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ASSESSMENT OF OCEAN-FLOOR HYDROTHERMAL SYSTEMS FOR ENERGY APPLICATIONS

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INTRODUCTION

Submarine hydrothermal systems are developed wherever magma ascends to or near the sea floor. The principal tectonic settings in which this occurs are spreading centers, convergent margins and hot spots. By far the largest resource is that which is found at the ocean spreading centers, and therefore they will be the principal topic of this study.

SPREADING CENTERS

Spreading centers are linear, large-scale features that cover over 50,000 km along the earth's surface (Rona, 1982; Figure 2). These are linear features where magma upwells between crustal plates forming new crust, and driving the two lithospheric plates away from each other. Spreading centers are not continuous but are found in rift segments offset by transform faults. The movement along the fault between the segments is opposite to that demonstrated by the offset of the spreading ridges. For example, north and south rift segments appear to have left lateral offset. The plate motion along the northern side of the transform is to the east, away from the northern spreading center. The plate motion on the southern side of the fault is to the west, away from the southern spreading center. Thus, the movement along the fault between the spreading centers is right lateral (Figure 2).

The average water depth over the spreading centers is 2-3 km versus 5 km depth for the abyssal plains. Spreading centers are classified by their spreading rate as slow (less than 2 cm/yr, half spreading rate), medium (2-10 cm/yr), or fast (greater than 10 cm/yr) (Francheteau and Ballard, 1983). High temperature hydrothermal systems appear to be correlated with increased spreading rate as all observations of high temperature discharge have occurred on medium and fast spreading centers found in the east Pacific Ocean. Francheteau and Ballard (1983) related the areal extent of these zones to spreading rate, as follows.

Location	Extent of Field	Spreading Rate
21°N	1.5 km	6 cm/yr
13°N	8 km	10 cm/yr
20°N	13 km	16 cm/yr

Fast spreading centers are characterized by a smooth topographic swell. The East Pacific Rise (EPR) has a crestal horst which is a linear volcanic peak (20-80 m high) assumed to be the axis of spreading (Anderson et al., 1978). In contrast, slow spreading centers are characterized by their extreme topographic relief with significant block faulting of the valley walls.

CONVERGENT MARGINS

Convergent margins occur where the relative plate motion is towards each other. Continents can collide, or ocean crust can be subducted underneath another plate. The overriding plate can be either continental or oceanic. In both cases volcanoes form. The volcanoes in ocean-ocean convergent settings rise well above sea level to form an island arc, such as Japan. An ocean-continent margin is exemplified by the Andes Mountains in South America.

Ocean crust subduction associated with Island Arcs has been suggested as possible tectonic setting for submarine hydrothermal systems by Cronan (1976) and Rona (1982). The back arc setting contains significant heat flow, volcanism, and basins where sulfide deposition is favorable. Abott et al. (1983) surveyed the Mariana trough, the back arc spreading center west of the Mariana Arc. Hydrothermal circulation is indicated by heat flow and pore water analyses, but no hot water discharge was observed. They suggest that this is due to the data being collected away from the spreading axis.

Associated with back arc spreading centers is a type of exhalative hydrothermal ore deposit. Kuroko-type volcanogenic massive sulfide deposits ~~are well exposed in~~ Japan. The deposits are hosted in rhyolite and acid tuff breccia, both of which are chloritized, a felsic equivalent to Archean greenstone belts. The volcanism at the time was bimodal (basalt and dacite), typical of rifting. A back arc basin undergoes crustal extension producing an ideal setting for high heat flow and faulting for fluid movement. The proposed tectonic setting for these deposits is the failed rifting of the Japanese island arc. The deposits are found in basins on the back side of, but closely associated with, the arc. These deposits may be the key to finding present day hydrothermal systems in this tectonic setting. Petrologic evidence closely relates the mineralizing processes of the ore to the processes and temperatures observed in hydrothermally formed chimneys from EPR 21°N. Through various paleontologic and petrologic studies depth of emplacement is cited at greater than 2000 m to 3500 ± 500 m, closely matching the observations of currently active hot water vents. Tamaki (1984) relates the number of rifts within a back arc basin to the angle of the subducting slab. If the slab has a high dip angle a single rift develops. If there is a low subduction angle a multi-rift back arc spreading center occurs. This idea has not yet been related to any heat flow measurements or hydrothermal circulation models.

INTRAPLATE SETTINGS

Intraplate heat flow studies generally observe the transition from areas of low temperature water circulation, affecting surface heat flow, to areas where surface heat flow matches pure conduction modeling. This transition is related to restricted fluid movement as precipitation from the fluid changes from carbonate to silica. The change in composition decreases permeability by filling cracks and fissures that serve as the fluid pathways (Anderson et al., 1977).

Few heat flow studies have been conducted around island hot spots not associated with formation near a spreading center. Von Herzon et al. (1982) modeled heat flow from the Hawaiian swell, the rise ~~which is to the immediate north and~~ includes the Hawaiian Islands. Their modeling does not preclude high temperature circulation, but it is not included as a necessary process. The movement of lithosphere over a thermal anomaly alone can explain the topographic feature of the swell and the observed heat flow.

Although other settings are possible, this assessment will concentrate on the high-temperature hydrothermal systems which have been observed at spreading centers. Future work should also consider resources which may be discovered along island arcs and "hot spots" which are characterized by oceanic islands and seamounts.

WORLD-WIDE RESOURCE ASSESSMENT

HEAT FLOW

Prior to their actual discovery, the existence of ocean hydrothermal systems was predicted on the basis of temperatures recorded near spreading centers (Wolery and Sleep, 1976). These authors compared the observed heat flow values with the heat flow which was calculated on the basis of theoretical conductive cooling of the newly formed lithospheric plate. The results of those comparisons are shown in Figure 4. It was found that observed heat flow was consistently lower than that which was predicted by theory. This difference was attributed to the removal of heat by hydrothermal circulation. The heat advected by the hydrothermal processes was estimated by integrating the heat flow anomaly from the time of formation to the time at which the theoretical and observed values merge. This age was found to be 17 my for fast spreading ridges and about 23 my for slow spreading centers. The calculated heat removed is 11.5×10^8 cal/cm^2 for fast ridges and 15.1×10^8 cal/cm^2 for slow ridges. This amounts to 32% of the heat production from fast centers and 42% from slow. By assuming an aerial spreading rate of 2.94 km^2/yr and a mean linear rate of 2.74 cm/yr, they estimate that $40 \pm 4 \times 10^{18}$ cal/yr is advected by hydrothermal processes. The significance of this process is further emphasized by calculation of mass flow rates of fluid through the systems. Wolery and Sleep give a best estimate of 1.3 to 2.7×10^{17} g/yr which is sufficient to cycle the mass of the world's oceans on the order of 5 to 11 my. The estimates of Wolery and Sleep compare favorably with the earlier estimate of hydrothermal heat flux of 6.4×10^{19} cal/yr by Williams and Von Herzen (1974).

HELIUM ISOTOPES

Study of helium isotopes has provided an independent estimate of the flux of heat and fluids through ocean hydrothermal systems. Helium from the mantle has a distinct $^3He/^4He \approx 10^{-5}$ compared with atmospheric He ($^3He/^4He \approx 10^{-6}$) and the helium produced by radioactive decay ($^3He/^4He \approx 10^{-7}$). Discovery of enrichment of ^3He in ocean waters relative to that which could be explained by nuclear decay or extraplanetary sources was interpreted as representing primodrial ^3He which was escaping from the mantle during intrusion into the crust (Clarke et al., 1969). This hypothesis was consistent with the distribution of excess ^3He in deep water, its presence in glassy ocean basalts, and the detection of a large ^3He excess in a thermal plume from the Galapagos spreading center. Jenkins et al. (1978) have established a relationship between ^3He concentration and temperature. Based on the fact that helium is conservative and that the flux through the ocean crust is balanced by the loss of ^3He from the atmosphere, they have calculated a convective hydrothermal heat flux of $4.9 \pm 1.2 \times 10^9$ cal/yr. Thus providing an independent estimate of the calculations of Wolery and Sleep (1976).

CONCLUSION

All lines of evidence indicate that the flux of heat through ocean spreading centers is quite large, accounting for more than 60% of the earth's heat loss. The estimates of heat dissipated by ocean hydrothermal systems alone amounts of 20% of the earth's total heat loss. However, in order to tap the resource, we will have to be concerned with the specific characteristics of individual systems such as temperature, flow rates, and longevity. The following section will review these characteristics as known at the present time. We will also describe some of the systems which have been explored to date. In conclusion, we will arrive at a conceptual model of submarine hydrothermal systems.

CHARACTERISTICS OF OCEAN HYDROTHERMAL SYSTEMS

INTRODUCTION

This section will describe the characteristics of ocean hydrothermal systems which are of importance in their discovery, development and exploitation. In this context, we will be interested in the same factors which control the economics of continental hydrothermal systems; namely, the heat source for the system, fluid flow paths and the fluids themselves. At this point in time, there have not been any drill holes into active submarine hydrothermal systems. However, abundant information exists on fossil systems which are exposed in ophiolites around the world. We will combine evidence from these sources as well as experimental and modeling work to arrive at a generalized model of an ocean floor magma-hydrothermal system.

