AEC
RESEARCH
and
DEVELOPMENT
REPORT

BNWL-47

GEOPHYSICAL SEISMIC EVALUATION STUDY AT HANFORD

DECEMBER, 1964

BATTELLE-NORTHWEST
RICHLAND, WASHINGTON

PACIFIC NORTHWEST LABORATORY operated by BATTELLE MEMORIAL INSTITUTE

LEGAL NOTICE

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON
Operated By
BATTELLE MEMORIAL INSTITUTE
For The
U. S. ATOMIC ENERGY COMMISSION Under Contract No. AT(45-1)-1830

PRINTED BY/FOR THE U. S. ATOMIC ENERGY COMMISSION

AEC-RLOO RICHLAND, WASH.

BNWL-47

UC-51, Geology and Mineralogy
(TID-4500, 40th Ed.)

GEOPHYSICAL SEISMIC EVALUATION STUDY AT HANFORD

By

R. E. Brown
J. R. Raymond

Chemistry
Chemical Effluents Technology

December, 1964

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in USA. Price $3.00. Available from the
Clearinghouse for Federal Scientific and Technical Information,
National Bureau of Standards,
U. S. Department of Commerce,
Springfield, Virginia

TABLE OF CONTENTS

INTRODUCTION 1

SUMMARY AND CONCLUSIONS 3

THE FIELD PROGRAM 5

- Seismic Problems Experienced 8
- Field Results 10

EVALUATION OF SURVEY RESULTS 12

RECOMMENDATIONS FOR FUTURE WORK 19

REFERENCES 21

APPENDIX A - PERFORMANCE OF ROTARY DRILLS 23

APPENDIX B - THE SEISMIC GEOPHYSICAL METHOD 27

APPENDIX C - SEISMIC EQUIPMENT, METHODS, AND TECHNIQUES 37

GEOPHYSICAL SEISMIC EVALUATION STUDY AT HANFORD

INTRODUCTION

In June, 1963, a geophysical seismic research study was conducted at the Hanford Works of the Atomic Energy Commission. Its basic purpose was to determine the practicability of this exploratory method to accurately detect relatively shallow subsurface features. Normally, seismic exploration, because of its speed and adaptability, precedes and guides more detailed exploration, including drilling. At the Hanford Works the seismic program followed a long-term drilling program in which more than 700 wells were drilled, totalling more than 140,000 ft. Consequently, a comprehensive and detailed geological picture has developed that differs significantly from previous concepts.(1-4)

Hanford's experience with radioactive waste disposal to the ground has repeatedly demonstrated the great importance of detailed geological and hydrological information in predicting the path of radioisotopes and in explaining and understanding their observed movement. Because surface exposures of formations of interest at Hanford are almost completely lacking, we have placed great reliance upon subsurface exploration. For years cable-tool drilled wells have supplied most of the information. Degrees of uncertainty of the data from the wells are:

1. Samples obtained are only a very minute part of the geologic units.
2. Even drive-barrel or core samples are disturbed and disoriented; therefore, the samples are not assuredly representative of the formations in place.
3. Wells so drilled must be cased to basalt and the in-place physical properties of the formations encountered cannot later be determined or measured except through the heavy steel casing.
4. Wells provide data along a vertical line, whereas most of the geological features extend long distances laterally. A single new well may provide data that modifies previous concepts due to the irregularity of the buried features. A well, of course, provides data only at a point on a surface.

The seismic work was conducted to serve the following purposes: (1) to determine the precision, detail, and kinds of data that can be obtained with seismic field techniques and data processing methods; (2) to trace significant strata laterally from a well or between two existing wells to help confirm or refute recently developed well data correlations or concepts; and (3) to determine the general applicability, cost, and speed of seismic methods for possible production surveys at Hanford or other sites.

Earlier geophysical seismic work was done at Hanford by the Corps of Engineers in the 1940's, the Division of Industrial Research of Washington State University in 1959, J. R. Raymond in 1959,(5) and Electro-Tech representatives in 1959. These studies determined that at some sites with optimum conditions the Ringold Formation surface, the basalt surface, and the ground water table could be detected by seismic means.

Geophysical Service, Inc. of Dallas, Texas, a subsidiary of Texas Instruments, Inc. was selected to perform the latest research study under Contract SA-269. A significant factor in the selection of G. S. I. was their use of advanced computer data processing methods. These methods materially reduce field time by permitting thorough interpretation of data and modification of methods as the work proceeds. Seven geological features were chosen for seismic detection and delineation:

1. The surface of the Columbia River basalt series
2. The surface of the Ringold Formation
3. Interbeds within the Columbia River basalt series
4. Beds within the Ringold Formation and the late Pleistocene to Recent glaciofluvial sediments
5. The ground water table
6. Evidence of faults within the basalt series
7. The base of the basalt series

These 7 features were divisible into two main groups: features that require penetration to the basalt surface and below the basalt surface.

The geological features of interest lie below the depths of normal interest in engineering work (less than about 100 ft) but above depths of interest in petroleum exploration (greater than about 1000 ft). Thus equipment and techniques, capable of both kinds of work, were needed to obtain the desirable detail and precision.

Field work began May 31, 1963 and ended July 2, 1963. Evaluation and interpretation of results were completed and the contractor's report submitted in October, 1963.(6) A preliminary appraisal of the G. S. I. report was concluded in December, 1963.(7)

SUMMARY AND CONCLUSIONS

In June, 1963, a geophysical research program was conducted at Hanford to determine the feasibility and desirability of using seismic methods in geohydrologic studies. Detection and delineation were desired of seven different geological features that in some sites affect the movement of liquid radioactive wastes discharged to the ground.

The basalt surface was readily detected along two of the three lines by refraction methods, and by reflection methods where it lay more than 600 ft deep. The variance in depth as determined by the two methods was less than 5 ft in 700 ft where data were good. Basalt was not detected along the third line in the time available and with the methods used along Lines 1 and 2. Differences in basalt velocities at various sites, together with other data, indicate that individual basalt flows can sometimes be differentiated by seismic methods.

The surface of the Ringold Formation was readily detected and traced, and data not otherwise obtainable were procured. Significant local revision in the configuration of the surface of the Ringold Formation resulted. Interbeds within the basalt series could not be used because of the complex layering. A low velocity bed along one line at the base of the Ringold Formation was identified by up-hole velocity surveys. Data from the wells, together with the seismic data on the basalt surface, helped confirm passage of that sedimentary bed beneath the topmost basalt flow and helped identify it as part of the Ellensburg Formation.

Individual beds within the Ringold Formation and the late Pleistocene to Recent glaciofluvial sediments were generally not distinguishable because most of them are thin and discontinuous, and together they act as a multiple generating complex. The ground water table was not detected along the lines tested. It generally lay too close to the Ringold Formation-glaciofluvial sediments contact and did not generate a great enough velocity contrast from the unsaturated Ringold Formation sediments to be distinguishable. The inability to obtain identifiable waves from horizons below the basalt surface precluded determination of the presence of faults or the base of the basalt series in the time available.

Rotary drilling methods exceeded expectations. They permitted in-well logging methods and produced information not obtainable from cable-tool methods.

Results obtained reinforced information received from wells drilled by cable-tool methods and validated concepts from cable-tool well data. By extending the information laterally, the seismic program provided line data where only point data had been available. The reliability and significance of the information and concepts derived from it thus were greatly increased. The importance of seismic methods as an adjunct to other exploration methods used at Hanford was proven.

Refraction methods proved the most usable and least expensive seismic techniques for Hanford studies and also minimized drilling needs. Rotary method drilling and in-hole logging provided adequate control on the geology at tie points. The use of fertilizer-grade ammonium nitrate primed with diesel oil was fully adequate and cheaper than other explosives. Surface detonation was completely satisfactory and minimized the drilling of shot holes.

The seismic evaluation study was successful in accomplishment of stated aims.

THE FIELD PROGRAM

Figure 1 shows the locations of the Geophysical Service, Inc. and the earlier Washington State University seismic test sites. Each GSI site selected was characterized by different conditions, combinations of conditions, or involved a different problem as noted in Table I. All lines also lay in areas where existing geological information from the wells drilled by cable-tool methods had proved inadequate.

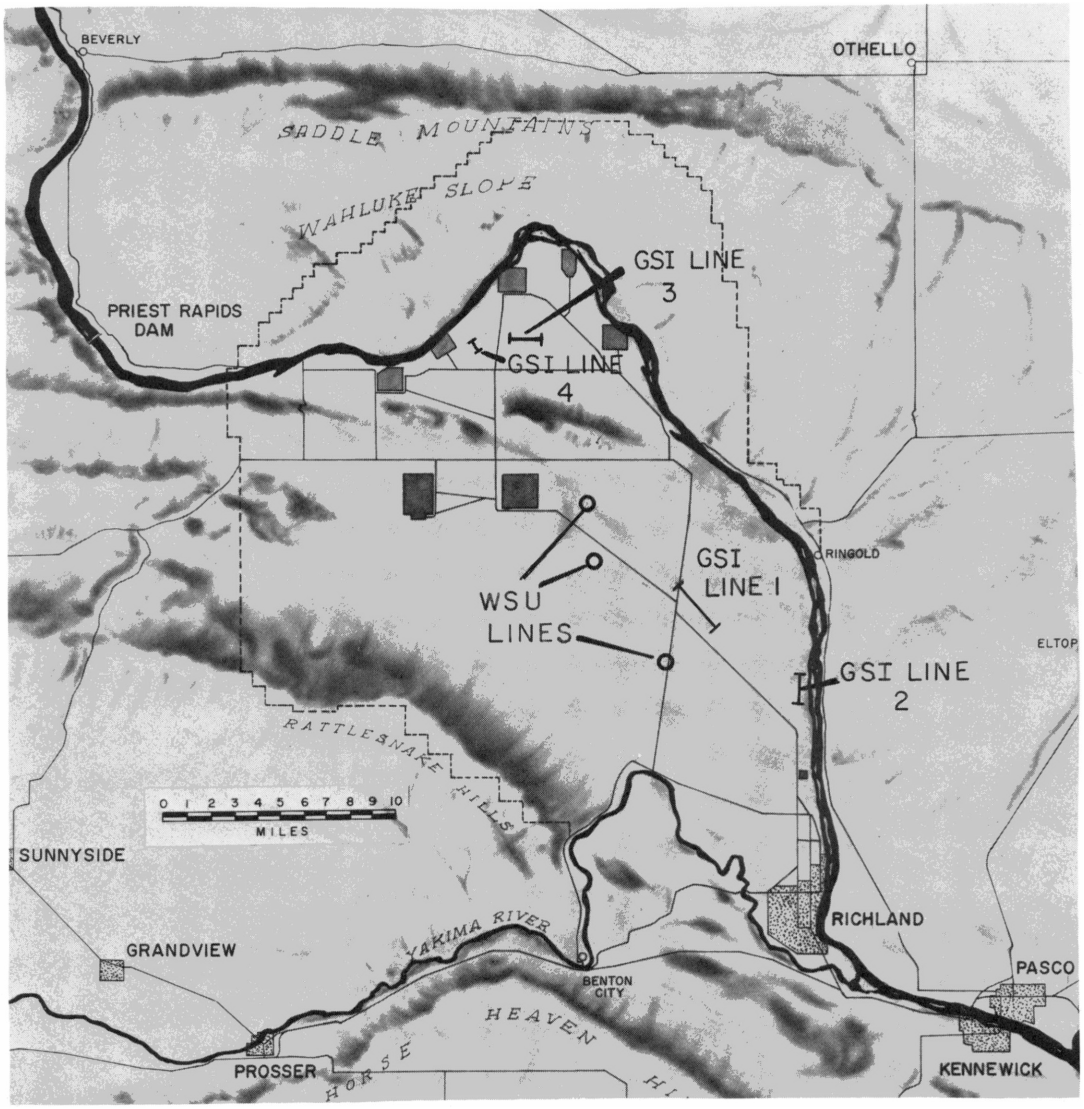

FIGURE 1

Index Map Showing the Location of the Geophysical Service, Inc. and Washington State University Seismic Lines

