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Evaluation of Hot Dry Rock Exploration Techniques in the Atlantic Coastal Plain: A Test Site on the Delmarva Peninsula of Maryland and Virginia

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Evaluation of Hot Dry Rock Exploration Techniques in the Atlantic Coastal Plain: A Test Site on the Delmarva Peninsula of Maryland and Virginia

D'Appolonia Consulting Engineers, Inc.*

This report is HDR Site Selection Report No. 4.

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Contract No. 4-X29-77456-1
1979

EVALUATION OF HOT DRY ROCK EXPLORATION TECHNIQUES IN THE ATLANTIC COASTAL PLAIN: A TEST SITE ON THE DELMARVA PENINSULA OF MARYLAND AND VIRGINIA

by

D'Appolonia Consulting Engineers, Inc.
(Introduction by M. J. Aldrich)

ABSTRACT

Detailed investigation of a potential Hot Dry Rock (HDR) energy extraction site in the area of Crisfield, Maryland, and Wallops Island, Virginia, (referred to as the "Cris-Wall" site) was carried out to evaluate HDR exploration techniques in the Atlantic Coastal Plain province. The findings favor the following HDR exploration program for locating a deep test hole in an area with presumed HDR potential (higher than normal heat flow):

(1) Use aeromagnetic and gravity maps to infer basement rock types and depth to the basement surface.

(2) Plan and obtain seismic reflection profiles to provide additional information, if required by the stratigraphy, or location of faults, structure, and depth to basement.

(3) Use existing wells and/or new shallow (∿300-m-deep) wells located within the area of interest to obtain data for making lithologic correlations and to measure heat flow.

(4) Obtain additional seismic coverage and drill deeper exploration wells at sites that look especially favorable.

(5) At each of these sites use an electrical technique, which is suitable for evaluating the nature of the fractures and water saturation in the basement rocks.

Six potential sites for extracting HDR energy have been identified within the Cris-Wall area. Each site is thought to have temperatures at the basement rock surface in excess of 75°C and to be at least 1 km away from the nearest fault.

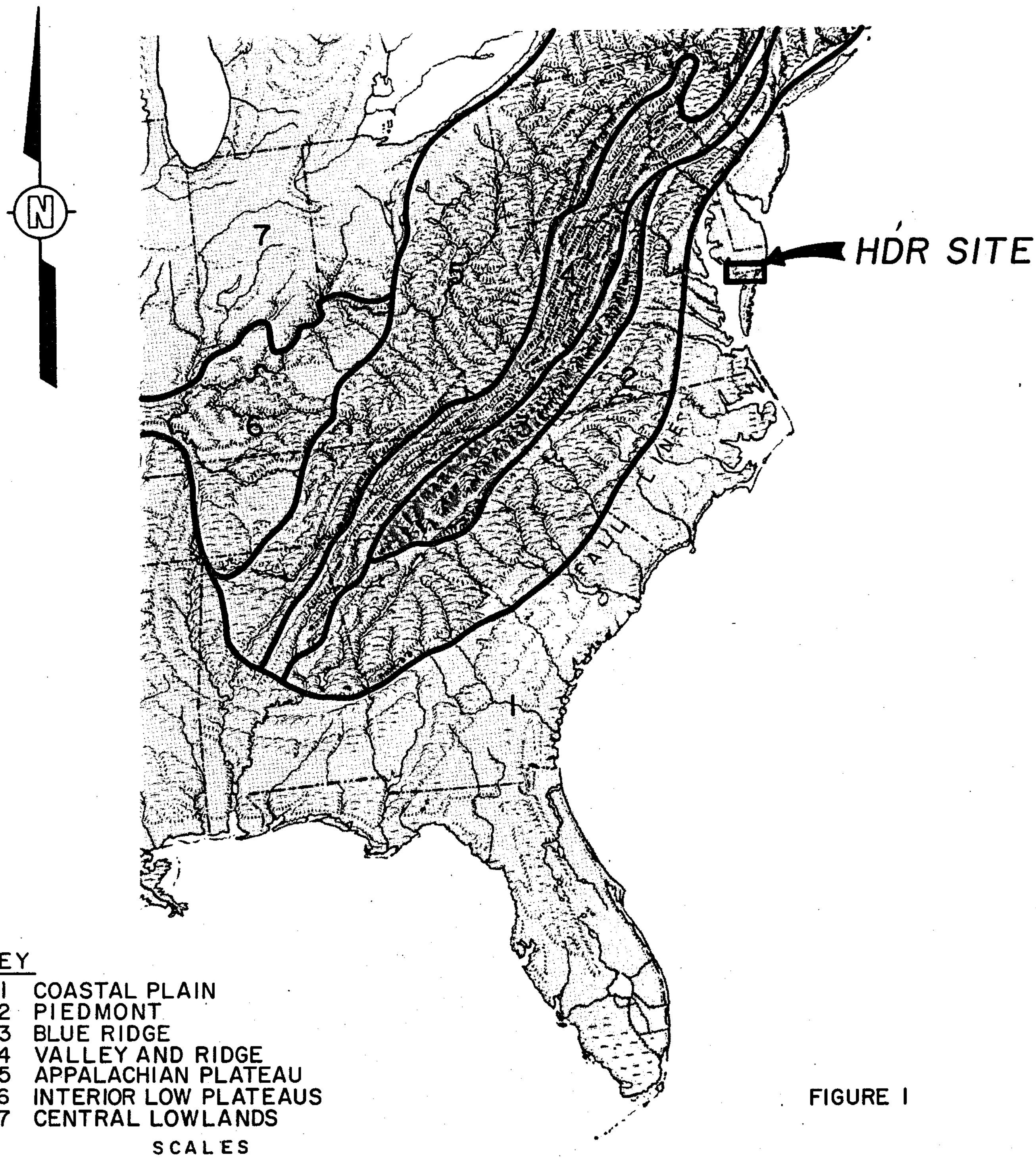
I. INTRODUCTION

As part of its effort to assess the Hot Dry Rock (HDR) resource of the United States and to locate favorable sites for extracting heat from HDR, the Los Alamos National Laboratory is evaluating various HDR exploration techniques in different geological settings. The Atlantic Coastal Plain province was selected for HDR exploration methodology tests because the largest part of the geothermal energy resource base in the eastern United States is possibly in that area. Investigators at Virginia Polytechnic Institute and State University (VPI&SU) have developed a model in which Piedmont-type radiogenic plutons (~300 Myr old) buried beneath thick insulating Coastal Plain sediments provide heat sources that may be suitable targets for geothermal energy extraction.

