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NUCLEAR REGULATORY COMMISSION
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FROM: Paul T. Prestholt, Sr. On-Site Licensing Representative

DATE: December 7, 1988

SUBJECT: PROTOTYPE UNDERGROUND GEOLOGIC MAPPING

Please find enclosed the above-referenced information.

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NH03
WM-11

PROTOTYPE UNDERGROUND GEOLOGIC MAPPING

WBS 1.2.6.9.4.1.1
and
WBS 1.2.6.9.4.1.2

Principal Investigator:

M. H. McKeown (USBR)

Co-Investigators:

C. C. Barton (USGS)
S. C. Beason (USBR)
G. M. Fairer (USGS)
R. A. Thompson (USGS)

Participating Organizations:

U.S. Geological Survey
U.S. Bureau of Reclamation

DETAILED TEST PLAN

PROTOTYPE UNDERGROUND GEOLOGIC MAPPING

WBS 1.2.6.9.4.1.1
and
WBS 1.2.6.9.4.1.2

5/4/88 Mark H. McKeown Date Principal Investigator	5/16/88 Christopher C. Barton Date Co-Investigator
5/4/88 Steven C. Beason Date Co-Investigator	5/13/88 George M. Fairer Date Co-Investigator
5/10/88 Ernest E. Glick Date Co-Investigator	5/10/88 Ren A. Thompson Date Co-Investigator
5/18/88 Richard P. Snyder Date Technical Reviewer	5/18/88 Larry R. Hayes Date Chief, Branch of NNWSI

CONTENTS

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NOV 4 1986

NOV 4 1988

1.0 INTRODUCTION

Prototype testing of underground geologic mapping methods is designed to test the equipment and methods used to address the needs of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project Performance Allocation and the NNWSI Issues and Information Needs. These issues and needs require that the geologic character of the repository be determined. Also, they require that those geologic factors be determined that contribute to prediction of the hydrologic behavior and tectonic stability of the repository for a period of 10,000 yr. Principally, the fractures (joints and faults) and the lithologic sequence (stratigraphy) need to be determined for geologic characterization of the repository block. The fracture network of the repository block must be determined to predict hydrologic behavior and mechanical stability. Tectonic stability can be determined, in part, by study of the nature of faults and by measurement of the age of movement on faults.

Experimental procedures or equipment tested during prototype testing will be used to finalize procedures and equipment to be used in the underground geologic mapping project, Site Characterization Activity Number 11502020400. Table 1.1-1 provides a list of all performance and design requests for site data on physical rock properties and for information related to the geologic framework and geologic processes at the site. Figure 1.1-1 provides a logic diagram for the derivation of the geologic model (diagonal hatching on line). Figure 1.1-2 provides a logic diagram relating the geologic framework to the geohydrologic model, whose logic is shown by Fig. 1.1-3. Finally, Fig. 1.1-4 shows the interface of the design performance and potentially adverse/favorable conditions with the geohydrologic model. These data needs were derived by applying performance allocation to the performance and design issues described in Sections 8.3.2 through 8.3.5 of the Site Characterization Plan (SCP).

1.1 Purpose

The purpose of this report is to describe the experimental procedures or prototype tests that will be used by the U.S. Bureau of Reclamation (USBR) and the U.S. Geological Survey (USGS) to test underground geologic mapping methods. Because experimental procedures for the shaft (WBS 1.2.6.9.4.1.1) and for the drifts (WBS 1.2.6.9.4.1.2) are similar, descriptions of the procedures for both are combined in this document.

1.1 Scope

The scope of this report is limited by the nature of prototype testing and by the present stage of the testing. Therefore, this report is limited to a description of the next step in prototype testing because only the next step in testing can be predicted at any time. Because prototype testing drift and shaft mapping methods were begun before this

Table 1.1-1. Rock characteristics, geologic parameters, design performance versus site characteristics

Parameter Code	Common Parameter Category (Design/Performance--Site Parameter Interface)	Goals and Confidences (NQ = Not Quantifiable)	Site Characterization Parameter	Site Characterization Activity Number
11110	Rock unit contact location and configuration	NQ	Lithology, stratigraphic sequence	11502020400
11110	Rock unit contact location and configuration	NQ	Repository stratigraphic sequence	11502020400
11120	Rock unit lateral and vertical variability	NQ	Lateral variability, lithostratigraphic units, exploratory shaft (ES) drifts	11502020400
11120	Rock unit lateral and vertical variability	NQ	Lateral continuity, repository host horizon	11502020400
11220	Fracture distribution	NQ	Fracture network, three-dimensional, exploratory shaft facility (ESF)	11502020400
11210	Fracture orientation	NQ	Orientations, fractures, statistical distributions	11502020400
11140	Rock unit petrology/petrography	NQ	Petrography, stratigraphic sequence	11502020400
11260	Fracture physical properties	NQ	Roughness, fractures	11502020400
11310	Fault orientation	NQ	Orientations, faults	11502020400
11350	Fault zone mineralogy and physical properties	NQ	Physical characteristics, faults	11502020400
11320	Fault location	NQ	Tectonic styles, faults, Ghost Dance Fault	11502020400
11340	Fault displacement	NQ	Structural domains	11502020400
11230	Fracture aperture	NQ	Aperture, fractures	11502020400
11320	Fault location	NQ	Structural domains	11502020400
11320	Fault location	NQ	Tectonic styles, faults	11502020400
11220	Fracture distribution	NQ	Spatial distribution, fractures	11502020400
11250	Fracture filling mineralogy	NQ	Mineralogy, fractures	11502020400
11220	Fracture distribution	NQ	Orientations, fractures, statistical distributions	11502020400
11340	Fault displacement	NQ	Tectonic styles, faults, Ghost Dance Fault	11502020400
11340	Fault displacement	NQ	Tectonic styles, faults	11502020400
11240	Fracture length	NQ	Trace length, fractures	11502020400
14000	Tectonism	NQ	Age, fracturing	11502020400

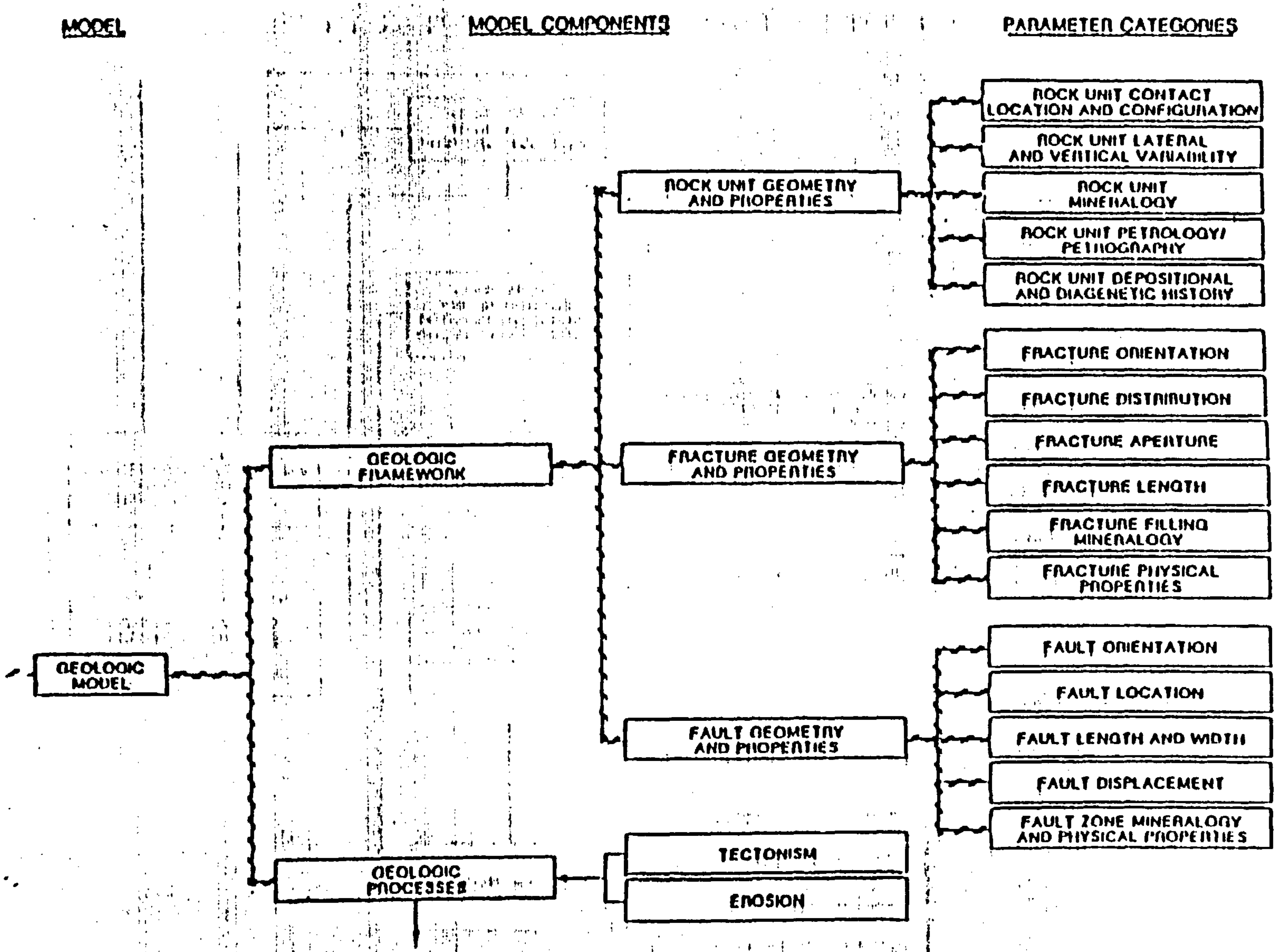

Fig. 1.1-1. Logic diagram--geologic model.