TABLE I

SELECTION OF SITES FOR SEISMIC EXPLORATION

Line	Purpose-To Determine	Geological Characteristics: Glaciofluvial Sediments	Geological Characteristics: Ringold Formation	Geological Characteristics: Basalt
1.	Depth to Ringold Formation and basalt; depth to water table. Profile Ringold Formation surface and basalt surface.	Dominantly sand and silt with only local gravel.	Sand, silt, clay and gravel, generally in well-defined beds. Contact with glaciofluvial sediments poorly defined.	Basalt surface about 700 ft deep; center of basalt basin poorly defined.
2.	Depth to basalt, Ringold Formation and water table. Detect interbeds in basalt series. Profile Ringold Formation surface and basalt.	Coarse cobble gravel to boulders, unconsolidated.	Gravel and boulders, locally cemented. Ringold Formation incised by old river channels.	Basalt surface about 200 ft deep. Numerous interbeds in series.
3.	Depth to basalt and the Ringold Formation; identify beds within Ringold Formation and the glaciofluvial sediments.	Gravel.	Silt, sand, gravel, and clay in complex series of beds. Formation incised by old river channels.	Basalt surface about 500 ft deep.
4.	Special purpose-measure ground motion amplitude and frequencies with varying size of explosive charge.	Same as Line 1.	Same as Line 3.	Same as Line 3.

Figure 2 is a columnar section of the geology in the Pasco Basin. The area is underlain by the basaltic lavas and related sedimentary interbeds of the Columbia River basalt series to unknown depths. They extend to depths greater than 10,000 ft, as indicated by the Rattlesnake No. 1 well of the Standard Oil Company of California, and probably to 14,000 ft or more. Above the basalt series are the gravels, sands, silts, and clays of the Ringold Formation. They are largely conformable to the basalts and gradational from the various sedimentary interbeds of the Ellensburg Formation. That formation is truncated by an unconformity, identified by a caliche layer, and locally overlain by silts and clays correlated with the Palouse eolian soil.(4) The Palouse soil is in turn truncated by another unconformity. The whole sequence is buried under Late Pleistocene to Recent glaciofluvial sands, silts, and gravels.

Lines 1 and 2 were pre-drilled for geological "tie holes", for uphole velocity surveys and for reflection shooting. A Mayhew 1000, truck-mounted, combination air-water rotary drill was used. Three wells on or near the two lines were drilled to basalt adjacent to existing cable-tool drilled wells as a means of guaranteeing maximum geological information at starting points. The rotary-drilled wells are identified by an "A" suffix

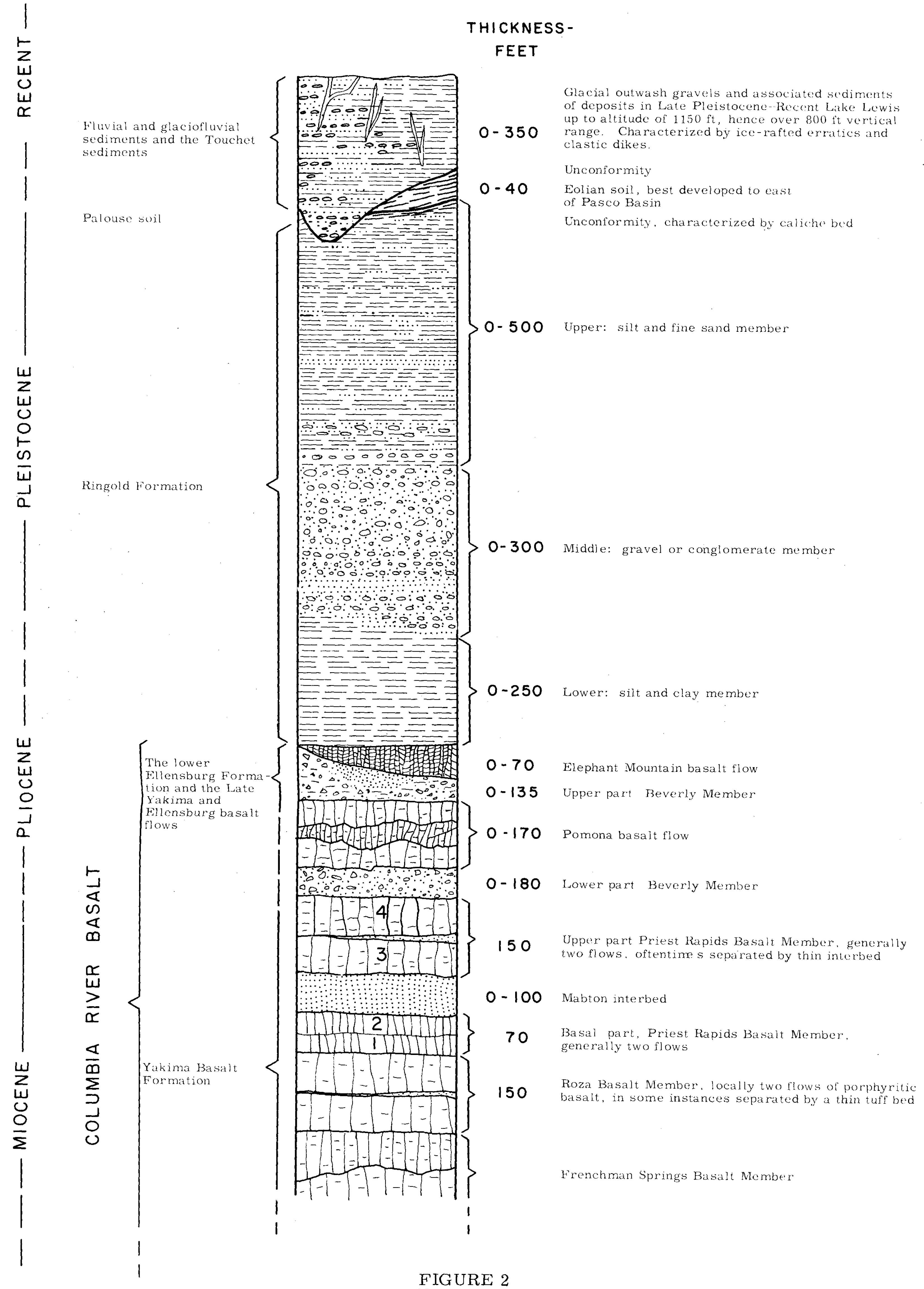

FIGURE 2

Geologic Columnar Section
Pasco Basin Area

following the well number to distinguish them from the adjacent cable-tool drilled wells. The rotary drilling provided an unusual opportunity to compare cable-tool and rotary drill performance (Appendix A) and the quality of the geological data obtainable. The rotary-drilled wells and the deep reflection shot holes were logged by electrical-resistivity, gamma ray and self-potential equipment prior to shooting.

Most refraction shots were detonated at the ground surface to minimize drilling. Shallow drilled holes gave no visible improvement in record quality over surface shots in dug holes. DuPont's Nitramon was the blasting agent normally used although in later work fertilizer-grade ammonium nitrate, liberally primed with diesel oil and detonated with TNT boosters, proved just as effective and appreciably cheaper. On Line 1, where the depth to basalt was great enough for reflection shooting to be successful, two shots per hole were fired at depths of 145 and 125 ft in that order. Five pounds of Nitramon were normally used. On Line 4, charge-size studies were made preparatory to a 3650 lb Nitramon quarry blast as a means of predicting the probable ground motion from the planned large blast.(8) Blasts of 100, 500, and 1000 lb of fertilizer-grade ammonium nitrate primed with diesel oil were fired at shallow depths in the weathering zone, but on top of basalt.

Figure 3 shows the near-surface detonation of a 100 lb Nitramon charge.

Seismic Problems Experienced

Numerous problems appeared in the refraction shooting as anticipated. The weathering zone (the late Pleistocene to Recent glaciofluvial and fluvial sands and gravels) contains many individual layers which are inconsistent in thickness and lateral extent and act as a multiple seismic generating complex. Secondary arrivals of waves were used to substantiate velocities observed from the basalt first arrival waves. Many waves generated in the near-surface materials obscured the record and required considerable interpretation. Time-distance plots show that these layers act as refractors but are so thin that mapping them by seismic means is

FIGURE 3

Near-Surface Detonation of 100 lb Nitramon Charge

operationally impossible. On Line 3, the presence of many thin layers of sediments with wide ranges of velocities resulted in uninterpretable first-wave arrivals. Time did not permit resolution of the problem which was not solved with techniques used on Lines 1 and 2.

Severe energy attenuation with distance proved to be characteristic, particularly in the glaciofluvial and fluvial sediments, and required the use of large charges of explosives. Smaller charges were used at greater depths, but high drilling costs nullified the savings from the smaller charges. The great energy attenuation with distance advantageously minimized the ground motion at critical sites during the 3650 and 21,000-lb ammonium nitrate quarry blasts reported by Jaske, for which the Line 4 charge-size studies were preliminary.

Near-surface reverberatory energy obscured primary reflections from the basalt and made individual trace static corrections impossible. Some of the problems were felt to be due to the scattering of reflected energy from highs in the basalt reflector and to changes in the basalt itself.

Field Results

Basalt velocities ranged from 14,700 to 27,000 ft/sec and averaged 16,400 ft/sec along Line 1. They ranged from 14,000 to 20,000 ft/sec along Line 2 with an average velocity of 16,300 ft/sec. The significance of these velocity differences and ranges is not fully understood. They may indicate areal variations in jointing or degree of alteration within a flow, as suggested by the indicated scattering of reflected energy from the basalt. Studies of data from wells(9) indicate that the topmost basalt flow beneath Line 2 is not present beneath Line 1, hence it pinches out westward about half-way between the two lines. Accordingly, different basalt flows lie at the top of the basalt series beneath the two lines. The indicated greater irregularity of the basalt surface beneath Line 2 than beneath Line 1 also suggests different flows. That difference may be due to initial irregularities near the end or edge of a basalt flow as it cooled, locally highly altered and jointed basalt there and/or subsequent irregular erosion of the basalt flow by the Columbia River. The occasional difficulty of drillers identifying the precise depth at which they encountered basalt near Line 2 corroborates the conclusion that the basalt is probably highly weathered and altered and consequently irregularly eroded.