D'Appolonia Consulting Engineers, Inc. was contracted (Contract No. 4-X29-77456-1) by Los Alamos National Laboratory in 1979 to study a site (Cris-Wall) in the vicinity of Crisfield, Maryland and Wallops Island, Virginia (Fig. 1) that was thought to overlie a deeply buried heat source. The final report (D'Appolonia, 1980) has been placed on file in libraries of the Los Alamos National Laboratory; U.S. Geological Survey (at Denver, Colorado; Menlo Park, California; and Reston, Virginia); Georgia Geological Survey; Maryland Geological Survey; New Jersey Geological Survey; North Carolina Department of Natural Resources and Community Development (Geological Survey Section); and Virginia Division of Mineral Resources. It contains considerable geological and geophysical data on the site and surrounding area. The Table of Contents in the report is reproduced in the Appendix.

The purpose of this report is to present Sections 5 and 6 of the D'Appolonia (1980) report, which summarize the conclusions and recommendations dealing with three objectives of the study:

- Evaluate exploration methodologies as they pertain specifically to Coastal Plain sites and generally to eastern U.S. sites,
- Evaluate the HDR potential of the Cris-Wall site in greater detail than heretofore accomplished,
- Target a deep test well or recommend additional research work, if appropriate.



KEY
1 COASTAL PLAIN
2 PIEDMONT
3 BLUE RIDGE
4 VALLEY AND RIDGE
5 APPALACHIAN PLATEAU
6 INTERIOR LOW PLATEAUS
7 CENTRAL LOWLANDS

SCALES

0 100 200 300 400 MILES

0 200 400 600 KM

FIGURE 1

PHYSIOGRAPHIC PROVINCES OF THE EASTERN UNITED STATES AND HDR STUDY SITE LOCATION
(D'APPOLONIA, 1980 - FIG. 1-1)

REFERENCES:

U.S. DEPT. OF THE INTERIOR, GEOLOGICAL SURVEY, 1970, THE NATIONAL ATLAS OF THE UNITED STATES OF AMERICA, PHYSIOGRAPHIC DIAGRAM, P.59, SCALE 1:17,000,000.

SHIMER, J. A., 1972, FIELD GUIDE TO LANDFORMS IN THE UNITED STATES, Mac MILLAN PUBLISHING CO., NEW YORK, 272P.

The two sections from the D'Appolonia report follow. They are reproduced without modification except for minor editing corrections.

II. HOT DRY ROCK EXPLORATION (D'Appolonia, 1980, Section 5)

A task of this project is to evaluate HDR exploration techniques so that suitable strategies for potential further work in the Atlantic Coastal Plain and other similar environs can proceed more effectively. The following sections discuss the philosophy of planning explorations and review the exploration experience of this project. These discussions emphasize the Atlantic Coastal Plain geologic setting; however, many of the judgments are applicable to any site with a deep (on the order of one to several kilometers) soil and sedimentary rock cover.

A. Exploration Planning

Exploration or site confirmation plans should consider:

- Project phase,
- Existing knowledge of territory or site,
- What must be determined, and
- Capabilities of techniques.

The phase of the project determines the required areal extent and the level of detail that can be achieved. For initial reconnaissance, highly mobile, relatively inexpensive arrays are frequently used to cover the territory of interest. The final project exploration step, which normally is deep drilling to or into the target of interest, usually is the most expensive. The reconnaissance type techniques normally lack the precise determinations made possible by deep drilling, but offer a basis upon which to delineate subareas for more intensive efforts. Subsequent, more detailed surveys generally are planned on the basis of existing information to resolve important interpretation conflicts or ambiguities, and to obtain specific information from a limited area of highest interest.

As knowledge about the site is developed, a model to integrate the data should be formulated. This model is subject to continual refinement or revision as new facts require. The factors incorporated should be determined, in part, by the requirements of an HDR system. The expected range of characteristics of a potential HDR resource form the basis of what must be determined. This should include a geologic model as well as a conceptual appreciation of the functional requirements of an HDR extraction system. For exploration in the Atlantic Coastal Plain geologic setting, the principal basement basement rock mass (HDR resource body) characteristics sought are:

- Depth. This has a major impact on ultimate costs of deep drilling and on resource temperature.

- Relative Temperatures. Areas of higher temperature are obviously sought to maximize energy recovery.

- Extraction Temperature. The expected extraction temperatures are critical toward defining potential uses or satisfying project use(s).

- Lithology. The fundamental rock mass characteristics have a major impact on heat generation and on ability to create and maintain a "closed" flow loop.

- Extent. The horizontal and vertical extent impacts the total amount of system energy, and the extent and flexibility of development.

- Quality. The degree of fracturing of the rock mass strongly impacts the ability to create and maintain a "closed" flow loop.

The above are considered positive factors, which if found suitable, support the location of a proposed deep drill site. Negative factors must also be considered. If present, these factors could preclude a successful HDR application:

- Active Convective Systems. Where active water convection is occurring, the insulating ability of capping sediments is circumvented, thus lowering the resource potential in the area affected.

