To: Harold Lefevre MS 623SS
2LTR

WM DOCKET CONTROL CENTER

'87 JUL 22 A9:51

WM Record File 101

WM Project 10
Docket No.
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A PRESENTATION TO THE

NATIONAL ACADEMY OF SCIENCES

BOARD ON RADIOACTIVE WASTE MANAGEMENT

JULY 14, 1987

Washington State Nuclear Waste Board

See Pocket 5 for encl.

8712030106 870714
PDR WASTE
WM-10 PDR

2690

CONCLUSIONS

- ON MAY 28, 1986, USDOE IGNORED THE RESULTS OF ITS RANKING METHODOLOGY AND SELECTED HANFORD FOR CHARACTERIZATION EVEN THOUGH IT IS THE LEAST SAFE AND MOST EXPENSIVE OF ALL THE SITES UNDER CONSIDERATION
- INFORMATION OBTAINED AND ANALYSIS PERFORMED SINCE MAY 28TH HAS FURTHER CONFIRMED THE SERIOUS TECHNICAL CONCERNS AT HANFORD
- THE CUMULATIVE EFFECT OF THE SERIOUS TECHNICAL CONCERNS SHOULD HAVE ELIMINATED THE HANFORD SITE FROM FURTHER CONSIDERATION

Washington State Nuclear Waste Board

end. to Presentation to the Nat'l Academy of Sciences 7/14/87

CONCLUSIONS

- USDOE'S FLAWED IMPLEMENTATION HAS DESTROYED THE CREDIBILITY OF THE SITE SELECTION PROCESS
- IF THE SITE SELECTION PROCESS IS TO BE SUCCESSFUL, IT MUST BE HALTED, RESTRUCTURED AND RESTARTED, WITH INVOLVEMENT BY NATIONALLY RESPECTED SCIENTIFIC GROUPS SUCH AS THE NATIONAL ASSOCIATION OF SCIENCES
- WE URGE THE NAS TO SUPPORT A SITE CHARACTERIZATION PROCESS WHICH REQUIRES EARLY IDENTIFICATION AND INVESTIGATION OF POTENTIAL FATAL FLAWS

SITE CONTAMINATION

- DATA BASE
- CONCENTRATIONS (MAPPING)
- POSSIBLE ROUTES
- SIGNIFICANCE

DISTRIBUTION AND NUMBER OF WELLS

Source: DOE, 1985

Area	Number of Wells Constructed
100	139
200	1455
300	39
400	16
600	1177
1100 (Richland)	105
3000 (N. Richland)	8
Total	2939

1984 SUMMARY OF WELL USE AT HANFORD SITE

McGhan et al, 1985

1984 Well Use	Number of Wells
Ground-Water Contamination Surveillance	± 328
Ground-Water Hydrological Data Collection	382
Dry Wells for Monitoring Waste Management Facilities	1170
Basalt Stratigraphy Characterization	146
Water Supply Wells	11
Wells for Geologic and Seismic Studies	503

REPORTED VOLUME OF WASTE DISPOSED IN THE 200 WEST AREA INACTIVE WASTE SITES

Disposal Method	Number of Sites	Volume Received	
		Gallons	Cu. Ft.
Ponds	5	1.4×10^{10}	-
Cribs	34	2.9×10^{9}	-
Trenches	28	$^{*}3.4 \times 10^{7}$	-
Ditches	7	$^{*}1.1 \times 10^{8}$	-
French Drain	8	1.7×10^{6}	-
Reverse Wells	4	4.8×10^{6}	-
Tile Fields	1	4.8×10^{6}	-
Burial Grounds	8	-	NA
Burial Vaults	2	-	NA
Burning Pits	2	-	NA
Total	99	1.7×10^{10}	8.9×10^{5}
Date of Last Use		Site Active	

Maximum Reported Depth of Waste Disposal = 206 ft. (3 million gallons)
Water Table Elevation for the Above Site = 249 ft.

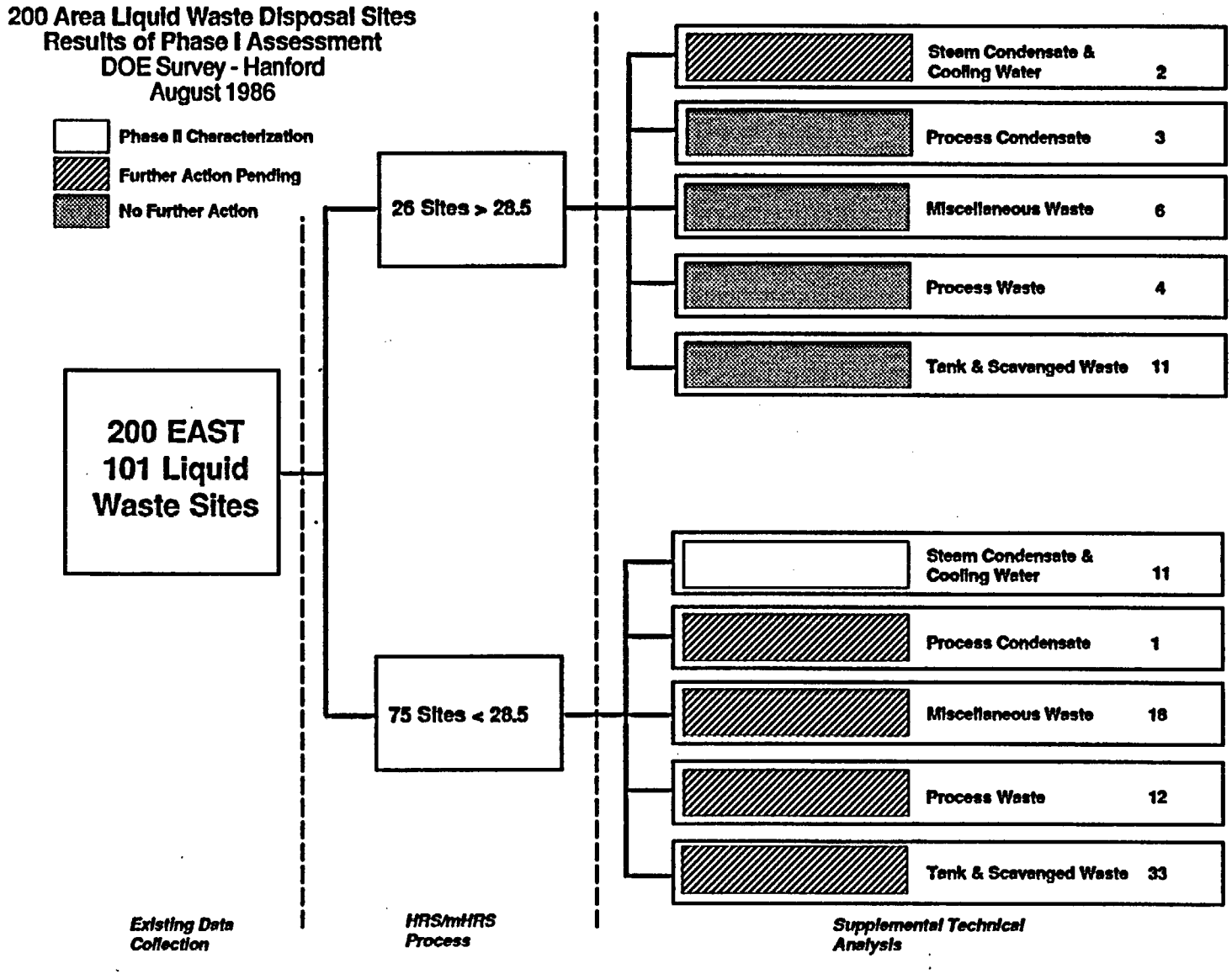
Notes:
* = Incomplete Information
NA = Not Available

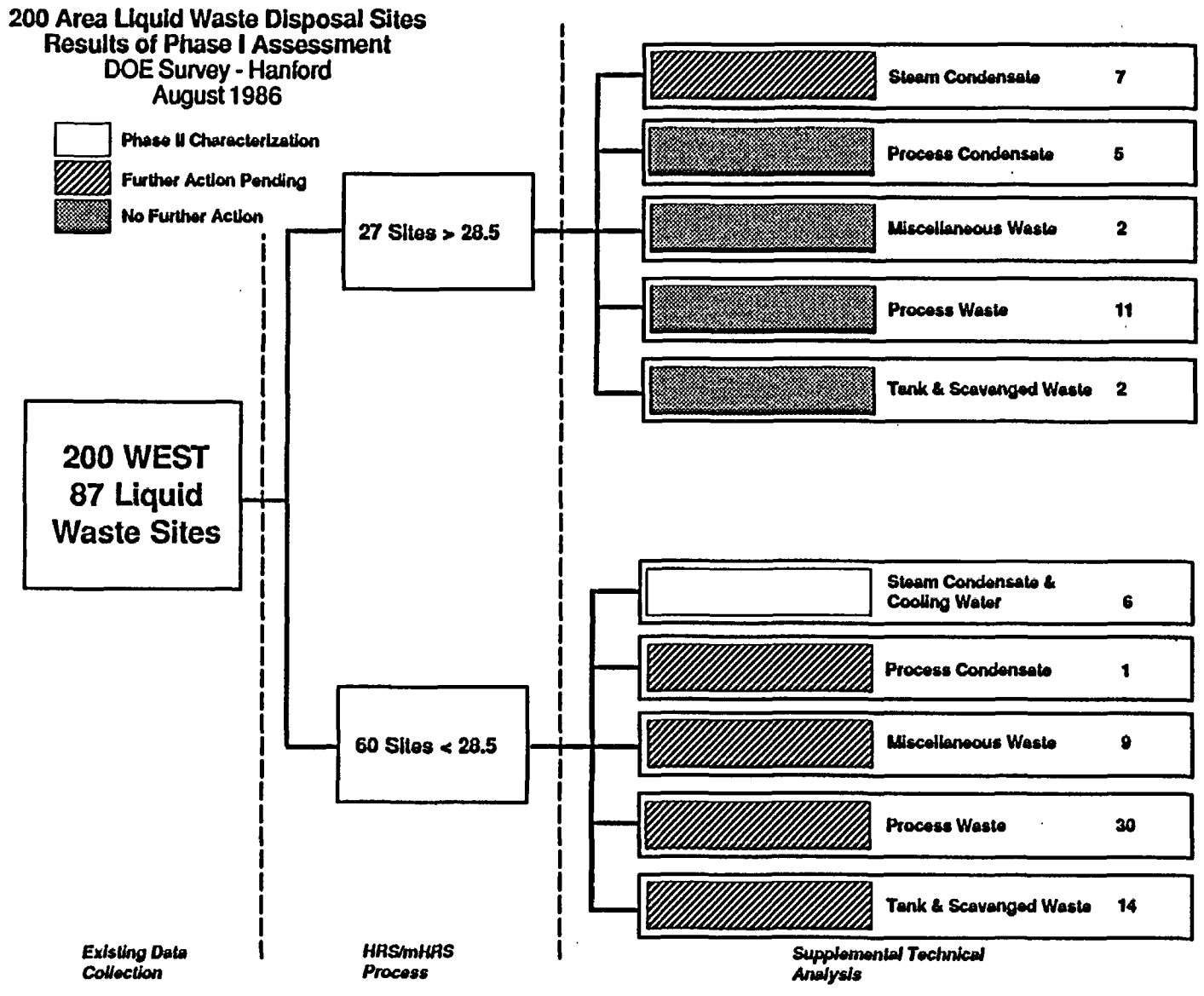
Source: DOE, 1986.

REPORTED VOLUME OF WASTE DISPOSED IN THE 200 NORTH AREA INACTIVE WASTE SITES

Disposal Method	Number of Sites	Volume Received	
		Gallons	Cu. Ft.
Ponds	**3**	**7.5×10^8**	**-**
Cribs	**4**	**8×10^6**	**-**
Total	**7**	**7.6×10^8**	**-**
Date of Last Use		**1952**	**-**

Maximum Reported Depth of Waste Disposal = 7 ft
Water Table Elevation for the Above Site = 173 ft
Source: DOE, 1986.


200 Area Liquid Waste Disposal Sites
Results of Phase I Assessment
DOE Survey - Hanford
August 1986
Phase II Characterization
Further Action Pending
No Further Action
200 EAST
101 Liquid
Waste Sites
26 Sites > 28.5
75 Sites < 28.5
Steam Condensate & Cooling Water 2
Process Condensate 3
Miscellaneous Waste 6
Process Waste 4
Tank & Scavenged Waste 11
Steam Condensate & Cooling Water 11
Process Condensate 1
Miscellaneous Waste 18
Process Waste 12
Tank & Scavenged Waste 33
Existing Data Collection
HRS/mHRS Process
Supplemental Technical Analysis


200 Area Liquid Waste Disposal Sites
Results of Phase I Assessment
DOE Survey - Hanford
August 1986
Phase II Characterization
Further Action Pending
No Further Action
200 WEST
87 Liquid
Waste Sites
27 Sites > 28.5
60 Sites < 28.5
Steam Condensate 7
Process Condensate 5
Miscellaneous Waste 2
Process Waste 11
Tank & Scavenged Waste 2
Steam Condensate & Cooling Water 6
Process Condensate 1
Miscellaneous Waste 9
Process Waste 30
Tank & Scavenged Waste 14
Existing Data Collection
HRS/mHRS Process
Supplemental Technical Analysis

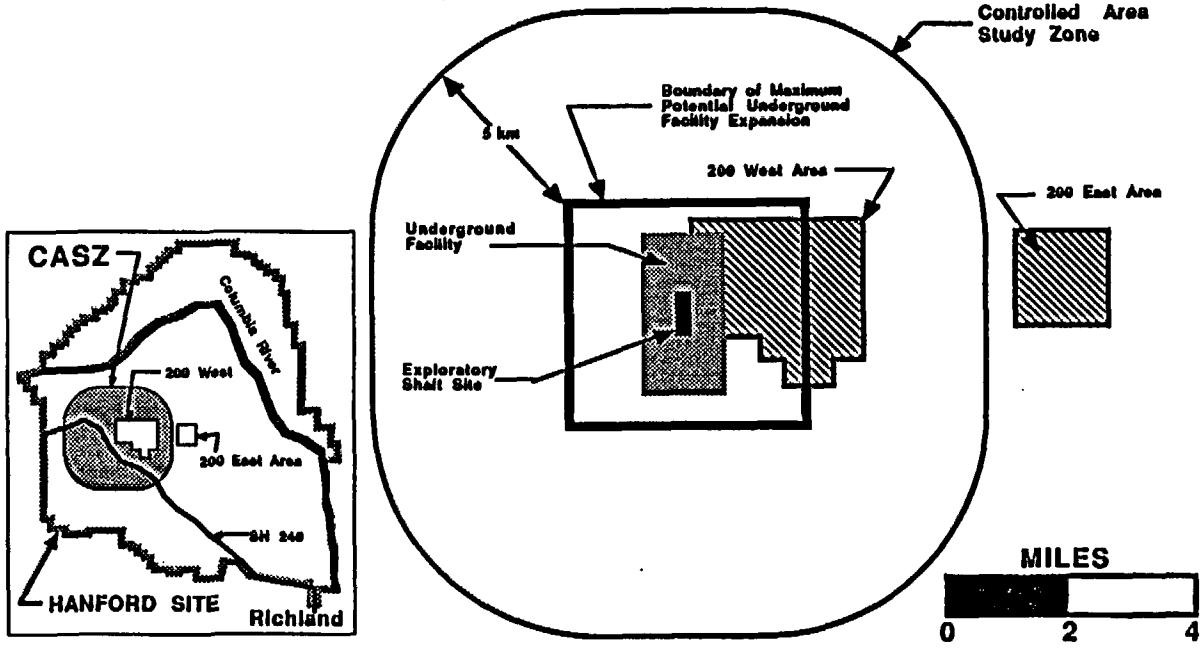
THE DEPARTMENT OF ENERGY
ENVIRONMENTAL SURVEY

PURPOSE

"TO IDENTIFY ENVIRONMENTAL PROBLEMS
AND AREAS OF ENVIRONMENTAL RISK"

SITE CONTAMINATION

CONTROLLED AREA STUDY ZONE
HANFORD RESERVATION



Washington State Nuclear Waste Board

transport are the targets, with the understanding that not all such structures are inherent pathways. But if they are pathways, they may well be disqualifiers.

The geologist would assemble all available data to see what others have done, and how well they did it. He would find seismic (epicenter) maps since 1969, from the Hanford instrument network; medium-resolution USGS aeromagnetic and gravity maps of the surrounding region; an unevaluated state map of satellite photolineaments published in 1975; and of greatest interest, a 1978 Weston Geophysical high-resolution aeromagnetic map of some 15,000 sq miles, centered on Hanford, which was used in NRC licensing of a nearby nuclear power plant.