Uphole velocity surveys in well 699-S6-E14A, identified a bed with a velocity of only 6600 ft/sec directly above basalt and at the base of the Ringold Formation sedimentary section. That low velocity member is a bed of silt and clay about 40 ft thick. Electrical resistivity, self-potential and radioactivity logs show that a bed of very similar characteristics lies directly above basalt in well 699-S11-E12A. Undoubtedly it is the same bed. The position of the bed in other wells, notably 699-15-15 and 15-15A, is less evident. However, the suggested pinching out of the basalt flow between Lines 1 and 2, and the emergence of the intervening interbed to a position atop the basalt series, indicates that the low velocity bed is the one bottoming about 70 ft above basalt in wells 699-15-15 and 15-15A. The self-potential, electrical resistivity and radioactivity logs show that a bed of silt and clay above that depth has physical characteristics similar to the bed directly above basalt beneath Line 2. Thus, the continuity of the silt and clay bed is substantiated.

The Ringold Formation at higher levels exhibited velocities close to 10,000 ft/sec which agrees with the 10,356 and 9425 ft/sec measured by Crosby and Cavin of Washington State University in 1959 at two sites within 4 miles of Line 1. Hence, 10,000 ft/sec can be accepted as normal velocity within much of the Ringold Formation sediments.

Velocities of 6600 ft/sec also were encountered in a 40 ft thick section of sandy gravels and cemented sands previously included within the Ringold Formation sediments. The low velocity in those types of materials suggests that they may be glaciofluvial and fluvial sands and gravels of the weathering zone. Crosby and Cavin noted at well site 699-1-18, 2 1/2 miles southwest of Line 1, that sediments which visually appeared in samples to be Ringold Formation materials were above a break between an upper 2910 ft/sec velocity and a lower 10,356 ft/sec velocity. They concluded that the difference between calculated depth to the Ringold Formation surface and the depth determined by sample study could be the result of the presence of an unidentified low velocity layer in the section or an error in the determination of the top of the Ringold Formation in the well. The close agreement of the seismic velocity of the Ringold Formation sediments as determined by G. S. I. and by Crosby and Cavin suggests that the Ringold Formation is mapped too high. The upper 40 ft of the gravel then is part of the late Pleistocene and Recent glaciofluvial and fluvial deposits.

The weathering zone (the glaciofluvial and fluvial sediments) as already noted showed considerable variation in velocities and evidence of numerous thin layers which are discontinuous vertically and horizontally. This is typical of such materials. Velocities ranged from 1080 ft/sec to 6600 ft/sec and averaged 2000 ft/sec along Lines 1 and 2. Those values agree with Crosby's and Cavin's velocities of 1890 and 2910 ft/sec at one site and 2195 ft/sec at a second site, both within 4 miles of Line 1.

It is significant to note the far more detailed characterization (possible with seismic methods) of the basalt surface and the Ringold Formation surface, particularly along Line 2. With wells alone, smooth interpolation is all that is possible, modified only by judgment and reflecting the regional geologic picture.

EVALUATION OF SURVEY RESULTS

The depths to basalt, calculated from refraction and reflection work, were compared along Line 1 for a distance of 2400 ft southeast of well 699-15-15A. The comparison disclosed a maximum variance in depth determined by the two methods of about 30 ft where the depth to basalt is about 700 ft (4.3% variance). The variance was felt to be partly due to scattered reflected energy and to variations in the basalt itself. Where data were good, the maximum variance was only 10 ft (1.4% variance), and the average was less than 5 ft (0.7%). The reflection method provides a more direct measurement of depth than the refraction method, but is not automatically more accurate, nor is the accuracy from the more direct measurement necessarily significant.

The site of Line 1 was chosen for the reasons in Table I, and because the line crossed a deep basin in the basalt(2), the lowest part of the Cold Creek syncline, where the basalt surface lies below sea level. An indication of the position of well 699-15-15 was desired, relative to the lowest point in the basin. The site also was excellent for testing reflection shooting because there basalt lies more than 600 ft deep, a depth where reflection work becomes more dependable. The results disclosed that at a point 5800 ft southeast of wells 699-15-15 and 15-15A, the basalt surface lies 260 ft below sea level, which is about 100 ft (14%) deeper than previously postulated wells data. The basalt surface there is at the lowest altitude yet detected at Hanford and accordingly in Eastern Washington. The seismic data, correlated to results from an air-borne magnetometer survey,(10) suggest that a still deeper spot lies slightly northeastward of the seismic line where the basalt surface probably lies 300 ft or more below sea level.

The appreciable depth to basalt in the structural center of the Columbia River basalt plateau (the Pasco Basin), the great local relief on that surface (to an altitude of more than 3500 ft above sea level in the Rattlesnake Hills less than 20 miles away) and the demonstrated basalt thickness in those hills of more than 10,000 ft, emphasize the as yet inadequately understood but profound nature of the basalt series.

The uppermost basalt flow beneath Line 2 (Figure 4), that pinches out toward Line 1, occupies the stratigraphic position of the Elephant Mountain flow(11) in the Yakima East quadrangle. Studies by Schmincke(12) indicate that the Elephant Mountain flow is present to the north, west, and south of the Hanford Works, and therefore can be expected to lie beneath the Hanford Works. The interbed that underlies the Elephant Mountain flow and emerges from beneath the flow to lie on top of the basalt series beneath Line 1 is the uppermost part of the Beverly Member of the Ellensburg Formation in the Priest Rapids area as described by Mackin.(13) Knowledge of the position, attitude and composition of the Beverly Member is important. Work by Brown, Brown, and Haney(9) has shown the presence in it of thermally warm water and trace concentrations of radionuclides identified as originating in the Chemical Separations areas. Wastes, discharged to ground there, enter the bed near the water table level and move downward and southeastward into confined parts of the bed. The next underlying basalt flow, the topmost flow beneath wells 699-15-15 and 15-15A, is the Pomona flow.(12) The Pomona flow is underlain by the lower portion of the Beverly Member. Below the Beverly Member (Figure 2) lie the Priest Rapids basalt flows, two Roza porphyritic flows (identified by Brown in Umtanum Ridge and by Bingham(14) at Devil's Canyon near Kahlotus), and other basalt flows that constitute the Yakima Basalt Formation.(15)

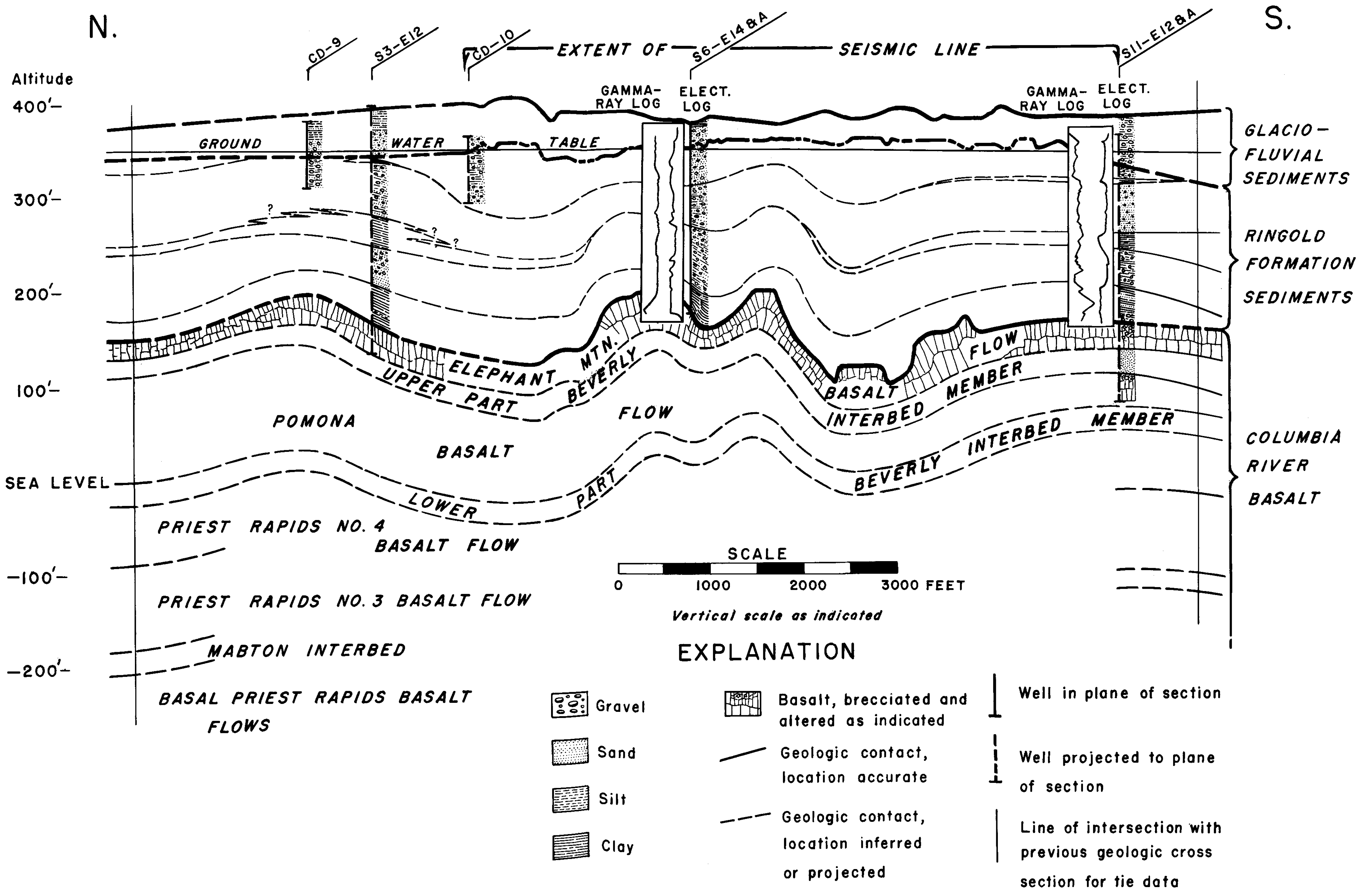

FIGURE 4

Geologic Section Along Seismic Line 2

The Ringold Formation was readily detected and traced along Lines 1 and 2. The 40 ft thick bed of sands and gravels at the base of the glaciofluvial sediments along Line 1 is probably reworked Ringold Formation sediments rather than more typical glaciofluvial sediments. The seismic velocity is higher than that for more normal glaciofluvial sediments (6600 ft/sec vs. 2000 ft/sec) and is equal to low velocity Ringold silts and clays, as traced beneath both Lines 1 and 2. Also, the sands and gravels contain more quartz and quartz-rich rock types than do more typical glaciofluvial sediments, which led to their earlier identification as Ringold. The presence of similar materials at corresponding stratigraphic positions in adjacent wells (699-17-5, 699-8-17, and 699-1-18) suggests that a saddle or shallow river channel (comparable to those earlier identified by Brown(3)) probably extends southeastward across the Ringold Formation surface toward the Columbia River (Figure 5) and across what was previously identified as a broad, gentle ridge. The channel evidently is partly filled with sediments eroded from the Ringold Formation at upstream points northwestward and then deposited in the channel as the river shifts to a more northerly, lower altitude course. The indicated channel and its orientation are consistent with the earlier data. The continuation of the channel also is indicated by seismic data from the south end of Line 2, near well 699-S11-E12, where the Ringold Formation surface drops quite suddenly. That site also appears to be the northern limit or takeoff point of the channel that was identified and outlined by wells and exposed in excavations for the plutonium-recycle test reactor and supporting facilities about three miles to the south. Alternatively, the old channel parallel to the current river channel may be merely a continuation of the trough trending southeastward. It may not have been formed at a different time nor be directly connected to the current Columbia River channel.