- Rock Condition. Zones of faulting, shear, intense jointing, or other discontinuities that are potential avenues for loss of circulation fluid should be avoided.

- Seismicity. The development and operation of an HDR energy extraction system has the potential to increase local seismicity. If an area has high seismicity or is shown to have large unrelieved stresses, it should be avoided.

The factors that must be determined should be cast into site context so that exploration signatures or specific evaluation criteria can be formulated. These signatures or criteria can include, for example, size of geophysical anomalies, level of seismicity, minimum temperatures, and others.

The capabilities of various techniques to discern the information sought should then be evaluated. Those techniques which can acquire the needed information, on a technical basis, then must be reviewed as to practical matters such as site access, cost, schedule, etc., to finalize the plans. Figure 2 illustrates an issues versus technique capability matrix which evaluates the merits of various techniques in the Atlantic Coastal Plain. The scoring is on the following bases:

Number	Attribute
0	No or little expected contribution.
1	Can be used in support of other techniques or under special circumstances, may yield useful information regarding the issue.
2	It addresses the issue but requires the support of one or more other techniques to be fully useful.
3	A primary sole source of issue resolution or information, considering that deep drilling is not competition during the exploration stage.
4	Full issue resolution capability considering deep drilling.

Short of deep drilling, the suite of seismic reflection, magnetics, gravity, an appropriate electrical method, and shallow boreholes provide the best means of evaluating a site of limited areal extent. Two issues are not elucidated by these techniques: actual basement temperatures, and seismicity. The former requires deep drilling; the latter (in this area and in most other areas) can be resolved from the literature. The parameters, which should be those that are determined the most satisfactory, are the depth to basement and the lateral extent of lithologic units. Lithology and estimates of gross impacts of faulting and discontinuities on flow containment can be reasonably well determined or estimated. Basement temperatures may be poorly estimated; drilling is required to determine the actual temperatures. During the planning process, it was recognized that drilling, coring, and logging (to depth of about 300 m) to obtain heat flow values was a potentially valuable technique, but one that was costly, technically uncertain, and yielded data of very limited spatial extent. This study shows that an individual heat flow value is likely to be uncertain to ±0.1 HFU at best, and more likely, the uncertainty could be ±0.2 HFU. Preliminary theoretical models suggest that the heat flow over the site is unlikely to differ by more than 0.2 to 0.5 HFU. Additionally, considerations included the potential obscuring effects of weak but persistent lateral water flows and the uncertainty of calculating absolute temperatures of basement, which would require downward extrapolations of over one to several thousands of meters. Thus, it was concluded for this program that the existing heat flow data were sufficient and that gradients alone would be a practical expedient to estimate lateral relative temperatures. In other types of geologic provinces, it is anticipated that heat flow values within a small exploration area would have far more value.

The last stages of planning include laying out survey points or lines, drilling sites and depths, and specifying other important field survey parameters. If time permits, wide area coverage surveys such as aeromagnetics or gravity should be completed and analyzed first. Surveys that are moderately restricted as to coverage, such as seismic reflection and electrical, or very restricted, such as drilling, should be planned so as to appropriately balance the technical advantages of a relatively uniform coverage and the practical considerations of placing limited resources on the highest priority areas.

B. Project Experience

The techniques, as applied, performed closely to predictions. Each is discussed in some detail below, including some advantages, disadvantages, and practical experience of potential value to others.

1. Shallow Slim Hole Drilling. The project team originally targeted the thermal gradient holes for 213 m; however, discussions with the staff of VPI&SU who had experience in the area led to a revision to 300 m. The advice, which was taken, proved to be good. Three hundred meters is a good compromise between technical value and cost; however, it is recommended that future programs consider at least one and probably more borings to double that depth. These moderate depth borings should, if practical, be located at sites which look most promising rather than constitute a part of a program which attempts to provide uniformity of coverage (i.e., a statistical layout).

Three-inch casing was drilled in directly to a depth of 300 m (bits were abandoned) instead of using drilling rods. This method of drilling proved to be practical and efficient and worthy of consideration in any program where casing is required for hole stability to permit logging and where coring is not being attempted. Deeper depths can probably be obtained by this method, but only if drilling is nearly continuous to prevent setup of the mud on the outside of the casing. Coring would be possible if a more expensive bit were used which permitted wireline coring. In this area, as noted by others, coring is difficult and sample recovery is poor, except in clays.

2. Aeromagnetics. An aeromagnetic survey and analysis is highly recommended for a coastal plain wetting. The signal, although muted by the flight altitude and thick sedimentary cover, responds to basement conditions. Very detailed coverage can be obtained inexpensively (at the cost of one or two shallow boreholes). Unfortunately for the schedule of this program, an unusually stormy winter (meteorologically and magnetically) delayed the survey, thus precluding use of its results to effectively plan other surveys.

The analysis of individual magnetic profiles permits an estimate of depth to crystalline rock. The project experience was that at the few control points available, the magnetic estimates of depth to basement were entirely consistent. The estimated error of ±15% of depth appears very conservative. In areas where seismic reflection does not track the top of crystalline basement, magnetic data are particularly valuable. Magnetics is also one of the best means of detecting lateral changes in the lithology of basement rocks under deep cover.

The relatively low cost, high density coverage, and the ability to infer lithologic rock type distribution and geometry, all inherent in the magnetic technique, argue strongly for its consideration in any HDR exploration and especially one where there is deep cover.

