COMPARISON OF THE BENEFITS OF PHOTOGRAMMETRIC, PHOTOMOSAIC, AND CONVENTIAL MAPPING OF UNDERGROUND GEOLOGIC FEATURES

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COMPARISON OF THE BENEFITS OF PHOTOGRAMMETRIC, PHOTOMOSAIC, AND CONVENTIONAL MAPPING OF UNDERGROUND GEOLOGIC FEATURES

SUMMARY

The benefits of close-range photogrammetric underground mapping methods are significantly greater than those of photomosaic or conventional methods: 1) The quality, quantity, and reproducibility of the scientific product is significantly greater for the photogrammetric methods than for the other methods. 2) The time required to complete the underground mapping using the photogrammmetric method is 9 and 17 months less than that required by the photomosaic and conventional methods, respectively. 3) The overall savings of close-range geologic photogrammetric methods, relative to the costs of photomosaic and conventional methods, are estimated to be greater than $5 million for underground mapping of the Exploratory Shaft Facility at Yucca Mountain. These savings take into account the initial outlay for a computerized analytical plotter (Kern DSR-11) for close-range photogrammetric mapping and data collection required by photogrammetric methods.

PURPOSE AND SCOPE

Yucca Mountain is a potential high-level nuclear waste repository site being studied by the Nevada Nuclear Waste Storage Investigations (NNWSI), administered by the U.S. Department of Energy. The purpose of this document is to decide whether close-range photogrammetry is the best method for underground geologic mapping and data collection for the Exploratory Shaft Facility (ESF) at the Yucca Mountain site. Costs of photgrammetric, photomosaic, and conventional mapping methods are compared. Scientific and other benefits from geologic mapping by close-range photogrammetry are compared with those benefits from other mapping methods.

OUTLINE OF METHODS

Three underground geologic mapping and geologic data collection methods are compared: 1) Photogrammetric, 2) Photomosaic, and 3) Conventional. These three methods are outlined below.

1. Photogrammetric: The basis for close-range photogrammetric mapping and data collection is precise stereographic photographic coverage of the underground exposures. High-precision laser surveys of targets on the exposures to be mapped, calibrated camera lenses, an analytical plotter, and minicomputers are the elements that make this method of mapping precise and rapid.

A laser theodolite system defines the centerline of drifts. Once in place, this survey system operates continuously during mining and mapping. After each round is mucked out and the walls cleaned for mapping, but before bolts and mesh have been installed, the surveyors, photographers, and geologists set up a center-line rail coincident with the laser beam (fig. 1). The precise locations of survey targets on the wall to be mapped are determined by use of a right-angle prism goniometer that is rotated on an axis coincident with the laser beam. Stereographic photographs of the targets and the walls are taken with a camera calibrated to remove distortion (fig. 2). These stereographic photographs are then set in models in the analytical plotter, which locates all features in 3-dimensional space. Features are digitized and plotted automatically on a large-format pen plotter creating an accurate geologic map of the rough wall surface or a theoretical smooth wall projection of the geologic features. In addition to the map of fracture traces, attitudes of fractures, roughness of fracture surfaces, apertures of fractures, the nature of fracture abutting will be determined on the analytical plotter.

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Normally, the entire fracture network of the right wall and the crown of the drift will be digitized. For the shaft, the entire circular wall will be digitized. Data are stored and analyzed by computer and plotted on the maps to represent the geology of each mapped interval. Map scales can be changed upon demand. Fractal analyses are made from this computer data base.

The only data that are collected by hand are lithogic samples and fracture coatings, and measurement of the attitudes of slickenside lineations using portable gyroscopic compasses.

2. Photomosaic: Photomosaic mapping also uses stereographic photographs as the basis for mapping the fracture network, but fracture orientation, aperture, and roughness are measured manually underground.

As in the photogrammetric method, a laser theodolite system defines the centerline. The same wall cleaning, surveying, and photographic procedures are used in photomosaic mapping as in the photogrammetric method described above. However, for photomosaic mapping, all the attitudes, roughness, and apertures of fractures must be measured manually at the underground exposure. The characteristics of the fractures along one datum line are collected by use of a strike-rail goniometer (fig. 3). Samples are collected and slickenside attitudes are measured underground, as in the photogrammetric method. After all underground measurements and photographs have been taken, further work is completed above ground. The film is developed, then photographs are assembled into a photomosaic of the exposure. The geologic features are traced onto the photographs, data collected underground are entered into a computer, and maps are digitized. All of the above ground work is manually performed. From this data base, fractal analyses are possible, and maps at different scales can be produced on demand.

3. Conventional: Conventional mapping consists of making a scaled sketch map of the exposure and collecting geologic data manually, all underground.

As in the photogrammetric and photomosaic methods, a laser theodolite system defines the centerline of drifts. The walls are cleaned after mucking, and mapping is done before wire mesh or bolts are installed. Several location points on the exposure to be mapped are surveyed to provide coordinates for the maps. A grid system is measured onto the walls using a measuring tape. A sketch map of the fractures and other geologic features is made underground, based on this grid system. All the attitudes, roughness, and apertures of fractures are measured underground. The attitudes of the fractures along one datum line are measured by use of a strike-rail goniometer (fig. 3). Samples are collected and slickenside attitudes are measured underground, as for photogrammetric and photomosaic methods. A photographic record of the exposures is also taken. All data are manually entered into a computer at the surface, and maps are manually digitized. From this data base, fractal analyses can be made, and maps at different scales can be produced on demand.

ESTIMATE OF PERSONNEL TIME

Geologic mapping is labor intensive. Figure 4 shows the number and type of personnel and the type of tasks required by 1) photogrammetric, 2) photomosaic, and 3) conventional methods. For the sake of uniform comparison, the shaft to be mapped is assumed to be about 480 m deep and the drifts to be mapped are assumed to be about 2,900 m long. It is also assumed that all shaft exposures will be mapped, and that the right wall and the crown of the drifts will be mapped. Furthermore, it is assumed that excavation will continue 24 hours per day and that geologists must be on call 24 hours per day to map whenever excavation reaches the proper stage.

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1) Photogrammetric methods personnel: The photogrammetric methods for mapping the shaft require 10 geologists, 5 geological assistants, and 2 technicians. There are three categories of geologists, a chief geologist, who manages the entire project from the photogrammetric laboratory; four liaison geologists, who coordinate work between the site and the photogrammetric laboratory; and five site geologists, who collect underground data and live within commuting distance of the site. During any 1-week period, one liaison geologist supervises the data collection at the site, and the other three analyze data at the photogrammetric laboratory. Liason geologists, while at the photogrammetric laboratory, analyze the data they personally collected in the shaft. After 1 week at the site, the liaison geologist is relieved by one of his colleagues. A site geologist is available for underground geologic data collection three 8-hour shifts per day, 7 days per week. This requires five site geologists who live within commuting distance of the site. Site geologists also act as quality control for the photographic record. One geological assistant is available to assist the site geologist during any one shift. This requires a total of five geological assistants. The geological assistants work with site geologists, until the drifts begin; at that time, the five geological assistants are transfered to work in the drifts. Two photogrammetry technicians are required to work at the photogrammetry laboratory to set photographic models and operate the analytical plotter. Photogrammetric analysis and report writing require the chief geologist, two liaison geologists, and two photogrammetry technicians.

The photogrammetric methods for mapping of the drifts require 4 liaison geologists, 5 geological assistants, and 4 photogrammetric technicians. The one chief geologist also directs drift work. The five geological assistants previously trained in the shaft work assume the role of the site geologists in the drifts. Thus, four additional liaison geologists will be required. When any tasks require data collection in more than one drift at the same time, the site geologists concurrently working in the shaft can help. Analysis and reporting assignments are unchanged.

2) Photomosaic methods personnel: The photomosaic methods for mapping of the shaft require a total of 8 geologists including 1 chief geologist, 2 liaison geologists, and 5 site geologists. Photomosaic methods in the shaft also require 5 geological assistants, 5 data-entry technicians, and 5 photomosaic technicians. During any one mapping shift both a site geologist and a geological assistant are required because of the additional underground measurements required. To provide for three 8-hour shifts per day requires a total of 5 site geologists and 5 geological assistants. Both the site geologists and the geological assistants must live within commuting distance of the site. The two liaison geologists and the chief geologist would alternate trips to the sit- One photomosaic technician is required to construct models of the photographs for each shift. Also, one technician is required to enter into the computer data collected from each mapped interval during each shift. Thus, 5 photomosaic technicians and 5 data-entry technicians are required. These technicians must also live within commuting distance of the site. Photomosaic analysis and report writing require the chief geologist, two liaison geologists, and two data-entry technicians.

The photomosaic methods for mapping of the drifts require the same chief geologist who also directs the shaft work, 2 liaison geologists, 5 site geologists, 5 geological assistants, and 10 technicians. Liaison geologists, site geologists, and geological assistants working with shaft mapping can help the drift mapping team when two drift mapping efforts overlap. Analysis and report writing require the chief geologist, at least two liason geologists, and two data-entry technicians.

3) Conventional methods personnel: The conventional methods for mapping the shaft require a total of 8 geologists including 1 chief geologist, 2 liaison geologists, and 5 site geologists. Conventional methods in the shaft will also require five geological assistants, and five data-entry technicians. During any one mapping shift, both a site geologist and a geological assistant are required because of the additional underground measurements required for these mapping techniques. Both the site geologists and the

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geological assistants must live within commuting distance of the site. The two liaison geologists and the chief geologist alternate trips to the site. One technician is required to enter into the computer data collected from each mapped interval during each shift. Thus, five data-entry technicians are required to fill all shifts. These technicians also must live within commuting distance of the site. Analysis and report writing for conventional methods require the chief geologist, one liaison geologist, and one data-entry technician.

The conventional methods for mapping of the drifts require the same chief geologist who also directs the shaft work, 2 liaison geologists, 5 site geologists, 5 geologic assistants, and 5 data-entry technicians. Liaison geologists, site geologists, and geological assistants working with shaft mapping can help the drift mapping team when two drift mapping efforts overlap. Analysis and report writing require the chief geologist, two liason geologists, and two data-entry technicians.

The cumulative numbers of geologists, geological assistants, and technicians required for these mapping and data collection methods are shown by histograms in figure 5. When shaft and drift mapping overlap in time, the difference between photogrammetric and the other methods is pronounced. Whereas a maximum of 25 persons are involved using the photogrammetric method, 45 are involved for photomosaic methods, and 35 are involved for conventional methods.

U.S. Geological Survey (USGS) personnel will work out of Denver and can fill roles of the project chief geologist, liaison geologists, and photogrammetric technicians. U.S. Bureau of Reclamation (USBR) personnel can either work out of Denver or live within commuting distance of the site; therefore, they can fill any of the positions. Most of the geological assistants probably will be Fenix & Scisson (F&S) geologists assigned to the Nevada Test Site. Some technicians or assistants may be retained by contract.

STANDBY TIME FOR SHAFT-CONSTRUCTION SUBCONTRACTOR

Different mapping and data-collection techniques require varying amounts of underground time. Underground collection of scientific data interrupts the process of mining. During this period, the shaft subcontractor must suspend excavation activities. This time includes transit time for the mapping crew, cleaning of exposures, surveying, photography, and geologic mapping and data collection. The transit, cleaning, surveying and photographic times remain about the same for the three methods, about 1 hour exclusive of mapping and data collection time. Some of the survey and photographic time will overlap with the geologic data collection time and is credited to geologic mapping and data collection time. The amount of time estimated for geologic mapping and data collection vary considerably. The photogrammetric methods require the least time at the exposure, estimated to be 1 hour. Photomosaic methods require at least an estimated 2 hours at the exposure, because all geologic measurements, except the map itself, are collected at the exposure. Conventional methods require that all geologic mapping and data collection be done underground, about 6 hours are estimated.

The sum of the underground time required for transit, cleaning, surveying, and for geological mapping and data collection will determine the excavation standby time. Two hours of standby time for the shaft subcontractor are estimated for the photogrammetric method, 3 hours for the photomosaic method, and 7 hours for the conventional method.

The total project standby time for the shaft and drift excavation is calculated based upon the number of intervals to be mapped. There will be about 3,400 m of linear exposure along drifts and down the shaft. Each mapped interval will be 2 m long. Thus, 1,700 intervals will be mapped. Therefore, using these estimates, photogrammetric methods require a total of 3,400 hours, photomosaic methods require 5,100 hours, and conventional methods require 11,900 hours of standby time.

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BENEFITS OF PHOTOGRAMMETRIC METHODS

There are several advantages of close-range geologic photogrammetric mapping and data collection methods over photomosaic and conventional methods. These advantages include 1) accuracy of geologic observations, 2) quality of data, 3) quantity of data, 4) an expandable data base, 5) duration of the mapping project, 6) fewer people underground at any one time, 7) fewer personnel demands, and 8) lower costs.

1) Accuracy of Geologic Observations: The combination of laser surveying, photographs made with calibrated lenses, and computerized analytical plotting of the photogrammetric method provides a level of accuracy and precision far greater than that provided by other methods. The position of any point on the exposures can be relocated within ± 1 cm of its true position. Even after the walls of the shaft have been lined or after the drift exposures have been covered with shotcrete, wire mesh, or dust, specific fractures or faults can be located for further study if the need arises. The accuracy of the photomosaic method is about ± 10 cm, largely because in the process of tracing the photographs, distortion is incorporated into the drawing of the geologic feature positions. Because conventional mapping requires a sketch map to be drawn of the geologic features with even less control, the accuracy is about ± 15 cm. The angular precision of the analytical plotter is less than 0.1°, considerably more precise than the 2° precision of a Brunton compass used by the other methods.

2) Quality of Data: The analytical plotter of the photogrammetric method automatically performs a best-fit solution of all the digitized points in order to calculate the attitude of any fracture surface being digitized. This process typically involves 10 to 50 digitized points. In contrast, only one measurement will be made on any one surface for the photomosaic and conventional methods. Thus, where it is desirable to extrapolate data or interpolate between data, the best-fit photogrammetric method is superior. Also, the analytical plotter will produce, not only a line drawing of the intersection of the fractures with the rough mined exposures, but also, will produce a "smoothed" projection of the intersection of fractures with a theoretical, smooth wall; this "smoothed" map of the geologic features will facilitate interpretation of the fracture network.

3) Quantity of Data: In the process of digitizing the geologic features from the photographs using the analytical plotter, the attitude of every fracture longer than 30 cm will automatically be recorded. The photomosaic and conventional methods will only gather data from fractures longer than 30 cm that intersect one datum.

4) Expandable Data Base: Although considerable effort has been made to predict the data needs for geologic mapping, the requirements for the project evolve as knowledge of the geologic, hydrologic, and engineering conditions of Yucca Mountain grows. Therefore, a data base that can be expanded to meet unforseen needs is desirable. The photogrammetric method will permit restudy of any portion of the shaft or drifts at a later date in greater detail. Other observers can also study the features if independent confirmation is called for. The photographs collected for the photomosaic and conventional methods cannot be used for expansion of the data base.

5) Duration of the Mapping Project: The photogrammetric methods take about 9 months less to complete than the photomosaic methods, and 17 months less than conventional mapping methods because there are fewer and shorter steps in digitizing and analysis of data in the photogrammetric methods.

6) Fewer Persons Underground: Only one geologist will be required underground during most of the mapping for the photogrammetric method in contrast to two geologists for other methods.

7) Fewer Personnel: The maximum number of persons involved in mapping for the photogrammetry method is 25, whereas the numbers required for photomosaic and conventional mapping are estimated to be 45 and 35, respectively. Even with personnel

from the USBR, the USGS, and contractor sources, the demands on organizations to provide numerous scientists are severe. The 10 geologists from the USBR and the USGS for the photogrammetric method will be considerably easier to obtain than the 15 required by other methods.

8) Table 1 is a summary of the costs associated with the three methods. One large item is the cost of personnel; these costs are based on data shown in figures 4 and 5. The most significant cost, however, is the standby time for the shaft-construction subcontractor. This standby time cost has been estimated by Dan Koss of REECo to be as high as $5,000 per hour. The lowest estimate of $1,000 per hour is considered unrealist. No estimates of ripple costs have been made because of a lack of data at this stage of planning. Ripple costs in a project as large as the NNWSI may be greater than the standby costs. Because of this imprecision in estimates of standby time cost and the lack of an estimate of the ripple costs, the $5,000 per hour estimate of standby time will be used (Table 1). The costs for equipment, maintenance contracts, and software programming contracts are also included.

Shorter underground time and fewer personnel required for the photogrammetric methods may save about $12,000,000 relative to the photomosaic method, and $46,000,000 relative to the conventional method, using the $5,000 per hour standby cost.

If the smaller standby cost of $1,000 per hour is used, the standby costs for the photogrammetric, photomosaic, and conventional mapping methods would be $3,400,000, $5,100,000, and $11,900,000, respectively, and the total mapping project costs would be $10,710,000, $15,947,000, and $22,450,000, respectively. This indicates that the photogrammetric methods would be about $5,000,000 less expensive than the photomosaic methods, and $12,000,000 less expensive than the conventional methods, even if the standby costs were as little as $1,000 per hour. Table 2 summarizes the savings as a function of different methods and different estimates of standby time costs.

BENEFITS OF PHOTOMOSAIC METHODS

Photomosaic methods, compared to photogrammetric methods, have two benefits 1) less dependence on equipment that can fail, and 2) less prototype testing.

1) Less Dependence on Equipment: Photomosaic mapping and data collection does not rely on an analytical plotter and related computers and software; these complex systems could possibly have equipment failure and cause delays or loss of data.

2) Less Prototype Testing: Photomosaic mapping and data collection require less prototype testing than do the photogrammetric methods because only the photogrammetric methods require prototype testing of the analytical plotter and related computers and software.

BENEFITS OF CONVENTIONAL METHODS

Conventional mapping, compared to other methods, has three benefits: 1) least dependence on equipment, 2) least prototype testing, and 3) familiar mapping procedures.

1) Least Dependence on Equipment: Conventional mapping does not depend on photography or analytical plotters; only on data storage and analyis by computers and on a digitizing system. Failure of anaytical plotters or photography will cause delays or loss of data to either the photogrammetric or photomosaic methods.

2) Least Prototype Testing: Because the methods used by conventional mapping and data collection are known and only data storage and analysis software need to be developed, the required prototype testing for the conventional methods is considerably less than those for the photogrammetric or photomosaic methods.

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3) Familiar Mapping Procedures: The procedures of conventional mapping and data collection are established in the literature and are familiar to mining engineers and engineering geologists.

CONCLUSION AND RECOMMENDATION

Clearly the photogrammetric method has significant scientific, time, personnel and cost benefits. The photogrammetric method has a potential saving in excess of $5 million compared to the other methods.

For several reasons, the benefits of the photomosaic and conventional methods are not comparable to those of the photogrammetric methods. These benefits are tabulated and ranked from 1 (most favorable) to 3 (least favorable) in table 3.

