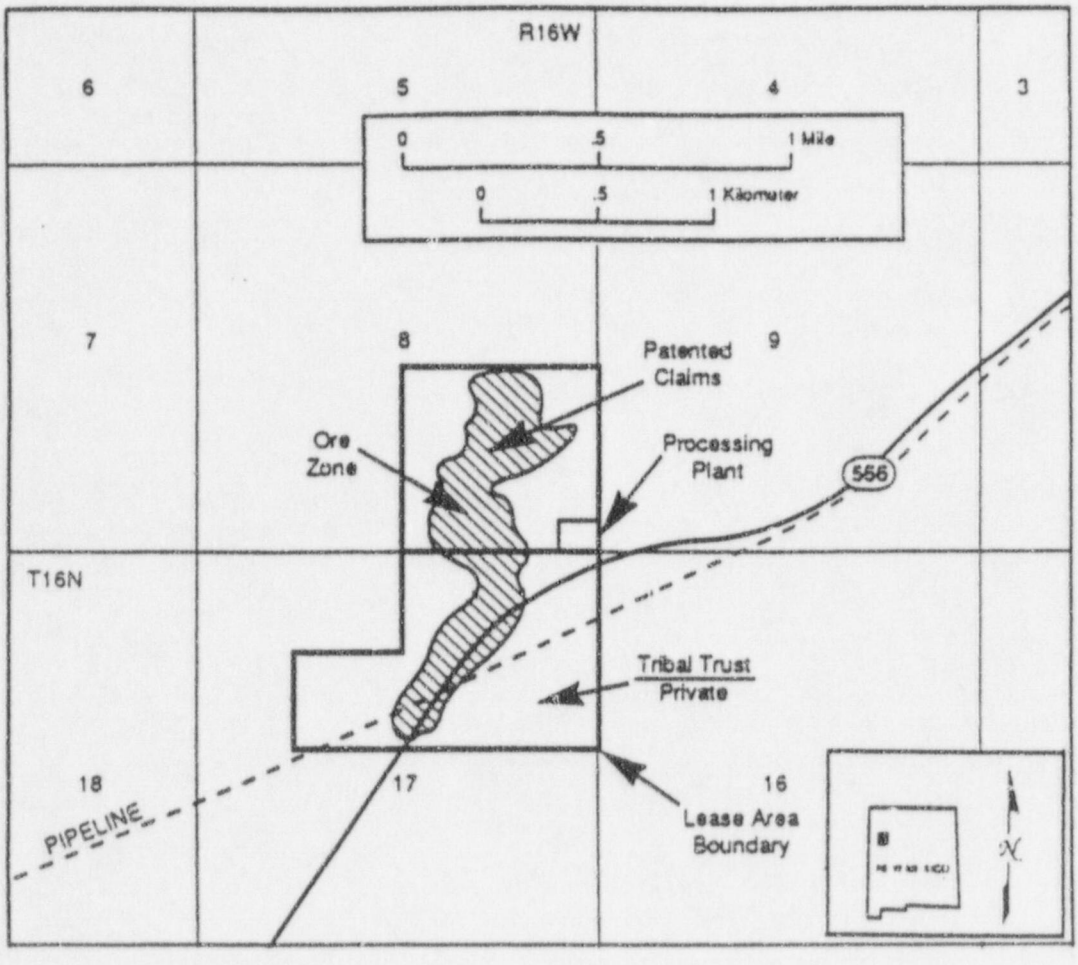


Fig. 5: Cross-Section Between Gallup and Grants, New Mexico [1]

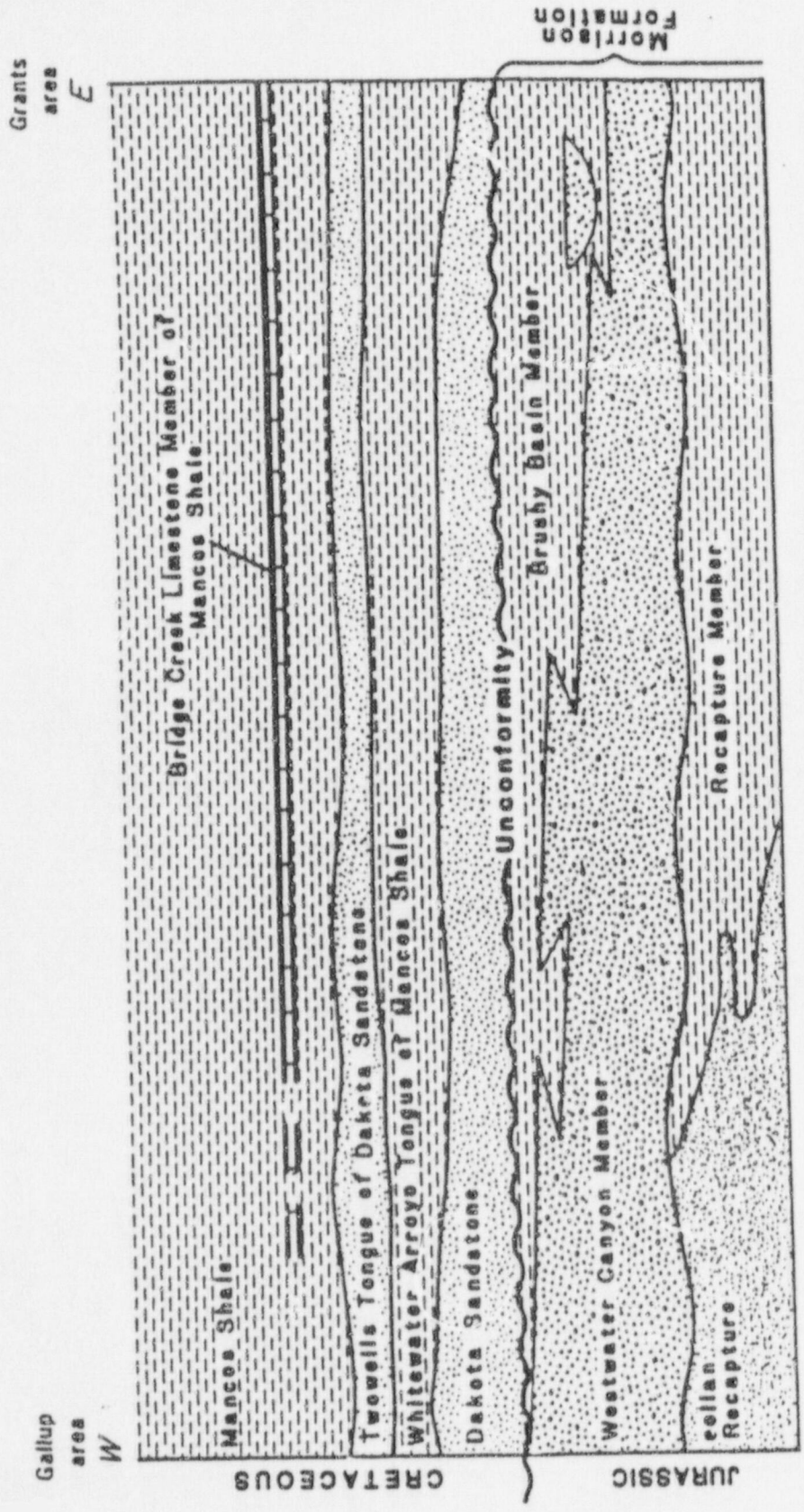


Fig. 6 Typical section of the Westwater Canyon Member

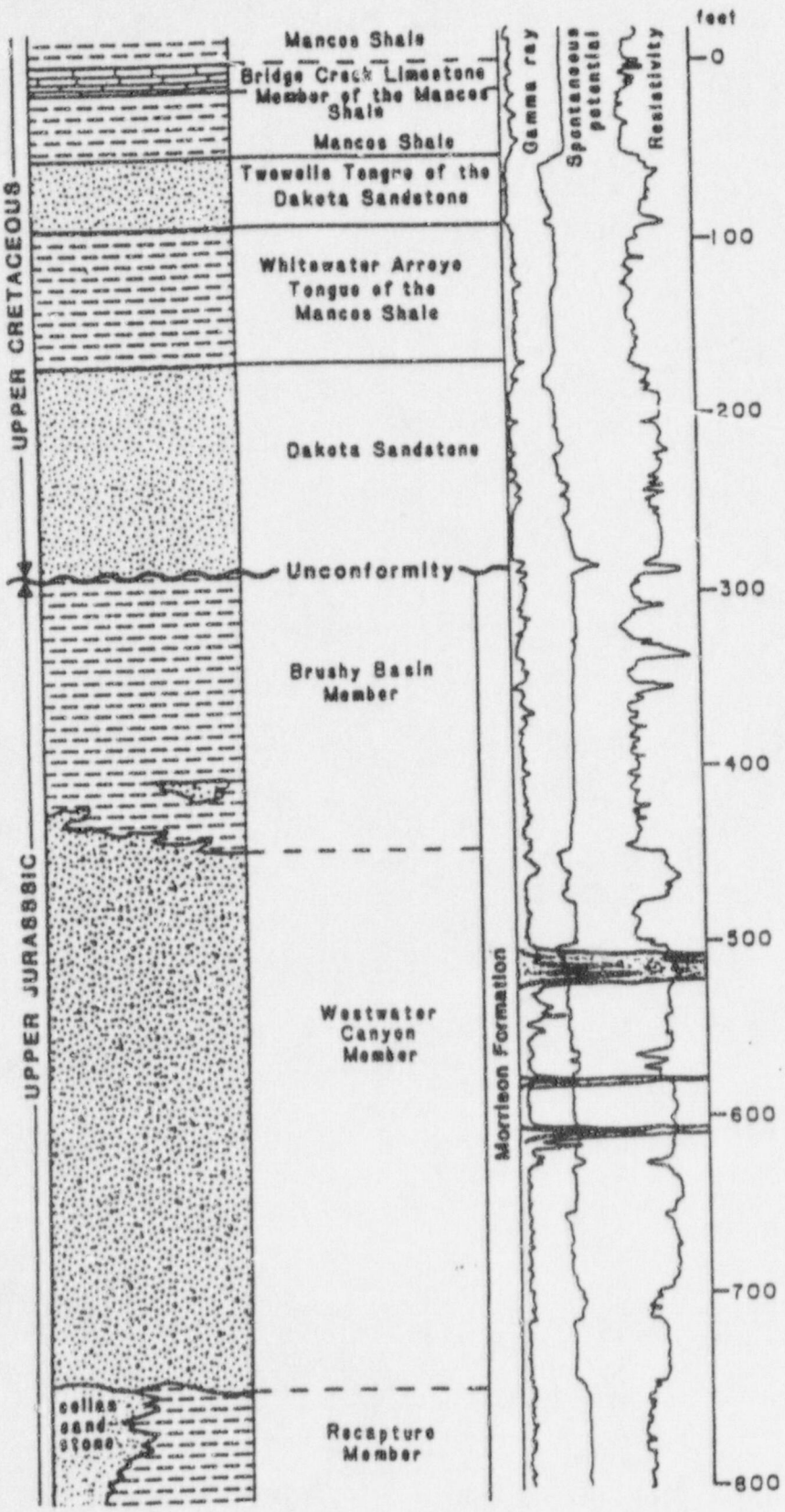


Fig. 7: Regional Redox Interface - From [1]