All these data would be assembled on a common scale and map projection, along with the field-mapped geology, as a stack of mylar transparencies. While aeromagnetic mapping proves nothing directly, the inferred geology can be checked against actual field mapping; in this case it would be evident that the degree of correlation between mapped faults and aeromagnetic linears is extremely high. That is, faults mapped in outcrops were also detected magnetically, and they can be extended into areas of alluvial cover with some confidence. The seismic and photolineament data would be found to complete a logical and consistent picture.

The picture would suggest that the Hanford repository site lies within a 5 by 6 mile rectangle bounded by four faults. The inferred precision of location would be about 1/4 mile. Considering the billion-dollar target, the geologist would propose a drilling program on the order of $10 million, deviating the holes at depth to intersect the suspect faults normal to their strike and at an angle greater than 30 degrees. The work would take up to a year with one rig; considering the widespread availability of rigs and expert drillers, he would recommend two in parallel to economize staff time.

A "discovery" in this exploration project would result in major dollar savings, plus clearing the way to focus resources on a better candidate site. "No discovery" would lend needed technical credence to other site studies at Hanford. Either way, it would appear advantageous to USDOE's national program to drill these anomalies before committing hundreds of millions of dollars to less focused studies.

Discussion and Conclusions

Expending $10 million on unproven or inferential geologic hypotheses is nothing new in industry practice. The condemnation principle often requires it. Since USDOE does not support the scenario described, it seems that either there is an institutional obstacle that needs articulation, or else the present system of rewards in not working in the best interest of the general public.

In December 1984, a national panel examined management alternatives for the civilian nuclear waste program, recommending a federally-chartered corporation along with two other alternatives it thought superior to the status quo. Somewhere in this matrix there should be an approach which rewards sound, but otherwise disinterested application of science and engineering to the search for a safe repository site. The conclusions of this paper are that:

- In both theory and application, the industry approach, based on the condemnation principle, is superior to the classic technocratic procedures of USDOE, and

- There should be a deliberate and thoughtful review of management and program design alternatives which would encourage efficiency in site studies through adoption of more industry practices in the early stages of screening and exploration; the academic approach is unsuited to the task as it wastes time and resources.

It should be apparent that application of better site selection and characterization methods will have the highest payoff as more sites are available for consideration. Experience gained in the past four years suggests that identification and characterization of candidate sites should be started again from the beginning on a nationwide basis. If scientists and citizens believe the site search is being conducted objectively and non-politically, USDOE may well be able to make up the time lost so far, and to avoid years of costly and nonproductive litigation which are on the horizon today.

Objectivity in the search for a repository site is harder to achieve, because there are lesser, and in principle no money constraints; Congress has set up the Nuclear Waste Fund through dedication of a portion of utility bills and told USDOE that if more is needed, it can be gotten. And the system of rewards is backwards - the discovery of a disqualifying geologic condition can clearly lead to the loss of work for USDOE's contractors and loss of jobs for their employees. Disqualification would create monstrous difficulties for USDOE as well; at Hanford and the Nevada site, both on controlled federal nuclear reservations, the avoidance of bitter (and probably losing) fights over condemnation of private land was a dominant factor in their selection as two of the three repository candidates.

Thus it is a credit to USDOE and its contractors that great efforts are made to work objectively, to obtain credible and quality-controlled data and to present the results in a carefully-documented academic format to outside reviewers. While these efforts are not universally successful, the fact that outside review by the states and NRC is a requirement in law means that any mistakes or omissions will eventually surface; the states have a further concern: that the site not be merely "good enough", but technically superior.

In some geotechnical areas the work is taking too long and costing too much. The work methods employed at Hanford, in at least the geological studies, are inefficient and not integrated, nor do they attack problems in a systems context.

Geotechnical Studies at Hanford

Enough is known about the Hanford site to state the critical "systems" question: can the longer-lived radionuclides in high-level wastes be safely contained at depth for long enough to meet the requirements of Title 40, Part 191 of the Code of Federal Regulations? This, by the way, is quite different from asking if they can be contained for long enough to pose little public health hazard; 40 CFR 191 is conservative.

The main geotechnical question then becomes: are there groundwater pathways through the layered basalts and interbeds which could introduce contaminants into the shallow aquifers and the Columbia River? These pathways could be diffuse, consisting of the pervasive intraflow fracture network, or they could be discrete, along faults, shears, and interbeds. Testing for diffuse pathways is difficult, slow and expensive, but that is

where much of the effort is being expended. Under close scrutiny by state and federal agencies, USDOE is proceeding with this and parallel studies in geochemistry, rock mechanics and hydrologic modeling - all documented, quality controlled and carefully reviewed internally before release. There is also a program in regional and local tectonic analysis, involving fault mapping and geophysics, but it is slow-paced.

The state has criticized USDOE for not moving more quickly and energetically in the search for faulting and shears near the repository site. The point has been made that not all the geological and geophysical information available in the open literature and in proprietary (syndicated) studies for the petroleum industry is being used. The state's reasoning is that if there is a disqualifying fault or related pathway, the cheapest and best thing that could happen is to find it quickly and abandon the site. If it is found not to exist, then the other, more expensive and laborious studies can proceed, but the condemnation principal applies just as surely as if the exploration target is a valuable resource.

USDOE's responses have varied. In the case of one syndicated geophysical study, its cost (about $40,000) is noted as a constraint, but in most other cases USDOE proposes to examine these issues for consideration during Site Characterization, a statutory phase under the Nuclear Waste Policy Act, estimated at roughly 5 years and $1 billion at each of the three repository sites. At present USDOE and its contractors are preparing a Site Characterization Plan, anticipated for issue in 1987. These responses are perfectly appropriate under current USDOE ground rules, but are vastly different from industry practice.

How an Exploration Manager Would Look at Hanford

Many years of surface geologic mapping around and on the Columbia Plateau provide a framework for structural analysis, but the repository site itself has a thick alluvial cover. Drilling to and through the basalts is costly, in excess of $1 million per deep hole. Looking for vertical or high angle faults with vertical holes is not likely to provide much satisfaction.

An industry-trained geologist would begin by asking himself some questions. For example, what are the targets? In money, the target is a saving of $1 billion, less the cost of condemnation studies. Geologically, faults and shears capable of groundwater

APPLICATION OF COMMERCIAL EXPLORATION TECHNIQUES TO SITE SELECTION AND CHARACTERIZATION

William A. Brewer
Department of Ecology
State of Washington

Presented at Waste Management '87, Tucson

ABSTRACT

Since 1976 the U.S. Department of Energy has conducted intensive geologic studies of the Hanford Nuclear Reservation in south-central Washington. With passage of the Nuclear Waste Policy Act of 1982 the process of search for a geologically suitable waste repository site became more structured, and it has been subject to outside review by the state, affected Indian tribes and other federal agencies, notably the Nuclear Regulatory Commission and the U.S. Geological Survey. This paper contrasts the USDOE approach with that of the mining and petroleum industries, highlighting fundamental differences in philosophy and techniques. It is proposed that the principle of "condemnation", which is fundamental in commercial exploration methods, could greatly benefit the USDOE siting program, which by comparison has been slow, costly and not very productive.

Exploration Philosophy and the Condemnation Principle

Few graduate schools fully prepare geologists and geophysicists for responsible assignments in mineral and petroleum exploration. Beginners need conditioning under experienced managers in order to appreciate certain harsh realities of the extractive industries. Among these are (1) that a depleted mine or well has only a negative value, so that money must be spent continually to find and develop new reserves, but exploration costs directly reduce profits; and (2) that "dry holes" cost about as much as discoveries, so that the payoff from a discovery has to be far greater than its direct cost just in order to break even. In recent years the high cost of borrowed money has forced exploration managers to become extremely conservative and tight-fisted, saving their big money for nothing less than a virtual sure winner.

After learning basic skills in the field and the company's proprietary methods, a promising young geologist may be given some money to develop a play or prospect. Now on his own, he determines to bring in a major discovery - there are few greater thrills in one's career, quite apart from the material rewards.

Unfortunately this leads to the universal syndrome miners call "falling in love with the prospect". The field man pleads for just a little more time, only a little more money . . . and is frustrated when he is turned down and reassigned. In a given case he could be right, of course, but his exploration manager fully appreciates that the ratio of commercial wells to "dusters" is about 1 in 16, and that in mining only about 1 in 100 prospects or geophysical anomalies is even drilled, with only a small fraction of those drilled becoming operating mines.

What the exploration manager does is known as "condemnation". That is, he looks for evidence that will condemn the prospect, freeing his money and people to search somewhere else. This loss-cutting philosophy is universal in the exploration departments of all successful companies. It takes time for the individual to understand and practice it, however, which can lead to heated debate between the manager and his staff. A good exploration manager is constantly questioning, doubting and discounting all but unequivocally favorable information; if he does not, he will soon be out of business.

The Hanford Philosophy

The job of a company is to make money. The job of USDOE at Hanford, or elsewhere, is to find a repository site which can be licensed by NRC. While the company is looking for a commercial accumulation of petroleum or minerals, USDOE is looking for the absence of disqualifying features.

How does one proceed objectively to search for something he earnestly hopes is not there? This question has not been resolved within the repository community. But the system of rewards between a commercial operation and USDOE can be compared, along with the practical constraints.

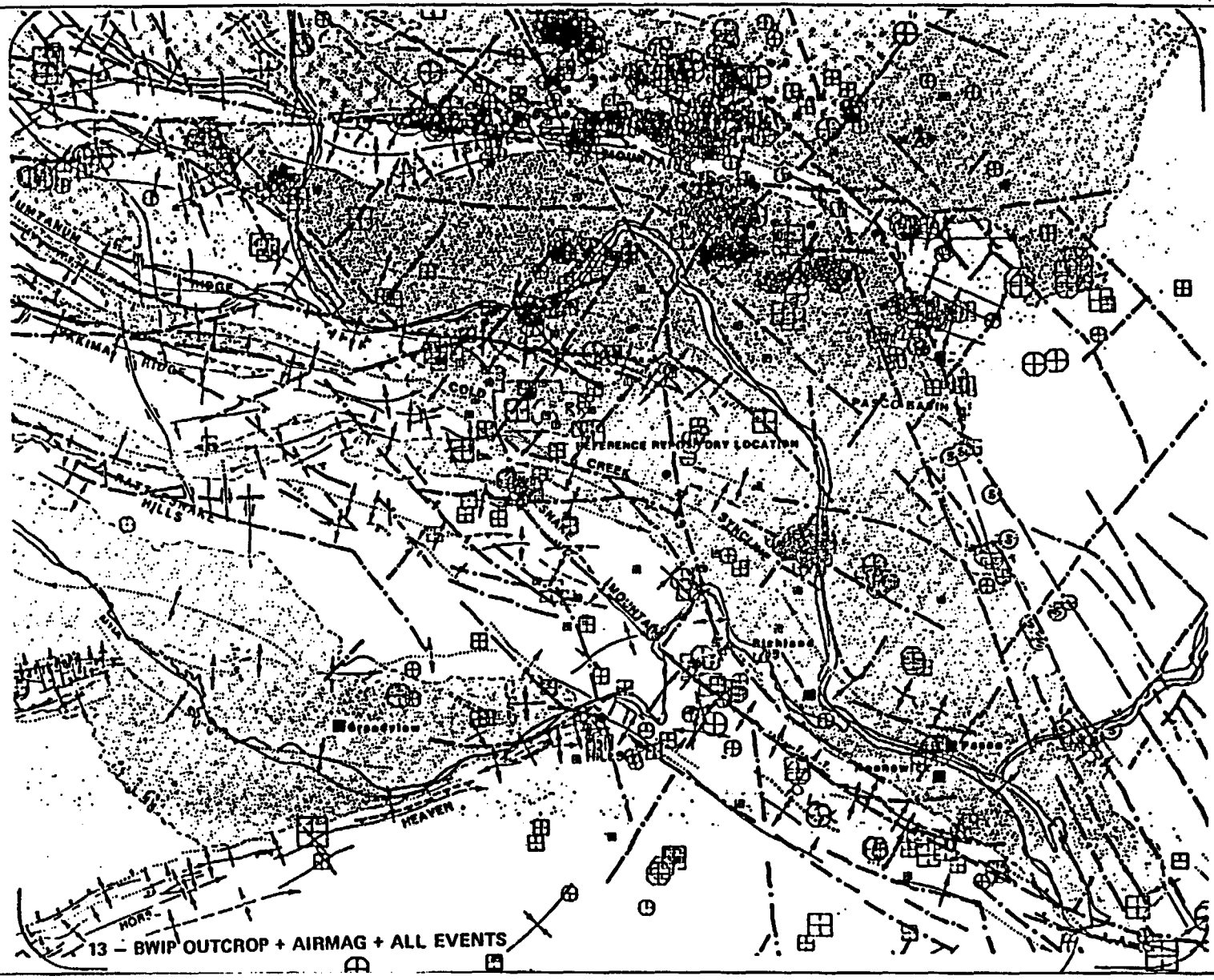
Objectivity in the search for petroleum or minerals is enforced by the condemnation principle, and the constraint is defined in terms of the money available. Rewards for success are defined by profits and professional recognition.

CONCLUSION

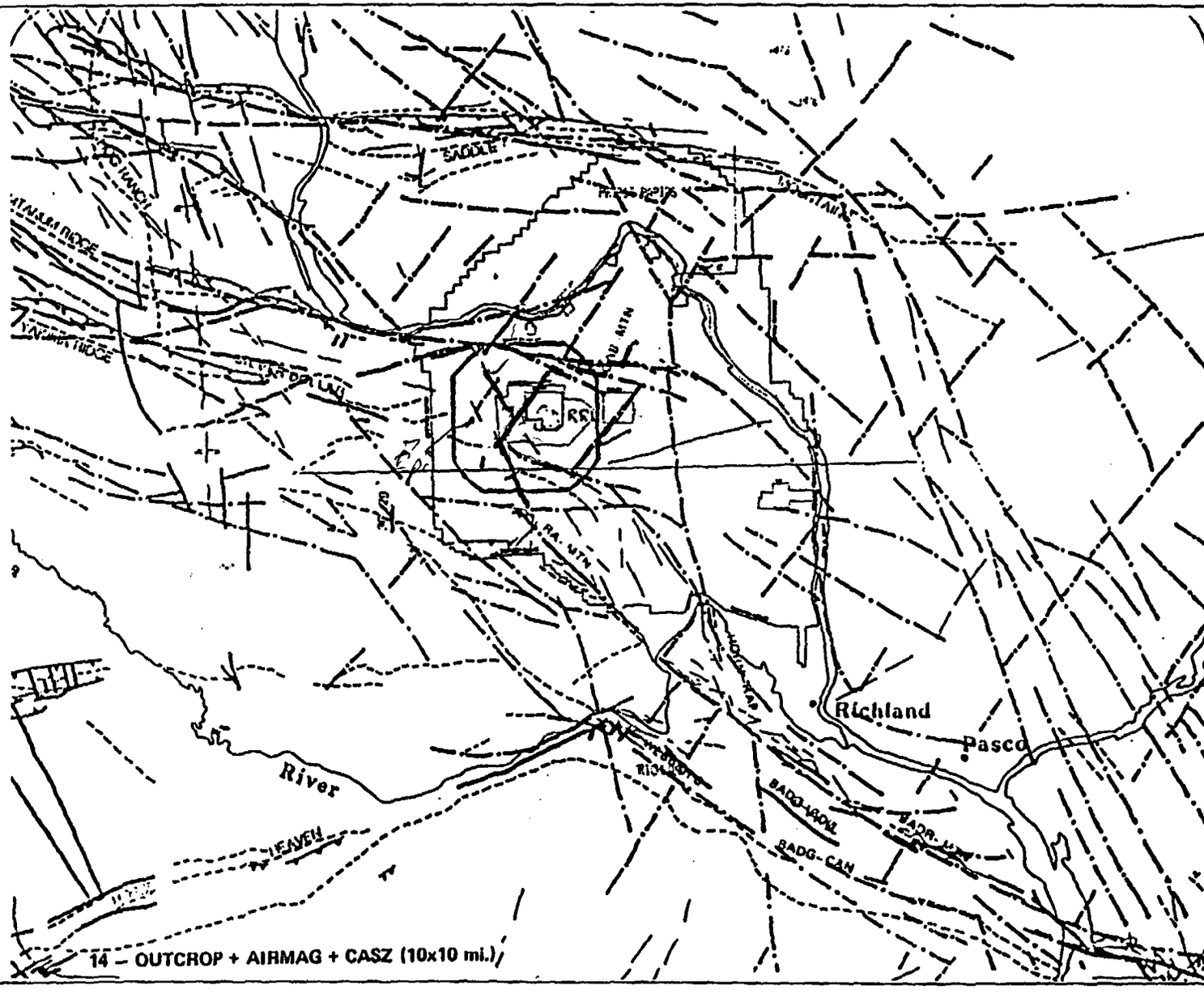
PROBABLE ACTIVE FAULTING WITHIN THE CASZ

