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PRELIMINARY TARGETING OF GEOTHERMAL RESOURCES IN DELAWARE

Progress Report, July 15, 1978—July 14, 1979

By
Kenneth D. Woodruff

July 1979

Work Performed Under Contract No. ET-78-S-02-4715

Delaware Geological Survey
University of Delaware
Newark, Delaware

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DELAWARE GEOLOGICAL SURVEY

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ABSTRACT

A one year program was undertaken in Delaware to assist the U. S. Department of Energy (DOE) in its evaluation of the geothermal potential of the East Coast. Results of temperature logging the five DOE 1,000 foot test wells in Delaware indicate that the potential is good for a relatively low temperature geothermal resource (temperatures less than about 80°C). A preliminary Bouguer gravity map was made for portions of Kent and Sussex counties in order to detect gravity anomalies possibly related to granitic plutons. The map indicates a gravity low trending northeast-southwest across Sussex County that could be indicative of other structural features within the basement rocks beneath the Coastal Plain. Other logging activities and study of the cores and drill cuttings in the DOE test holes were useful in better defining the stratigraphic framework and in determining the fresh-salt water interface in southern Delaware.

INTRODUCTION

Background

In 1977 the U. S. Energy Research and Development Administration (ERDA) began a geothermal exploration program in the eastern coastal states of the United States. About this same time the Mid-Atlantic states (New York, New Jersey, Delaware, Maryland, and Virginia) were attempting to assess the impact of petroleum exploration and possible discoveries in the adjacent offshore areas. In Delaware, the Delaware Geological Survey (DGS), supported by the Delaware Office of Management, Budget, and Planning, was actively engaged in the collection and evaluation of all available data from the deep subsurface of Delaware and the adjacent continental shelf.

Some very limited data from this evaluation of hydrocarbon resources indicated a possible potential for geothermal resources in the Delmarva Peninsula. This potential was pointed out in informal discussions with ERDA staff members at a meeting in the Washington offices of ERDA. Of particular interest was a bottom hole temperature recorded on a Schlumberger electric log from a petroleum test hole known as Maryland ESSO No. 1, drilled in 1946 near Ocean City, Maryland. The bottom hole temperature at a depth of 7,710 feet (2,351 meters) is listed on the log heading as 216°F. This temperature was about 1.5 times the temperature that might be predicted from known temperature gradients in the general area. Of equal interest were the results of an offshore seismic survey extending from the mouth of Delaware Bay south to about Ocean City, Maryland. The survey was run by Digicon, Inc. under a contract by the DGS and the U. S. Geological Survey. The data indicated that crystalline basement rocks appeared to be deeper than previously believed and dropped off rather steeply only a few miles from shore (Brown and others, 1972; Woodruff, 1977). Earlier data (e.g., Marine and Rasmussen, 1955) showed a depth to basement of about 6,000 feet near Lewes at the northern end of the seismic line. The geophysical survey indicates possible basement (crystalline?) at about 6,500 feet near Lewes but deepening rapidly in a southerly direction to greater than 10,000 feet near Fenwick at the Delaware-Maryland line. Interpretation of magnetic surveys (Woodruff, 1977) and continued work by DGS (unpublished) suggests that basement rocks may be even deeper than 10,000 feet in the southeastern part of the State.

In later meetings, ERDA officials and representatives of interested coastal states discussed methods of cooperation and data exchange. ERDA invited proposals from the states to assist the Federal government in its assessment of eastern geothermal potential. As a result, on October 17, 1977, the DGS submitted a proposal to assist in the evaluation of geothermal resources in Delaware. Subsequent discussions with the newly created U. S. Department of Energy (DOE) resulted in some modifications to the original proposal. A contract between DOE and DGS became effective July 15, 1978 for an initial period of one year.

Purpose and Scope

The products called for in the contract with DOE can be grouped into three main categories: (1) a Bouguer gravity map of portions of Kent and Sussex Counties, (2) consultation and assistance to DOE and its subcontractors with regard to siting 1,000 foot test holes in Delaware, and, (3) geophysical logging. The contract also provided for bottom hole cores in crystalline rock beneath the Coastal Plain. However, this was to be done only in those cases where DGS, by means of the contract with DOE, might purchase this service in holes drilled by others of suitable depth and at proper locations.

Work undertaken by the Department of Geological Sciences at Virginia Polytechnic Institute and State University (VPI and SU), a major contractor to DOE, had indicated that granitic plutons buried beneath Coastal Plain sediments were possible geothermal heat sources due to the decay of radioactive elements in the granite (isotopes of uranium, potassium, and thorium). The Coastal Plain sedimentary cover apparently acts as an insulating cover and traps the heat generated by the radioactive decay (Costain and others, 1978, 1979). Changes in the local gravity field should reflect a density contrast between the granite and surrounding basement rocks. Thus the gravity measurements were thought to be a prime tool in targeting possible buried heat sources.

A second exploration tool for determining the location of possible heat sources is temperature measurements in bore holes or wells. The temperature measurements permit the calculation of the temperature gradient which in turn is a factor in the heat flow through a given area. Theoretically, the highest gradients should be in areas underlain by buried heat sources, assuming a constant thermal conductivity. Areas with gradients above "normal" might, therefore, be worthy of further investigation.

DGS also suggested in the proposal that part of DOE's work should include the completion of aerial magnetic and radioactivity surveys in the State. The U. S. Geological Survey was recommended to DOE to be the prime contractor. However, copies of the raw data were requested by DGS from DOE for use in the present study. This suggestion was acted upon by DOE and a contract was subsequently initiated between the DOE and the USGS. The magnetic data provides a check on the interpretation of the gravity data, particularly in regard to determining buried geologic structures and their depths.

The radioactivity data were proposed for and included in the same survey because they could be obtained at only a small additional cost and would be of direct value in DOE's National Uranium Evaluation Program (NURE).

Acknowledgments

A number of State agencies provided full cooperation in all phases of the project. Access to State owned forest lands was provided through the Delaware Department of Agriculture, Division of Production and Promotion, Forestry Section. Mr. O. D. Bailey, Forest Manager (retired) of the Redden State Forest assisted in locating and field checking possible drilling sites in the Redden Forest Preserve.

Mr. William C. Wagnor, Director of the Division of Fish and Wildlife, Delaware Department of Natural Resources and Environmental Control, granted permission for drilling in the Assawoman Bay Wildlife Area.

The Delaware Department of Natural Resources, Division of Environmental Control, Water Supply Section expedited the well permitting procedure and assured compliance with Delaware well construction standards. Dr. Kent Price, College of Marine Studies, University of Delaware, offered the use of University lands for a drilling location at Lewes,Delaware on behalf of the College and the University.

Deputy Base Commander, Lt. Colonel Carl B. Johnson, of the Dover Air Force Base granted permission for drilling and subsequent logging activities at the Dover Air Force Base. The Base Civil Engineering Office provided the necessary coordination in all phases of the work at the Base.

The City Manager, City of Milford, allowed the use of City property to store casing and other drilling supplies while drilling was being done in Delaware.

Dr. John K. Costain, Department of Geological Sciences, Virginia Polytechnic Institute and State University suggested the method used for temperature instrumentation. Frequent consultations were held with other staff members of the Geothermal Program at VPI and SU, particularly with Sam Dashevsky and Dr. Joe Lambiase. Their assistance in various phases of the program is gratefully acknowledged.

Allen H. Cogbill, Research Assistant at the time with VPI and SU, provided a copy of the computer gravity program he developed and all gravity data that he had compiled for Delaware.

Michael Boos, student assistant for DGS, assisted in collecting additional field data in Delaware and in modifying the VPI and SU program for use with the University of Delaware's B7700 computer.

Field transportation and basic geophysical logging facilities were provided by the DGS in accordance with the contract requirements.

GRAVITY MEASUREMENTS

Area of Study

Figure 1 shows the approximate area of study. The boundaries of the area vary slightly from those suggested in the original proposal due to availability of previous data and final configuration of stations established in this project. In general, the area is bounded by Delaware Bay and the Atlantic Ocean on the east, by the Maryland-Delaware boundary on the south, by a north-south line on the west through approximately the middle of the State terminating to the north at Dover, and on the northern end, by an east-west line through Dover.

Gravity data that were compiled by VPI and SU outside of the area described above, particularly in the Bridgeville-Seaford area, were also used in this study.