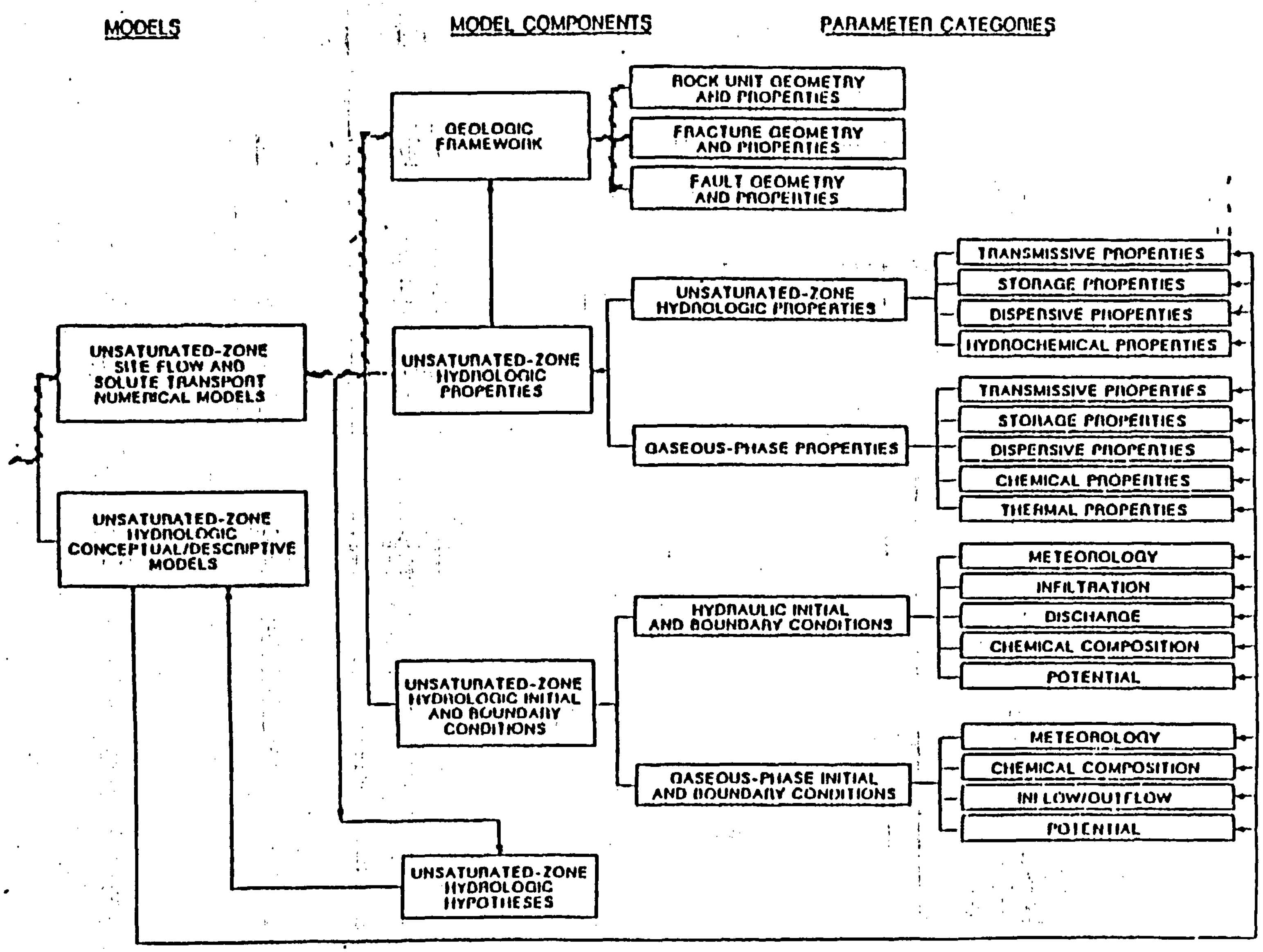

Fig. 1.1-2. Logic diagram--unsaturated zone hydrologic model.

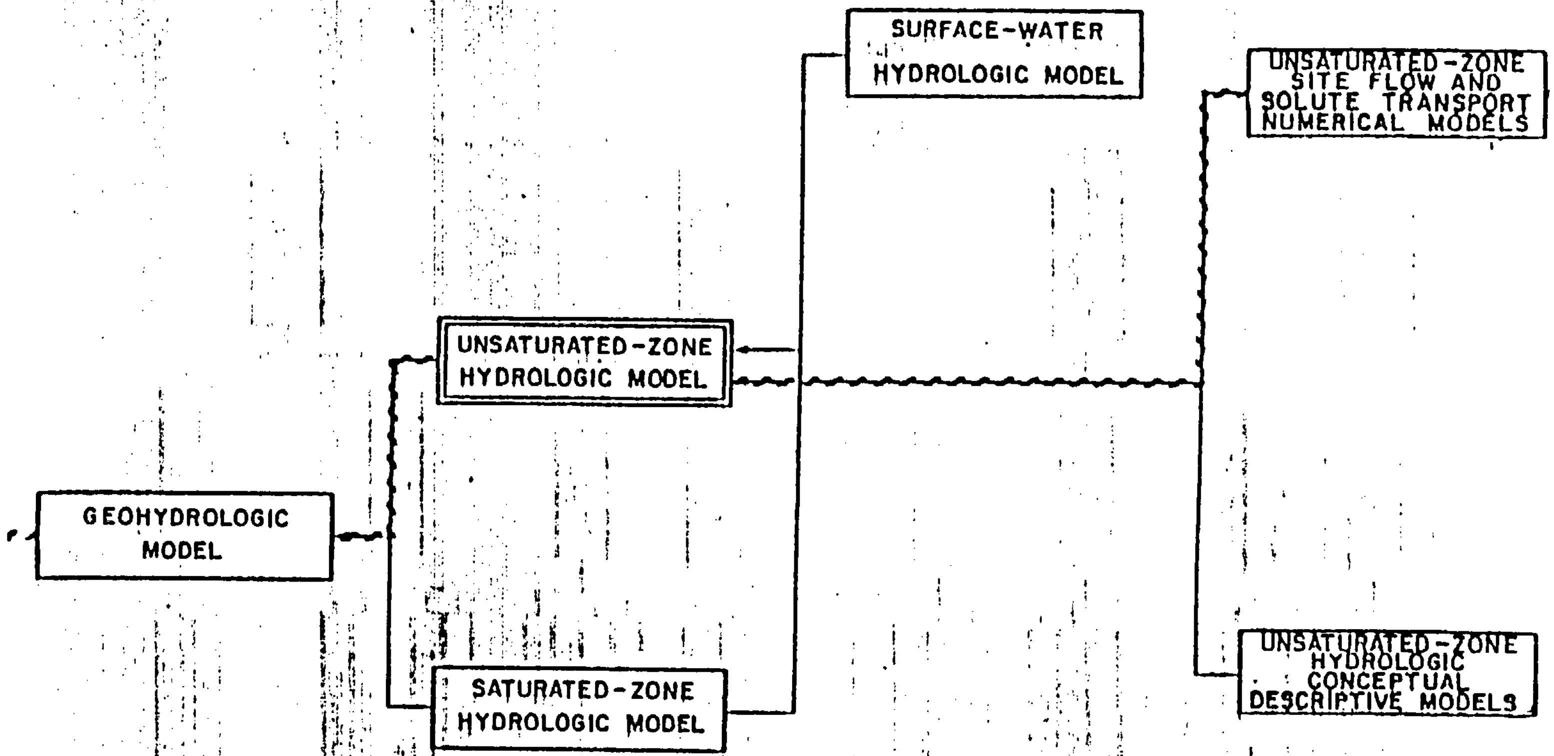

Fig. 1.1-3. Logic diagram--unsaturated zone hydrologic model.

NOV 4 1988

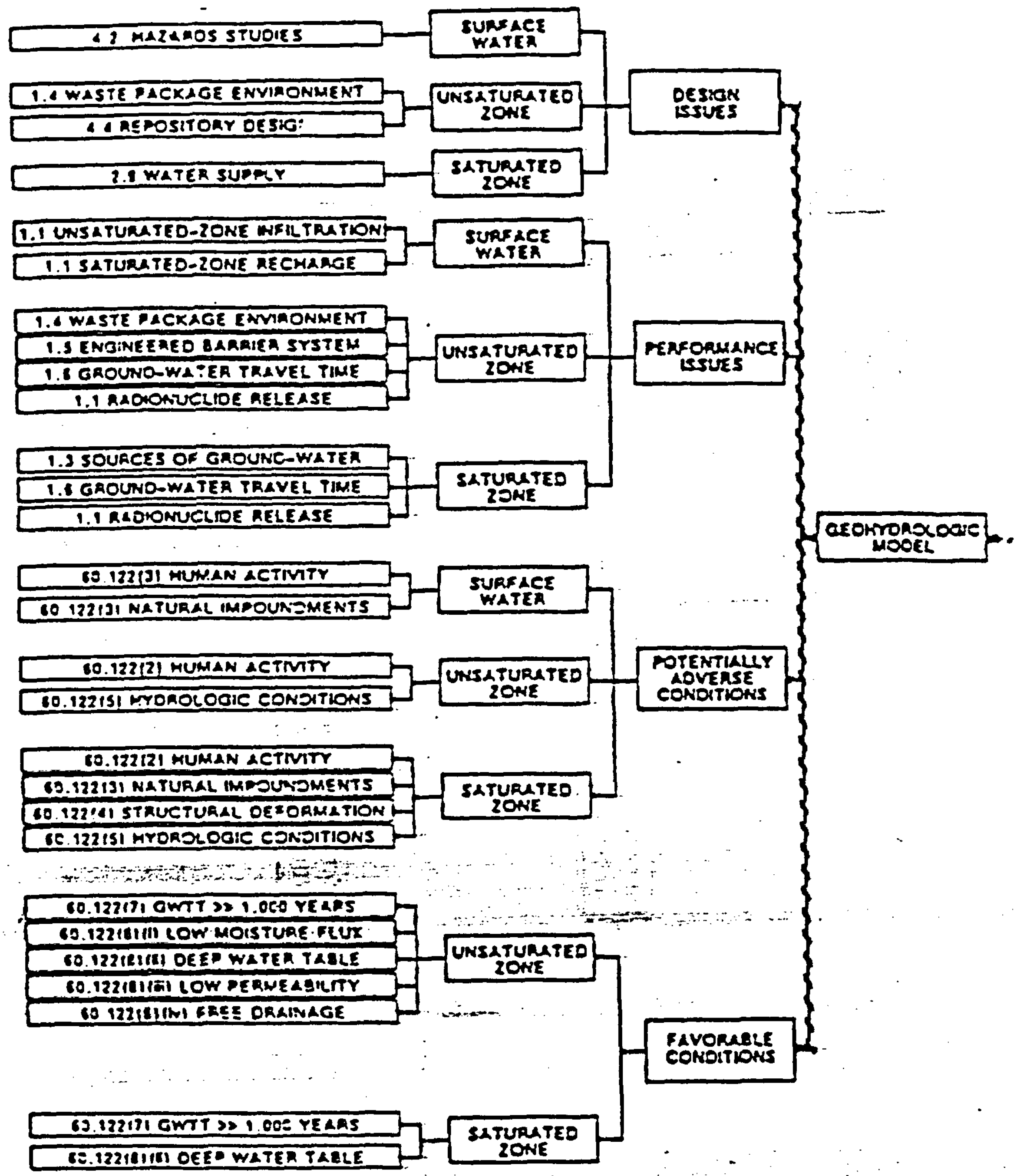

Fig. 1.1-4. Design performance and potentially adverse/favorable conditions interface with geohydrologic model.

NOV 4 1988

1.4.2 Development of Efficient and Specialized Surveying Techniques

Use of laser surveying techniques to reduce the amount of time spent orienting the shaft mapping platform, camera rail, and photographic equipment has been investigated. In future prototype testing, these techniques will be used in the test pits at Fran Ridge (Fig. 1.1-5), located about 5 km east of the repository boundary and in the test drift in G-tunnel (Fig. 1.1-6). Representatives of Holmes and Narver (H&N), Pan American World Services (Pan Am), and Reynolds Electric and Engineering Company (REECo) have cooperated with the USGS and USBR on this phase of prototype testing.