1) Less Dependence on Equipment: Because there is greater reliance on equipment by the photogrammetric methods, the photomosaic methods will be used as a backup in case of failure of the plotter. If such a failure occurs, only a short change in schedule will occur; once the plotter is repaired, the photographic data can still be analyzed with only a loss of time before comparable data are produced. The photomosaic data and map used as a backup can fill the immediate needs of the project. The dependence on photography by both the photogrammetric and photomosaic methods requires that particular attention be paid to avoid photographic failures. Use of Polaroid-type films to check exposures, and systematic and immediate development of the film after photographing the underground exposure are advised. The benefits of the photogrammetric method outweigh the potential for either equipment or photographic failure.

2) Less Dependence on Prototype Testing: The greater time and money spent during prototype testing of photogrammetic and photomosaic methods are small compared to the time and money saved by photogrammetric and photomosaic methods during actual testing.

3) Procedures Familiar to Engineers: Confidence in the photogrammetric and photomosaic methods will be provided by prototype testing and prototype test reports before mapping begins.

The benefits of all three methods are tabulated and ranked 1 (most favorable) to 3 (least favorable) in Table 3.

This comparison of the benefits of the photogrammetric, photomosaic, and conventional mapping and data collection methods indicates that the photogrammetric methods have significantly greater benefits for accuracy, data reproducibility, and management and could save in excess of $5,000,000.

Therefore, the recommendation is made to the U.S. Department of Energy that approval for purchase of a computerized analytical plotter (Kern DSR-11) for photogrammetric mapping by the U.S. Geological Survey be given as soon as possible. The photogrammetric methods should be the primary means of mapping and data collection, and photomosaic methods should be reserved for backup purposes.

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Table 1. Summary of Comparison of Costs for Photogrammetric, Photomosaic, and Conventional Mapping. Estimated costs for shaft-construction and drift-excavation contractor standby time are included, but ripple costs are not estimated. The number of personnel require are given in figures 4 and 5.

ITEM	PHOTOGRAMMETRIC	PHOTOMOSAIC	CONVENTIONAL
	(COSTS IN THOUSANDS OF DOLLARS)		
A. PERSONNEL			
1. Geologists ($120,000 per yr)	3,730	4,700	5,470
2. Geological Assistants ($80,000 per yr)	1,067	1,700	2,067
3. Technicians ($80,000 per yr)	1,213	3,747	2,413
B. STANDBY TIME FOR SHAFT-CONSTRUCTION SUBCONTRACTOR			
Estimated at $5,000 per hour	17,000	25,500	59,500
C. EQUIPMENT			
1. Analytical plotter (Kern DSR-11) and related minicomputers	400	0	0
2. Mapping, photographic and surveying equipment, and supplies	650	600	500
D. CONTRACTS			
1. Maintenance for analytical plotter and minicomputers	150	0	0
2. Software for data analysis and set up for plotter	250	100	100
E. TOTAL	24,460	36,347	70,050

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Table 2. Predicted savings by use of photogrammetric methods rather than photomosaic or conventional methods.

Standby Cost Estimate	Savings over Photomosaic Methods	Savings over Conventional Methods
$5,000 per hour	$12,000,000	$46,000,000
$1,000 per hour	$5,000,000	$12,000,000

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Table 3. Summary of benefits of photogrammetric, photomosaic, and conventional mapping methods. 1 = most favorable, 2 = less favorable, 3 = least favorable.

Benefit	Photo-grammetric	Photo-mosaic	Conven-tional
1. Accuracy of geologic observations	1	2	3
2. Quality of data	1	2	3
3. Quantity of data	1	2	2
4. Expandable data base	1	2	3
5. Duration of mapping project	1	2	3
6. Fewer persons underground	1	2	2
7. Fewer Personnel	1	3	2
8. Less dependence on equipment	3	2	1
9. Less prototype testing	3	2	1
10. Familiar mapping procedures	2	2	1

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Figure 1. Three-dimensional sketch of the surveying system to be used in photogrammetric and photomosaic mapping. The laser theodolite is aligned parallel to the centerline of the drift and the right-angle prism goniometer (RAPG). The combination of 1) the distance and direction from the theodolite to the RAPG, 2) the distance and direction from the RAPG to the surveying target, and 3) the angle at which the RAPG is rotated to project the laser beam onto the target define the target position relative to the theodolite.

Figure 2. Three-dimensional sketch of the camera mount used to produce stereoscopic photographs of the exposures in the drift. The camera is mounted on the rail parallel to the centerline of the drift and the camera is moved along the rail to three pre-set positions to obtain overlapping photographs.

Figure 3. Three-dimensional sketch of the use of a strike-rail goniometer to measure the attitudes of fractures along a datum line on a drift wall. The attitude to the strike rail is known from surveys and a goniometer allows the strike (aziumuth) of planar features to be measured by visually sighting parallel to the feature. This device avoids magnetic deviations of the Earth's field caused by metal in the underground environment.

Figure 4. The tasks and personnel required for the photogrammetric, photomosaic, and conventional methods of mapping and data collection plotted in time in fiscal years (FY).

Figure 5. Number of scientific personnel required to map and collect data for the photogrammetric methods compared to those required for other methods plotted against time in fiscal years (FY). Geologists will come from the USBR and the USGS. Assistant geologists will come from the USBR, F&S, or some other contract organization. Technicians will come from the USGS, USBR, or F&S. Any USGS personnel will work out of Denver; USBR personnel can be based either in Denver or within commuting distance of the site.

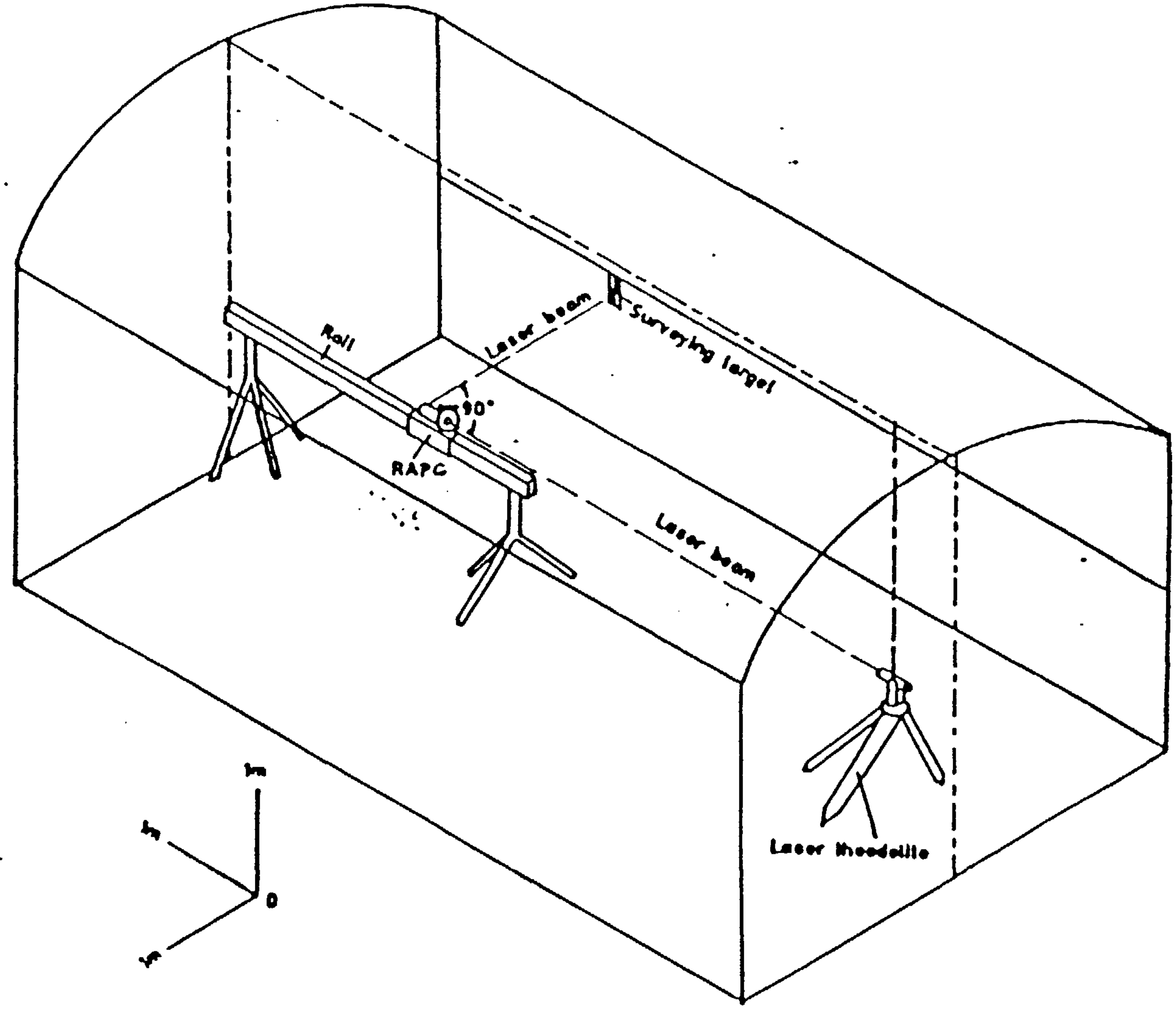

Figure 1

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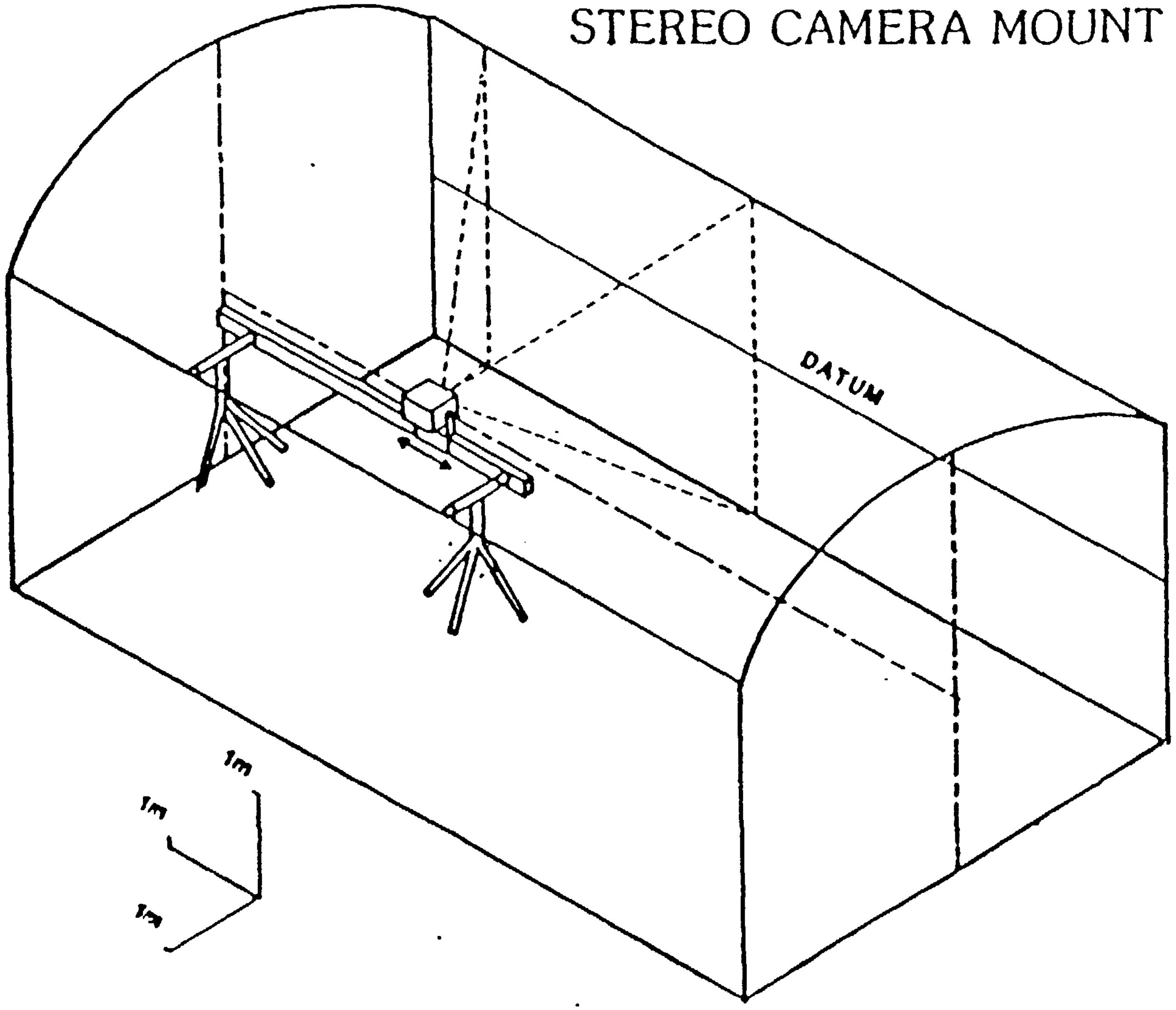
STEREO CAMERA MOUNT



G.M. Fairer, USGS
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Figure 2

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STRIKE-RAIL GONIOMETER

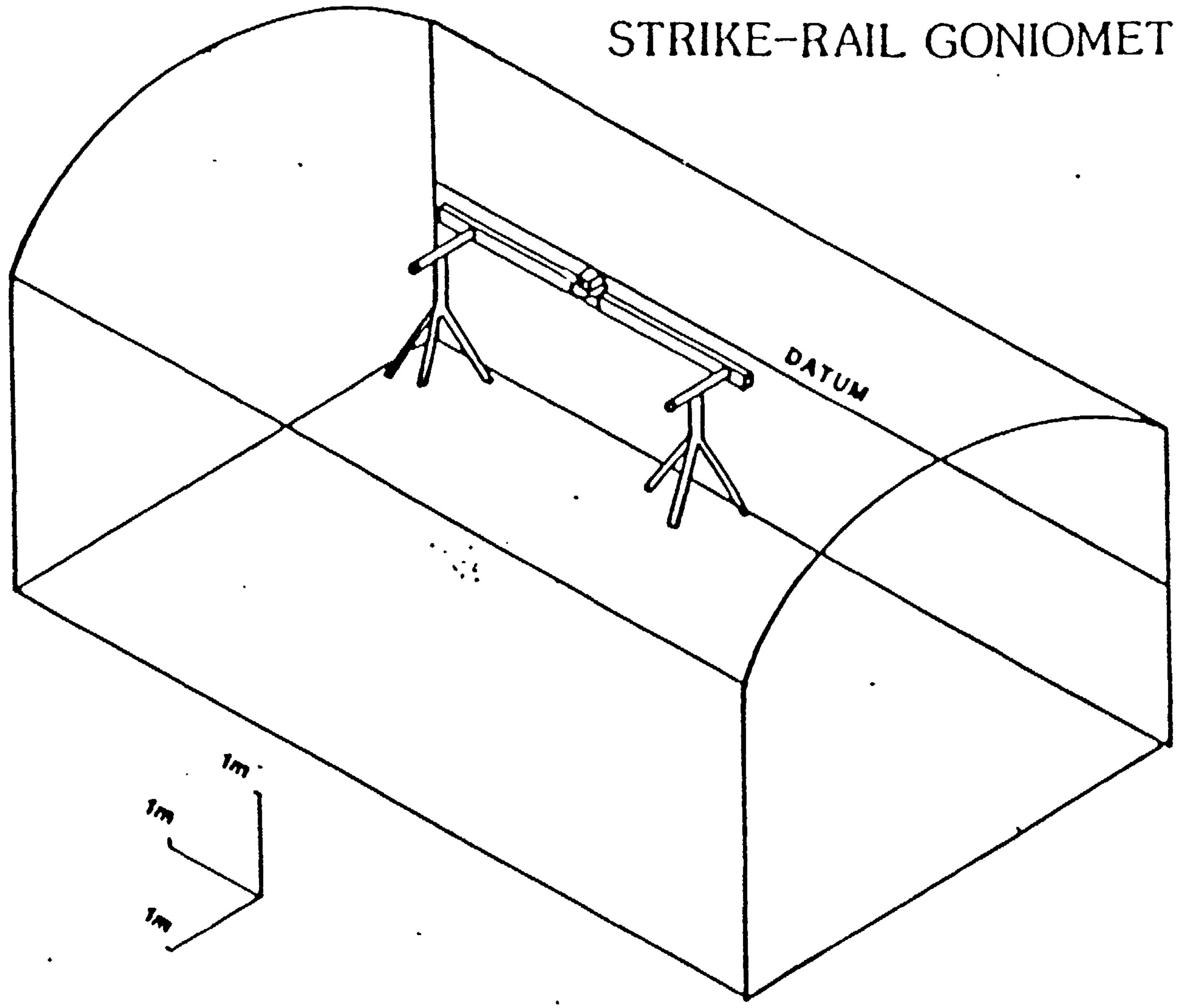

Figure 3

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EXPLANATION

The specific duties of the personnel are indicated by abbreviations: CG=project chief geologist; LG=[illegible] geologists who coordinate site data collection and data [illegible] in the geologic laboratory; SG=site geologists who live within commuting distance from the site and collect [illegible] underground data; GA=geological assistants who live within commuting distance from site and aid the site geologists; PT=photogrammetric technicians who run the photogrammetric laboratory; DT=data entry technicians who live within commuting distance from the site; PMT=photomosaic technicians who live within commuting distance from the site and are responsible for constructing photomosaic models.