Data Collection

Gravity measurements for the DGS work were made with a reconditioned Worden Gravity Meter (Prospector Model). The instrument was purchased from a geophysical consulting firm and was returned to the manufacturer by the seller for inspection and calibration before delivery to DGS. Accuracy of the meter is listed by the manufacturer as about 0.02 milligal (Mgal). A new factory warranty was issued by Texas Instruments as part of the purchase agreement. Delivery time on new instruments was quoted by manufacturers as six months to one year. Thus it was not possible to obtain a new instrument and complete the field work within the one year contract period.

The primary base station used in this study is located at Bridgeville, Delaware (see Figure 2) and was established by VPI and SU from the Washington "C" base of NOAA. Observed

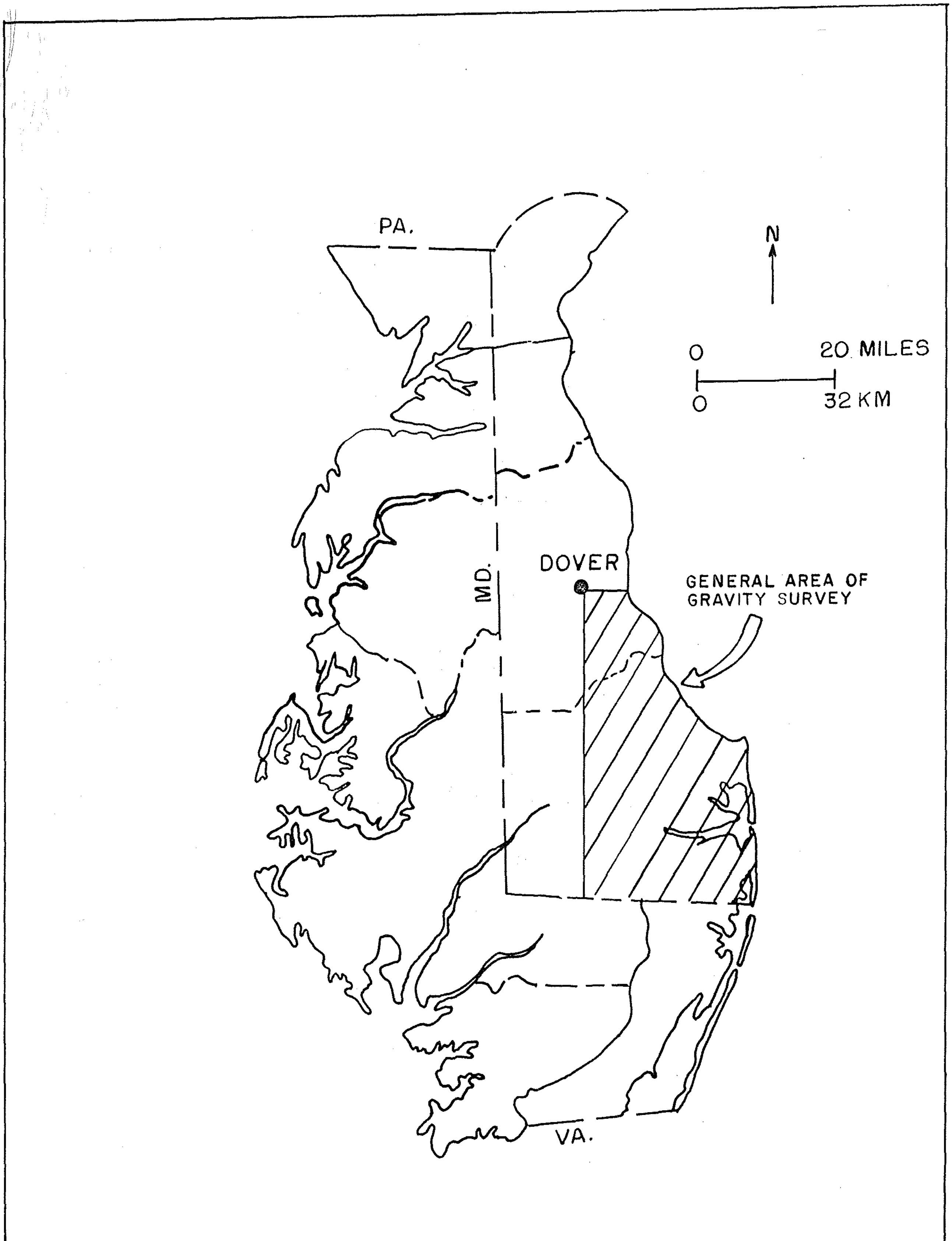

Figure 1. Map showing area of gravity survey.

gravity at the Bridgeville base was 980,021.15 milligals adjusted to the 1971 gravity standard. Additional temporary base stations were established at Lewes (DeVries Monument), and at Dover (Coast and Geodetic Survey Bench Mark U36) by running loops from the Bridgeville base.

U. S. Geological Survey 7.5 minute quadrangle maps were used as the initial base maps for the gravity survey. In nearly all cases, road intersections with spot elevations listed on the topographic maps were used for the gravity stations. A few USGS or Coast and Geodetic Survey bench marks were available. The uncertainty of the exact point to which the elevations were referenced was probably the main source of error in the gravity survey. However, this was primarily a reconnaissance study and neither time nor funding permitted precise leveling of the gravity stations.

Instrument drift and gravity variations due to tidal influences were accounted for by returning to the base station at regular intervals, usually every three to four hours. Station spacing varied from one-half mile to one mile intervals depending on the availability of points with known elevations. A few locations where measurements had already been made by VPI and SU or others were also included in the survey in order to check for compatibility of results.

During approximately the first half of the DGS field program Bouguer anomalies were calculated using a programmable desk calculator (Texas Instruments SR-52 with printer). Later, all data were placed on punched cards and the University of Delaware's Burroughs B7700 computer was used to calculate Bouguer anomalies using a slightly modified version of the VPI and SU computer program. The density used in the Bouguer anomaly calculation is 2.67 grams per cubic centimeter (gr/cc). The Bouguer values were plotted on a Delaware Department of Highways and Transportation base map at a scale of 1 inch to 2 miles, and hand contoured. The field base maps (USGS 7.5 minute quadrangles) at a scale of 1 inch to 2,000 feet with the station locations and Bouguer values indicated are available for inspection at DGS.

Results

The following 7.5 minute Delaware quadrangles were completed in the gravity program: Bethany Beach, Cape Henlopen, Fairmount, Frederica, Lewes, Milford, Milton, Mispillion River, and Rehoboth Beach. In addition, partial gravity coverage was obtained in the following quadrangles: Assawoman Bay, Dover, Frankford, Harbeson, Harrington, Little Creek, and Wyoming. Portions of the latter group of quadrangles not mapped were, in many cases, outside the area of immediate interest, or outside of Delaware.

Plate 1 shows the contoured Bouguer values. Those data gathered by VPI and SU, both in and outside of the immediate study area, previous to the DGS program were incorporated into the map. Most of their data were concentrated in southwestern and western Delaware (Costain and others, 1979). Any differences in the contoured Bouguer values are probably due to the method of contouring. DGS values were hand contoured while the data of VPI and SU were computer contoured. Differences in Bouguer values at the same station as measured or compiled by VPI and SU and as measured by DGS ranged from a low of 0.02 milligal to a high of 1.1 milligal. The 1.1 milligal difference was exceptionally high and in an area where major changes in topography had occurred due to road construction. Generally, the larger differences were in areas where there was uncertainty in the compiled data about the exact location of the gravity station due to cultural changes.

The outstanding feature of the Bouguer map is a northeast-southwest trending gravity trough, or low, entering Delaware at Primehook Beach on Delaware Bay and extending southwest through the Laurel-Seaford area and into Maryland. This trough is flanked on the northern side by a second, closed gravity low, centered on Bridgeville. The Bridgeville low was apparent in the work described by Costain and others (1979), and by Sabat (1977). It may be a continuation of a low mapped by Woollard (1943) which extends partly across Cape May in an east-west direction. A gravity high is centered approximately on Bethany Beach and is also confirmed by Sabat (1977) although he refers to it as the "Ocean City high." A gravity low of relatively small amplitude and extent seems to occur in the Dover-Camden area in Kent County. The interpretation in the Dover area must be considered tentative until additional points are measured to better define the configuration of the Bouguer contours.