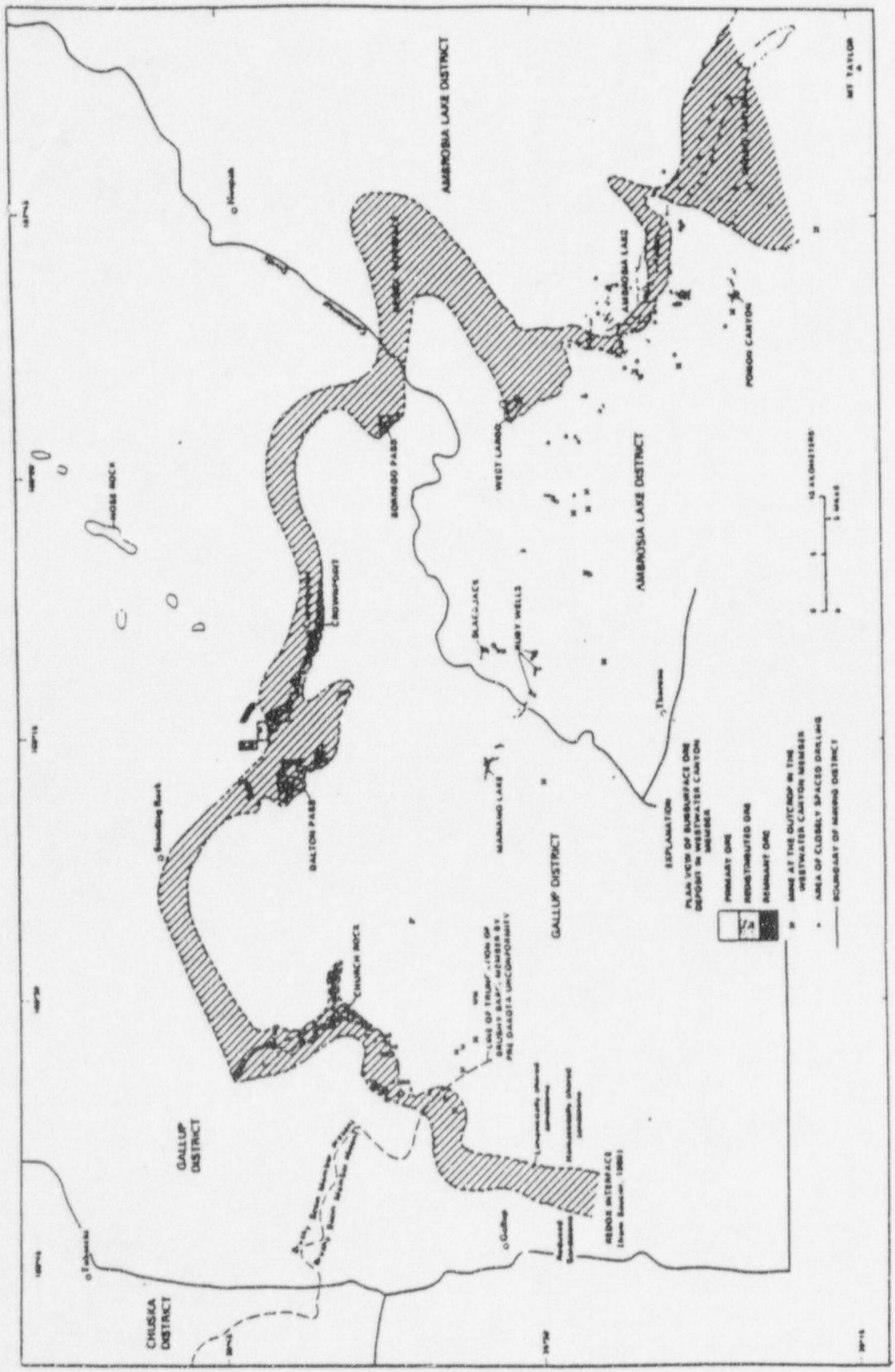


Fig. 8: Stacked Roll Fronts in the SE ¼ of Section 24 at Crownpoint

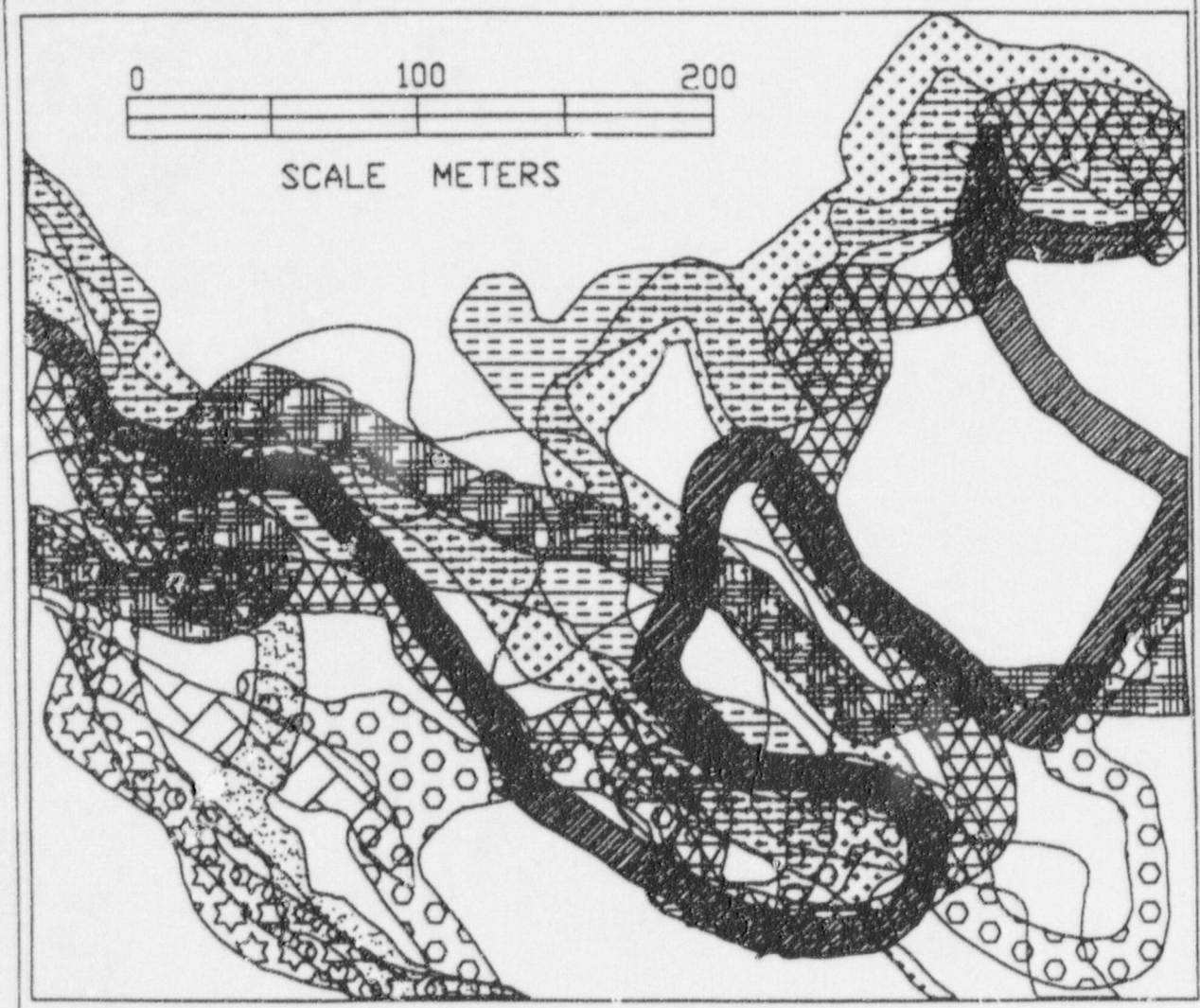


Fig. 9: Typical Wellfield Design

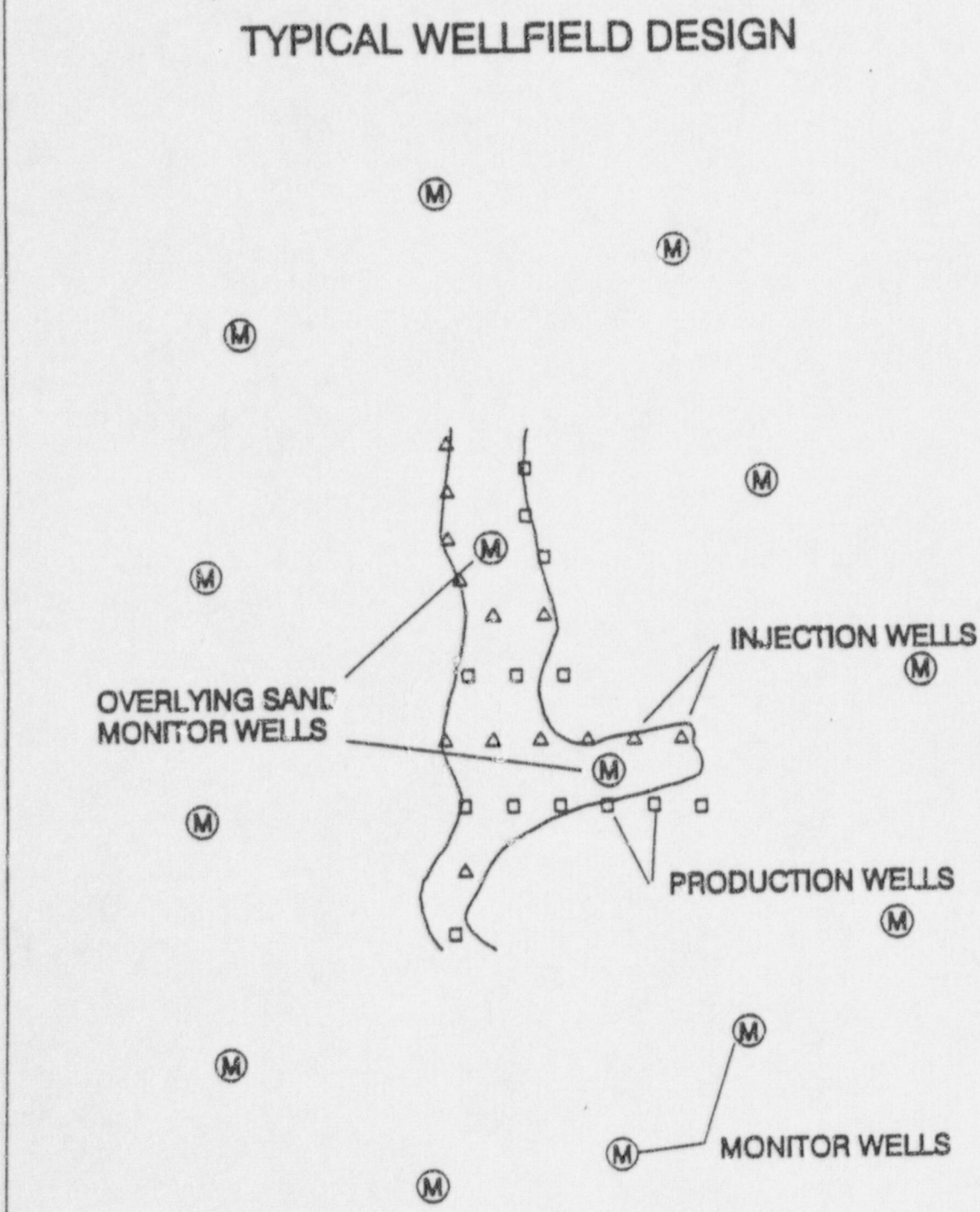
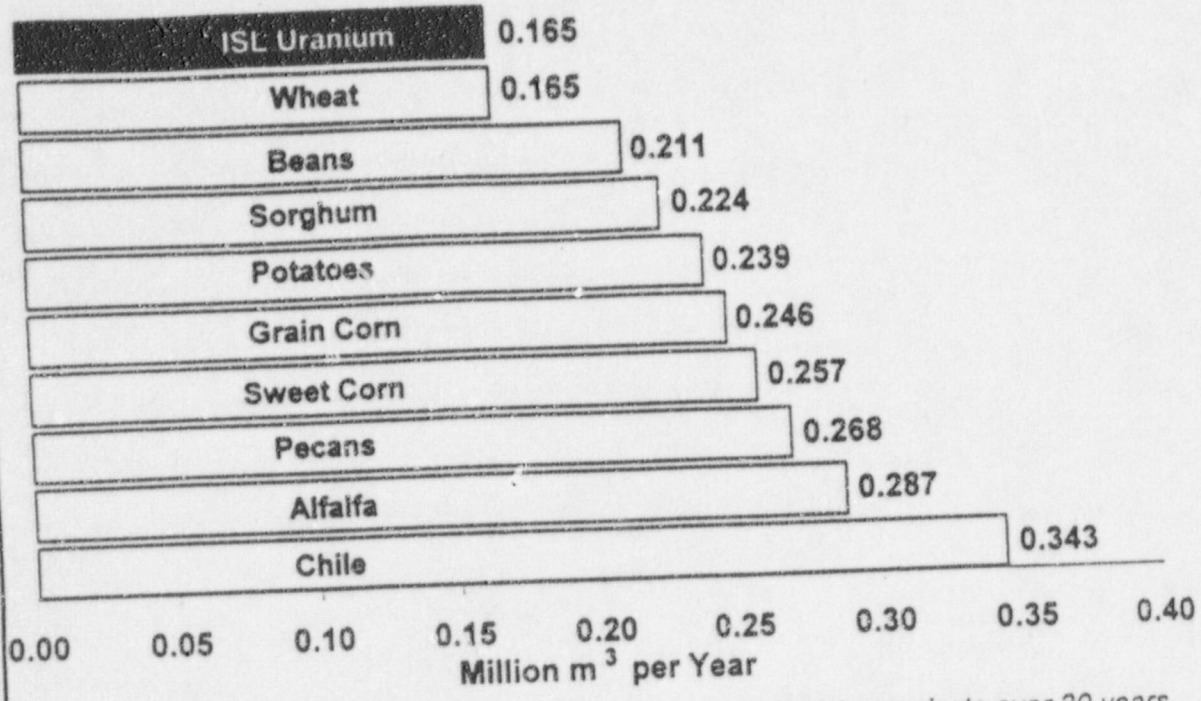


Figure 10: Comparative Consumptive Water Use
50 Hectares of Crops and ISL Mining



Based on 3.3 x 10^6 m^3 water requirement for all foreseen mining projects over 20 years
Restoration by reverse osmosis - 4 pore volumes
Source: USDA, Natural Resources Conservation Service, Grants, New Mexico, 1997

Table I:

Water Requirements for Crownpoint, Unit 1, and Churchrock [8]

Restoration Method	4 Pore Volumes (Millions M^3)	9 Pore Volumes (Millions M^3)
Groundwater Sweep	13	29
Reverse Osmosis	3.3	7.7
Brine Concentrator	0.03	0.07

Exhibit Q

attached: Phelps, Zexh and Huffman

A Basin Analysis Case Study: The Morrison Formation Grants Uranium Region New Mexico

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Seismic Studies in the Church Rock Uranium District, Southwest San Juan Basin, New Mexico

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A seismic reflection survey, using conventional field techniques and a computer-intensive data processing program, has identified basement structures that had an effect on the deposition of the uranium-bearing Upper Jurassic Morrison Formation. The structural style is one of block faulting defined by northwest- and northeast-trending high-angle normal faults with major periods of movement occurring in the Late Permian and Late Jurassic. The seismic survey, combined with detailed subsurface stratigraphic studies, shows that thickness and sand content of the Westwater Canyon Member increase within a downdropped block. Most of the deposits of the Church Rock uranium district are located within rocks of the Westwater Canyon Member in this block.

Introduction

This study is a test of the feasibility of using conventional seismic techniques to define lithology, structure, and unit thickness of the Upper Jurassic Morrison Formation in the San Juan basin, so that we can better understand the controls and describe the patterns of deposition.

Although many have studied sedimentology and stratigraphy at the outcrop and along the basin periphery, relatively little is known about the Morrison buried in the deeper parts of the basin. Yet because much of the uranium produced from sedimentary deposits in the United States has come from the Morrison Formation along the southern margin of the San Juan basin, the distribution and character of the Morrison deeper in the basin are potentially significant.

The study area of this report is the Church Rock district at the west end of the Grants uranium region, in the southwestern San Juan basin (Figure 1). The area is particularly suitable because the seismic lines cover a proven orebody for which there is excellent subsurface control from drill data. In addition, surface geologic mapping (Kirk and Zech 1976a, 1976b) and detailed subsurface stratigraphic studies (Kirk and Condon, this volume) have been completed in the area. Depths to the Westwater Canyon Member range from 656-2,300 ft (200-700 m). The orebody is within the Westwater Canyon Member of the Morrison Formation at a depth of approximately 1,930 ft (600 m) from the surface.

Fifteen miles (24 km) of 12-fold Vibroseis seismic-reflection data were collected and processed by the Department of Geophysics of the Colorado School of Mines, Golden, Colorado, under contract to the U.S. Geological Survey. The layout of the seven seismic lines was limited by access and steep canyon topography (Figure 2). A single vertical vibrator was used as an energy source, with a group spacing interval of 110 ft (34 m).

Geologic Setting

Topography of the study area is dominated by cuestas and cliffs formed by resistant Cretaceous sandstones. The major

uranium mined in the Grants uranium region and all the uranium in the Church Rock district is mined from this unit.

The Brushy Basin Member, the upper unit of the Morrison Formation, intertongues with the Westwater Canyon Member and is composed of greenish- to purplish-gray bentonitic claystone and sandy siltstone with lenses of fine- to coarse-grained feldspathic sandstone. The contact with the overlying Upper Cretaceous Dakota Sandstone is marked by an angular unconformity that bevels the Brushy Basin Member to the south.

Methods of Data Acquisition and Data Processing

The energy source for the 15 mi (24 km) of 12-fold Vibroseis seismic data was a single 13-ton, Litton model 311 vertical vibrator. The source array consisted of 10 sweeps spaced in a line, over a distance of 99 ft (30 m). The vibrator swept from 10-80 Hz for a period of 14 s (seconds), and a 220-ft (67-m) source interval was generally used. Each receiver group consisted of six equally spaced Geospace model 20D geophones in a linear array 91.6 ft (28 m) in length with a group spacing interval of 110 ft (33.5 m).

The data were recorded on a nine-track tape by a Texas Instruments DFS-V 48 - channel recording system. Each record was 16 s in length, including 2 s of listening time following each 14-s sweep. A 4-ms (millisecond) sample rate was used with an 83 Hz high-cut anti-aliase filter, and a 60 Hz notch filter was used on lines 1, 2, 3, and 7 in order to reduce powerline noise.

A split-spread line geometry was used with the vibrator located between traces 24 and 25. A 110-ft (33.5-m) gap existed between the source and the closest receiver group. At the beginning and end of each line, the vibrator moved in and out of the split spread in order to obtain the maximum common depth point (CDP) coverage.

The seismic data processing was done at the Colorado School of Mines, Golden, Colorado, on Texas Instruments TIMAP and Control Data Corp. CYBER 720 computers. The TIMAP computer used a Digicon SPRINT software package for the preprocessing phases of demultiplexing, cross-correlation, vertical summing, and sorting. All further processing was done on the CYBER 720 using C.G.G. seismic software.

Each field record was first demultiplexed and cross-correlated. After bias (DC) removal and binary gain recovery, the output consisted of 2-s, trace-sequential records. In the next phase, the 10 records per vibrator position were vertically summed to create one output record. A diversity stack algorithm was used to suppress high-amplitude noise. The final step of preprocessing involved the sorting of records into common depth point gathers. Since none of the seismic line traverses were straight, the X-Y coordinates of each line were added during the sorting operation to correct the source-receiver distance.

Field static corrections were calculated to compensate for elevation and near-surface velocity variations along each seismic line. Because neither refraction surveys nor uphole time from shot holes was available in this study, the first-break information on the field records was used to approximate the near-surface velocity distribution. The velocity of the weathering layer was derived from the inverse slope of the direct arrival event; calculations were made along each line wherever there was a detectable change in slope. Because of some difficulty in determining the intercept time of the first refracted event, a floating datum was used during processing and all lines were referenced to a flat datum in the final processing.

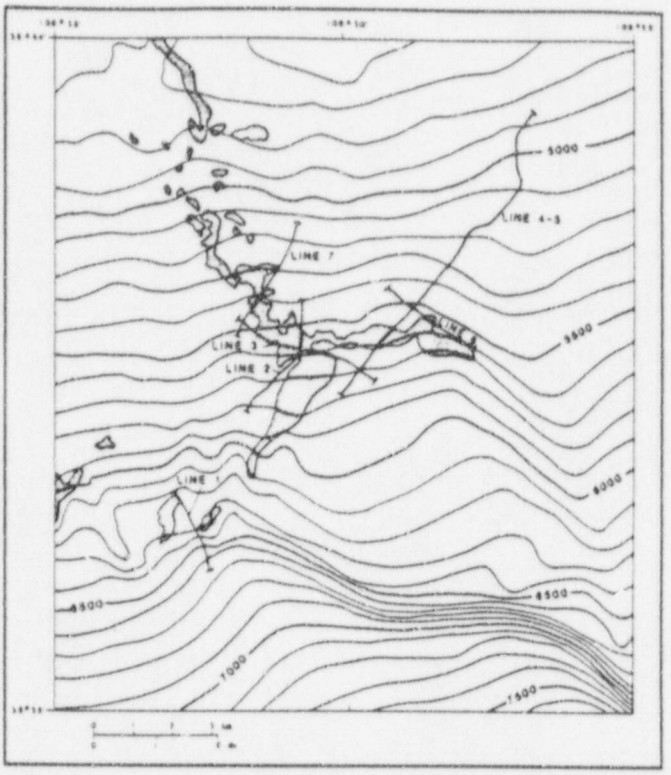

Figure 3: Structure contour map on the base of the Dakota Sandstone, with locations of uranium orebodies (pattern) and seismic lines. Contours in feet above sea level, contour interval 100 ft (30 m). (Modified from Kirk and Condon, this volume).

After the field statics were calculated, amplitude recovery, first-break muting, deconvolution, and filtering procedures were performed. Amplitude recovery consisted of two steps, a linear gain function and an automatic gain control. In addition, a spiking deconvolution operator was determined from a previously run test and applied to the data, followed by a 10-80 Hz bandpass filter.

The next step consisted of a velocity analysis and residual-static correction program. In the first pass of this step, the constant-velocity stacks were run along the entire length of each line and the velocity functions were determined by selecting the best stacked time-velocity pairs. A surface-consistent residual-statics program followed, and a second pass through the velocity analysis was completed. Final stacking velocities were determined by comparing the stacked sections and selecting the velocities that best focused the data. The final pass through the residual-static correction program was run with a spiking-deconvolution operation that improved the data.

A filter test and an inside mute test were used to improve the signal-to-noise ratio and coherency of the data. Coherency of the data was further improved by applying a coherency-weighted stack program. Before the final time variant filtering, wave equation migration and a filter test were run. As a final step, velocity (fan or dip) filtering was performed.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	THICK-NESS (m)	LITHOLOGY
Cretaceous	Upper	Mesaverde	Menefee Formation	Cleary Coal	20+	Shale, sandstone, siltstone
			Point Lookout Sandstone	Main body	12-88	Sandstone
				Hosta Tongue	24-40	Sandstone
			Crevasse Canyon Formation	Gibson Coal	84-114	Shale, sandstone, coal
				Bartlett	0-9	Shale, sandstone
				Dalton Sandstone	18	Sandstone
				Dilco Coal	46	Shale, sandstone, coal
			Gallup Sandstone		33	Sandstone
			Mancos Shale		205	Shale
			Dakota Sandstone	Twowells Sandstone Tongue	1-5	Sandstone
				Main body	27-48	Sandstone
			unconformity			
Jurassic	Upper		Morrison Formation	Brushy Basin	6-30	Claystone, siltstone
				Westwater Canyon	85-128	Sandstone
				Recapture	13-95	Claystone, sandstone
	Middle	San Rafael	Cow Springs Ss		50	Sandstone
			Wanakah Formation	Beclabito	18-23	Sandstone, siltstone
				Todilto Limestone	3-12	Limestone
			Entrada Sandstone	Upper sandy	61-70	Sandstone
				Medial silty	12-18	Siltstone
				Iyanbito	14-18	Sandstone
			unconformity			
Triassic	Upper		Chinle Formation	Owl Rock	5-12	Limestone, claystone, siltstone
				Petrified Forest	207-256	Claystone, siltstone, sandstone
				Monitor Butte	118	Claystone, siltstone, sandstone
			unconformity			
Permian	Lower		San Andres Limestone		33-42	Limestone
			Glorieta Sandstone		36-42	Sandstone
			Yeso Formation		396	Sandstone, siltstone
			Abo Formation		365-396	Sandstone, siltstone
			unconformity			
Precambrian						Gneiss, rhyolite, granite

Figure 4: Nomenclature, unit thickness, and lithology of rock units in the Church Rock area, New Mexico.