REPORT

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ANALYSIS REPORT

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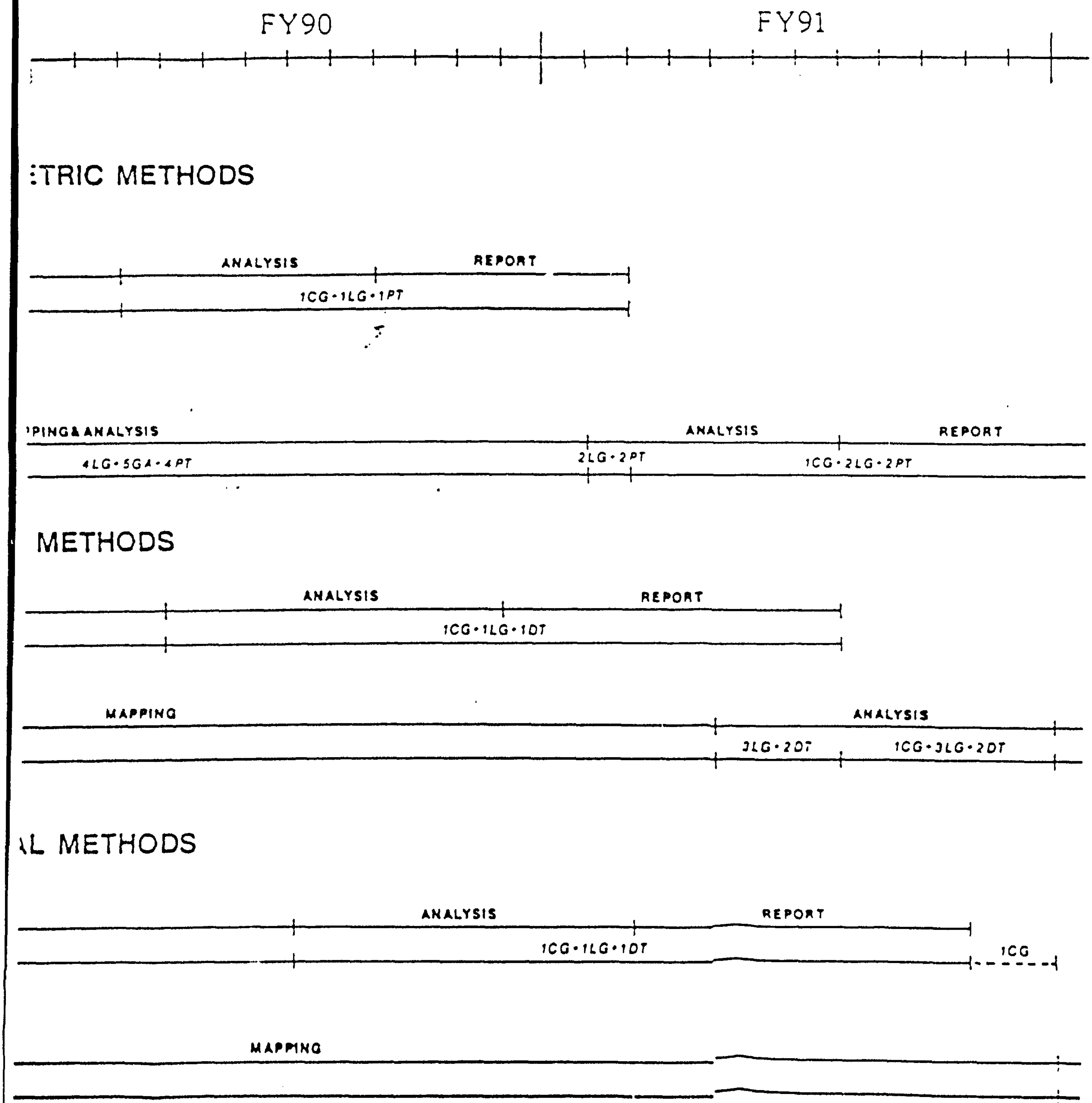

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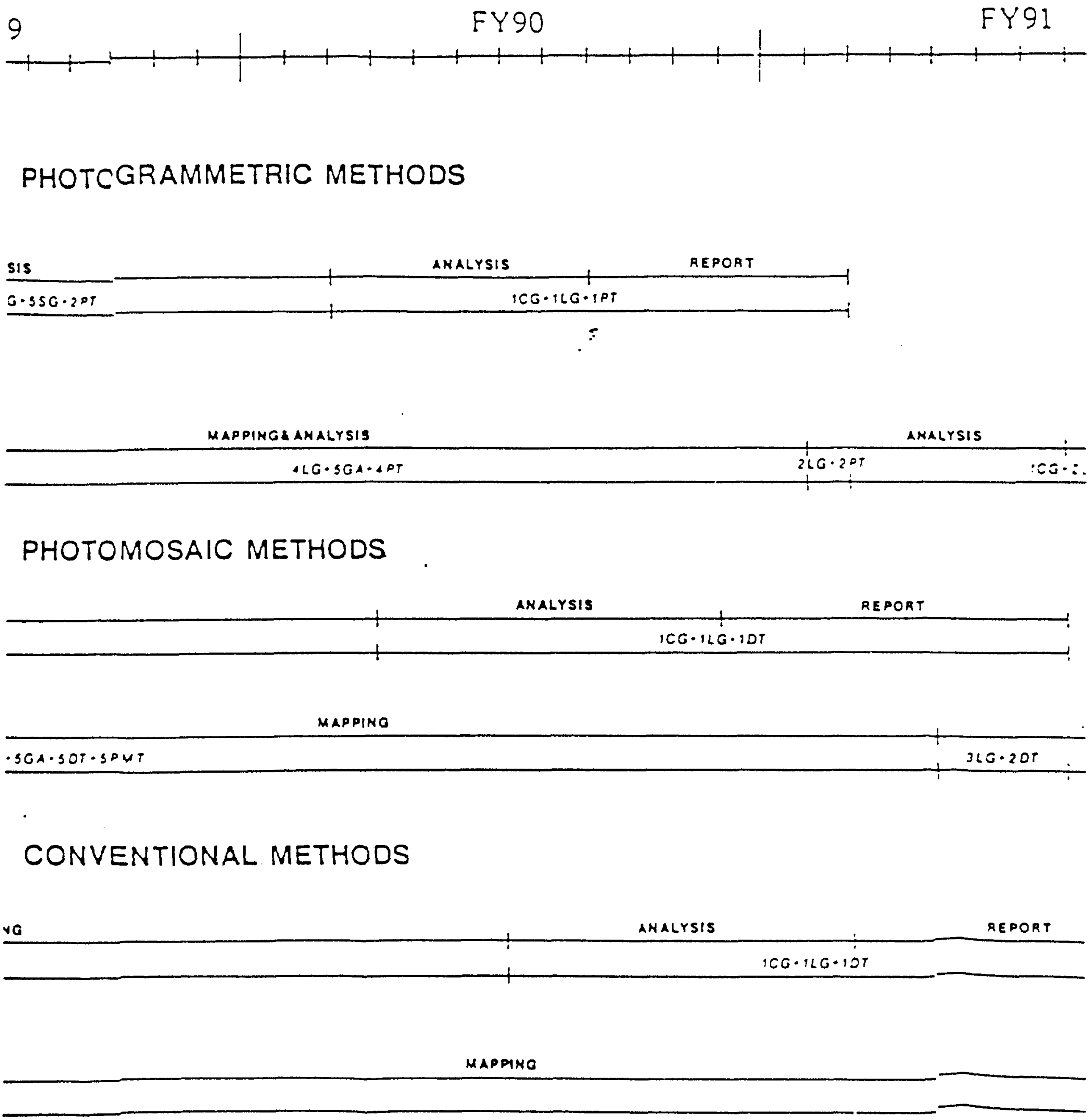

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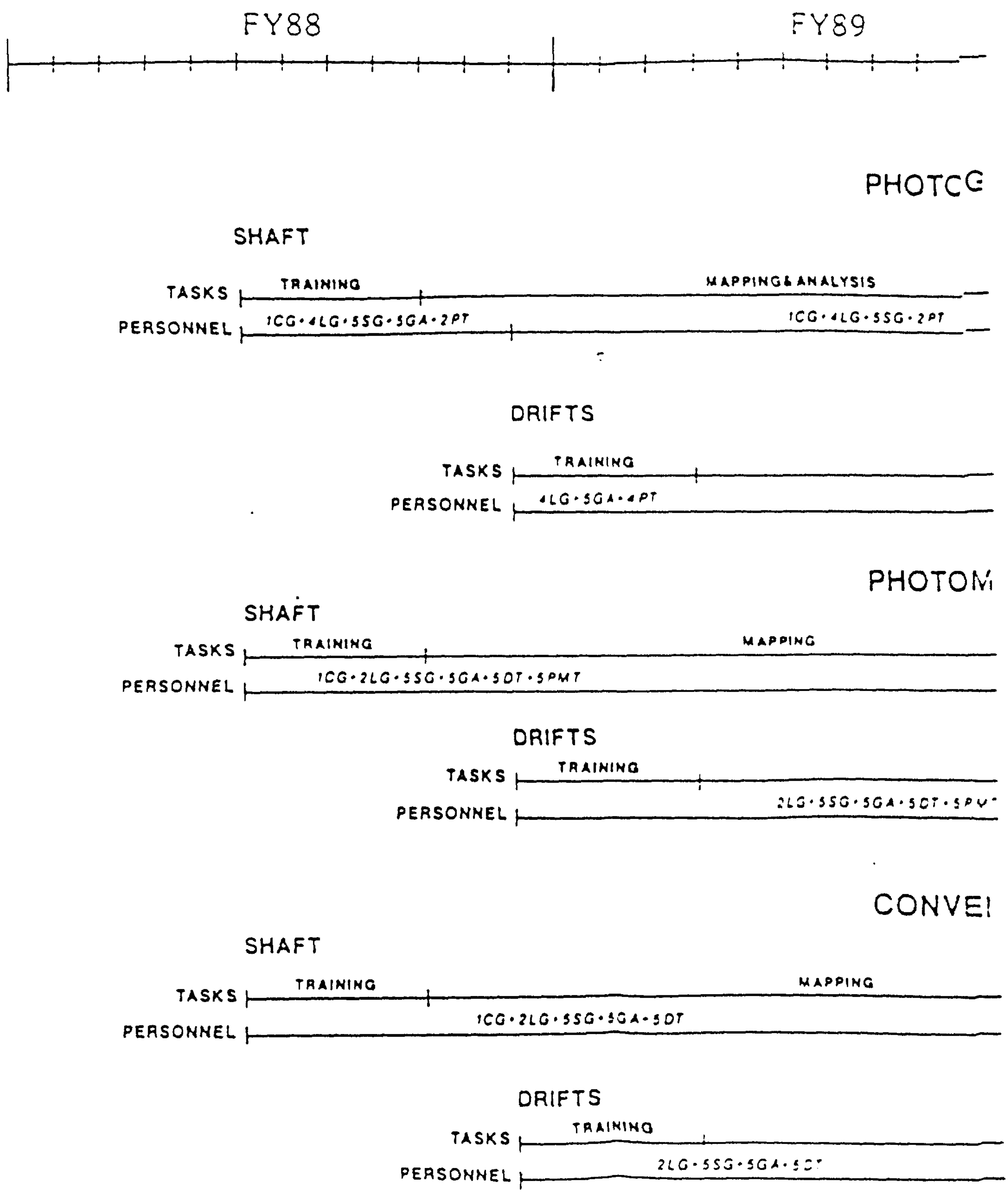

Figure 4

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EXPLANATION

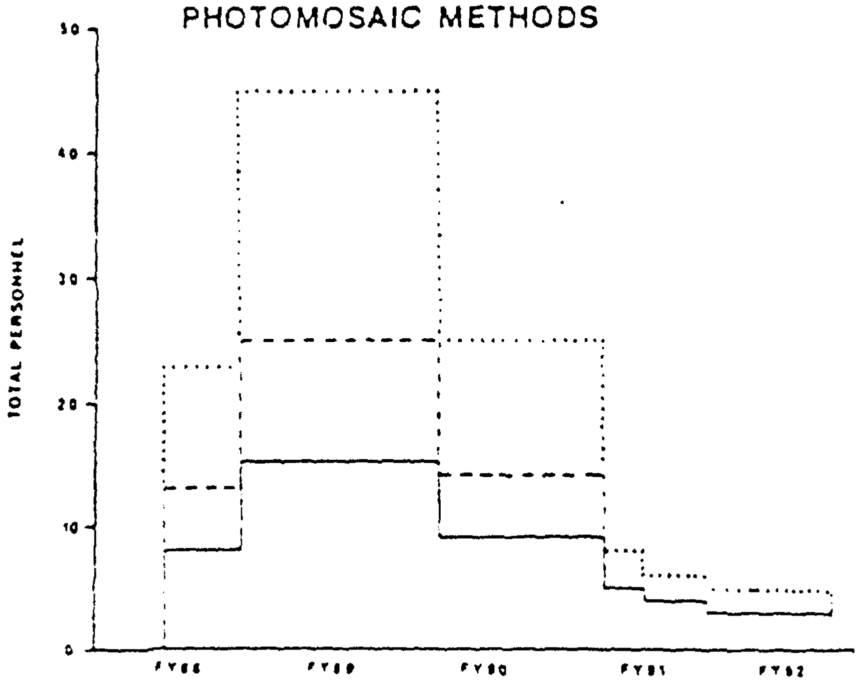
——— -CHIEF GEOLOGIST+LIAISON GEOLOGISTS +SITE GEOLOGISTS (USBR+USGS)

- - - - -GEOLOGICAL ASSISTANTS (F&S) ADDED TO GEOLOGISTS

······· -PHOTOGRAMMETRY TECHNICIANS, DATA TECHNICIANS (USGS, USBR, CONTRACT) AND PHOTOMOSAIC TECHNICIANS ADDED TO GEOLOGISTS AND ASSISTANTS

OS

PHOTOMOSAIC METHODS



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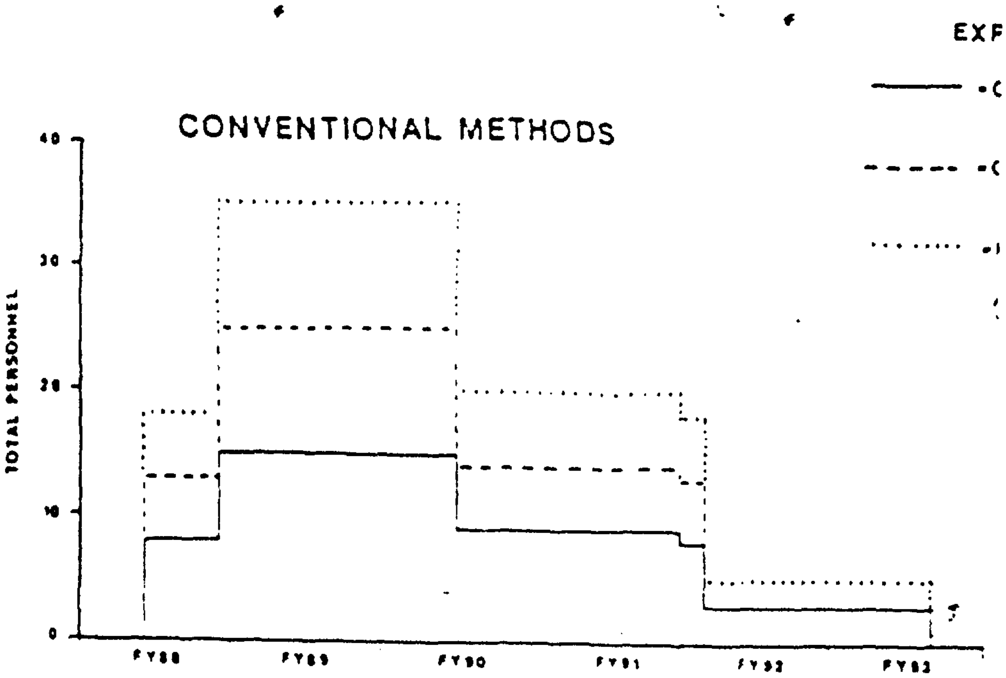