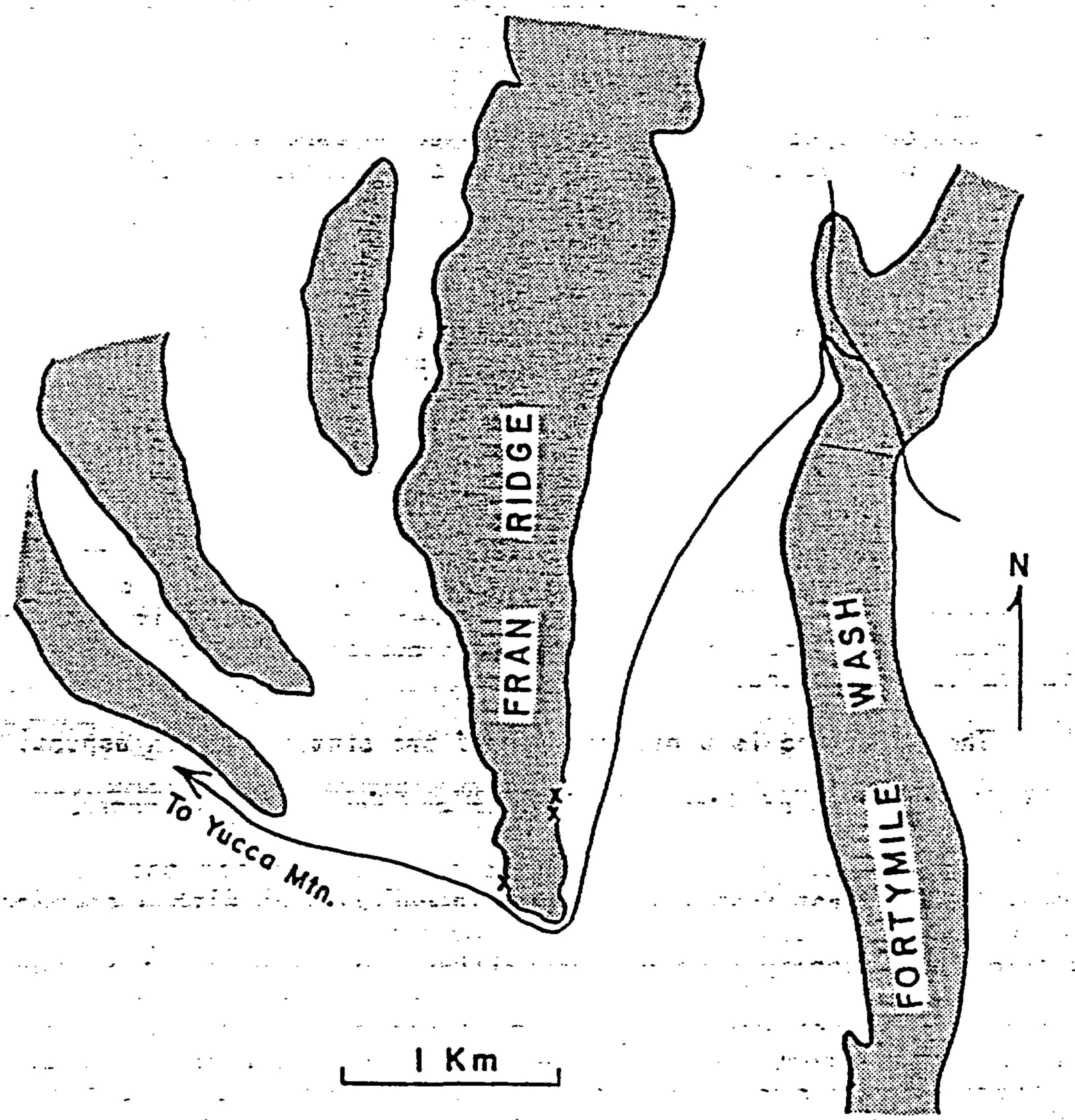

Fig. 1.1-5. Map showing location of test pits designed for prototype testing of shaft mapping. Pit locations shown by X.

NOV 4 1988

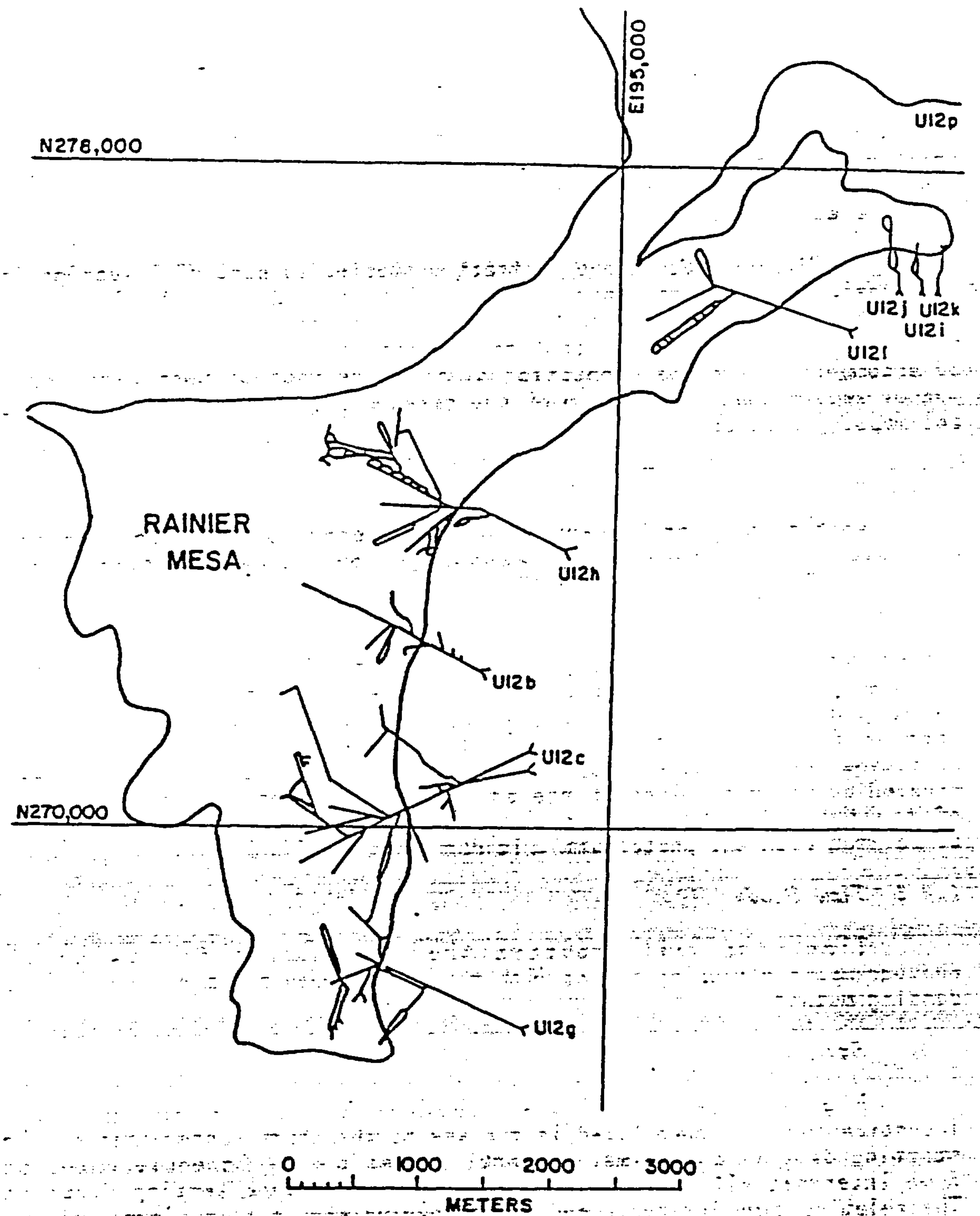

Fig. 1.1-6. Map showing location of G-tunnel (U12g) at Rainier Mesa. Test drifts for prototype testing are not shown.

1.4.3 *Investigation and Development of Close-Range Geologic Photogrammetric Techniques*

Close-range photogrammetric geologic mapping has been successfully used in Europe (Dueholm, 1981; Dueholm et al., 1977; Pillmore et al., 1980). Also, USGS and USBR have done considerable work investigating the use of close-range photogrammetry as the primary method for mapping of fractures and other geologic features exposed on shaft and drift walls in the exploratory shaft (ES) (Curry, 1986; Dueholm, 1979; Pillmore, 1959; Pillmore et al., 1980).

The USGS and USBR have contracted studies as part of investigating the feasibility of close-range geologic photogrammetry in the ES (Curry, 1986; included in the Appendix). Vexcel Corporation will be doing an additional study to further confirm and refine previous work. Items to be accomplished include production of fracture maps of test pits and G-tunnel sections and evaluation of the relationship between survey control and mapping accuracy.

1.4.4 *Back-up Mapping Techniques*

An alternate or back-up method of underground geologic mapping will employ more conventional methods (Brown, 1981; Cregger, 1986; Hatheway, 1982; U.S. Army, 1970). These conventional methods will include mapping from a photographic mosaic (Goodman, 1976), augmented by measurement and sketching of geologic features on the photographs. A back-up method is needed to ensure against survey or photographic system failure. Minor problems, such as analytical plotter failure, computer failure, or machine malfunction, will result only in temporary delay of processing data but no actual loss. Conventional methods will be prototype tested because they must be tailored to specific mapping needs created by the conditions in the shaft and drifts and to the data needs of the NNWSI Project. This conventional mapping will be used for comparison with the photogrammetric mapping method.

1.4.5 *Time Study*

Time study will compare the time needed for using the photogrammetric mapping method with the time needed for more conventional mapping methods.

1.5 *Schedule*

Figure 1.1-7 shows the schedule for prototype geologic investigations. Figure 1.1-8 is the key to the chart abbreviations. The starting date is an estimated starting time only. Schedule dates and time intervals will have to be adjusted as prototype testing dictates. The relative time intervals and relationships should remain constant with date adjustments as appropriate for the actual starting date.

NOV 4 1988

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Schedule Name:   Prototype test program for USGS/USBR ES study
Project Manager: USBR engineering office
As of date:      12-May-88  9:23am   Schedule File: C:\TLDATA\ENGR\A_NNWSIT


This is a selective report.  All items shown
  * Task name begins "Q", and
  * Notes (2) contains "123241G"

                    86  87                                88                              89
                    Oct Dec Feb AprMay Jul Sep Nov  Feb   Apr Jun Aug Oct Dec Feb Apr Jun Aug OctNo
             Status 1   1   2   1  1   1   1   2    1     1   1   1   3   1   1   3   1   1   2   1

QPROTOSIP     D   ===.  .   .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QINTSIP       D    ===. .   .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
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QCAMPROC      D      =====  .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QLANLREV      D      ===.   .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QSAICRITIQ    D      .= .   .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QSIPAPPROVE   D      .=======. .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QC/BANALYSIS  D      . ==.  .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QEDITPLAN     D      .  ==  .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QPHOTODEC     pD     .   == .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QPLOTERBUY    D      .   .================ .    .     . |.  .   .   .   .   .   .   .   .   .
QPGDEC        D      .   .M .  .   .   .   .    .     . |.  .   .   .   .   .   .   .   .   .
QPLATCON      D      .   .  ==========  .  .    .     . |.  .   .   .   .   .   .   .   .   .
QPROTOFAB     pD     .   .  =============== .   .     . |.  .   .   .   .   .   .   .   .   .
QSTUDYPLAN    D      .   .   . .  =====.   .    .     . |.  .   .   .   .   .   .   .   .   .
QPTPREWRITE   D      .   .   . .  ==.  .   .    .     . |.  .   .   .   .   .   .   .   .   .
QVEXTEST             .   .   . .  ++++++++++++++++++++++++++++++++  .   .   .   .   .   .   .
QPTPAPP       D      .   .   . .  ===  .   .    .     . |.  .   .   .   .   .   .   .   .   .
QPLOTINSTALL  D      .   .   . .   .   .   .  ===     . |.  .   .   .   .   .   .   .   .   .
QMAP                 .   .   . .   .   .   .   +++++++|.  .   .   .   .   .   .   .   .   .
QPROTOPROG           .   .   . .   .   .   .   .+++++++++++++   .   .   .   .   .   .   .   .
QPITCLEAN     p      .   .   . .   .   .   .    .     . |==  .  .   .   .   .   .   .   .   .
QPLATTEST            .   .   . .   .   .   .    .     . | ===-  .   .   .   .   .   .   .   .
QSHAFTWRITE          .   .   . .   .   .   .    .     . |.   ==========  .   .   .   .   .   .
QSHAFTREP            .   .   . .   .   .   .    .     . |.  .   .   .  .M---- .   .   .   .   .
QTUNSUPPORT   p      .   .   . .   .   .   .    .     . |.  .   .   .   .  ===-.  .   .   .   .
QPHOTOMETH           .   .   . .   .   .   .    .     . |.  .   .   .   .  .M  .   .   .   .   .
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Fig. 1.1-7. Schedule for prototype geologic investigations.