Data Interpretation

Correlating seismic events to the geology, delineating structure, and determining the direction of offset and timing of faults were the objectives of data interpretation. This was accomplished by integrating the seismic data with sonic logs, from which synthetic seismograms were made; with a velocity survey from a nearby basement test; and with isopach and net sandstone thickness maps of the Westwater Canyon Member provided by A. R. Kirk, U.S. Geological Survey (see Kirk and Condon, this volume).

Correlation

Seismic reflections were tied to geologic horizons by the use of synthetic seismograms and a velocity survey. Drill holes from which these data were obtained are the Pure Oil Co. Navajo No. 1, the Kerr-McGee Church Rock No. 135-36, the J. F. Maddox Long Shot No. 1, and the USGS Mariano Lake–Lake Valley No. 6 (see Figure 1 for locations).

On Figure 5, parts of the three synthetic seismograms are shown and correlated with parts of the seismic data. The Kerr-McGee Church Rock No. 135-36 well was closest to a seismic line, and its synthetic seismogram gave the best match. The Mariano Lake–Lake Valley No. 6 synthetic seismogram extends to the Middle Jurassic Todilto Limestone Member of the Wanakah Formation, a prominent seismic marker; the other synthetic seismograms extend only into the Westwater Canyon Member.

Differences between the synthetic seismograms and the seismic data can be attributed to lateral changes in geology over the several miles that separate the seismic data from the well data and to local variations in geology. Seismically, most of the contacts between Cretaceous units and some of the contacts between Jurassic units are gradational, making them difficult to recognize; only those horizons that have distinct seismic boundaries have been successfully correlated. The horizons that could be correlated include the Jurassic-Cretaceous unconformity and the Todilto-Entrada contact. The base of the Westwater Canyon has only been approximated, because its contact with the underlying Recapture Member of the Morrison Formation is locally gradational or interbedded.

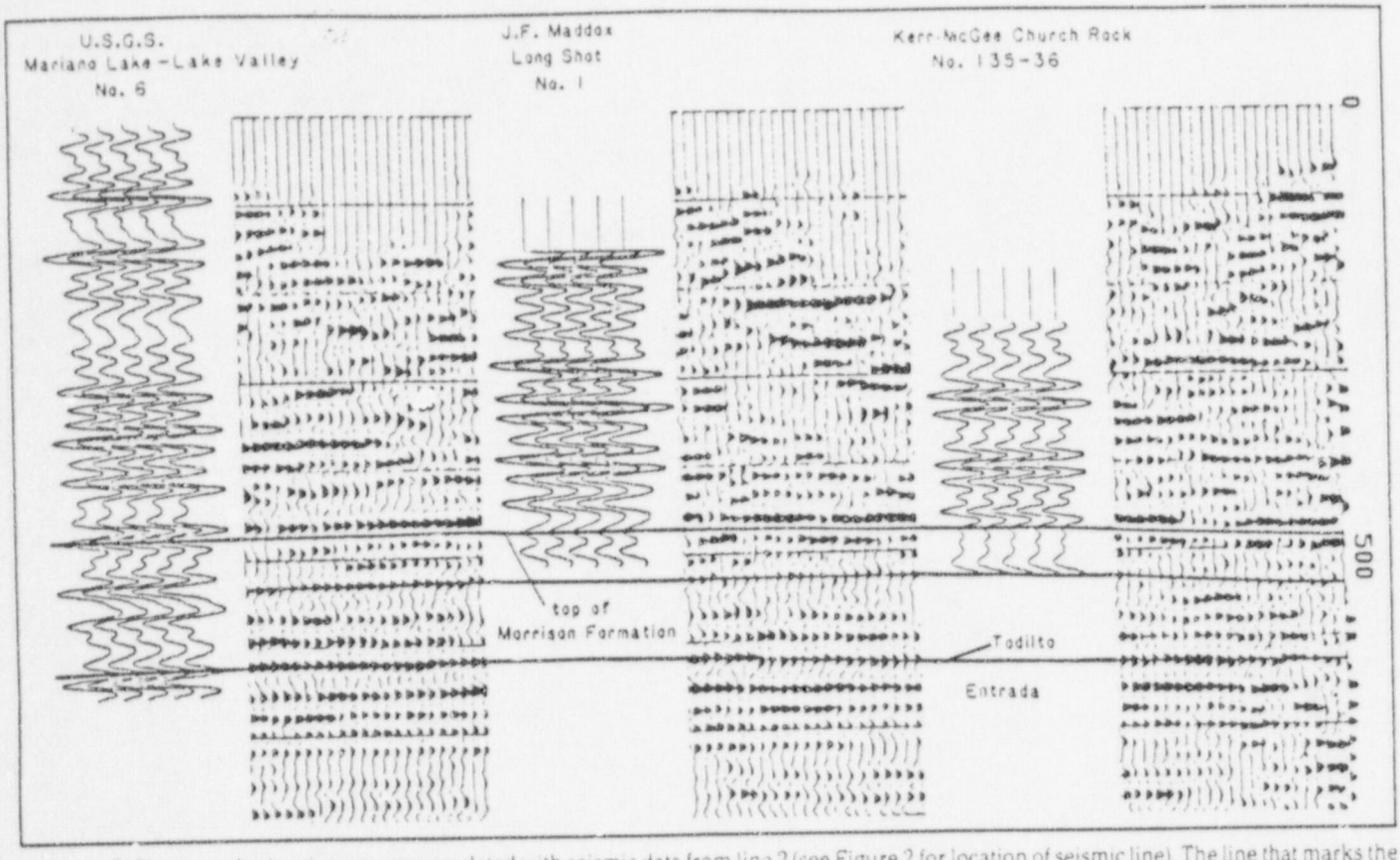

Figure 5: Three synthetic seismograms correlated with seismic data from line 2 (see Figure 2 for location of seismic line). The line that marks the top of the Morrison Formation is placed along a prominent trough.

A velocity survey was used to correlate key horizons below the Entrada Sandstone where the synthetic seismograms ended. The survey was obtained from the Pure Oil Navajo No. 1 well, located about 18 mi (29 km) northwest of the closest seismic line to it (Figure 1; line 2, Figure 2). A correlation of the survey with the seismic data constitutes Figure 6. The correlated horizons include the Triassic-Jurassic, Permian-Triassic, and Precambrian-Permian unconformities.

Structure

The structure of the study area, as interpreted from the seismic data, consists of a number of high-angle normal faults that cut northward-dipping strata. Most of the faults die out in the Permian rocks; however, several extend into Triassic and Jurassic rocks. The amount of displacement at the top of the Precambrian does not exceed 329 ft (100 m).

Drape folding or a dip change in the overlying sedimentary rocks is associated with prominent faults (Figures 7-10). On seismic line 2, fault A is downthrown to the northeast and extends upward into the Jurassic rocks (Figure 7). Approximately 230 ft (70 m) of displacement occurs at the top of Precambrian basement, but offset decreases to about 72 ft (22 m) at the Permian-Triassic unconformity. The same amount of displacement (72 ft or 22 m) occurs at the Entrada-Todilto interval, and displacement dies out beneath the base of the Westwater Canyon. The increase in dip or drape of the Westwater Canyon north of fault A appears to be directly related to movement along the fault.

Another prominent fault (fault B) crosses line 4-5 (Figure 9); the fault is down to the northeast approximately 252 ft (75 m) at the top of the Precambrian. The Permian-Triassic boundary and the Entrada-Todilto interval show about 79 ft (24 m) of displacement, and 38 ft (12 m) of movement can be detected at the base of the Westwater Canyon. Fault B does not appear to cut into Cretaceous rocks with any observable displacement, nor is there as much drape associated with this fault as with fault A.

A listric normal fault crosses line 4-5 in the vicinity of fault B (Figure 9) but is higher in the section (also visible on line 6, Figure 10). This style of faulting commonly results from penecontemporaneous sediment loading related to a change in depositional slope. Slight movement along fault B might have been responsible for the slope change that caused the listric fault to develop.

Other faults shown on the seismic lines do not appear to cut Jurassic rocks but have a dip increase or gentle drape associated with them. On line 4-5 (Figure 9), fault C is downthrown to the southwest with as much as 279 ft (85 m) of displacement at the top of the Precambrian basement. Very little if any displacement can be measured at the Permian-Triassic boundary. Jurassic rocks show very subtle draping over this fault; the Jurassic-Cretaceous unconformity shows even less drape.

Fault D on line 4-5 (Figure 9) and fault D on line 6 (Figure 10) have a similar displacement history and are interpreted to be the same fault with downward movement to the west. Displacement at the top of the Precambrian ranges from 124 ft (40 m) on the north end of line 4-5 to 197 ft (60 m) on line 6. Displacement

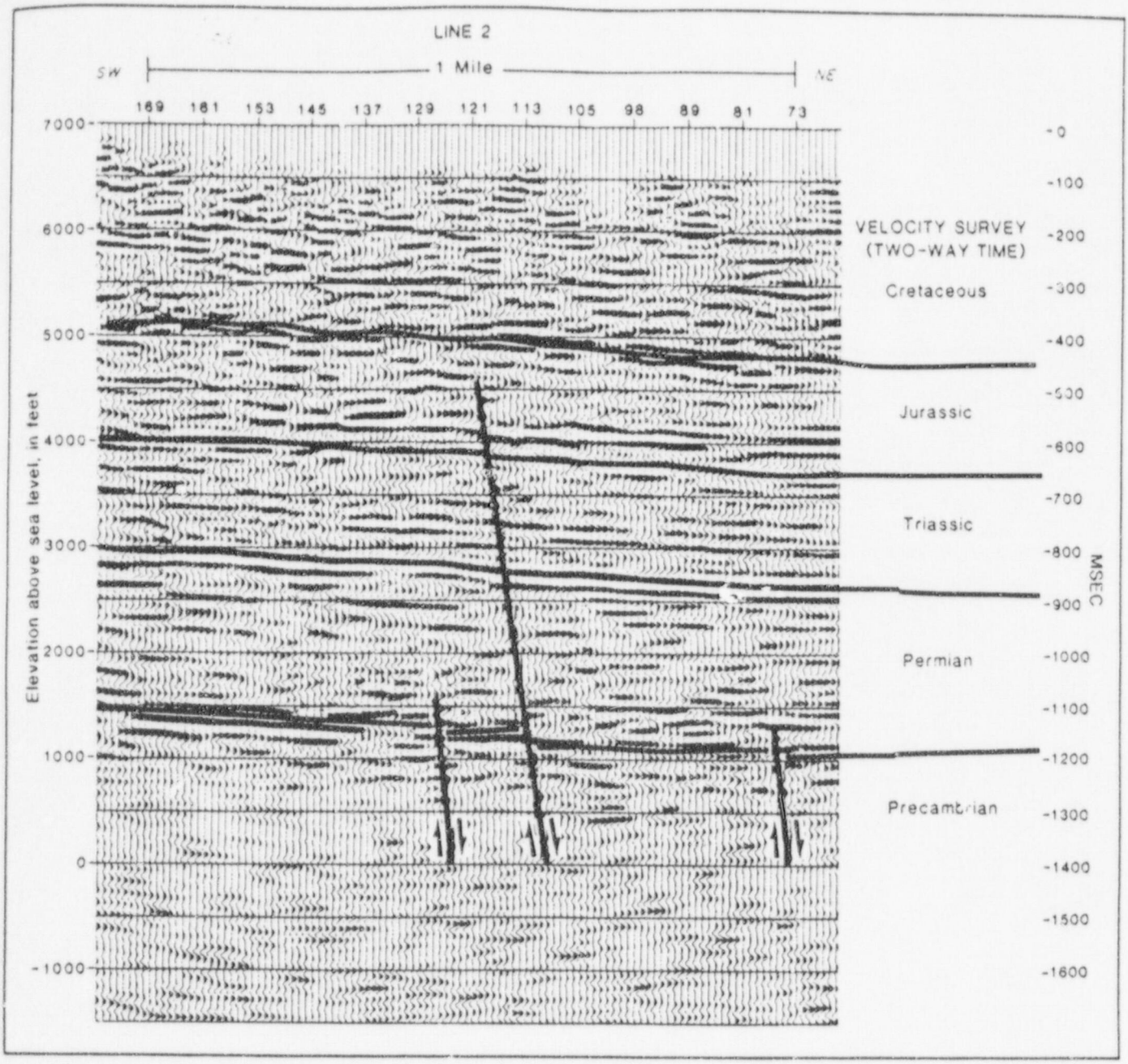

Figure 6: Seismic line 2 correlated with velocity survey from Pure Oil Navajo No. 1 well. Heavy near-vertical lines are faults; arrows show direction of movement.

dies out at the top of the Permian or within the lower part of the Triassic rocks. Both lines exhibit a significant increase in dip on the down side of fault D. Line 6 may show more dip than is actually present because of a possible improper replacement velocity used in the static corrections. Fault D may terminate or be offset to the southeast by fault B.

Line 7 (Figure 10) contains a fault at position B with displacement of about 171 ft (52 m), down to the north at the top of the Precambrian. As with fault D, there is an increase in dip in the rocks that overlie this fault. Displacement dies out within the Permian strata. Because of similar displacements, this fault has been considered an extension of fault B of line 4-5 on Figure 11.

Line 3 (Figure 8) contains no significant basement faults with any associated drape or slope change. Line 1 (Figure 7) contains several basement faults; one extends through most of the Permian section. The drape associated with this fault may actually be referable to another near-surface velocity problem not properly corrected in the datum statics.

Fault Orientation and Time of Movement

The orientation of the basement faults is difficult to determine because of the geometry of the seismic lines. Most of the signifi-

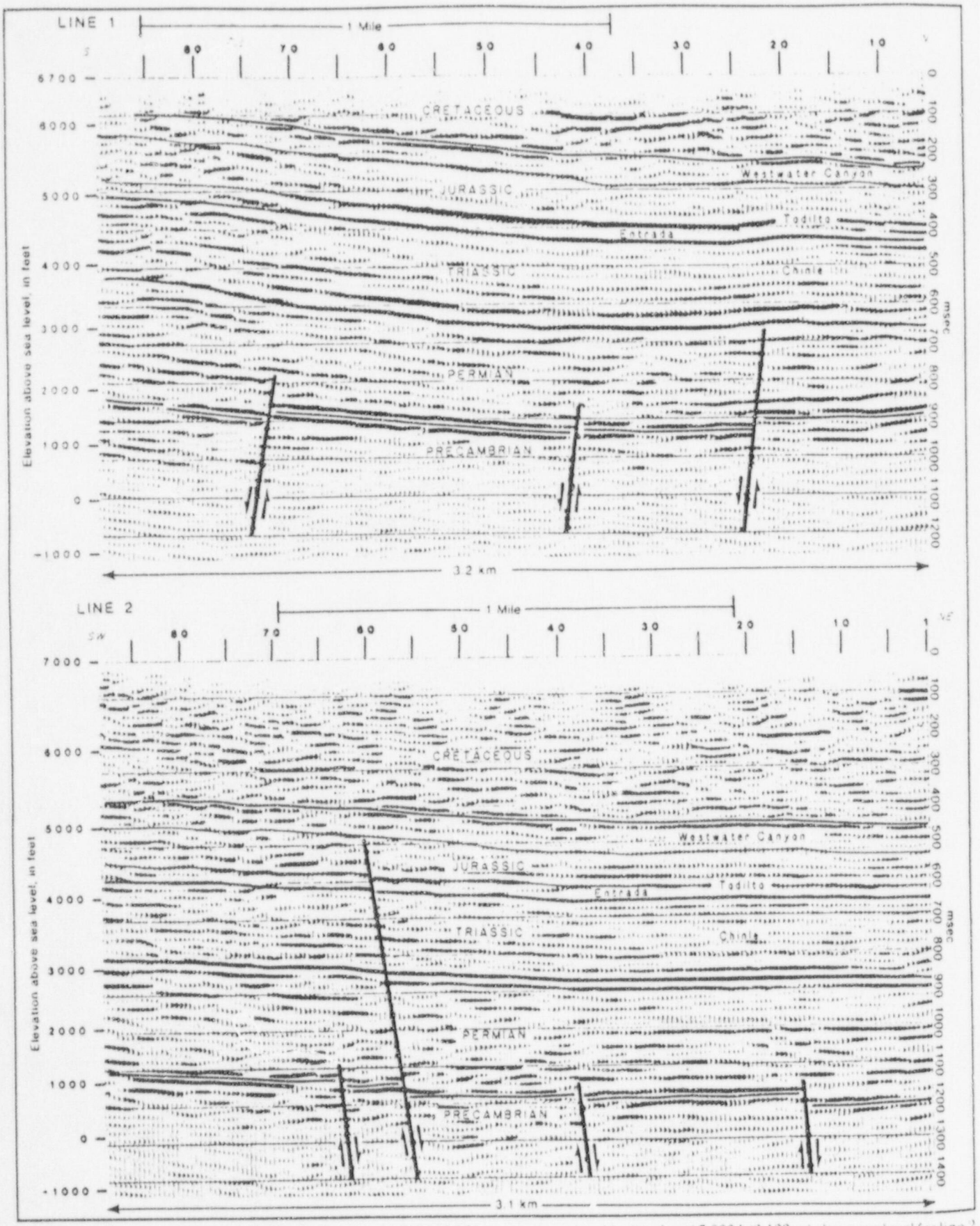

Figure 7: Migrated seismic lines 1 and 2. Datum plane 6,700 ft (2,050 m) above sea level for line 1 and 7,000 ft (2,133 m) above sea level for line 2 (see Figure 2 for locations of lines and shot points). Heavy lines are faults; arrows show direction of movement.