RECOMMENDATION

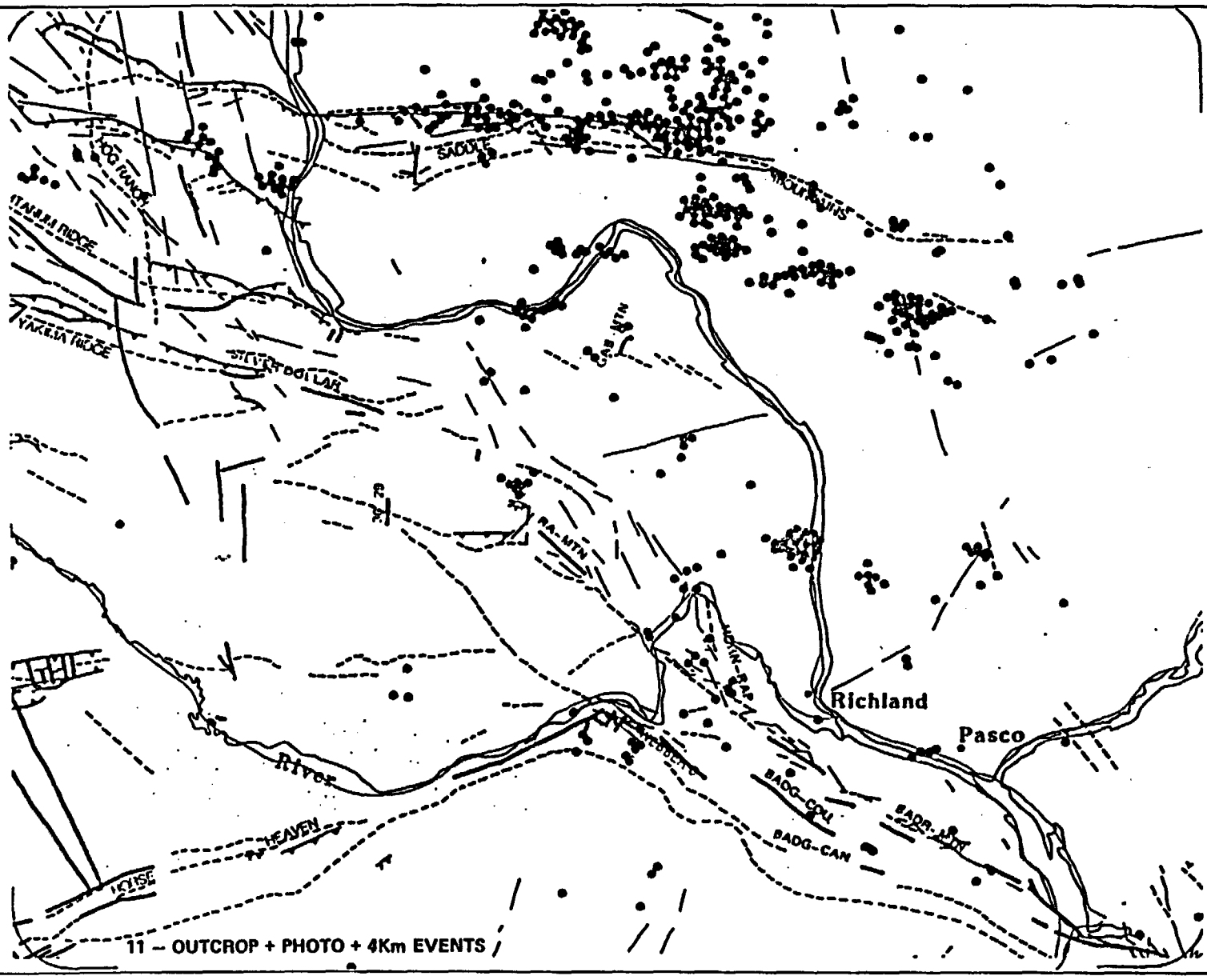
EXPLORE BY DIRECT DRILLING

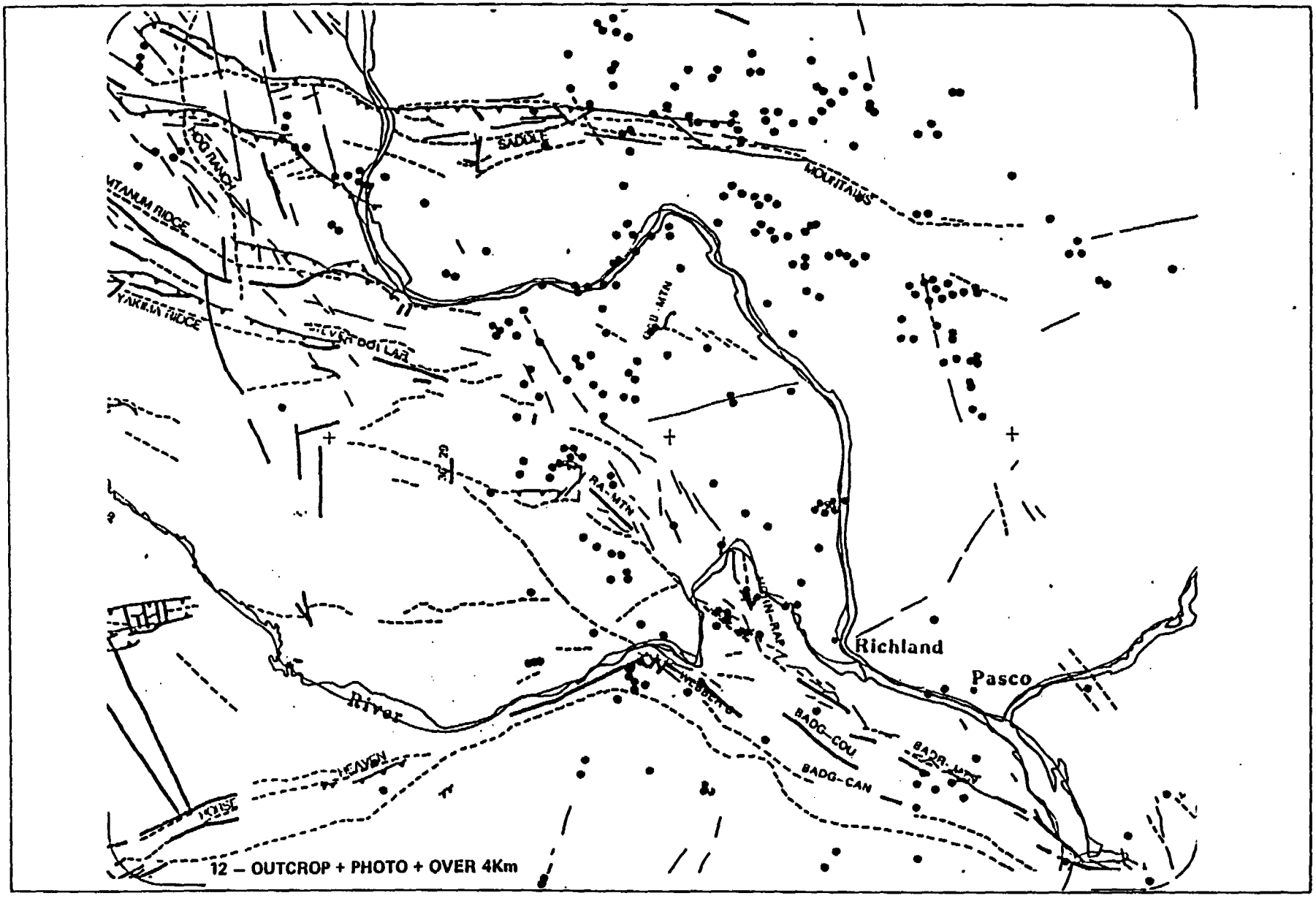


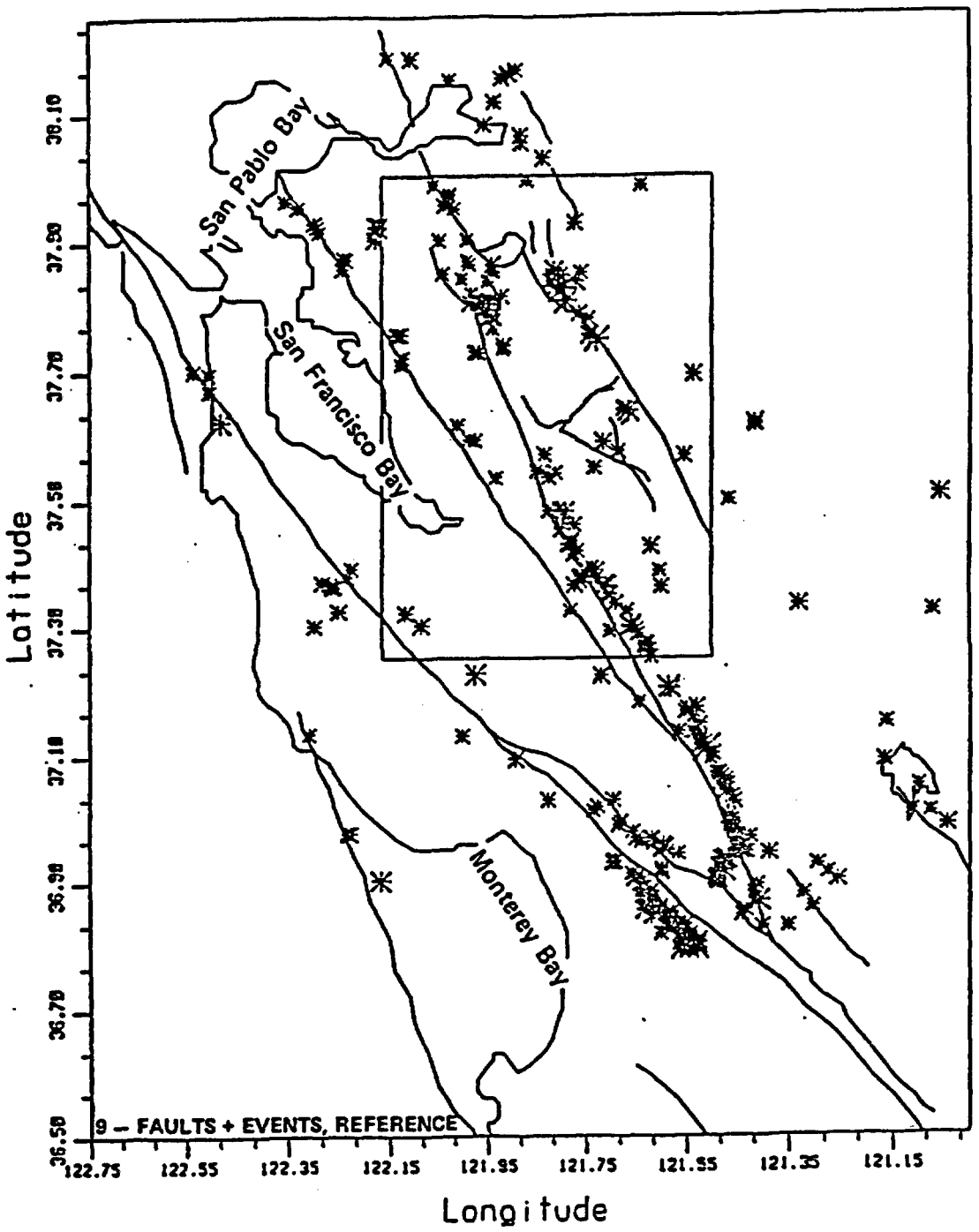
13 – BWIP OUTCROP + AIRMAG + ALL EVENTS



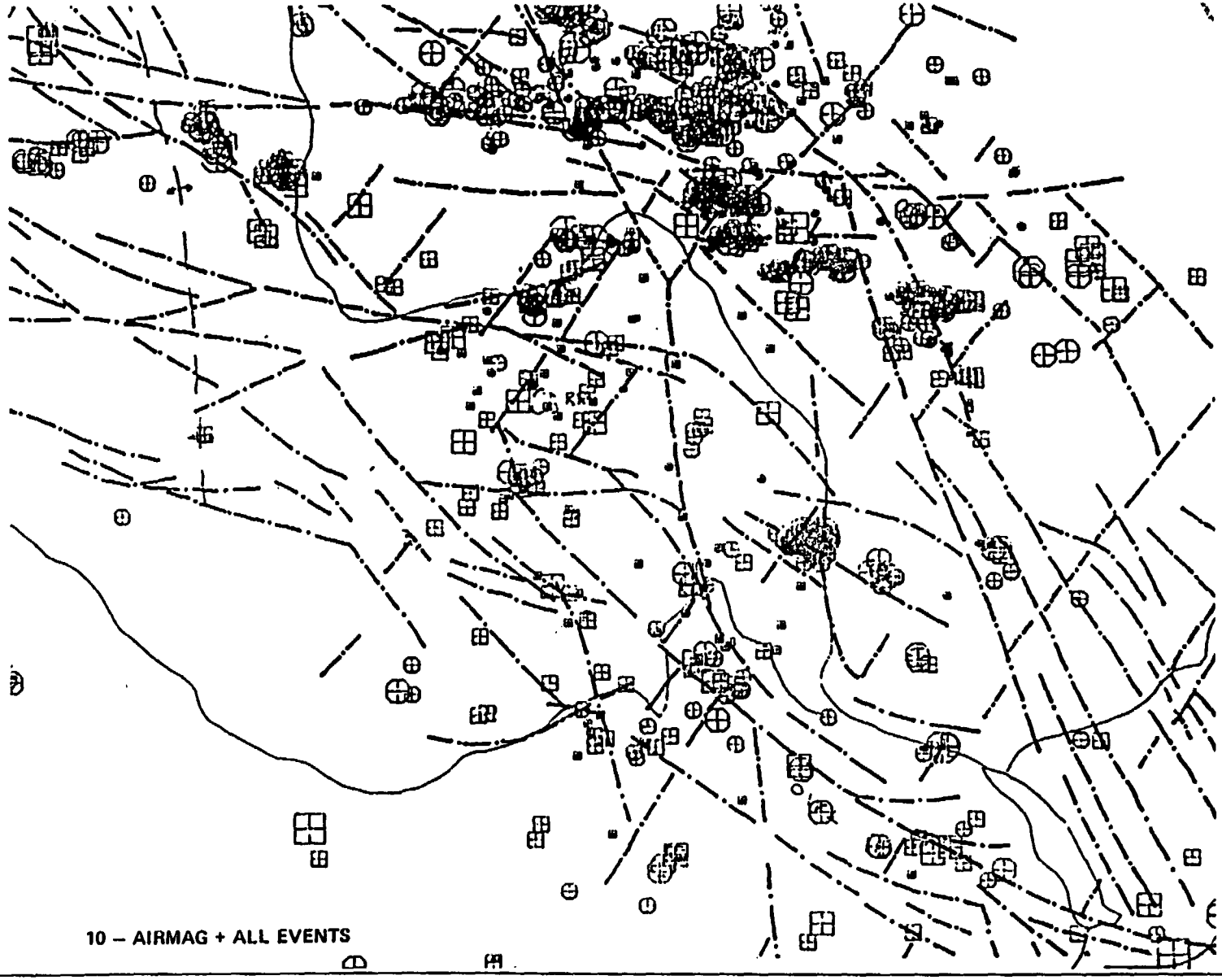
14 – OUTCROP + AIRMAG + CASZ (10x10 mi.)