This is a selective report. All items shown
* Task name begins "Q", and
* Notes (2) contains "123241G"

Task	Notes 1
QPROTOSIP	Writing of Prototype SIPs
QINTSIP	Writing of Interim SIPs and QALAS.
QDETEXP	Writing of Draft Detailed Test Plan
QCAMPROC	Procurement of calibrated cameras
QLANLREV	LANL review of detailed test plans
QSAICRITIQ	Respond to critique of proto SIPs
QSIPAPPROVE	DOE approval of Prototype SIPs
QC/BANALYSIS	Cost/Benefit Analysis of Photogrammetry vs. Conventional
QEDITPLAN	Editing of detailed test plan and return to LANL
QPHOTODEC	Decision on use of Close-Range Photogrammetry
QPLOTERBUY	Procurement of Analytical Plotter from Kern
QPGDEC	Milestone of Photogrammetry Decision
QPLATCON	Construction of Shaft Mapping Platform
QPROTOFAB	Fabrication of Prototype Equipment for Shaft/Drift Mapping
QSTUDYPLAN	Writing of Study Plan for the SCP
QPTPREWRITE	Rewriting of the Prototype Test Plan at WMPO request
QVEXTEST	Testing of Photogrammetry Techniques at Vexcel
QPTPAPP	DOE approval of Prototype Test Plan
QPLOTINSTALL	Installation and Testing of Analytical Plotter
QMAP	Prototype Mapping of Test Pits and G-Tunnel
QPROTOPROG	Prototype Programming of Analytical Plotter
QPITCLEAN	Cleaning around Fran Ridge pits and set Platform
QPLATTEST	Testing of Prototype Mapping Platform at NTS
QSHAFTWRITE	Writing of Report on Prototype Shaft and Drift Mapping
QSHAFTREP	Report on Prototype Shaft and Drift Mapping Techniques
QTUNSUPPORT	Support Mapping of Prototype Excavations in G-Tunnel
QPHOTOMETH	Report on Methods for Photogrammetric Mapping

Fig. 1.1-8. Key to abbreviations used in schedule for prototype geologic investigations.

2.0 EQUIPMENT, TESTING, AND DELIVERABLES SUMMARY

2.1 *Primary*

Several pieces of equipment have been fabricated to facilitate the mapping of the shaft and drifts. The emphasis on the equipment has been speed and accuracy. Figure 1.1-9 summarizes this equipment testing. The following describes each piece of equipment; the testing involved, including the anticipated results; and the deliverables.

2.1.1 Items Common to Shaft and Drift Mapping.

Strike Rail Goniometer

Because of the natural magnetism of the rock and the proximity of support steel, measurement of geologic structures using magnetic

EQUIPMENT	TEST
A. Shaft	
1. Platform *	Photo Angle and Overlap
2. Radial Arm Strike Rail Assembly *	Manual Measurement of Attitudes
3. Goniometer *	Manual Measurement of Attitudes
a. Laser	Manual Measurement of Attitudes
b. Optical	Manual Measurement of Attitudes
4. Geogyrocompass *	Attitudes, Durability
5. Telescoping Camera Pedestal *	Photo
B. Drift	
1. Right-Angle Prism Goniometer *	Survey
2. Pivoting Camera Mount *	Photo

* Common to all methods

TECHNIQUES	TEST
A. Photogrammetry	
1. Photography	Underground Techniques
2. Survey Methods	Control vs. Precision
3. Fracture Characterization	Apertures, Trace Lengths, etc.
4. Analytical Plotter (Software)	Necessary to Complete Item 3.

Fig. 1.1-9. Prototype testing of shaft and drift wall mapping.

compasses is not possible. This problem is overcome by referencing the angular aspects of the geologic structures to a known bearing obtained by surveying. The goniometer relates the structure angles to a reference or strike rail.

Testing of the device will include field measurement of actual geologic structures with the goniometer and comparing the results obtained with other methods. An instrument accuracy of ±1° or better is expected.

The deliverable of this test will be a goniometer of sufficient accuracy to measure angular relationships for geologic mapping in the ES. If the photogrammetric technique performs as expected, this instrument will be used only for backup procedures.

Geogyrocompass

Certain situations, such as behind the platform supports and certain orientations and locations of geologic structures, make using the goniometer difficult or impossible. A hand-held device such as a gyrocompass must be available for use in these instances.

Testing of the device will include field measurement of actual geologic structures with the geogyrocompass and comparison of the results obtained with those obtained using other methods. Compass drift rates and resetting times will also be determined. An accuracy of ±2° and a reset interval of 10 min is expected.

The deliverable of this test will be a gyrocompass (Brunton compass equivalent) with sufficient accuracy to measure angular relationships for geologic mapping in the ES.

2.1.2 Items That Apply to Shaft Mapping Only.

Radial Arm Strike Rail

A reference rail is necessary to use a goniometer for angular measurement. An accurate, movable, and easily transportable rail is necessary for use on the lower deck of the Galloway during shaft sinking.

Testing of the device will include field measurement of actual geologic structures with the radial arm strike rail assembly (and goniometer) and comparing the results obtained with other methods. An accuracy of ±2° or better is expected.

The deliverable of this test will be (in conjunction with the goniometer) a rapid, accurate, and easily transportable strike rail with sufficient accuracy to measure angular relationships for geologic mapping in the ES. As with the strike rail goniometer, if the photogrammetric method performs as expected, this item will serve only in a back-up capacity.

Telescoping Camera Pedestal

A means of mounting, spatially locating, and indexing a camera for stereophotography is necessary for geologic mapping in the shaft. The mount must be transportable, accurate, and fast and must utilize as much of the radial arm strike rail assembly as possible. The radial arm strike rail assembly should share as much structure as possible for convenience and because the shared structure pedestal needs to be surveyed only once. The pedestal must index the camera every 60° horizontally and raise and lower the camera vertically to get the necessary overlap for stereo coverage.

The testing of the device will include photography of geologic features, utilizing all capabilities of the telescoping camera pedestal and using these photographs with the analytical plotter to construct maps and photomosaics. The criteria for evaluation will be whether the pedestal is durable, accurately holds and locates the camera, is stable, operates quickly, and is compatible with the radial arm strike rail assembly. Photograph quality will be a major evaluation item.

The deliverable of this test will be a rapid, accurate, and easily transportable camera mount with sufficient accuracy and stability for stereophotography for geologic mapping in the ES.

Shaft Mapping Platform

Evaluation and testing of the above-described equipment, alone and as a system, requires a stable platform similar to the lower deck of a Galloway located in a geologic environment similar to that of the ES. The prototype shaft-mapping platform is not intended to be used in the ES. The platform is designed and intended to be a mockup or simulated lower deck of a Galloway.

Testing of the platform will include placing the platform in the Fran Ridge test pits and performing the four tests described above. In addition, the camera pedestal centering and leveling capabilities and platform photographic aperture will be tested. Centering should easily be attainable within 1 cm, leveling within 1°, and the platform aperture should allow sufficient photograph overlap between rounds.

The deliverable of this test will be (in conjunction with the four items described above) a rapid, accurate, and stable mapping unit for geologic mapping in the ES. In addition, the test should demonstrate equipment compatibility with the contractor's lower deck operations.

2.1.3 Items That Apply to Drift Mapping Only.

Right-Angle Prism Goniometer (Laser Deflectometer)

A rapid, accurate means of locating survey points in the drifts is necessary for accurate geologic mapping and for keeping the mapping time to a minimum. The instrument will sit on the previously surveyed camera rail and, using the beam from the laser theodolite, will locate any point on the drift walls in three dimensions.

Testing of the right-angle prism goniometer will include surveying various points in various locations in G-tunnel and comparing the results with those of other survey methods. Accuracy should be easily within 1 cm.

The deliverable of this test will be an instrument for surveying points for geologic mapping rapidly and with sufficient accuracy for use in the ES.

Pivoting Camera Mount

A means of mounting, spatially locating, and indexing a camera for stereophotography is necessary for geologic mapping in the drifts. The mount must be transportable, accurate, and fast and must use the strike rail for location and support. The mount must index the camera every 60° vertically and move along the strike rail to get the necessary overlap for stereo coverage.

Testing of the device will include photography of geologic features using all capabilities of the pivoting camera mount and using these photographs with the analytical plotter to construct maps and photomosaics. The criteria for evaluation will be whether the mount is durable, accurately holds and locates the camera, is stable and fast, and is compatible with the strike rail assembly. Photograph quality will be a major evaluation item.

Camera Rail

The camera rail is a horizontal, graduated, aluminum rail on which the pivoting camera and right-angle laser goniometer are mounted. The rail will be mounted on a pair of tripods and will be oriented using the beam from a laser theodolite. It will be oriented parallel to the drift centerline at a height of approximately 1.46 m. The camera mount and right-angle laser goniometer will then slide along the rail during use.

The deliverable of this test will be a rapid, accurate, and easily transportable camera rail with sufficient accuracy and stability for stereophotography for geologic mapping in the ES.

2.2 Secondary

Secondary deliverables consist of geologic mapping for the prototype controlled blasting investigation (previously known as the mining demonstration test), WBS 1.2.6.9.4.3.1, and the prototype bulk permeability test, WBS 1.2.6.9.4.2.10.

3.0 DESCRIPTION OF WORK

3.1 Management

Prototype testing for the underground geologic mapping methods is being done by personnel from two organizations: the USGS (E. Glick, C. C. Barton, G. M. Fairer, and R. A. Thompson) and the USBR (M. H. McKeown and S. C. Beason). E. Glick is the Project Chief for the USGS geology project in the ESF. M. H. McKeown is the principal investigator for the geologic tests for the ESF for the NNWSI. S. C. Beason, E. Glick, and C. C. Barton are assigned to shaft prototype mapping methods. M. H. McKeown and G. M. Fairer are assigned to drift prototype mapping methods. R. A. Thompson manages the computer hardware and software for the project.

3.2 Experimental Configuration

The concept of close-range photogrammetric mapping underground in the ESF has evolved during the course of ongoing work by the USGS and USBR. At the present stage, shaft and drift mapping will use close-range photogrammetry to collect the bulk of geologic data. Conventional underground mapping methods will be used as a back-up system for the photogrammetric mapping to avoid loss of data only in the event of failure of surveying or photographic equipment.

The photogrammetric geologic mapping method has the following major advantages over conventional and/or photomosaic methods.

- The time required for mapping is significantly reduced using photogrammetry. Approximately 2 hr/round will be needed to do manual data gathering and stereophotography. Conventional mapping is estimated to require up to 8 hr/round, and the photomosaic method would require approximately 4 hr/round.

- The accuracy of the photgrammetric method is inherently greater than that of conventional (sketch) mapping. With photogrammetry, accuracy is a function of survey accuracy and control point quantity and not of artistic ability. The accuracy of the photogrammetric method easily will be within 1 cm as compared with conventional mapping accuracy of approximately 15 cm.

- Reproducibility is much better using photogrammetry. A major problem with conventional mapping is consistency of results between geologists and over long time periods.

- An expandable data base is developed in the form of the stereophotographs acquired for photogrammetry. Analysis of the stereophotographs can be expanded after the shaft has been lined, whereas conventional mapping cannot be expanded or checked after lining is complete (or the forms are set)...

- Personnel requirements using photogrammetry are significantly less than those for other methods. Not only are costs less but personnel problems are reduced.

- The cost of photogrammetric geologic mapping is significantly less than that of the other methods. A cost/benefit analysis indicates a savings of up to approximately $5 million, mostly as a result of the reduction of contractor down time.

The above points summarize the major reasons why the USGS and USBR have chosen to concentrate on photogrammetric geologic mapping. Figure 1.1-10 summarizes the advantages and disadvantages of the three methods. A thorough discussion of the different methods is described by Scott (1987).

Mapping in both the shaft and drifts will proceed at 2-m intervals. If excavation schedules make it more reasonable to map several intervals during one underground period, such a schedule can be adopted.

Analytical Plotter

The photogrammetric mapping will utilize a computerized Kern DSR-11 analytical plotter (the Appendix provides an equipment list). The plotter will use 2-1/4- by 2-1/4-in. film diapositives of the shaft and drift walls. The operator will trace fractures and stratigraphic contacts directly from the photos. The analytical plotter uses a dedicated Micro-VAX computer to determine the strike and dip of structural and stratigraphic features. For example, when a fracture surface is traced by the cursor, the computer automatically digitizes the trace in three-dimensional space. This set of digitized points is then processed by the computer to determine strike and dip, fracture trace length, and the location of the fracture in three-dimensional space.