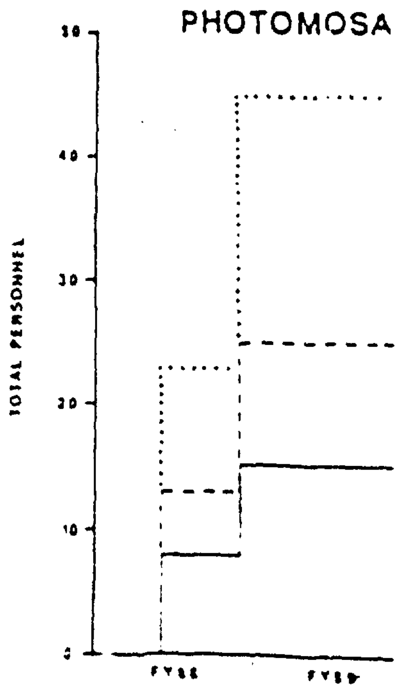

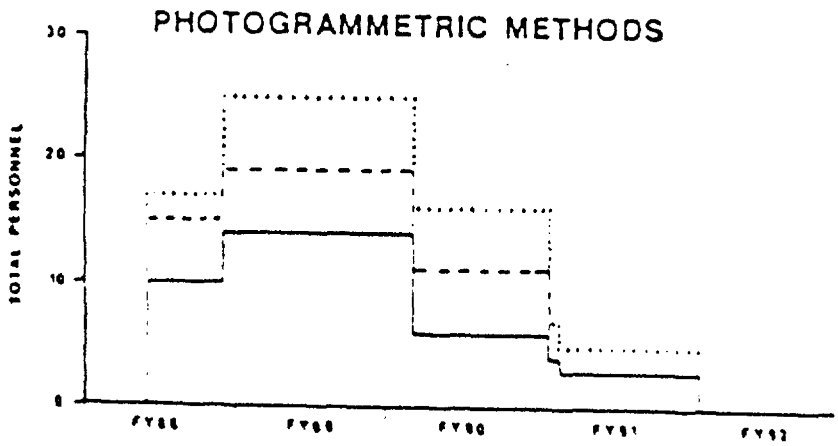

Figure 5

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U.S. DEPARTMENT OF ENERGY

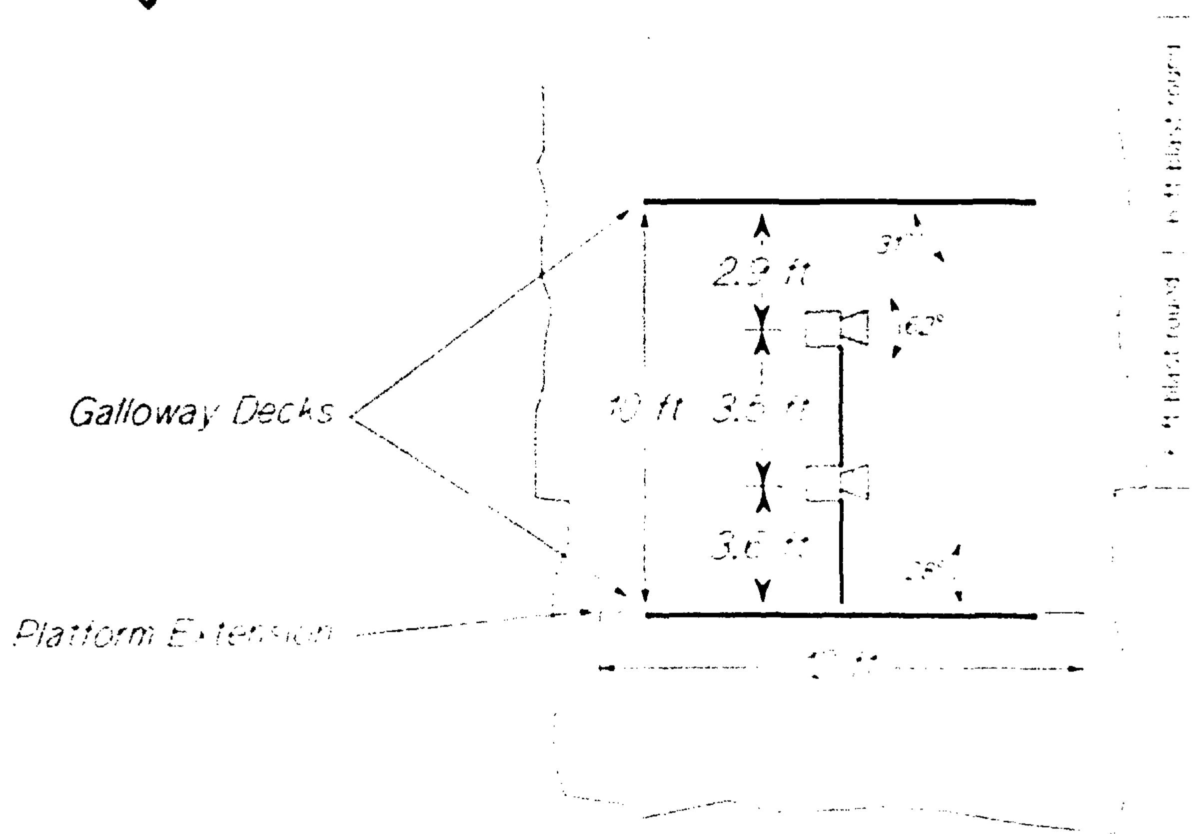
OCRWM

OGR

Yucca Mountain Project

Underground Geologic Mapping – Exploratory Shaft Facility

Camera Position and Field of View Angles for Shaft Mapping



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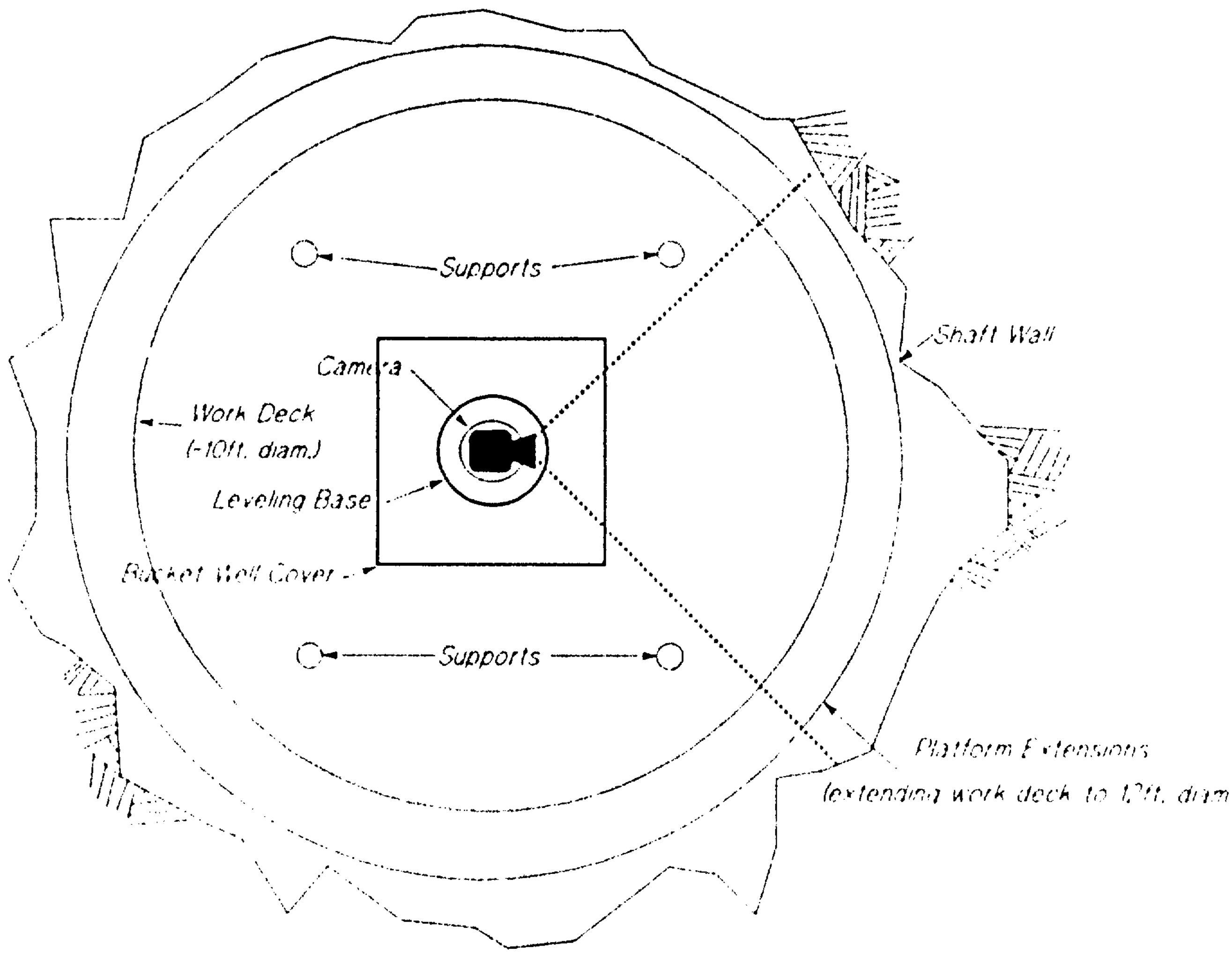
Plan View of Exploratory Shaft

Showing Camera Coverage



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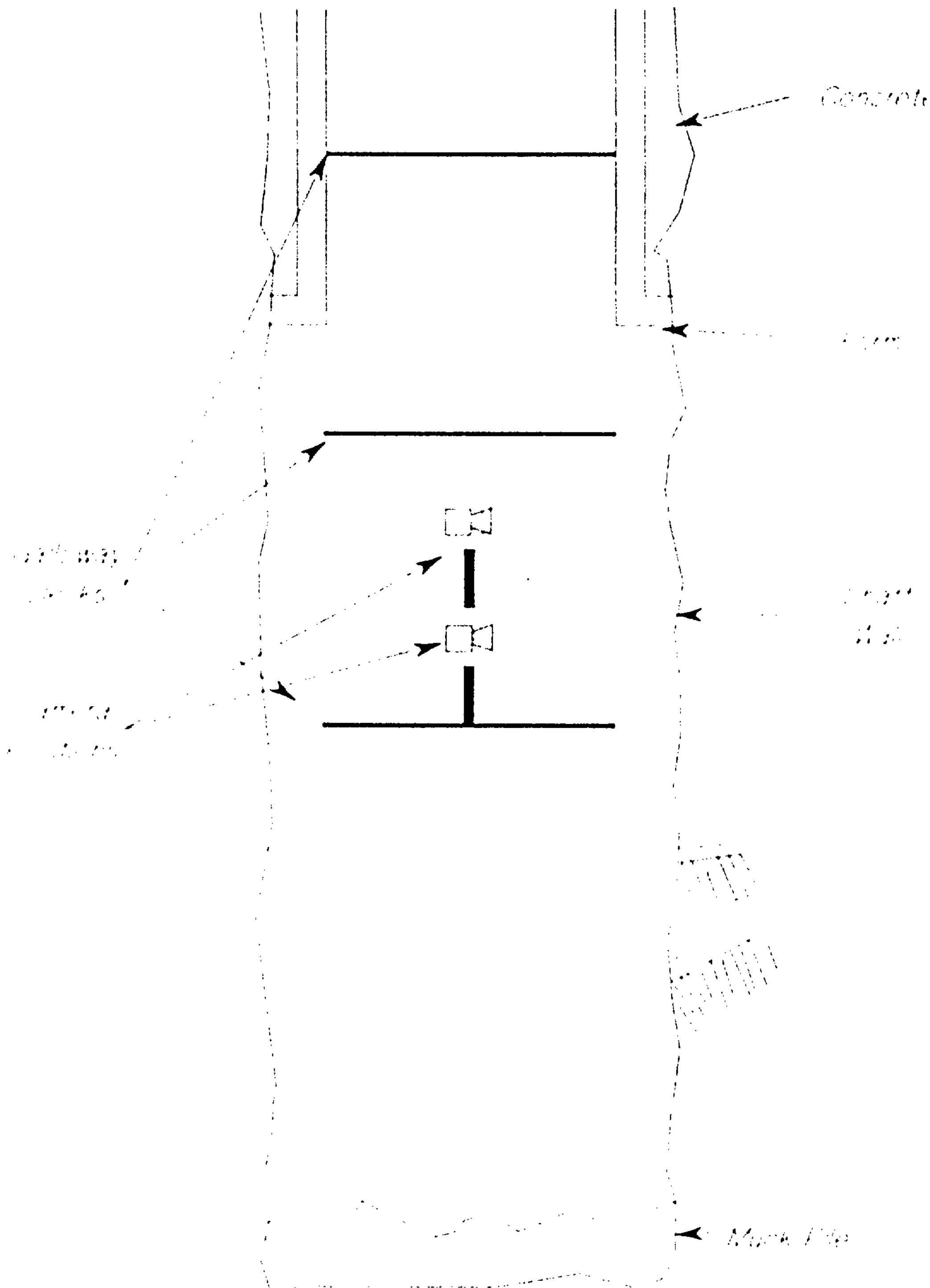
Cross Section of Exploratory Shaft

showing Camera Coverage



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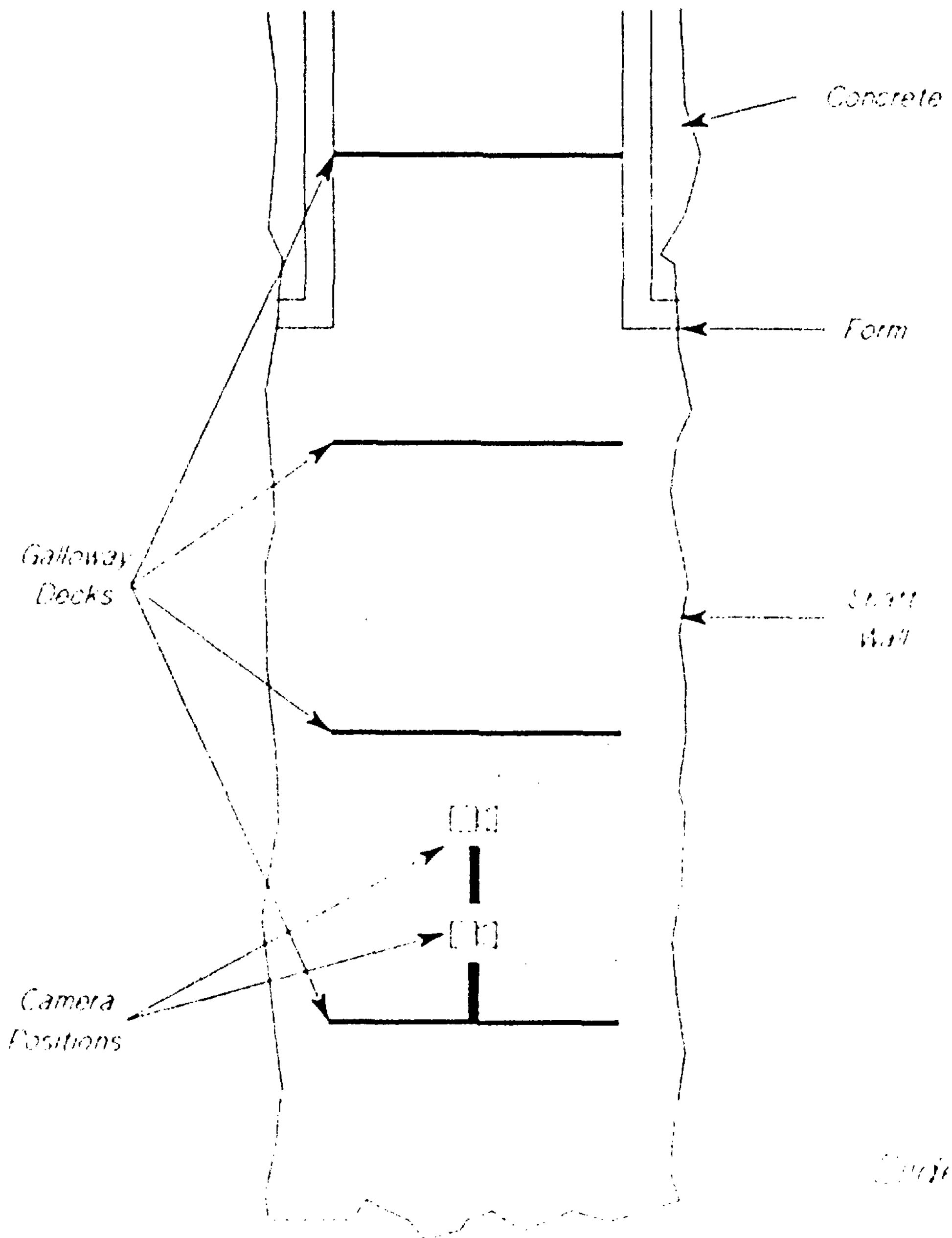
Cross Section of Exploratory Shaft

showing Camera Coverage



XEROX OF A PHOTO OF A PAIR OF STEREOPAIRS
COVERS THREE RINGS OF DRIF**INFORMATION COPY**
THIS IS TYPICAL OF WHAT DSR-11 LOOKS AT.

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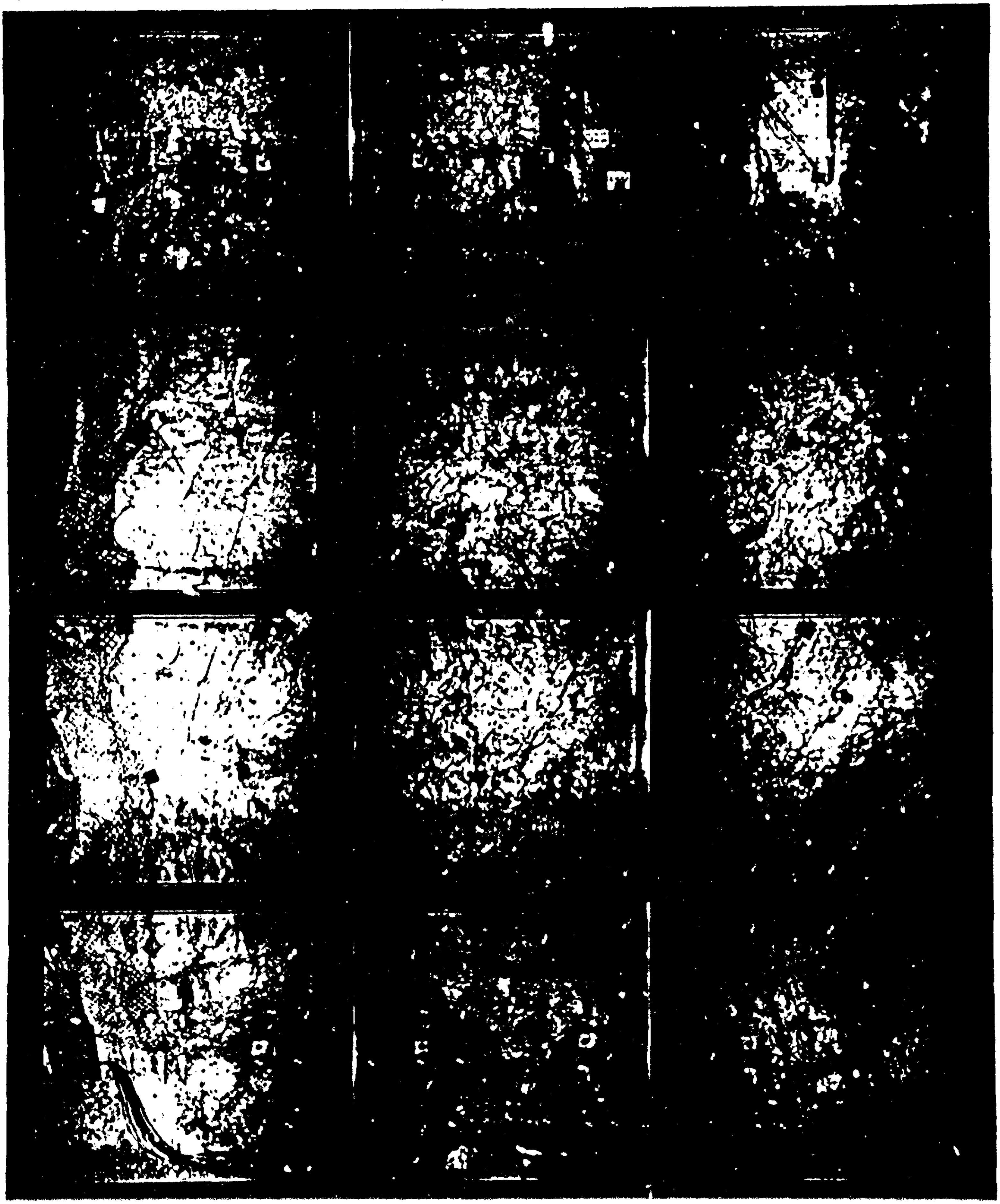

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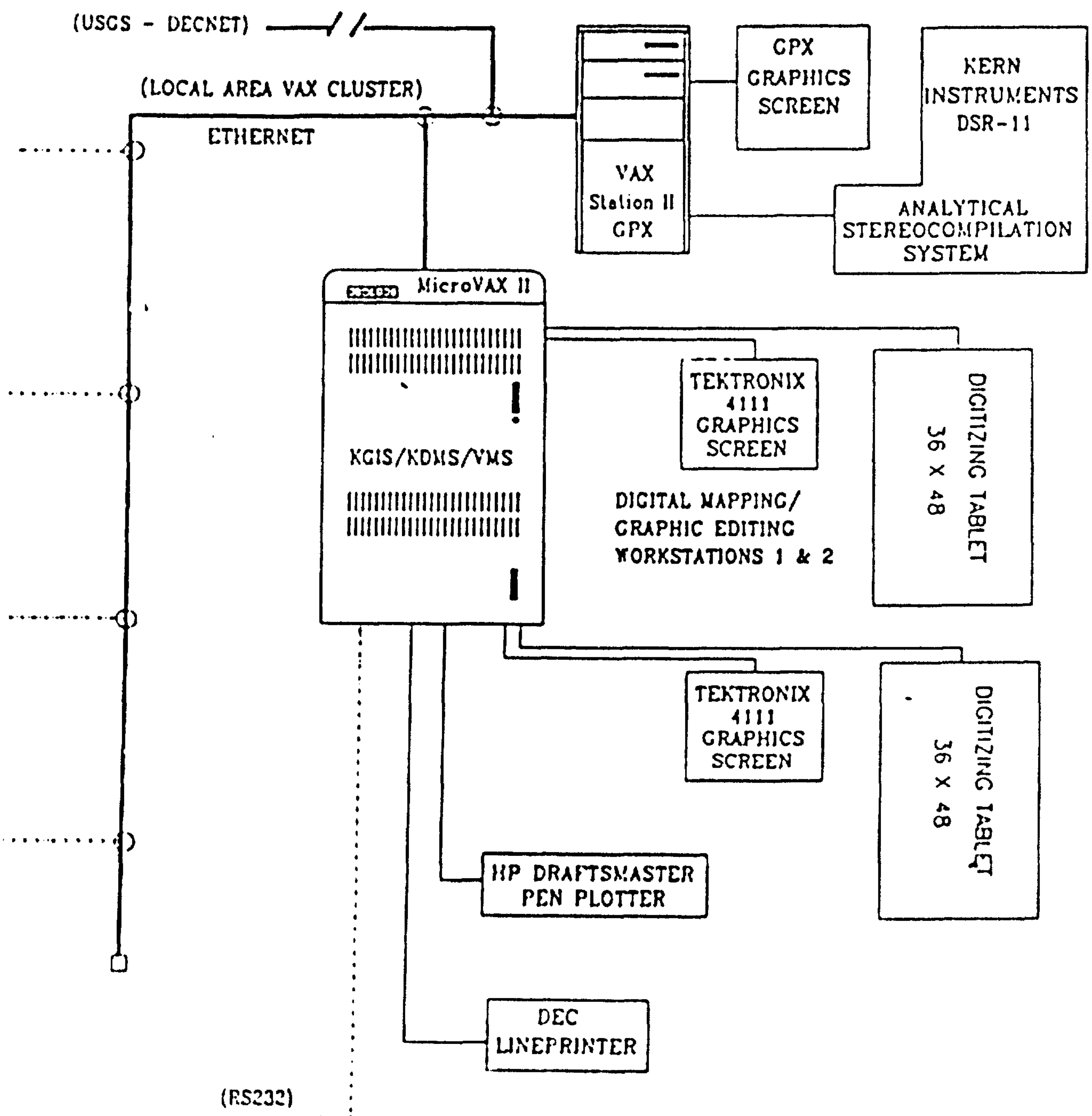
SGS STEREO COMPILATION/DIGITAL MAPPING FACILITY
DENVER, CO.