3. Gravity. Gravity has many of the technical advantages of magnetics; however, the analysis, in practice, is less satisfying. In the project area, the magnitude of the gravity anomalies is small; they overlap each other, and are superimposed upon a somewhat complex regional gravity gradient. In the eastern half of the site, there is an eastward thickening wedge of high density sediments, which are nearly as dense as the average basement. These high-density sediments must be modeled accurately as any uncertainties here are directly translated to uncertainties in interpretations of intrabasement features. Unlike magnetics, where contact points can be predicted reasonably accurately if the orientation of the present earth's field and the profile are known, the location of the cause of a gravity anomaly (either free air or Bouguer) can be displaced laterally from the anomaly by unaccounted mass distributions. For example, a gravity low, thought to be an expression of a granitic pluton, can have its center point shifted several kilometers if the

effect of rapidly thickening sediment wedges are taken into account. We conclude that gravity has excellent potential; however, its ultimate resolving power is limited by knowledge of the actual topography of the basement and the density distribution of deeper sediments.

4. Electrical. The electrical techniques were considered primarily for their ability to detect planar conductors. It was believed that the deeper formation waters would be saline and highly conductive. Thus, major faults or fractures filled with this fluid would show up as either basement of anomolously low resistivity or as discrete planar conductors. Neither feature was found; the TDEM survey operated close to the detection limit for these features so an unequivocable evaluation of the value of the technique is not possible. The TDEM survey did pick up anomaly patterns, present in the basement or on the basement surface, which were consistent with the magnetic results. Considering the relatively higher cost of an electrical survey over an aeromagnetic survey, if only one were done, the aeromagnetic method would be preferred. An electrical survey, in a coastal plain environment, is probably best applied as a last step to detail and confirm a proposed drill site. In other geologic settings, or in broader regional reconnaissance programs, electrical surveys clearly would have more significance. The results of the electrical survey could be useful in resolution of pending issues regarding the location of aquifers for the current hydrothermal investigations in the Coastal Plain.

5. Seismic Reflection. Seismic reflection surveying in the Coastal Plain is relatively easy--there are numerous lightly-traveled roads and little topographic relief. Several good-to-excellent reflectors can be traced for long distances; however, crystalline basement cannot always be detected nor profiled over any significant distance. The documented presence of a very strong acoustic basement reflector which bears no relationship to crystalline basement, other than the fact that it is stratigraphically higher, can lead to erroneous extrapolations and interpretations of other geophysical data. The use of more simultaneous vibrators and higher-fold coverage than used in this study could improve the profiling of crystalline basement somewhat, but at increased expense. The targeting and predrilling estimates of a well drilled at the airport at Crisfield, Maryland faced this problem before it was fully recognized. Had this "first" well been drilled farther east, the difference between observed and predicted depth to crystalline basement would have been far larger.

III. CONCLUSIONS AND RECOMMENDATIONS FOR TARGETING OF DEEP TEST BORING (D'Appolonia, 1980, Section 6)

The Cris-Wall HDR site has been evaluated in accordance with the following project objectives:

- Evaluate exploration methodologies as they pertain specifically to Coastal Plain sites and generally to Eastern U.S. sites,
- Evaluate the HDR potential of the site area in greater detail than heretofore accomplished, and present this assessment,
- Target a deep test well, or any additional research work as part of recommended further action.

The results of these assessments are reiterated briefly below.

A number of exploration techniques were utilized to define a geologic and thermal model of the site from which the potential for HDR extraction is evaluated. The overall usefulness of the different techniques used in this project is presented in Fig. 2 and their effectiveness in terms of locating a deep exploration test well is summarized as follows:

- Shallow Borings. Shallow (300-m depth) borings are essential in that they provide the only basis for calculating heat flow and distinguishing any variations in heat flow necessary to estimate basement temperatures. These borings can be used as a reconnaissance tool. Deeper borings to approximately 600-m depth should also be considered after the most promising areas have been identified.
- Aeromagnetics. This method is the most cost-effective method for assessing basement lithology, structure, and depth to basement in a coastal plain environment. This method should be performed at the beginning of a project to locate favorable basement rock types and to locate fault zones that should be avoided.
- Gravity. The analysis of gravity data is also highly recommended to aid in the interpretation of basement geology from the aeromagnetic technique. The gravity method should not be used by itself to interpret basement conditions.
- Geoelectric Methods. Strong resistivity variations within the Coastal Plain sediments limit the effectiveness of these techniques to infer basement conditions, and the high costs associated with these methods preclude their use as a reconnaissance tool. Given these limitations, it is recommended that electrical techniques be considered, only when a favorable site has been identified and specific data about basement electrical properties are available.

TECHNIQUE / DATA OR SITUATION TO BE EVALUATED		ACOUSTIC				POTENTIAL FIELD					SHALLOW BOREHOLE		DEEP BOREHOLE
		ACTIVE		PASSIVE		MAGNETIC		GRAVITY	ELECTRIC	ELECTRO-MAGNETIC	LOG	CORE AND LOG	
		REFLEC-TION	REFRAC-TION	MICRO-SEISMIC	TELE-SEISMIC	CONVEN-TIONAL	CURIE POINT						
BASEMENT CHARACTERISTIC	DEPTH	3–4	2–4	0	0	2	0	1	1	1	0	0	4
	RELATIVE TEMPERATURE	0	0	0	0	0	2	0	0	1	1	2	0
	ABSOLUTE TEMPERATURE	0	0	0	0	0	0	0	0	0	0	0	4
	LITHOLOGY	0	1	1	1	2	0	2	1	1	0	0	4
	EXTENT	1	2	1	0	3	0	2	1	1	0	0	0
	QUALITY	0	1	1	0	0	0	0	1	2	0	0	2
OTHER FACTORS	CONVECTION	0	0	0–1	0	0	0	0	2	2	1	1	1
	FAULTS/FLOW CONTINUITY	3	1	1–2	0	1	0	1	1	1	0	0	1
	SEISMICITY	0	0	3	2	1	0	0	0	0	0	0	0