After all fractures greater than 30 cm in length have been traced, the information can be developed by the computer into a full-periphery map of the excavations at approximately 1:125 scale. Because the data are stored digitally, map scale can be changed easily and the map can be replotted at any scale from 1:50 to 1:1000. The location of fractures sampled for aperture, roughness, and slickenside lineation pitch will be digitized, along with locations of hand samples, fracture-filling samples, seeps (if present), and rock bolts.

In addition to full-periphery maps, the analytical plotter/computer system will be able to produce statistical compilations of fracture data, such as stereonets, histograms, joint roses, and line graphs.

One photogrammetry technician is needed to assemble models (a series of photos tied together in three-dimensional space with correction for any photo distortion) and to trace geologic features onto the data report was written, earlier stages of prototype testing that have already been completed will be described only if appropriate. Geologic photogrammetric mapping feasibility studies are discussed in detail.

1.3 Objectives

The objectives of prototype testing the underground geologic mapping equipment and methods are

- test the specific mapping methods to be used in the shaft and drifts, which will provide the basis for describing the geologic framework of the exploratory shaft facility (ESF) and provide part of the basis for extrapolating geologic conditions from the ESF through the entire repository block,
- test the specific mapping methods to be used in the drifts, which will provide the geologic data to characterize the ESF,
- test the data analysis methods to be used for both shaft and drift geologic data, and
- determine the role of each subcontractor needed by the geologists to accomplish the mapping and data analysis goals.

1.4 Present Status of Prototype Tests

Work has begun or has been completed on several aspects of the prototype testing, including fabrication of surveying devices and fracture measurement equipment, development of efficient and specialized surveying techniques, feasibility investigation of close-range photogrammetric techniques, development of conventional mapping techniques, development of a cost/benefit comparison, and development of data analysis software.

The following is a description of the status of each aspect.

1.4.1 Fabrication of Surveying Devices and Fracture Measurement

Fabrication is either complete or under way for the specialized surveying equipment that will be used in conjunction with a commercially available laser theodolite to perform much of the surveying and orienting functions for mapping. Laser theodolites are presently in standard use in G-tunnel at Rainier Mesa at the Nevada Test Site (NTS). The specialized survey equipment has been designed to reduce greatly the amount of time required to set up the camera rail and to locate the photogrammetric survey targets for stereophotography control. In addition, items such as a gyroscopic geologic compass, a right-angle prism goniometer, and a strike rail goniometer are being constructed.

NOV 4 1988

COMPARISON OF MAPPING TECHNIQUES

Photogrammetric Method A	Conventional Sketch Method B	Photomosaic Method C
ADVANTAGES		
Shorter time underground	Established method	Greater accuracy then sketching
Most accurate	Low equipment cost	Small initial cost
Not dependent on artistic skills	Relies on human-based system	Used reliably on other projects
Objective		Objective
Reproducibility		Data base somewhat expandable
Expandable data base		
Easy map editing		
Easy data transfer and manipulation		
Requires less staff		
DISADVANTAGES		
High initial cost	Requires 300% more mapping time than A	Requires 200% more mapping time than A
State-of-the-art equipment	Relies on artistic ability of mapper	Considerable time and difficulty in mosaic assembly
	Subjective, varies with each person	Photo distortion
	Data base not expandable	More personnel than A or B
	Map data must be measured manually	Editing difficult
	Least accurate	No reproducibility
	Editing requires redrafting	Data require manual entry

Fig. 1.1-10. Summary of advantages and disadvantages of geologic mapping methods.

base. (During prototype testing, this job is being done on a machine under contract with Vexcel Corporation of Boulder, Colorado.) Once the analytical plotter to be used during construction has arrived and has been installed, prototype testing will be completed on this plotter. During excavation of the ESF, USGS and USBR technicians will operate the machine on a 16 hr/day basis.

During ESF construction, the photgrammetry technicians will receive film diapositives brought to Denver on a weekly basis by the principal geologist. The technician will assemble the models using the diapositives and data supplied by the site surveyors. The technician and principal geologist will then plot

- all fracture traces longer than 30 cm,
- bedding or stratigraphic contacts (where visible),
- breccia zones,
- unique geologic features,
- hand sample locations,
- rock bolt locations, and
- photographic control point (survey target) locations.

The principal geologist, who has been at the site while the week's mapping has been done, will then edit the map. In addition, the geologist will add whatever notes were taken in the field, such as stratigraphic or petrographic items, information regarding offset of faults, and character of fault breccias and gouge. When the geologist is satisfied with the map, the map data will be sent to the plotter to produce a hard copy.

Camera

Pan Am will take stereophotographs for photogrammetry with a Rollei 6006 camera equipped with a 40 mm calibrated lens and a graduated Reseau at in the focal plane. Under the supervision of the geologists, the camera will be used to photograph exposed rock surfaces in both the shaft and drifts.

In the shaft, the camera will be mounted on a telescoping camera pedestal. The pedestal will allow the camera to rotate 360° around a vertical axis with click stops every 60°. The calibrated lens has a diagonal field of view of approximately 90°. Vertical overlap to produce a stereoscopic image is accomplished by raising the camera mount, taking a series of six photos, then lowering the mount and taking a second set of photos. Vertical overlap is used to avoid the distortion caused by horizontal overlap on a curved surface.

In the drifts, the camera will be positioned on a horizontal rail located in the center of the drift. The rail will be located using a surveying laser. The camera will be mounted on a pivoting camera mount, allowing the camera to rotate about a horizontal axis. Longitudinal overlap will be used in the drifts to avoid the distortion that would be caused by the curved surfaces in the crown. The distance between rings of photos (and consequently the amount of overlap) will be determined during prototype testing.

Electronic strobes will be used for lighting during photography. The specifications and configurations of the strobes will be determined during prototype testing.

Goniometer

USBR has constructed an instrument for obtaining the strike and dip of a geologic feature nonmagnetically. The goniometer is designed to be used in conjunction with a radial arm strike rail assembly or strike rail. The base of the goniometer can be indexed to the azimuth of the strike rail, and then the instrument is aligned with the geologic feature. The strike and dip of the feature can then be read directly from the instrument. The goniometer can be used to measure any planar geologic feature (with some exceptions) exposed in the excavation walls. The goniometer will be used only in the back-up technique if the photogrammetry system performs as expected.

Laser Theodolite

Surveyors (H&N) will use a laser theodolite to locate three dimensionally photogrammetry control targets. The target locations will be confirmed by a second survey done at the same time as the first to ensure that coordinates are correct. This procedure is necessary to guarantee that no loss of data occurs after the shaft has been lined.

3.2.1 Shaft-Mapping Configuration

Full periphery, close-range photogrammetric geologic mapping is planned as the primary method for mapping the shaft. The lower working deck of the Galloway will be used as a mapping platform. The photogrammetric method planned for shaft mapping uses the metric camera mounted on a vertical pedestal in the center of the mapping platform (Figs. 1.1-11 and 1.1-12). Primary photographic data will be taken by the same type of camera as that used in the drifts: a camera with a 2.25- x 2.25-in. format and a Rouseau plate. Three-dimensional control for the photogrammetric modeling will be established by survey targets affixed to the wall, which will appear in the photographs. Photographs of the entire shaft wall will be made in a clockwise direction, starting from the north. Overlap of the photographs will be about 10% horizontally. Vertical overlap of at least 60% will achieve stereographic coverage. Contact color diapositives and color prints (9 x 9 in.) will be made of each photograph. Figures 1.1-13 and 1.1-14 show photo coverage and round overlap.

Structural data, such as slickenside lineations on faults, will be measured and recorded manually. Fracture coatings that can be dated isotopically will be collected underground. Representative lithologic samples will also be collected underground. The locations of structural data points and samples will be identified by markers affixed to the wall and recorded on the photographs.

The technique will use recommended international standards for recording geologic features and characteristics (Brown, 1981).

Using the diapositives on a Kern DSR-11 analytical plotter, a geologist and a photogrammetry technician will produce a data base and a

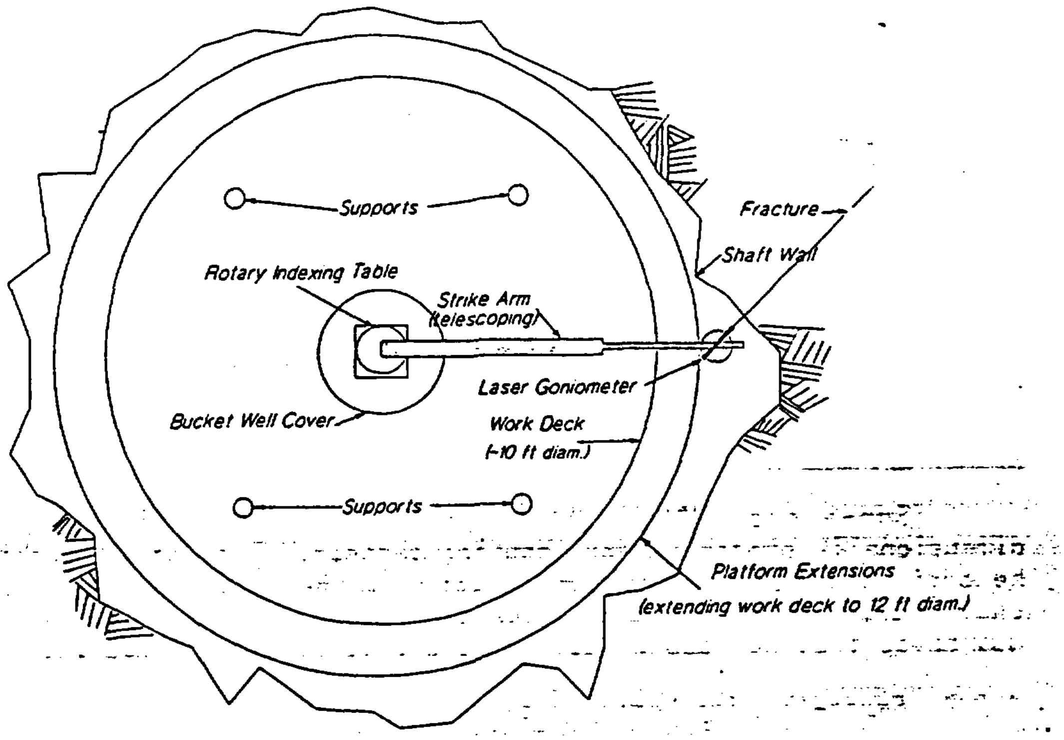

Fig. 1.1-11. Plan view of test pit and mapping platform. The strike rail and goniometer are shown schematically.

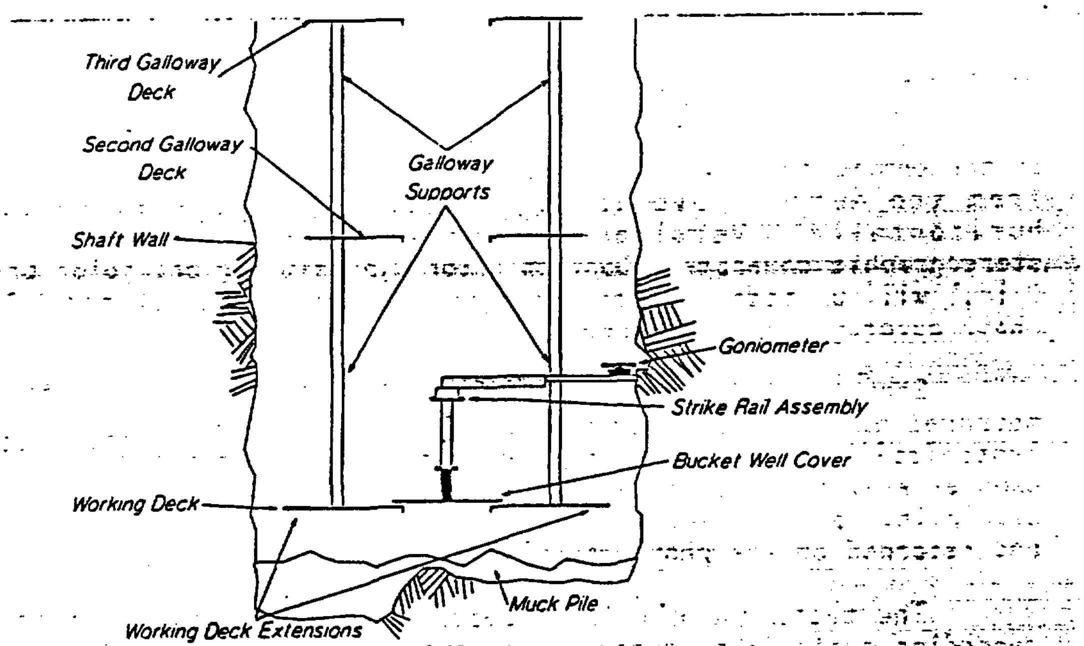

Fig. 1.1-12. Side view of test pit and mapping platform.