Detailed attempts at interpretation are beyond the scope of this report. However, it is expected that continuing work on compilation of all existing geophysical data in Delaware and surrounding areas will address the problem of basement configuration and type. Results of some of this work should be available at the end of the extended contract period (May 15, 1980). At the moment, it appears that differences in gravity values are due to differences in type of basement rocks or to basement structure (faulting?) in rocks beneath the unconsolidated

Coastal Plain material. The configuration of the Salisbury Embayment with its relatively thick sedimentary sequence is not reflected by the gravity map (Plate 1). It is possible that the northeast-southwest trending gravity low across Sussex County is due to a buried sedimentary Basin (Triassic?) bounded on the north and south by crystalline basement rocks of higher densities. This gravity feature also correlates exactly with a linear feature mapped by Spoljaric and others (1976) using satellite imagery. They interpreted the linear as an existing (?) stream valley and were uncertain if the stream valley is structurally controlled. The gravity data suggest that the location of the stream valley is indeed structurally controlled by faulting within basement rocks. NOAA (1971) indicates that an earthquake occurred in 1906 in the Seaford area, (see Figure 2 and Plate 1), which is located along this gravity low.

In southeastern Delaware the Bouguer gravity contours appear to broaden and deflect around Cypress Swamp. This seeming anomaly may be due to lack of gravity stations in the area. However, Benson (personal communication) points out that surface drainage is radial from the Swamp and that the area appears to be topographically unique on the Delmarva peninsula.

TEMPERATURE LOGGING

Well Numbering System

The DOE test holes drilled in Delaware are referred to in this report by the DOE well number. Other wells are referred to by the DGS well numbering system which is described in any number of DGS publications (Rasmussen and others 1960). A table showing the correlation between the DOE well number and the DGS numbers is found in the Appendix.

Data Collection

The contract called for DGS to log two of the nominal 1,000 foot (300 meters) test holes drilled in Delaware by DOE. DOE holes in nearby states could be logged at the request of DOE with mutual agreement between DGS and the Geological Surveys of the adjacent states. Other holes in Delaware of suitable depth and location that might become available during the contract period were also to be logged.

The temperature sensor used in this study is a Fenwal K2502 thermistor mounted at the end of a brass probe approximately 18 inches long and $1^7/_8$ inches in diameter. The probe mates to a 4-conductor logging cable of the DGS geophysical logger. All internal electrical connections in the probe were potted in epoxy and the probe body was filled with a lightweight oil. The open circuit or leakage resistance of the cable pair used for the sensor signal was greater than 100 x 10^6 ohms in air and about 2 x 10^6 ohms at the end of a logging run in a fluid filled bore hole or well. A shorting plug was constructed to fit the cablehead at the end of the logging line so that the logging line resistance could be measured before and after a logging run. The thermistor resistance was measured directly with a Fluke 8500A Multimeter in a 4-wire lead configuration. This instrument also has an internal memory which will store the value of lead resistance (in this case the logging cable resistance) and automatically subtract it from the total measured resistance which includes the thermistor resistance plus the lead resistance. The maximum change of cable resistance over the range of temperatures encountered in the 1,000 foot deep test holes is calculated to be about 0.4 of an ohm. During logging, the thermistor resistance values were entered directly into a desk calculator and printer which had been programmed to print out the temperature for the corresponding depth.

Temperature measurements were made at five foot intervals (1.5 meters) in two holes (DOE No. 35, Jb54-1), and at ten foot intervals (3.0 meters) in all other holes. Experience with the first two holes indicated that the 10-foot interval provided sufficient data points for the purposes of the study. Usually it took only a few seconds at any given depth for temperatures to stabilize. Occasionally, temperatures could be seen to "cycle" through a range of a few hundredth's of a degree centigrade at a given depth. Similar phenomenon was noted by Dashevsky (personal communication) of VPI and SU and has been attributed to convection cells in the water column within the well casing.

Temperature data were punched on IBM cards and a duplicate card set was submitted to VPI and SU for comparison with temperature measurements made earlier in their program.

Results

All five of the DOE test holes in Delaware and one private well were temperature logged (see Figure 2 for location). The gradients at the indicated intervals (Figures 3, 4, and 5) were

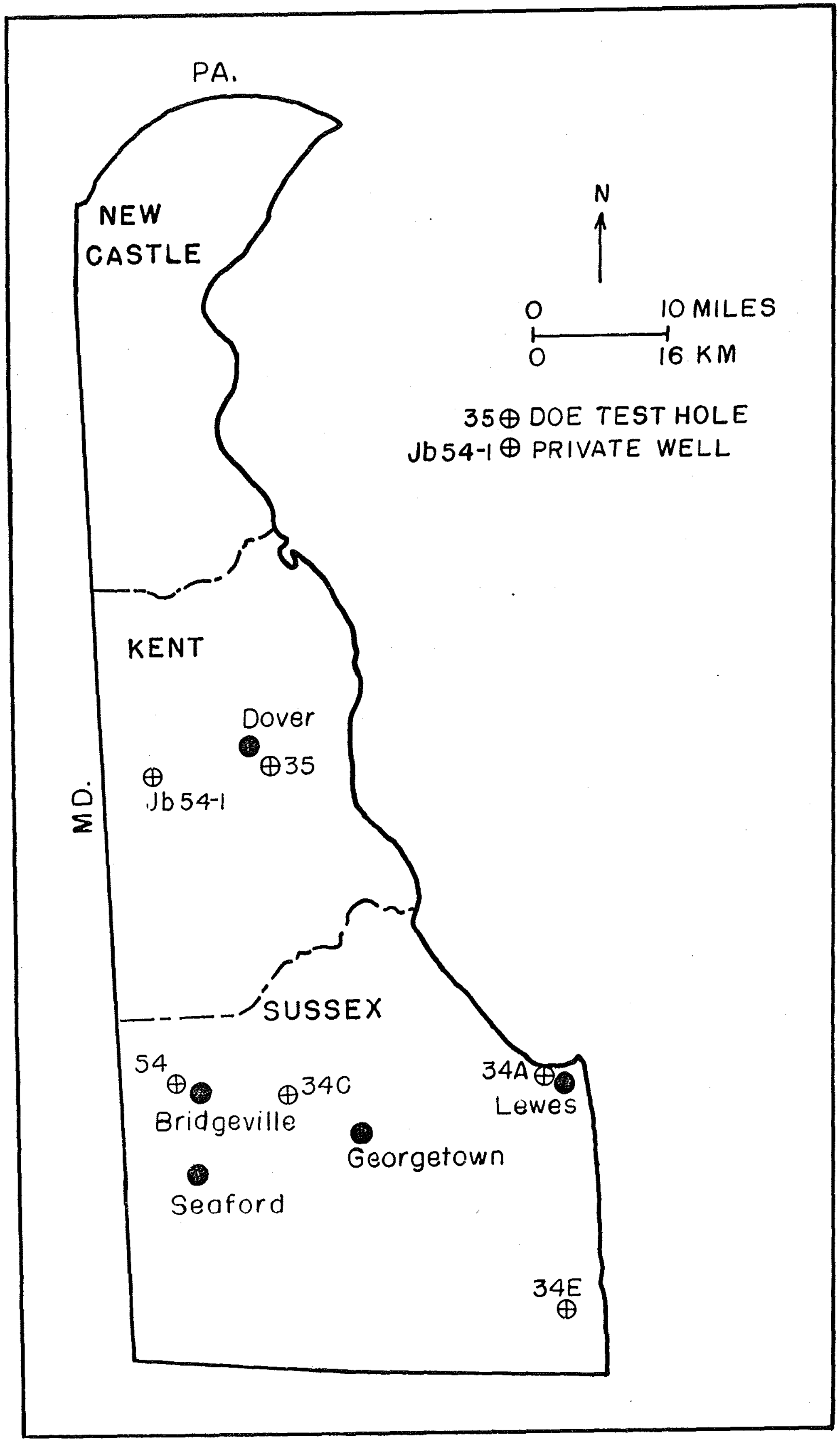

Figure 2. Map showing location of wells logged in this study.