RATING KEY : POTENTIAL VALUE

4 : HIGH, PRECISE MEASURE

3 : A PRIMARY OR SOLE TECHNIQUE; OR "BEST THAT CAN BE DONE"

2 : POTENTIAL VALUABLE CONTRIBUTION; MAY REQUIRE SUPPORT FROM OTHER TECHNIQUES

1 : PRIME USE IS TO SUPPORT OTHER TECHNIQUES– MAY BE USEFUL IN SPECIAL CIRCUMSTANCES

0 : LOW TO NO CONTRIBUTION TO QUESTION

FIGURE 2

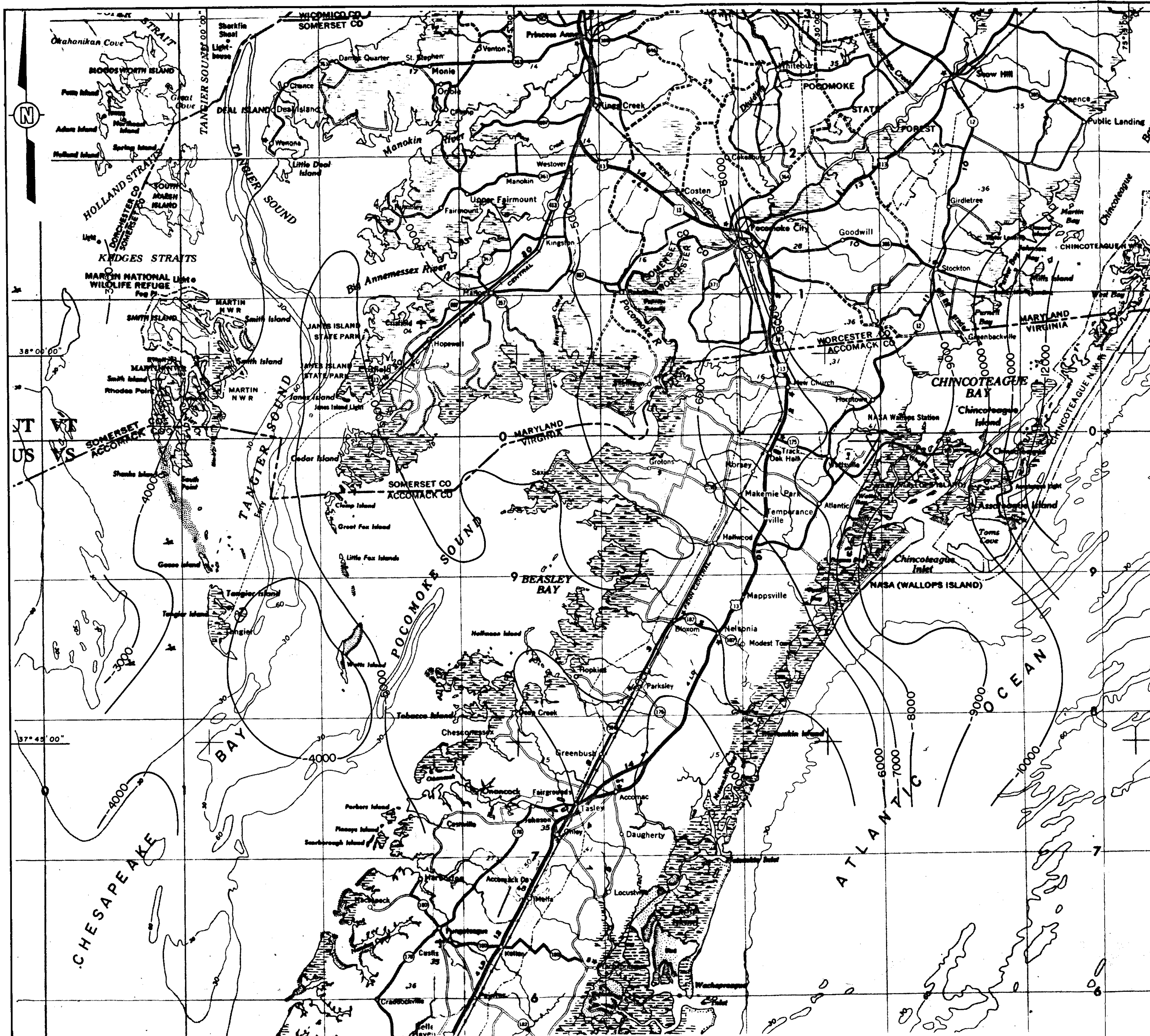
MATRIX COMPARISON OF TECHNIQUES TO BASIC QUESTIONS IN HDR EXPLORATION, ATLANTIC COASTAL PLAIN
(D'APPOLONIA, 1980- FIG. 5-1)

- Sesimic Reflection. This technique is the only basis for determining the disposition and continuity of deep sedimentary horizons. These data are necessary to model the characteristics of the deep sedimentary units in order to estimate basement temperatures. The method also provides information on the depth to basement that is important for control in interpreting other geophysical methods. However, it should be noted that, at least in the Cris-Wall site, seismic basement was generally not true igneous/metamorphic basement, but rather the top of an indurated sedimentary unit. Higher powered and hence, more expensive, seismic surveys have the potential to delineate the basement. The method did not provide any inferences about basement lithology or structure. Due to the high cost of the method and limited area that it covers, the technique is recommended for only limited regional reconnaissance, with the greatest concentraton of effort made at potential sites identified by other techniques.