SADDLE
WOLF HILLS
YAKIMA RIDGE
STRATTON LAKE
RA-MTN
Richland
Pasco
BADG-COLL
BADG-CAN
BADG-MOT
RIVER
HEAVEN
11 – OUTCROP + PHOTO + 4Km EVENTS

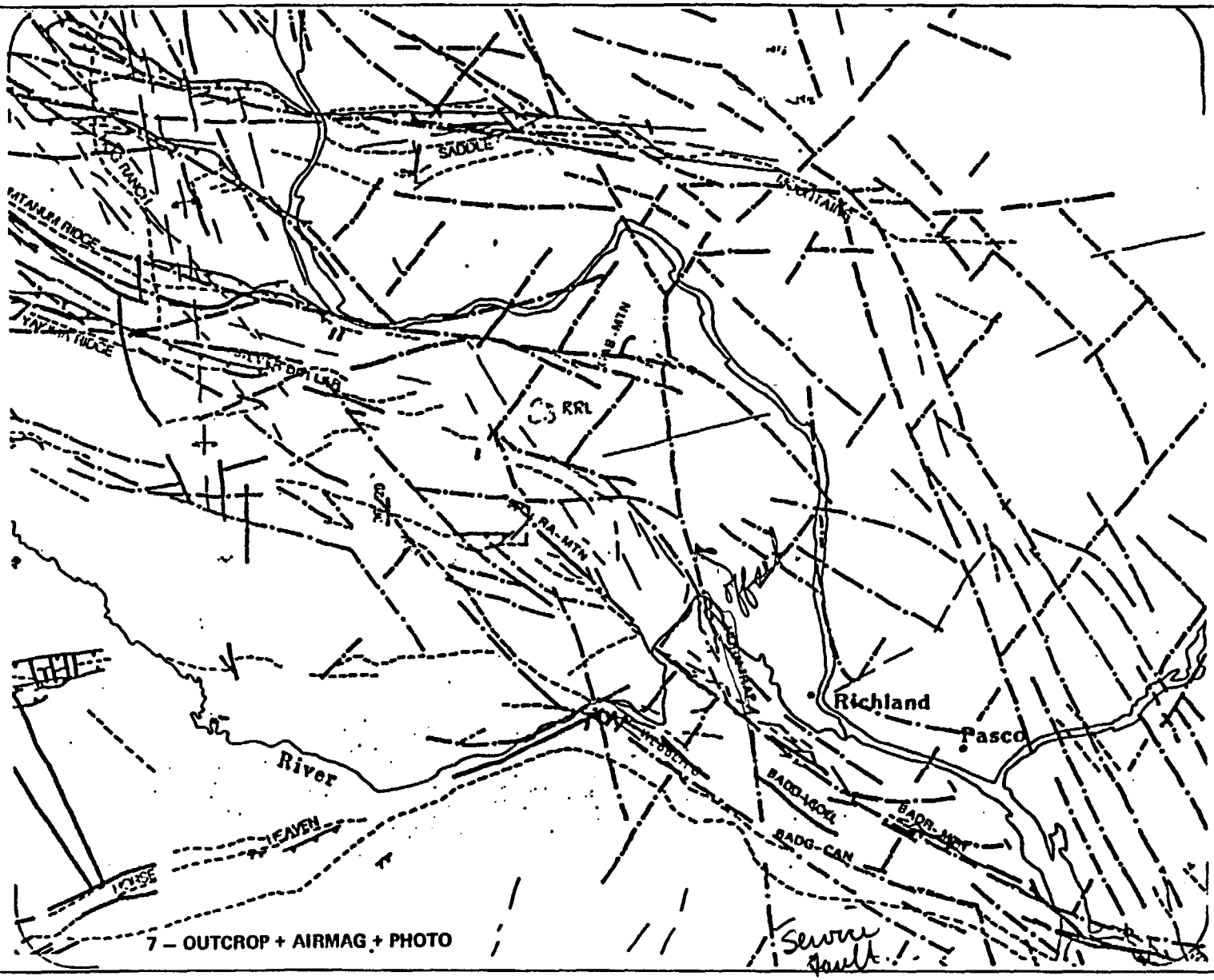

SADDLE
MOUNTAINS
TITANIUM RIDGE
YAKIMA RIDGE
RIVER DOLLAR
RA-MTN
Richland
Pasco
BADG-COU
BADG-CAN
BADR-MTN
River
HEAVEN
12 – OUTCROP + PHOTO + OVER 4Km



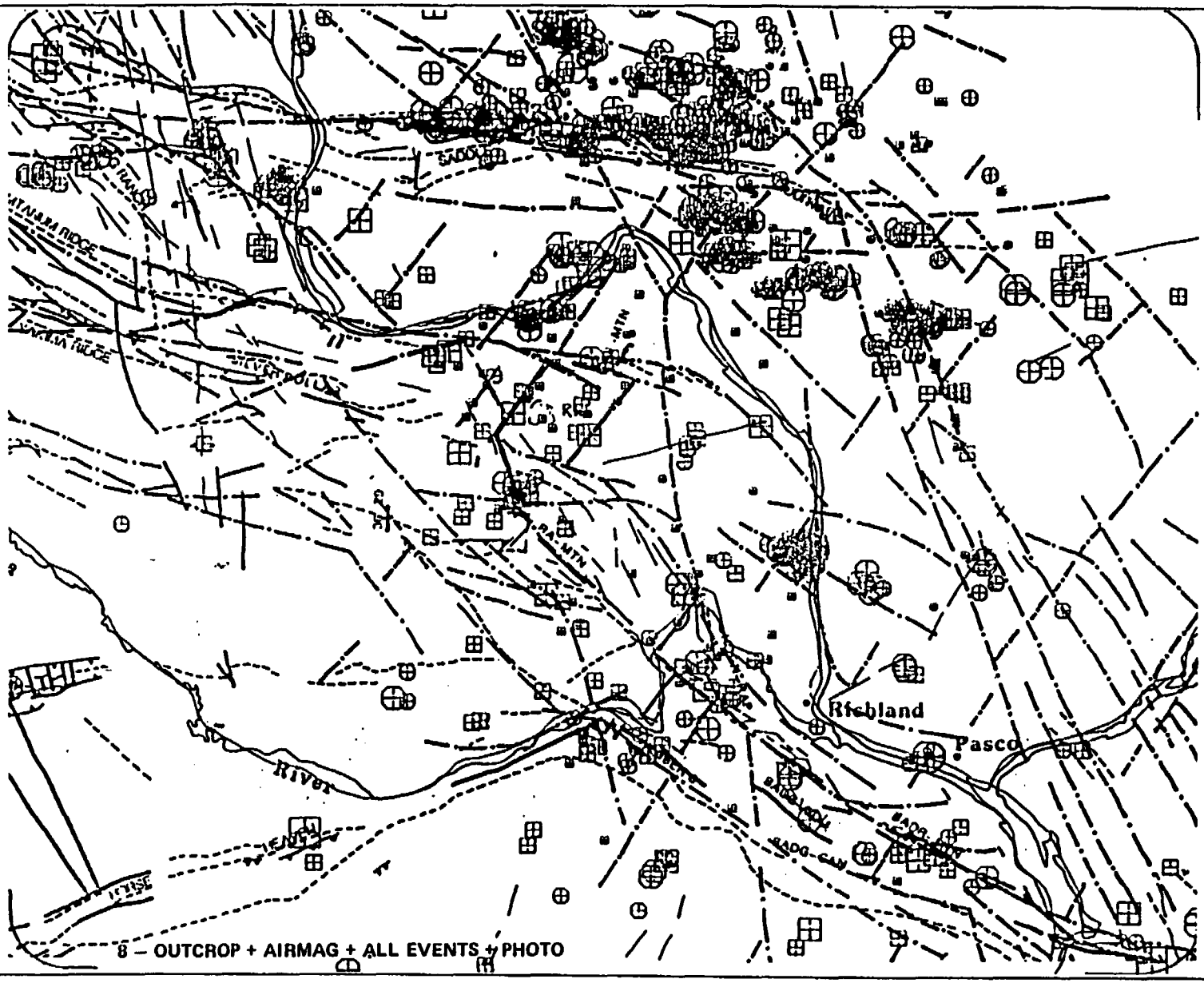
All events from the combined catalogs with $M_L \geq 2.75$.



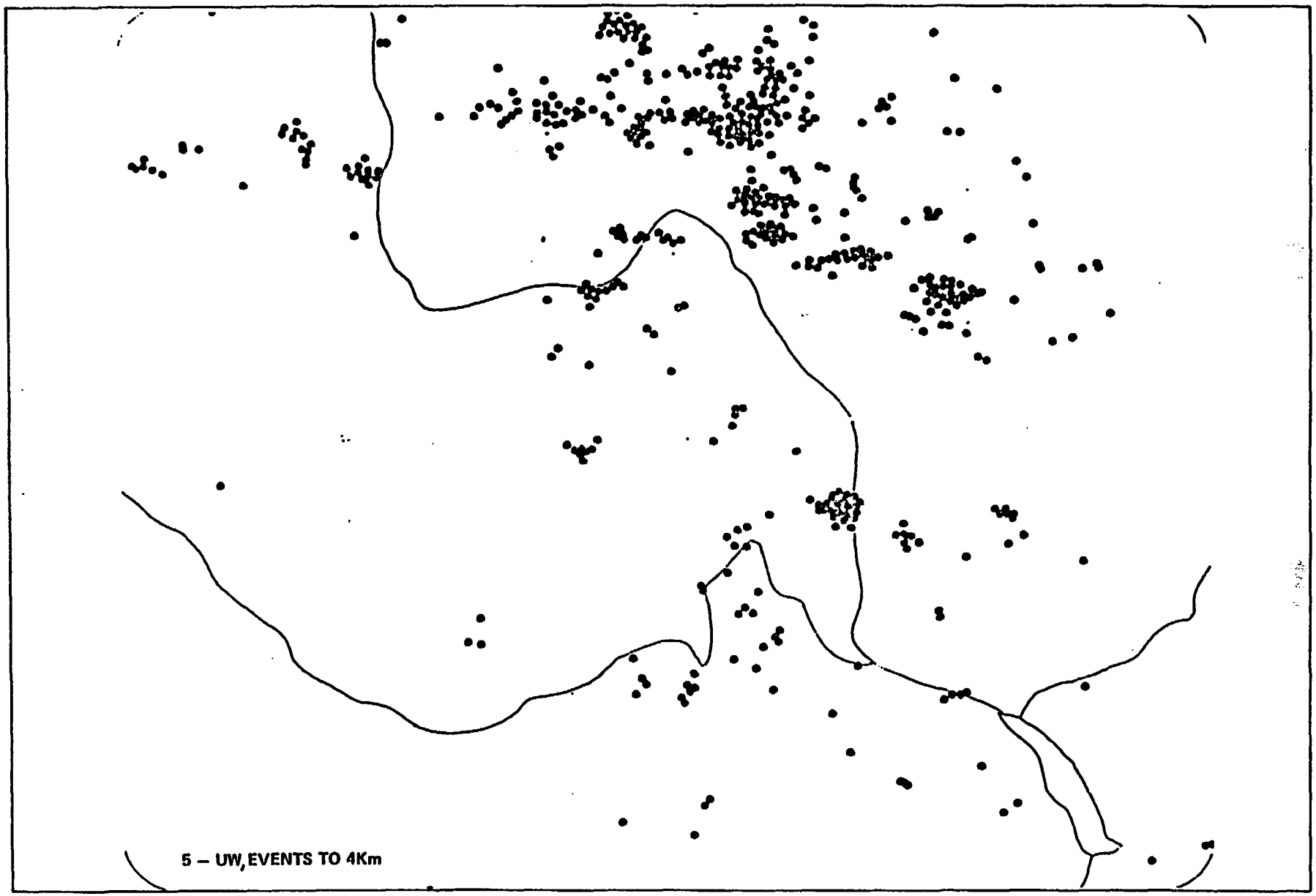
10 – AIRMAG + ALL EVENTS



7 – OUTCROP + AIRMAG + PHOTO



8 – OUTCROP + AIRMAG + ALL EVENTS + PHOTO



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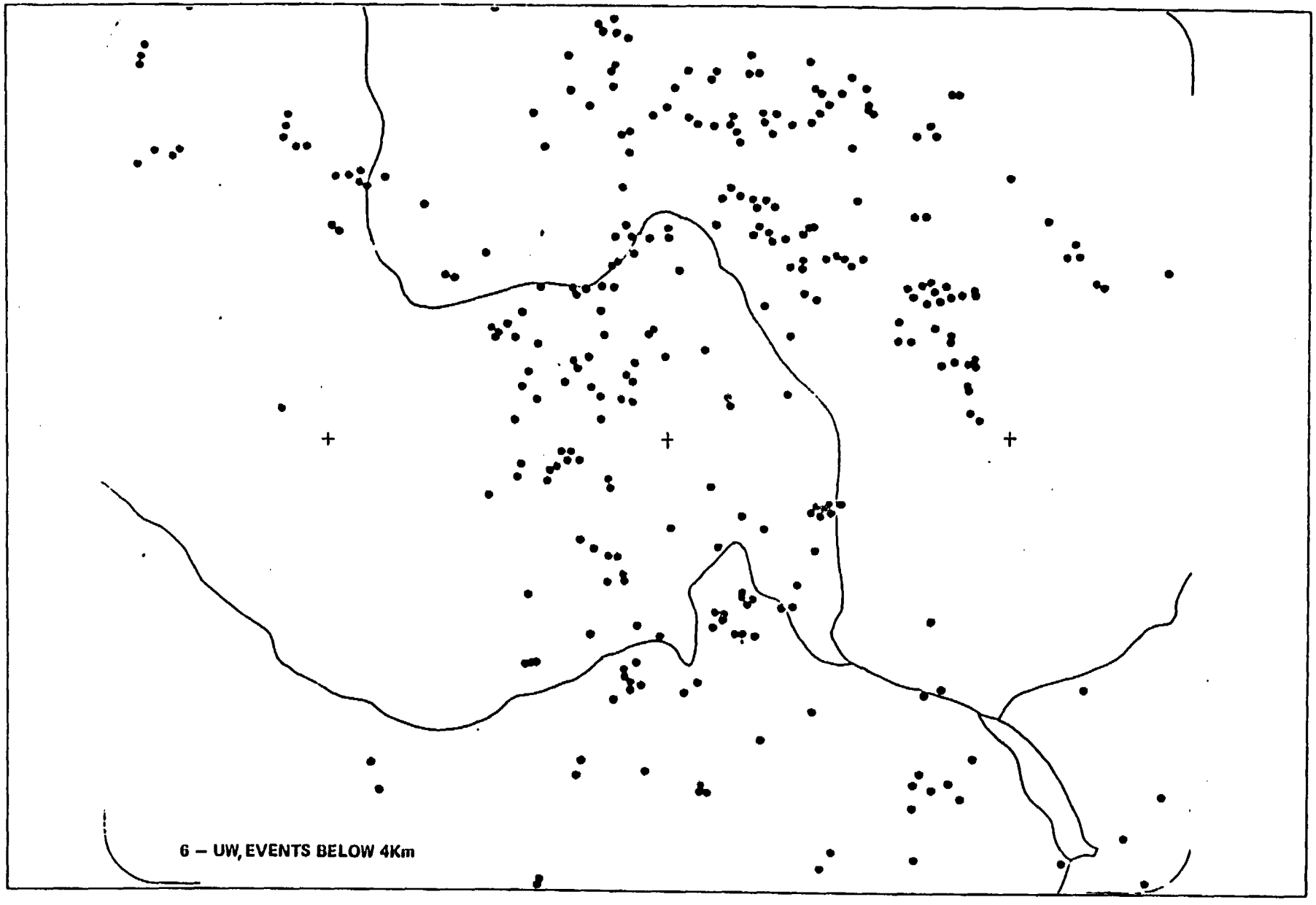
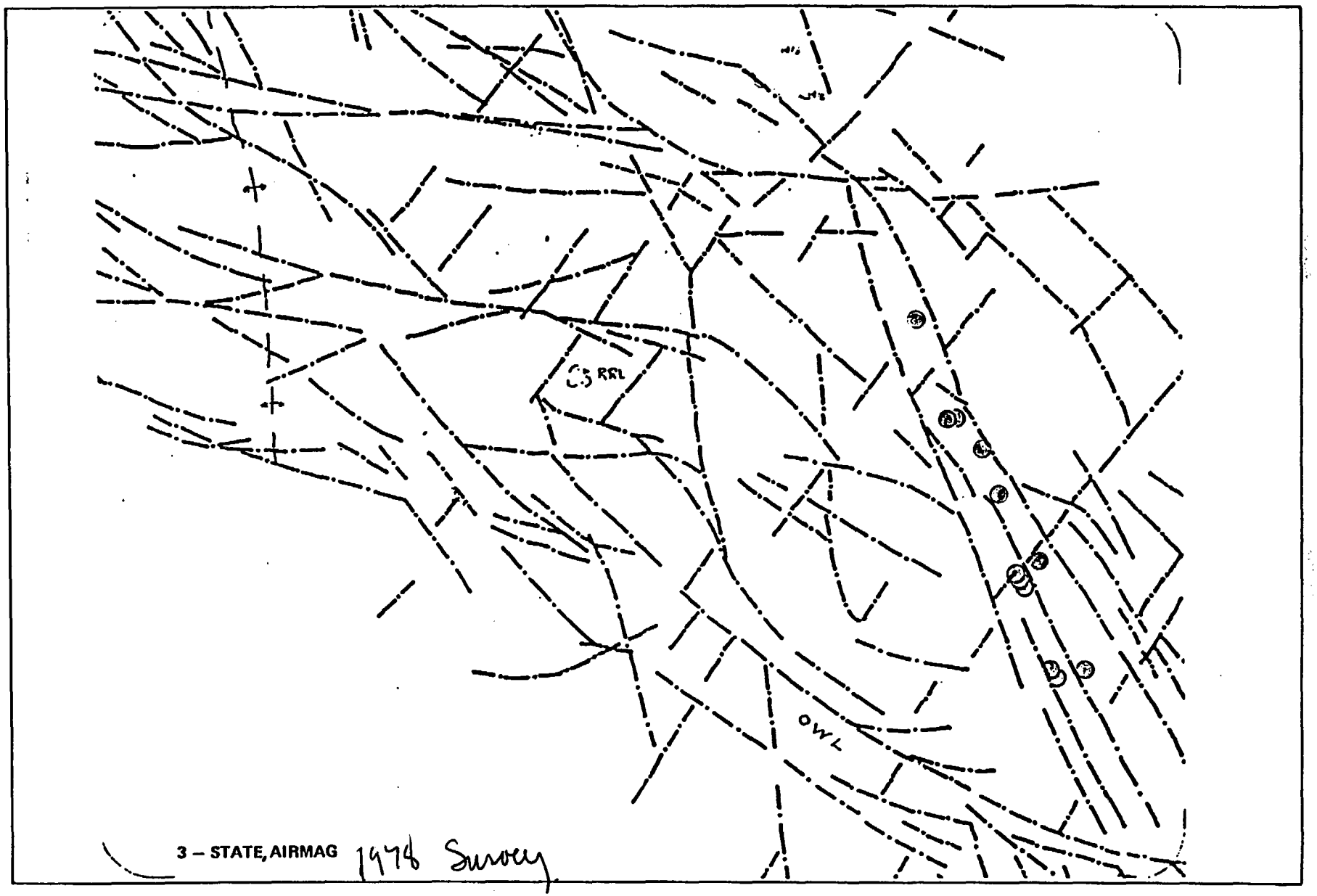
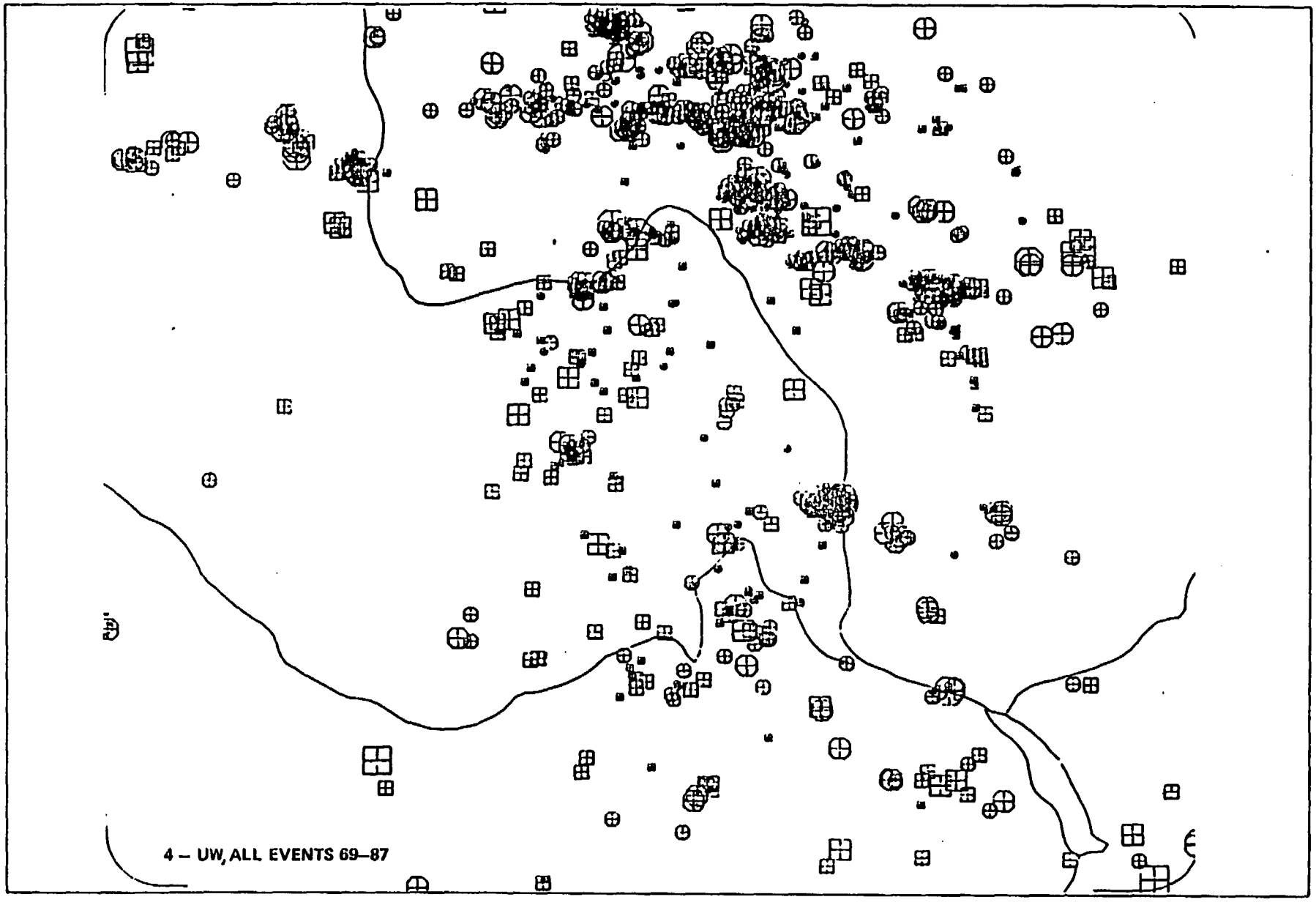