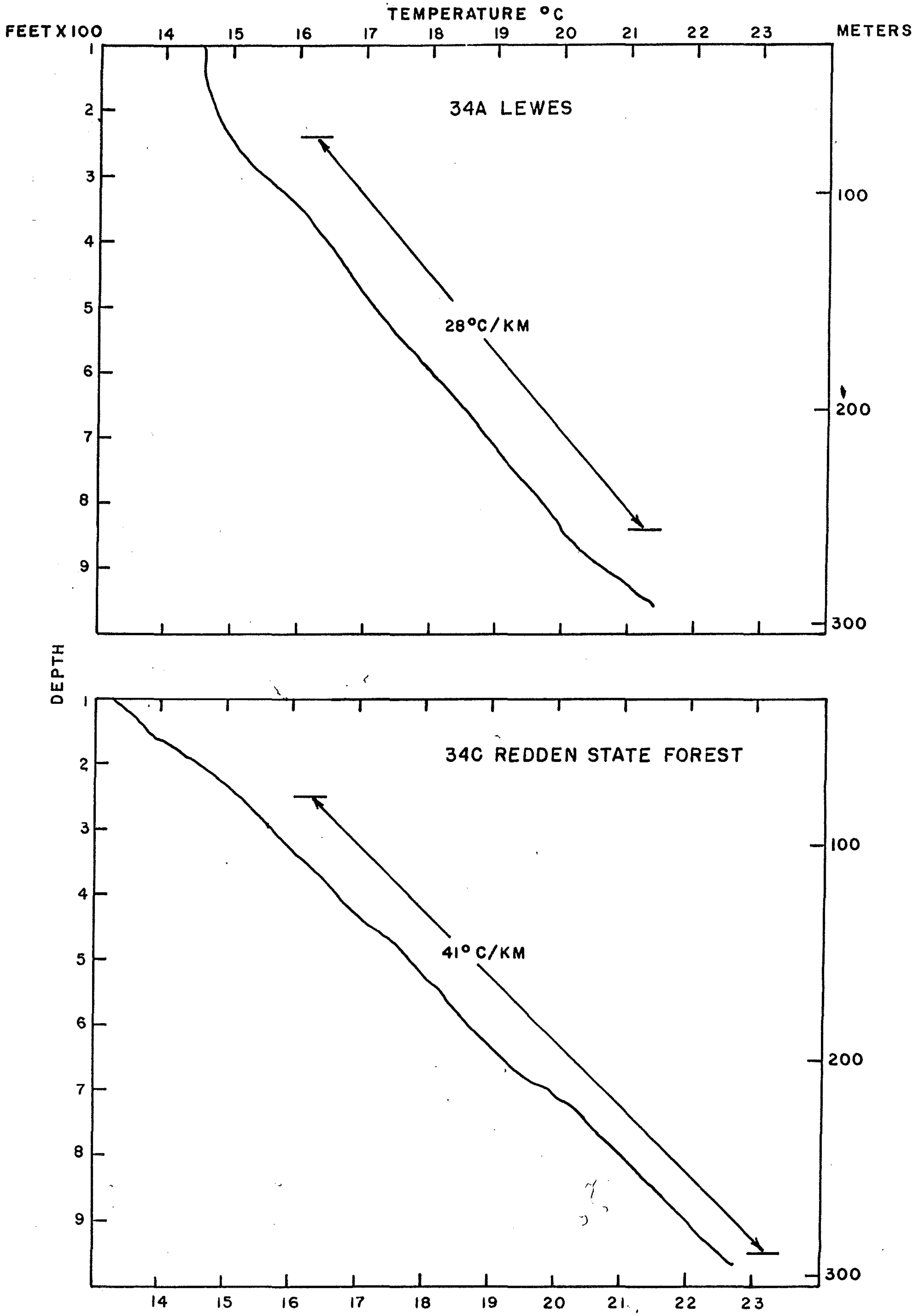

Figure 3. Temperature profiles in DOE test wells 34A and 34C.

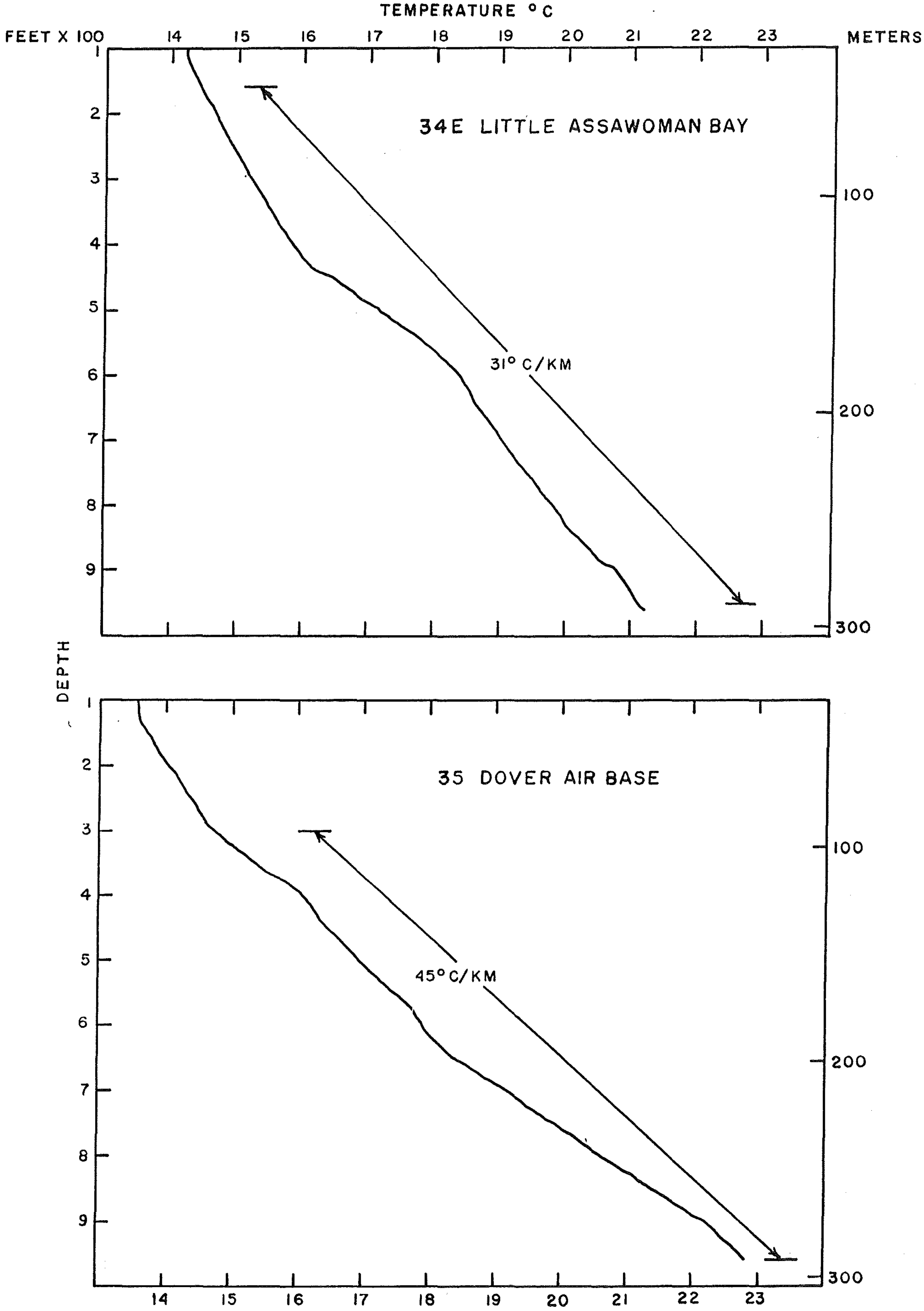

Figure 4. Temperature profiles in DOE test wells 34E and 35.