Of the relatively extensive well network at Hanford, only one well, 699-1-18, lies within the identified channel. The difficulty in finding sinuous, narrow, linear features by means of wells or drill holes is emphasized. Moreover, sediment samples from well 699-1-18 were inadequate by themselves to indicate the surface of the Ringold Formation. The pumping test

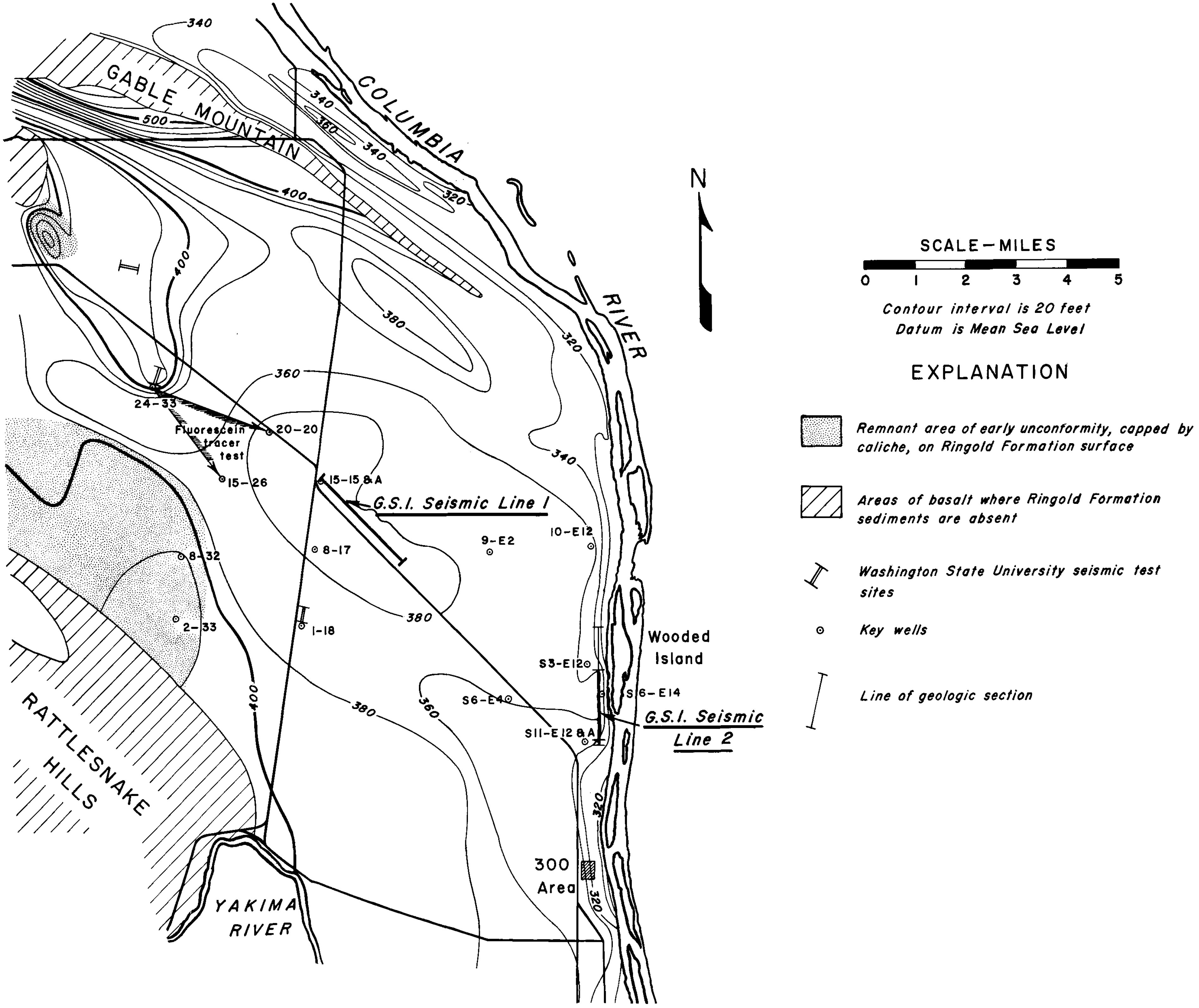

FIGURE 5

The Ringold Formation Surface Beneath Part of Hanford reported by Bierschenk(16) suggested that the ground water there lay entirely within the Ringold Formation, corroborating the identification by sample examination. Evidently the permeability of the few feet of glaciofluvial sediments below the water table was not as high as the permeability of glaciofluvial sediments elsewhere. Hence, the 140 ft of true Ringold Formation sediments tapped by the well masked the increased flow rate contributed by the glaciofluvial sediments. If the sediments are reworked Ringold sands and gravels, they probably are lower in permeability than typical glaciofluvial gravels. This is suggested by their high seismic velocity.

Two reasons supporting the concept of the southeastward-trending channel are the absence of caliche capping the Ringold Formation surface, as noted in wells 699-8-32 and 699-2-33, and the tracer test reported by Bierschenk. In the tracer test, fluorescein was detected flowing from well 699-24-33 southeastward to well 699-15-26 almost as fast as from well 699-24-33 east-southeastward to well 699-20-20. No obvious high rate path from 699-15-26 was then recognized, although from 699-20-20, the fluorescein flowed along the edge of an eastward-trending channel directly toward the Columbia River.

The refinement of the Ringold Formation surface between Lines 1 and 2, as the result of the seismic data, is important to Hanford operations. Downward revision of the Ringold Formation surface near Line 1 means that, as shown on Figure 6, the ground water table will generally lie within the glaciofluvial sediments rather than the Ringold Formation as earlier postulated. Relatively high ground water flow rates can be expected in that region. The low flow rates determined by Bierschenk at numerous wells in that general area are not invalidated, however. Water table maps made in 1959 show that the water table in the vicinity of Line 1 has risen from 5 to 8 ft, or enough to move it from what are still Ringold Formation sediments into the highly permeable glaciofluvial sediments.

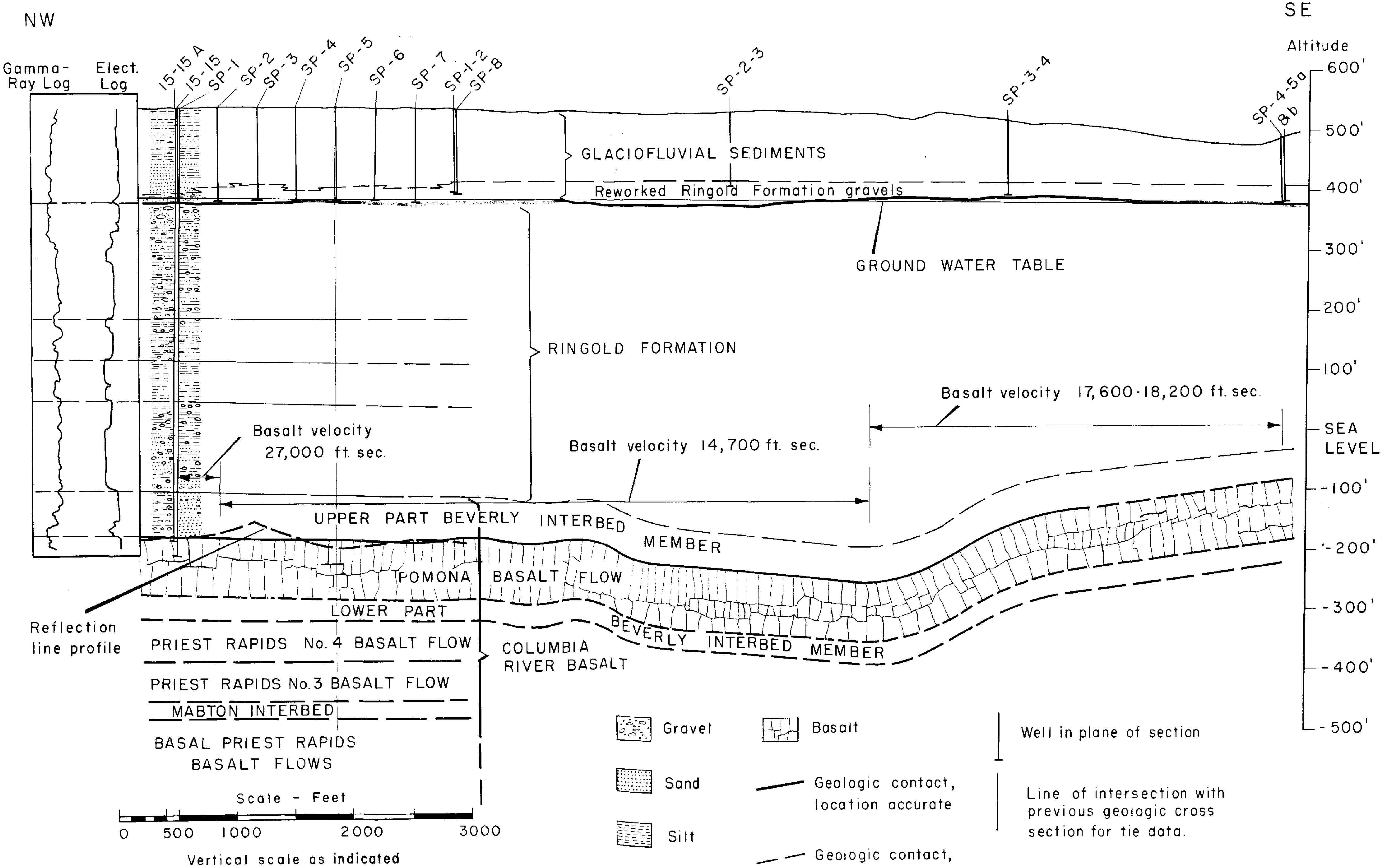

FIGURE 6
Geologic Cross Section Along Seismic Line 1

RECOMMENDATIONS FOR FUTURE WORK

The successful completion of the aims stated for the seismic program suggests its possible applicability in further work.