AXIAL MAGMA CHAMBERS (AMC)

Ocean hydrothermal systems are driven by the heat from the high level magma chambers along the mid-ocean spreading centers. These chambers are created by the influx and high-level storage of basaltic magma which originates in the mantle. Although no evidence for AMCs have been found to the present time beneath slow spreading centers, they have been interpreted from seismic surveys beneath both intermediate and fast spreading centers (Macdonald, 1983). Macdonald also suggests that the presence of magma chambers beneath all investigated ridges spreading at half rates of greater than 3 cm/yr suggests that these magma chambers may exist in a quasi-steady state beneath all fast spreading centers. However, there is also evidence to indicate that AMCs do freeze even along fast spreading centers. This question is one of on-going research in the oceanographic community and will have obvious implications for the longevity of hydrothermal systems which are driven by these magmas.

Additional evidence from the study of exposed AMCs in ophiolite complexes suggests that both steady state and episodic magma chambers exist along MORs. Pallister and Hopson (1981) have studied the plutonic rocks of the Samail ophiolite in Oman. Textural evidence suggests that the magma chamber cooled by crystal settling rather than downward from the roof as would be case if crystallization were solely a result of the heat transfer to the overlying zone affected by cooling through hydrothermal circulation. Their study also suggests that the magma chamber existed in a steady state condition as a result of frequent replenishment by the injection of new batches of magma. They feel that the chamber they studied was both large and long-lived and was probably similar to systems which exist today along the EPR.

Stern and de Wit (1980) have investigated AMCs in ophiolite complexes in Chile. They have identified two types of chambers. One has behaved as a closed system where there was no replenishment of magma. The other was similar to that described by Pallister and Hopson (1981) in that it showed evidence for continuous replenishment with parental magma. They attributed a difference in spreading rate to the different behavior of these two types of chambers with the steady state chamber being related to fast spreading rates.

The AMCs represent an upper level holding chamber for magmas which are derived from the mantle. Within the AMC, magmas crystallize to form the gabbroic complexes which make up seismic layer 3 of the oceanic crust. Magma from the AMC is injected upward to form the sheeted dike complex and some of the magma reaches the seafloor to form pillow basalts. On the basis of ophiolite studies and seismic studies of the ocean floor, the upper contact of the AMCs are thought to be located between two to three kilometers of the ocean floor.

Pallister (1981) has studied the structure of a sheeted dike complex in the Samail ophilite. The complex has a thickness of 1.2 to 1.6 km. Both the upper and lower contacts are quite abrupt. The sheeted dike complex is composed of parallel to subparallel dikes of basaltic composition that often comprise 100 percent of the rock.

PERMEABILITY

The flow of hydrothermal solutions through the oceanic crust will be controlled by both the interconnected primary porosity of the volcanic rocks and fracturing and faulting. The only measurements of permeability in this environment were completed in DSDP Hole 504B (Anderson and Zoback, 1982). These studies indicate a 10^3 decrease in permeability at depths greater than 800 meters beneath the sediment-basalt interface. Hole 504B is located about 200 km south of the spreading axis of the Costa Rica Rift in crust which is 6.2 my old. The hole was drilled in 3460 m of water and was cored to a depth of 1350 m beneath the sea floor. The site surveys had established that this area had a heat flow close to that which was predicted by conductive cooling models of the oceanic crust. This implied that the sediment cover was sufficient to inhibit the removal of heat by the circulation of cold ocean water in the upper portions of the crust. The hole was drilled through 274.5 m of sediment, 571 m of pillow basalts, and 209 meter transition zone, and 295 m of the sheeted dike complex. Figure 5 shows the temperature logs which were measured at the site. The upper 370 m of the hole are cooled by the flow of sea water down the hole and into the basalts. However note that the bottom hole temperature reaches about 160°C. Figure 6 shows measurements of bulk porosity and bulk permeability from the hole. There is a dramatic decline in permeability at about 900 meters at the transition between the pillow basalts and the underlying sheeted dike complex. This decline in permeability with depth is greater than had been predicted by previous modeling. The authors inferred that any continuing hydrothermal circulation would be confined to the basaltic basement at depths above 900 m.

Since exploration of active hydrothermal convective systems has been limited to the short distance beneath the sea floor, we once again look at ophiolite complexes to evaluate the depth of penetration of hydrothermal solutions into the oceanic crust. Gregory and Taylor (1981) have performed an oxygen isotope investigation of the Samail ophiolite in Oman. They and Pallister and Hopson (1981) indicate that hydrothermal alteration continues to be the base of the sheeted dike complex and top of the gabbro section. The gabbros have seen little alteration. Adamides (1980) describes Cyprus-type sulfide ore bodies which are widely acknowledged to be the fossil analogs of "Black Smokers". These ore bodies show that the hydrothermal solutions strongly prefer a direction of faulting which has also controlled the intrusion of basaltic dikes. These directions are thus parallel to the spreading axis. Offset on the faults is normal and they dip inward toward the spreading center. The Petra orebody is thought to represent a feeder pipe. It is 35 m in maximum width and about 300 m in length. Alteration shows that solutions were pervasive in the lower portions of the volcanic section but became localized in the fault and fracture zones near the paleo-sea floor.

Mottl (1983) suggests that the upper portion of the oceanic crust is so pervasively permeable that it never really becomes heated by ascending hydrothermal solution. Although it is not known how deep this very permeable zone extends, it is thought to go down several hundred meters. Beneath this zone, Mottl suggests that temperature increase is rapid. This is due to the onset of greenschist facies metamorphism and possibly due to the precipitation of anhydrite from downwelling seawater.

Mottl infers that conditions at the base of the upflow zone are a temperature of 365°C, pressure of 700-750 bars and water/rock ratios of about 1. The pressure estimates suggest circulation depths of 4.5 to 5 km which in turn implies that the hydrothermal circulation cells have begun to penetrate crystallized gabbro.

FLUIDS

Weiss et al. (1977) were the first to observe high-temperature water discharging onto the sea floor. Since that time fluids have been collected and analyzed, and a great deal of experimental work has been done to document chemical changes in these systems. The fluids which comprise ocean hydrothermal systems are derived from seawater through interaction with basalts at elevated temperatures. This interaction results in a change in both the chemistry of the fluids and the chemistry and mineralogy of the basalts.

When sea water interacts with basalt, the waters become depleted in Ca, Mg, and SO_4 and pH decreases (Bischoff and Seyfried, 1978; Mottl, 1983). Analyses of fluids which have been sampled from active hydrothermal systems and fluids which have been derived through experimental sea water-basalt interaction are shown in Table 1.

Mottl (1983) summarizes the results of sampling of ocean floor springs. The data indicate that the lower temperature springs are a result of mixing of cold water with a 350°C hydrothermal end member. He concludes that the temperature at the base of the hydrothermal upflow zone is probably in the range of 350° to 375°C. He also cites suties which have used various means to estimate the water-rock ratios of the spring systems. For the two systems which had been sampled at the time of his paper, the East Pacific Rise and the Galapogos Rift, estimates run from .7 to 3 by mass, with a value of 1 being most likely.

Spooner and Bray (1977) have measured the filling temperatures of fluid inclusions which have been collected from the Troodos ophiolite complex on Cyprus. The inclusions contain fluid of sea water composition and were trapped at temperatures ranging from 301° to 351°C. The samples represent fluids from the discharge zone of the hydrothermal convective systems. Spooner (1980) has found evidence of boiling at 390°C from fluid inclusion studies of the stockwork zones from beneath the massive sulfide deposits on Cyprus.

Delany and Cosens have considered the question of boiling in submarine hydrothermal systems principally from the standpoint of the precipitation of sulfide minerals. The present Figure 7 which shows the boiling curve as a function of seawater salinity. The fluid path shown considers adiabatic cooling of a fluid with the 350°C temperature found along the East Pacific Rise. Also shown are the depths of other ocean hydrothermal systems. They conclude that the fluids are most likely to boil in shallower hydrothermal systems. Note that the critical point is at temperatures which are higher than any measured surface temperatures. Some evidence suggests that temperatures of 400°C or more may be possible in the lower portions of the convective system. However, pressures at those depths are estimated to be 700 to 900 bars, above the critical pressure for those temperatures.

The presence of convecting water does not indicate high temperature water. In fact, low temperature hydrothermal convection has been suggested by Embley et al. (1983) in 80 million year old oceanic crust, far from any tectonic settings involving high heat flow. Lister (1982) considers two types of hydrothermal systems in his modeling. An active system has high temperature and fast flow with a lifespan on the order of hundreds of years. Passive systems are lower in temperature, and water residence times are on an order of hundreds of years. It is not known if, and when, steady state conditions can be applied. Variable data indicates non-steady state modeling is necessary (Lowell, 1975).

EXPLORED OCEAN HYDROTHERMAL SYSTEMS

A number of ocean hydrothermal systems have been explored in detail, and we will use a discussion of these systems to further define some pertinent characteristics. In addition, much of the numerical modeling of ocean spreading centers is constrained by the relationships determined by surveys. This discussion will also illustrate some of the exploration techniques which have been used in the location and assessment of the hydrothermal systems.

The systems for which detailed studies have been performed are illustrated in Figure 8. As illustrated in this figure, most of the explored systems are located along fast to intermediate spreading centers with only the TAG field located on the slow spreading Mid-Atlantic Ridge.