In summary, the following HDR exploration program for locating a deep test boring is recommended. First, use aeromagnetics and gravity as the reconnaissance tools. The magnetics can be used to infer depth to basement and structure. A gravity map in combination with an aeromagnetic map can be used to infer rock types within the basement. Using the above information, limited seismic coverage should be planned to give information on the overlying sediments where this information is clearly required. These could include lithostratigraphic correlation, fault detection, depths to basement, gross geologic structure, and qualification/constraint of geophysical models. Using a few shallow wells, correlate lithology and measure heat flow. If a particular area looks interesting, additional seismic coverage and deeper exploration wells are recommended. Finally, before siting a deep well, the use of one of the deep electrical techniques to evaluate the fracture and water saturation nature of the basement rocks should be considered.

The overall results of the evaluation of the Cris-Wall HDR site can be presented in terms of the constraints for HDR extraction.

- A rock volume inherently free of working fluid (water) loss paths (e.g., permeable strata or highly fractured rock). The bedrock in the Cris-Wall site (Fig. 3) is interpreted to be metamorphic rock intruded by both silicic and mafic plutons. All the interpreted rock types are essentially impermeable, except where fault zones exist and a fracture permeability can be inferred. By avoiding inferred fault zones, it should be possible to locate areas of reasonably sound basement rock.



LEGEND

—-4000— MAGNETIC BASEMENT ELEVATION CONTOUR INTERVAL 1000 FEET.

REFERENCES:

USGS TOPOGRAPHIC MAPS OF

- SALISBURY, MD, DEL, NJ, VA DATED 1946 - REVISED 1969 (NJ 18-5) SCALE 1 250,000
- EASTVILLE, VA, NC, MD DATED 1946 - REVISED 1969 (NJ 18-8,11) SCALE 1 250,000
- RICHMOND, VA, MD DATED 1973 (NJ 18-7) SCALE 1 250,000
- WASHINGTON, DC, VA, MD DATED 1957 - REVISED 1979 (NJ 18-4) SCALE 1 250,000

SCALES

0 2 4 6 8 10 MILES

0 5 10 15 KM

FIGURE 3

DEPTH TO BASEMENT ROCK INTERPRETED FROM AEROMAGNETIC DATA

(D'APPOLONIA, 1980 - FIG. 4-1)

- A region with minimum risk of seismic activity. The entire Cris-Wall site possesses a very low level of seismic activity and may be aseismic based on historical records extending back to the 18th century. Stress conditions in the basement rock at the site are unknown, but the risk of induced seismicity from fluid injection is considered minimal. Nevertheless, it is recommended that any local microearthquake activity be monitored should an HDR extraction system be established within the site area.

- A rock volume sufficiently hot to be worthwhile (a subjective judgment outside the scope of this project but considered to be greater than 75°C). Temperatures at the basement rock surface of between 75 and 100°C are estimated to be present east of a line connecting Pocomoke City, Maryland and Atlantic, Virginia (Fig. 4). The elevated temperatures of this restricted area are interpreted to be due primarily to an increase in the depth to basement.

- Rock volume at a sufficient depth to contain induced fractures but not so deep as to be untenable considering drilling and development costs (assumed to be no greater than 4.0 km). The entire site area appears to meet the assumed depth requirements, except possibly the extreme eastern section of Assateague Island where depths to basement between 3.5 and 4.0 km have been interpreted from the aeromagnetic data.

In summary, areas are present within the Cris-Wall site which meet all of the assumed constraints for HDR extraction.

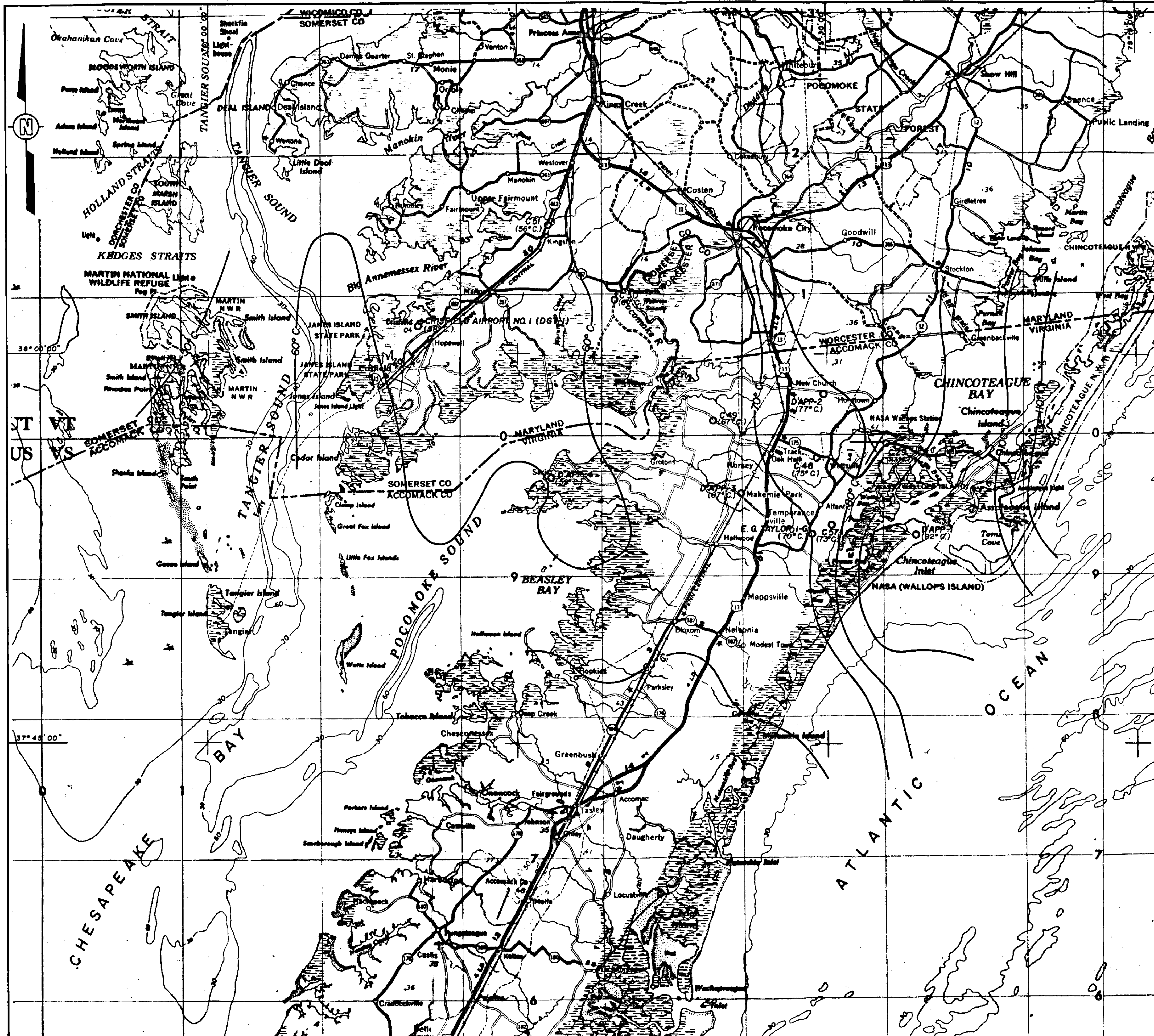
Potential sites for a deep exploration boring can be located considering two possible goals:

- The drill site will be suitable for an HDR extraction experiment and will encounter temperatures estimated to be 75°C or greater at the basement surface, and the basement rock will be reasonably competent.

- The drill site will achieve the greatest geologic/geothermal benefit versus drilling depth in terms of knowledge of deep conditions that will aid in the understanding of the site as a whole.

Six potential HDR extraction sites have been identified, and two sites have been located which offer good potential for obtaining the maximum geologic/geothermal data considering the depth to basement (Fig. 5).

E4



REFERENCES:

USGS TOPOGRAPHIC MAPS OF:

- SALISBURY, MD., DEL., N.J., VA. DATED 1946- REVISED 1969 (NJ 18-5) SCALE 1:250,000
- EASTVILLE, VA., N.C., MD. DATED 1946- REVISED 1969 (NJ 18-8,11) SCALE 1:250,000
- RICHMOND, VA., MD. DATED 1973 (NJ 18-7) SCALE 1:250,000
- WASHINGTON, D.C., VA., MD. DATED 1957- REVISED 1979 (NJ 18-4) SCALE 1:250,000

SCALES

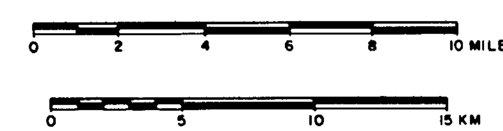
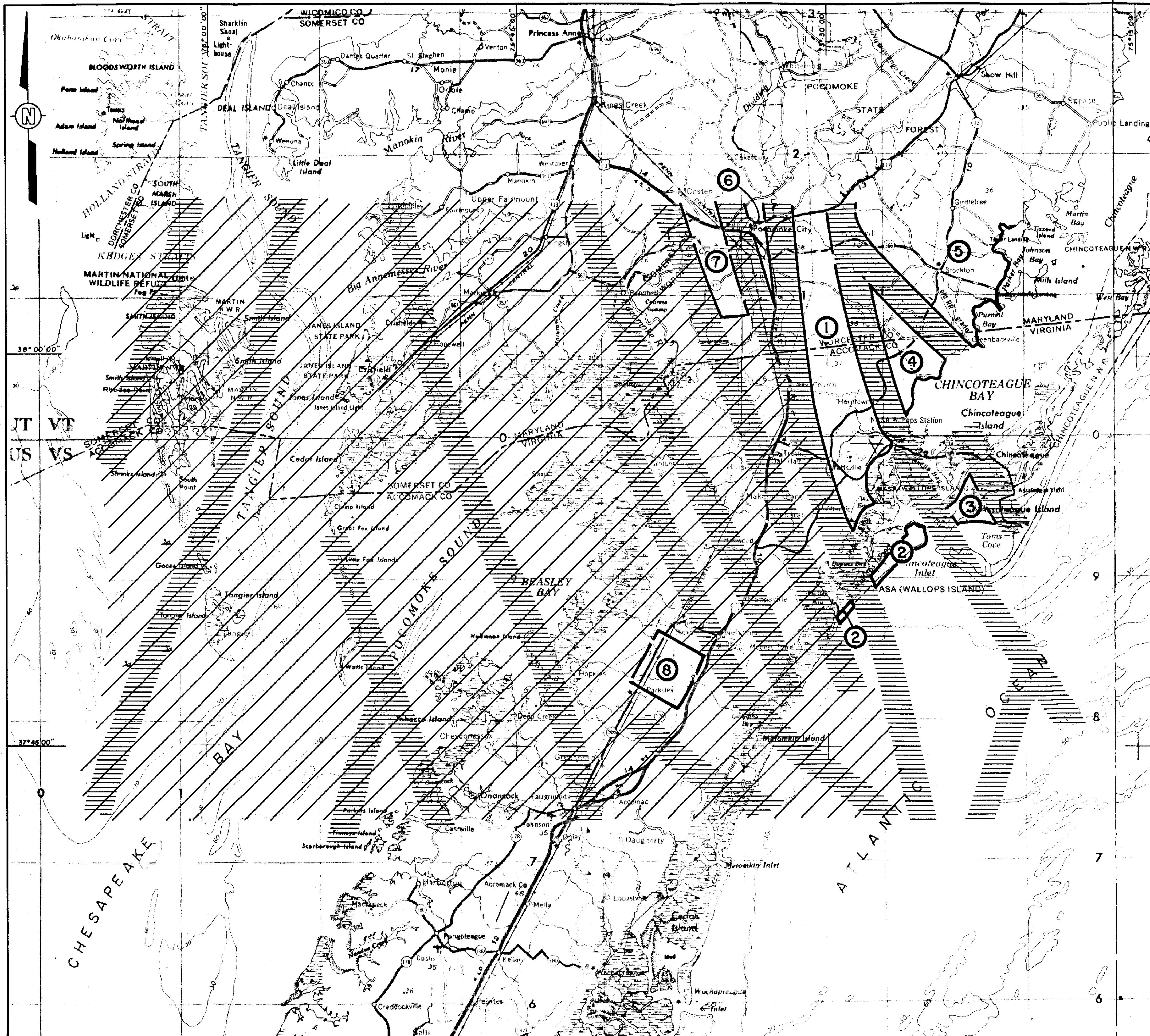