Existing cable-tool drilled wells, the mainstay of Hanford's geological and hydrological research program, serve multiple purposes. They provide geological data during drilling operations, provide samples of the formations encountered for later examination and laboratory study, provide test structures for field tests, a means of sampling ground waters, and permit the determination of piezometric heads. Hence, extensive substitution of seismic methods for cable-tool drilling is not practicable nor feasible. John A. Donaldson, Party Chief of Party 340, Geophysical Service, Inc. , concludes that:

> "It is apparent that while geophysical evidence can be gathered and interpreted to make more complete the geologic picture at Hanford, no one method (of drilling or of various seismic techniques) has the qualities of being both completely definitive and economical. An optimization of costs, information desired, and explorational schemes providing this information, is necessary and can be realized by a combination drilling and refraction profiling program."

Seismic methods are optimum for the procurement of information at Hanford bearing on two separate but related geohydrological problems. These are: the movement of ground waters and contaminants in the unconfined or water table aquifer, and the movement of ground waters and contaminants in confined aquifers, particularly the upper portion of the Beverly Member.

In the first instance, the fastest ground water flow is largely down the channels which are cut in the surface of the Ringold Formation and filled with highly permeable fluvial gravels. The channels are at least locally irregular, of variable depth, and they were controlled in part by variations in the lithology that cannot be properly evaluated from cable-tool-drilled samples alone. Therefore, their exact location, cross-sectional profile and maximum depth are not logically predictable. Wells drilled to permit sampling of ground waters may or may not lie adequately within the streams of interest. Should the water table altitude be changed upward or downward, the location of flow paths relative to the monitoring wells may change. For this reason knowledge of the extent of the channels and their cross-sectional profile is desirable. This is particularly true near the Columbia River where the sites of entrance of the ground water into the river may vary appreciably with seasonal river fluctuations or longer term changes.

The sampling and monitoring situation at depth is comparable. There the aquifers are structurally controlled and their location, thickness and composition can be better predicted than can erosional features. Seismic techniques will not, however, trace the aquifer but will detect and permit tracing of the first basalt flow to which the Beverly Member aquifer or other confined aquifers can be related.

In the vicinity of well 699-15-15, the depth through the upper part of the Beverly Member to the first basalt flow is more than 700 ft. The time required to drill well 699-15-15 was more than two months, and the cost about $11,000. For less than $22,000, the Ringold Formation surface and the basalt surface were traced 11,500 ft southeastward in about 12 days. Production-type surveys and minimal drilling would decrease the cost even more. Rotary drilling methods were demonstrated to be far faster and cheaper than cable-tool methods. Optimum sites for locating ground-water sampling wells could be determined once profiles were procured.

Refraction seismic surveys appear desirable if, at a future time, greater assurance of the extent of trace contaminants is desired, or if possible flow paths as deduced from geologic data need to be better delineated.

REFERENCES

1. R. E. Brown and M. W. McConiga. "Some Contributions to the Stratigraphy and Indicated Deformation of the Ringold Formation," Northwest Sci., vol. 34, no. 2, pp. 43-54. May 1960.

2. R. E. Brown and D. J. Brown. "The Surface of the Basalt Series in the Pasco Basin, Washington," Geol. News Letter, vol. 25, no. 4, pp. 23-27. April 1959.

3. R. E. Brown. An Introduction to the Surface of the Ringold Formation Beneath the Hanford Works Area, HW-66289. General Electric Company, Richland, Washington, August 1, 1960.

4. R. E. Brown and D. J. Brown. The Ringold Formation and Its Relationships to Other Formations, HW-SA-2310. General Electric Company, Richland, Washington, November 1961. Also Northwest Sci., vol. 35, no. 4, pp. 154-155. November 1961.

5. J. R. Raymond and C. A. Ratcliffe. A Test of the Refraction Seismic Method on the Hanford Project. HW-61796. General Electric Company, Richland, Washington, September 25, 1959.

6. J. A. Donaldson. Seismic Survey, Hanford Atomic Products Operation, Richland, Benton County, Washington, GEH-26275. General Electric Company, Richland, Washington, June 1963.

7. R. E. Brown and J. R. Raymond. A Geophysical Seismic Evaluation Study at the Hanford Works, Washington, HW-SA-3280. General Electric Company, Richland, Washington, November 1963. Also Northwest Sci. vol. 37, no. 4, pp. 157-158, November 1963.

8. R. T. Jaske. Large Scale Quarry Blasting on the Hanford Reservation, HW-79614. General Electric Company, Richland, Washington, January 15, 1964.

9. D. J. Brown, R. E. Brown and W. A. Haney. Appraising Hanford Waste Disposal by Integration of Field Techniques, HW-SA-2707. General Electric Company, Richland, Washington, August 21, 1962.

10. J. R. Raymond and V. L. McGhan. Unpublished Data, General Electric Company, Richland, Washington, September 1963.

11. A. C. Waters. "Geomorphology of South-Central Washington, Illustrated by the Yakima East Quadrangle," Geol. Soc. Am. Bulletin, vol. 66, no. 6, pp. 663-684. June 1955.

12. H. U. Schmincke. "Tracing a Basalt Flow on the Columbia River Plateau, South-Central Washington," *Proc. 60th Ann. Meeting, Geol. Soc. America, Cordilleran Section, Seattle, Washington, March 27-28, 1964*, pp. 55-56.

13. J. H. Mackin. *A Stratigraphic Section in the Yakima Basalt and the Ellensburg Formation in South-Central Washington*, Washington Div. Mines and Geol. Report of Invest. , no. 19, 1961.

14. J. W. Bingham. Unpublished Data, U. S. Geological Survey, Tacoma, Washington, 1963. (Personal Communication)

15. A. C. Waters. "Basalt Magma Types and Their Tectonic Associations: Pacific Northwest of the United States," *Geophysical Monograph Number 6, The Crust of the Pacific Basin*, Amer. Geophys. Union NAS-NRC no. 1035, pp. 158-70. 1962.

16. W. H. Bierschenk. *Aquifer Characteristics and Ground Water Movement at Hanford*, HW-60601. General Electric Company, Richland, Washington, June 9, 1959.

APPENDIX A

PERFORMANCE OF ROTARY DRILLS

The more than 700 wells totalling about 140,000 ft drilled at Hanford since 1947 were drilled entirely by cable-tool methods. Although adequate in many respects and the optimum method in some instances, cable-tool drilling has many disadvantages. These include the slow drilling rate, the need to case the well as it is drilled, and the relatively high cost (attendant in part on the slow drilling rate). Cased wells permit the easy collection of bailer samples and of drive-barrel samples, both of which are routinely obtained at Hanford. However, measurement of in-place properties of the formations through a steel casing, even where perforated, is difficult. If the well is modified by installation of piezometer tubes, then the casing is not only superfluous but a drawback because of its additional restriction to ground water flow. Moreover, some risk is involved in the complete reliance upon samples from cable-tool drilled wells. That belief is now supported by the downward revision of the Ringold Formation surface as determined by the seismic velocity of the materials along Line 1.

Records were kept of the rate at which the rotary drill completed the wells, and the type and quality of data that were obtained to better characterize the geologic materials.

Loose cobble to boulder gravel is the most difficult material for small exploratory rotary drills to penetrate. This material also has proved difficult to drill by cable-tool equipment. An abundance of loose sand and cobble to boulder gravel in the glaciofluvial sediments at the seismic line sites, guaranteed an exacting test of rotary equipment. A total of 5863 ft of 4 3/4 in. uncased hole was drilled by the Mayhew 1000, truck-mounted combination air-water rotary drill (Figure A-1) used by Geophysical Service, Inc. A comparison between rotary drilling and cable-tool drilling at Hanford is presented in Table A-I. Comparisons are between the per hour basis for rotary equipment, which normally operates 24 hr/day, and the per 8 hour day that is normal for cable-tool equipment operation.

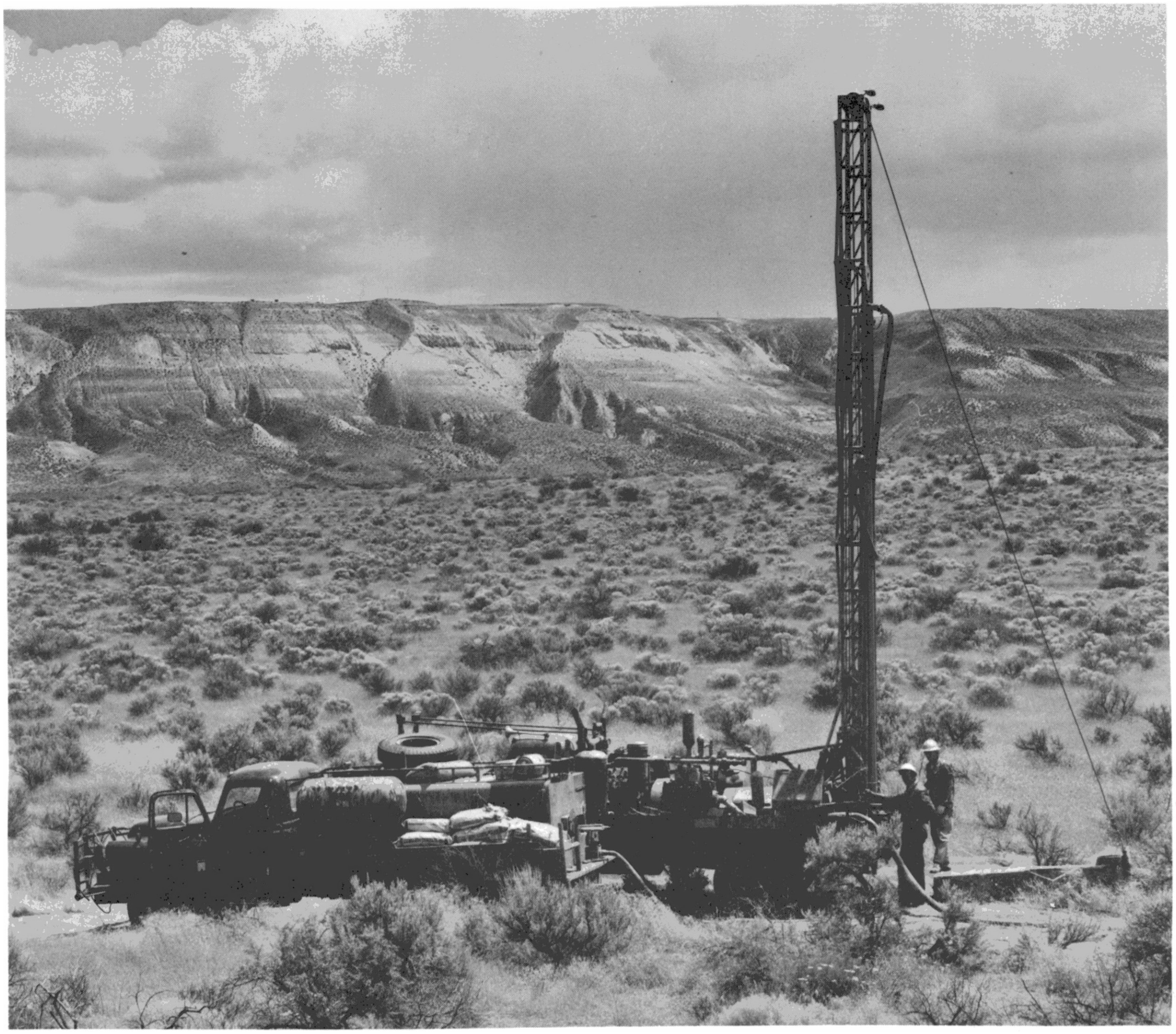

FIGURE A-1

Mayhew 1000 Combination Air-Water Rotary Drill at Hanford

TABLE A-1

COMPARISON BETWEEN ROTARY AND CABLE-TOOL DRILLING RATES AT HANFORD

Site	Footage, ft	Rotary Rate, ft/hr	Cable-Tool Rate, ft/8 hr day	Elapsed Time to Complete Rotary, hr	Elapsed Time to Complete Cable-Tool, 8-hr days
All Sites	5863 (this study)	32.2	--	--	--
	138427 (through 1962)	--	15.7	--	--
699-S6-E14	205 (to basalt)	14.7	12.0	52	26
699-S11-E12	215 (to basalt)	20.2	21.0	32	17
699-15-15	748 (to and into basalt)	19.0	19.5	92	69