NOV 4 1988

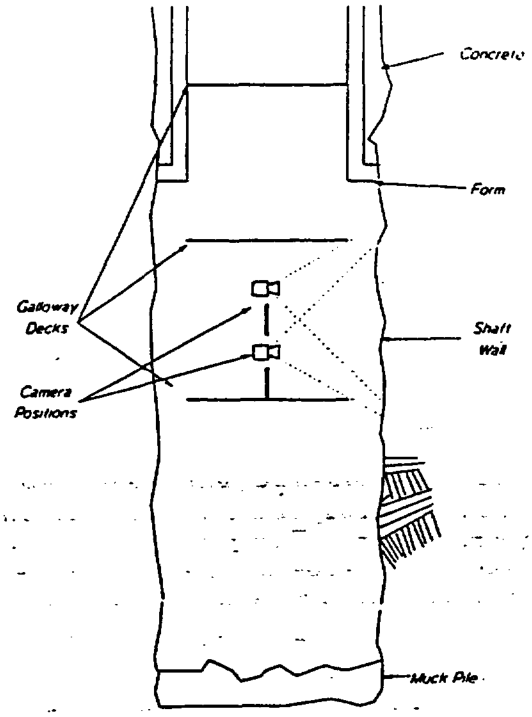

Fig. 1.1-13. Cross section of pit showing camera positions.

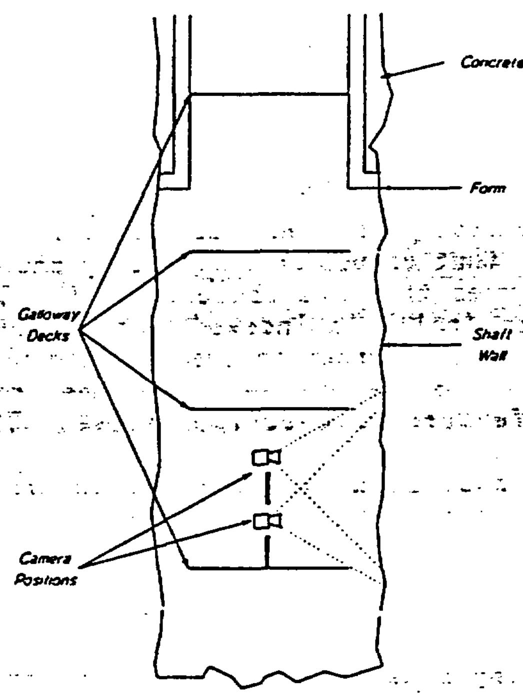

Fig. 1.1-14. Cross section of shaft showing next deeper platform and camera positions. Note photographic coverage overlap.

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map. These data will be stored on magnetic tape or disks. Maps of the structural and stratigraphic features and sample locations will be plotted by computer at desired scales. Statistical fracture data will be compiled by computer.

The conventional mapping (back-up) method will consist essentially of the same survey and photographic steps as those used in the photogrammetric method. However, most of the geological data will be collected by measurements made at the shaft wall. Maps of the fractures will be drawn by hand and/or from a mosaic of the photographs.

Equipment

Shaft Mapping Platform

A platform built to simulate the lower working floor of the contractor's shaft-sinking Galloway will be used during prototype testing to test techniques and equipment. The platform is a mockup of the lower Galloway floor, complete with bucket well and platform supports intended to reproduce the configuration of obstructions that will be present during ESF shaft mapping. The platform is 12 ft in diameter, approximately 13 ft high, and weighs approximately 2700 lb. The platform is designed to be used in the circular test pits at Fran Ridge. The platform has been designed so that, with minor modification, it could be safely used during the collaring operation of the ESF to allow standard geologic mapping before the contractor's Galloway is in place. The prototype platform will not be used in ES-1 during standard shaft-sinking operations. All standard shaft-mapping operations in the ESF will be performed from the contractor's lower Galloway floor. The prototype platform permits testing and refinement of shaft-mapping equipment during prototype testing.

Radial Arm Strike Rail Assembly

A center pivot assembly has been fabricated by the USBR for manual measurement of features that cannot be recorded by photogrammetry. These features include fractures that are obscured by the Galloway supports. The direction of the arm (rail) is indexed to true north as provided by the surveyors, and the arm is turned to the fracture to be measured (Fig. 1.1-15). The goniometer, located on the end of the arm, is then used to measure the geologic feature as described above. The strike rail is designed to retract to a length of less than 4 ft to allow it to clear the inside of the Galloway supports. The strike rail assembly bolts directly onto the same center mount as that used for the telescoping camera pedestal.

Geogyrocompass

USBR is developing a hand-held gyroscopic compass that will be used to measure the strike of fractures that are not visible to photogrammetry and that cannot be reached by the radial arm strike rail

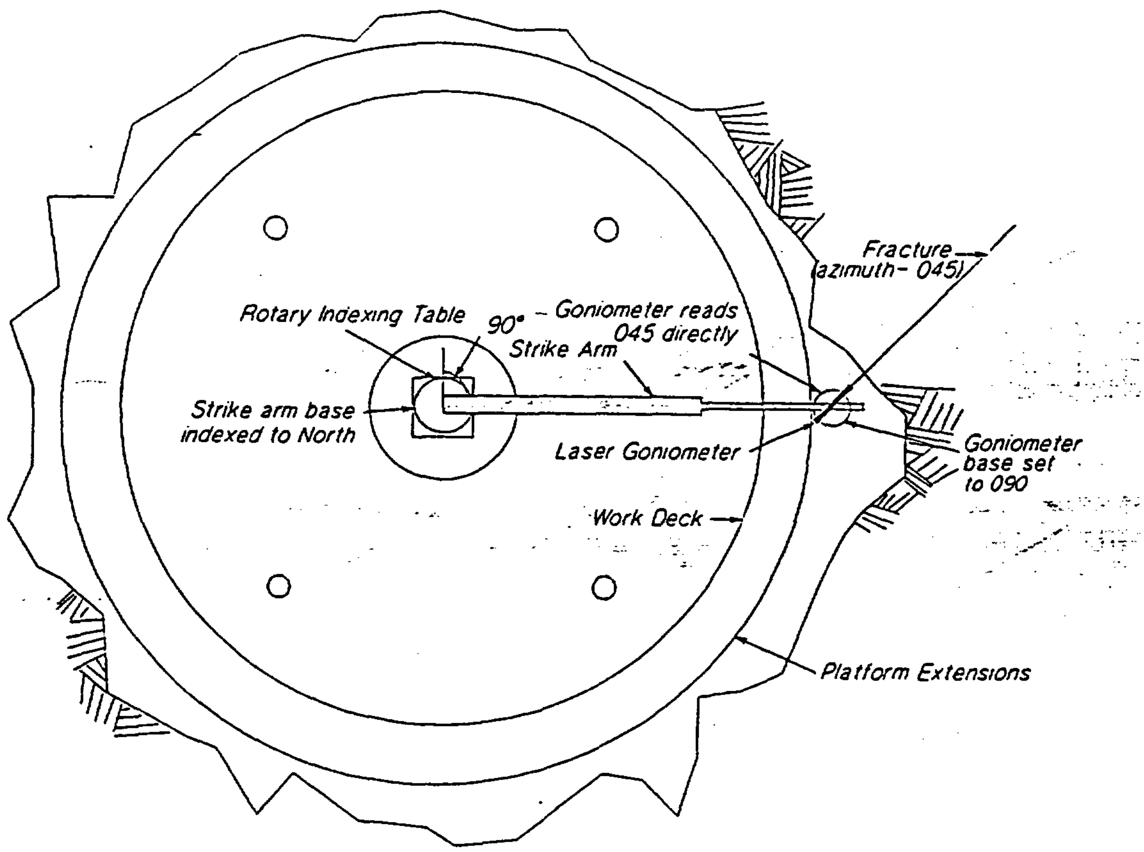

Fig. 1.1-15. Angular relationship among the radial arm strike rail, goniometer, and fracture.

assembly. The gyrocompass may supplant the primary function of the radial arm strike rail assembly if the gyrocompass proves to be accurate and durable enough for underground use. The gyrocompass is an aircraft directional gyroscope mounted in a shock-absorbent case with an orienting sight on the top of the case. The gyrocompass is also equipped with a small portable battery pack and coil cord for maximum versatility underground. It is expected to be accurate to ±2°, with a drift of 1-2°/hr of use. This unit can be used both for shaft and drift mapping.

3.2.2 Drift-Mapping Configuration

Plans for drift mapping are similar to those for shaft mapping; only differences in the configuration will be described here.

The photogrammetry method for drift mapping will fit the linear character of the drifts. In conjunction with the laser survey of the drifts, a camera will be mounted on the camera rail, which has been aligned by a laser beam coincident with the centerline of the drift (Fig. 1.1-16). Photographs of each wall will be taken in a horizontal

 NOV 4 1988

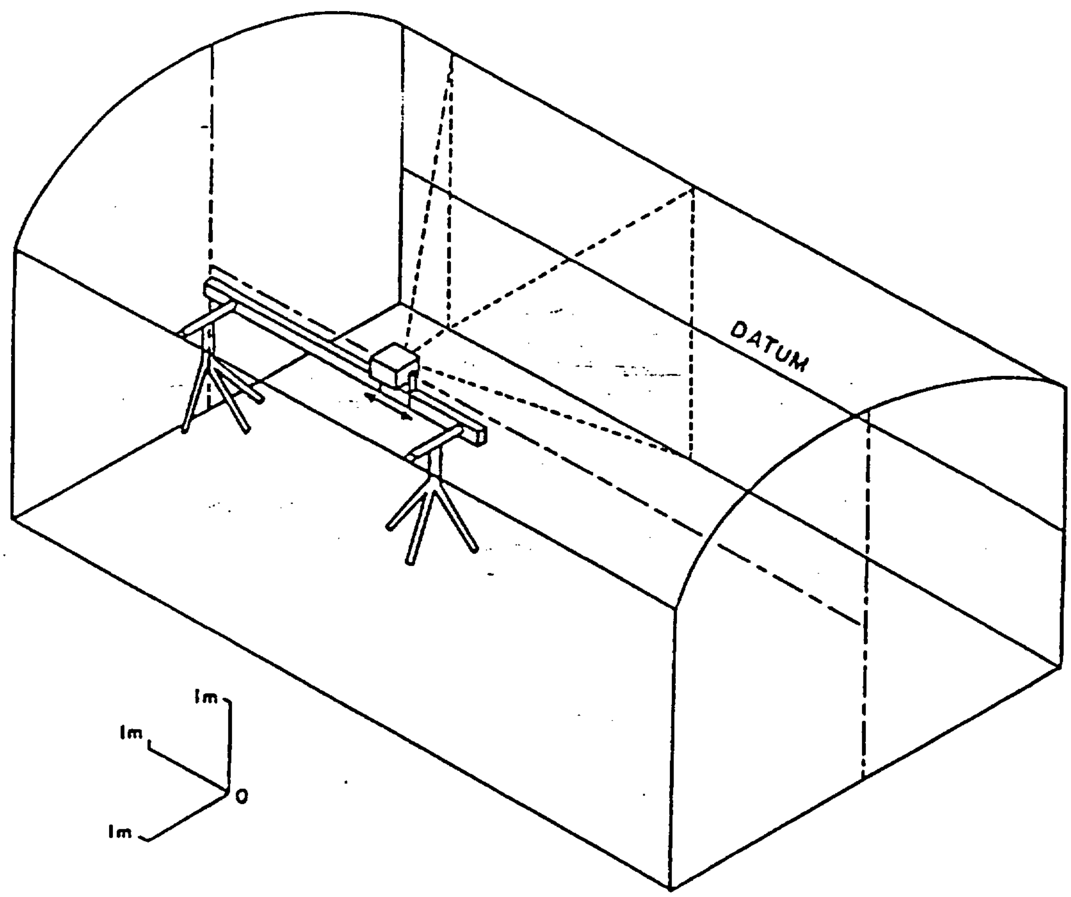

Fig. 1.1-16. Configuration of drift prototype test showing the camera mount on the camera rail. Horizontal stereoscopic overlap on a series of exposures will provide coverage for the 2-m interval mapped. Rotation of the camera in a vertical plane at 60° intervals will provide coverage of the roof and both walls.

direction, and photographs of the crown will be taken at 60° angles to cover each half of the crown.