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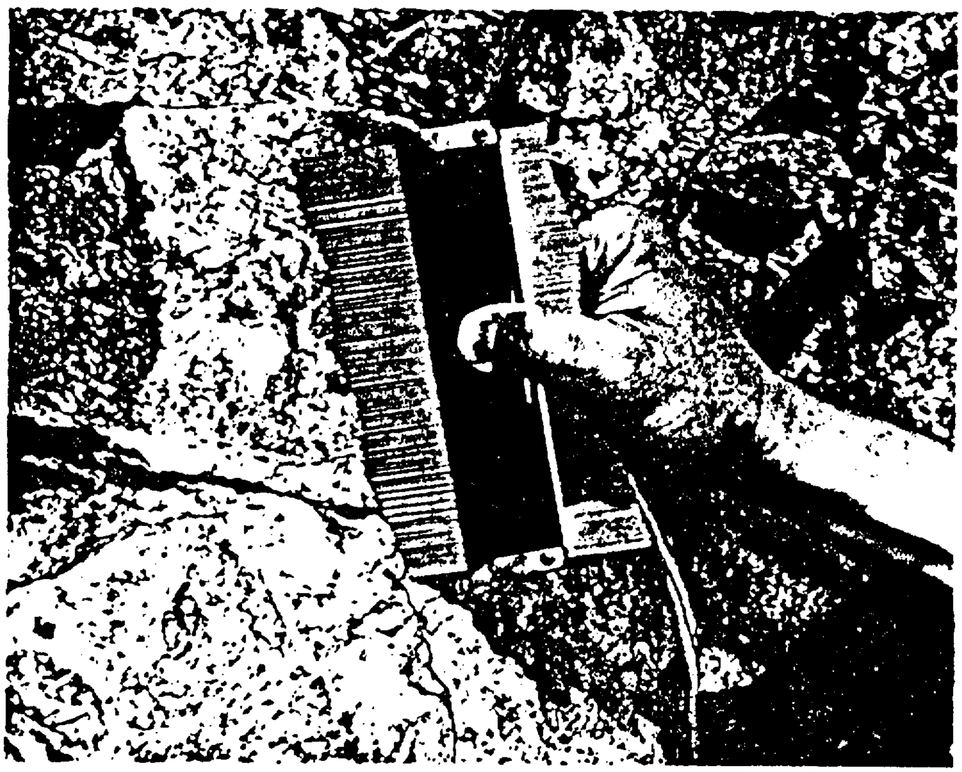

15. Pan Am - DNA Photo Neg. No. NF-5016: Close-up of a shape copier used to record the small-scale roughness of a fracture surface. The shape of the surface is immediately transferred by tracing to the data sheet for the detailed line survey.

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14. Pan Am - DNA Photo Neg. No. NF-5015: Close-up of a taper gauge, used to measure the aperture of a fracture. This gage is utilized during detailed line survey mapping, which records geologic information which is not measurable by photogrammmetric mapping methods.

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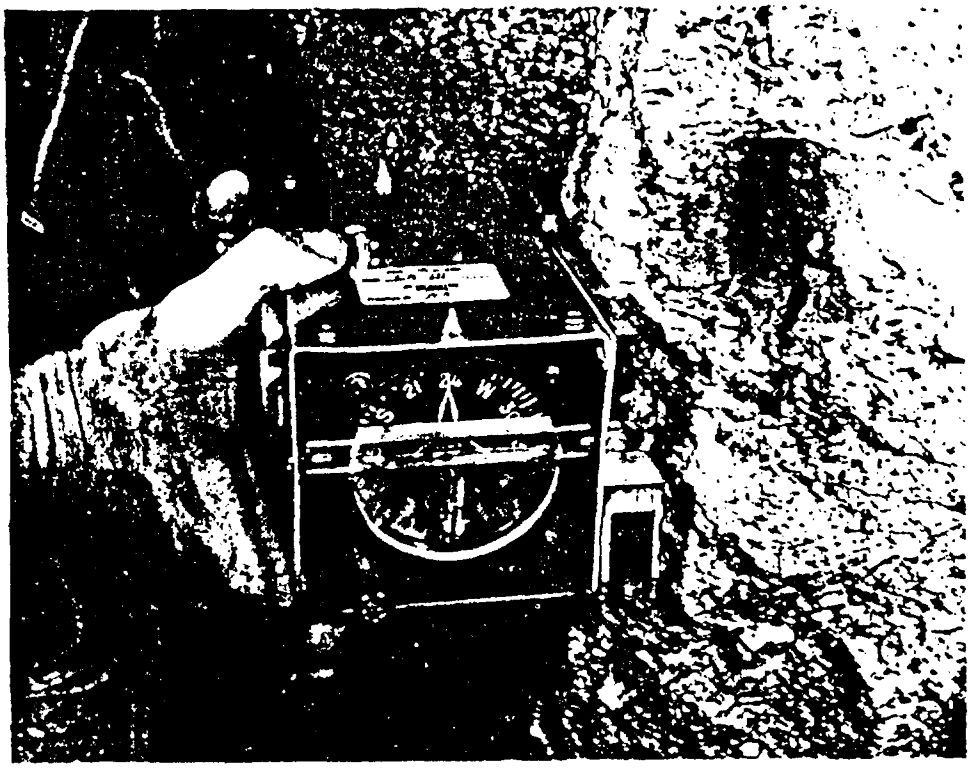

13. Pan Am - DNA Photo Neg. No. YM-431: Close up of the prototype Geological Gyrocompass. After initial setting, the compass is aligned with the feature and both strike and dip can be read directly from the front dial. The compass is equipped with sliding bars on the instrument sides to allow measurement of small features or features in hard-to-reach areas.

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12. Pan Am - DNA Photo Neg. No. YM-430: View of geologist using the prototype **Geological Gyrocompass.** The compass is first aligned to known azimuth, and then used in the same way a Brunton compass would be used to measure the strike and dip of geologic features. The compass is equipped with a belt-mounted battery pack, and features a lighted dial.

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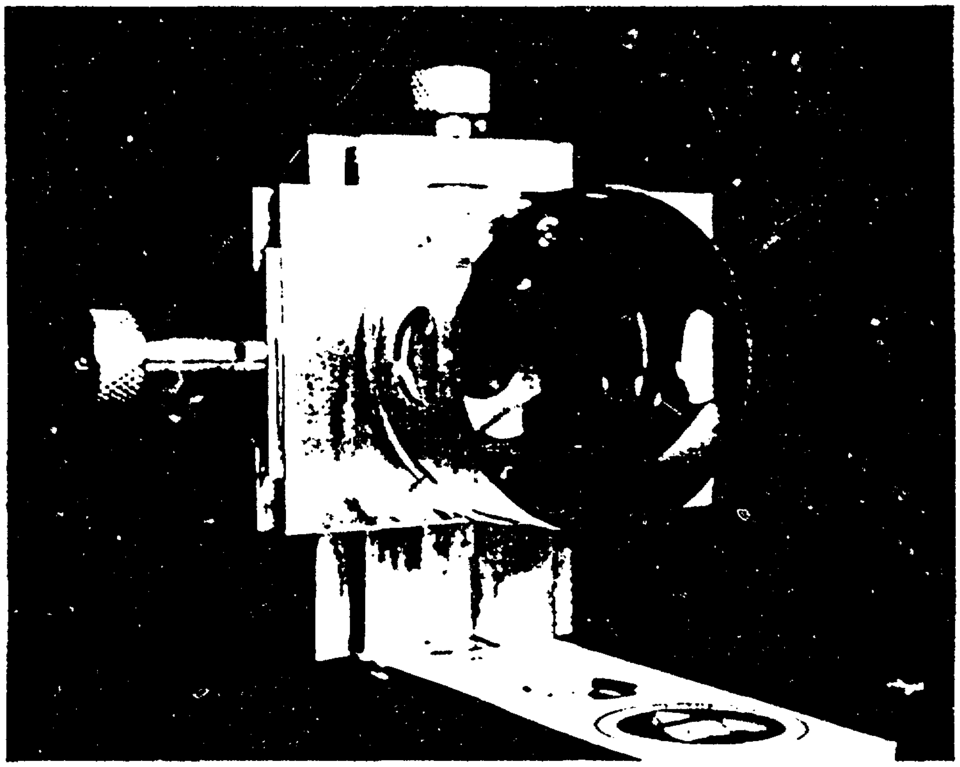

11. Pan Am - DNA Photo Neg. No. YM-429: Close up of the prototype **Pyramid Beam Splitter**. The pyramid is used to split the surveying laser beam into a maximum of four beams for locating photogrammetry targets on the excavation walls. The pyramid can also be used by the surveyors for locating the targets using an EDM instrument.

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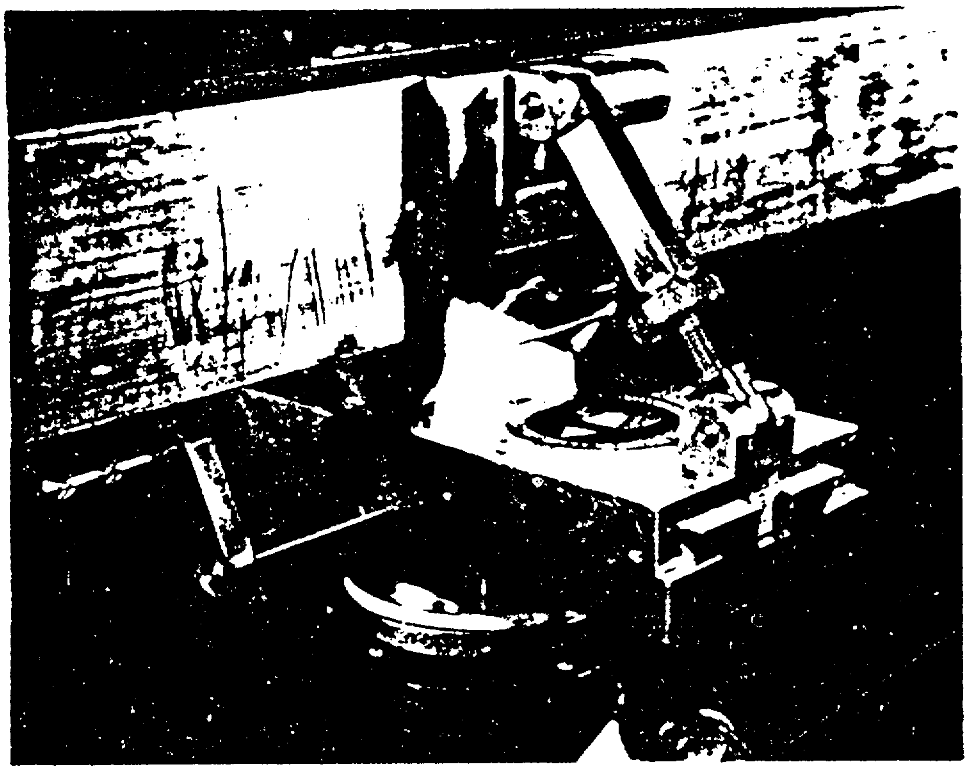

10. Pan Am - DNA Photo Neg. No. YM-428: Close up of the **Camera Rail Supports**. The supports allow the rail to be quickly aligned with the surveying laser. The supports allow the rail to be moved side-to-side and vertically, as well as tilted for easy levelling.

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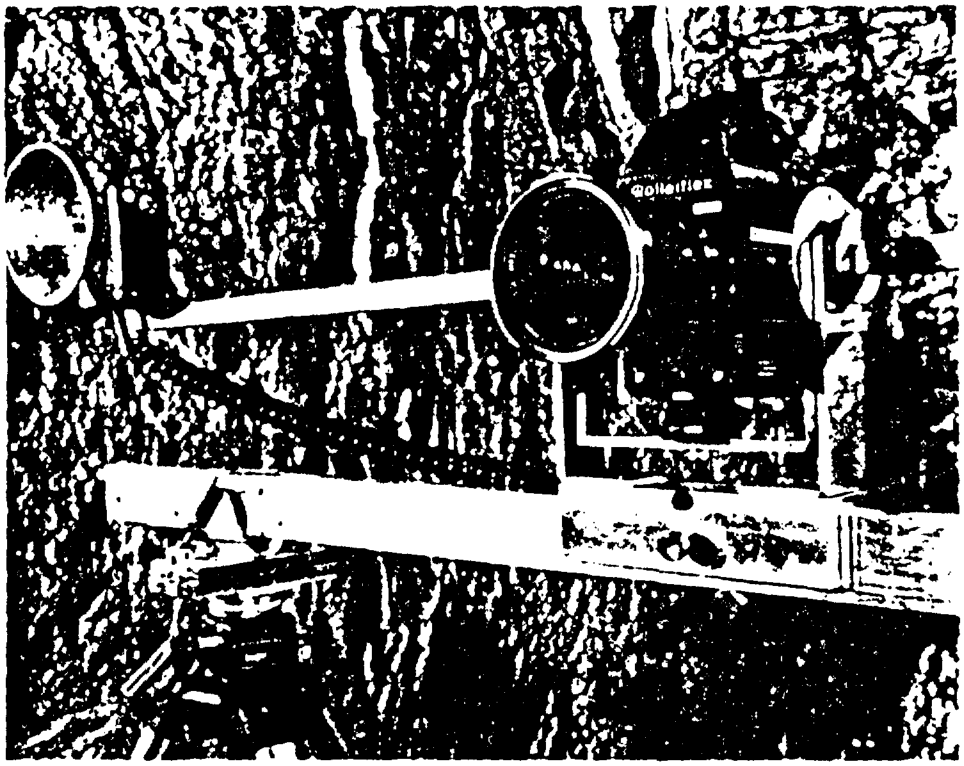

9. Pan Am - DNA Photo Neg. No. YM-427: Close up of the Photogrammetric Camera and flash strobe mounted on the pivoting camera mount. The mount is equipped with "click" stops which allow the camera to be oriented at pre-determined angles for optimum photo-overlap.

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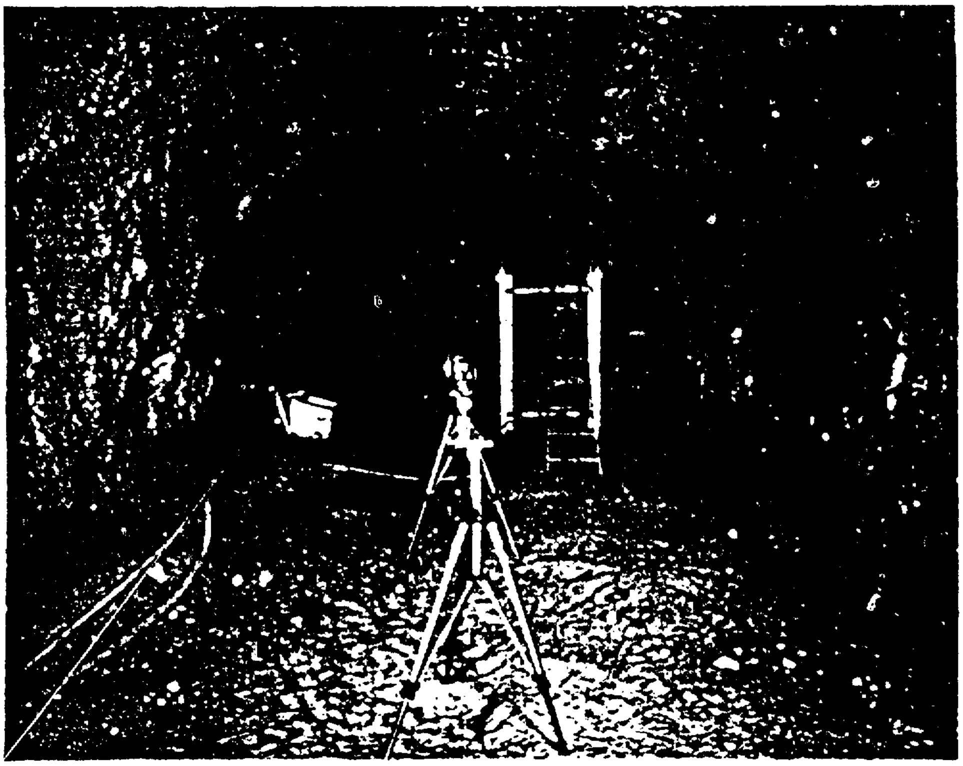

8. Pan Am - DNA Photo Neg. No. YM-426: View looking toward the heading of the Demonstration Drift during prototype testing for Underground Geologic Mapping. In the center of the drift are the tripods supporting the camera rail. A number of photogrammetry targets are visible on the walls and crown of the drift (small white cards with round black targets). The surveying laser used to align the camera rail is also visible just beneath the ladder in the center photo.