Basalt was drilled at a rate of 4.2 ft/hr by rotary methods compared to the cable-tool rate of 5 to 10 ft/8 hr day. Rotary drilling rates far surpass the cable-tool drilling rates. Because of the few comparisons made and some unusual conditions present, the total elapsed time shown must not be considered as necessarily representative. Moreover, should a sufficiently open work gravel occur, mud return and wall support of the open hole may not be possible with rotary methods, and the well may have to be drilled with cable-tool equipment, albeit with difficulty under such conditions. Nevertheless, a great disparity in drilling rates is evident even considering that the rotary drilled wells were only 4 3/4 in. in diameter and were uncased.

Varel VH-1 hard rock bits were effective in penetrating the cobble and boulder gravel in the glaciofluvial sediments and Ringold Formation; they were inadequate in drilling basalt. A drill time improvement in basalt of 5 to 1 and a bit life improvement of 8 to 1 were achieved by the use of tungsten carbide button bits. Sufficient weight could be placed on the bits to satisfactorily drill the basalt.

Drilling rates for the equipment tested were 5 to 10 times as fast as cable-tool equipment on a per hour basis (Speed-Star 71 or equivalent drilling and casing a 6 in. or 8 in. well). On a per day or per month basis the rotary equipment is even faster.

APPENDIX B

THE SEISMIC GEOPHYSICAL METHOD

The seismic method of geophysical investigation, like other geophysical methods, depends on differences in subsurface physical properties; in this case, differences in sound wave velocity. Unlike some other methods (gravity and magnetic) in which ambient fields are measured, seismic exploration requires introduction of energy into the earth. This energy is usually introduced by a controlled explosion. Unique problem solution is possible with the seismic technique, whereas unique solution is not possible with magnetic or gravimetric methods.

When an explosive is detonated at or below ground surface, waves comparable to sound waves are initiated in the earth material. These waves are most accurately designated as elastic waves, for they depend on the resistance to deformation of the materials through which they propagate. The travel of these waves in a homogeneous medium is analogous to the reaction that occurs when a pebble is dropped into a pool of water. Waves travel out radially in all directions from the point where the pebble is dropped. The velocity of elastic waves is governed by the elastic constants of the material through which they are passing. The speed of compressional (longitudinal) waves with which seismic studies are concerned is related to the elastic constants as follows:

$$V_L = \sqrt{\frac{k + \frac{4}{3}u}{\rho}} = \sqrt{\left(1 + \frac{2\sigma^2}{1-\sigma-2\sigma^2}\right)\frac{E}{\rho}} \qquad (1)$$

where V_L = velocity of the longitudinal wave, k = bulk modulus of the material, u = shear modulus of the material, ρ = density, E = Young's modulus, and σ = Poisson's ratio.

When elastic waves generated in the ground encounter stratigraphic discontinuities where those constants change, the waves will be reflected and refracted by the discontinuity. Depths to discontinuous horizons are determined by the reflection method by measuring the time required for the waves to travel down to the discontinuity and back to detectors located near the initiating source. Depths to discontinuities are determined by the refraction method by determining the travel time required for waves refracted along the interface to be deflected back to ground surface at greater distances from the source.

Refracted seismic rays obey the same general laws as refracted light rays (Snell's law). Figure B-1 shows two discrete rock units: the upper (layer A) transmitting seismic waves at a speed of V_1 and the lower (layer B) transmitting waves at a speed of V_2, with $V_2 > V_1$. If an explosion occurs at point S, the elastic waves move outward in all directions. Some of the energy follows path SR, and upon reaching layer B, is refracted to follow path RT according to the relationship:

$$q = \frac{\sin i}{\sin r} = \frac{V_1}{V_2} \qquad (2)$$

where q = index of refraction, i = angle of incidence, and r = angle of refraction. The greater the angle of incidence, the greater the angle of refraction. There is a critical angle of incidence for which r is 90° and RT is parallel to the contact (Figure B-2) described by:

$$\sin i_c = \frac{V_1}{V_2} = q \qquad (3)$$

where i_c is the critical angle.

If the angle of incidence exceeds the critical angle (Figure B-3), the energy is totally reflected. The angle of reflection e is equal to the angle of incidence.

The concept of the critical angle is most important in the refraction method, for the elastic wave that follows path RT (Figure B-2) travels with the velocity of the lower layer but transmits energy into the overlying layer. This energy is transmitted upward to ground surface with the velocity characteristic of the upper layer. The angle of emergence is the same as the angle of incidence. Figure B-4 shows a few of the refracted ray paths

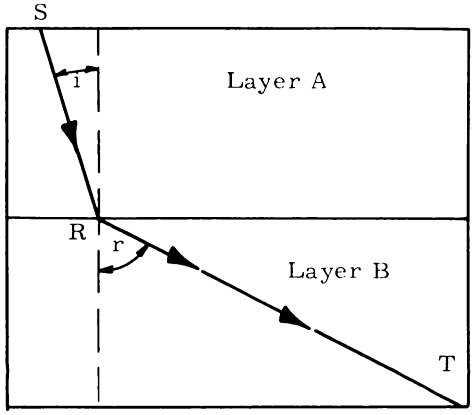

FIGURE B-1

Refracted Ray

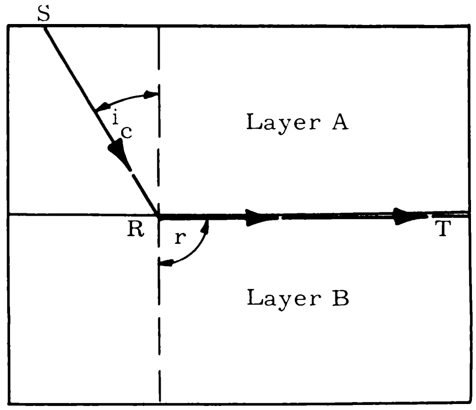

FIGURE B-2

Refracted Ray
at Critical Angle

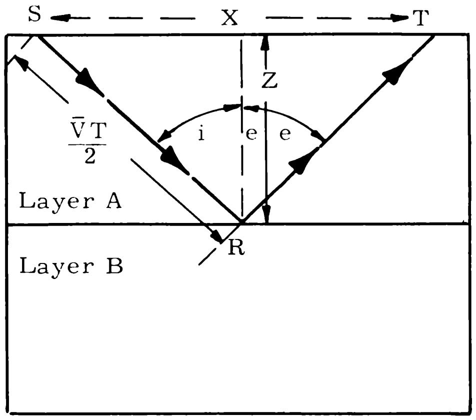

FIGURE B-3

Reflected Ray

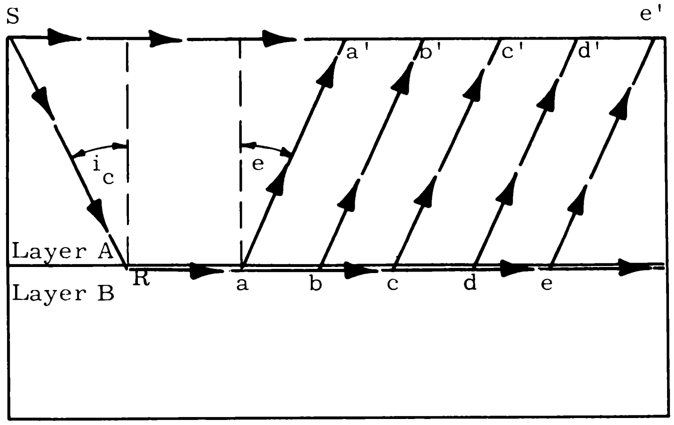

FIGURE B-4

Refracted Ray Paths

traveling from shot point S to seismic detectors located on ground surface at a', b', c', d', and e'. There is a finite distance from shot point S where energy travelling the more circuitous path SRaa', SRbb', etc., will reach a surface detector at the same time as the direct surface wave travelling from Sa', Sb', etc. This is due to the fact that the refracted ray, though travelling a greater distance than the surface ray, is moving for part of the time at the higher velocity of V_2 in layer B. The point where both direct surface wave and refracted wave arrive simultaneously is called the critical distance.

Take a hypothetical case where layer A is of unknown thickness and transmits seismic waves at a velocity of 1000 ft/sec and layer B transmits seismic waves at a velocity of 2000 ft/sec. Devices to detect first arrival of seismic energy from an explosion are placed at ground surface at 200-ft intervals from the shot point. Instrumentation is also used to record the instant of shot detonation and the time of first seismic energy arrival at each detector. A chart is made by plotting time of first energy arrival against distance to the detector from shot point. Figure B-5 shows such a