Galapagos Spreading Center - 86°W

Crane and Ballard (1980) develop a comprehensive summary of the exploration activities on the Galapagos to the data of that publication. Surveys were initiated in 1972 with an investigation of the intermediate rate (6.5 cm/yr) GPC between 90 and 85°W. At that time evidence was found to suggest hydrothermal circulation of seawater through the crust. Follow-up surveys were run in 1976 with photography, temperature measurements and water chemistry. In 1977 the area was studied using the DSRF *Alvin* and the deep-towed *Angus* camera system. These systems located and investigated five hydrothermal systems which contained several active warm springs (Figure 9).

The morphological features of Figure 9 were characterized by Van Andel and Ballard (1979). All of the hydrothermal areas are within the central zone which is .5 to 1 km wide. Fissuring is confined almost exclusively to pillow basalts, while sheet flows apparently respond to extension by subsidence. A wedge of fissuring seems to be extending from a densely fractured zone in the east into a non-fractured zone in the west. This transition zone is 2.8 km across, and it is within this area that all of the hydrothermal fields are found. The active vents within any field are associated with the smaller scale fracturing rather than the larger fissures. The authors favor a model of radial fracturing within the central zone as a response to the intrusion of magma bodies. The localization of the hydrothermal phenomena suggests that the process may be geologically short-lived. Corliss et al. (1980) suggest that the depth of penetration in the crust is about 1-2 km. Lister (1978) estimates that the fluid descends at a rate of 10 m/yr, attains a temperature of 200° to 350°C and then rises rapidly back to the surface.

Fehn et al. (1983) have used numerical models to evaluate heat flow from the GSC. They find that temperature are everywhere below 300°C except for some areeas which are located on the ridge axis. They also propose that once a hydrothermal circulation cell is established, it will migrate with the moving plate and prevent the reheating of the plate. It is also likely that the depth of penetration of the hydrothermal cell increases with distance from the axis.

East Pacific Rise (EPR)

Numerous studies have been carried out along the EPR including those at 21°N (Rise Project Group, 1980), 13°N (Michard et al., 1984), 15°S (Lupton and Craig, 1981), and 20°S (Ballard et al., 1981). Along its length, the EPR varies from an intermediate spreading rate at 21°N to an ultra-fast rate of 16-18 cm/yr at 20°S. Much of the detailed work along this spreading center has been done at the 21°N site.

EPR-21°N. This area is located at the spreading center which forms the boundary between the Pacific and Rivera Plates which are spreading at a rate of about 6 cm/yr. In 1979, studies were carried out using the DSRV Alvin. This followed dives by the French submersible CYANA (Cyamex Scientific Team, 1981) which had documented sulfide deposits and other evidence of hydrothermal alteration. The Alvin dives were able to discover and photograph active hydrothermal vents with temperatures of 380 ± 30°C. Figure 10 shows the setting of the active vents which were visited during the Alvin dives. All of the vents are locate dwithin the zone where lava flows are freshest (1, Fig. 10) and where there is little evidence of faulting and fissuring. Zone 2 is characterized by extensional features including open faults and fissures. In zone 3 the active fissure are less common, but faults with large vertical displacements form scarps which can be traced for several kilometers. The hydrothermal vents observed were of two distinct types. One type which was characteristic of those seen in the Galapagos investigations involved the flux of a clear fluid from fissures. The fluid temperatures were as high as 23°C. The most notable feature of these vents is the fauna which they support. This consists of galatheid crabs, clams, and giant tube worms. The other type of hydrothermal vent, observed for the first time in this survey, are the "black smoker" and "white smoker" hydrothermal vents. These occur as discrete chimneys superimposed on basal mounds. The "black smokers" are depositing particulate sulfides, while the "white smokers" contain a clear to milky white fluid. Flow rates from the black smokers are on the order of several meters per second. The measured heat flux for a single "black smoker" is on the order of 10^7 cal/sec. This is three to six times the total theoretical heat flow of a 1 km segment out to 30 km on each side of the ridge. It is on the basis of this extremely high heat flux that Macdonald

(1983) estimates that individual vents have a lifetime of only about 10 years. This is consistent with the time required to build sulfide mounds and the age of clams near the vents.

EPR-13°N. This segment of the EPR is located about 1000 km to the south of 21°N between the Orozco and Clipperton Fracture Zones. The spreading rate of this portion of the EPR is about 12.4 cm/yr. The area was selected for study on the basis of ^3He and Mn anomalies in deep water samples. Hekinian et al. (1983) performed a reconnaissance survey over the ridge in preparation for dives by submersible. They found a large number of sulfide deposits similar to those which were found forming at 21°N. These sulfides were discovered not only along the axial portion of the spreading center, but also on a seamount located approximately 6 km off axis. This raises the intriguing question of the geothermal resources which may exist around seamounts. These resources may be shallower, easier to access, and more predictable than those directly on the ridge axis.

Subsequent studies with the submersible Cyana were able to locate and sample hydrothermal vents (Michard et al., 1984). The maximum measured temperature was 317°C with a minimum pH of 3.8. The chemistry of collected samples is shown in Table 2. The high silica content of these fluids indicates that reaction between the fluids and rocks took place at relatively high pressure of greater than 600 bars. The authors propose that the high values of chlorine are a result of the input of chlorine of magmatic origin. They infer a water/rock ratio of 5 which is much higher than the value of 1.5 determined at 21°N.

EPR-15°S. Hydrothermal activity has been detected through geochemical means at 15°S along the EPR (Lupton and Craig, 1981). To date, little additional work has been done on the site, but it deserves mention because of the magnitude of hydrothermal activity implied by the geochemical results. The core of the plume exhibits a $^3He/^4He$ anomaly which is 50% higher than the atmospheric ratio. The magnitude of this anomaly suggests that hydrothermal vent systems larger than those previously discovered may lie in this area. One other remarkable aspect of this plume is that it can be traced for over 2000 km to the west of the EPR, carried by deep currents.

EPR-20°S. The EPR at 20°S is a super-fast spreading center with a rate of 16.1 cm/yr. The geology of the area is shown in Figure 11 (Francheteau and Ballard, 1983). A series of active hydrothermal vents are situated along the spreading axis. Sulfide deposits and "white smokers" were discovered along with the animal communities similar to those discovered along the Galapagos Spreading Center. In addition, high methane concentrations were discovered in fluids from one of the "white smokers".

JUAN DE FUCA RIDGE

The Juan de Fuca Ridge is an intermediate spreading center with a spreading rate of about 5.8 cm/yr. Crane et al. (1985) have completed a study of the geothermal fields which are located along the crest of the ridge, and these areas are shown in Figure 12. Their principal source of data is temperature measurements along the strike of the ridge. Crane et al. develop a model for hydrothermal fluids emanating from spreading centers (Fig. 13). Temperatures will fall to 10^{-2} of emanating value about 20 m above the vent. Above 20 m there is a lid of warm water which reaches up to about 300 m above the bottom. Area 1 (Fig. 12) is located on a morphological dome which is 150-200 m high. This is an area where sulfides had been reported previously (Normark et al., 1982). A detailed temperature survey in this area outlined an area 20 km long which warmed the bottom 1.8 to 2.0°C. Area 2 is a dome 800 to 1000 m high. A temperature increase of 0.1°C was measured for 65 km along strike. Area 3 is 30 km long and located on a dome which is 140-200 m high. The average temperature increase is .1 to .14°C. Area 4 is less than 6 km long and is located on a volcano 450 m high. The thermal anomaly in area 5 is 10 to 15 km long. These measurements average the effluent from many springs, but they do provide a mechanism for calculating the heat loss from this portion of the spreading system. Crane et al. estimate a heat loss of a line source for all 5 areas at 13,004 MW. If the effect of bottom current is taken into account, the estimate increases to 15,597 MW for velocities of .1 cm/sec to 1,559,700 MW for velocities of 10 cm/sec.

GULF OF CALIFORNIA

The precursor to the fast spreading center is represented by the Gulf of California. Lawver and Williams (1979) discuss several basins associated with crustal spreading. The Guymas and Farallon basins both show anomalous heat flow implying hydrothermal circulation. (Small basins like the Carmen have anomalous heat flow but are assumed to have lost heat through conduction to cool continental blocks.) The average heat flow values of the Guymas and Farallon basins are similar but are distributed differently suggesting the systems are not the same. Discharging hydrothermal mounds have been observed in the southern section of the Guymas basin along the rift axis (Lonsdale, 1980, and Simonetti and Lonsdale, 1982). Superficially the mounds are similar to those seen at the Galapagos Rift. Some dredging samples were stained with a petroleum-like oil and had a strong diesel fuel odor to them. Complicating the heat flow studies and inhibiting active hydrothermal systems in the Gulf of California is the high sedimentation rate (greater than 1 m/yr).