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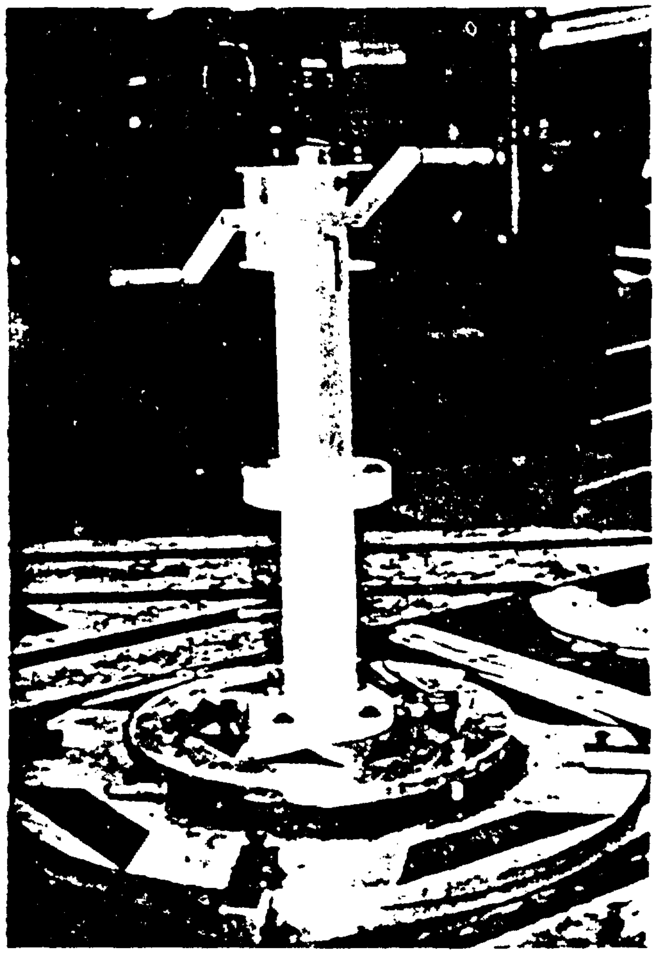

6. 1269412-PP-6: The **Telescoping Camera Mount (TCM)** -- The TCM uses the same pedestal as the radial arm strike rail assembly, and is used for taking stereo-photographs of the shaft walls. The mount is equipped with click stops every 60° to assure correct horizontal overlap. Vertical overlap is achieved by telescoping the mount to approximately 7 feet high. The mount also will accommodate the **Laser Azimuth Pointer** and a surveying total station.

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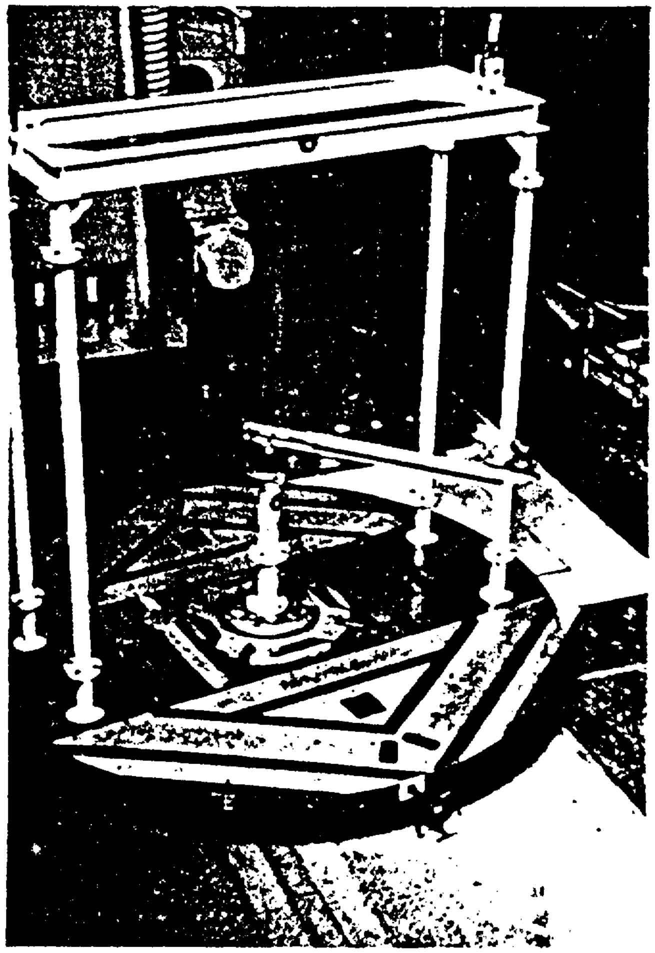
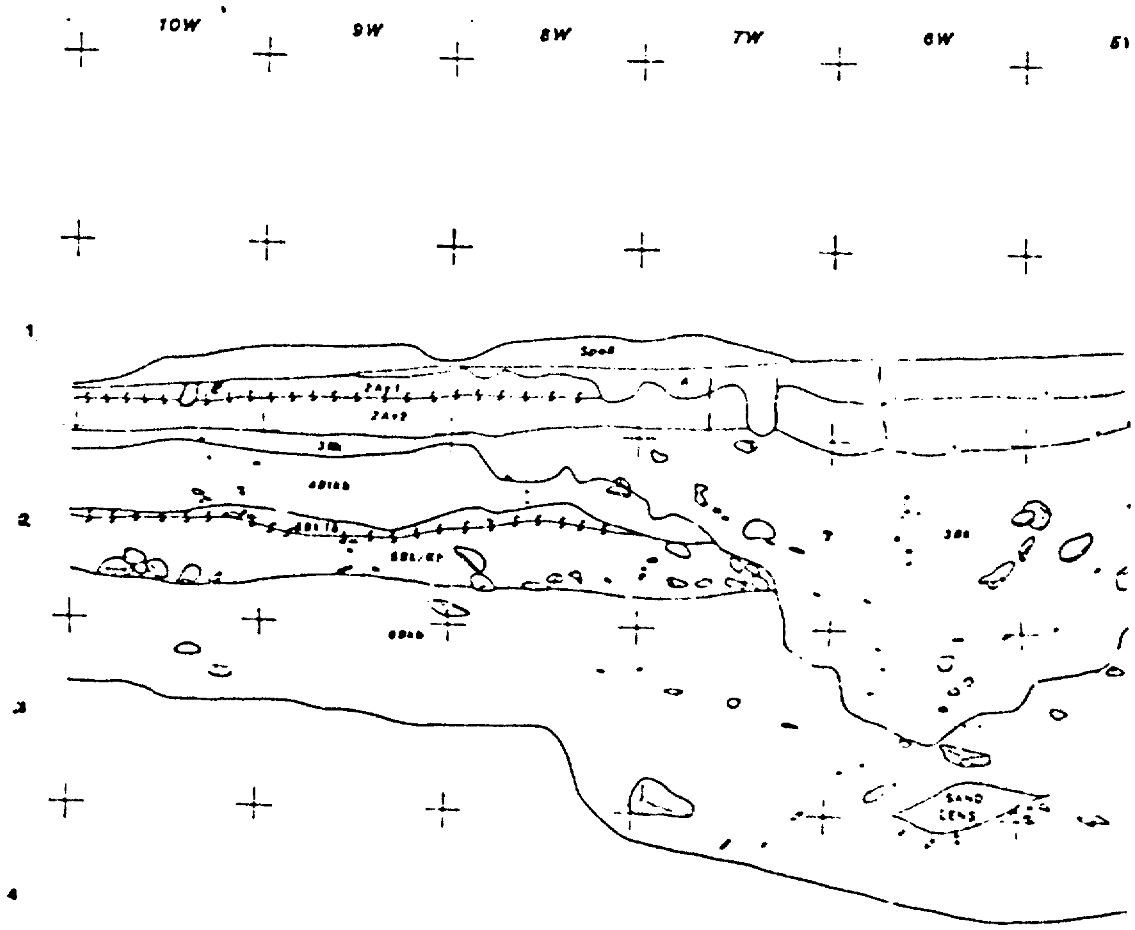


4. 126941Z-PP-4: The **Prototype Shaft Mapping Platform** -- The platform was constructed to simulate the lower working deck of a shaft sinking galloway. The prototype platform will be used to test the RASRA (radial arm strike rail assembly) and other prototype mapping equipment under simulated shaft conditions in the Fran Ridge test pits.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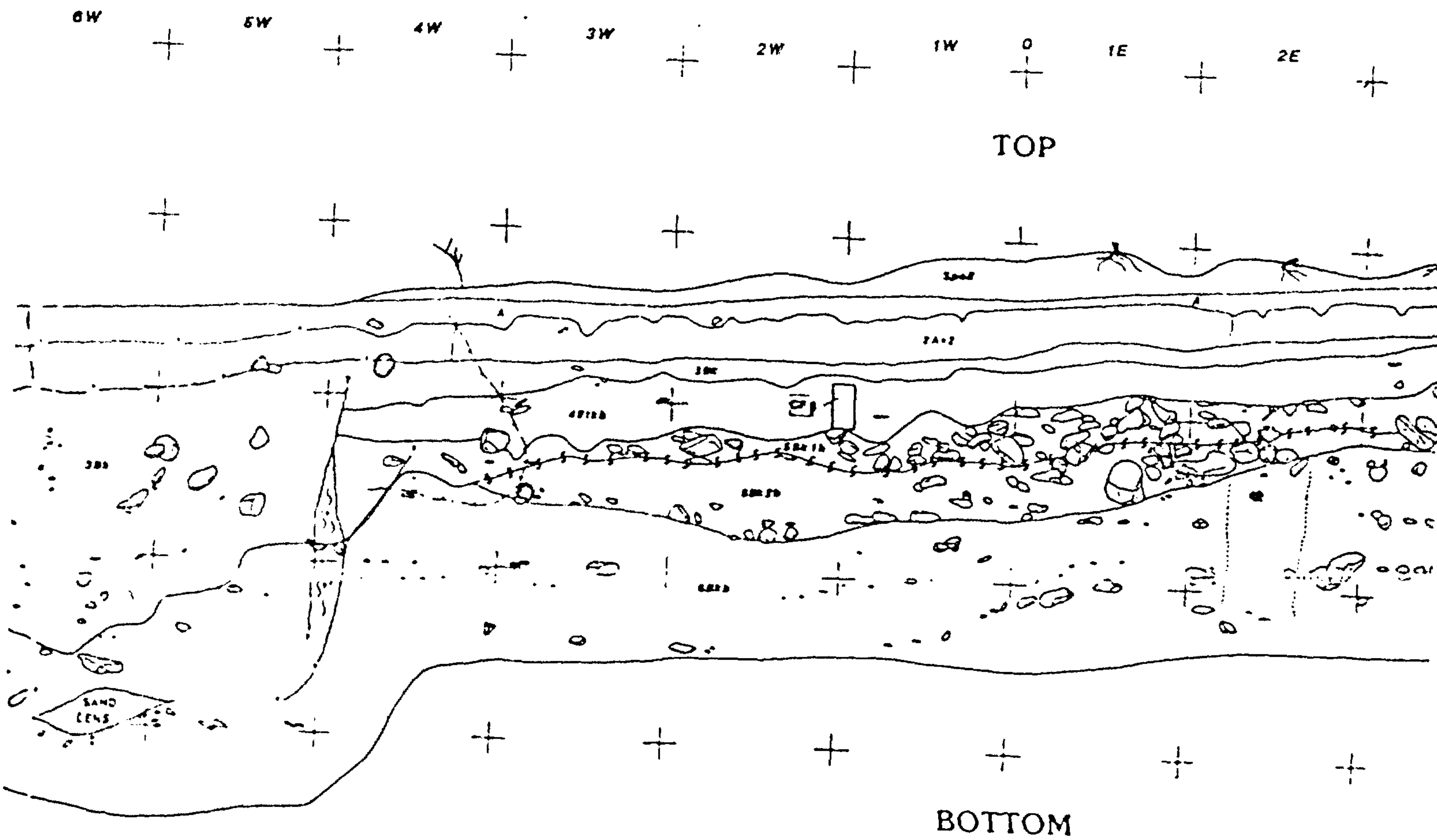

CONVENTIONAL TRENCH

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FOR TIME COMPARISON

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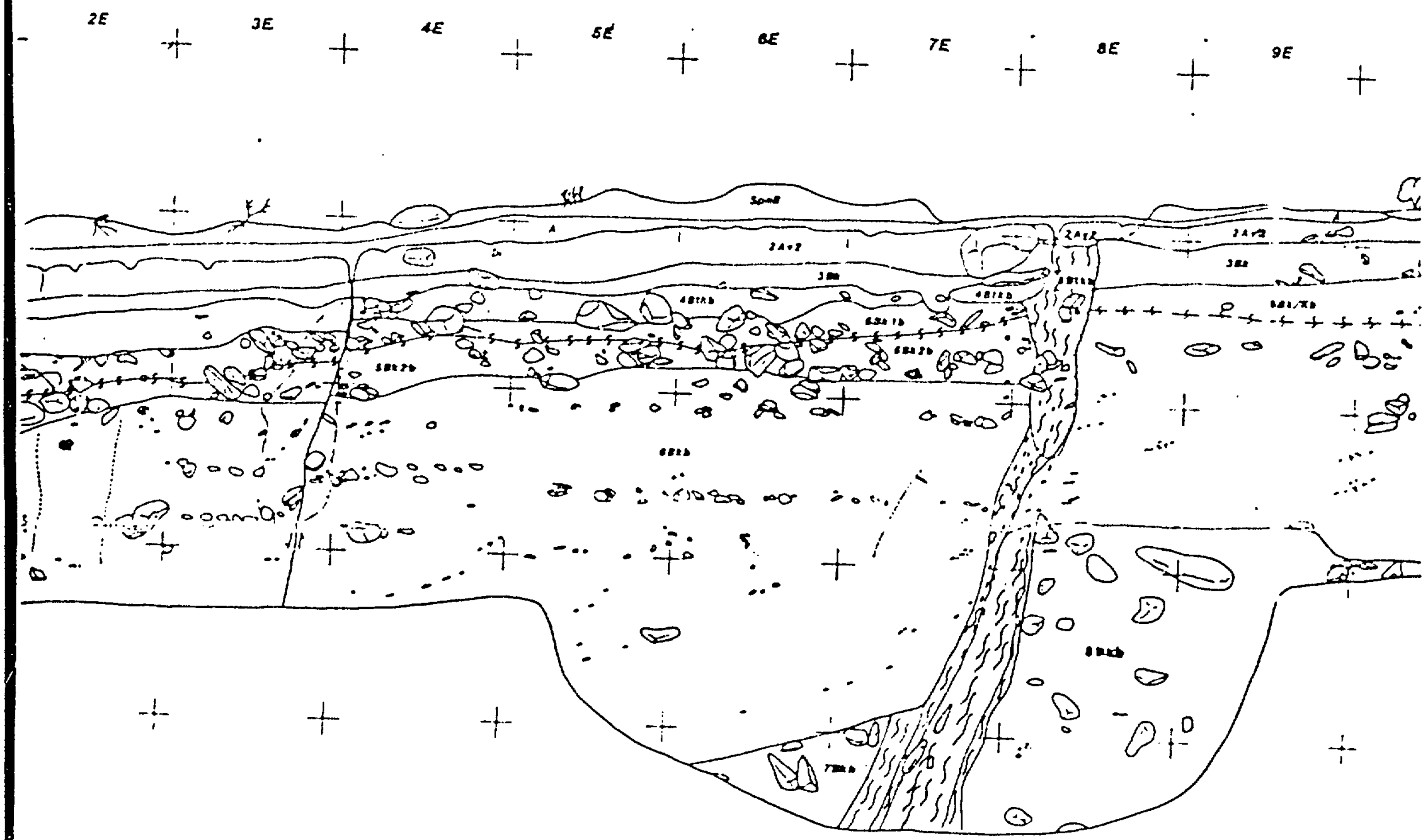

TRENCH MAP

Produce

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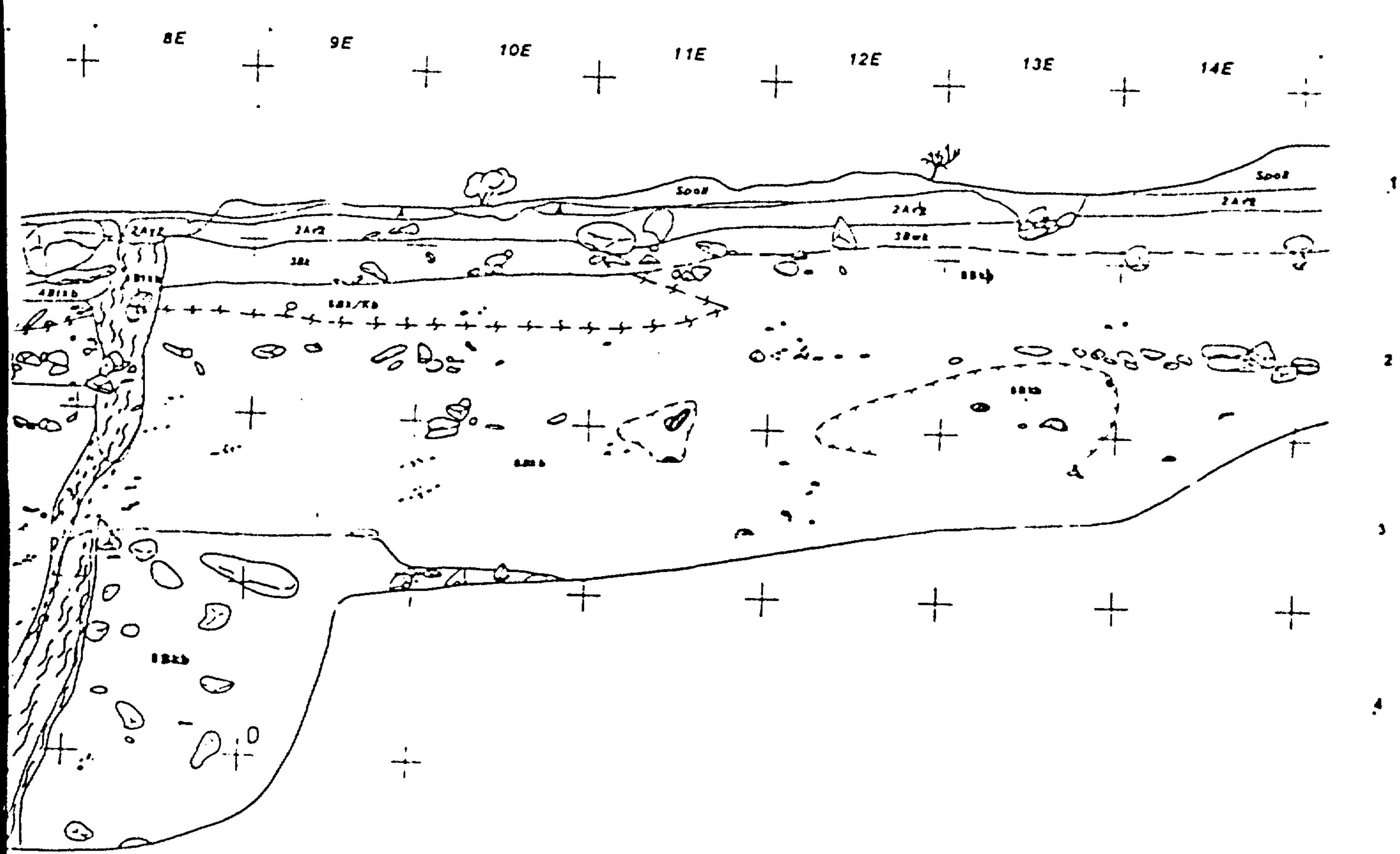
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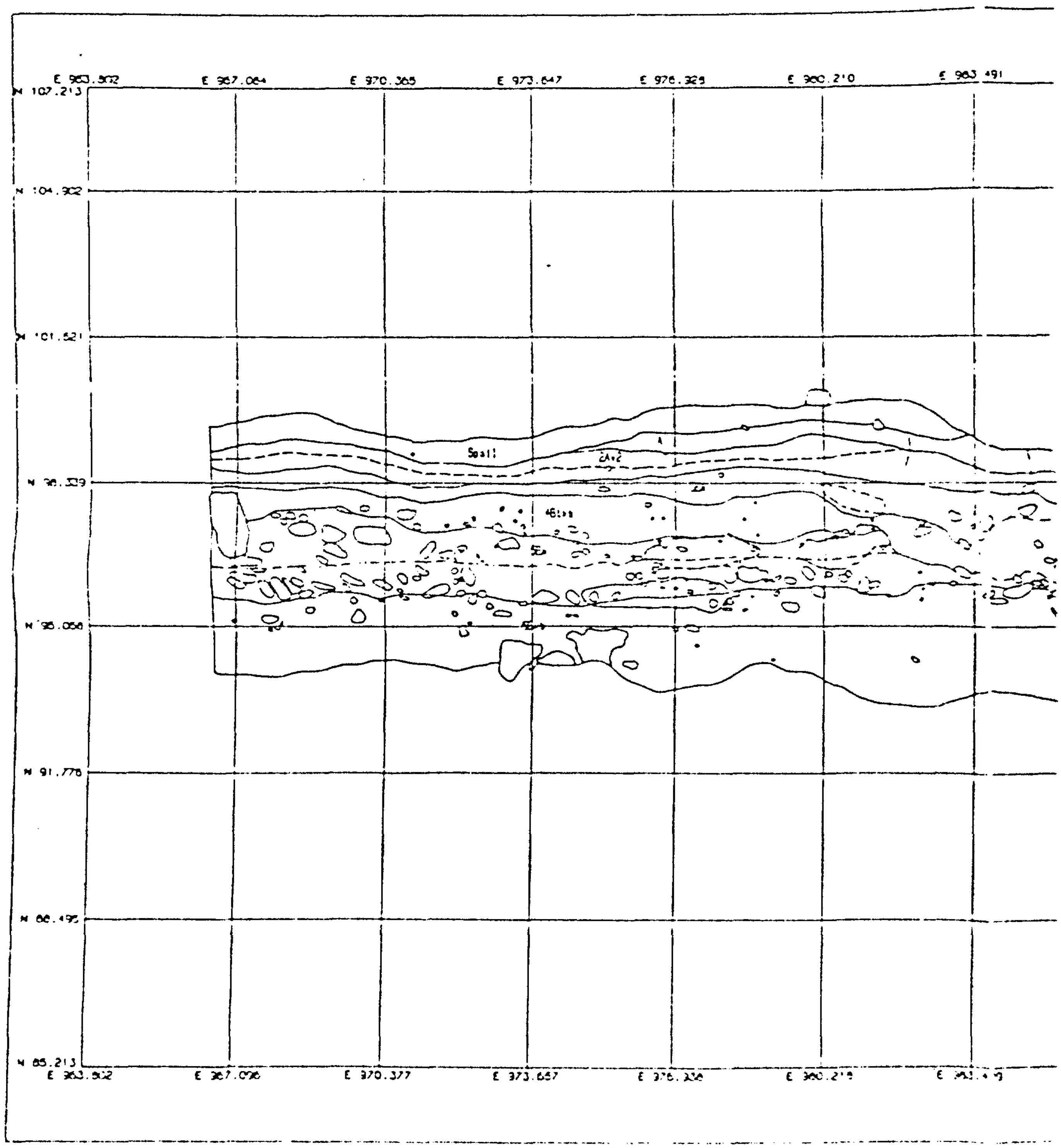