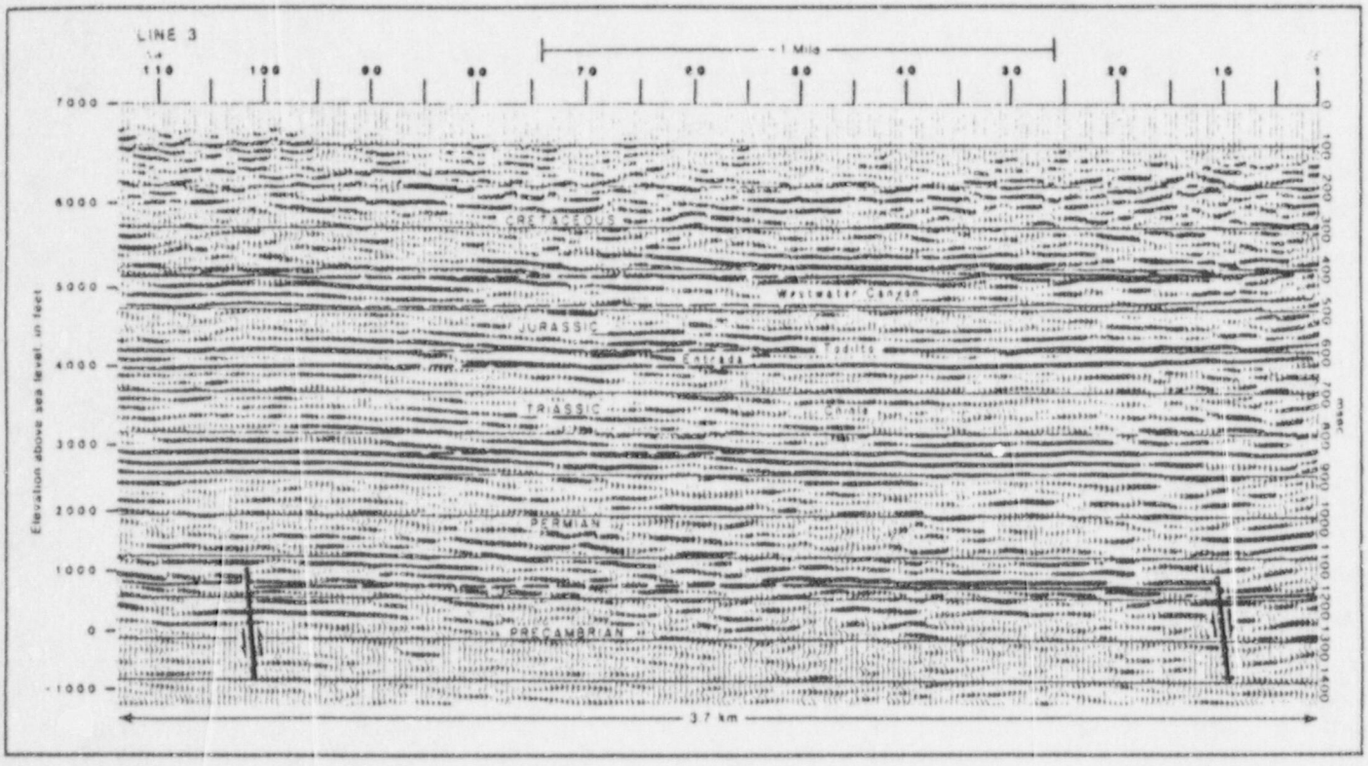

Figure 8: Migrated seismic line 3. Datum plane 7,000 ft (2,133 m) above sea level (see Figure 2 for locations of line and shot points). Heavy lines are faults; arrows show direction of movement.

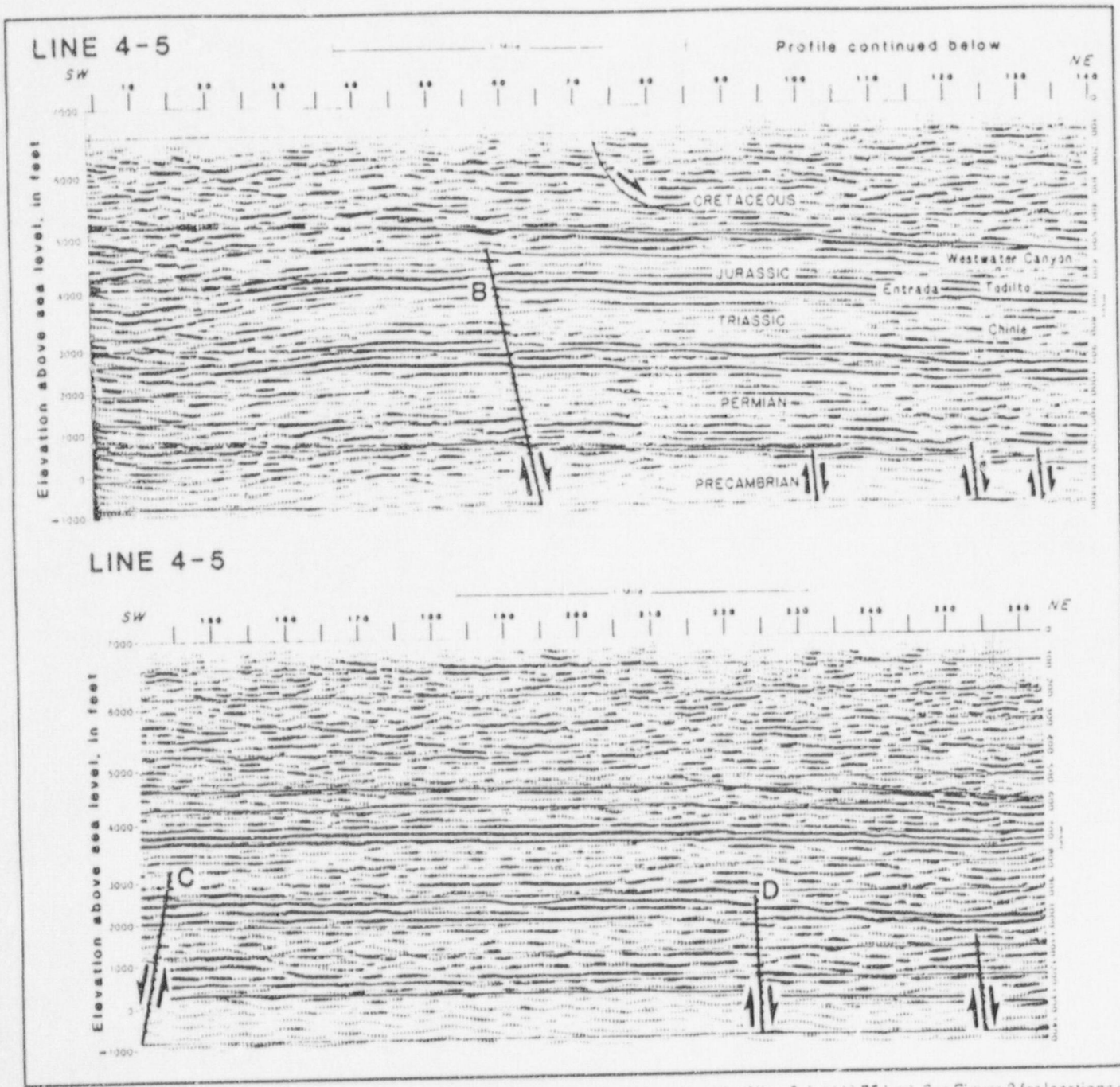

Figure 9: Migrated seismic line 4-5. Datum plane 7,000 ft (2,133 m) above sea level. Length of line 5.4 mi (≈ 75 km). See Figure 2 for locations of line and shot points. Heavy lines are faults; arrows show direction of movement.

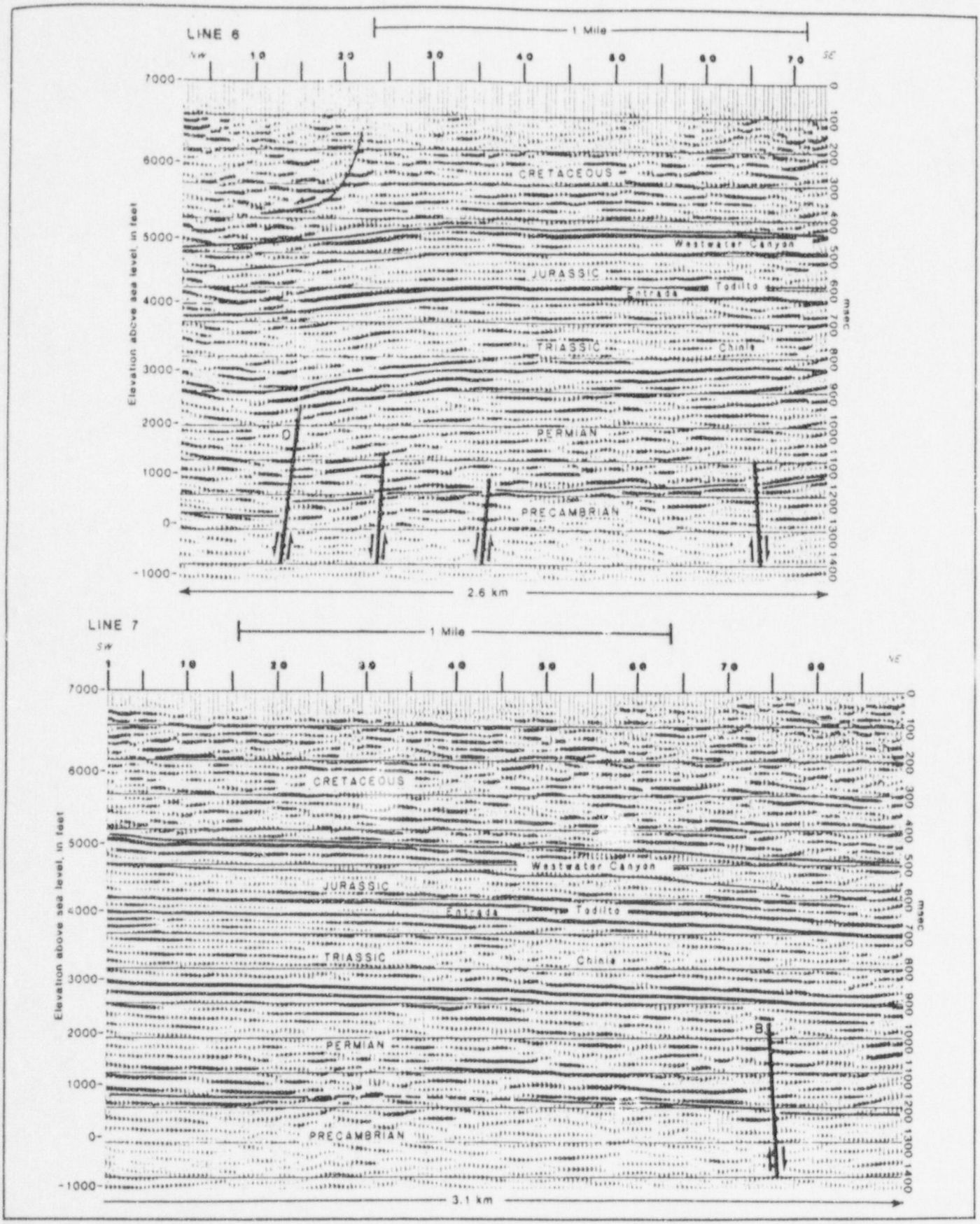

Figure 10: Migrated seismic lines 6 and 7. Datum plane 7,000 ft (2,133 m) above sea level (see Figure 2 for locations of lines and shot points). Heavy lines are faults; arrows show direction of movement.

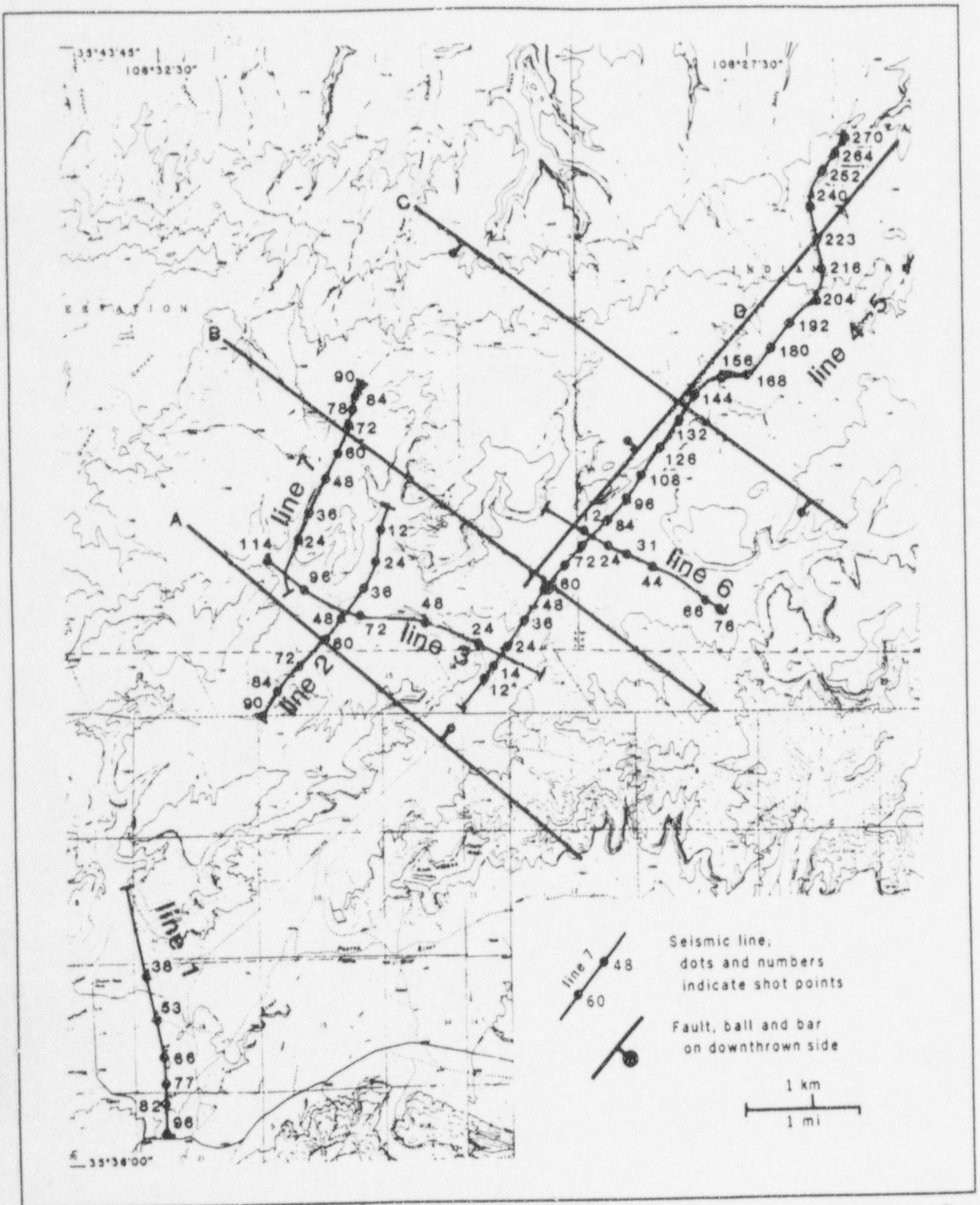

Figure 11: Location map showing faults, seismic lines, and shot points. Topographic base from U.S. Geological Survey Hard Ground Flats, Church Rock, and Oak Spring (1963) 1:24,000 quadrangles. Contour interval 40 ft (12 m).

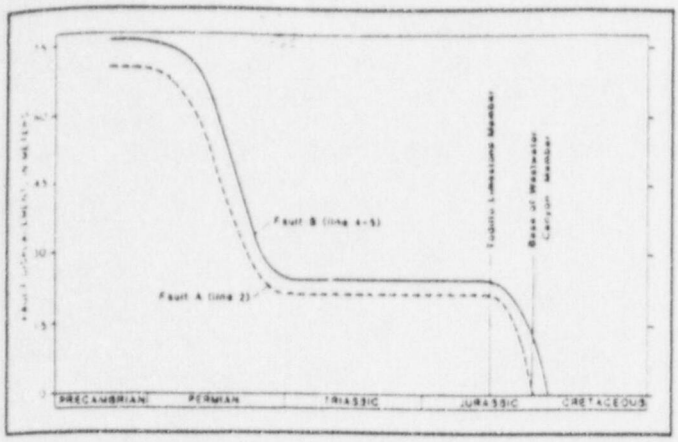

Figure 12: Diagram showing fault displacements plotted versus geologic time for faults A and B (see Figure 11 for locations of faults).

cant faults previously discussed do not cross more than one seismic line; thus the major fault trends are probably either parallel or perpendicular to the seismic lines.

Previously published data have helped establish general subsurface fault trends in the study area, even though available geologic and structural mapping as such shows little or no surface faulting. The fracture patterns in the vicinity of the study area have a predominant northwest and northeast strike (Kelley, 1957). Both Landsat (Knepper, 1982) and geophysical (U.S. Geological Survey, 1980; Suits and Cordell, 1981) studies demonstrate these to be the dominant directions of linear features both at the surface and in the basement. Baars and Stevenson (1977) observed similar fault directions in the pre-Carboniferous section of the northwestern San Juan basin. On a more regional scale, the Colorado Plateau has a northwest structural grain that may have developed as early as the Precambrian (Kelley, 1950). This structural grain most likely had a strong influence on later deformation on the plateau.

The fault pattern in the study area has been developed with a northwest-northeast bias in mind (Figure 11). The predominant trend of faulting is northwest-southeast, which corresponds to the structural grain just discussed. The displacements of the northwest-trending faults may be either up or down basinward (northeast). The one significant northeast-trending fault (D) is downthrown to the northwest. This fault is coincident with a linear valley along which most of line 4-5 runs, but it apparently does not cut line 3, so it is shown ending near fault B.

The direction of the faults that cut line 1 could not be established because of the isolation of this seismic line from the others. It is likely that these faults follow the same trends established for the other faults, based on evidence from Kelley (1950) and Knepper (1982).

The timing of fault movement for faults A and B was determined by plotting displacement from seismic information versus geologic time (Figure 12). This figure shows that fault movement occurred primarily in the Permian and Late Jurassic. Apparently these faults were inactive during the Triassic, because the amount of displacement is the same for the base and the top of this interval. The listric fault on line 4-5 may indicate that some fault movement occurred in the Late Cretaceous, but the seismic data showed no significant displacement above the top of the Jurassic.