MID-ATLANTIC RIDGE (MAR)

Tag Hydrothermal Field - MAR-26°N

The TAG (Trans-Atlantic Geothraverse) hydrothermal field is presently the only active geothermal system which has been discovered along the Mid-Atlantic Ridge (Jenkins et al., 1980; Rona et al., 1984). The field extends for about 10 km along the east wall of the rift valley. Bathymetry (Fig. 14) shows a distinct step pattern in the area which is attributed to offsets due to faulting. Faults have an average spacing of about 10 m which implies a great deal of structural permeability. Although no active "black smokers" have been discovered in the TAG field, sediments enriched in Fe, Cu, and Zn are interpreted as being produced by the effluent of such features. Both Alvin dives and data from the Angus deep-tow show hydrothermal discharge through discrete vents. Various lines of evidence have allowed Rona et al. to place approximate time limits on various phases of hydrothermal activity. The activity itself has persisted for at least 10^6 years. Intervals of black smoker type venting have had a periodicity of 1×10^4 years with a duration of about 10^1 years.

Famous Area -MAR-37°N

At the Famous area, 37°N, there is only suspected hydrothermal activity from heat flow and from observation of altered basement rock exposed at transform faults (Williams et al., 1977). The morphology of the rift zone in the Famous area, as described by Ballard and Van Andel (1977), is an inner floor with central volcanoes and central depressions (volcanic collapse?) demarcating the rift axis. The lack of faulting in this central area indicates a wide extension zone (1 km, Ramberg and Van Andel, 1977). The volcanoes are rifted to one size or the other. Towards the inner walls nearly vertical tension cracks and faults appear. At the inner walls pure tension is replaced by a vertical shear component resulting in walls of about 60° dip. At the walls uplifted blocks readjust and the original volcanic edifaces are recognizable.

CONCEPTUAL MODEL OF OCEAN HYDROTHERMAL SYSTEMS

Figure 15 represents a composite model of an ocean hydrothermal system at an intermediate to fast spreading center. The energy for the circulating hydrothermal system is derived from an axial magma chamber which is being replenished by input from the mantle at a steady state. Injections from the axial magma chamber form the sheeted dike complex which feeds lava flows at the ridge axis. Cold sea water descends into the rock column along faults and fractures. These waters are heated rapidly and ascend at the ridge axis to form hot spring vents. The total penetration of the sea water into the rock column is about two kilometers and may range up to 5 km. Ancient sequences show pervasive alteration within the sheeted dike complex, but little hydrothermal alteration within the underlying magma chamber. Temperatures in the upflow portion of the hydrothermal system are expected to be over 350°C at the ridge crest.

I. INTRODUCTION

In the last decade, discoveries in the area of plate tectonics have unfolded a new understanding of how the earth's surface is formed and destroyed. It is now known that the earth's surface is made up of finite plates which are in constant motion relative to each other. Some of the earth's surface is being consumed and deposited back into the earth mantle as a plate "dives" or subducts under an adjoining plate. The Pacific Plate subducting under the North America Continental Plate is an example of this. At the other end of the colliding plates, new earth surface is being formed as the plates move apart or spread. These areas are called spreading centers. An example of this situation is the Mid-Atlantic Rift which extends from Iceland to the Antartic.

Spreading centers are characterized by active volcanism. Magma raising up from the earth's mantle as the plates part give rise to land surface expressions such as hot pools, geysers, and active volcanos. Iceland which sets astride such a spreading center has well known hydrothermal fields which have been extensively developed for commercial uses. Seabed surface expressions of spreading center activity take the form of basalt pillow lava formations that are formed when lava extrudes out of the fissure and rapidly solidifes; hot water vents that are heavily mineralized and that support colonies of bacteria, tube worms, clams, and other organisms; and lack of a sea floor sediment layer. There are approximately 40,000 miles of spreading centers on the earth surface. 95% of these lie below the oceans of the world.

The ocean spreading centers represent a tremendous source of unexplored-untapped energy. A rough estimate of the amount of energy available in the spreading centers is 0.15×10^6 to 7.5×10^6 quads equivalent to 2,000-to 100,000-yr U.S. energy supply at the current annual total energy consumption rate of 75 quads.[1] It should be noted that this estimate is for energy available IN-SITU in the rift zones. As the tectonic plates spread, new magma flowing into these zones replenishes the heat that is lost. As long as tectonic plates continue to move and the earth's core remains hot, this heat source will be available.

With such a huge resource available, a logical question to ask is: "Why hasn't it been developed?" Part of the answer has already been given. That being the understanding of plate tectonic theory is relatively new --- developed in the last ten years. Actual viewing of mineralized hot water vents on the ocean spreading centers occurred as late as 1979. Another reason was the seemingly inhospitable environment. Since most of this resource is located 2.5 km below the surface of the world's ocean's it was easy to be overwhelmed by the technological difficulties in utilizing the energy. This inhospitable view of the environment also prevented people from looking at the spreading centers as being uniquely qualified for certain processes.

In this TDP task, we took a different view of the ocean spreading center environment. We viewed its high pressure, temperature, etc., as assets to be utilized to the maximum extent. A team of INEL personnel,

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(1) "Final Report - Magma Energy Research Project", SAND 82-2377, October 1982, p. 8.

UNIVERSITY OF UTAH RESEARCH INSTITUTE

UURI

EARTH SCIENCE LABORATORY
420 CHIPETA WAY, SUITE 120
SALT LAKE CITY, UTAH 84108
TELEPHONE 801-581-5283

MEMORANDUM

November 30, 1983

TO: Jack Ramsthaler

FROM: Mike Wright

SUBJECT: Potential UURI Participation in Development of Ocean Geothermal Applications

1. ESL/UURI is interested in participation in such a project.

2. We realize that a large percentage of the earth science community will be interested in either participation or results or both, and that the USGS will be heavily involved, probably in the primary role in the geological sciences. However, the project should be large enough for a number of entities to participate.

3. It seems to us that aspects in which we could contribute include 1) developing and carrying out exploration and drill hole siting procedures and 2) in recovery of metals from produced brines. Other avenues may become apparent as the project progresses.

4. We would be happy to contact Utah's congressional delegation to make them aware of the project and enlist their support.

Regarding exploration and drilling strategies, it is apparent that careful selection of drill sites will be very important. The plumbing system can be shown to be fracture-dominated, and typical examples of this plumbing system can be seen in several locations on earth today. On the Island of Cyprus there occurs a slice of oceanic crust in which massive sulfide ore deposits are found that were in all likelihood formed in association with an acient oceanic hydrothermal system. The regions beneath the deposits, encompassing the ancient plumbing system, can be studied on land.

The same geologic situation exists in the Sultanate of Oman, on the Persian Gulf, where the largest slice of former oceanic crust, formed at a spreading center, is now part of the land mass, and can be studied. We propose that studies of such areas would help develop models of such hydrothermal systems that would be an integral part of the strategy to site drill holes to exploit today's oceanic hydrothermal systems. Our background and experience in mineral deposits would be a material aid in such studies.

The project would also need to include detailed geologic studies of potential sites themselves from deep submarines. Geochemical studies could be used to identify the waters that are in most direct contact with the magma and perhaps those that issue most directly to the surface. Geophysical studies could be carried out using state of the art, but currently available, ocean bottom seismic, magnetic, gravity and perhaps electrical equipment. We could certainly help design and carry out this work.

Selection of one or more primary test sites would also be important. Criteria for alternate selection would need to be set up based on exploration models discussed above.

I personally see a lot of opportunity here to not only exploit a new energy source but also to exploit the environment down there as a laboratory and ultimately for large scale production of resources using techniques that cannot be easily duplicated on the surface, as you have discussed with me. Please continue to let me know if and how I can help.

PMW/jp

OCEAN HYDROTHERMAL ENERGY CONVERSION

ESL-UURI FY84 TASKS -- $20K

1. Resource Model
   (a) location of resources, esp. near CONUS
   (b) physical, chemical properties
   (c) lifetime

2. Pick one or more oceanography groups to work with in future
   - Scripps
   - Oregon
   - Woods Hole
   - Lamont-Doherty
   - Texas A&M

3. Strategy for obtaining funding to carry on post FY85. (Proj funds $200K FY85)
   (a) work with OBES
   (b) workshop

4. Comments on program plan

OCEAN HYDROTHERMAL ENERGY CONVERSION

Solaries

Wright	0.75	
Sibbett	1.00	
See	0.25	9280

Travel

3 trips @ $1200 Lamont, Scripps, Woods Hole	3600

Bibliographic Search	400

	Total Direct	13280
Indir 0.43		5710
	Total Indirect	18990
G&A	0.135	2560
	Total	21554
Fee	.055	1185
		22740

VLM
11/22/83

SMOKERS – Preliminary Investigation

1. Literature Review of Exposed "smokers"

2. Site visits to paleo hydrothermal system in ancient oceanic crust. Cyprus, Noranda. – character of fractures. duration of activity etc (3-D physical & chemical character of system.)

3. Deep sea aspects – site visit in submersibles / DSDP Red Sea, Galapagos, ...

4. Exploration strategy. – strategy for finding and developing submarine hydrothermal system.

3 year effort. – 3 member team – 1 geologists, 1 thermal modeler, 1 geochemist

expense / year

100K × 3 =	300K	personnel.
	50K	travel
	50K	Analyses – Chem, XRD, gas, microprobe
	400K	
	100K	contingency
	500K / year. for 3 years.	

UNIVERSITY OF UTAH RESEARCH INSTITUTE

UURI

EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

November 5, 1984

Jack:

Here is a proposed report outline on Ocean Hydrothermal. It looks like it solves the world's problems. Although available money will not allow complete coverage of each topic, we should be able to discuss each meaningfully. We have hired a UU student to do much of the background work for cheap.