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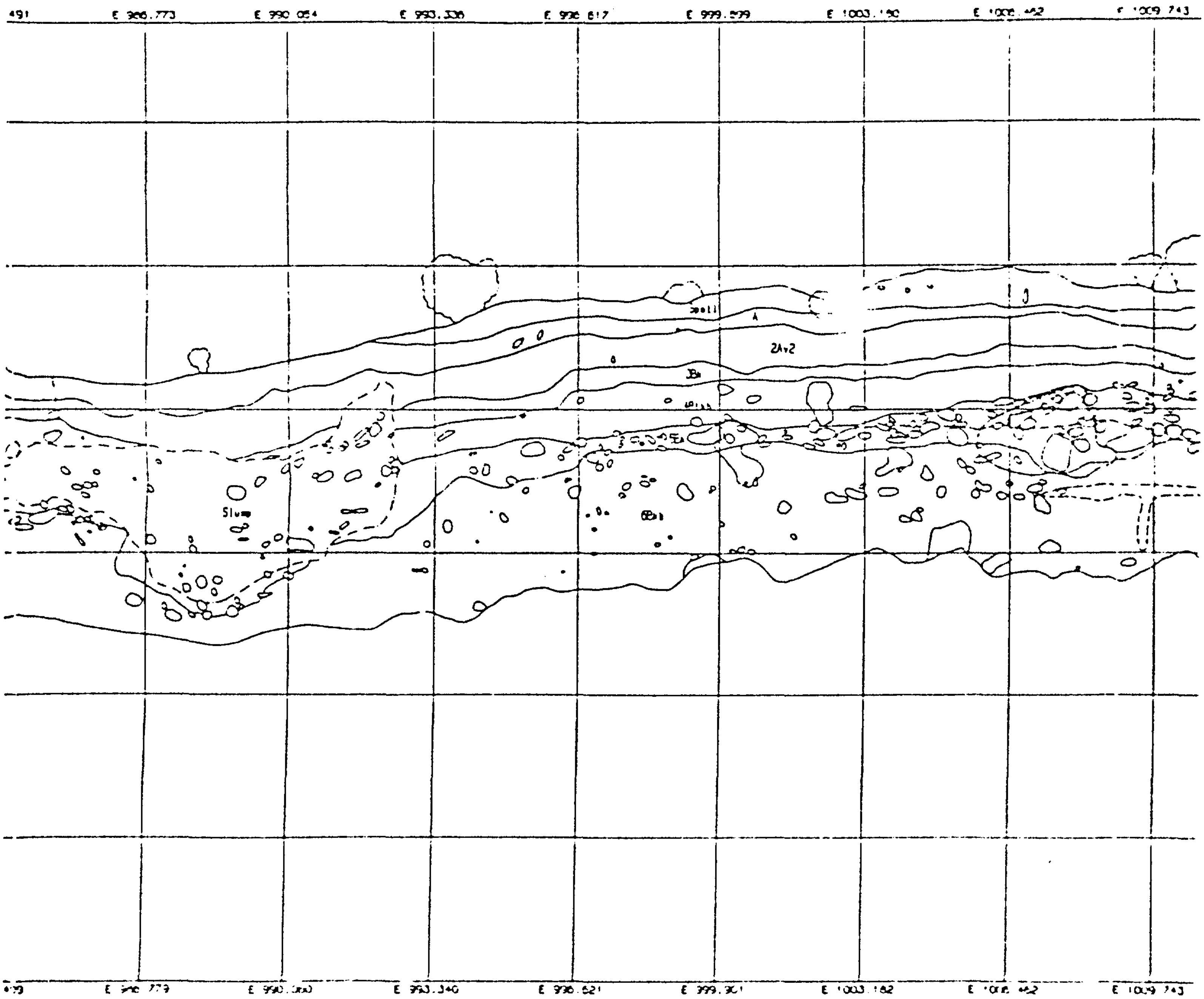

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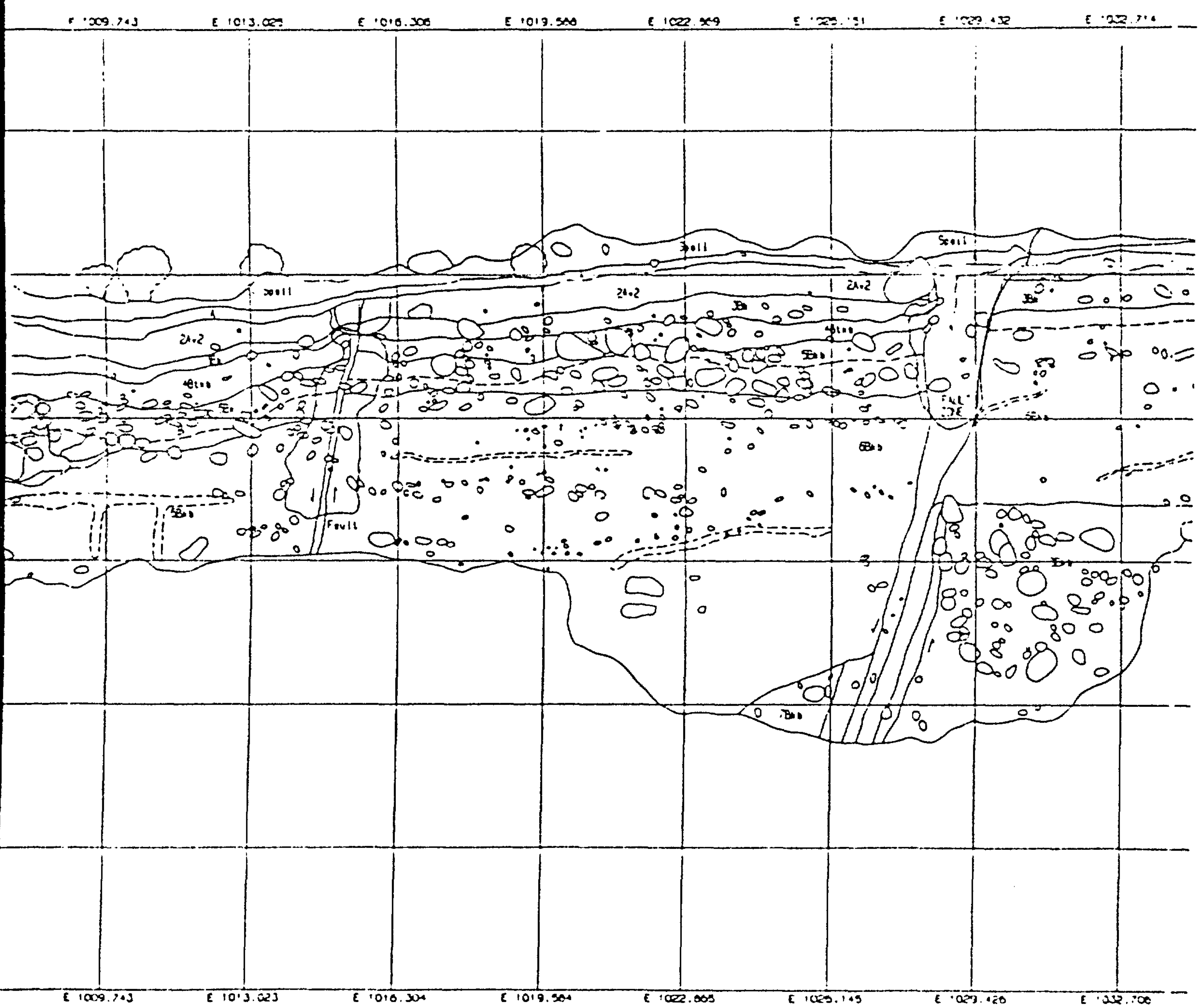

METRIC TRENCH MAP

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OMPARISON ONLY !

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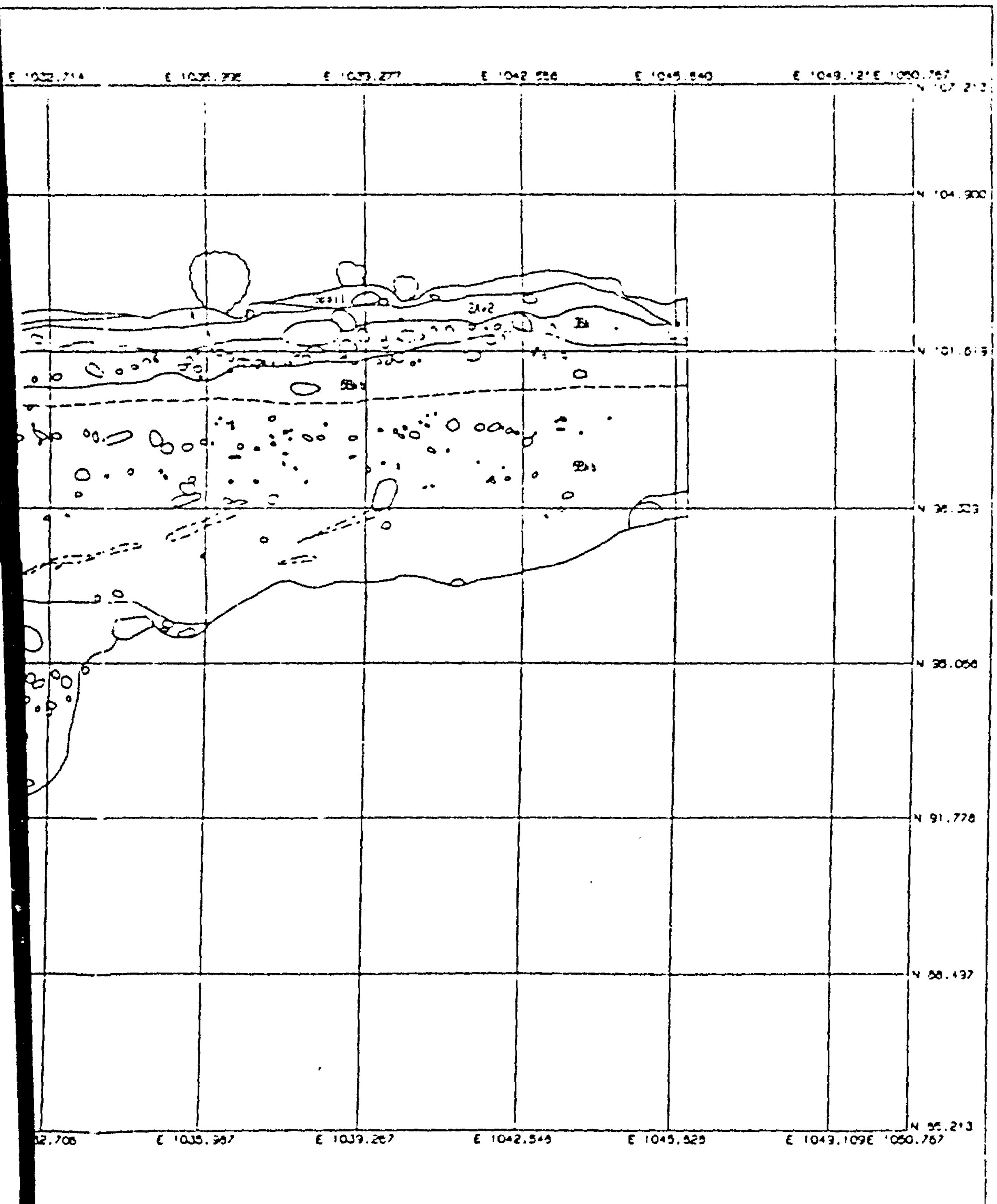
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NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS
UNDERGROUND GEOLOGIC MAPPING

In 1982, Congress passed the Nuclear Waste Policy Act, beginning the process of finding a suitable site for the United States' first long-term, high-level nuclear waste storage facility. Since then, the Department of Energy has supervised investigations to determine the suitability of siting a nuclear waste storage repository at or near the Nevada Test Site. Early investigations concentrated on evaluating granites and argillites for waste storage. Later investigations shifted to ash-flow tuffs at Yucca Mountain.

For the Nuclear Regulatory Commission to grant a license to construct a high-level nuclear waste repository, the Department of Energy must show that the proposed site will prevent waste radionuclides from entering the accessible environment for 10,000 years. To accomplish this task, the Department of Energy will construct an Exploratory Shaft Facility (ESF) to investigate the geologic and hydrologic conditions that exist at Yucca Mountain.

The ESF will have two 12-foot diameter shafts for access to the proposed repository horizon: one approximately 1430 feet deep; the second approximately 1120 feet. At the 1050-foot deep Main Test Level, roughly 9200 lineal feet of drifts will be excavated. A portion of the drifts will contain experiments to characterize the rock which would host the nuclear waste. Three long drifts will investigate three faults which could form the boundaries of the proposed repository. Experiments at the Main Test Level include geological, hydrological, chemical, container, and rock mechanics studies.

The Bureau of Reclamation is currently working jointly with the U.S. Geological Survey in characterizing the geologic and hydrologic setting of Yucca Mountain. The Bureau is applying its engineering and construction experience to the design of state-of-the-art instruments and test procedures to be used during ESF investigations. The Bureau will be involved in mapping ESF underground geologic features, as well as hydrologic experiments to describe ground-water movement into and through the host rock.

PHOTOGRAMMETRY

Mapping in the shafts and drifts will provide a detailed description of stratigraphic, lithologic, and structural features. Descriptions of fracture networks and intersections are enhanced by continuous observation because fracture spacing and attitude commonly vary over distances

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of tens to hundreds of meters. Both objectives will be met by a two-tiered approach to the mapping: (1) analysis of stereoscopic photographs (photogrammetric geologic mapping) and, (2) continuous detailed mapping along reference lines (detail line surveys).

Stereoscopic photographs will be taken of all exposed surfaces in the exploratory shafts and walls and crown of all drifts as mining progresses; floors and working faces will not be mapped unless anomalous geologic features are exposed. Geologic maps will include discontinuities such as faults, fractures, breccia zones, as well as lithology and stratigraphy. The maps will be prepared from stereoscopic photographs using close-range photogrammetry and direct observation.

Stereophotography and in-situ mapping of the shafts and drifts will be done between mining operations. Close-range photogrammetry will provide continuous data in the shafts and drifts. In the shafts, detailed in-situ measurements will be made of geologic features along detail line surveys approximately 2 m apart in ES-1, and approximately 15 m apart in ES-2. In the drifts, line surveys will be done continuously along one wall, or more as required at significant changes or special geologic features.

MAPPING

Geologic mapping requires a significant amount of time. The time will be minimized (from eight hours to two hours per round or 6-foot interval) by using photogrammetry. This two-hours-per-round time requirement will allow mapping up to three 6-foot rounds per shift, i.e. six hours to map three rounds or 18 feet.

The heart of photogrammetric mapping is the analytical plotter. The advent of the analytical plotter, a computerized stereographic plotter, made possible the photogrammetric geologic mapping of complexly shaped excavations at close range while calculating locations and structural attitudes (i.e. strikes and dips) simultaneously. All mapping and structural data are stored digitally allowing further analysis. Because of the extreme accuracy of an analytical plotter, the accuracy of the mapping is limited only by the accuracy of the control surveys. Geologic photogrammetric mapping is considerably more accurate and faster than conventional mapping, and applicable to inaccessible areas.