Faults B and C are nearly identical in their displacement histories where they intersect line 4-5. The amount of displacement in the Permian section decreases upward from 230-247 ft (70-75 m) at the Precambrian contact to 61-76 ft (20-25 m) at the Triassic-Permian unconformity. The same amount of displacement is present at the Middle Jurassic Todilto Limestone Member. Neither fault shows any displacement above the Westwater Canyon. This indicates that 66-82 ft (20-25 m) of vertical displacement occurred along faults B and C between the end of Todilto time and the end of Westwater Canyon time. If fault B of line 4-5 is the same fault that intersects line 7, and if Permian displacement (164 ft or 50 m) is the same at both points, then Jurassic movement differed by as much as 66 ft (20 m) over a distance of 2 mi (3.2 km). Even if the differential movement were not this great, the east end has unquestionably moved at a different rate than the west end. Similar differences noted along fault D would produce a rotational movement in a block bounded by faults B and D.

Timing of the other faults was not as easily established. Most of the fault movement occurred in the Permian, but some displacement must have occurred later to account for the draping and dip changes associated with faults C, D, and E. Apparently the later movement was not significant enough to cause displacement in the Jurassic rocks, or else most of the displacement was taken up in the mudstones of the Triassic Chinle Formation.

Tectonic Control on Westwater Canyon Deposition

The possibility of tectonic influence on deposition of the Westwater Canyon Member of the Morrison Formation was studied by examining the relationship between fault patterns, fault timing, and the distribution of sandstone in the Westwater Canyon. Because the seismic survey is located within the area studied by Kirk and Condon (this volume), isopach, net sandstone, and other contoured parameters are available with which to compare the results. These compilations are based on outcrop measurements and abundant well control.

Parts of Kirk and Condon's isopach and net sandstone thickness maps (this volume) are shown in Figures 13 and 14, respectively, along with our major basement faults and seismic line locations. A thick zone of the Westwater Canyon that trends east-southeast across the study area can be seen on the isopach map. The Westwater Canyon reaches a maximum thickness of more than 393 ft (120 m) within this zone, and several miles southeast of this zone it thins to as little as 196 ft (60 m). These thickness variations are not due to pre-Dakota truncation, because the Brushy Basin Member is present within this part of the study area. Comparison with the net sandstone thickness map (Figure 14) shows areas of thick Westwater Canyon corresponding closely to the greatest amounts of sandstone.

The seismic data suggest the presence of a predominantly northwest-trending basement fault system (Figure 11). The fault history diagram (Figure 12) shows as much as 82 ft (25 m) of post-Todilto, pre-Late-Cretaceous fault movement on the two most prominent faults; the major isopach and net sandstone thicks are located on the downthrown sides of the basement faults (Figures 13, 14). Maximum development of these thicks is

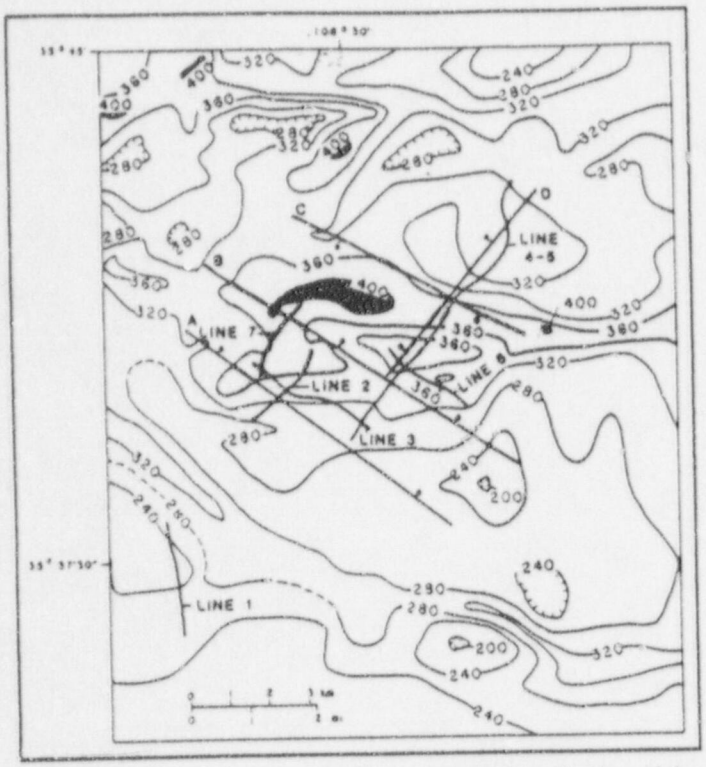

Figure 13: Isopach map of the Westwater Canyon Member of the Morrison Formation. Contours dashed where approximately located; contour interval 40 ft (12 m); shaded areas indicate thicker intervals; hachures indicate closed lows. (From Kirk and Condon, this volume).

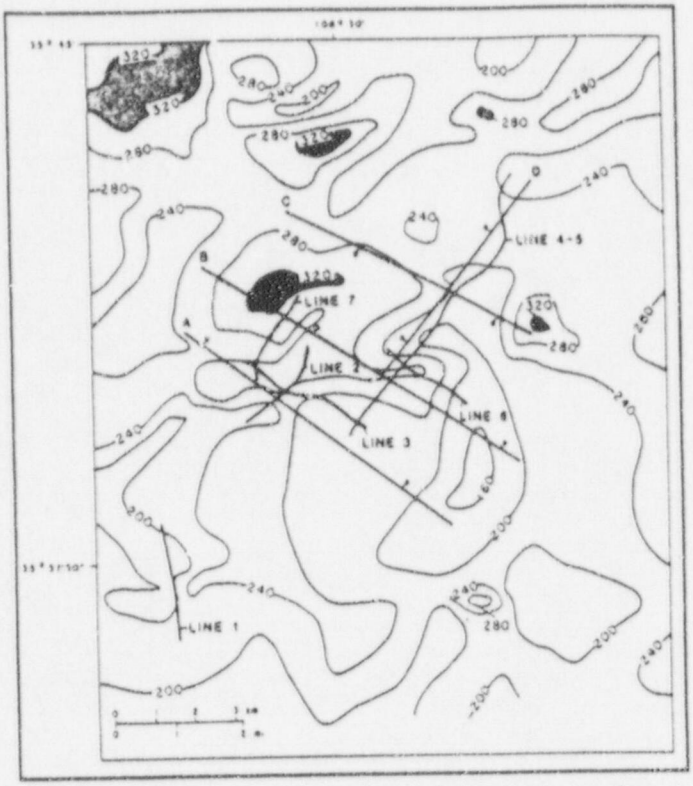

Figure 14: Net sandstone thickness map of the Westwater Canyon Member of the Morrison Formation. Contour interval 40 ft (12 m); shaded areas indicate greater sandstone thickness. (From Kirk and Condon, this volume).

largely confined to the graben block bounded by the northwest-trending faults B and C and the northeast-trending fault D (Figures 13, 14).

Conclusions

A seismic reflection survey, using conventional field techniques and a computer-intensive processing program, has defined structures in a study area of the San Juan basin that had a demonstrable effect on deposition of the Upper Jurassic Morrison Formation in an area of known uranium mineralization.

The structural style is one of block faulting with the bounding high-angle normal faults trending northwest and northeast. A number of faults offsetting the Permian were identified, but only a few extend into or affected the Jurassic. Cumulative movement on the northwest-trending set was generally down to the northeast. One notable exception is fault C (Figure 9), which is downthrown to the southwest, thus creating a compound graben between it and faults A and B (Figure 11). Movement on the northeasterly trending faults was down to both the northwest and southeast. The only fault that offsets the Morrison (fault D; Figures 9, 10) is downthrown to the northwest.

Movement on the major faults (A-D) was greatest in the Late Permian with lesser amounts in the Late Jurassic. There is no evidence of post-Jurassic movement on any of these faults, although the presence of a listric fault in the Upper Cretaceous immediately above one of the major faults suggests the possibility of some later movement. Seismic evidence for Late Jurassic movement is both direct, as in the offset along fault D (Figures 9, 10) or draping of Morrison sediments along fault B (Figure 9), and indirect, as in the dip reversal in the Westwater Canyon Member over fault C (Figure 9).

One of the major objectives of this study was to investigate possible structural control on sedimentation patterns in the Westwater Canyon Member. Taken alone, neither the seismic studies nor stratigraphic studies utilizing geophysical logs (Kirk and Condon, this volume) have sufficient resolution to reach this objective; however, various combinations of the two contain significant evidence bearing on the solution. The thickness of the Westwater Canyon increases dramatically in the downdropped blocks that are partially defined by faults A, B, C, and D (Figure 13), suggesting downward movement of the blocks during deposition. Moreover, the Westwater Canyon is sandier within these blocks than in the surrounding area (Figure 14), which further suggests that this was a depocenter.

In an attempt to further define the time of movement on these faults, similar techniques were used to compare the Brushy Basin Member with the fault pattern. No thickness or lithologic change is present to indicate any significant movement on any of the faults during Brushy Basin time. Data are insufficient to test for movement after Todilto time and before Westwater Canyon time, but stratigraphic evidence would suggest little or no tectonic activity before Recapture time.

Although seismic studies of the type described here could prove extremely valuable in understanding the depositional history and tectonic setting of the host units, no evidence bear-

ing directly on the location of uranium resulted from this study. A second phase of seismic investigations into areas of uranium mineralization will incorporate source, receiver, and processing improvements based on this study and will be in the area of Crownpoint, New Mexico, parallel to the Mariano Lake–Lake Valley drilling project (Kirk, Huffman, and Zech, this volume). Control for interpretation of the seismic data is better in this area, the layout of the lines is not as tightly constrained by topography, and the lines cross several known uranium deposits. The relationship of the various types of ore deposits to depositional environments is still poorly understood, but studies such as this, combined with ore deposit studies, hold considerable promise for determining primary ore controls.

Acknowledgments

The authors gratefully acknowledge the staff and individuals of the United Nuclear Corporation, Kerr-McGee Corporation, the Navajo Tribal Mineral Department, and the Bureau of Indian Affairs, who granted access to their properties and cooperated in the planning and logistics of the project.