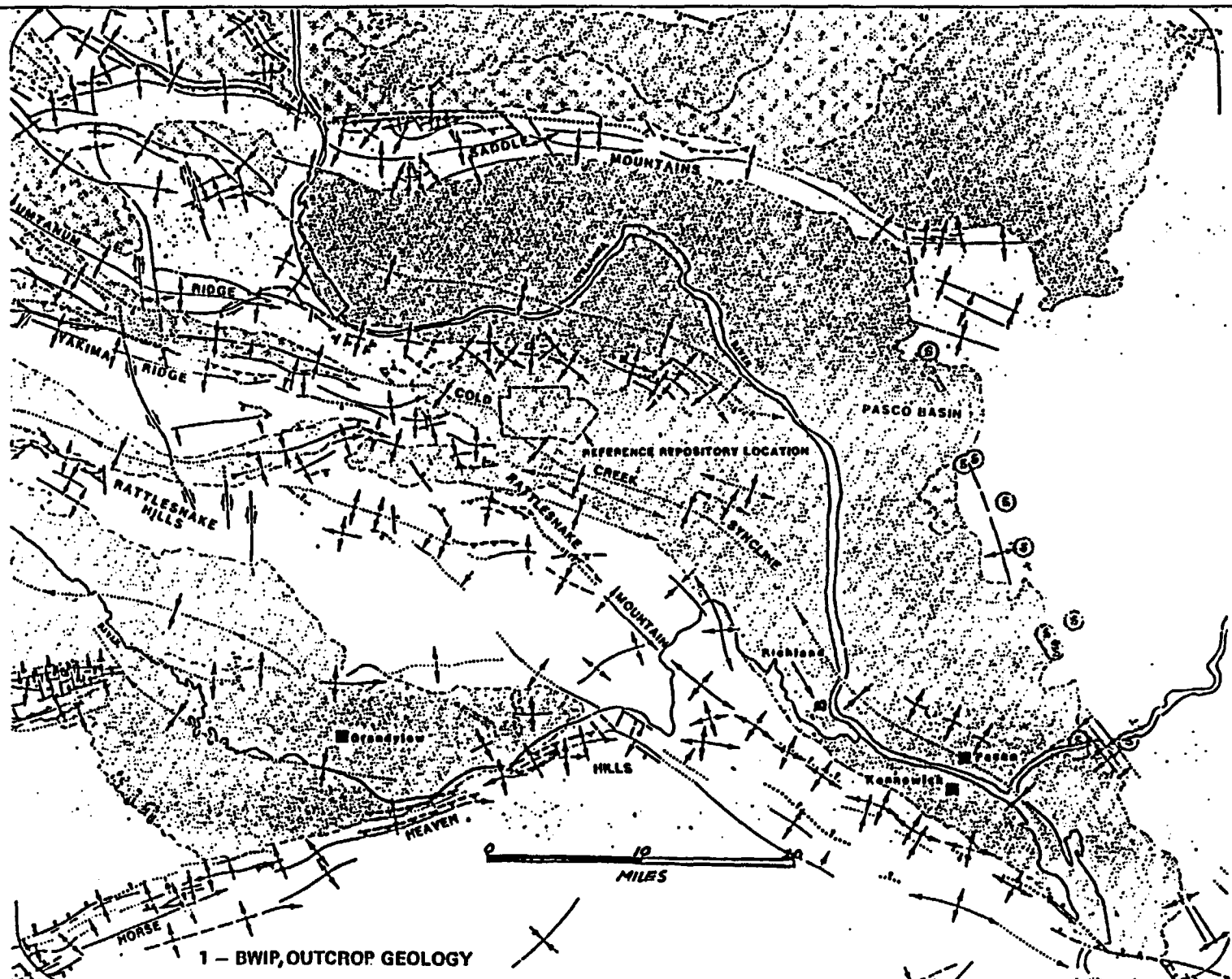
6 – UW, EVENTS BELOW 4Km



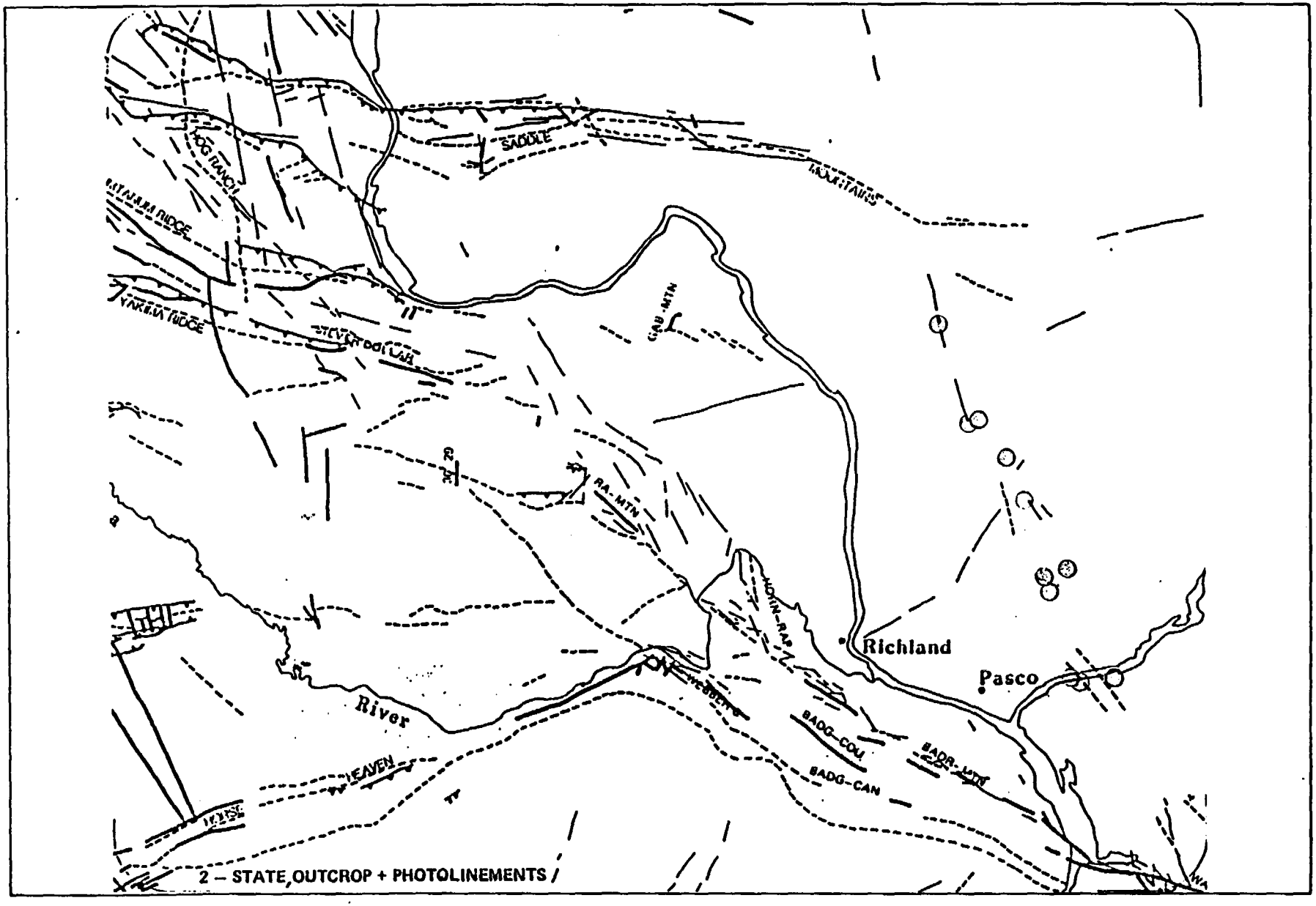
3 – STATE, AIRMAG 1978 Survey



4 – UW, ALL EVENTS 69–87

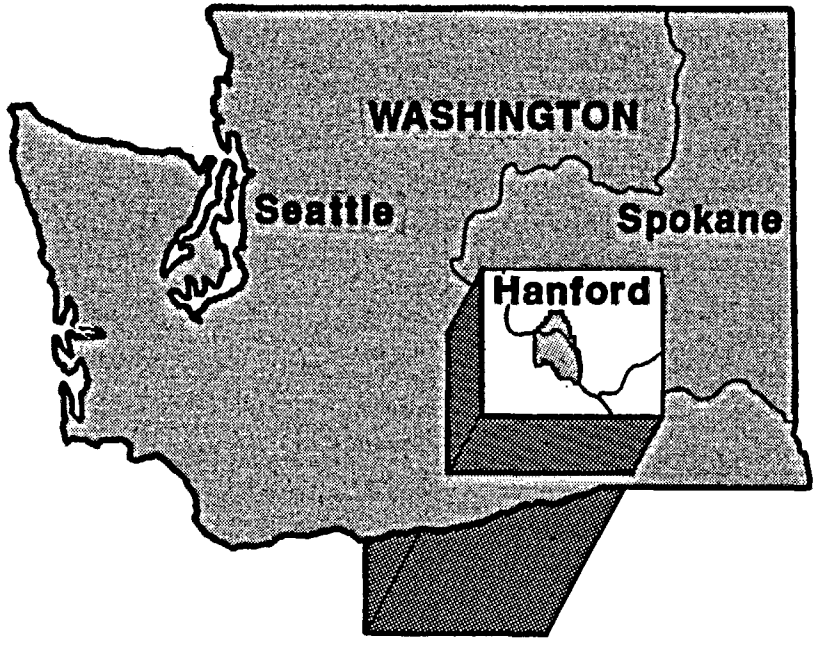


1 – BWIP, OUTCROP GEOLOGY



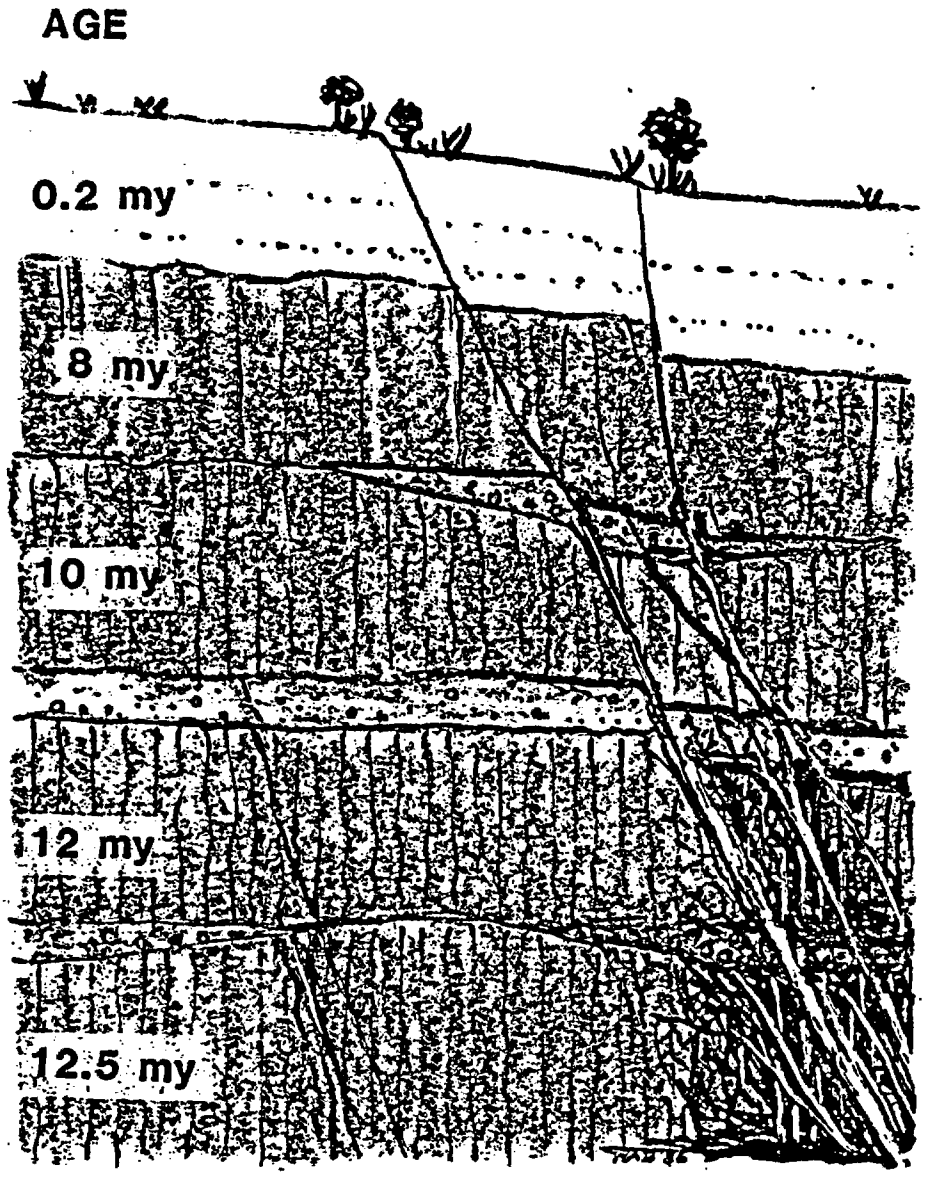
2 – STATE, OUTCROP + PHOTOLINEMENTS /

GEOTECHNOLOGY



Washington State Nuclear Waste Board

POSSIBLE MODEL FOR SUCCESSIVE FAULT MOVEMENTS



1,000 YEAR GROUNDWATER TRAVEL TIME (GWTT) TEST

USDOE - CURRENT GEOHYDROLOGIC INFORMATION SUGGESTS WITH A HIGH PROBABILITY THAT THE HANFORD SITE WILL MEET THE 1,000 YEAR GWTT TEST

NRC - DISAGREES THAT THERE IS A HIGH PROBABILITY THAT THE HANFORD SITE WILL MEET THE 1,000 YEAR GWTT TEST

NRC CONSULTANT - THERE IS A SIGNIFICANT LIKELIHOOD THAT THE HANFORD SITE WILL NOT MEET THE 1,000 YEAR GWTT TEST

FAULTS AND SHEARS DETECTED THROUGH...