The analytical plotter being used for geologic mapping at the exploratory shaft is a Kern DSR-11 and dedicated MicroVAX II computer with associated peripheral equipment. Stereophotographs obtained in the excavations are mounted on plates that hold and locate several stereopairs. These

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stereopairs or models are then located spatially utilizing the surveyed locations of targets shown in the photos. The analytical plotter compensates for any camera lens aberration and can then locate any point shown in the model in three dimensions. Because several models are located on the mounting plates at once, when the edge of a model is reached while viewing, the plotter automatically drives to the next appropriate model to continue viewing adjacent areas. During geologic mapping, the geologist-operator follows geologic features such as fractures, faults, etc. with a marker (light pip projected into a 3-D field of view in 3-dimensions). This marker is movable in all three dimensions. As the marker follows the feature being mapped, the analytical plotter digitizes or records the location of the light pip at hundreds to thousands of points. These points are then stored in the computer for later plotting of fracture trace locations and for calculation of geologic structural data. The digitized locations are used to calculate strike and dip, curve fitting and statistical analysis.

The data obtained photogrammetrically is then combined with data obtained from in situ mapping. In-situ mapping consists of detailed mapping of every geologic feature such as lithology, fractures, etc. along a reference line. The location, attitude, and fracture characteristics such as aperture, filling materials, roughness, etc. are recorded. These data are then stored in a data file for specific and statistical analysis.

The data obtained photogrammetrically and in-situ are then made available to users as data files and as full periphery geologic maps and cross sections generated by the analytical plotter and as statistical plots such as histograms, stereoplots, etc.

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NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

Underground Geologic Mapping
Contractor Interface and Support

CONSTRUCTION IMPACTS

The major impact on shaft and drift construction is the amount of time the contractor must stand by while geologic mapping is accomplished. We reduced this time from eight hours (a complete shift) to two hours per round by using photogrammetry. (Note: Prototype testing in G-Tunnel indicates that two hours per round is a practical time estimate.) This two-hours-per-round time requirement will allow mapping up to three 6-foot rounds per shift, i.e. six hours to map three rounds.

Figure 1 depicts the advantages and disadvantages of geologic mapping during or between each phase of the excavation cycle. Mapping is possible between several phases of the excavation cycle as shown in Figure 1a. However, because of the reasons shown in Figure 1b, mapping during all but one interim period between excavation cycle phases is impractical. We rated each mapping window from the standpoints of the contractor and the USBR/USGS (no. 1 being the most preferred). Figure 1a shows close agreement between the preferences of the contractor and those of the mappers. The preferred window, between support and lining, is the most advantageous from both the geologists' and the contractors' standpoint.

Several scenarios have been studied to evaluate data collection and its relationship to construction costs and personnel needs. The most acceptable plan, as formulated through discussions with the Waste Management Projects Office and REECo, assumes that personnel will be available to map the shafts and drifts at any time during three shifts per day, seven days a week. This scheme allows maximum flexibility for the contractor. The number of active headings contributes significantly to the number of mapping staff. Whether 1, 2, or 3 six-foot rounds are mapped at a time does not impact the number of personnel required for mapping. When not actually underground mapping, these personnel will process data, maps, and samples. Mapping logistics also require time for equipment maintenance and calibration, preparation, and travel to and from the mapping sites.

Other mapping scenarios evaluated are for mapping during one or two shifts per day. These assume that contractor activity will be restricted with mapping done only on shifts covered by geologic mapping teams. Because mapping is practical only between the support and lining phases, the contractor is

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severely restricted. Even though the one- and two-shift scenarios show geologic mapping costs significantly less than for the planned three-shift-per-day scheme, overall project costs will be higher due to restrictions on the contractor and other experiments. If the contractor has placed support and a mapping team is not available, he must standby or do maintenance until a team is available. This standby time can exceed two complete shifts. Assuming the contractor loses an average of a shift per day, or accounts for this loss in his bid or schedule, then the cost and the time required to excavate the shaft and drifts increases accordingly. Also, total mapping costs increase because the number of staff required per year remains high due to the longer duration of maximum contractor effort. The increase in cost and time for construction more than offsets the cost of having mapping teams available three shifts per day.

CONTRACTOR INTERFACE

Mining Contractor

Since the shafts will probably be constructed by a subcontractor, the exact logistics of how equipment will be handled once excavation reaches the Main Test Level is not known. Therefore the term "mining contractor" may apply to either the shaft sinking contractor or the contractor excavating the drifts.

Summary of Requirements:

1. Provide transport for geologists, photographers, and surveyors to shaft bottom or drift heading.

2. Clean walls with air/water blowpipe.

3. Set up deck extensions and bucket well cover on galloway in shaft or set up portable platform in drifts.

4. Provide adequate lighting in the area to be mapped.

5. Move galloway as needed to allow mapping of multiple blast rounds.

6. Assist geologist with equipment and obtaining samples.

7. Transport photographer to surface after photography is complete (shaft mapping only).

8. Transport geology and survey crews to surface after mapping is complete (shaft mapping only).

9. Provide a platform for access to the drift crown (drift mapping only).

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Geologic mapping will employ close-range photogrammetry as part of the process of recording the geology as exposed on the excavation walls. This will require thorough cleaning of the shaft and drift walls prior to photography. While rock bolts are acceptable as ground support, the installation of chain-link fabric is not permissible until the walls have been photographed by the mapping crew. The mining contractor should ensure that all loose blocks and slabs have been barred or scaled prior to mapping. The walls will be cleaned with an air/water blowpipe to remove all dirt and accumulated debris from the rock surface. Although the cleaning of the walls will be a QA level III activity, cleaning is critical to the success of geologic mapping and the walls must be free of all dirt. Therefore, the geologist's acceptance of the wall cleaning will be QA level I. The geologist will require additional cleaning if any part of the area to be mapped is obscured by dirt and debris. Previous tests have indicated an application of 2 gallons per minute of water at 100 psi air pressure with a 2" blowpipe is an acceptable mixture for wall cleaning. Previous testing shows that of the 2 gallons per minute of water at 100 psi air pressure approximately 80-90% of the water used is converted to mist and removed by the ventilation system. The contractor(s) will be required to supply the blowpipe (constructed to our design) and the air/water systems to accomplish the cleaning. The contractor should demonstrate prior to excavation that the blowpipe functions are satisfactory subject to the approval of a representative of the geologic mapping group.

The contractor will clean the area to be mapped immediately before mapping begins. If necessary, the contractor will be required to rewash any areas the geologist feels are not adequately clean for mapping. After washing is completed, the contractor's representative (miner) should re-position the galloway (if necessary) at the round exposed, deploy the deck extensions, secure the bucket well cover, and help transport and install the mapping equipment if necessary. The miner should then assist with the assembly of the geology equipment and taking of hand samples as needed. The contractor will be required to supply a minimum of three 500-watt floodlamps to light the mapping area before mapping can begin. After each blast round is mapped, the contractor will move the galloway to the next blast round for photography and mapping. After all exposed blast rounds have been photographed, the contractor must provide transportation for the photographer to the surface. After geologists and surveyors have completed mapping the last round, the contractor must provide transportation for the crews back to the surface along with their samples and equipment.

The intention of the geologic mapping crew is to map just before concrete forms are set and concrete placed. In areas where the ground stands sufficiently, this should afford 20-30 feet per mapping cycle (2-3 rounds). If areas are encountered

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that can only stand for 6-10 feet with rock bolt support, mapping will be done as part of each round.

Mapping in the drifts will require contractor support similar to that necessary in the shafts. The contractor will be required to provide a miner or laborer to clean the walls with an air/water blowpipe. The contractor must provide some type of portable platform for the geologists and surveyors to access the crown of the drifts. We recommend some type of scissor platform because of the varying height of different drifts (up to 22 feet high). As with the shafts, photographs of the crown and walls must be taken before chain-link is installed. In the drifts, this will require that mapping generally be done one round at a time, unless the ground is stable with only rock bolt support.

Survey Contractor

Summary of Requirements:

1. Help set up and orient the camera pedestal in the shafts. Help set up and orient the camera rail the drifts.

2. Determine elevation for mapping deck (shaft only).

3. Establish an oriented laser beam for locating photogrammetry targets.

4. First-order survey any targets which cannot be located with the pyramid beam splitter.

5. Provide target coordinates and elevations to principal geologist on a weekly basis. These data must be supplied as a computer file and hard copy.

The contractor will provide survey control for both construction of the shafts and drifts and the geologic mapping. The primary survey requirement for underground geologic mapping is to provide three dimensional coordinates of photogrammetry control targets placed on the rock surface by geologists. The information from this survey will be used to develop maps from stereo-photographs. The accuracy of the surveying will be the limiting factor in the accuracy of the photogrammetric mapping. Therefore, the mapping will require that the surveyors locate photogrammetry targets within 2mm accuracy. The data should include: (1) target number, (2) north coordinate, (3) east coordinate, and (4) elevation.

Survey data will be transferred to the analytical plotter lab on a weekly basis. All raw survey data must be reduced for the days Sunday through Saturday and a printout of the data provided to the principal geologist at the site by 12:00 pm. each Sunday. Data must be transferred by modem to the data base in Denver. The principal geologist will hand carry the

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data hard copy to Denver where it will be used for comparison with the information transferred by modem over phone lines. A copy of the survey file will also be transferred by phone modem to the Denver Office of the Bureau of Reclamation on the same day. Please note this will require less than 24 hour turn-around time on survey data collected on Saturday.

The survey crews will be working in the excavation concurrently with the geologic mapping crew. In the shafts, upon arriving at the lower deck the survey crew will assist geologists in setting up and orienting the camera pedestal. Where possible, photogrammetry targets will be located on the excavation walls using a beam splitter developed for this project. The beam splitter will be used with a laser, deflecting the beam at right angles and splitting the beam into four beams at right angles to each other. Targets which cannot be located using the beam splitter will require conventional surveys to 2 mm accuracy to determine their coordinates and elevation. The surveyors must also determine the elevation of the galloway deck at each mapping level. The geologist will use the elevation information to determine the elevation of detailed line surveys performed by the mapping crew.

Mapping in the ESF drifts will require support similar to that in the shaft, except that many of the surveying techniques will differ due to the horizontal and less-crowded nature of the drifts. Drift mapping will require that the survey contractor establish a horizontal laser beam parallel to the centerline of the tunnel at a height of 4.6 feet on centerline. This will be used to align a camera rail and determine the location of the photogrammetry targets on the drift walls and crown. A beam splitter will be used to deflect the beam as described above and targets will be glued to the rock where those beams intersect the walls. Any target points which cannot be established by this method must be located by conventional survey methods.

Survey data from drift mapping must be delivered to the principal geologist on the same schedule and in the same format as data from the shafts.

Photographic Contractor

Summary of Requirements:

1. Handle and care for all photographic equipment including storage and cleaning.

2. Transport photographic equipment to shaft and drift headings.

3. Set up cameras and strobes and take stereo-photographs.

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4. Return to surface immediately after photography is completed with exposed film.

5. Develop film immediately.

6. Call heading and confirm successful film development or return to heading and re-shoot photos.

7. Make film diapositives and color prints for archival and working files.

7. Number and arrange photos for archival and working files.

7. Deliver required diapositives and prints to principal geologist on a weekly basis.

The photographic contractor will have the responsibility to stereo-photograph the exposed rock surfaces in the ESF, develop the film, and produce both archival prints and contact diapositives from the stereo-photos. The contractor must provide a photographer(s) to handle, operate, and maintain photographic equipment in the ESF.

Geologic mapping in the ESF will be accomplished by close-range photogrammetry. This system requires full photographic coverage of the excavations prior to the installation of chain-link fabric or permanent lining. The walls of the ESF will be thoroughly cleaned with an air/water blowpipe prior to photography.

The photographer will accompany the geologic mapping crew and surveyors down to the portions of the excavation to be mapped. The geologists and surveyors will glue a number of photogrammetry targets to the excavation walls and also mark the locations of samples to be collected. After targets are applied to the walls, the photographer will mount the photogrammetric camera and strobes on the telescoping camera pedestal in the center of the lower galloway deck. The photographer will then take two rounds of six photos each for each blast round. One of the rounds of photos will be taken at about a 7-foot height; the second at about a 3-foot height. The photographer will then remove the camera and strobes and allow the geologists and surveyors to complete the mapping of that blast round. After the mapping is complete, the galloway will be lowered to the next round and the mapping and photographing repeated. After all exposed blast rounds are photographed, the photographer will return the surface with the photographic equipment. The photographer or technician will then develop the film immediately to insure a suitable image has been obtained. Since the shafts will be lined as construction progresses, it is necessary that successful development of the film be confirmed before the geologic mapping crew leaves the bottom of the shaft. As soon as the development of the film has been confirmed, the photographer will call the geologist at the galloway and verify the film has been successfully processed. If an acceptable image has not been achieved, the photographer must return to the heading and re-shoot any photos which did not develop correctly. The photographer will then return to the surface, and repeat the development process until satisfactory results are achieved.

After initial development of the film, the contractor shall make two sets of contact diapositives and three sets of 8" by 8" color prints. The negatives, one set of diapositives, and one set of color prints shall be numbered and permanently archived at the NTS or other location as determined by DOE (Department of Energy). A numbering system for the negatives and photographs must be developed in concert with the geologic mapping crew prior to construction so that the photographs can be kept in an orderly fashion and easily referred to. The remaining set of diapositives and one set of color prints will be numbered and delivered to the principal geologist at the NTS. The photos from each week must be furnished to the mappers on Sunday by 12:00 pm. The geologist will hand carry the photographs to the analytical plotter laboratory in Denver on a weekly basis.

The contractor will be responsible for maintenance of all photographic equipment for photogrammetric mapping. This includes camera, strobe and/or lighting equipment, and film development. The contractor must maintain a lab or room at or near the ESF to insure rapid development and confirmation of stereo-photograph quality. The diapositives and color prints cam be developed at any location, as long as the sets of photos described above can be provided to the principal geologists on a weekly basis.

Operations for mapping in the drifts will be similar to those in the shaft. Photographs in the drift will be taken from a camera rail which will be set up and located by geologic mapping and survey crews. Stereo imagery will be produced by horizontal overlap rather than vertical overlap as in the shafts. The photographer will be able to take up to three rounds of photos at one session rather than having to wait for other mapping and surveying to be completed as in the shafts.

Since the drifts will remain unlined, the requirement to confirm development of the film can be relaxed. Most drifts will be covered with chain-link after mapping is completed however, and the chain link will have to be removed if any re-photographing is necessary. Photos from the drifts will also be delivered to the principal geologist on the same schedule as the shaft photos.

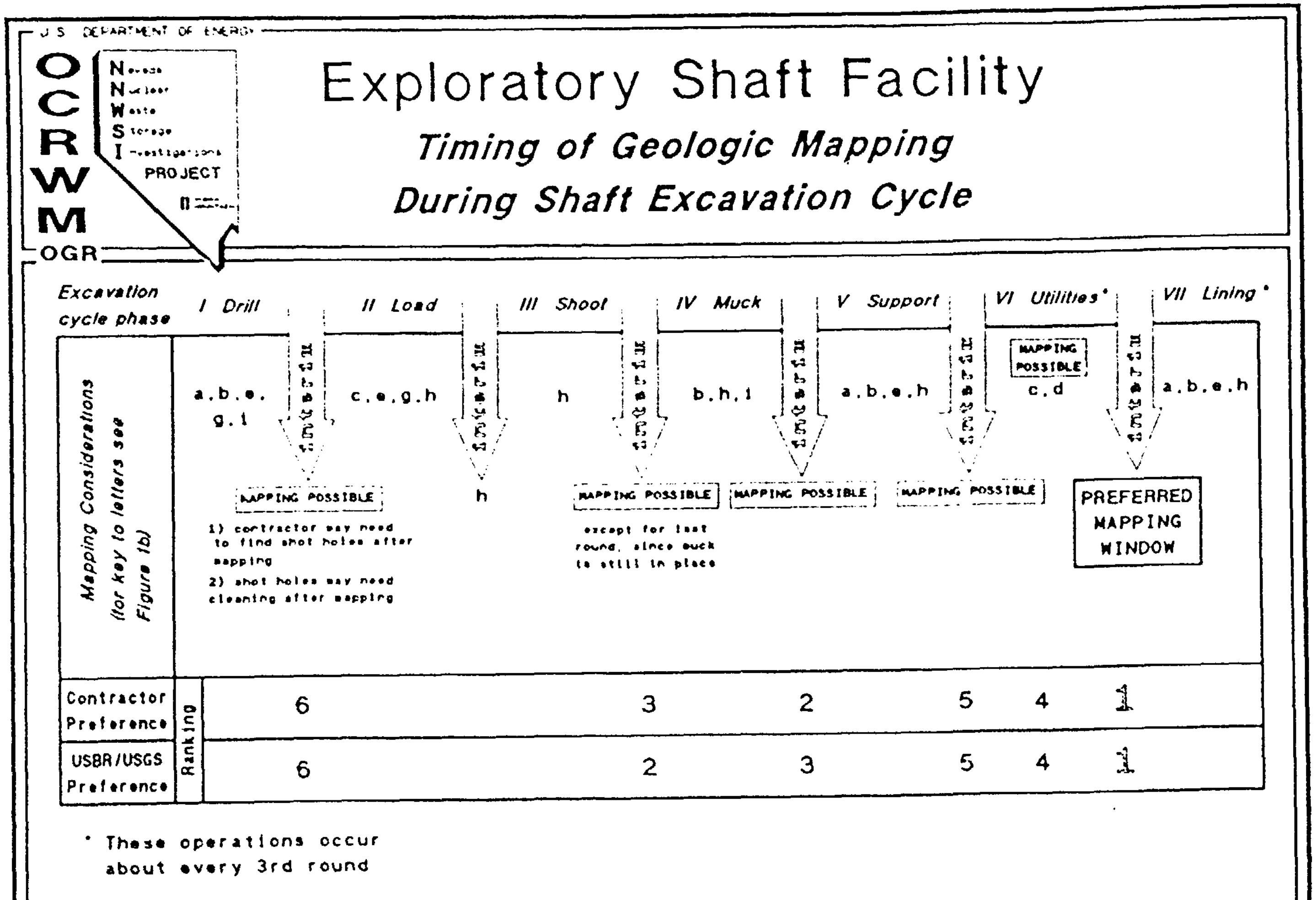

Figure - 1a

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OCRWM OGR — U.S. DEPARTMENT OF ENERGY — NNWSI PROJECT

Nevada Nuclear Waste Storage Investigations Project

CONSIDERATIONS for MAPPING IMPACTS on CONSTRUCTION

NNWSI, Exploratory Shaft Facility

a. Mapping always consists of washing and mapping
b. Must be able to move galloway (up and down) during mapping
c. Must have power for lighting
d. Must have water and air for washing
e. Must be able to see walls
f. Must be able to overlap photo with last mapped round
g. Limited exposure without support (no chain link until photographed)
h. General Safety
i. Bucket well will be covered during mapping

Figure - 1b


MAPPING

INFORMATION

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