Comments please.

M

Mike Wright

OCEAN HYDROTHERMAL RESOURCES

I. Executive Summary

II. Introduction

III. Location of Ocean Hydrothermal Systems
- A. Tectonic settings
  - 1. Spreading centers
  - 2. Convergent margins
    - a. Island arcs
    - b. Ocean - continent
  - 3. Hot spots
- B. Systems within the EEZ

IV. Characteristics of Ocean Hydrothermal Systems
- A. Fluid composition and properties
- B. Fracturing and faulting
- C. Stratigraphy
  - 1. Eruptive processes
  - 2. Petrochemistry
- D. Heat flow and convective circulation--system life
- E. Location of magma bodies
- F. Position of hydrothermal system with respect to tectonic processes
- G. Ancient analogs - ore deposits (include discussion of water depth, frequency of occurrence, system size)
- H. System model(s)

V. Assessment of Resource Potential
- A. World-wide heat balance
- B. Conclusions from ocean chemistry
- C. Assessment of known systems
- D. World-wide potential

VI. Exploration Technology
- A. Review of available technology (including costs)
  - 1. Temperature measurements
  - 2. Water chemistry
  - 3. Magnetics
  - 4. Gravity
  - 5. Topographic profiling
  - 6. Active seismicity
  - 7. Submersibles
  - 8. Seismic surveys
  - 9. Electrical methods
- B. Exploration Strategy

VII. Research Needs
- A. Physical properties
- B. Tectonic processes
- C. System models
- D. Exploration techniques

VIII. Conclusions and Recommendations

IX. Bibliography

1. Bibliographic Search
    Oceanography
    Hydrothermal
    Polymetallic sulfides
    Head Flow

2. Abstracts of pertinent articles (copies)

3. Divide writing effort
    Wright   I, II, VI A1,3,4,6,8,9
    Nielson   IV, V, VI A 2, 5, 7
    Ackerman   III, IX
    All   V, VI B, VII

OCEAN HYDROTHERMAL ENERGY CONVERSION

UNIVERSITY OF UTAH RESEARCH INSTITUTE

PROPOSED FY 84 TASKS

Scope of Work

UURI proposes to provide support to DOE-ID for research in ocean hydrothermal energy conversion. We will work cooperatively with EG&G, Idaho in this effort. The tasks we propose are as follows:

1. Resource Model. Assemble data on the nature and occurrence of ocean hydrothermal resources. These data will include physical and chemical properties of the hydrothermal fluids. Formulate a preliminary resource model, including present concepts of the hydrothermal plumbing system beneath the ocean floor.

   This task will be be performed by (a) conducting a selective literature search and review, and (b) initiating contact with and working with the principal oceanographic institutions in the U.S., namely:

   Scripps Institute of Oceanography
   Woods Hole Oceanographic Institution
   Lamont-Doherty Geological Observatory
   University of Maine
   Texas A&M University
   Oregon State University.

   In addition, information will be gathered from oceanographers at the U.S. Geological Survey and at the National Oceanic and Atmospheric Association.

2. Planning. Assist ID and EG&G in formulating future program plans. Assist in setting up a workshop of scientists from the oceanographic community to discuss the promises and problems of using ocean hydrothermal resources.

Deliverables

A technical report on the results of Task 1, including a preliminary resource model, will be prepared and submitted by 1 October 1984.

Written and oral material will be submitted to ID and EG&G as required for Task 2.

Budget

Salaries and Wages (Burdened) $16,955

P. M. Wright	0.5 months
D. L. Nielson	0.5 months
Geol. Assist.	0.75 months
Draftsperson	0.50 months
Secretary	0.25 months

Travel

Three trips to oceanographic institutions @ $1200 - each 1,980

Miscellaneous $645 1,065

TOTAL $20,000

Wright	10	10
Nielson	10	10
Ackerman	15	25
Drafting	~~10~~ 5	5
Secretary	5	5
Travel	3600	2400
Misc	650	650
	20,049	18942

WRIGHT
24 April / 84

Ocean Hydrothermal Energy Utilization Technology

Agenda

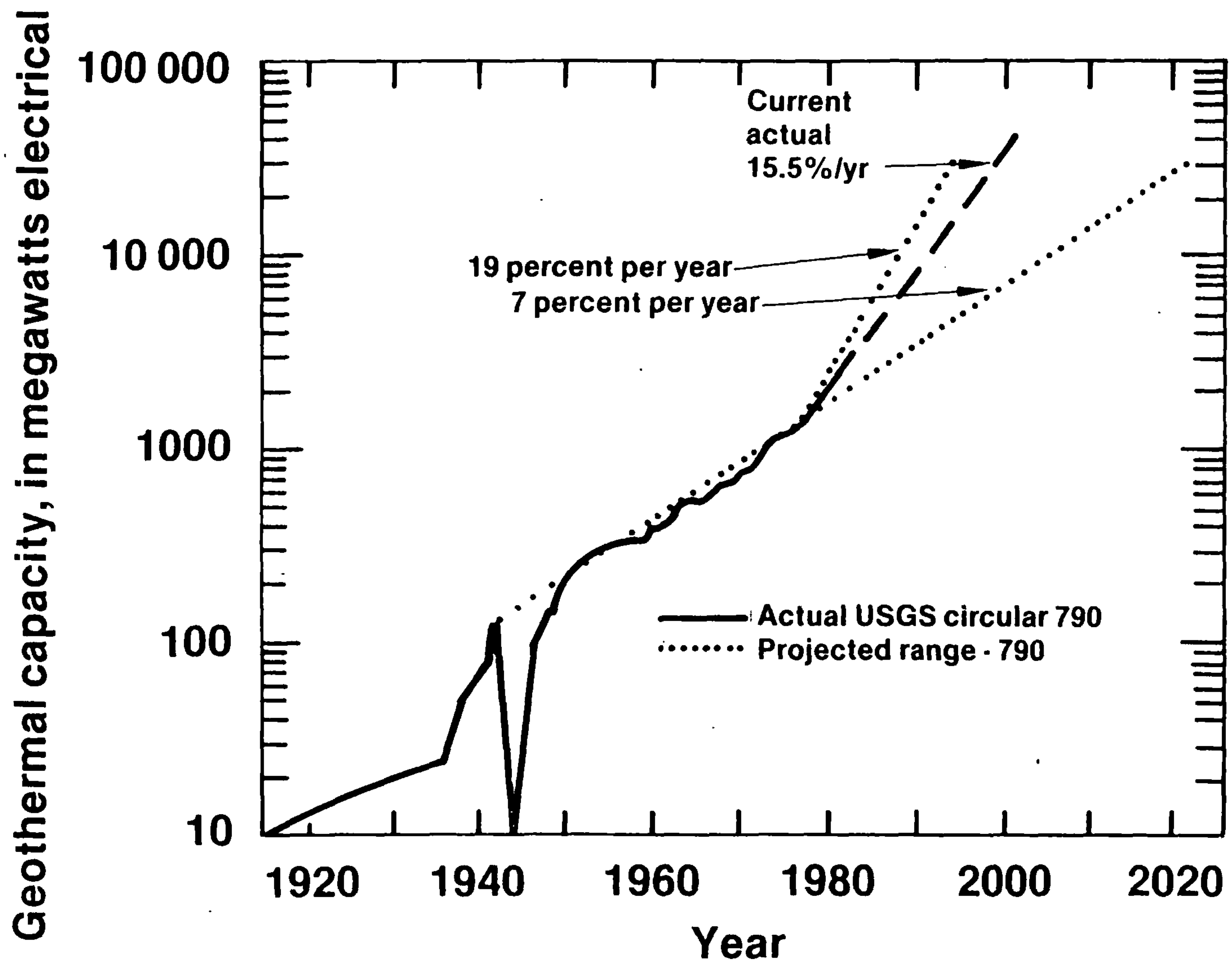
- Meeting Objectives
- Status Geothermal Development
- DOE Ocean Hydrothermal Program
  - Objective
  - Background
  - Work breakdown structure
  - FY-84 product