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Exhibit R

CROWNPOINT URANIUM PROJECT
CONSOLIDATED OPERATIONS PLAN

HRI, Inc.
2929 Coors Road
Albuquerque, New Mexico

Revision 2.0
August 15, 1997

2-018

Churchrock Section 8 Mine Plan

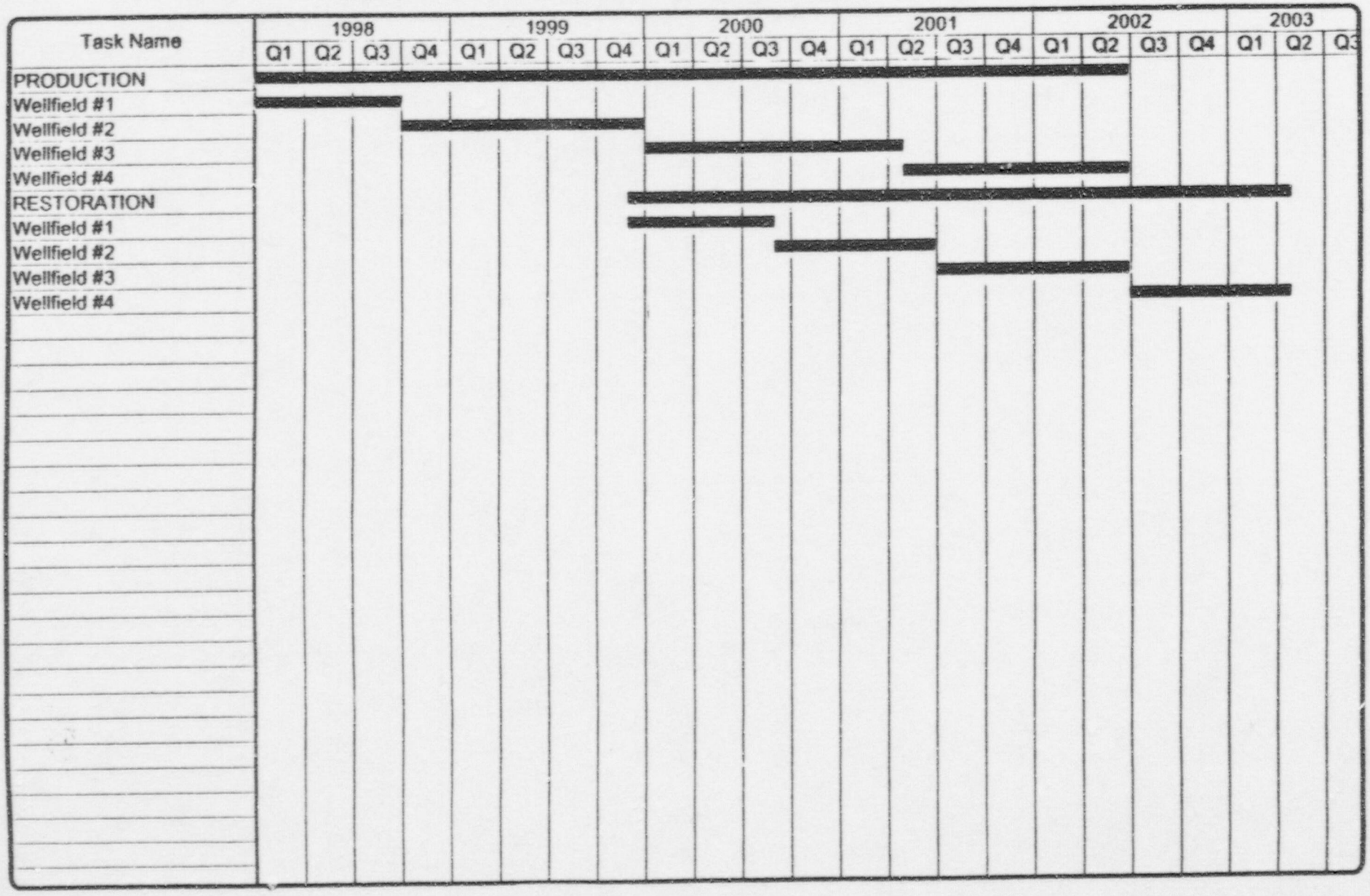

FIGURE 1.4-6

Churchrock Section 17 Mine Plan

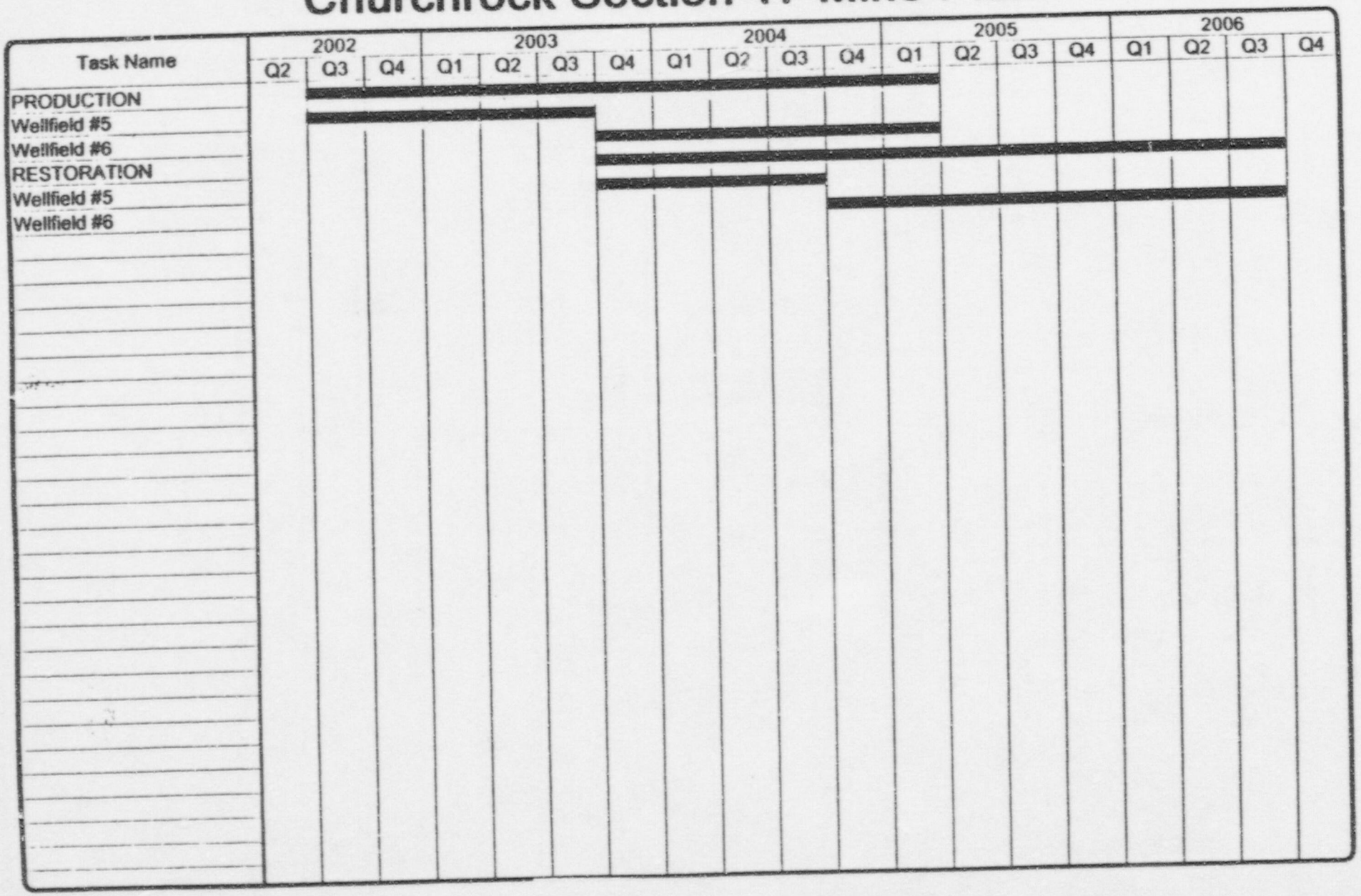

FIGURE 1.4-7

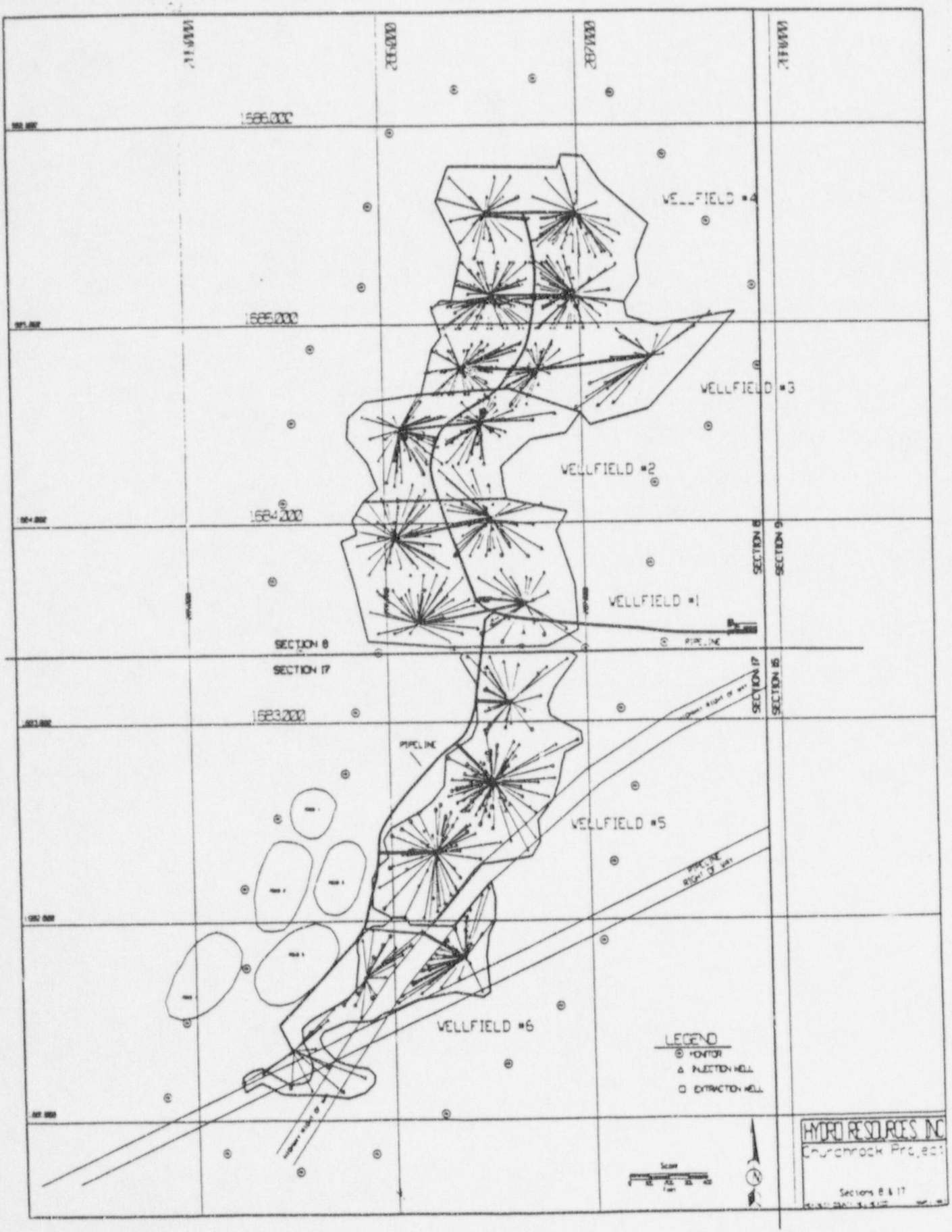
WELLFIELD #4
WELLFIELD #3
WELLFIELD #2
WELLFIELD #1
WELLFIELD #5
WELLFIELD #6
SECTION 8
SECTION 17
SECTION 16
SECTION 9
PIPELINE
LEGEND
MONITOR
INJECTION WELL
EXTRACTION WELL
HYDRO RESOURCES INC
Crawford Project
Sections 8 & 17

FIGURE 1.4-8

Exhibit S

40-8968

MEMORANDUM

TO: See Distribution List

FROM: Mark S. Pelizza

DATE: October 11, 1993

SUBJECT: **Replacement Pages to the Churchrock Project Revised Environmental Report, March, 1993.**

Please find attached, replacement pages for the subject report. These pages represent changes in the mine plan or editorial corrections which have been made since the report was initially distributed in March. Your report copy is updated by removing the old pages and replacing them with the attached pages. The pages numbers are the same for old and new.

The copy(s) of the subject report that will be given to the examiner at the upcoming NMED Public Hearing on October 26, 1993, will contain the attached corrected pages.

MSP

9312140083 encl+r

OFFICIAL DOCKET COPY

94-0022

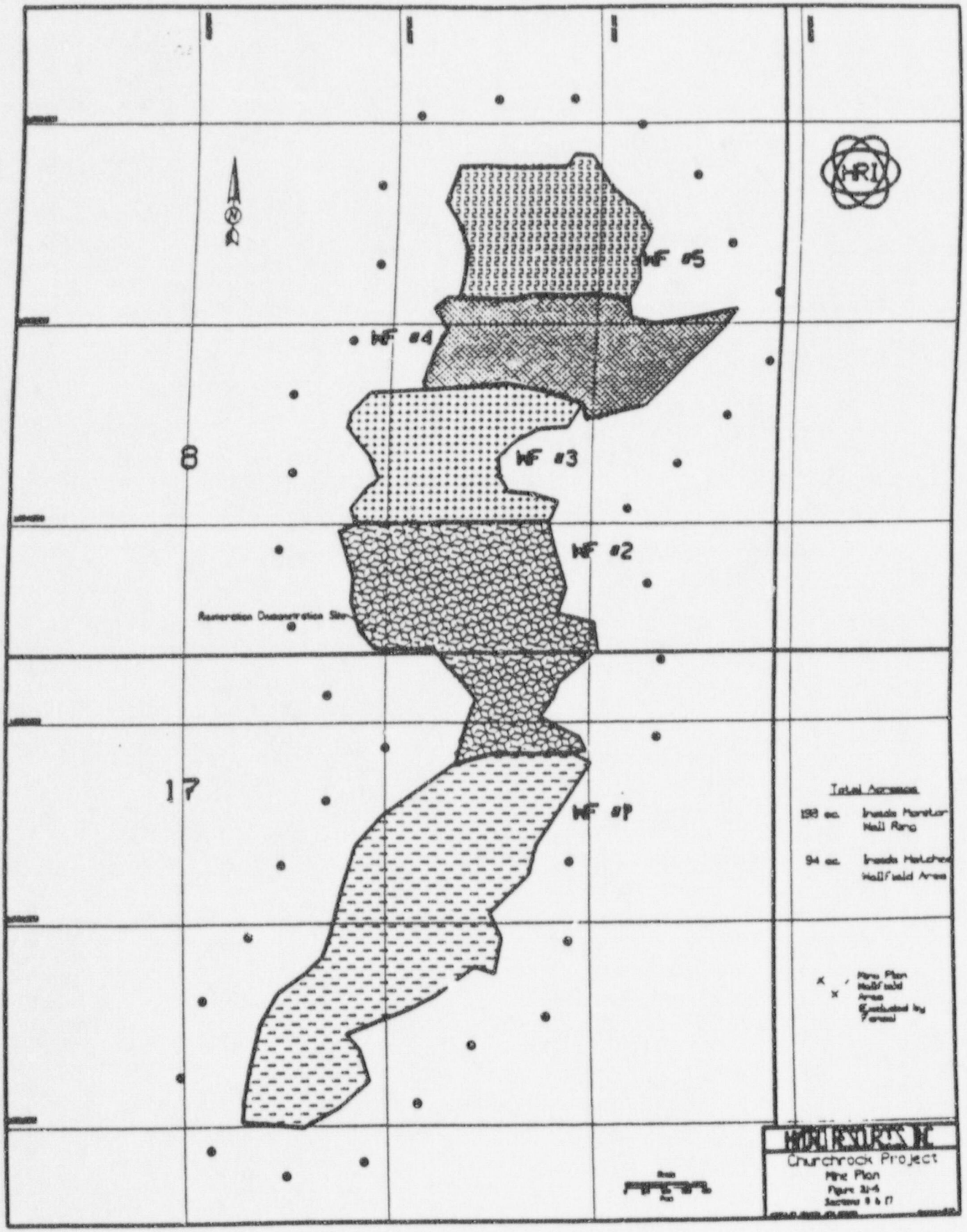
HF #5
HF #4
HF #3
HF #2
HF #1
8
17
Restoration Demonstration Site
Total Acreage
198 ac. Inside Monitor Well Ring
94 ac. Inside Hatched Well field Area
Mine Plan Well field Areas Evaluated by Permit
HRI
Churchrock Project
Mine Plan

Exhibit T

HRI, INC.

(A Subsidiary of Uranium Resources, Inc.)

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Crownpoint, New Mexico 87313
Telephone: (505) 786-5845
Fax: (505) 786-5555

Mark S. Pelizza
Vice President
Health, Safety and Environmental Affairs

February 4, 1997

Mr. James D. Walker
Environmental Engineer
Ground Water Office
U.S. Environmental Protection Agency
Region IX, 75 Hawthorne Street
San Francisco, California 94105-3901

RE: Notice of Deficiency - Operating Area #1

Dear Mr. Walker

The following is a response to your letter dated December 20, 1996, requesting additional information pertaining to the Operating Area #1 UIC Application. I have formatted these responses by first restating your question and then responding accordingly. Each response is tabulated.

Note that a number of responses are general in nature. However, they do form the basis for further discussion in our forthcoming meeting in Albuquerque.

Also attached herein is an agenda for the February 7 meeting in Albuquerque at HRI, Inc.'s offices. This agenda roughly follows the format of your letter and this response.

Thank you for your attention in this matter

Sincerely,

Mark S. Pelizza
Vice President
Health, Safety and Environmental Affairs

MSP/dlg
Encl.

cc: Mr. Ben Cohoe, Navajo Nation E.P.A.

1. Part X of the application form indicates that a permit for both Class III and V injection wells is requested. In addition, Section K includes the following statements: 1) *"product" or cleaned water is returned to the luxiviant injection or the formation outside the wellfield pattern* and 2) *Product water will be injected into Class IV wells which are part of this application.* Class IV wells are prohibited. We assume you meant to say Class V wells. You must submit a separate application for authorization of Class V injection wells. Injection wells within the existing wellfield pattern that receive product water retain their Class III well status. The discussion in this section is unclear and seems inconsistent with discussion of bleed water disposal in other sections. Please clarify your application on this point.

We agree that the reference should be Class V wells. We view these wells as a type of aquifer recharge well.

HRI use of Class V wells would be only for the treated process bleed. Fundamental to hydrodynamic control at a ISL wellfield is the net overproduction of leach solution or process bleed. By continually maintaining the process bleed (HRI expects this bleed to be 1% of capacity), a cone of depression is maintained around the production zone, thereby confining the leach solution to the target area. The bleed serves two purposes. Environmentally, it assure that affected water does not migrate from the orebody during mining. Economically, it assures maximum recovery of uranium bearing solutions.

The simple fact is that in order to maintain a bleed, the water must be managed. There are a number of choices available to ISL operators for managing bleed water. The aquifer recharge option being discussed here is one of those choices.

Restated the option: after the uranium is removed by the ion exchange the process bleed is removed from the luxiviant stream, it is treated by R.O. and the "product" or cleaned water is returned to the formation outside the wellfield pattern. The reinjected water quality will meet EPA drinking water standards or the quality of the receiving groundwater. Fundamental to the bleed concept is that the reinjection must take place outside the wellfield pattern to achieve its intended purpose. In terms of hydrodynamic control, it does not matter if the recharge occurs inside or outside the monitor well ring; it simply cannot be within the production pattern. This is why HRI did not include these wells as Class III.

Reinjection of bleed product water may offer some other benefits to hydrodynamic control. By targeting the location of reinjection an operator can increase the effect of the cone of depression (gradient into the production zone). In other words in the location where fresh water is being reinjected, the effect of the bleed will be compounded.

If HRI Class V wells are chosen to manage groundwater bleed, we will submit a separate application for Class V wells.

2. There is a reference to Q3's dated September 30, 1996 in the Introductory Statement of the application. We have not received that submittal. If it is intended to be included as part of the application, please forward a copy to EPA Region IX. In addition, it would be helpful in our technical review if you provided an index that cross references the questions and responses related to the DEIS comments to the permit application attachments.

Q3's are within Attachment 2-1.

It should be noted that response Q3 96 is out of date. We have agreed to a restoration goal of baseline average or the EPA drinking water standard on a parameter basis. A detailed discussion of the revised restoration criteria will be presented in the revision of the Consolidated Operations Plan. A copy of this revised plan will be submitted to EPA when complete.

Exhibit U

NUREG-1569

DRAFT
STANDARD REVIEW PLAN
for *In Situ* Leach Uranium Extraction License Applications

Manuscript Completed: September 1997
Date Published: October 1997

Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

been found acceptable by staff. The staff has decided that in areas with good water quality (a TDS less than 500 mg/L), setting the UCL at a value of 5 standard deviations above the mean of the measured concentrations is an acceptable approach. However, in some aquifers of good water quality, low chloride concentrations have been found to have such a narrow statistical distribution that a specified concentration (15 mg/L) above the mean or the mean plus 5 standard deviations approach, which ever is greater, has been used to establish the chloride UCL.

The same UCLs may be assigned to all monitor wells within a particular hydrogeologic unit in a given well field if baseline data indicate little chemical heterogeneity. Alternatively, if individual monitor wells in a given unit exhibit unique baseline water quality, UCLs may be assigned on a well-by-well basis. If UCLs vary from well to well, a table should be included listing all monitor wells and their respective UCLs.

(3) The applicant establishes criteria for determining monitor well locations. Ore zone perimeter monitor wells are used to detect horizontal excursions outside the well field boundary. They generally surround the entire well field and are screened over the entire ore zone hydrogeologic unit. Local groundwater gradients, velocity, and dispersion of the excursion indicators should be considered when choosing the location and spacing for these wells. A horizontal excursion may be more likely to occur downgradient from the well field due to the background gradient of the groundwater. As an excursion migrates away from the well field, it will tend to spread laterally due to dispersive processes. Excursions may also occur upgradient or crossgradient of the natural flow direction if the flow balance between production and injection wells is incorrect, or if flow velocities away from the well field are low enough that dispersion is the dominant transport process. The criteria should ensure that perimeter monitor wells will be placed close enough to the well field to provide timely detection, yet they should be far enough away from the well field to avoid numerous false alarms. They must also be spaced close enough to one another so that, by the time an excursion reaches them, the expected width of the excursion plume is likely to encounter at least one monitor well. In previous reviews, the NRC staff has commonly found the location of horizontal monitor wells to be acceptable if the wells were located ~~140~~ m (400 ft) from the edge of the production or injection wells with ~~140~~ m (400 ft) between each monitor well so that the angle formed by lines drawn from any production well to the two nearest monitor wells would not be greater than 75 degrees. The NRC staff has also approved horizontal monitor well locations based on a modeling demonstration that a theoretical excursion can be controlled at the monitor well locations within 60 days of excursion detection at a monitor well.

~ 122 M

Upper and lower aquifer monitor wells should lie within the well field and be completed in the appropriate hydrogeologic unit. Their location within the well field should not be arbitrary, and the technical basis for their selection should be discussed in the application. The appropriate number of these monitor wells may vary from site to site. It may be appropriate to exclude the requirement to monitor water quality in the underlying aquifer if (i) the underlying aquifer is a poor producer of water, (ii) the underlying aquifer is of poor water quality, (iii) there is a large aquitard between the ore zone and the underlying aquifer and few boreholes have penetrated the aquitard, or (iv) deep monitor wells would

Exhibit V

40-8706

HRI, INC.

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Crownpoint, New Mexico 87313
Telephone: (505) 786-5845
Fax: (505) 786-5565

April 5, 1996

Via Federal Express

Mr. Joe Holonich, Chief
High-Level Waste and Uranium Recovery Projects Branch
United States Nuclear Regulatory Commission
Division of Waste Management
Office of Nuclear Materials Safety and Safeguards
Mail Stop T-7-J9
11545 Rockville Pike
Rockville, MD 20850

RE: Request for Additional Information, Questions 92, Cost/Benefit Analysis for Hydro Resources, Inc. (HRI) Uranium Solution Mining License Application, Crownpoint, New Mexico.

Dear Mr. Holonich:

As promised, here are the responses to Question 92. There are three copies of of the response for each property; Churchrock and Crownpoint (in Volumes 1 and 2) and Unit 1 (in Volume 1 only). For continuity, I have placed one copy of the question and response in Volume 1 of each notebook.

Please give me a call if you have any questions.

Sincerely,

Mark S. Pelizza/dlg

Mark S. Pelizza
Vice President
Health, Safety and Environmental Affairs

MSP/dlg

NLOS 1/1

delete: PM
OC/LFMB
OGC/LEGD/LFFC

150037

9604260063 XA

ADDITIONAL INFORMATION REQUEST
HYDRO RESOURCES, INC. IN-SITU LEACH URANIUM MINE
CROWNPOINT, NEW MEXICO

ISSUE: Cost/Benefit Analysis

Comments Applicable to
UNIT 1 Site

92.

Discussion - The applicant provided much of the information necessary to conduct a cost/benefit analysis of the proposed project in the license application and supporting materials. However, staff need additional information to conduct cost/benefit analyses of alternatives to the proposed project and to make an economic comparison between the proposed project and alternatives.

Action Needed: Provide the investment costs and operating costs for the life cycle of each alternative described in the Description of Proposed Action and Alternatives (DOPAA, see Enclosure 2), including the proposed project. Provide the costs by major category (e.g., capital costs, operating costs) and by subcategory (e.g., land, labor, equipment, buildings, improvements such as roads, taxes, well production, restoration, reclamation, decommissioning, monitoring) for each major category. For each alternative, discuss and quantify the major causes of cost uncertainty. Provide a time profile of costs over the life cycle of each alternative so that costs can be discounted (i.e., provide information on when costs would occur relative to the beginning of the project).