- LOCAL GEOLOGY
- REGIONAL TECTONICS
- SURFACE MAPPING
- DRILL HOLE LOGGING
- REMOTE SENSING*
- GEOPHYSICS*
- SEISMOLOGY*

CONDEMNATION PRINCIPLE

"DELIBERATE, EARLY SEARCH FOR
FATAL FLAWS (DISQUALIFIERS) IN ORDER
TO SAVE TIME AND RESOURCES,
CUT LOSSES "

DISQUALIFIER 1.
GROUNDWATER TRAVEL TIME FAILS
40CFR191

SUBISSUES

STRATIGRAPHY
HYDRAULIC TESTING
EFFECTIVE POROSITY
UNCERTAIN K_V
FAULTS AND SHEARS*

LOCAL GEOTECHNICAL ISSUES AT HANFORD

1. *GROUNDWATER TRAVEL TIME*
2. METHANE - *RESOURCES*
3. MINING CONDITIONS - *COST*
4. MINE SAFETY - *ENVIRONMENT*
5. WASTE PACKAGE DEFINITION - *10CFR60*
6. *RETRIEVABILITY*

(ITALICS ARE SPECIFIC DISQUALIFIERS)

GEOTECHNOLOGY

"MOST MEASURED VALUES FOR METHANE CONCENTRATION FROM REFERENCE REPOSITORY BOREHOLES ARE IN THE RANGE OF FROM 350 TO 700 MG/L FOR THE COHASSETT FLOW TOP. BECAUSE OF UNCERTAINTIES ASSOCIATED WITH THESE MEASUREMENTS, IT IS CURRENTLY RECOMMENDED THAT A CONSERVATIVE METHANE CONCENTRATION OF 1200 MG/L (METHANE SATURATED) IN GROUNDWATER BE CONSIDERED THE MOST REASONABLE UPPER-BONDING VALUE"

Rockwell Hanford Operations
SD-BWI-TI-296

We predict that fault traps are more likely than anticlinal traps at depth in the basin.

The average porosity of the Paleogene sandstones known to contain gas in the Columbia Basin ranges from less than 6 to approximately 18 percent (Fig. 5). Our work shows that the average thickness of sandstone reservoirs logged in the BN 1-9, Yakima Minerals 1-33, and Bissa 1-29 wells that have greater than 6 percent porosity is approximately 26 feet (Fig. 6). We calculate that the volume of typical Columbia Basin natural gas that can be contained in one cubic foot of pore space at the predicted reservoir pressure and temperature at 5,000 feet drilled-depth is approximately 150 standard cubic feet of gas. At 14,000 feet drilled-depth, approximately 350 standard cubic feet of gas can be contained in one cubic foot of pore space because gas is highly compressible.

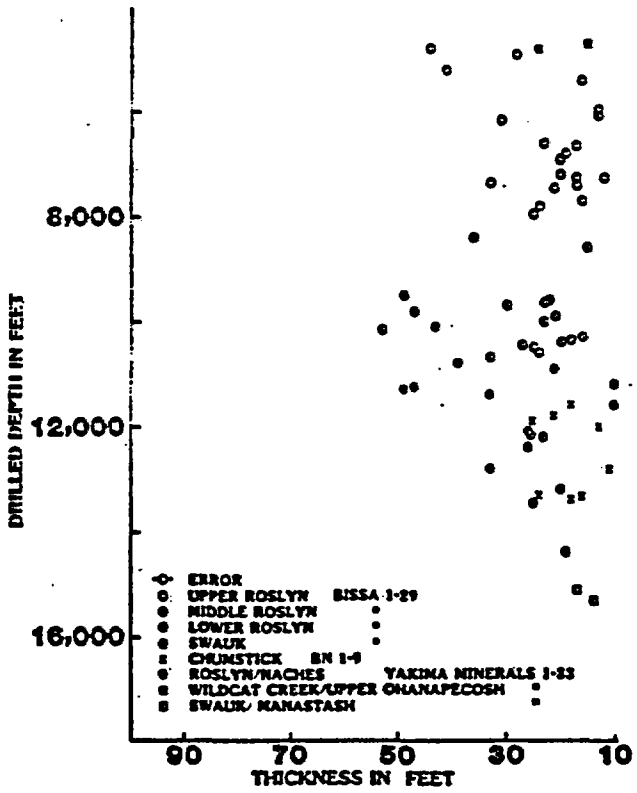


Figure 6. Thicknesses of sandstone having greater than six percent porosity versus drilled depth referenced to the kelly bushing for three Columbia Basin wells. Porosity was determined using the technique given in Figure 5. The thicknesses given represent only those sandstones having relatively uniform porosity; thick siltstone or claystone interbeds are considered to segregate a unit into two or more sandstones for the purposes of this figure. Error bar indicates the uncertainty for each thickness measurement.

These data and interpretations suggest to us that possible petroleum reserves in the vicinity of the proposed repository site range from 40 billion to 1 trillion cubic feet of gas initially in place per trap. The larger volume estimate is based on assumptions of good reservoir characteristics and three stacked pay zones; less conservative gas reserve estimates determined by using these same data will be much greater. Typical recovery currently achieved from gas reservoirs is 60 percent of the gas initially in place in the trap. A giant gas field, that is, a field with sufficient reserves to have major favorable economic impact, is defined as one in which 1 trillion cubic feet of gas can be produced. The potential for reserves of this magnitude is the reason why Shell and others persist with difficult and expensive exploration in the Columbia Basin. It is also the reason why the potential for accidental breaching of a high-level nuclear waste repository, if sited at Hanford, requires thorough investigation before it will be known whether this site will meet the minimum Federal guidelines. More detailed study of the petroleum geology of the greater Columbia Basin is now in progress.

References Cited

Bentley, R. D., 1980, Structure contour maps on the top of the Grand Ronde, eastern Washington and northern Idaho: [Privately published by the author], 1 sheet, scale 1:250,000

Brewer, W. A.; Lasmanis, Ray, 1986, Nuclear waste debated: Geotimes, v. 31, no. 1, p. 2

Campbell, N. P.; Banning, D. L., 1985, Stratigraphy and hydrocarbon potential of the northwestern Columbia Basin based on recent drilling activities: Rockwell Hanford Operations SD-BWI-TI-265, 55 p.

Kontorovich, A. E., 1984, Geochemical methods for the quantitative evaluation of the petroleum potential of sedimentary basins. In Demaison, Gerard; Murris, R. J., editors, Petroleum geochemistry and basin evaluation: American Association of Petroleum Geologists Memoir 35, p. 79-109.

Leaming, G. F.; Davis, J. D., 1983, Mineral resource analysis of the proposed site for underground storage of high-level commercial nuclear waste, Hanford, Washington. In Post, R. G.; Wacks, M. E., editors, 1983, Waste Management '83; Proceedings of the symposium on waste management: University of Arizona, v. 2, p. 235-241

Lingley, W. S., Jr.; Walsh, T. J., 1986, Some comments on the petroleum potential of the proposed Hanford, Washington, high-level nuclear waste repository (abs.): Northwest Petroleum Association Symposium, May 16, 1986, 1 p.

McFarland, C. R., 1983, Oil and gas exploration in Washington, 1900-1982: Washington Division of Geology and Earth Resources Information Circular 75, 119 p.

Montgomery, S. L., editor, 1985, Investigating the potential of the Pacific Northwest: Petroleum Frontiers, v. 2, no. 4, 83 p.

Schlumberger, 1984, Log interpretation charts: Schlumberger Well Services: Houston, p. 106.

Swanson, D. A.; Brown, J. C.; Anderson, J. L.; Bentley, R. D.; Byerly, G. R.; Gardner, J. N.; Wright, T. L., 1979, Preliminary structure contour maps on the top of the Grande Ronde and Wanapum basalts, eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1364, 3 sheets, scale 1:80,000.

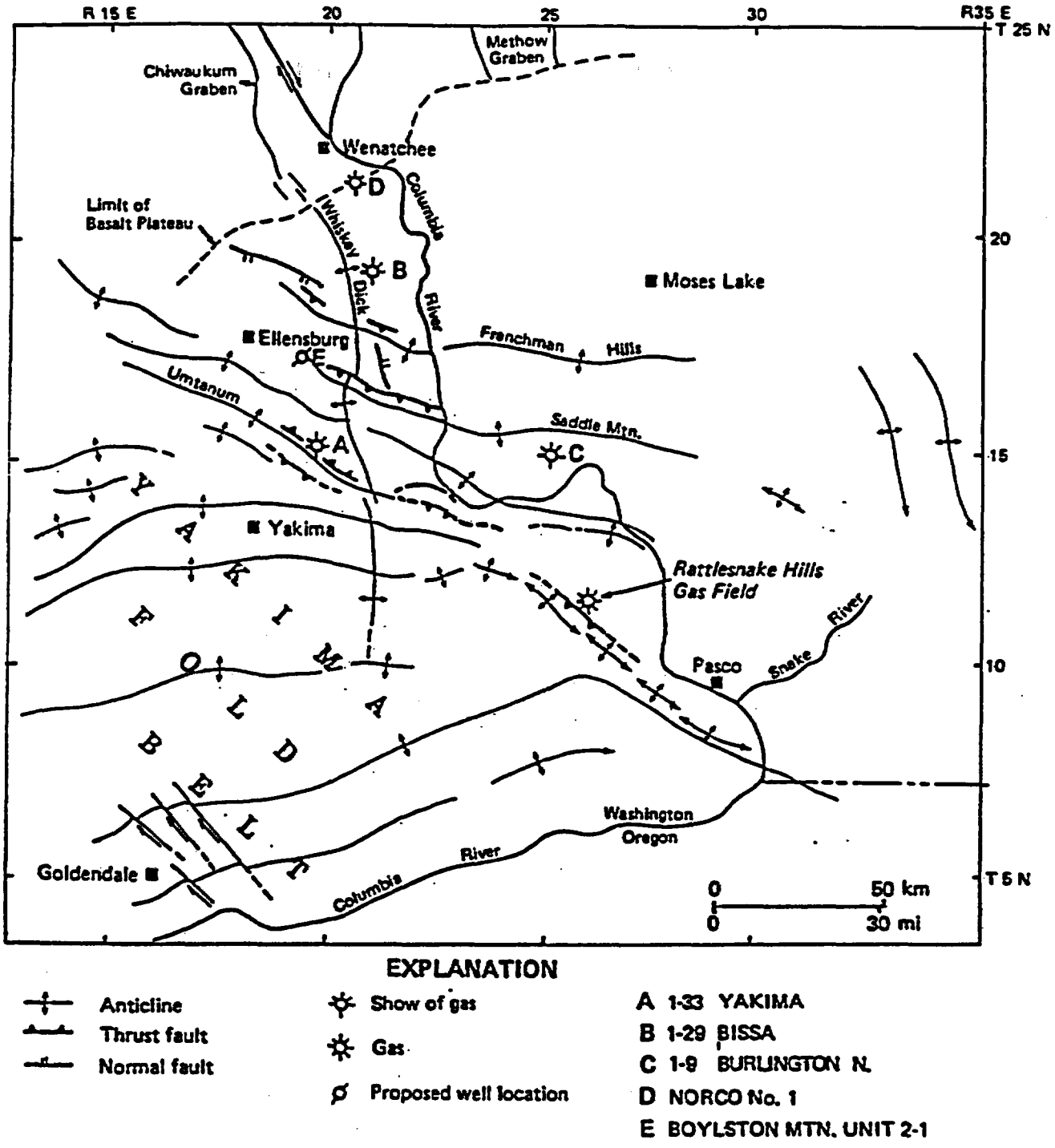


Figure 4. Structure map of the Yakima fold belt and adjacent basins to the north (from Montgomery, 1985).

We determined that mean sandstone porosity, expressed as a percentage of the bulk volume of the rock, is 18 percent at 6,000 feet drilled-depth. Mean sandstone porosity is reduced to only 8 percent at 14,000 feet, regardless of the age or composition of the sandstone present at this depth (Fig. 5). Generally, petroleum cannot flow at high rates through rocks having 8-percent porosity unless expensive and risky mechanical fracturing of the strata is performed to artificially increase permeability.

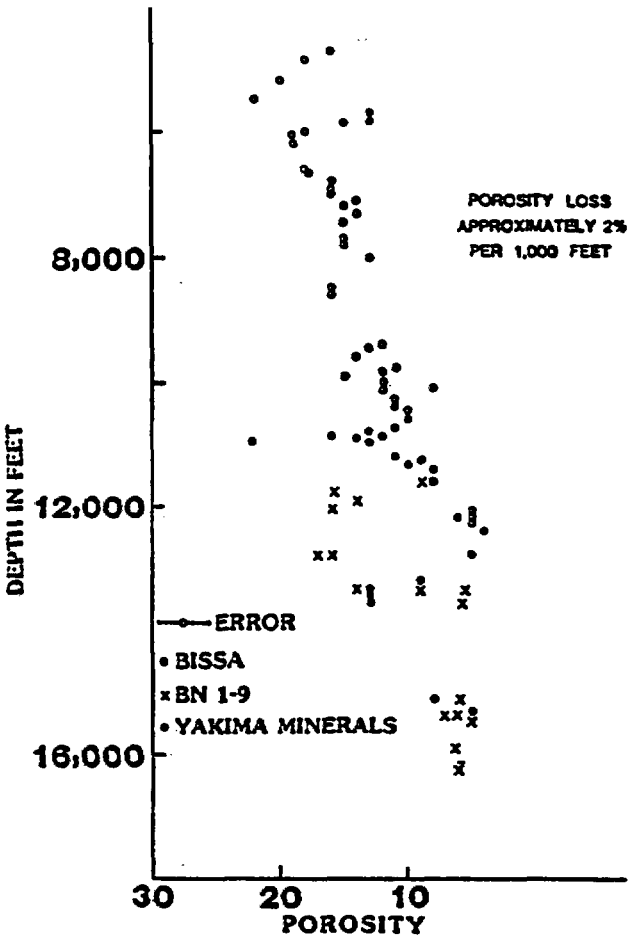


Figure 5. Interpreted porosity versus drilled depth referenced to the kelly bushing for three Columbia Basin wells. Schlumberger (1984) charts Por-14b and Por-15 were used to determine the bore hole environmental corrections and chart CP-1d was used to calculate porosity. The error bar shows the uncertainty in each porosity interpretation.

These problems relating to the porosity and permeability may not exist elsewhere in the Columbia Basin, where the reservoir sandstones may have been derived from a less volcanogenic and more quartz-rich source and where prospective Paleogene rocks lie at a shallower depth. One area having potential for better porosity is located in the east-central part of the basin, directly east of Hanford. Shell is presently concentrating their seismic acquisition program in this area.