S4 10 236

Ocean Hydrothermal Energy Meeting Objectives

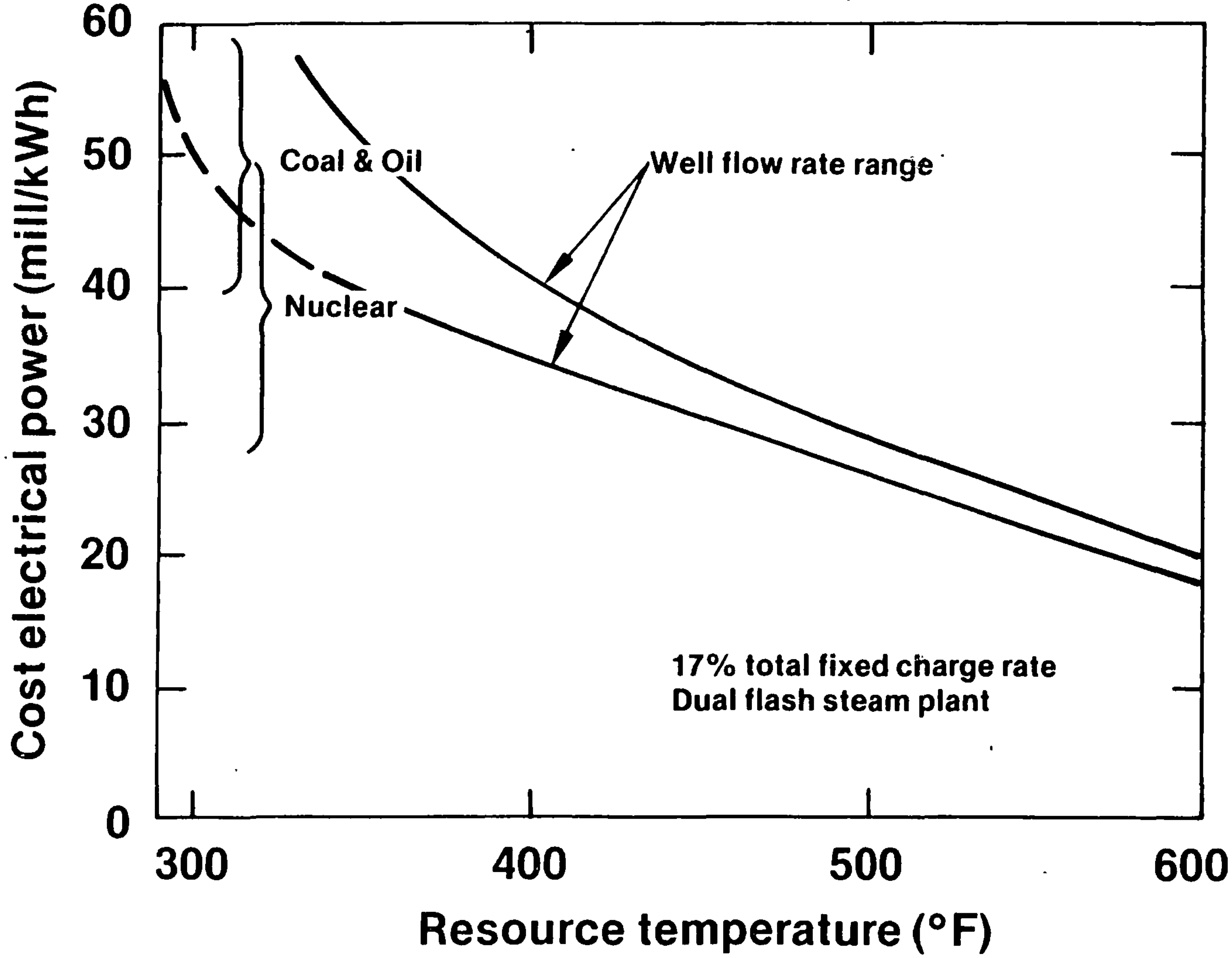
- Obtain comments on DOE Plan
- Open discussion on energy potential
- Initiate additional thinking on energy potential

Worldwide Growth
Geothermal Electrical Capacity



S4 10 233

Cost of Geothermal Electrical Power ~1980 Costs



S4 10 234

Ocean Hydrothermal Energy Utilization Technology

Objective

- Assess feasibility of converting ocean spreading center hydrothermal energy into economically transportable fuels

S4 9423

Ocean Hydrothermal Energy Utilization Technology

Literature Results

- Relatively recent discovery
- Little known about hydrothermal systems
- Potentially enormous source of energy
- Nothing published on use of energy
- Innovative thinking required

S4 10 237

Ocean Hydrothermal Energy Utilization Technology

Positive Considerations

- Large source of energy ~20,000 years world energy consumption
- Renewable
- High quality (350-1100°C)
- Drilling technology advancing rapidly
- Remote technology advancing rapidly
- Unique environment

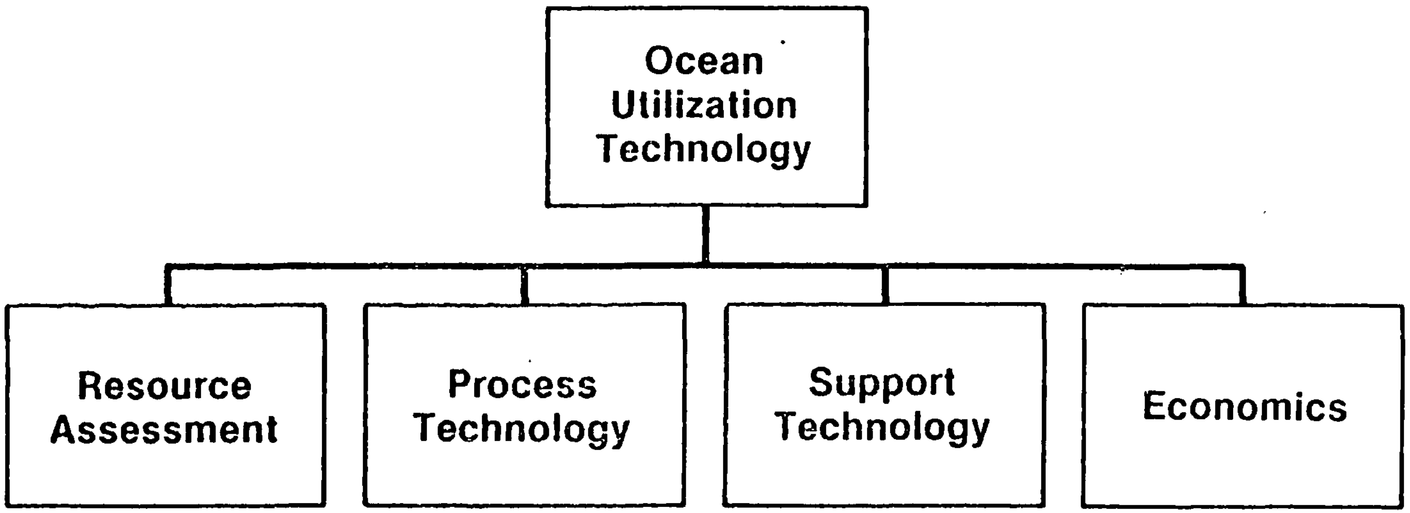
Negative

- Very very expensive

S4 10 238

Ocean Hydrothermal Energy Utilization Technology

Work Breakdown Structure



S4 9421

Ocean Hydrothermal Energy Utilization Technology
Current Status

- Concepts studied
  - 60 considered
  - 10 studied
  - 2 under development
- Laboratory work
  - Reductive formylation studies underway
  - Bioconversion work initiated
- Oceanographic participation
  - Consultants contacted
  - Well costs being developed

S4 10 259

Ocean Hydrothermal Energy Utilization Technology

100,000 Acre Ocean Farm Product Value

	Product Value * ($/yr)
• Kelp	
- Max	170,000,000
- Min	140,000,000
• Algae	
- Max	897,000,000
- Min	285,000,000

*Diesel fuel only

S4 9485

Resource Assessment

- Objective
  - Develop theoretical hydro-thermal systems
- Information Sources
  - USGS, NOAA, Universities
- FY-84
  - Survey current theories
  - Select theory for analysis
  - Identify research needs

Process Technology

- Objective
  - Develop and study innovative processes
- Information Sources
  - EG&G and engineering labs
- FY-84
  - Study concepts for converting energy in sub surface and surface locations
  - Evaluate concepts for liquid fuel production
  - Identify research needs

S4 10 242

Support Technology

- Objective
  — Evaluate technology to drill, control, and process ocean hydrothermal fluids
- Information Sources
  — Scientific and Industrial drilling
- FY-84
  — Survey state of art
  — Project future technology
  — Identify research needs

S4 10 241

Economics

- Objective
  - — Assess cost of ocean hydrothermal energy utilization processes
- Information Source
  - — EG&G
- FY-84
  - — Assess basic costs of energy at sub surface and surface locations
  - — Evaluate liquid fuel processes
  - — Project future costs
  - — Prioritize research needs relative to cost impact