Provide projected revenues for the life cycle of each alternative described in the DOPAA, including the proposed project. Discuss the uncertainty in revenues associated with each alternative and describe the factors that affect uncertainty (e.g., market conditions, quality of the product). Provide a time profile of revenues over the life cycle of each alternative so that revenues can be discounted and compared to costs.

Based on the cost and revenue information described above, evaluate and compare the life-cycle profitability and financial feasibility of each alternative, including the proposed project.

Response

Full cycle feasibility studies were compiled for each of the three New Mexico projects proposed by Hydro Resources, Inc. (HRI). Each study's economics is divided into five major cost categories. These categories include: Plant Capital, Wellfield Replacement Capital, Plant Operating Expense, Wellfield Operating Expense and Restoration and Reclamation. Each major category is further subdivided into costing classifications from which the company's accounting code is derived.

There are approximately 150 individual classifications contained within this set of codes which has demonstrated its effectiveness in budgeting over the past decade. This set of codes are further classified into eleven areas. They include; labor, auxiliary costs, environmental, well completion costs, chemicals, electrical, wellfield hardware maintenance, plant hardware maintenance, ancillary plant costs, yellowcake drying and handling, and vehicles.

Labor costs (subcodes 1-8) include all labor, hourly and salary assigned to the project. Auxiliary costs (subcodes 9-88, 100) consist of various fixed and variable costs associated with managing that portion of the project. They include; telephone, copier, licenses, travel, rental, ad valorem tax, insurance, postage, freight, advertising, legal, office supplies, and safety. Environmental costs (subcodes 90-99) contain charges associated

with routine monitoring, well plugging, and decommissioning/decontamination. Well completion costs (subcodes 101-127) consider all aspects and materials needed to drill and complete monitor, injection, and production wells. Chemicals (subcodes 190-210) needed for the recovery and mining process include; oxygen, hydrochloric acid, hydrogen peroxide, caustic, ion exchange resins, brine (NaCl), and biocides (Zn and Cu sulphates). Electrical cost (subcode 211) is a major cost component of production which is reported separately. Wellfield maintenance hardware costs (subcodes 220-230) contains all costs affiliated with the operations of an operating wellfield. These include; submersible pumps and motor, field piping and valves, oxygen delivery equipment, water meters, electrical panels and cables, and miscellaneous charges. Plant hardware maintenance (subcodes 250-260) include operation items necessary for the continuing processing of mine waters, and their mineral values, within the plant area. Such items include; pumps, tanks, instrumentation, plant electrical, filters, steel, and miscellaneous items. Ancillary plant costs (subcodes 261-275) comprise areas outside to immediate processing area. These areas include; roads, disposal (brine concentrator/disposal well) pipelines, gas, oil, reverse osmosis lab supplies, plant office equipment and furniture. Yellowcake drying and handling charges (subcodes 280-286) contain those costs with the processing, shipment, transportation, and fees related to shipping finished uranium oxide product. Finally, vehicles charges (subcodes 290-405) are defined. These charges include the maintenance of, and purchase costs for all mobile equipment required at the project.

For each category of operations (plant capital, wellfield replacement capital, etc.) a detailed monthly listing containing all subcodes detailed above, is presented for each or HRI's New Mexico projects, which provides corporate management a schedule of construction, mining, and restoration/reclamation. Marketing utilizes the estimated production rates and costs to gauge contract requirements and pricing. The company enters into long-term guaranteed contracts with domestic nuclear utilities based on this data.

Feasibility Model

The feasibility model is a projection of costs that a company would incur throughout the life of the project being studied. Geological, hydrological, ore kinetics, and processing equipment information are required to forecast estimated production rates, capital and operating costs, and staffing to insure a reasonable mining and permitting schedule. Exhaustive site and area information has been compiled and is contained within each project's feasibility study. With this information, plant and wellfield sizes can be designed to meet the specifications of the property.

Plant Capital Details

Each processing facility is designed to be a downflow ion exchange operation. A comprehensive cost tabulation, that utilizes cost details contained on a separate equipment specification sheet, is basis for the plant capital costs. All major items for the recovery facility have been specified and priced in 1996 dollars. These specific item charges are contained on the tabulation sheet opposite its chargeable subcode and month for which the equipment will be sited. Pumps, tanks, ion-exchange resins, brine concentrator, reverse osmosis, vehicles, piping and valves, filters, synthetic double-lined ponds, concrete, buildings, lab supplies, computers, and miscellaneous fixed costs (phone, electrical, postage, ad valorem tax, insurances, etc.) are all accounted for and contained on this report. Labor is detailed by job description at the heading of each month. This provides the basis for estimating the wages, salaries, insurance, and taxes applied.

Wellfield Replacement Capital

The second section of the feasibility assesses the work required to drill, complete and develop wells for the mining process. Comparable to the plant capital details, a cost listing of individual components associated with each type of well completion is detailed on the sheet titled Well Details. Each component bears a subcode to which the item is charged. The rate at which drilling progresses is based on the need to replace mined out reserves. Decline curves, which approximate the rate for which mining is expected, is detailed for each ore sand based on its average open interval of thickness, ore grade, tonnage factor, recovery factor, porosity, areal extent, and lixiviant circulation. This provides the company with the anticipate time required to mine various segments of the ore

deposit classified as "wellfields". All development costs chargeable to this segment are tallied in the same way that charges were assessed in the preceding plant capital details section.

Plant Operations Details

Plant operations commence upon completion of the first group of Class III wells and the recovery plant. Flowrate through the plant is based on the number of projected instantaneously operating production wells. As these wells deplete in uranium values, new operating wells are brought on-line for their replacement. This insures efficiency and maximization of the capital. The process of well replacement is replicated throughout the operating life of the project and becomes a function of the Wellfield Replacement tabulation.

All costs associated with the loading, eluting, precipitation,, filtering, drying, and packaging are charged to the project from which the uranium was recovered. These costs are contained within each study even though the actual precipitation, filtering, and drying might not occur at the project site of genesis. The Nuclear Regulatory Commission has requested that separate feasibilities be developed to forecast cost sensitivities of the following conditions:

1. Haul loaded resin to an adjoining HRI project site; i.e., Churchrock, Crownpoint, or Unit 1.
2. Ship yellowcake slurry to a centeralized drying facility at one of HRI's project sites.
3. Ship yellowcake slurry to URI's Kingsville Dome project for drying.
4. Each project is a stand alone unit where precipitation, filtering, drying and packaging is achieved.

Table I is a tabulation of all 12 cases.

	Churchrock	Crownpoint	Unit I
Haul Loaded Resin	$11.36	$9.46	$10.46
Ship Yellowcake Slurry	$11.32	$9.40	$10.48
Ship Yellowcake Slurry to Texas	$11.83	$9.87	$11.05
Stand Alone Project	$11.30	$9.38	$10.51

The lowest cost for each project is the stand alone case, except of Unit 1. Unit 1's total transportation costs for the 8 miles round-trip between Unit 1 and Crownpoint does not exceed the installation costs for all the needed equipment to facilitate elution precipitation, filtering, drying, and packaging. Transportation costs for the other projects exceeded the capital required for this same equipment.

Shipping yellowcake slurry to Kingsville, Texas requires the installation of another vacuum dryer at URI's Kingsville Dome project as that dryer is dedicated for URI's Rosita and Kingsville Dome projects.

The Plant Operating Details tabulations includes a section near the beginning that calculates the number of resin or yellowcake slurry trips for each month's projected production. Shipping to Kingsville for drying would require slurry storage tanks at each New Mexico project to handle the surges in production. This correspondingly would retard making timely deliveries of dried material to the customer. The distance from Gallup to Kingsville is approximately 1,175 miles transversing though Albuquerque, New Mexico and San Antonio, Texas.

Hauling resin from one HRI New Mexico project site to another will aid employment in the area for professional truck drivers, as in all instances, multiple daily resin trailer transfers will be required.

All costs associated with the integral operation of the recovery plant are inclusive in this section of the feasibility. Chemical and electrical demands and projected price are detailed on the Chemical Detail sheet.

Wellfield Operating Details

All charges for operating the wellfield department are tallied in this section of the report. many costs are pro-rated on the number of operating wells or the flow produced from the wellfield. Again, as in the other sections that make up the overall feasibility, fixed and variable costs have been assigned accordingly.

Sustaining flowrates through the ion exchange recovery plant, new wells are brought into production as required. Depleted wells are shut-in prior to being placed into restoration. Restoration is scheduled to commence shortly after mining in defined areas has ceased.

Restoration and Reclamation

The Restoration and Reclamation schedule provides a restoration fluid balance based on circulating four pore volumes of processed water through the mine-out reservoir. In each of the twelve cases provided, a brine concentrator has been employed to treat brine generated from a reverse osmosis unit. Restoration waters are first introduced to ion exchange to remove any trace amounts of uranium. The solutions are then "ionically filtered" using reverse osmosis. The larger purified volume portion is returned to the wellfield area and reinjected. Brine generated from the reverse osmosis process is "distilled" inside a brine generator thereby producing additional quantities of pure water for wellfield injection. The resulting slurry rejected by the brine generator is very small in overall volume. It is directed to double-lined hypolan ponds for storage. The solids will later be transferred to an approved site.

All costs associated with the pumping, treatment of wellfield solutions are accounted. Plugging of all production wells occurs 15 months after restoration for selected areas have been achieved. Just prior to the last wellfield plugging, reclamation of the surface recovery structure commences.

Conclusion

Each feasibility is very complete and addresses each question from the NRC contained within their Question 92. A discussion on the future of the uranium market can not be provided by this author. I believe history has demonstrated that there are no accurate and true market forecasters. Based on other uranium projects, the author has evaluated over the past 20 years, the properties controlled by HRI are expansive, average grade of ore is high, and the full cycle economics make them one of the lowest-cost deposits in the United States.

Hydrology & Geologic

Ore Thickness	11.489877 :	Total Lbs. U3O8	10414268
Open Interval	11.49 :	Recoverable Lbs.	6,769,274
Width	158 :	Total Pore Vols.	
Depth	825 :	To Recovery	40
Porosity	0.25 :	Average PPM	92.33
Cu.Ft./Ton	15.9 :	GPM/Well	14.92
Length	33,100 :		
PV Factor	1.95 :	No. of Producers	868
%Overlap	0 :	No. of Injectors	834
Average Grade	0.138 :		
GT	1.58 :		

Hydrology & Geologic

Ore Thickness	9.15 :	Total Lbs. U3O8	7,316,655
Open Interval	10 :	Recoverable Lbs.	4,755,826
Width	139 :	Total Pore Vols.	
Depth	2100 :	To Recovery	40
Porosity	0.2 :	Average PPM	149.29
Cu.Ft./Ton	15.87 :	GPM/Well	40
Length	25,629 :		
PV Factor	1.95 :	No. of Producers	305
%Overlap	0 :	No. of Injectors	302
Average Grade	0.178 :		
GT	1.63 :		

Hydrology & Geologic

Ore Thickness	9.02 :	Total Lbs. U3O8	19,416,107
Open Interval	10 :	Recoverable Lbs.	12,620,470
Width	126 :	Total Pore Vols.	
Depth	2100 :	To Recovery	40
Porosity	0.2 :	Average PPM	140.91
Cu.Ft/Ton	15 :	GPM/Well	40
Length	80960 :		
PV Factor	1.95 :	No. of Producers	823
%Overlap	0 :	No. of Injectors	767
Average Grade	0.158 :		
GT	1.43 :		

Exhibit W

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Fax: (505) 786-5555

April 1, 1996

40-8968

Mr. Joe Holonich, Chief
High-Level Waste and Uranium Recovery Projects Branch
United States Nuclear Regulatory Commission
Division of Waste Management
Office of Nuclear Materials Safety and Safeguards
Mail Stop T-7-J9
11545 Rockville Pike
Rockville, MD 20850

RE: Request for Additional Information, Questions 49-91, Water Resources and Protection and Cost/Benefit Analysis; Safety Analysis Review and Environmental Review for Hydro Resources, Inc. (HRI) Uranium Solution Mining License Application, Crownpoint, New Mexico.

Dear Mr. Holonich:

Please find attached the responses to the subject request for additional information. The response to question #92 will be mailed under separate cover.

The responses addressed herein cover many different technical concerns, however, they all are centered around two basic questions pertaining to the proposed mining operations, namely:

1. Can water be controlled during mining?

2. Can restoration be accomplished after mining is completed?

In the case of the Crownpoint properties, these questions require careful consideration due to the location of the community water supply wells.

We believe that our operations will not affect water supply wells because mine solutions cannot reach them during mining activities. We have documented through conservative model output in these responses, that under static conditions, (i.e., mine or restoration bleed is shut off) that water in the Crownpoint mine zone would require 35+ years to migrate to the closest community water

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1/1

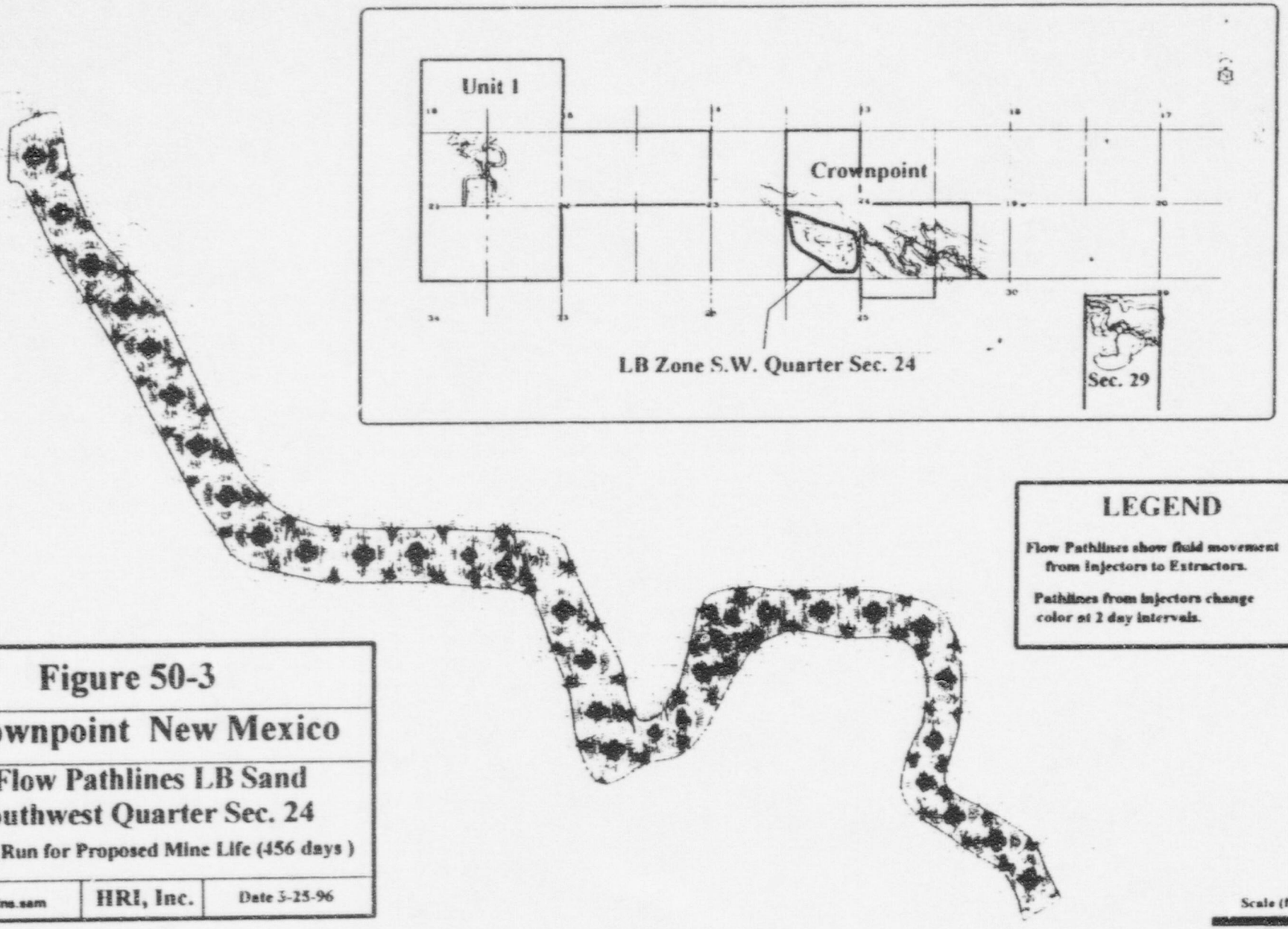

Figure 50-3

Crownpoint New Mexico

Flow Pathlines LB Sand
Southwest Quarter Sec. 24

Model Run for Proposed Mine Life (456 days)

File: Strwlns.sam	HRI, Inc.	Date 3-25-96

Exhibit X

STAFF TECHNICAL POSITION PAPER

GROUNDWATER MONITORING AT URANIUM IN SITU SOLUTION MINES
#WM-8102

Uranium Recovery Licensing Branch
U.S. Nuclear Regulatory Commission

December 1981

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underlying aquifers. The system as presented should be modified to suit unique conditions. Two linear arrays consisting of eight wells each and two wells near the boundary of the ore body are completed in the ore-zone aquifer, and three wells each are installed in both the overlying and underlying aquifers. The ore-zone wells describe baseline water quality conditions within approximately 250 ft (76 m) on either side of the ore body. Because baseline data is needed for all operational excursion groundwater monitoring wells and a representative group of injection/recovery wells, it is recommended that wells used to collect preoperational baseline water quality data serve this multiple purpose. Frequency of analysis and baseline indicators are discussed in Part IV.

D. Operational Excursion Groundwater Monitoring Locations

Monitoring wells are necessary at all uranium in situ solution operations to detect any flow of lixiviant from the ore zone of the wellfield area. The toxic composition of the lixiviant due to the presence of acid or alkaline solution, excessive dissolved solids, uranium, and/or low concentrations of heavy metals such as arsenic, selenium, and vanadium, necessitates its confinement to the ore zone within the mining area. The high value of the uranium laden lixiviant provides additional incentive for control and recovery of pregnant lixiviant.