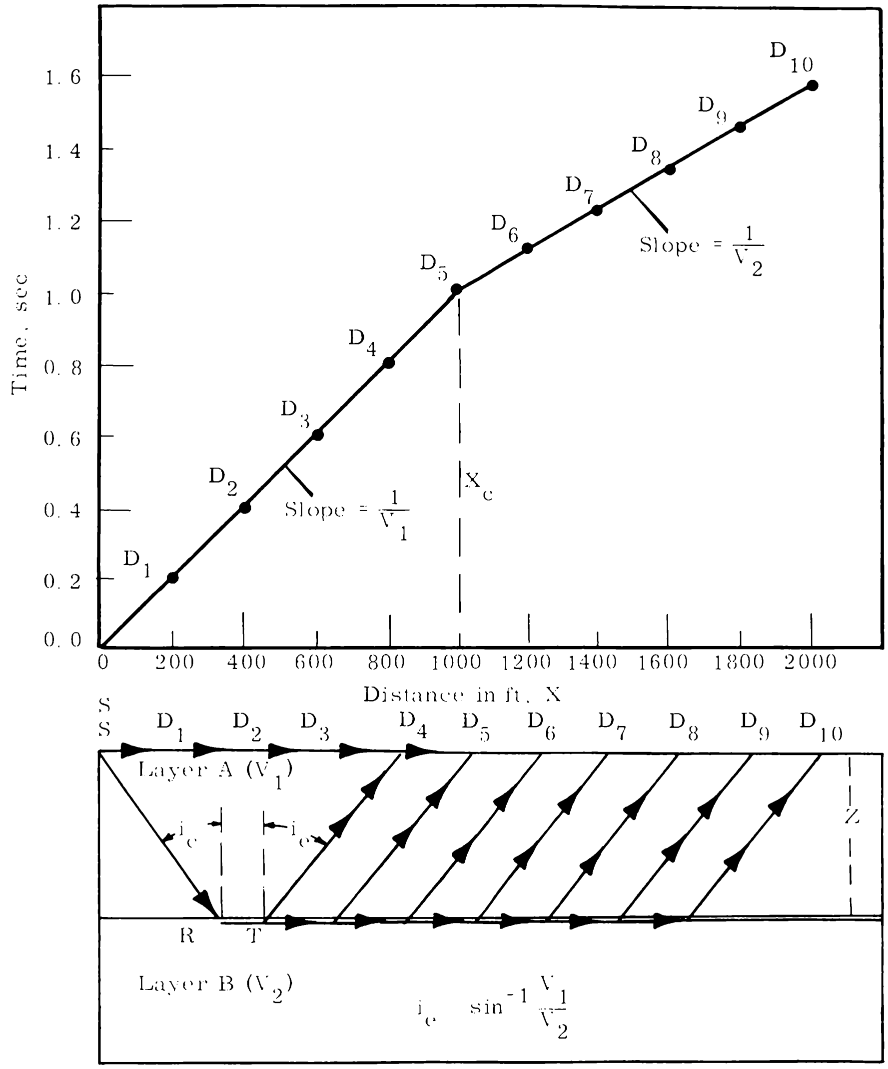

FIGURE B-5

Hypothetical Time–Distance Chart and Equivalent Ray Path Section hypothetical chart and the equivalent ray path cross section. A two-component curve is presented with a change in slope at point X_c. The slope of the curve to the left of X_c portrays the velocity of the upper layer, and the slope of the curve to the right of X_c shows the velocity of the lower layer. It is evident then that X_c is the critical distance where the direct wave and the refracted wave arrive simultaneously. To the left of X_c the direct wave arrives first, and to the right of X_c the energy that has followed the more circuitous route arrives first.

The thickness of layer A (depth to layer B) can be determined as follows. From equation 3, the following identities are apparent:

$$\cos i_c = \left(1 - \frac{V_1^2}{V_2^2}\right)^{1/2}, \quad \tan i_c = \frac{\sin i_c}{\cos i_c} = \frac{V_1}{\sqrt{V_2^2 - V_1^2}}$$

The total time along refraction path SRTD (Figure B-5) is

$$T = T_{SR} + T_{RT} + T_{TD} \tag{4}$$

or

$$T = \frac{Z}{V_1 \cos i_c} + \frac{X - 2Z \tan i_c}{V_2} + \frac{Z}{V_1 \cos i_c} \tag{5}$$

$$= \frac{2Z}{V_1 \cos i_c} - \frac{2Z \sin i_c}{V_2 \cos i_c} + \frac{X}{V_2} \tag{6}$$

where Z is the thickness of layer A.

This may be changed to

$$T = \frac{2Z}{V_1 \cos i_c}\left(1 - \sin^2 i_c\right) + \frac{X}{V_2} \tag{7}$$

$$= \frac{X}{V_2} + \frac{2Z\sqrt{1 - \left(\frac{V_1}{V_2}\right)^2}}{V_1} \tag{8}$$

and finally,

$$T = \frac{X}{V_2} + \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_2 V_1} \qquad (9)$$

The depth can be solved for in terms of the critical distance, X_c, because the times

$$T_1 = \frac{X}{V_1} \text{ and } T_2 = \frac{X}{V_2} + \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$

are equal at X_c:

$$\frac{X_c}{V_1} = \frac{X_c}{V_2} + \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_1 V_2} \qquad (10)$$

$$Z = \frac{1}{2} \frac{V_1 V_2 X_c}{\sqrt{V_2^2 - V_1^2}} \left(\frac{1}{V_1} - \frac{1}{V_2}\right) \qquad (11)$$

$$Z = \frac{1}{2} \sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \; (X_c) \qquad (12)$$

Therefore, solving for depth to the interface in the hypothetical problem:

$$Z = \frac{1}{2} \sqrt{\frac{2000 - 1000}{2000 + 1000}} \; (1000)$$

$$Z = (0.5)(0.577)(1000)$$

$$Z = 288 \text{ ft}$$

Problems involving dipping contacts and several layers of earth materials are more complex, but can be solved fairly easily in much the same manner as the simple hypothetical case. It should be noted that the refraction method breaks down if a low speed (less dense) bed underlies a high speed (more dense) bed of unknown thickness and velocity. The rays entering the low speed bed are deflected downward and will never travel horizontally through the layer; thus, the bed will not be detected. Use of the refraction method is possible only if the first energy arrival is from either a direct or refracted wave.

Figure B-6 shows the relationship of the reflection-time-distance curve to the corresponding refraction curve for the case of two media of speed V_1 and V_2 separated by a horizontal interface at depth Z. A is the first refraction segment (direct wave), B is the second refraction segment (refracted wave), and C is the reflected wave time-distance curve.

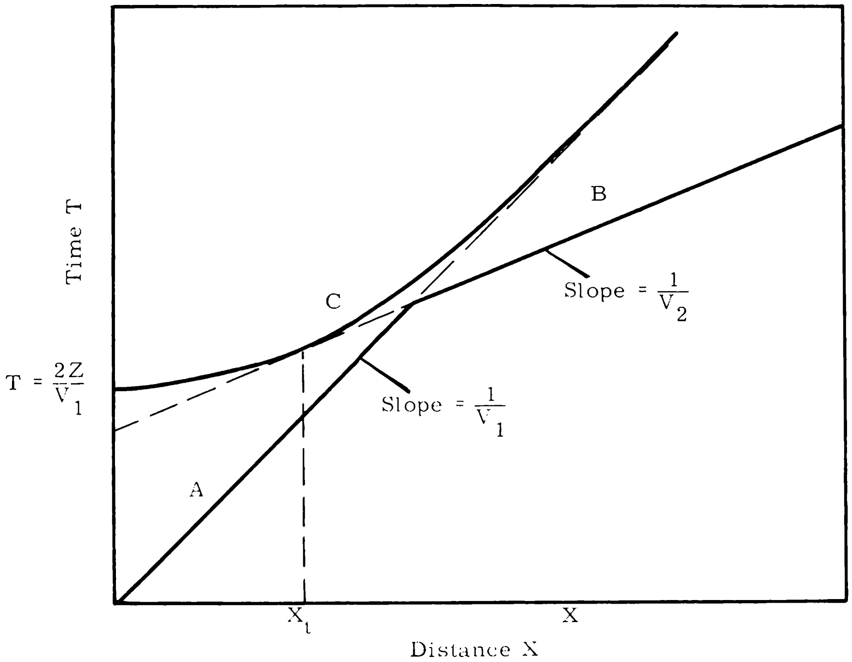

FIGURE B-6

Reflection and Refraction Curve Relationship

The reflection hyperbola is tangent to the second linear segment of the refraction curve and asymptotic to the first, although not along the portion of either segment representing first arrival times. The reflection curve joins the T axis at

$$T = \frac{2Z}{V_1} \tag{13}$$

This time corresponds to vertical reflection. The point of tangency is at the distance X_t where the wave reflected from the interface arrives at the critical angle. X_t is also the smallest value of X at which a refracted wave will be obtained from the interface. At large values of X, the reflection hyperbola approaches the first refraction segment asymptotically; the direct travel and reflection times approaching one another as X become very much larger than Z. From Figure B-6 and from the discussion, we see that the first arrival energy is always from the direct wave or the refracted wave.

Depth evaluation from reflection data is theoretically as simple or simpler than refraction determination. On Figure B-3, we see that the length L of the wave path from shot to detector via the reflecting surface is:

$$L = 2\sqrt{X^2 + \left(\frac{X}{2}\right)^2} = \bar{V}T \qquad (14)$$

where $\bar{V}$ is the average speed of a seismic wave through the section reflected from a horizontal bed at depth Z, X is the shot to detector distance and T is the total travel time.

$$T = \frac{2}{\bar{V}}\sqrt{Z^2 + \left(\frac{X}{2}\right)^2} \qquad (15)$$

and

$$Z = \frac{1}{2}\sqrt{(\bar{V}T)^2 - X^2} \qquad (16)$$

Operationally, however, reflection evaluation is much more complex than refraction evaluation. Detection of a reflected wave from a responding horizon is indicated by an almost simultaneous recording oscillograph galvanometer deflection on all geophone traces. A number of events (reverberations, horizontally or vertically travelling noise, multiples, etc.) can interfere with or obscure the observed reflected event on the oscillograph record. Also an accurate average velocity ($\bar{V}$) must be known for the entire geologic section to permit calculation of depths to responding horizons. $\bar{V}$ may be determined by in-well shooting or by difference analytical methods. Many different reflection data enhancement techniques are available. Most of them consist of frequency or wave number filtering to attenuate and/or separate the noise from the desired signal. Some techniques utilize digital or analog computers for data enhancement.

Two raw seismic record corrections must be made before the data can be used for depth determination. These are the weathering zone correction and elevation correction. The weathering zone correction removes the effect of the low speed surficial layer. The elevation correction compensates for differences in shot hole and detector altitudes. These corrections, formerly done manually, are now often made by digital computers.

Modern seismic instrumentation consists of detectors, amplifiers and recording oscillograph. The detectors (geophones) are transducers placed on the ground to detect ground movement and convert this movement into an electric voltage. The amplifier increases this voltage and transmits it to galvanometers in the recording oscillograph. A chronometer provides time control for the oscillograph. All commercially available reflection seismographs and most refraction seismographs are multichannel instruments providing simultaneous readout from a number of geophones.

APPENDIX C

SEISMIC EQUIPMENT, METHODS, AND TECHNIQUES

EQUIPMENT

The Geophysical Service, Inc. Digital Field System (DFS*) was used for the Hanford study. The system consists of Texas Instruments, Inc. series 9000 seismic amplifiers, a reel-to-reel magnetic tape recording unit, analog-to-digital converters and associated control and playback equipment. Incoming seismic signals, as varying voltages from the field detectors (geophones), are input to the amplifiers where signal gains up to 120 dB (amplification of 10^6) may be realized. Twenty-four inputs (from 24 geophones) are generally used. The amplified analog signals as voltages are fed into the converters and subsequently recorded in digital form on the magnetic tape. The DFS is the most advanced seismic system currently available and is a great forward step by GSI and Texas Instruments, Inc. Conventional exploration seismic systems present an analog record directly from a 24 trace recording oscillograph. Amplifier parameters (gain, filtering, type of gain control, etc.) are pre-set; and if the set parameters are incorrect, the line must be shot over again in a trial and error fashion. Some later systems utilize analog magnetic tape or disc recording. The amplifiers may be run essentially wide open (except for initial gain) and the data played back through the amplifiers with appropriate filtering and gain control for data enhancement. However, the data are always in analog form, and both the amplifiers and the recorder create distortion and limit the quality of analog seismic records. Digital recording introduces no distortion and the series 9000 amplifiers, designed especially for use with DFS, have a wide dynamic range, generate little noise, have excellent fidelity and create a minimum of signal distortion. The DFS provides for field and office playback and simultaneously records a conventional oscillograph seismogram.