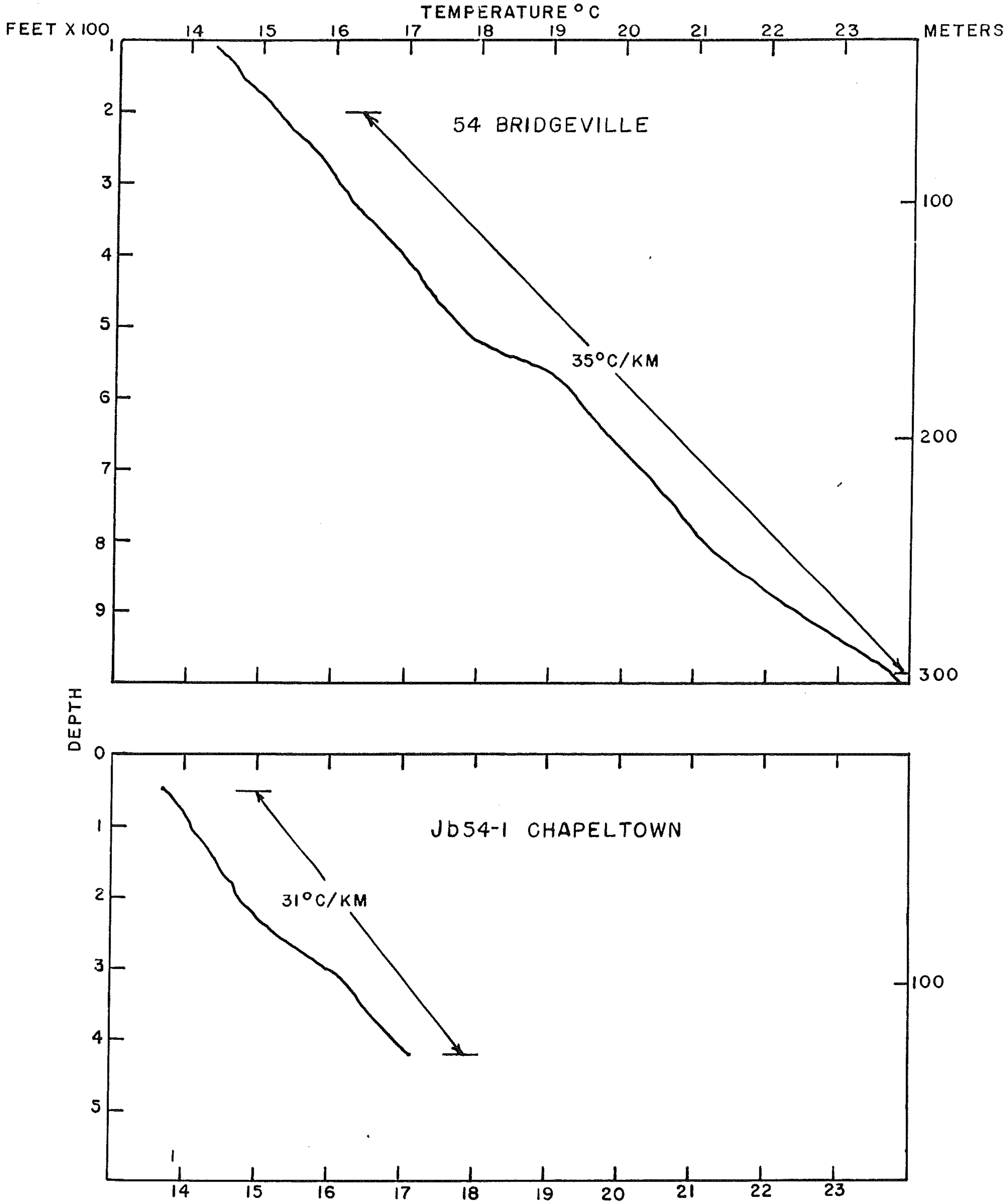

Figure 5. Temperature profiles in DOE test well 54 and domestic well Jb54-1.

calculated by fitting a least squares straight line to the data points. The gradients may vary as much as several degrees centigrade depending upon the depth intervals that are chosen to calculate the gradient.

The influence of ground-water circulation is apparent in at least the upper 100 feet (30 meters) of the DOE holes and results in gradients that are lower than in deeper portions of any given hole. Thus, data from the upper portions of the holes were not used in calculating the temperature gradients. The highest gradient found was in the Dover Air Force Base hole (DOE No. 35) - 44.5°C/km (see Figure 4). The lowest gradient measured in this study was in the Lewes hole (DOE No. 34A) - 27.9°C/km (see Figure 3).

Throughout the study DGS maintained liaison with the Delaware Department of Natural Resources and Environmental Control, Division of Environmental Control, Delaware's well permitting agency, in order to learn of wells scheduled for construction by private contractors. A particularly hard winter and wet spring during the contract period considerably slowed drilling activity in the State and only one new private well (Jb54-1) was suitable for temperature logging. Other wells drilled during this time were generally too shallow or had pumps installed immediately after well completion.

Before the contract between DOE and DGS was in effect, DGS identified a number of existing wells that were potentially suitable for temperature logging. Field checking showed that two such wells, Og31-1 at Gravel Hill, and Nc13-1 at Greenwood, could be logged. These two wells were subsequently logged by VPI and SU. Higher than normal gradients were encountered in well Nc13-1 and this eventually led to DOE Well No. 54 being drilled near Bridgeville, a few miles south of Nc13-1. Measurements in the Bridgeville well confirmed the relatively high local gradients suggested by the temperatures in the Greenwood well.

OTHER LOGGING

DGS logging equipment was used to run standard electric logs in four of the five DOE test holes drilled in Delaware. The hole at Lewes (No. 34A) was not logged because of caving in the hole. Several attempts were made by the drilling contractor to clean the hole but it was not possible to log below a depth of about 130 feet. Gamma logs were later obtained in all five of the cased holes after construction had been

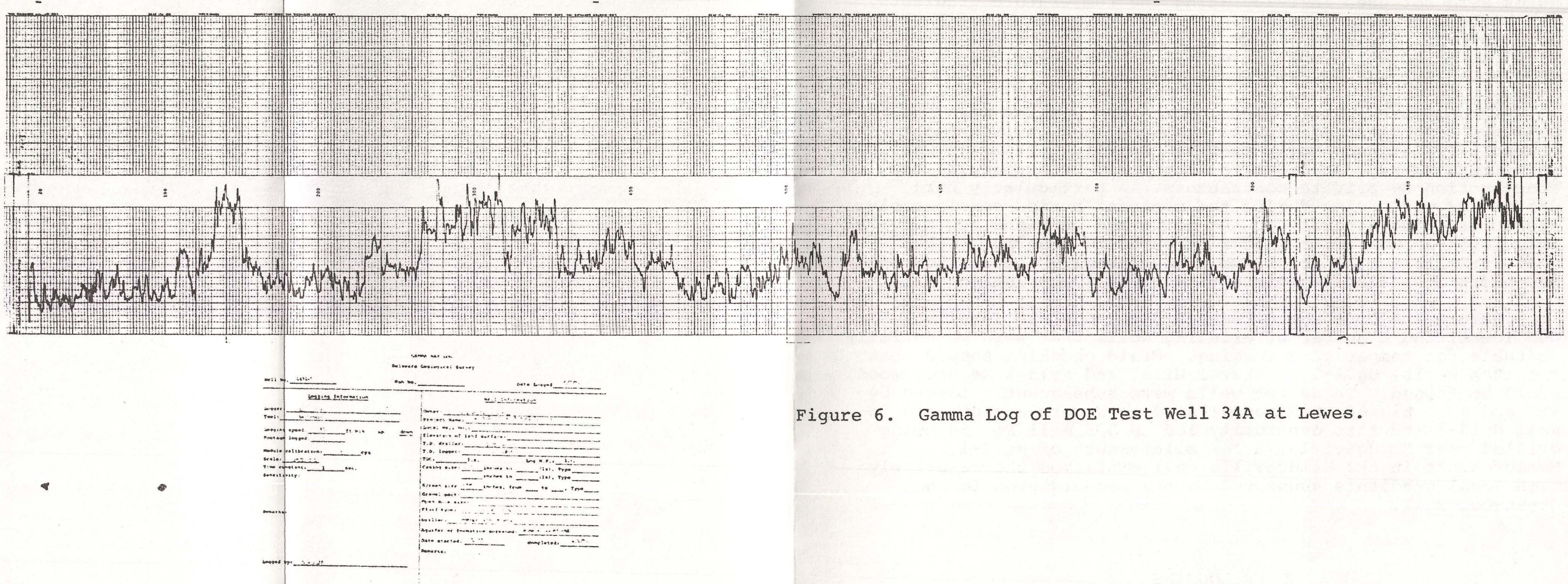

Figure 6. Gamma Log of DOE Test Well 34A at Lewes.