If future explorationists wish to undertake further investigations in the basin, they may have to convince management that major reserves are present in order to justify expenditure of considerable amounts of risk capital. To simulate the arguments that these explorationists might invoke, we have estimated the range of possible reserves in the event of a commercial discovery. To make these estimates, the potential range of reservoir volumes and the amount of petroleum that can be squeezed into a unit volume of reservoir rock must be determined. Reservoir volume is a function of porosity of the rock, thickness of the reservoir, areal extent of the trap, and percentage of the reservoir that is actually filled with petroleum. The amount of petroleum that can be held in a unit volume of pore space within a reservoir rock is a function of pressure, temperature, petroleum composition, and water saturation.

Normally, the most significant variable is the size of the petroleum trap. The proposed nuclear waste repository lies within the Yakima fold belt where large anticlines, including the Rattlesnake Hills, the Yakima Ridge, and Umtanum anticlines, impinge on the Hanford Reservation (Fig. 4). These complex folds are mostly asymmetric, commonly verge to the north, range from 3 to 6 miles across strike, and are from 75 to more than 100 miles long as measured along trend. The surface expression of these folds is similar in size and morphology to folds that entrap the giant oil and gas fields of Iran, Rumania, western Alberta, and western Wyoming. Our analysis of mapping by Bentley (1980) and Swanson and others (1979) suggests that trap areas within the fold belt could range from 3,000 to 25,000 acres. The average area of potential anticlinal petroleum traps at the Paleogene sandstone horizons, as interpreted herein, is significantly less than the area of these same anticlines as mapped at the surface. This is because the anticlines are thought to plunge more steeply towards the center of the basin at depth owing to basinward thickening of the basalt. The thickness of the basalt cannot be determined with precision, but interpretation of well and geophysical data suggests that the basalt thickens toward a depocenter in the Pasco subbasin directly north of the repository. However, no data are available to indicate whether the Yakima fold belt anticlines maintain anticlinal morphology within the sedimentary rocks underlying the basalt at the repository.

low signal-to-noise ratios and because of poor coupling between the seismic signal receivers and basalt outcrops. Complex faulting, which is common in the vicinity of the proposed repository, also diminishes the quality of seismic records and hinders interpretation. However, a future explorationist may regard this complexity as an advantage because complex faulting generally results in numerous potential petroleum traps.

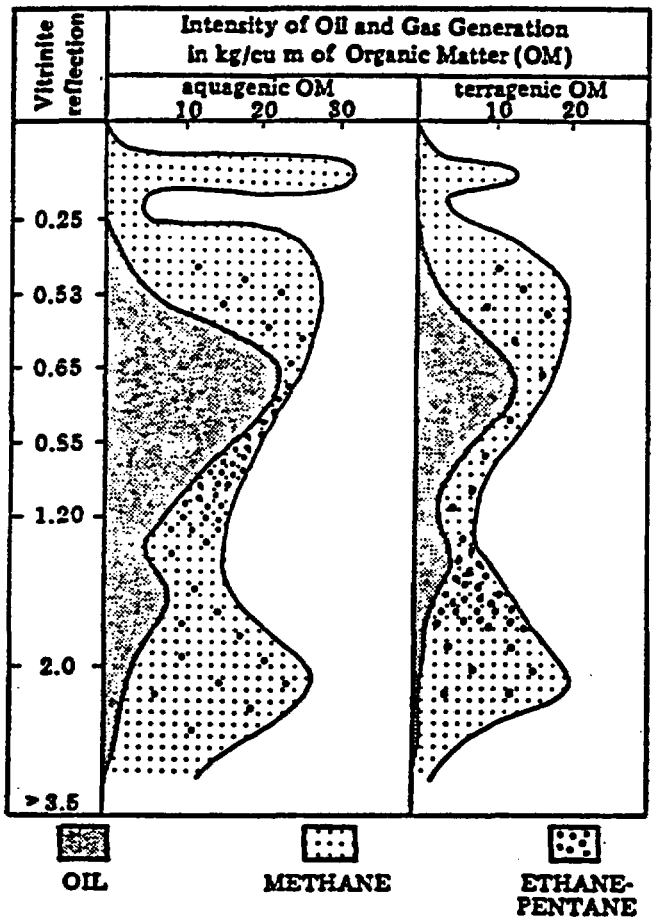


Figure 3. Suggested correlation between vitrinite reflectance and hydrocarbon generative potential (from Kontorovich, 1984.)

No public data, except those herein and in Lingley and Walsh (1986), are available to characterize the quality of the petroleum source-rocks. The USDOE and the Washington State Office of Nuclear Waste Management plan to evaluate the source potential and maturation levels of selected intervals in the Shell wells and in the Norco well (Fig. 1) during the site characterization study.

Despite the paucity of data, petroleum shows logged to date give an indication of the general nature of the source potential of the northern part of the basin. These shows suggest that the source rocks in this part of the basin will probably generate natural gas only. Gas or gas-condensate shows have been recorded throughout the sedimentary section of the northwestern part of the basin, but no oil shows have been logged to date. Much of the sedimentary section in the basin lies within the oil-generative thermal window (Fig. 3), and therefore, we infer that if areally extensive oil-prone source rocks were present in the basin, oil shows should have been observed. Although we expect most future wildcats will penetrate some gas zones, the possibility for an oil discovery cannot be ruled out because few holes have been drilled through the basalt. On the other hand, gas source-rocks are evidently present in abundance in the basin. Gas shows are so ubiquitous that few 100 percent water-bearing reservoirs are present in the Paleogene section. Water-bearing zones are critical for normalizing the responses of sondes used to determine such petrophysical characteristics as porosity and water saturation (the percentage of water that partially fills most pore space below the water table). Nevertheless, natural gas is a less attractive product than oil because of traditionally soft markets and because of high transportation costs. Gas pipeline construction can cost $40 per linear foot, and gas gathering and compression generally cost in excess of a million dollars per field. Because only small markets exist nearby, gas would have to be transported large distances to users.

Even if these three technological problems related to exploring this basalt-covered basin are solved, there remains a question as to whether the potential petroleum reserves in the basin are sufficient to encourage further exploration. In order to answer this question, it is necessary to determine why tests drilled through the basalt into prospective rocks have been sub-commercial discoveries at best. The Yakima Minerals 1-29, located 45 miles west-northwest of the proposed repository, tested 500 thousand cubic feet of gas per day (MCFGPD), and the BN 1-9 tested 3,100 MCFGPD. These rates are commercial for typical wells, but not for wells in the Columbia Basin where the development wells

Table 1. Mean random vitrinite reflectance measurements on coals from selected wells in the Columbia Basin

Well name	Depth interval (feet)	R_o (mean)	Standard deviation	Number of Measurements
Shell BN 1-9	11280-11290	0.54	0.02	50
Grant County	11990-12000	0.63	0.03	50
965' FWL, 1869' FNL	15110-15120	1.13	0.09	50
sec. 9, T. 15 N., R. 25 E.	15160-15170	1.15	0.11	31
	15810-15820	1.32	0.12	50
Shell Bissa 1-29	4620- 4630	0.43	0.05	50
Kittitas County	5150- 5160	0.39	0.04	38
1318' FEL, 1928' FSL	5820- 5830	0.45	0.05	75
sec. 29, T. 18, R. 21 E.	6480- 6490	0.51	0.05	77
T.D. = 14,965 ft.	6890- 6900	0.50	0.05	75
	7600- 7610	0.53	0.06	75
	8560- 8570	0.57	0.06	100
	9210- 9220	0.53	0.06	79
	9590- 9600	0.47	0.08	41
	10070-10080	0.57	0.05	53
Shell Yakima Minerals 1-33	9840- 9850	0.86	0.11	76
Kittitas County	10070-10080	0.91	0.07	74
925.5' FNL, 1445.6' FWL	10370-10380	1.08	0.08	75
sec. 33, T. 15 N., R. 19 E.	10805-10810	1.11	0.09	61
T.D. = 16,199 ft.	11010-11020	1.20	0.13	75
	11860-11870	1.38	0.12	75
Norco No. 1	1751- 1760	0.39	0.03	54
Chelan County	1920- 1930	0.39	0.03	7
NW1/4 NW1/4 SW1/4 sec. 26,	2253- 2260	0.51	0.05	51
T. 22 N., R. 20 E.	2400- 2410	0.49	0.08	53
	2535- 2540	0.48	0.06	24
	2690- 2700	0.32	0.02	45
	2785- 2790	0.42	0.17	4
	2885- 2890	0.28	0.03	25
	3144- 3150	0.35	0.03	51
	3305- 3310	0.47	0.04	48
	3444- 3450	0.42	0.06	26
	3692- 3700	0.51	0.05	50
	3972- 3980	0.50	0.06	24
	4208- 4220	0.77	0.07	11
	4671- 4680	0.66	0.07	57
	4840- 4850	0.51	0.06	69

necessary to establish commercial production may cost $8 to 14 million each. Flow-test data indicate that the reservoir sandstones penetrated by the Yakima Minerals 1-29 and the BN 1-9 wells are not sufficiently extensive to sustain production. Furthermore, many of the sandstones are composed mostly of volcanogenic detritus. This detritus tends to break down to form clays or other minerals that reduce porosity and/or permeability within the reservoir. The alteration appears to be a function of depth of burial.

netic data, have failed to yield prospect-scale information owing to limited resolution.

In order to locate possible prospects, we recommend that mapping of surface structure be augmented with state-of-the-art, regional reflection seismograph traverses across the site. These new traverses should be included in the ongoing petroleum assessment that is part of the Hanford site characterization study. The traverses should be planned so as to avoid interference from known faults and so as to decrease accoustical noise by having the line laid out on alluvium rather than on basalt. We believe that a meaningful assessment cannot be accomplished without acquisition of these seismic data.

An alternative to seismic traverses being considered by the U.S. Department of Energy (USDOE) and the Nuclear Regulatory Commission is drilling a well at the repository site through the basalt and into the more prospective Paleogene rocks to a total depth of approximately 15,000 feet. The estimated cost of this drilling program exceeds $10 million. We oppose this proposal because the results of such drilling may be equivocal, providing information for only one point, and therefore may not justify the high cost to utility ratepayers. Shell's experience gained by drilling and testing three sub-commercial discoveries in the vicinity of Hanford indicates that numerous gas zones are likely to be penetrated if a well is drilled at Hanford. In order to determine the magnitude of gas reserves in these zones, many will have to be stimulated and tested at additional expense. The probable result of this testing program will be that none of these zones is commercial under present-day economic constraints. However, it is not difficult to envision a wellhead gas price many times greater than the present $1.50 per thousand cubic feet, considering the non-renewable nature of petroleum resources and the likely demand for natural gas to be used as a petrochemical feedstock in the future. It is likely that a future wildcatter would find a greatly increased gas price to be a strong incentive for re-entering a well already drilled and cased through the basalt. Hundreds of wells originally abandoned as dry holes were re-entered for just this reason during the 1970s. If public records should cease to exist, the plugged well could be located because of the magnetic signature of the casing. Under this unpleasant but possible scenario, the well drilled for the very purpose of deciding if it is necessary to keep future explorers out of the repository area would have precisely the opposite effect (unless a carefully reasoned plugging program for this 15,000-foot test and for the numerous shallower wells already drilled by USDOE is developed).

Regional Petroleum Potential of the Columbia Basin

It is reasonable to assume that some form of direct petroleum detection technology may be developed during the life span of the repository and that use of this technology may result in successful exploration in areas such as Hanford where no obvious manifestations of petroleum potential exist today. Direct detection or other new exploration technology could be applied to the greatest advantage in unexplored basins that have significant theoretical but untested potential to produce hydrocarbons. Historically, petroleum has been discovered by drilling at locations proven by mapping to be analogous to existing oil or gas fields. Some small accumulations, trapped by structure, hydrodynamics, or stratigraphic pinchouts too subtle to map using existing technology, have been discovered accidentally by drilling in thoroughly explored basins. However, closely spaced drilling in almost all onshore basins in the United States diminishes the probability of large new oil or gas discoveries from anticlinal or subtler types of traps because the remaining unexplored area is insufficient for typical large petroleum fields. For example, the Powder River Basin, a productive basin in northeastern Wyoming roughly equal in size to the Columbia Basin, has had more than 27,000 wells drilled for oil and gas. On the other hand, the Columbia Basin, where only nine wells have been drilled to date, is the least explored, large onshore basin in the United States. Consequently, it is likely to have more intensive exploration in the future if reasonable hope for a commercial discovery exists.

The basic ingredients of a petroleum-generative province are present in the Columbia Basin. For example, sedimentary rocks in excess of 10,000 feet thick were penetrated in the Yakima Minerals 1-29 well (Figs. 1 and 2). Gas shows were logged in

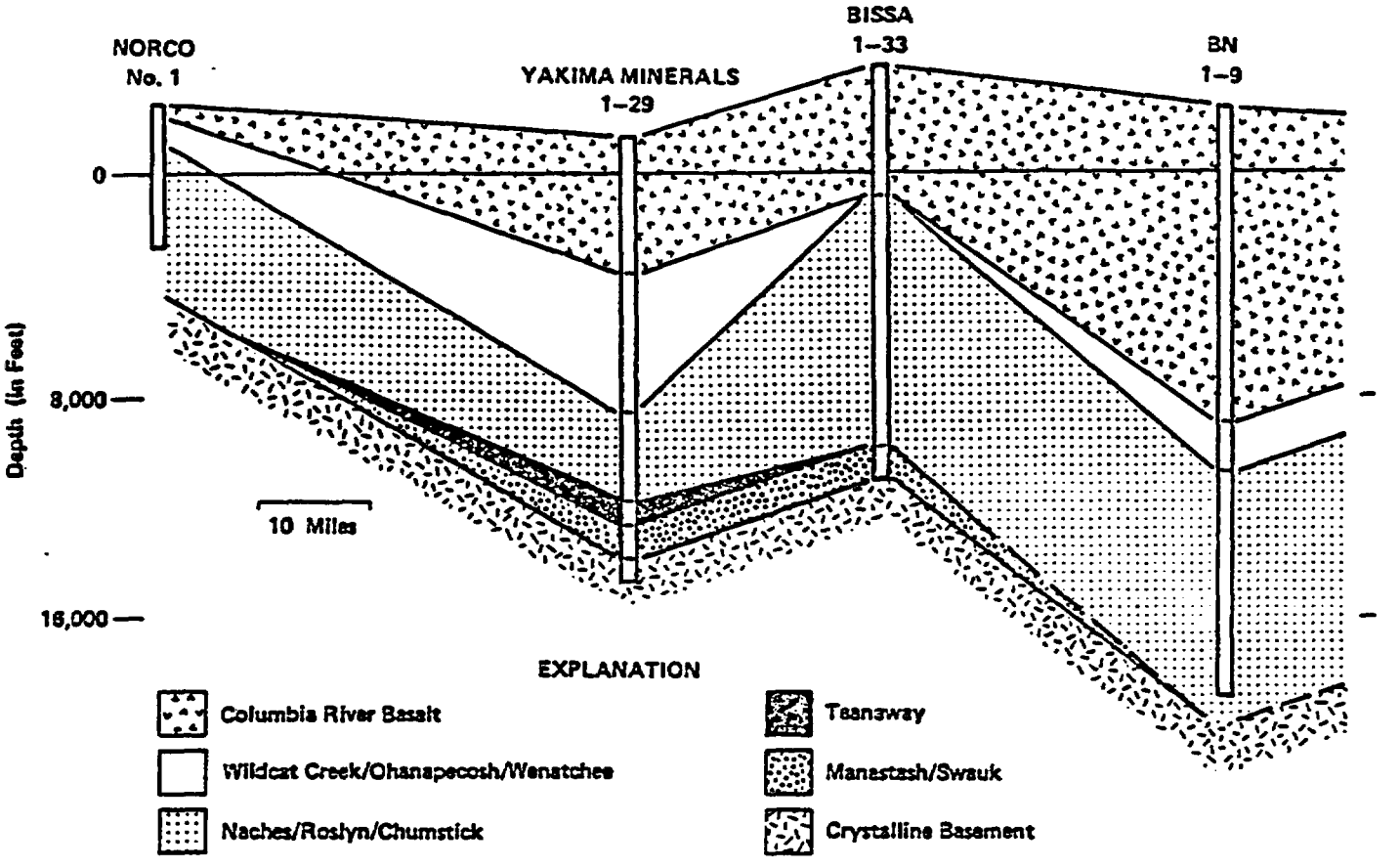


Figure 2. Correlation diagram for selected Columbia Basin wells. Interpretation is from Campbell and Banning, 1985; N. E. Campbell, personal communication, 1986; and J. E. Evans, University of Washington, written communication, 1985.

all wildcat wells drilled into the sedimentary section and in numerous water wells drilled into the Columbia River basalt. We calculate moderately high geothermal gradients (+/- 40°C/kilometer), which are optimally conducive to generation and preservation of petroleum. The reflectance of vitrinite, a coal maceral, is considered to be a maximum-reading paleo-thermometer. We have measured vitrinite reflectance values between 0.5 and 1.0 which also demonstrate that much of the sedimentary section is thermally mature for petroleum generation (Fig. 3, Table 1). Large, doubly-plunging or faulted anticlines are common (Fig. 4) and provide abundant traps. Furthermore, 1.3 billion cubic feet of natural gas were produced from the Rattlesnake Hills gas field prior to its abandonment in 1941 (McFarland, 1983). This field, located in a subsidiary fold on the north flank of the Rattlesnake Hills anticline, lies within the Hanford Reservation a few miles from the proposed repository (Fig. 1).