As in the case of shaft mapping, the conventional mapping (back-up) method will consist essentially of the same survey and photographic steps as those used in the photogrammetric method. However, most of the geological data will be collected by measurements made at the drift wall. Maps of the fractures will be drawn by hand or from a mosaic of the photographs.

Equipment

Right-Angle Prism Goniometer (Laser Deflectometer)

This device uses a right-angle laser-surveying prism (commercially available) to locate three dimensionally 3- by 5-in. photogrammetry targets attached to the wall (Fig. 1.1.17). The instrument will allow the surveyor to measure the vertical angle and distance to the target (or any other point in the drift) by using a laser theodolite. The beam from the laser theodolite will be oriented parallel to the centerline of the drift at a height of approximately 1.46 m. The instrument will slide along the camera rail in the center of the drift at the height of the laser beam (Fig. 1.1-18). The beam will be deflected at a right angle out to a small, hand-held prism on the drift wall. The surveyors can then calculate the distance to the target and use the vertical angle from the instrument to calculate the coordinates and elevation of the point. This information will be used by the analytical plotter to build the photogrammetry models.

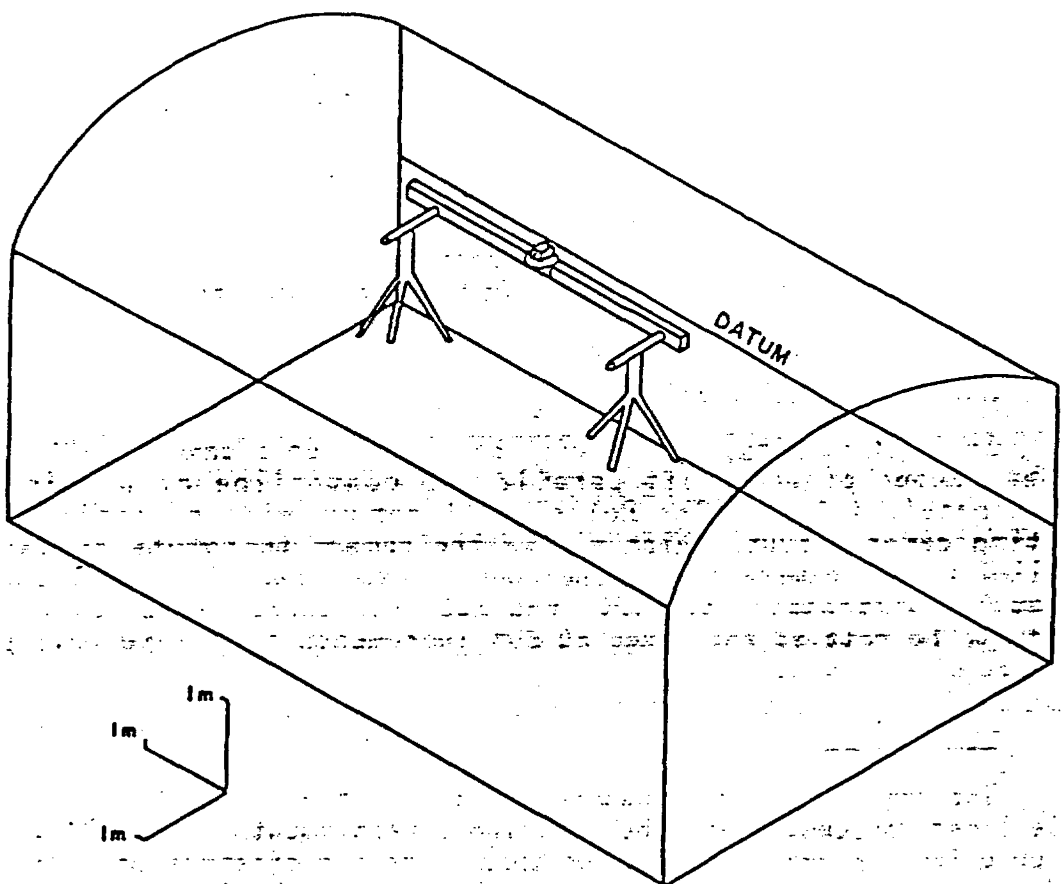

Fig. 1.1-17. Configuration of drift prototype test showing the strike rail goniometer and strike rail.

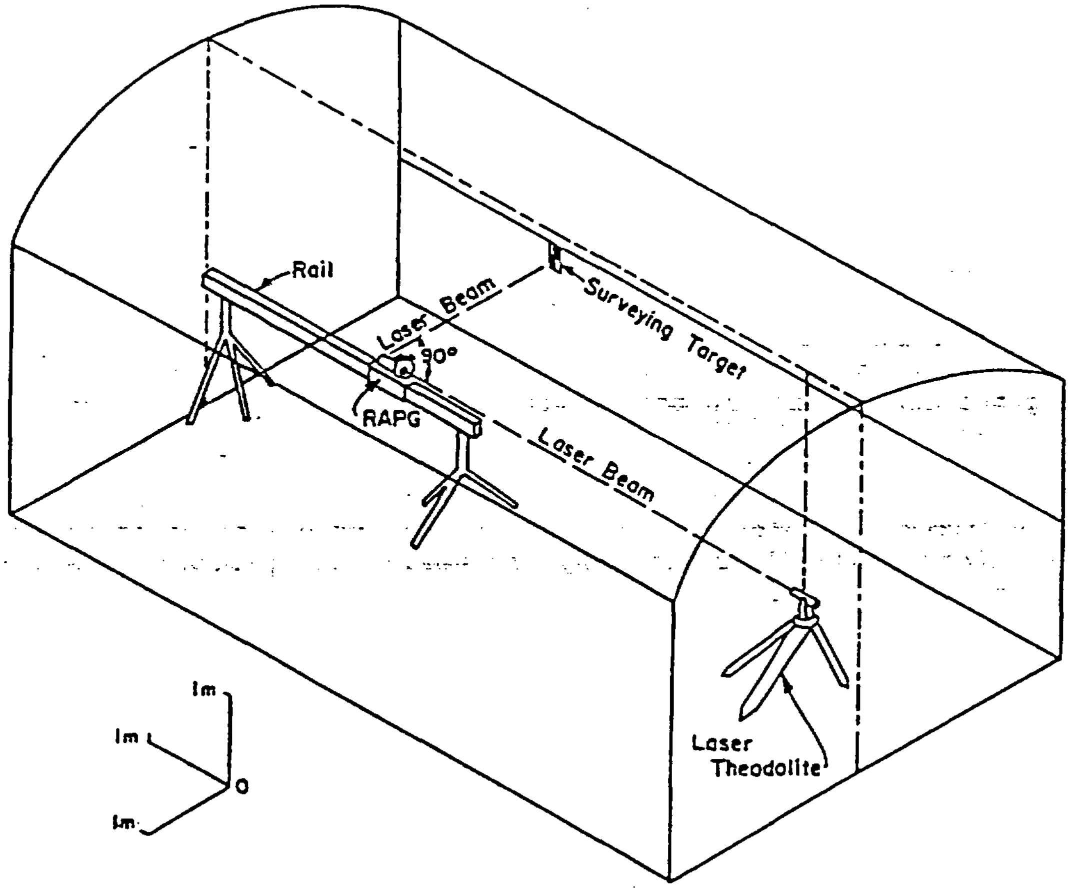

Fig. 1.1-18. Configuration of drift prototype test showing the right-angle prism goniometer (RAPG) and camera rail.

Pivoting Camera Mount

In drift mapping, photos will be taken from a camera rail set up in the center of the drift parallel to centerline at a height of approximately 4.8 ft. The Rollei 6006 camera will be affixed to a pivoting camera mount, which allows the camera to rotate on an axis parallel to the camera rail. The mount is equipped with level bubbles set at 0 (horizontal), 60, 120, and 180° positions, which allows the camera to be rotated and fixed at 60° increments to ensure full photo coverage of the walls.

Camera Rail

The camera rail will be used in conjunction with both the right-angle laser goniometer and the pivoting camera mount. The rail will be set up using the beam from a laser theodolite for orientation. The rail will be set parallel to the centerline of the drift at a height of 1.46 m. The camera rail will be mounted on tripods for maximum flexibility in setup.

 NOV 4 1988

3.3 Underground Test Methods

3.3.1 Shaft-Mapping Methods

Prototype testing that will involve coordination of activities of support organizations with those of the USGS and USBR geologists are described below. These activities include mapping platform testing, surveying and photographic prototype testing, prototype photogrammetric shaft mapping, prototype conventional shaft mapping, and test pit mapping.

Mapping Platform

A prototype model of the mapping platform has been designed by USBR to meet the requirements of both the geologist and the shaft construction subcontractor. Meetings have been held with personnel of the USGS, USBR, H&N, Fenix & Scisson (F&S), Pan Am, and REECo in an effort to include all platform design needs.

Mapping Platform Construction

A prototype of the mapping platform has been constructed by USBR for use in the Fran Ridge test pits.

Mapping Platform Testing

Testing the platform will consist of several stages. First, the platform must be lowered into position in the test pits and suspended just off the floor of the pit by REECo. Second, the platform must be fixed against the walls of the shaft. Third, H&N surveyors must survey the azimuthal position of the platform. Fourth, the Pan Am photographers must test the platform and appurtenances to be certain the design is compatible with their needs. Finally, the USGS and USBR geologists must test their mapping methods to be certain that platform design is compatible with those methods. Procedures for cleaning the shaft walls will not be tested in these pits. This test will be performed in the G-tunnel drifts, where better facilities exist.

Surveying and Photographic Prototype Testing

H&N will test the surveying equipment and techniques for locating the position of survey targets on the test pit walls. H&N will demonstrate the ability to locate and confirm the shaft working platform elevation, horizontal azimuth, and horizontal coordinates. USGS and USBR will test camera mounts on the working platform in conjunction with Pan Am; Pan Am also will test camera and film types and develop a plan for processing film. Pan Am must ensure that photos have been successfully processed before shaft lining of each mined round occurs. This step is necessary to prevent any loss of photogrammetry data. Pan Am is also responsible for archive storage of the photographs.