Currently, the primary means of detecting excursions is sampling and analyzing the changes in groundwater quality surrounding the area being leached. While water level data may be an early indicator of an excursion, water level data alone have not been used to define an excursion. Water level data and water quality samples are obtained through a series of wells tapping the perimeter of the uranium strata and the immediately adjacent overlying and underlying aquifers.

The excursion-monitoring system should be designed to detect excursions of lixiviants into the ore-zone aquifer outside of the wellfield area being leached, and into aquifers above and below the ore-zone aquifer both within and outside of the wellfield area (Figure 3). Monitor wells installed to collect hydrologic and water-quality baseline data should be incorporated into the excursion monitoring system.

Premining aquifer test(s) results and other data should be used to determine the extent of monitoring required in aquifers above and below the ore-zone aquifer. For example, if an aquifer test(s) shows no evidence that an adjacent aquifer is susceptible to excursion from the ore-zone aquifer, the need for extensive monitoring of that adjacent aquifer during mining is decreased. As a precaution, however, monitor wells should at least be constructed in whichever adjacent aquifer has a water level or potentiometric level that is lower than the water level in the ore-zone aquifer. As an additional level of safety, monitor wells should also be constructed into any other surrounding water-bearing units, particularly if the unit(s) are or could be used as a water supply source.

Excursion monitoring within an ore-zone aquifer can be accomplished using two tiers of monitor wells as illustrated in Figure 3. Wells are installed 50 ft (15 m) and 250 ft (76 m) outward from the outermost injection wells. The location of the monitor-well tiers should correspond to locations used to collect premining water-quality data. This is necessary because baseline data will be needed to set upper control limits for the excursion-monitor wells. In addition, the location of monitor wells should be selected to provide meaningful data for the water-level monitoring program.

Locations and numbers of ore zone monitor wells (i.e., distance from the wellfield area and directional distribution) should be based primarily on the transmissivity and anisotropy of the ore zone aquifer, with greater numbers of monitor wells located in zones of major transmissivity and aligned in the principal flow directions. The number of monitor wells should be such that an excursion can be detected early before lixiviant has traveled significant distances outside the wellfield.

The procedure generally followed to detect excursions of lixiviants during mining is to collect water-quality samples from monitor wells located 200 to 400 ft (61 m to 122 m) from the well field. However, since the hydraulic properties of most ore-zone aquifers are such that the natural groundwater flow rate is very slow, even with the addition of pressure provided by injection of lixiviants, there is little likelihood of detecting water-quality changes in widely spaced monitor wells unless a large volume of material has escaped over a long period of time. Thus, trend wells or perimeter monitor wells located approximately 50 feet from the ore zone or at the ore zone perimeter are generally necessary for early detection of excursions.

E. Post-Operational Groundwater Monitoring Locations

The post-operational groundwater monitoring system should be designed to monitor the water quality in the production zone and any surrounding zones affected by mining operations (i.e., zones contaminated as a result of production excursions, evaporation pond leaks, waste disposal practices, etc.). Post-operational monitoring includes monitoring during restoration as well as several months after restoration operations have ceased (generally 6 to 12 months or longer, until the water quality has stabilized and reached equilibrium).

During restoration the groundwater monitoring plan should consist of water quality sampling and water-level measurements taken at the following locations:

1. All operational excursion groundwater monitoring wells.

2. All (or those most representative) injection/recovery wells which were used in the preoperational (baseline) groundwater monitoring program.

3. Any additional ore-zone aquifer wells necessary to accurately assess the effectiveness of restoration operations.

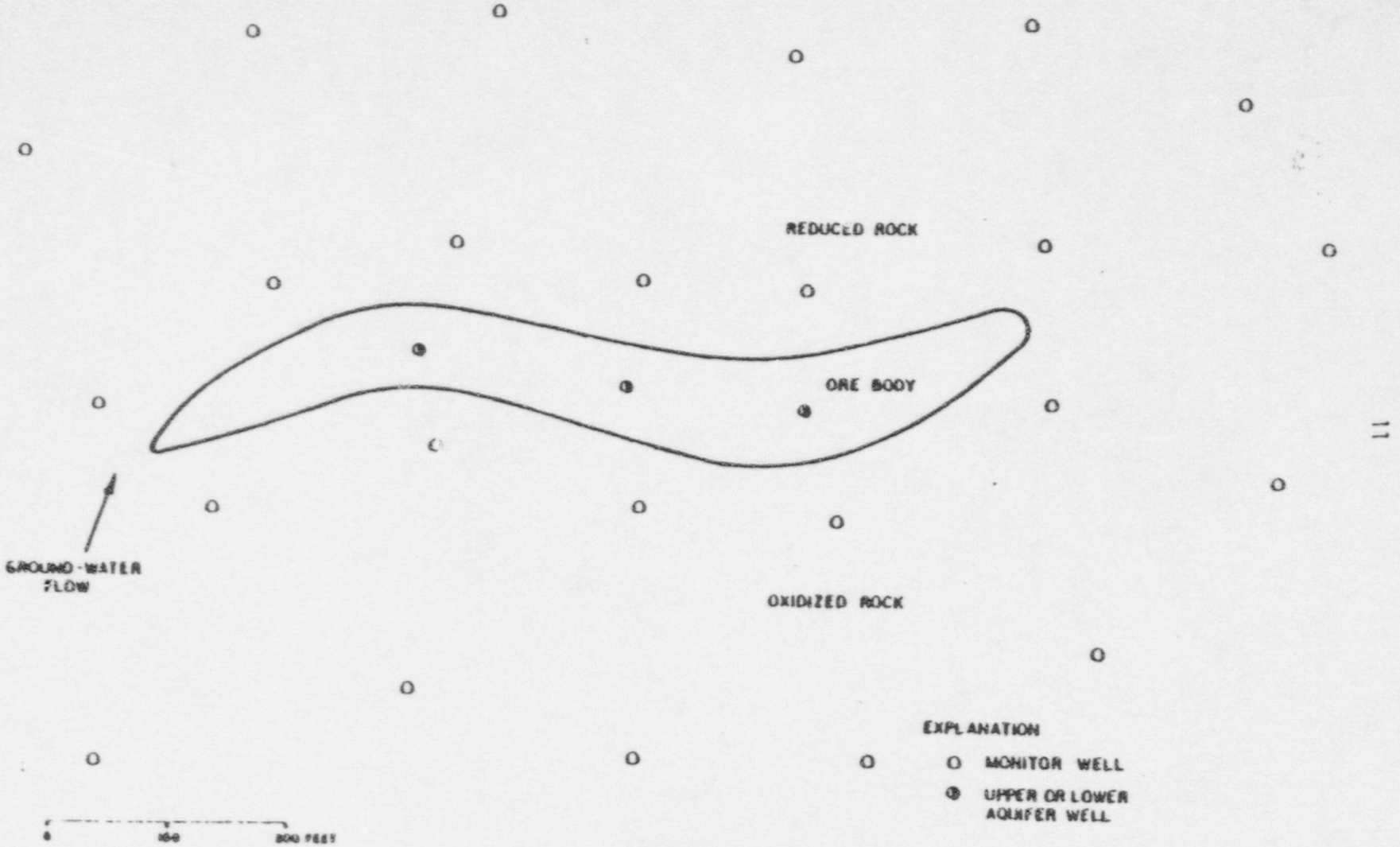

Figure 3. Location of wells in the excursion-monitor network at an in-situ leach mining site. (Modified from NUREG/CR-0311)

During the post-restoration monitoring period the groundwater monitoring plan should consist of water-quality sampling and water-level measurements taken at the following locations:

1. Any wells outside the production zone that were contaminated by the operation (this may include operational excursion groundwater monitoring wells or trend wells).

2. All (or those most representative) injection/recovery wells which were used in the preoperational (baseline) groundwater monitoring program (should include those injection/recovery wells monitored during restoration).

3. Any additional ore-zone aquifer monitor wells (operational excursion groundwater monitoring wells, centrally located injection/recovery wells) if needed to evaluate groundwater conditions in the ore-zone aquifer within and around the well field area.

Exhibit Y

URI, INC.

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Rosita Plant
HCO1, Box 50
San Diego, Texas 78384
Telephone: (512) 279-3342
Telecopy: (512) 279-3343

APRIL 3, 1992

MR. DALE KOHLER
TEXAS WATER COMMISSION
P.O. BOX 13087
CAPITOL STATION
AUSTIN, TEXAS 78711-3087

RE: EXCURSION ON MONITOR WELL #18

DEAR MR. KOHLER:

AS PER YOUR CONVERSATION WITH MR. MARK PELIZZA, THIS IS A LETTER OF CONFORMATION ON AS EXCURSION WHICH WAS DETECTED FOR THE FIRST TIME ON APRIL 1, 1992 DURING OUR ROUTINE BI-WEEKLY SAMPLING OF OUR MONITOR WELL RING. SINCE THAT TIME WE HAVE BEEN SAMPLING DAILY TO CONFIRM THE EXCURSION. ALL INDICATIONS AT THIS TIME SHOW AN EXCURSION HAS OCCURRED ON MONITOR WELL #18. SAMPLING IS CONDUCTED ACCORDING TO STANDARD OPERATING PROCEDURES OUTLINED IN URI'S "STANDARD OPERATING PROCEDURES MANUAL" AS SPECIFIED BY THE TWC (COPY ENCLOSED).

ENCLOSED PLEASE FIND A HISTORY OF THE FLUID QUALITY ON MW #18 SINCE SAMPLING BEGAN. THE PARAMETERS WERE ESTABLISHED ACCORDING TO STANDARDS SET BY TWC, PERMIT # UR02380-011, SECTION VII. SPECIAL PROVISIONS, SUB-PART A " CONTROL PARAMETERS AND UPPER LIMITS" (BASELINE READINGS ATTACHED). THE CONTROL PARAMETER UPPER LIMITS FOR MONITOR WELL IN A CONTROL ZONE ARE:

CONTROL PARAMETERS AND UPPER LIMITS

CONDUCTIVITY (UMHOS)	4988
URANIUM (MG/L)	6.20
CHLORIDE (MG/L)	1296

HISTORY OF THE FLUID QUALITY OF MW #18 (ATTACHED) BEGAN 9/11/90 AT TIME OF START-UP FOR THE PLANT. SINCE THEN SAMPLES HAVE BEEN TAKEN BI-WEEKLY. CONDUCTIVITY TO DATE HAS NOT EXCEEDED THE CONTROL PARAMETERS. CHLORIDE READINGS HAVE STAYED UNDER CONTROL PARAMETERS TO DATE. URANIUM SHOWS READINGS OF <1 FROM START-UP TO 2/13/92. AN INCREASE IN THE URANIUM BEGAN TO SHOW ON MARCH 25, 1992 WITH THE FIRST READING INDICATING A SIGNIFICANT INCREASE OF VOLUME OF URANIUM GOING FROM <1 TO 4.300. CONTINUED SAMPLING INDICATED AN EXCURSION ON 4/1/92 WITH A READING OF 12.7 MG/L. A VERIFYING ANALYSIS ON 4/2/92 SHOWED A READING OF 12.5 MG/L. CONFIRMING AN EXCURSION AND CORRECTIVE ACTION WAS STARTED AT ONCE.

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Telecopy: (512) 279-3343

CORRECTIVE ACTION

DURING PLANT STAND-BY TIME, A CONTINUOUS BLEED WILL BE UTILIZED TO MAINTAIN A CONE OF DEPRESSION IN THE WELLFIELD. FOR THE DURATION OF THE ELEVATED URANIUM LEVELS IN MW #10, THE MAJORITY OF THE BLEED WATER WILL BE PRODUCED FROM THE PRODUCTION WELLS NEAREST TO MW #10. ONCE THE CHEMICAL PARAMETERS ARE REDUCED TO SATISFACTORY LEVELS, THE BLEED WILL BE REDUCED IN RATE, BUT MAINTAINED FOR THE DURATION OF THE PLANT STAND-BY TIME. THIS WILL ENSURE A CONSTANT CONE OF DEPRESSION IN THE AREA AND SERVE TO PULL BACK TO THE WELLFIELD ANY LEACH SOLUTIONS IN THE VICINITY OF MW #10.

IF ELEVATED URANIUM CONCENTRATIONS CONTINUE FOR LONGER THAN ANTICIPATED, MORE DRASTIC MEASURES WILL BE TAKEN TO CLEAN UP THE WATER CHEMISTRY IN MW #10.

THANK YOU FOR YOUR ATTENTION TO THIS MATTER AND IF THERE IS ANY FURTHER INFORMATION YOU MAY REQUIRE, I WILL BE GLAD TO FORWARD IT TO YOU. FOLLOW-UP REPORTS ON A MONTHLY BASIS WILL BE SUBMITTED TO YOUR AGENCY AS DICTATED BY THE TAC 331.65 (F) WITH A COMPLETE LAB ANALYSIS FROM JORDAN LABORATORIES TO BE DONE EVERY TWO WEEKS. AN INTERNAL LAB ANALYSIS WILL BE DONE ON THE MONITOR WELL ON A DAILY BASIS (EXCEPT WEEKENDS AND HOLIDAYS) TO INSURE CORRECTIVE ACTION IS EFFECTIVE. A WATER SAMPLE WAS BROUGHT IN THIS MORNING FOR ANALYSIS WHICH SHOWED URANIUM BACK DOWN TO 5.62 MG/L WHICH IS BELOW OUR UPPER CONTROL LIMITS. YOUR AGENCY WILL BE KEPT INFORMED ON THE FURTHER PROGRESS OF THIS CORRECTIVE ACTION.

SINCERELY,

Lille Annelle Canales

LILLE ANNELLE CANALES
RSO/MSHA INSTRUCTOR

cc: MARI PELIZZA
ENVIRONMENTAL MANAGER

PHILIP E. SHAVER, M.P.H., CHIEF
TEXAS DEPARTMENT OF HEALTH

TEXAS WATER COMMISSION
[illegible] MONITORING REPORT
[illegible]

COMPANY: URI, INC.
ADDRESS: [illegible] MERIT [illegible]
[illegible], TEXAS [illegible]
MINE NAME: [illegible]

TWC PERMIT: [illegible]
TWC WELL NO: [illegible]
COMPANY WELL NO: [illegible]
WELLHEAD ELEVATION: [illegible]

Parameter	Conductivity	Uranium	Chloride
Units	[illegible]	mg/l	mg/l
Sample Frequency	2/month	2/month	2/month
Sample Type	Grab	Grab	Grab
Initial Baseline	[illegible]	[illegible]	82[illegible]
MDL	4998	[illegible]	1295
Date Sampled			
11/05/91	[illegible]	<1	[illegible]
11/20/91	[illegible]	<1	841
12/02/91	2930	<1	810
12/02/91	[illegible]	<1	[illegible]
12/17/91	[illegible]	<1	865
12/31/91	[illegible]	<1	867
01/14/92	[illegible]	<1	841
01/28/92	[illegible]	<1	817
02/13/92	[illegible]	<1	[illegible]
02/27/92		INSUFFICIENT SAMPLE	
[illegible]		INSUFFICIENT SAMPLE	
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
03/31/92	[illegible]	5.100	840
04/01/92	[illegible]	~~[illegible]~~ 12.7	82[illegible]
04/02/92	[illegible]	~~[illegible]~~ 12.5	817

I certify that I am familiar with the information contained in this report, and to the best of my knowledge and belief such information is true, complete, and accurate.

SIGNATURE [signature] DATE 4/2/92

TEXAS WATER COMMISSION
IN-SITU GROUNDWATER MONITORING REPORT

COMPANY: URI, INC.
ADDRESS: 12077 MERIT DRIVE
DALLAS, TEXAS 75251
MINE NAME: ROSITA ISL

TWC PERMIT: UR[illegible]
TWC WELL NO: MW-1[illegible]
COMPANY WELL NO: MW-1[illegible]-1
WELLHEAD ELEVATION: 449.[illegible]

Parameter	Conductivity	Uranium	Chloride
Units	umhos	mg/l	mg/l
Sample Frequency	2/month	2/month	2/month
Sample Type	Grab	Grab	Grab
Initial Baseline	3240	0.030	826
UCL	4935	6.200	1295
Date Sampled			
09/11/90	3850	<1	801
09/25/90	3740	<1	817
10/12/90	2740	<1	795
10/23/90	2760	<1	835
11/07/90	INSUFFICIENT SAMPLE		
11/21/90	2920	<1	824
12/03/90	3090	<1	804
12/17/90	[illegible]	<1	776
01/07/91	2900	<1	778
01/14/91	[illegible]	<1	768
01/23/91	2990	<1	807
02/12/91	2950	<1	793
02/25/91	3000	<1	888
03/11/91	3090	<1	870
03/27/91	[illegible]	<1	903
04/12/91	2860	<1	835
04/24/91	2890	<1	80[illegible]
05/08/91	2780	<1	809
05/22/91	3170	<1	830
06/05/91	2950	<1	827
06/20/91	2850	<1	833
07/01/91	2840	<1	827
07/19/91	2810	<1	829
07/29/91	2930	<1	871
08/13/91	2930	<1	871
08/27/91	2990	<1	903
09/09/91	2920	<1	857
09/25/91	2940	<1	850
10/07/91	2940	<1	895
10/21/91	2940	<1	879

I certify that I am familiar with the information contained in this report, and to the best of my knowledge and belief such information is true, complete, and accurate.

SIGNATURE William Paul [illegible] DATE 4/2/92

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judge Peter B. Bloch

In the Matter of	)	
	)	
HYDRO RESOURCES, INC.	)	Docket No. 40-8968-ML
(2929 Coors Road, Suite 101	)	ASLBP No. 95-706-01-ML
Albuquerque, NM 87120)	)	
	)	

INTERVENORS WRITTEN PRESENTATION IN OPPOSITION TO HYDRO RESOURCES, INC.'S APPLICATION FOR A MATERIALS LICENSE WITH RESPECT TO:

GROUNDWATER PROTECTION

January 11, 1999

VOLUME IV

EXHIBITS