The obvious questions many laypersons ask when presented with this information are, "Why aren't hydrocarbons being produced at present, and why haven't more exploratory wells been drilled if the Columbia Basin is such a good place to search for petroleum?" Three obstacles have impeded successful exploration in the Columbia Basin: (1) the difficulty in drilling through the basalt (2) the difficulty of obtaining seismic data, and (3) the gas-generative nature of the source rocks.

Basalt is difficult to drill because of its hardness and because of the problems of maintaining drilling-mud circulation while penetrating numerous, highly permeable fracture zones that characterize these rocks. The Shell BN 1-9 well located directly north of the repository and the Standard Oil of California Rattlesnake Hills No. 1 well located within the Hanford Reservation both drilled through more than 10,000 feet of basalt (Figs. 1 and 2); these were unusually expensive projects, and neither penetrated commercial gas zones.

It is particularly difficult to acquire high-quality seismic data in basalt because of

ISSUES RELATING TO PETROLEUM DRILLING NEAR THE PROPOSED HIGH-LEVEL NUCLEAR WASTE REPOSITORY AT HANFORD

by

William S. Lingley, Jr.
and Timothy J. Walsh

In February 1986, the Office of Nuclear Waste Management of the Washington State Department of Ecology requested that the Division of Geology and Earth Resources assist in a study of future petroleum activities in the vicinity of the proposed high-level nuclear waste repository at Hanford. The objective of this study is to determine the probability that the repository could be accidentally breached as the result of drilling for oil or gas. If significant probability for such an accident exists, then Hanford will not meet the U.S. minimum qualifying conditions for nuclear waste repository siting (10 CFR 960-4-8-1a). Our preliminary findings suggest that the probability of such an accident is low. These findings were presented to the Northwest Petroleum Association during their 1986 annual meeting (Lingley and Walsh, 1986). This article discusses the issues and describes some ongoing studies designed to reach a more conclusive decision on the breaching issue.

The U.S. Nuclear Regulatory Commission is concerned that, in the distant future, accidental breaching may occur at the repository despite prohibition of access to the Hanford Reservation and despite the elaborate hazard warning system planned for the repository. The minimum effective life span of the repository must exceed the 10,000 years necessary for the waste to decay to minimum acceptable radiation levels (Brewer and Lasmanis, 1986). Consequently, it is probable that the repository will outlast present political institutions, and it might also outlast written record of the presence and dangers of the radioactive nuclides stored in the repository chambers.

Accidental breaching could result from drilling directly into the repository or from drilling nearby and, as a result, exposing rocks contiguous with the repository to formation fluids or drilling fluids capable of leaching fracture-filling minerals in the chamber walls. The apparent probability of either type of breach is low, given that the Columbia Basin, in which Hanford is located, is covered with a thick section of Columbia River basalt which is relatively unprospective for oil and gas and given that petroleum is not presently produced in Washington State. ("Prospective" is used as in the industry idiom to indicate favorable possibilities for oil or gas accumulation(s) at a given location. "Petroleum" is used here in the legal sense and includes oil, gas, and gas condensate).

However, Shell Western Exploration and Production, Inc., and others have undertaken a relatively aggressive exploration program in the basin. During 1986 alone, the Division of Geology and Earth Resources has received permit applications for acquisition of more than 250 line miles of seismic data and for drilling a 15,000-foot wildcat well, the Boylston Mountains Unit No. 2-1. This well will be located 40 miles northwest of the proposed waste repository site (Fig. 1). This exploration program, undertaken during a severe recession for the petroleum industry, suggests that this part of the Columbia Basin is prospective.

A central question is whether the proposed repository site is sufficiently prospective to attract drillers to those areas having hydrologic continuity with the repository. In order to answer this question, we have commenced studies of the petroleum potential of the repository proper and of the northwestern Columbia Basin. Previous work by Leaming and Davis (1983) dealt only with the petroleum potential of the basalt, and work by Campbell and Banning (1985) concentrated on regional stratigraphy.

Petroleum Potential at the Proposed Repository Site

The first step in assessing the probability of accidental penetration of the repository is to find obvious prospects for petroleum accumulations at or near the proposed repository site. Prospects are usually delineated by mapping anticlines or faulted anticlines having potential to trap oil and/or gas migrating out

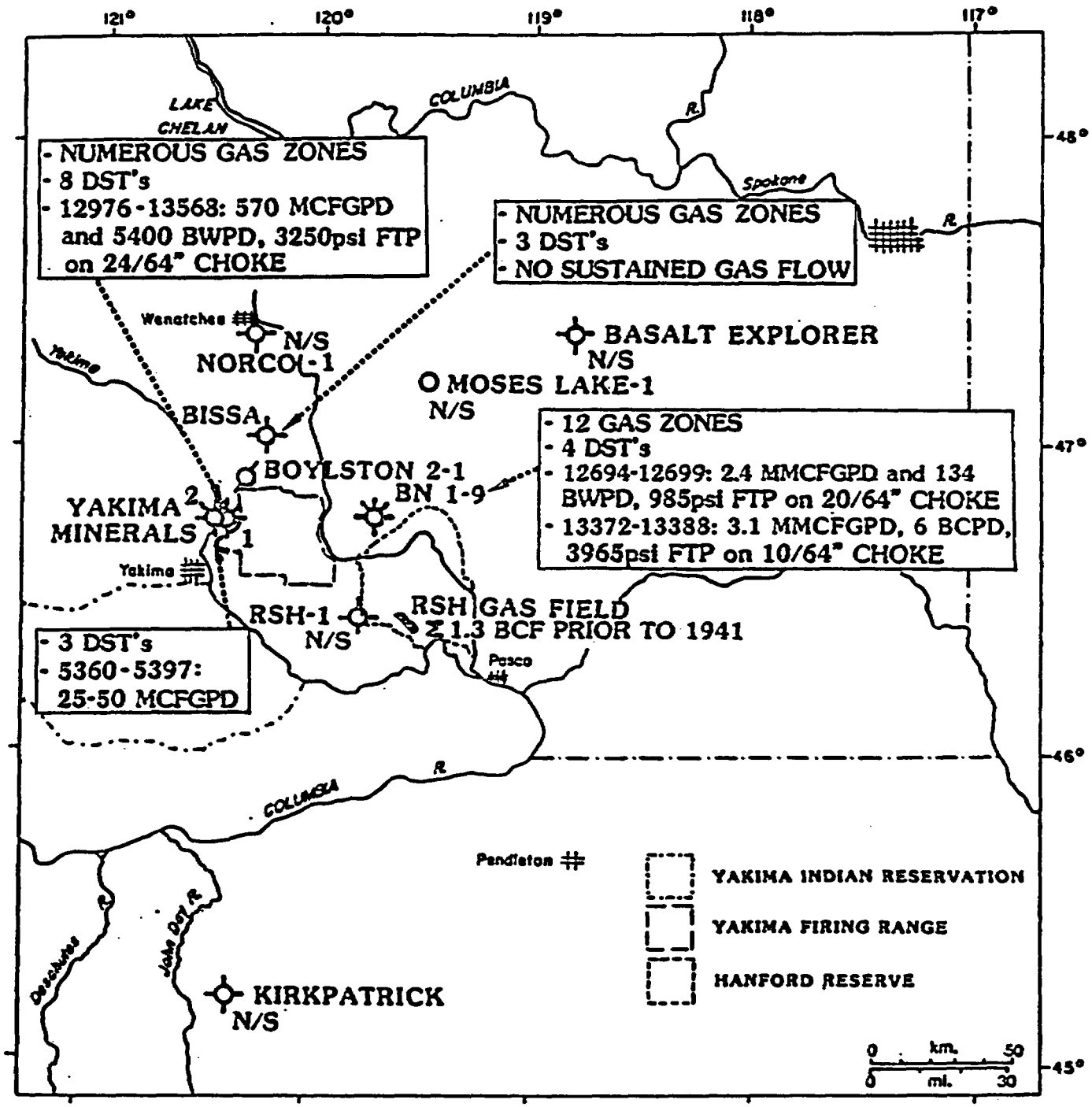


Figure 1. Index map showing locations of important northern Columbia Basin wildcat wells with data on relevant petroleum shows and drillstem tests (DST's). BWPD, barrels of water per day; BCPD, barrels of condensate per day; FTP, flowing tube pressure; N/S, no shows; BCF, billion cubic feet; MCFGPD, thousand cubic feet of gas per day. All depths in feet referenced to the kelly bushing.

of petroleum source rocks. In some parts of the Columbia Basin, structural geometry at depth can be deduced by extrapolation of structure as mapped at the surface downward to the most prospective horizons. These horizons comprise Paleogene sandstones, which generally lie at depths of 5,000 to 14,000 feet. However, it is likely that some Columbia Basin anticlines fold only Paleogene strata and have no manifestation in the basalt or at the surface. There is no definitive, yet inexpensive means of mapping these deeper structures in the Columbia Basin with present technology. Relatively inexpensive prospecting techniques, including interpretation of gravity, magnetic, and electromag-

CONCLUSIONS

- POTENTIAL FOR A GIANT NATURAL GAS DISCOVERY PROVIDES INCENTIVE FOR DRILLING
- DATA PRESENTLY AVAILABLE INDICATE THE PROBABILITY OF A DISCOVERY WITHIN THE CONTROLLED AREA STUDY ZONE IS LOW
- SEISMIC DATA ARE REQUIRED TO ASSESS THE POTENTIAL THAT DRILLING MAY OCCUR WITHIN THE REFERENCE REPOSITORY LOCATION
- DEEP DRILLING MAY BE OF LIMITED VALUE IN ASSESSING THE NATURAL RESOURCES ISSUE

CENTRAL COLUMBIA BASIN
VOLUMETRIC GAS RESERVE ESTIMATE MODELING PARAMETERS

VARIABLE	DEPTH IN FEET		
	5,000	10,000	14,000
RESERVOIR TEMPERATURE (^{o}R)	628	738	826
COMPRESSIBILITY FACTOR (Z)	0.75	0.85	1.00
RESERVOIR PRESSURE (PSI)	2100	4500	8700
RESERVOIR POROSITY	0.18	0.12	0.08
RESERVOIR THICKNESS (FEET)	28	27	25
TRAP AREAS			
RANGE - 3,000 to 25,000*			
MEAN - 8,500			
WATER SATURATION (%) = 65			
NET TO GROSS PAY RATIO (%) = 80			
PERCENTAGE OF TRAP FILLED WITH GAS= 80			

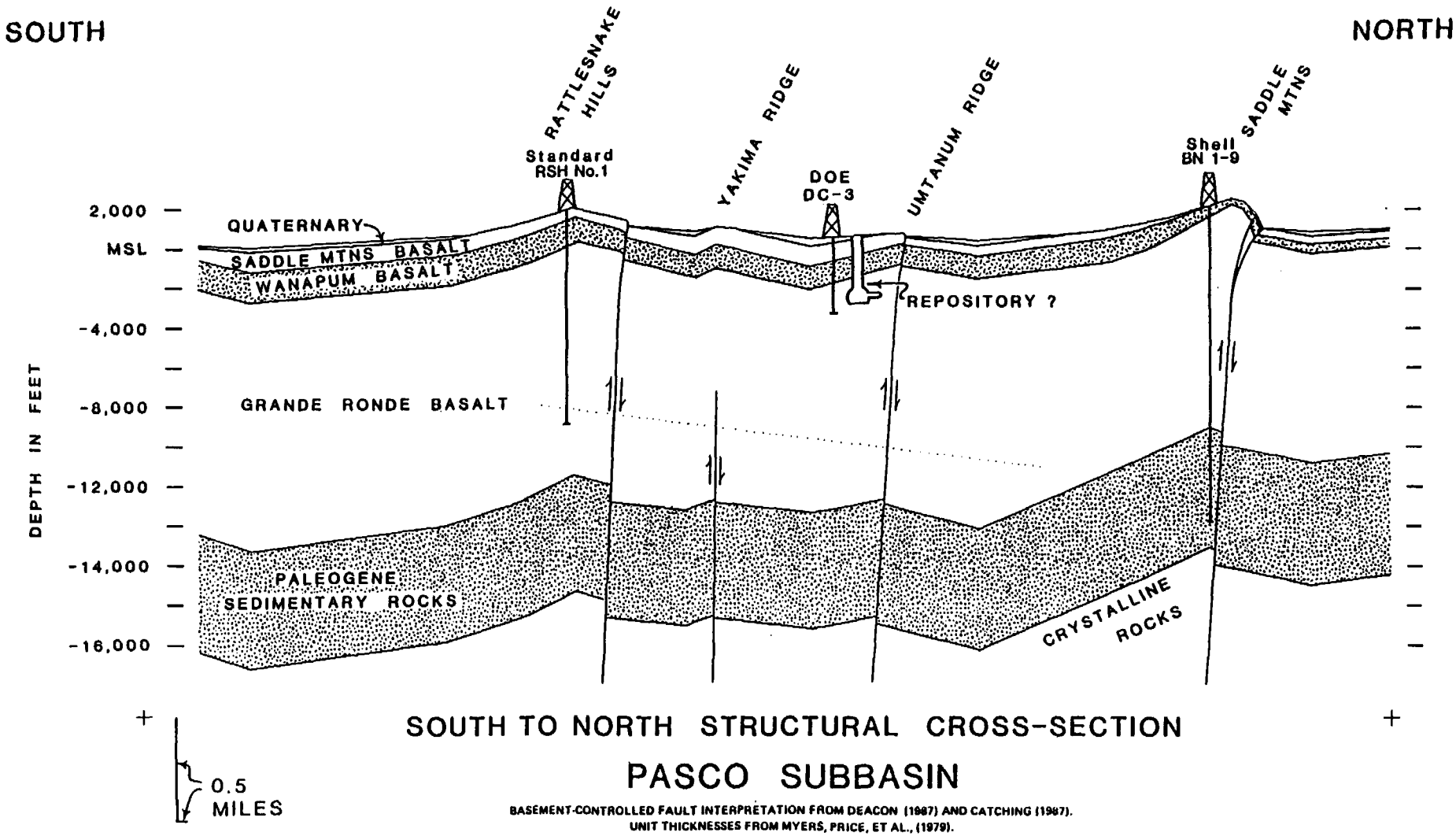
* Recent work suggests presence of faulted anticlines having structurally-closed areal extents in excess of 50,000 acres

PETROLEUM POTENTIAL OF THE CENTRAL COLUMBIA BASIN

- GAS INITIALLY IN PLACE
  Range = 50 Billion to 1 Trillion Cu. Ft.
  Expected Value = 110 Billion Cu. Ft.
- < 25 POTENTIAL TRAPS FOR NATURAL GAS IDENTIFIED TO DATE
- PROBABILITY FOR ANY DISCOVERY IS LOW

NATURAL RESOURCES POTENTIAL

- NATURAL GAS EXPLORATION
- GROUNDWATER PRODUCTION



SOUTH TO NORTH STRUCTURAL CROSS-SECTION

PASCO SUBBASIN

BASEMENT-CONTROLLED FAULT INTERPRETATION FROM DEACON (1987) AND CATCHING (1987).
UNIT THICKNESSES FROM MYERS, PRICE, ET AL., (1979).

ENVIRONMENTAL ASSESSMENT
COMPOSITE RANKING

*1. Yucca Mountain
2. Richton Dome
*3. Deaf Smith
4. Davis Canyon
*5. Hanford

* Selected by USDOE for Site Characterization

ISSUES

NATURAL RESOURCE POTENTIAL- Bill Lingley

GEOTECHNOLOGY - Bill Brewer
- GEOLOGY
- HYDROLOGY
- GEOMECHANICS
- CONDEMNATION APPROACH

SITE CONTAMINATION - Don Provost

FINAL ENVIRONMENTAL ASSESSMENT

OVERALL PRECLOSURE ANALYSIS

* 1. Yucca Mountain
  2. Richton Dome
* 3. Deaf Smith
  4. Davis Canyon
* 5. Hanford

* Selected by USDOE for Site Characterization

FINAL ENVIRONMENTAL ASSESSMENT

OVERALL POSTCLOSURE RANKING

1. Davis Canyon
2. Richton Dome
*3. Deaf Smith
*4. Yucca Mountain
*5. Hanford

*Selected by USDOE for Site Characterization

OPENING REMARKS

WASHINGTON STATE
NUCLEAR WASTE BOARD

STATE OFFICIALS

LEGISLATORS

OPENING REMARKS

WASHINGTON STATE
NUCLEAR WASTE ADVISORY COUNCIL

CITIZENS

LOCAL GOVERNMENTAL
OFFICIALS