NOV 4 1988

Prototype Photogrammetric Shaft Mapping

The method will consist of using vertically aligned pairs of stereoscopic photographs taken at 2-m intervals in the pit. Close-range geologic photogrammetry and an analytical plotter will be used to map the intervals from the photographs. All attitudes of planar features will be determined in this fashion. Also, the ability of the analytical plotter to determine apertures and roughnesses of fractures will be tested. Geologists will test methods of measuring the attitudes of slickenside lineations using a portable gyroscopic compass and clinometer. They will also collect pertinent notes to augment the photographic record and will collect samples of lithology and fracture-coating minerals.

Prototype Conventional Shaft Mapping

The back-up method will consist of the conventional full-periphery method of mapping by the USBR and USGS. Specifically, the geologists will perform all the measuring tasks in the test pits. Photographs will be taken by Pan Am to provide a mosaic to construct the map base. The on site methods for measuring fracture roughness will necessitate the fabrication of a profilometer longer than the 15-cm-long shape copier presently used to calibrate roughness. Several instruments will be tested for measurement of apertures.

Test Pit Mapping

When the mapping techniques have been tested, all three of the test pits will be mapped by USBR, F&S, and USGS geologists. A report will be prepared similar to those reports ultimately planned for the ES work.

Areas of approximately 400 m^2 (excluding the muck piles) will be cleared with a fire hose or a blow pipe by F&S geologists around each of the test pits to provide complete exposure of the rock surface. These surfaces will be photographed and mapped. Maps will be horizontally continuous with the vertical maps of the pit walls. These maps will provide valuable information on the relationship between vertical and horizontal fractures and techniques for mapping excavation intersections. These relationships need to be tested to determine whether similar clearing and mapping should be done at the ES site.

3.3.2 Drift-Mapping Methods

Several aspects of prototype testing that involve coordination of activities of support organizations with those of the USGS and USBR geologists are described below. These activities include wall-cleaning photographic prototype testing, surveying prototype testing, photographic prototype testing, prototype photogrammetric drift mapping, and mapping of test drifts.

Wall-Cleaning Photographic Prototype Test

Before either surveying or photography can be done, the walls and crown of the drifts must be washed. Conventional mapping techniques also require clean exposures. Techniques for cleaning will be evaluated by USBR and USGS geologists and REECo. After the technique has been refined, the minimum volume of water needed per unit area of wall and crown will be determined by placing meters on water lines. This information will apply to both drift and shaft-wall mapping.

Surveying Prototype Test

H&N surveyors will use laser surveying methods to locate photographic equipment, mapping equipment, and targets for photographic control of mapped intervals. The right-angle prism goniometer must be tested for location of points on the wall. The precision with which data points can be located must be determined. Methods for calculating the distances, recording data, and transferring of data to the geologists must be established by H&N surveyors. A redundant method for checking the locations of photogrammetry targets before leaving the shaft will be developed.

Photographic Prototype Test

Pan Am photographers will finish prototype tests of the photographic technique by determining the optimum conditions for close-range geologic photogrammetry. At present, the center line of the drift defines the position of the photographic rail. It is possible that photographs taken from a location nearer the opposite wall may be a better technique. The optimum number of survey targets for photographic control is being determined by separate contract. The sequence of events for photography for both photogrammetry and conventional mapping must be determined. A system for ensuring reliability and confirmation of film processing will be developed to ensure against loss of data.

Prototype Photogrammetric Drift Mapping

The photogrammetric method will consist of using photographs with horizontal stereoscopic overlap to map each 2-m interval in a drift in G-tunnel under Rainier Mesa. Close-range geologic photogrammetry and an analytical plotter will be used to make the base map for each interval. Attitudes of all planar features (both structural and stratigraphic) will be determined from photographs. Also, the capacity of the analytical plotter to determine aperture and roughness of fractures will be tested. Geologists will test methods of measuring the attitudes of slickenside lineations using a portable gyroscopic compass. They will also collect pertinent notes to augment the photographic record and will collect samples of lithology and fracture-coating minerals. These methods will be similar to those for shaft prototype tests; however, the differences between drift and shaft methods are sufficient to require testing in both test pits and drifts.

Test Drift Mapping

When the mapping techniques have been tested, the entire section of drift will be mapped and a report will be prepared similar to those reports ultimately planned for the exploratory drift work in the ESF. Also, USBR, USGS, and F&S geologists will map the controlled blasting excavation and bulk permeability room in G-tunnel.

3.4 Data Analysis

Several facets of data analysis are being tested. These facets include analysis of fracture data to produce maps, graphs, stereographic plots, and histograms. At the heart of data analysis is the creation of the software to produce these graphical displays at the scales and formats that will be most useful to present the results of geological mapping. Statistical analysis of data is important because of the need to evaluate very large quantities of data in a meaningful way.

The following data analysis tasks need to be accomplished:

- determine how fracture trace lengths should be calculated,
- determine how the abundance and types of fracture intersections should be expressed,
- solve the remaining problems in the expression of fracture roughness,
- solve the remaining problems in the expression of fracture aperture,
- determine how structural domain data will be defined and expressed,
- determine how fracture analysis will be done and expressed,
- develop a method to integrate existing software and software under development with the DSR-11 analytical plotter,
- develop a data base management system for geographic information obtained from the DSR-11 and a method for integration with a descriptive information data base,
- determine what map scales will be used, and
- determine what publication and reproduction problems exist for maps and statistical displays and what solutions will be used.

4.0 QUALITY ASSURANCE LEVEL

This work has been approved as QA Level III in accordance with NNWSI-QALA-6941G-01 (Scott et al., 1986).

5.0 OPERATIONS

5.1 List of Activities

5.1.1 Underground Tests

Installing Work Platform in Test Pits	REECo
Prototype Test of Surveying Techniques	H&N
Design and Construction of Specialized Surveying Apparatus for Shaft and Drift Mapping	USGS, USBR
Prototype Tests of Photogrammetric Mapping for Shaft and Drift Mapping	USBR, USGS
Prototype Tests of Conventional Mapping for Shaft and Drift Mapping	USBR, USGS
Clearing of Area Surrounding Test Pits	USBR, USGS, F&S
Mapping of Areas Surrounding Test Pits	USGS, USBR, F&S
Mapping Test Pits, Test Drifts, and Prototype Test Areas for Other Tests	USBR, USGS, F&S
Survey Targets on Test Pit Walls from Platform and Within Test Drifts	H&N
Photographing of Test Pit Walls from Platform and Test Drift Walls	Pan Am

5.1.2 Data Analysis

Making Map Using Analytical Plotter	USGS, USBR
Measurement of Orientation, Aperture, and Roughness of Fractures Using Analytical Plotter	USGS, USBR
Development of Computerized Data Base System	USGS
Development of Computer Programs for Data Analysis Including Stereonets, Histograms, Curve Fitting, and Fracture Analysis	USGS

5.2 Changes in Experimental Procedures

Changes in experimental procedures occur as the result of prototype testing. After the results of a step have been studied, further experimental procedures can be defined for the subsequent step. Changes are expected to occur until the geologists performing prototype testing have determined that the mapping techniques have been successfully defined.

6.0 DATA ACQUISITION SYSTEM

Geologic data will be collected in the ESF using several methods, including laser surveys, photography, on site measurement by geologists, and geological measurements from photographs. The primary method to be used will be close-range geologic photogrammetry. The degree of dependence on measurements from photographs will be a function of the success of photogrammetry. Conventional mapping methods, with dependence on on site measurements, are intended to be a back-up method.

6.1 Shaft Mapping

Most of the mapping in the shaft will be done from a mapping platform either consisting of or suspended from the contractor's working deck. The location system for the shaft will be an azimuthal system. This coordinate system will be established by H&N laser survey. Stereographic photographs will be taken from the platform for each round, maintaining 60% vertical overlap at all times. The negatives will be immediately processed aboveground to ensure both quality production and archival records.

Detailed fracture maps will then be made from the photographs using a Kern DSR-11 analytical plotter. The plotter allows the operator not only to plot the trace of the fracture but also to determine strike, dip, and possibly aperture and roughness. The analytical plotter will utilize a dedicated Micro-VAX computer and flatbed plotter. The exact models of these and other peripherals are described in the appendix.

A back-up data acquisition system will be developed during prototype testing to be used in case of temporary failure of the primary system. This system will consist of a photographic mosaic utilizing many of the same procedures used for the photogrammetry, with the fracture surfaces being manually traced from the photos by a geologist or technician.

In addition to geologic data collected by conventional mapping methods and data processed by the analytical plotter, samples of representative lithologies and fracture coatings will be collected by the geologist for each mapped blast round. Sample localities will be shown on the photographs by location cards and will be shown on the fracture trace maps.

6.2 Drift Mapping

Data acquisition in the drifts will be essentially identical to that of the shaft, with only minor procedural differences caused by the horizontal orientation of the drifts and linear coordinate systems. Photographs will be taken in a manner similar to that of the shaft, using 60% horizontal overlap to allow sterographic photogrammetry. As in the shaft, the geologist will also manually collect some geologic data, with the fracture tracing done on the Kern DSR-11 analytical plotter. Drift mapping will also have a back-up technique consisting of a photographic mosaic method.

7.0 PERSONNEL QUALIFICATIONS

Quality Assurance Level III does not require formal certification of project personnel; however, personnel involved in this testing are certified.

8.0 NONCONFORMANCE ACTIONS

Nonconformance of QA Level III items or processes will be documented, and corrective action will be documented in compliance with QMP 16.01 of the NNWSI-USGS-QA Manual.

9.0 DOCUMENTATION

9.1 Field Notebooks

All data collected in written form will be kept in approved notebooks in accordance with standard practice. Data acquisition forms will be used for easier and more efficient recording of information and QA.

9.2 Analysis Notebooks

All data analysis will be documented in notebooks in accordance with standard practice.

9.3 Photographs

All photographs will be kept in indexed photo albums.

9.4 Data Storage

All data produced by the analytical plotter and entered manually from field sheets will be stored on magnetic tape or disk for permanent storage. The possibility of using a compact disc format for archival storage of data will be investigated during prototype testing.

10.0 SAFETY

There are no special safety problems associated with the performance of tasks performed during geologic studies. All work will be carried out in accordance with applicable site requirements.

11.0 MILESTONES AND REPORTS

The results of prototype testing will be presented in reports on the following subjects:

- photogrammetry decision (Appendix),
- methods for photogrammetric mapping,
- methods for conventional mapping (back-up method), and
- test shaft and drift report.

These reports or milestones are shown on the testing schedule for prototype geologic investigations (Fig. 1.1-7).

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 NOV 4 1988

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APPENDIX

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MAJOR EQUIPMENT LIST
FOR
PHOTOGRAMMETRIC GEOLOGIC MAPPING

Item	Description
DSR-11	Analytical stereoplotter, which includes 5-20x differential and common zoom optics; 360° image rotation; variably sized illuminated floating mark; freehand tracing with Z hand disk for use with original format black and white or color photography up to 9.5 by 9.5 in. from any camera with any focal length accommodating tilts up to high oblique and utility software to compensate for earth curvature, atmospheric refraction, camera distortion, restitution instrument calibration coefficients and service diagnostics, with a DEC Micro 11/73 computer for plate processing.
MAPS 350 System	Includes PDP 11/73 with 512 Kb memory, dual 5-1/4" 0.4 Mb disk drives, 30 Mb hard disk, VT220 alphanumeric CRT, Tektronics 4125 graphics display, RM128 mechanical cradle, image superposition monitor, MAPS 350 software.
Correlator ACOR	Includes two high-resolution CCD cameras, Imaging Technology digitizing equipment with direct interface to Q-bus of DSR-11 computer, software to specify exterior and interior windows, and regular grid intervals.
DH-630OQ5-EA	MicroVAX II high-capacity 32-bit microcomputer, which includes MicroVAX II CPU, 8 Mb memory, TK50 95 Mb cartridge tape drive and controller, KDA50 disk controller, DEQNA, DHV11, H9642 STYLE JA/JB cabinet with dual BA23 boxes, documentation, and installation diagnostics.
RA81-HA	456 Mb fixed disk drive.