FIGURE 4

ESTIMATED TEMPERATURE AT THE SURFACE OF CRYSTALLINE BASEMENT

(D'APPOLONIA, 1980-FIG. 4-3)



LEGEND

/// ZONE HAVING ESTIMATED BASEMENT ROCK TEMPERATURE OF LESS THAN 75°C

≡ ZONE WITH POTENTIAL FOR EXCESSIVE ROCK FRACTURING

(1) POTENTIAL DRILL SITE ZONE

REFERENCES:

USGS TOPOGRAPHIC MAPS OF

- SALISBURY, MD., DEL., NJ., VA. DATED 1946 - REVISED 1969 (NJ 18-5) SCALE 1:250,000
- EASTVILLE, VA., NC, MD. DATED: 1946 - REVISED 1969 (NJ 18-8,11) SCALE 1:250,000
- RICHMOND, VA., MD. DATED 1973 (NJ 18-7) SCALE 1:250 000
- WASHINGTON, DC., VA., MD. DATED 1957 - REVISED 1979 (NJ 18-4) SCALE 1:250,000

SCALES

0 2 4 6 8 10 MILES

0 5 10 15 KM

FIGURE 5

LOCATION OF POTENTIAL SITES FOR DEEP BORINGS TO BASEMENT BASED ON A SCREENING SELECTION PROCESS

(D'APPOLONIA, 1980-FIG.6-1)

The six most favorable areas for an HDR extraction experiment were identified by eliminating areas where the estimated basement rock temperature is less than 75°C and where a fault is interpreted to pass within a distance of 1 km, or where the site is covered by water (Fig. 5). These sites have been numbered 1 through 6 and are described as follows:

- Site 1. This site is located along a band extending from the NASA Wallops Island Station north into Maryland and passing between Pocomoke City and Goodwill. This area is interpreted to be free of major faulting and to offer basement temperatures of about 80°C or more at depths not exceeding 2600 m. This site is considered to be the prime site.

- Site 2. This site (which consists of two sections; see Fig. 5) is located on Wallops Island where basement temperatures could be greater than 90°C at the northeastern part of the island, but where depth to basement is interpreted to be about 2900 m. The central part of the island could have basement temperatures in excess of 80°C at depths between 2450 to 2750 m, but the area free of possible faults is very small.

- Site 3. Chincoteague, Virginia is a potential site that is thought to have basement temperatures in the range of 90 to 100°C. This temperature range appears promising considering the potential users in this small area. However, the depth to basement, which is interpreted to be between 3050 to 3350 m, is quite deep.

- Site 4. This site is a triangular-shaped area between Horntown, Virginia and Stockton, Maryland. Basement temperatures between 85 and 90°C are inferred to exist at an average depth of about 2750 m.

- Site 5. The area between Girdletree and Stockton, Maryland probably has basement temperatures between 85 and 100°C, but the depth to basement, interpreted to be between about 2750 to 3650 m, is rather deep.

- Site 6. A small area at the eastern edge of Pocomoke City, Maryland offers a possible basement temperature of about 80°C at a depth of slightly more than 2450 m. This area is probably confined between two fault zones which may affect the integrity of the basement rock.

Two other areas of geologic significance also have been identified (Fig. 5):

- Site 7. An area west of Pocomoke City has been selected as being a possible drill site as this area is over the North Intrusive, interpreted to be a granite. A boring in this area would have the possibility of determining whether a granite is actually present and, if present, whether the unit possesses an anomalously high heat flow. Thermal properties of all major sedimentary units could be determined which would greatly assist in the interpretation of adjacent areas. This study did not uncover evidence that the North Intrusive is a heat generating body. The estimated temperature at the basement surface (1800 m) is slightly less than 70°C.

- Site 8. In the area between Parksley and Bloxom, Virginia is another area where a boring could encounter a granite (the Taylor Intrusive), which is geologically similar to Site 7. The estimated depth to basement is only 1200 to 1500 m in this area. However, the anticipated temperature of the basement surface is only about 60°C.

In conclusion, areas can be selected within the Cris-Wall site that fulfill the requirements of an HDR target. The determination of the economic viability of HDR heat extraction would have to consider the costs of drilling deep borings, the relatively low temperatures (in comparison with the western U.S.) which presumably exist, and the types and technologies of end use. It is anticipated that the future cost of conventional forms of energy and improvements in technology will make the economics of HDR extraction more attractive in the near future. Experiments from deep borings to determine the viability of HDR extraction in this area should be considered as necessary and beneficial at the present time.

REFERENCES

D'Appolonia Consulting Engineers, Inc., "Hot Dry Rock Geothermal Evaluation, Cris-Wall Site, Eastern Shore of Maryland and Virginia, report and appendices A, B, C, D, and E (1980).

APPENDIX

HOT DRY ROCK GEOTHERMAL EVALUATION, CRIS-WALL SITE, EASTERN SHORE OF MARYLAND AND VIRGINIA

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