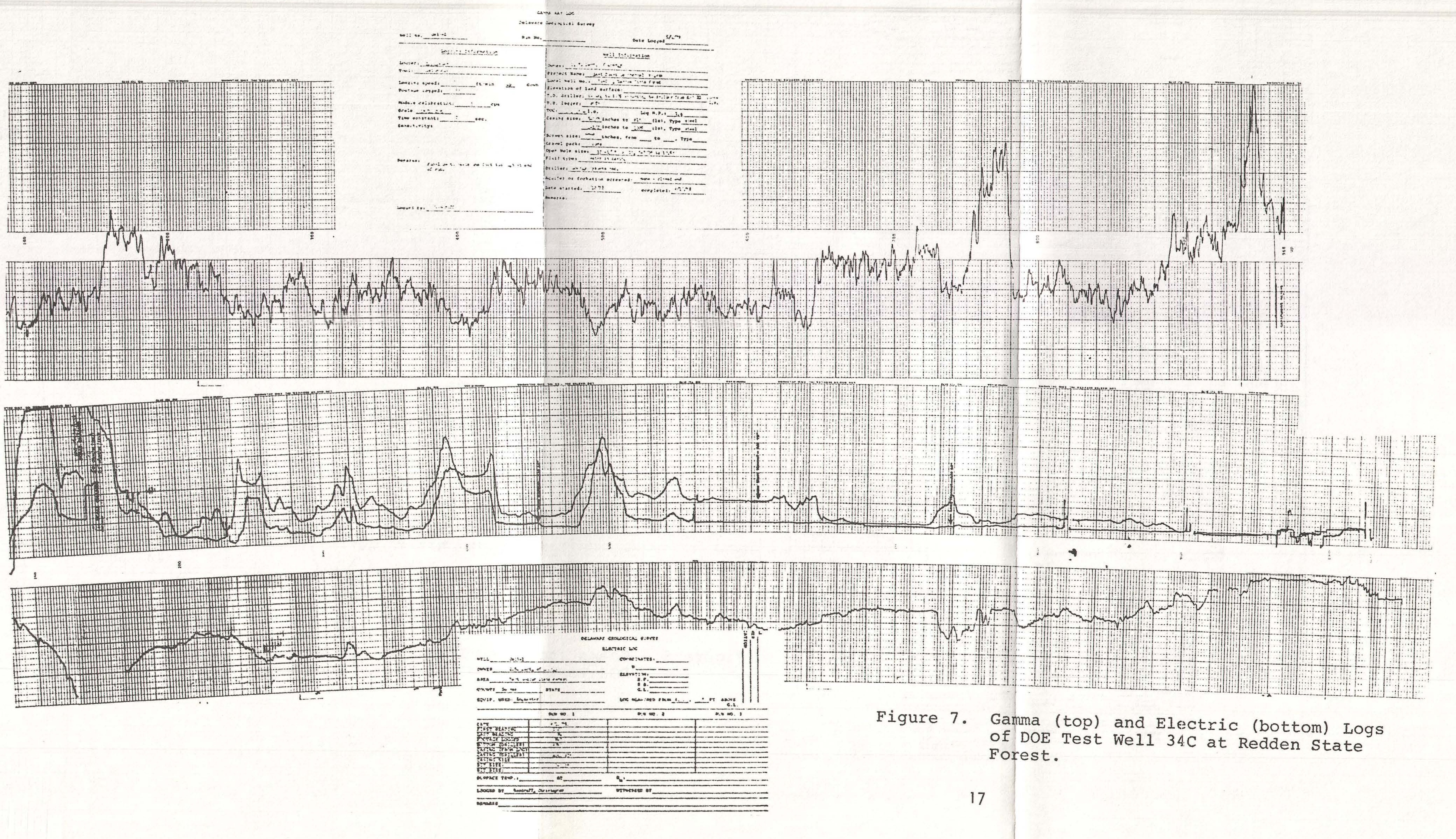

Figure 7. Gamma (top) and Electric (bottom) Logs of DOE Test Well 34C at Redden State Forest.

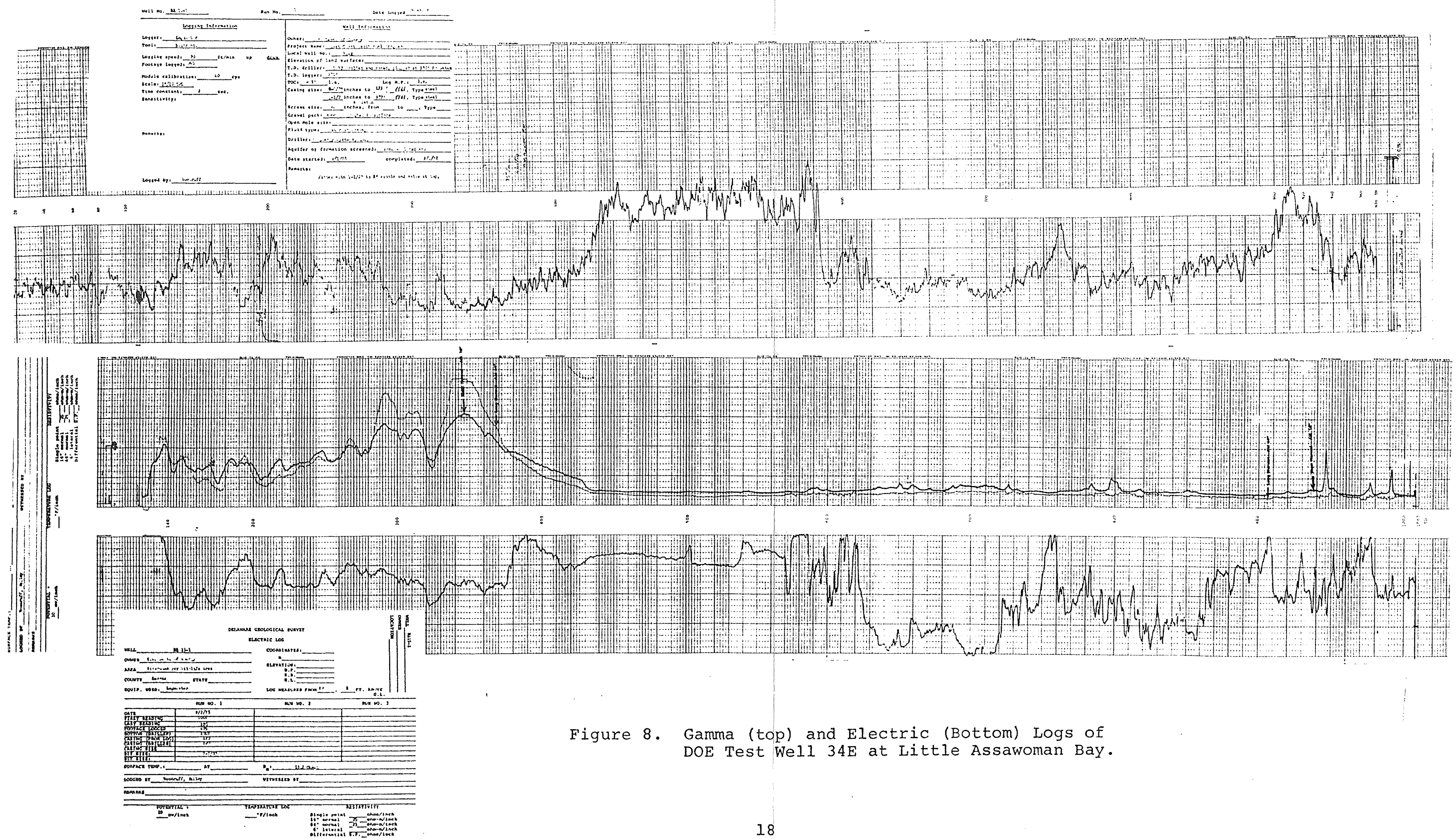

Figure 8. Gamma (top) and Electric (Bottom) Logs of DOE Test Well 34E at Little Assawoman Bay.