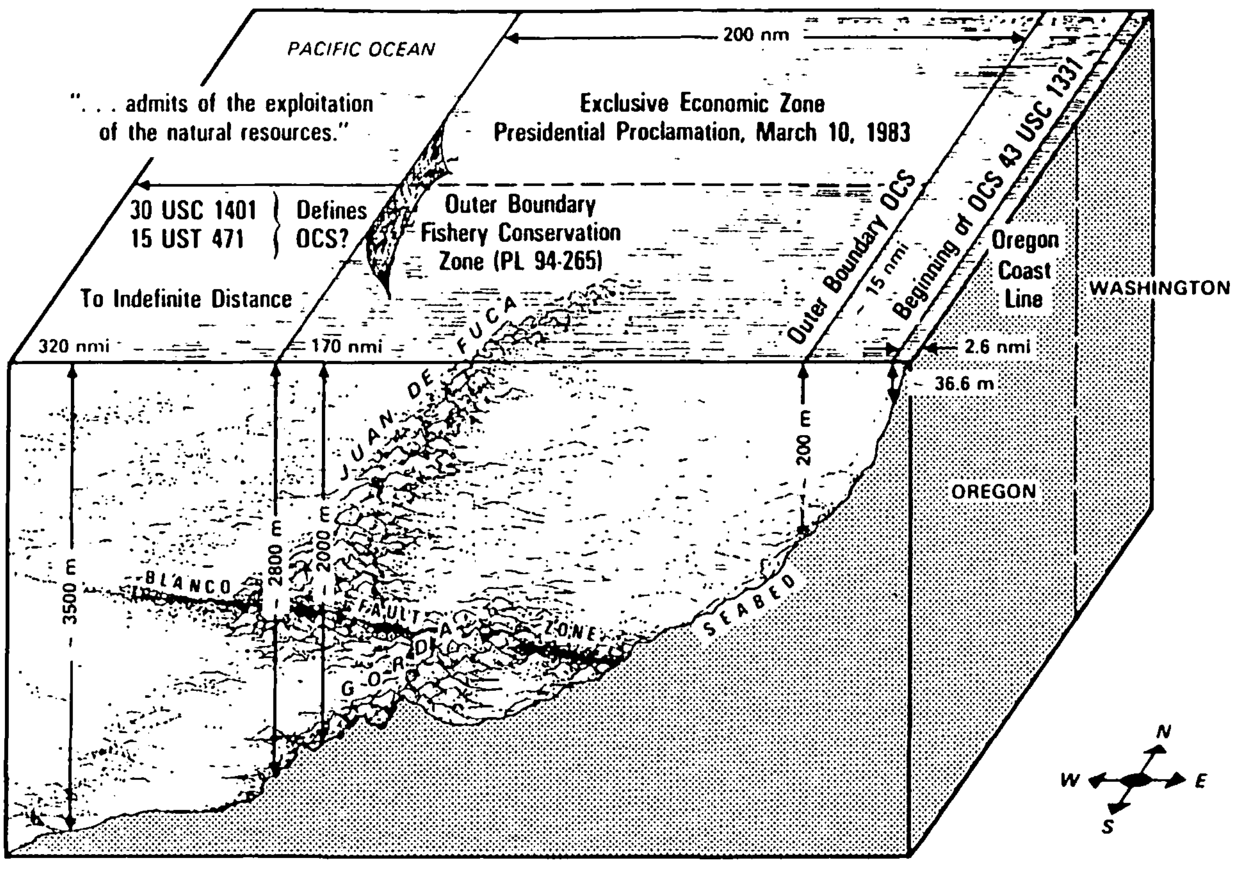
S4 10 244

Ocean Hydrothermal Utilization Technology

FY-84 Product

- Accumulation of information on energy aspects of Ocean Hydrothermal System
- Evaluation of innovative conversion processess
- Projection on economics
- Identification of research priorities

S4 10 239


PACIFIC OCEAN
". . . admits of the exploitation of the natural resources."
200 nm
Exclusive Economic Zone
Presidential Proclamation, March 10, 1983
30 USC 1401
15 UST 471
Defines OCS?
Outer Boundary
Fishery Conservation
Zone (PL 94-265)
To Indefinite Distance
Outer Boundary OCS
15 nmi
Beginning of OCS 43 USC 1331
Oregon
Coast
Line
WASHINGTON
320 nmi
170 nmi
2.6 nmi
36.6 m
JUAN DE FUCA
200 m
2000 m
2800 m
3500 m
BLANCO
FAULT
ZONE
GORDA
SEABED
OREGON
N
W
E
S

EARTH'S ENERGY PICTURE

1. TOTAL HEAT LOSS FROM INTERIOR OF EARTH

	10^6 MW
CONTINENTS	9.0
OCEAN BASINS (except spreading centers)	17.0
SPREADING CENTERS	16.7
	42.7

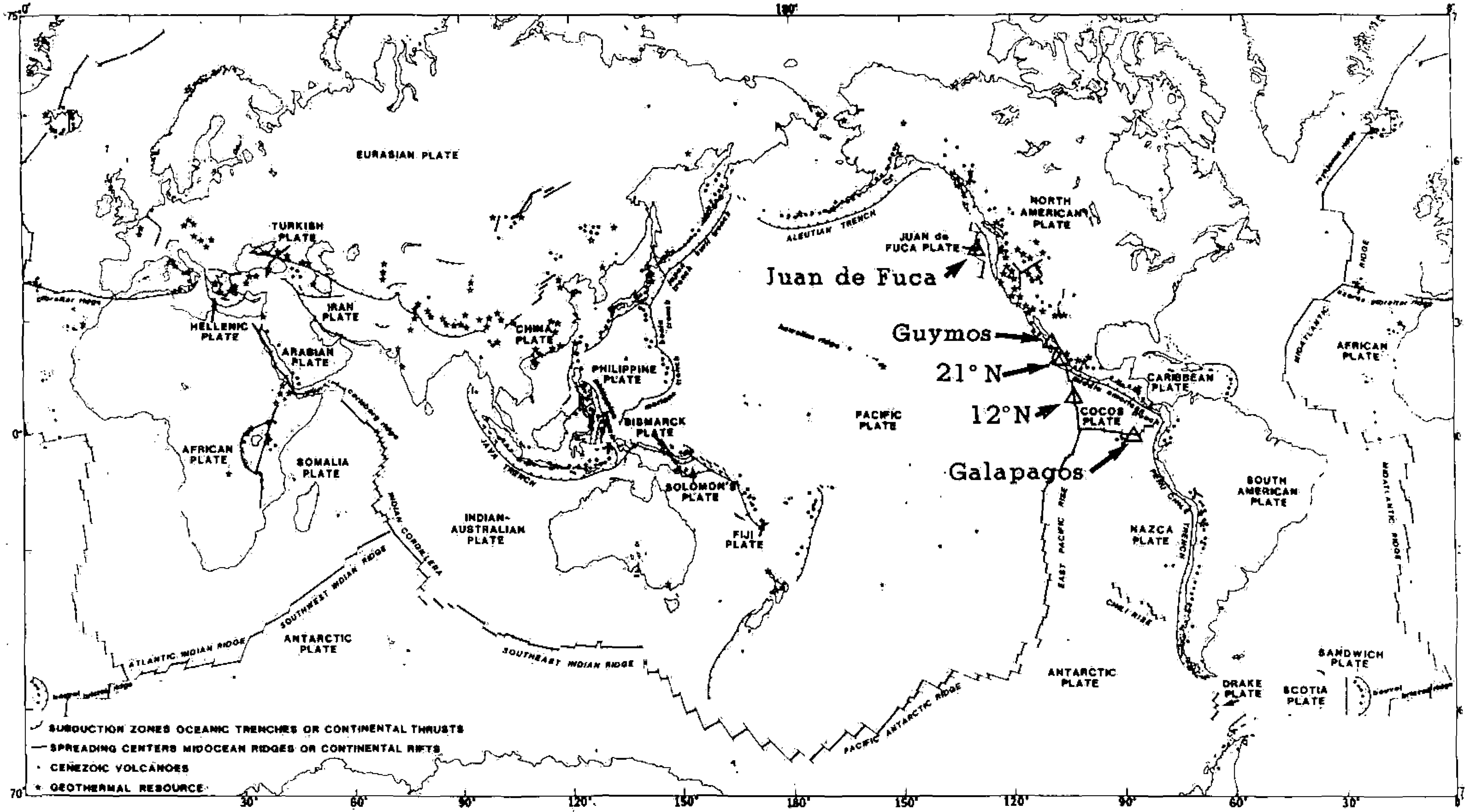
2. SOLAR HEAT INTERCEPTED 167,000

3. TOTAL HUMAN ENERGY USE (fossil, nuclear) 8.5

4. ESTIMATED 20% SPREADING CENTER HEAT LOSS DUE TO HYDROTHERMAL CONVECTION 3.3

KNOWN OCEANIC HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS

GALAPAGOS RIDGE	86° W
EAST PACIFIC RISE	12° N
EAST PACIFIC RISE	21° N
GUYMAS BASIN (East Pacific Rise)	27° N
JUAN DE FUCA RIDGE	