---

* GSI service mark

These improvements create a better seismic record and increase the speed of seismic surveying. More importantly, the seismic data, recorded digitally on magnetic tape, are in proper form for direct digital computer input for further refinement.

A special purpose digital computer was designed to operate in conjunction with the DFS. The Texas Instruments Automatic Computer (TIAC*) is a high-speed, stored-program, single-address unit that uses a binary number system. The magnetic core, random-access memory has a capacity of about 1000 eighteen-bit words. An additional 600,000 words can be bulk-stored on a magnetic loop tape. The key to successful seismic data processing is the "software" programs. GSI has developed a number of computer programs for data enhancement to recover seismic signals buried in a background of unwanted noise. Unwanted signals may be caused by multiple reflections and refractions, charge detonation noise, vertical and horizontal reverberations, and inherent amplifier and geophone noise which may interfere with seismic signal recognition. Programs are also available to make weathering and altitude corrections.

Texas Instruments, Inc. S-41, 4 1/2 cycles/sec seismometers (geophones), damped 50% critical, were used for all refraction work, and Electrotech S-32, 14 cycles/sec geophones, damped 70% critical, were used with reflection shooting. The geophones are essentially transducers, coupled to the ground, which generate a voltage when ground motion takes place. The generated voltage is proportional to the displacement velocity of an armature supported in the geophone case.

METHODS AND TECHNIQUES

Uphole Studies and Noise Analysis

Two uphole surveys were made for velocity measurement by detonating water-work booster charges at different depths in wells. The uphole surveys provided data for correcting reflection records, timing reflections and indicating anomalous velocity conditions important to both reflection and

---

* GSI service mark

refraction interpretation. Travel times were recorded on a 12 detector spread with a 20 ft detector spacing, with one additional geophone (uphole phone) offset 10 ft from the hole. Times from the uphole phone were corrected to a vertical travel path.

One noise analysis survey was shot using 24 seismometers spaced 10 ft apart. This microgroup interval was used for recording low-frequency, short-wavelength, shot-generated noise to establish an optimum reflection-spread geometry.

Reflection Shooting

The continuous profile reflection method was used. Spreads were 345-0-345 ft with two group overlaps. Group intervals were 30 ft with six geophones spaced 1 ft apart per group. The group spacing was designed to provide wave number filtering and attenuation of low-velocity, surface ground waves.

Two shots per hole were recorded at depths of 145 ft and 125 ft. Five-pound charges of Nitramon were used, and the charges were detonated directly by a short firing line from the recording truck.

Initial amplifier gain varied from 20 to 33 1/3 dB, depending on the expected energy absorbing characteristics of the earth materials. Programmed Gain Control (PGC) was used to increase amplifier gain with time after detonation to compensate for seismic energy decay. PGC varies from 18 to 22 dB/sec to a final gain of 66 2/3 to 80 dB. Data were recorded with low-cut filters set "out" and high-cut filters set at 350 cycles/sec. Playbacks were recorded at various low and high filter settings to optimize noise attenuation.

A correctional velocity of 6600 ft/sec (as determined by the velocity survey) was used for depth determination, and records were computed to a 500 ft reference plane. Computer processing (TIAC) was used to correct the profiles to reference, to remove normal moveout, and to equalize traces to remove effects of differential geophone coupling. The TIAC "Pie Slice"*

---

* GSI trade name

operator was applied to the corrected seismic data. The Pie Slice program provides velocity filtering to pass the desired seismic reflections while greatly attenuating signals in the noise region. Because of the poor signal characteristics, reflections could not be "picked" with any certainty from the standard analog records. Computer processing of seismic reflection data is definitely required on the Hanford Project.

Refraction Shooting

The refraction spreads were 2300 ft long and were designed to give forward and reverse coverage. Detector group interval was 100 ft with one seismometer per group. Where required for weathering control, shorter spreads of 460 ft were also used.

Nitramon or fertilizer-grade ammonium nitrate charges from 5 to 120 lb were used, with the charge size scaled to the shot-to-detector distance. The shots were detonated near the surface with only 2 or 3 ft of earth covering to minimize air blast. Charge detonation was by remote radio tone signal from the recording truck site. The radio signal tripped the blasting machine (located near the shot point) which in turn detonated the charge.

All refraction data were recorded with the amplifiers set to operate in the initial mode (straight gain) to provide true amplitude recovery of seismic signals. Low-cut filters were set "out" and high-cut filters were set at 350 cycles/sec. Various filter settings were used on record playbacks for data enhancement.

The field seismograms served as the basis for interpretation by standard techniques and by the Baumgarte method.[*] TIAC was used in preparing variable density sections for graphic display. Also, the Pie Slice operator was applied to pass basalt refraction arrivals while attenuating direct and Ringold arrivals.

---

[*] J. Baumgarte, "Konstrucktive Darstellung Vor Seismischen Horizonten unter Berücksichtigung der Strahlenbrechung im Raum," *Geophysical Prospecting*, vol. 3, no. 2, pp. 126-162, June 1955.

INTERNAL DISTRIBUTION

Copy Number	
1	G. J. Alkire
2	J. L. Boyd
3	D. J. Brown
4-13	R. E. Brown
14	W. A. Haney
15	R. A. Harvey
16	J. F. Honstead
17	E. R. Irish
18	R. T. Jaske
19	R. L. Junkins
20	C. E. Linderoth
21	O. M. Lyso
22	R. W. Nelson
23	D. W. Pearce
24	O. W. Priebe
25	H. E. Ralph
26-35	J. R. Raymond
36	L. C. Schwendiman
37	W. G. Spear
38	F. W. Van Wormer
39	M. T. Walling
40	Technical Publications
41-45	Technical Information Files

EXTERNAL DISTRIBUTION (SPECIAL)

Number of Copies	
2	Atomic Energy Commission, Health and Safety Division, P. O. Box 2108, Idaho Falls, Idaho Attn: J. Horan B. Schmalz
1	City of Richland, 505 Swift Boulevard, Richland, Washington Attn: J. A. McCool
2	District Engineer, U. S. Army Engineer District Corps of Engineers, 1519 Alaska Way South Seattle, Washington Attn: A. S. Cary H. S. Bardsley

EXTERNAL DISTRIBUTION (SPECIAL)(contd)

Number of Copies	
7	General Electric Company, Richland, Washington Attn: G. E. Bachman L. B. Bradley N. T. Hildreth T. G. LaFollette H. P. Shaw E. F. Smith, Jr. R. E. Trumble
3	Geophysical Service, Inc., P. O. Box 35084, Airlawn Station, Dallas 35, Texas Attn: R. C. Dunlap, Jr. G. A. Cloudy D. Brown
1	Geo-Recon, Inc., 1105 N. 38th Street Seattle, Washington Attn: S. D. Schwarz
3	J. A. Jones Construction Co., Richland, Washington Attn: D. L. Short R. W. Harrison F. Devine
1	Office of the State Engineer, 516 Public Service Bldg. Salem 10, Oregon Attn: J. Sceva
6	Richland Operations Office Attn: Technical Information Library K. L. Englund P. G. Holsted G. W. Knoeber R. K. Sharp C. N. Zangar
1	U. S. Geological Survey, Water Resources Division Ground Water Branch, Tacoma, Washington Attn: J. W. Bingham
1	U. S. Geological Survey, Water Resources Division, Bldg. CF-690, Rm. 215, National Reactor Test Station P. O. Box 2230, Idaho Falls, Idaho Attn: D. A. Morris

EXTERNAL DISTRIBUTION (SPECIAL) (contd)

Number of Copies	
2	Washington Department of Conservation 335 General Administration Building Olympia, Washington Attn: R. H. Russell M. T. Huntting
1	Washington State University Division of Industrial Research Pullman, Washington Attn: J. W. Crosby, III
2	Washington State University Department of Geology Pullman, Washington Attn: J. W. Mills W. F. Scott
1	Vitro Engineering, Richland, Washington Attn: C. F. Gabel

UC-51
GEOLOGY AND MINERALOGY

TID-4500
(40th Ed.)

Ptd.	Standard Distribution
1	ABERDEEN PROVING GROUND
3	ARGONNE NATIONAL LABORATORY
1	ATOMIC ENERGY COMMISSION, BETHESDA
1	AEC SCIENTIFIC REPRESENTATIVE, FRANCE
1	AEC SCIENTIFIC REPRESENTATIVE, JAPAN
3	ATOMIC ENERGY COMMISSION, WASHINGTON
2	BATTELLE MEMORIAL INSTITUTE
2	BEERS (ROLAND F.), INC.
1	BEERS (ROLAND F.), INC., LAS VEGAS
1	BROOKHAVEN NATIONAL LABORATORY
1	BUREAU OF MINES, ALBANY
1	BUREAU OF MINES, WASHINGTON
1	DEFENCE RESEARCH MEMBER
4	DIVISION OF RAW MATERIALS, WASHINGTON
8	GRAND JUNCTION OFFICE
1	HAZLETON NUCLEAR SCIENCE CORPORATION
1	IOWA STATE UNIVERSITY
1	MOUND LABORATORY
2	NASA SCIENTIFIC AND TECHNICAL INFORMATION FACILITY
1	NATIONAL BUREAU OF STANDARDS (LIBRARY)
1	NAVAL POSTGRADUATE SCHOOL
1	NEVADA OPERATIONS OFFICE

Ptd.	Standard Distribution
1	NRA, INC.
1	OFFICE OF ASSISTANT GENERAL COUNSEL FOR PATENTS (AEC)
6	OFFICE OF NAVAL RESEARCH
1	OHIO STATE UNIVERSITY
1	PETROLEUM CONSULTANTS
1	PUBLIC HEALTH SERVICE, LAS VEGAS
1	PUBLIC HEALTH SERVICE, MONTGOMERY
1	SOUTHWEST RESEARCH INSTITUTE
1	U. S. GEOLOGICAL SURVEY, ALBUQUERQUE
2	U. S. GEOLOGICAL SURVEY, DENVER
1	*U. S. GEOLOGICAL SURVEY, MENLO PARK
1	U. S. GEOLOGICAL SURVEY (NOLAN)
2	U. S. GEOLOGICAL SURVEY, WASHINGTON
2	UNIVERSITY OF CALIFORNIA, LIVERMORE
1	UNIVERSITY OF PUERTO RICO
1	WESTINGHOUSE ELECTRIC CORPORATION
1	WHITE SANDS MISSILE RANGE
285	DIVISION OF TECHNICAL INFORMATION EXTENSION
75	CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

*New listing or change in old listing.