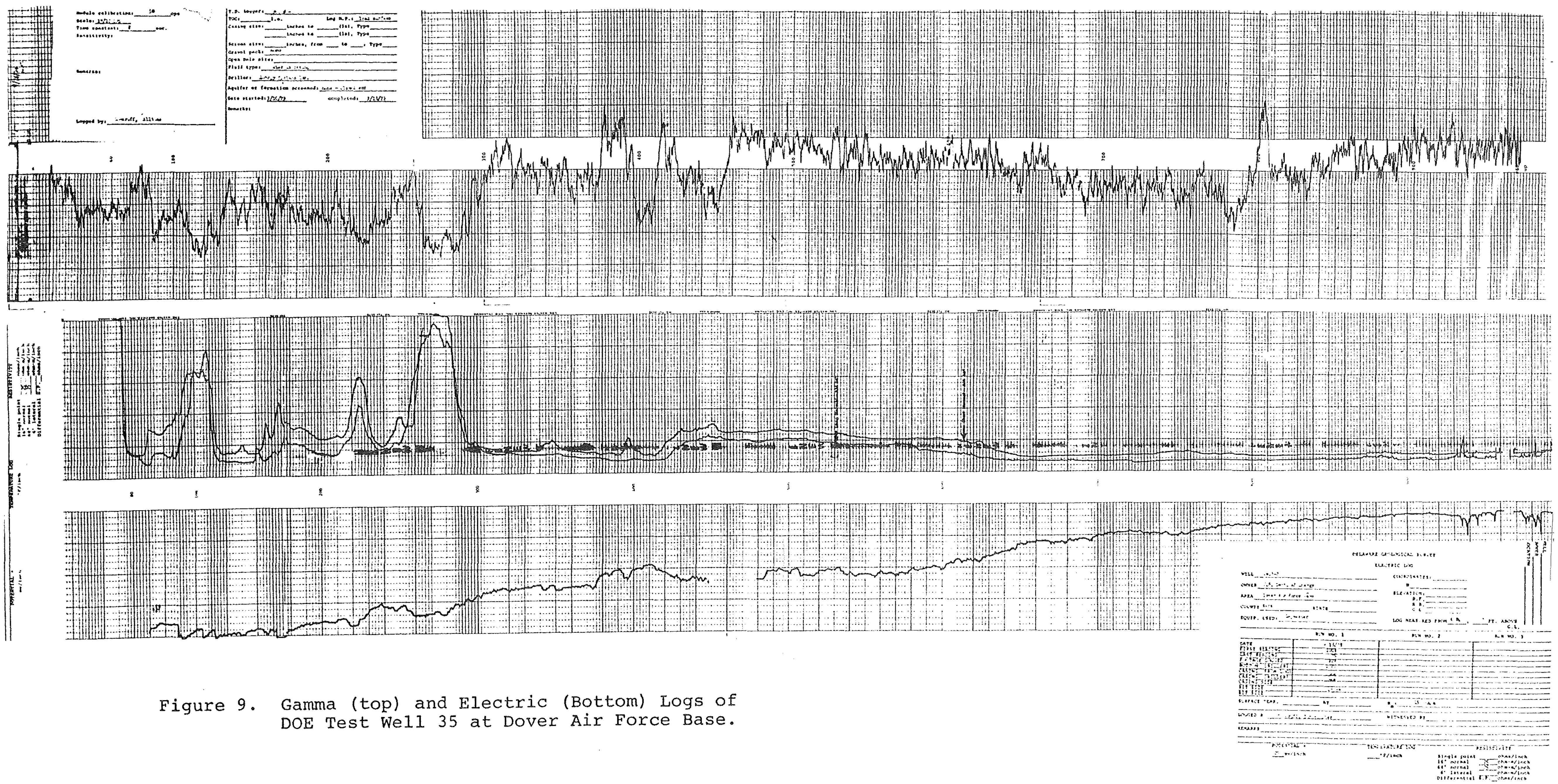

Figure 9. Gamma (top) and Electric (Bottom) Logs of DOE Test Well 35 at Dover Air Force Base.

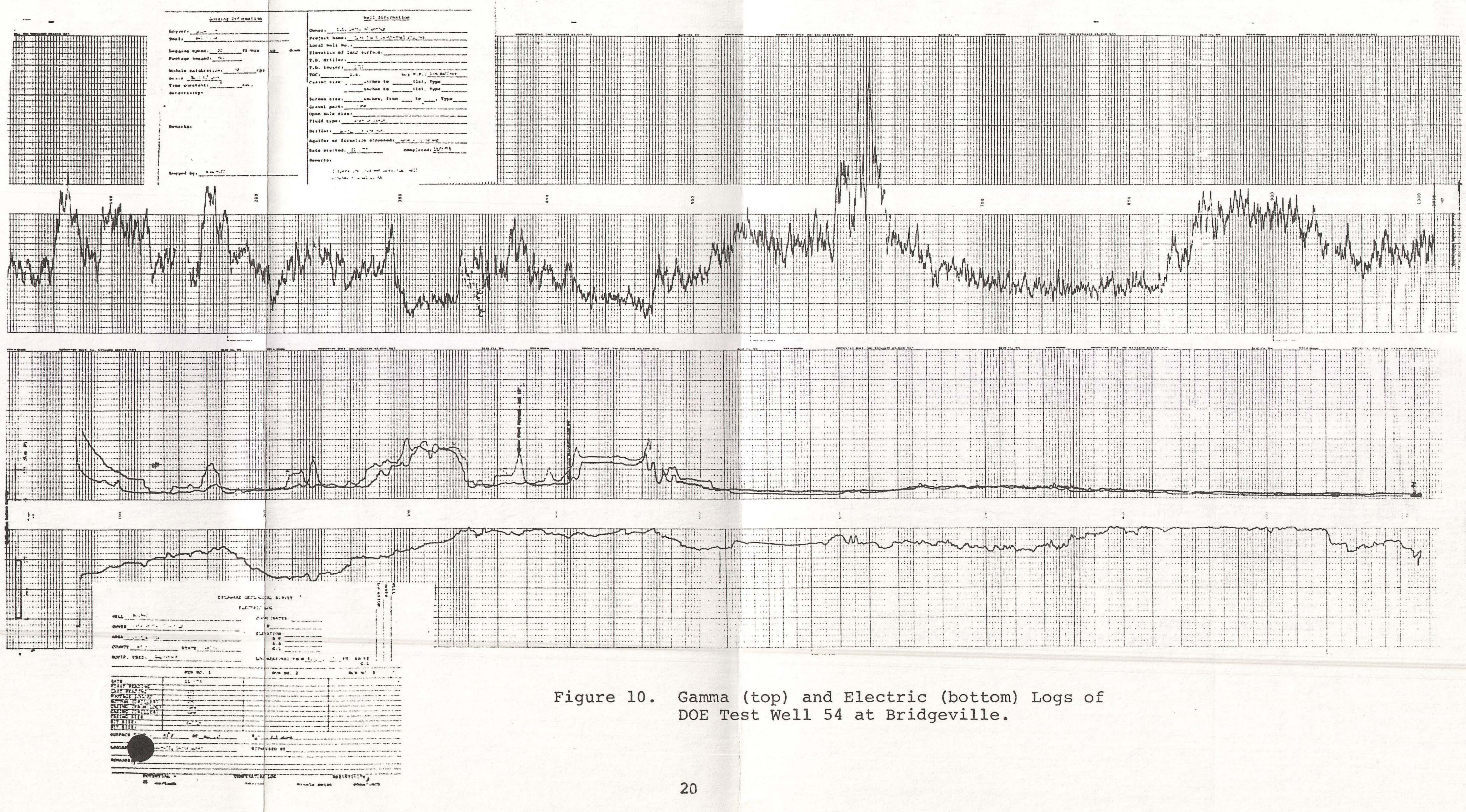

Figure 10. Gamma (top) and Electric (bottom) Logs of DOE Test Well 54 at Bridgeville.

completed. The logs are presented in Figures 6 - 10. Copies of the field logs were submitted to the Department of Geological Sciences at VPI and SU and the originals remain on open file with the Delaware Geological Survey.

The 3/16" logging cable used in the DGS logging unit was over ten years old and was damaged in several places before initiation of the present study. In anticipation of further logging activity and possible sidewall coring in support of the DOE program, a heavier logging cable and winch assembly was purchased according to contract terms. By contract amendment, a used van truck was also purchased to replace the logging vehicle used in the beginning of the contract period. There was no increase in funding for this latter purchase. The vehicle used up to this time was routinely 800 to 1,000 pounds over the specified gross weight and frequent replacement of tires and other parts was common.

The logs and drilling samples were analysed by DGS staff and preliminary stratigraphic interpretations were provided on request. Richard N. Benson (DGS) provided tentative identification of microfossils separated from splits of the cores taken in each hole.

ADMINISTRATIVE AND FIELD ASSISTANCE

Copies of all pertinent DGS publications and unpublished open file data were provided to DOE's contractors in the initial phases of the program. Such data were used to help select the DOE test drilling sites in the State.

Initially, land owners of potential sites were contacted by DGS and preliminary clearances were obtained. The sites were then field checked with a representative of Gruy-Federal, Inc. - the drilling management firm, and a representative of the land owner. Every attempt was made to utilize State or Federal properties in order to minimize access and other legal problems. Final site selection was then made in consultation with VPI and SU and Gruy-Federal, Inc. Some documentation of these activities has been provided by Cobb and others (1979) and additional documentation can be found in letters and memorandum on file at DGS. It should be emphasized that the overall DGS role in this phase of the DOE work in Delaware was one of advisement and field assistance. The general target areas had already been selected by others. Likewise, DGS has no regulatory or permitting functions. However, information was provided to the other DOE contractors on all pertinent regulations including well permitting and the licensing and registering of drilling contractors and geologists. DGS staff remained at each drilling site during the drilling in Delaware and on occasion provided assistance to VPI and SU in sample collection and storage. Liaison was also maintained with Gruy-Federal, Inc. during the hole abandonment phase of the project in order to insure the proper disposition of the wells in accordance with the wishes of the various State agencies.

SUMMARY AND INTERPRETATION OF PROJECT RESULTS

Geothermal Applications

In general, the temperature gradients calculated for the DOE holes drilled in Delaware are encouraging and indicate the possibility of a low temperature geothermal resource. Temperature gradients in two of the holes, No. 35 at Dover and No. 34C at Redden State Forest, are at least twice the normal temperature gradient of about 20°C/km (1.2°F/100 ft) calculated for the Delaware Coastal Plain and adjacent areas (Neiss, 1979; Woodruff, 1976). Temperature gradients in some portions of all of the holes logged in this study are higher than the normal gradient indicated above. A correlation between temperature gradients and Bouguer gravity anomalies is not entirely clear at this time using only the Delaware data. However, the Bridgeville test hole is located nearly in the center of a gravity low and has a temperature gradient of about 35°C/km, considerably above normal. The well at Redden State Forest (No. 34C) to the east has an even higher gradient (approximately 41°C/km) but the negative Bouguer anomaly at this location is about 9 milligals lower (more positive) than at the Bridgeville site. The Dover test hole has the highest temperature gradient of all of the holes measured in Delaware to date. At the moment, this location does not correlate with any outstanding feature on the gravity map. There is the suggestion of a small closed gravity low just to the west, centered in the Camden area. However, more gravity stations are needed in the Camden-Dover area to better define this feature.

Gravity data as a whole are not inconsistent with the known or postulated tectonic history of the Delmarva Peninsula (Brown and others, 1972; Sheridan, 1974; Spoljaric and others, 1976) and suggest that basement faulting played an active role. This in turn suggests that possibly some higher than normal temperature gradients could be associated with basement structural features. As yet, no basement hole has been drilled in Delaware south of southern New Castle County and thus basement type has never been directly sampled.

Other Applications

The data obtained from the DOE test holes has immediate application in two other areas: (1) study of the ground-water resources of the State and, (2) geologic correlations and development of a State-wide stratigraphic framework. One of the questions frequently encountered by the Delaware Geological Survey is the depth to the fresh-salt water interface in southern Delaware and the depths and locations of various sandy zones or aquifers. The combination of electric and gamma logs were extremely valuable in helping to answer some of these questions. For instance, the set of logs from DOE hole No. 34E at Little Assawoman Bay (Figure 8) indicates the presence of relatively thick Miocene sands from the top of the hole to about 400 feet. These are correlative with previously mapped aquifers in the area. However, deeper sands, not previously known to exist with certainty, are indicated between about 600 feet and 900 feet on the gamma log. These sands however contain water with relatively high total dissolved solids as indicated by the long normal curve of the electric log. Indeed, the fresh-salt water interface can be determined quite accurately in this hole by use of the electric log.

Likewise, the coring operations in the Little Assawoman Bay hole indicated the presence of consolidated sandstones at depth (about 940 feet). This was the first time that the presence of consolidated rocks at these relatively shallow depths had been sampled in the subsurface of southern Delaware. It is possible that this zone could be a valuable seismic marker although the extent of this indurated bed (or zone) is still unknown.

Both the drill cuttings and the cores from the DOE holes will be used in a continuing DGS study of the biostratigraphic zonation of the Coastal Plain sediments. This is a necessary step in helping to determine the history of sediment deposition and the relationship of this history to resource potential.

RECOMMENDATIONS

Based on temperature gradients, thickness of Coastal Plain sediments, and gravity data it is recommended that further drilling in Delaware should initially be concentrated in a triangle formed by joining with an imaginary line the communities of Bridgeville, Seaford, and Georgetown. It is true that the highest gradient found in the Delaware test holes was at the Dover Air Force Base. However, the thickness of Coastal

Plain sediments at this location is estimated to be only about 3,000 feet (915 meters). This would limit bottom-hole temperatures to about 53°C (127°F). In southern Delaware, basement is at least twice as deep as at Dover so that even though gradients are somewhat lower, higher bottom-hole temperatures might be obtained. Among other things, testing should be concerned with accurately determining aquifer parameters, preferably by conventional water-well techniques using properly sized well screens. Experience in northern Delaware in the same formation likely to be tapped by a geothermal well in southern Delaware indicates that reservoir values cannot be extrapolated beyond a few miles.

The most favorable locations for further testing from a geologic standpoint may not necessarily be the most favorable from an economic or user standpoint. The Lewes area for instance has a number of potential users and offers an attractive possibility for a multiple use application of low temperature geothermal resources. However, the temperature data indicate that the Lewes test well had the lowest gradient of the five DOE holes in Delaware. Thus it may be necessary to balance the potential demand with the most favorable geologic situation.

Results of the gravity survey should be compared with the aeromagnetic data obtained by DOE under contract to the U. S. Geological Survey. DGS has no contractural arrangements in this portion of the DOE work along the east coast except to assist in possible interpretation when requested. It should be noted that aeromagnetic work was initiated when it was pointed out by DGS that no coverage existed in Delaware comparable to coverage in adjacent states. The final aeromagnetic data is not yet available from the subcontractor (Zeitz, personal communication) so this comparison cannot be made at the moment.

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APPENDIX

Department of Energy
Washington, D.C. 20545

June 20, 1978

Dr. Kenneth Woodruff
Assistant State Geologist
Delaware Geological Survey
University of Delaware
Newark, Delaware 19711

Dear Ken:

The enclosed draft material reflects my understanding of our recent telephone conversations about the proposed contract between the Delaware Geological Survey and DOE. Our Chicago office should be contacting you on this matter in the near future.

Sincerely,

David B. Lombard
Division of Geothermal Energy

Enclosure

STATEMENT OF WORK

SUMMARY

A. Products

The work described here would make available at the end of one year, or within the year, according to project demands:

1. Bouguer gravity map of parts of Kent and Sussex countries, Delaware,

2. Consultation to DOE and its contractors with regard to selection of site areas for three to five wells to measure heat flow, and if necessary) one geothermal exploratory well.

3. Consultation to DOE and its contractors with regard to selection of specific sites within the areas denoted in (2) above,

4. Assistance to DOE contractors in preparing and filing drilling permits for the wells denoted in (2) above,

5. Consultation with DOE and its contractors with regard to selection of coring points in any or all of the wells denoted in (2) above,

6. Geophysical and temperature logs in two of the heat flow wells denoted in (2) above, wells to be selected by Delaware State Geologist,

7. Temperature and/or geophysical logs from available wells in states adjacent to Delaware; these wells are to be selected by the Delaware State Geologist in consultation with DOE, its contractors, and the State Geologist affected,

8. Temperature and/or geophysical logs from all wells in the Delaware coastal plain deeper than 500 feet that are suitable for logging,

9. Bottom hole cores in crystalline rock in available wells at Delaware locations to be selected by the Delaware State Geologist in consultation with the DOE and its contractors.

10. Assistance in the interpretation of aeromagnetic (and possibly aeroradioactivity) data and maps in the Delaware coastal plain, to be procured independently of this contract by DOE and USGS.

B. Applications

The data collected should:

1. provide a basis for interpretation of crystalline basement beneath the Coastal Plain of Delaware,

2. allow the calculation of temperature gradients at selected locations in Delaware and adjacent States,

3. help determine basement rock lithology at selected locations in Delaware,

4. be the basis for the siting of possible seismic reflection profiles and later test holes for the determination of heat potential of the basement rocks and surrounding sediments,

5. provide as a by-product, at minimum cost, support for the NURE program by means of radioactive mapping,

6. contribute to knowledge of stratigraphy and correlation of Coastal Plain units in Delaware that may be geothermal insulators or reservoirs at future test drilling sites.

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CORRELATION OF DOE-DGS WELL NUMBERS

DOE No.	Location	DGS No.
34A	Lewes	Ni31-7
34C	Redden State Forest	Oe13-1
34E	Little Assawoman Bay Wildlife Area	Ri15-1
35	Dover Air Force Base	Je43-2
54	Bridgeville	Nc43-2
--	Chapeltown	Jb54-1

PLATE I. BOUGUER GRAVITY MAP OF SOUTHERN DELAWARE