GEOTHERMAL RESOURCES AND PLATE TECTONIC FEATURES

GENERAL DESCRIPTION

1. Known high temperature fields [+ 250%C] confined to spreading axes

2. Each field composed of 3-5 vent systems separated by ±2km

3. Each vent system composed of 6-12 vents [chimneys] that issue hot water

4. Vents aligned along fracture zone over area 200 - 500m wide by ± 1km long

5. Vents 10-30m high

   Black Smokers : 350°C

   METALLIC SULFIDES PRECIPITATING

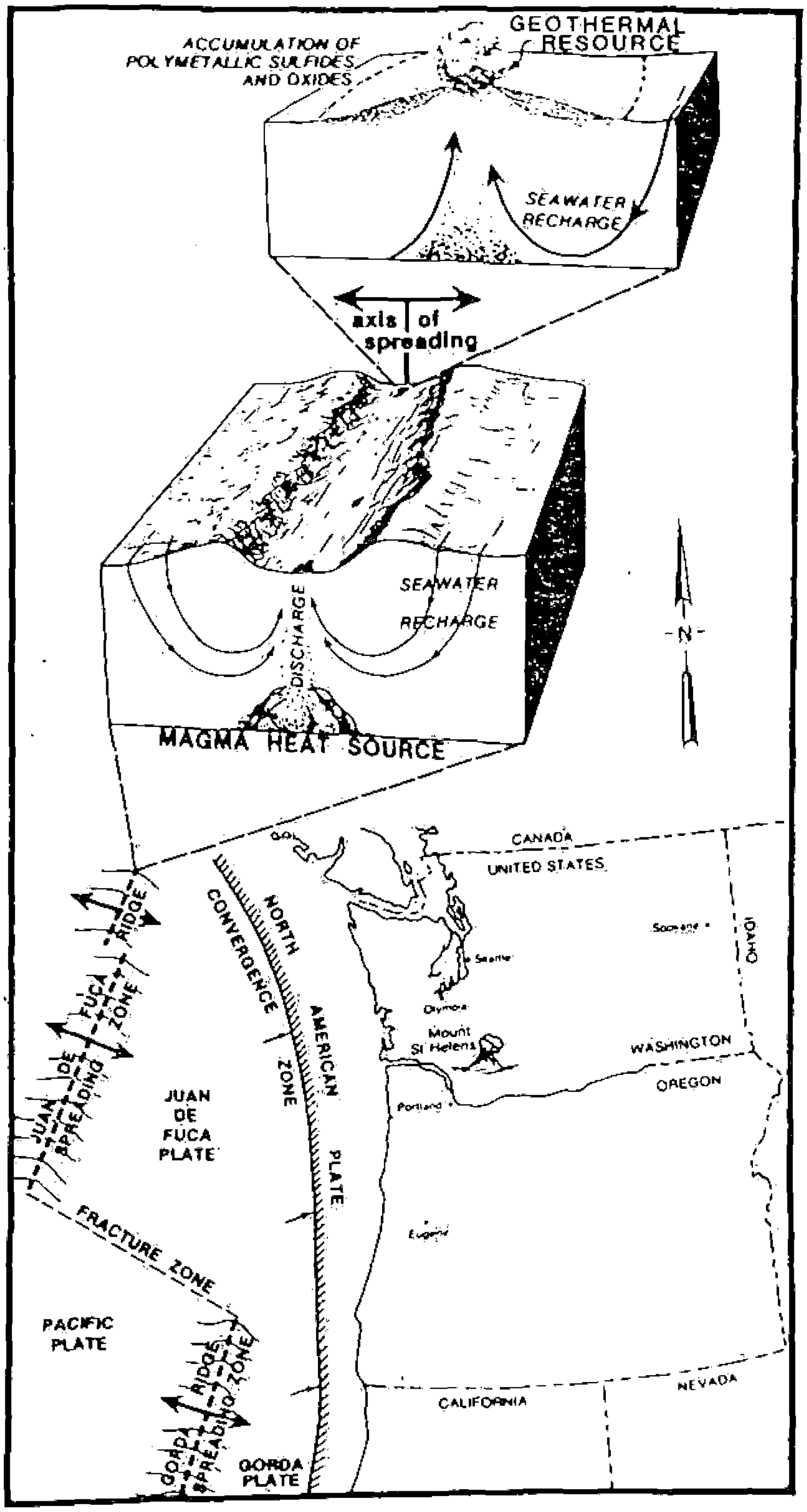
   White Smokers : 100-300°

   SILICA, SULFATES PRECIPITATING

6. Postulated lifetime of vent system 30-100 years

7. Depth to magma postulated ±2km on geophysical evidence

8. System at 21°N emanating ± 11,500MW



GEOTHERMAL RESOURCE
ACCUMULATION OF POLYMETALLIC SULFIDES AND OXIDES
SEAWATER RECHARGE
axis of spreading
SEAWATER RECHARGE
DISCHARGE
MAGMA HEAT SOURCE
N
CANADA
UNITED STATES
IDAHO
WASHINGTON
OREGON
CALIFORNIA
NEVADA
Mount St Helens
Portland
NORTH AMERICAN PLATE
CONVERGENCE ZONE
JUAN DE FUCA RIDGE
JUAN DE FUCA SPREADING ZONE
JUAN DE FUCA PLATE
FRACTURE ZONE
PACIFIC PLATE
GORDA RIDGE
GORDA SPREADING ZONE
GORDA PLATE

TYPICAL CHARACTERISTICS OF VENT FLUIDS

TEMPERATURE:		
	Black Smokers	350°C+
	White Smokers	100-300°C
	Hot Springs	10-100°C
	Magma	1000-1400°C
	Ambient Ocean	2°C
PRESSURE:	12°N, 21°N, Galapagos	2600m water (260 bars)
	Juan de Fuca	1300m water
CHEMISTRY:	pH	4
	SiO	saturated
	Major ions relative to sea water	
	Mg, SO_4	depleted
	Ca, K	enriched 2-4x
	Na, Cl	enriched 10%
	Li, Rb, Ba, Mn	enriched

Contains: H_2S, Fe, Cu, Zn, other base and precious metals

GUYMAS BASIN [27°N]

1. IN GULF OF CALIFORNIA

2. 315°C FLUIDS OBSERVED

3. 0.5 km SEDIMENTS DEPOSITED BY COLORADO RIVER OVER SPREADING AXIS

4. LIGHT, MOBILE HYDROCARBONS OBSERVED BEING DISTILLED FROM CARBONACEOUS COMPONENTS OF SEDIMENTS

EXPLORATION ASPECTS

1. Only ±150km of ridge explored in any detail
2. Five high temperature areas discovered, all on fast spreading ridges [6 - 18 cm/yr]
3. 53,700km total ridge length, ±30% fast spreading
4. Some evidence that EPR hydrothermal centers occur every 100km on ridge axis
5. Hydrothermal processes at spreading centers are known to have been active for the last ±2 billion years due to polymetallic sulfide deposits formed
6. No oceanographer doubts the existence of a very large hydrothermal resource

EXPLORATION PROBLEMS

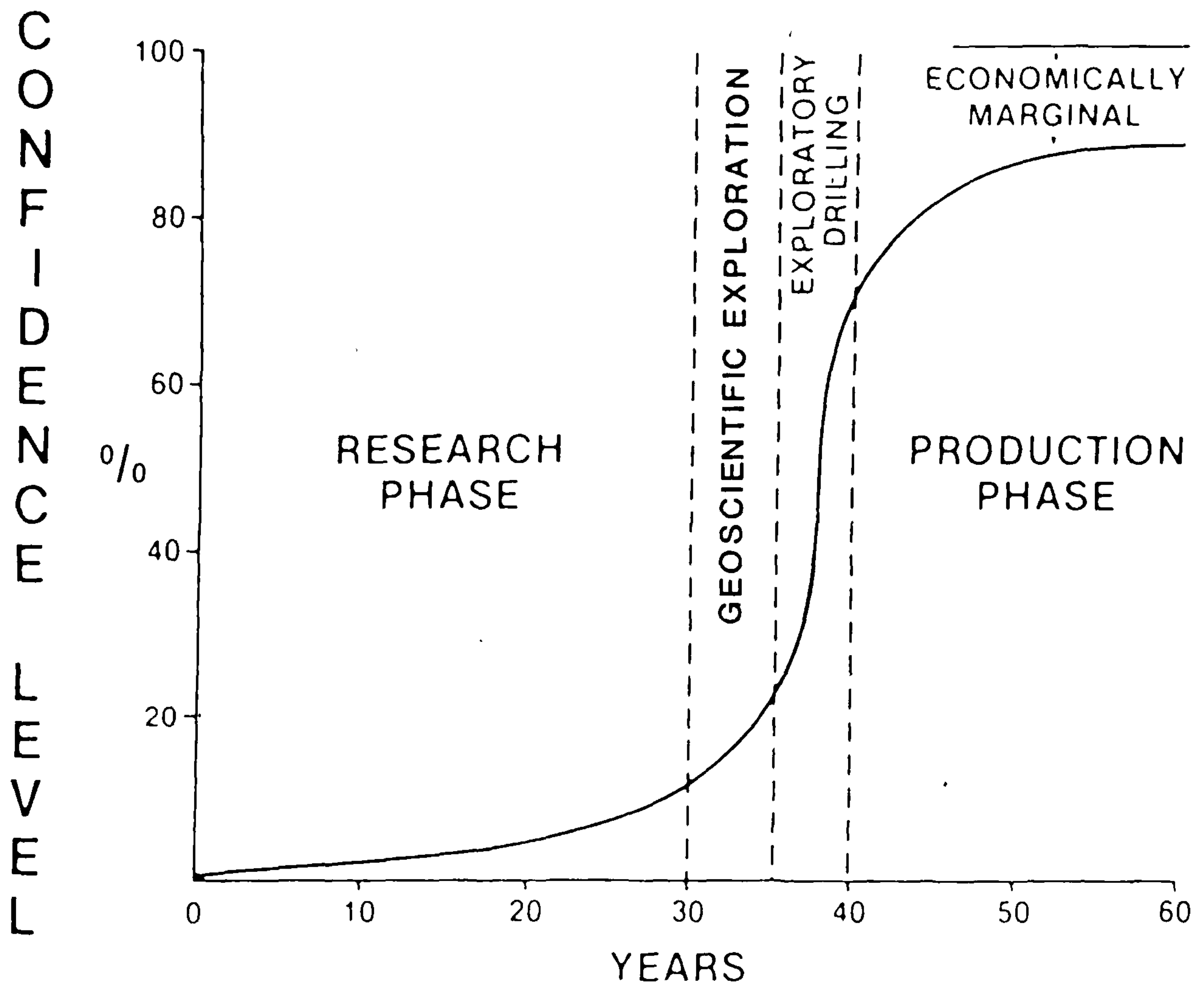
1. No known geophysical expression of vent field

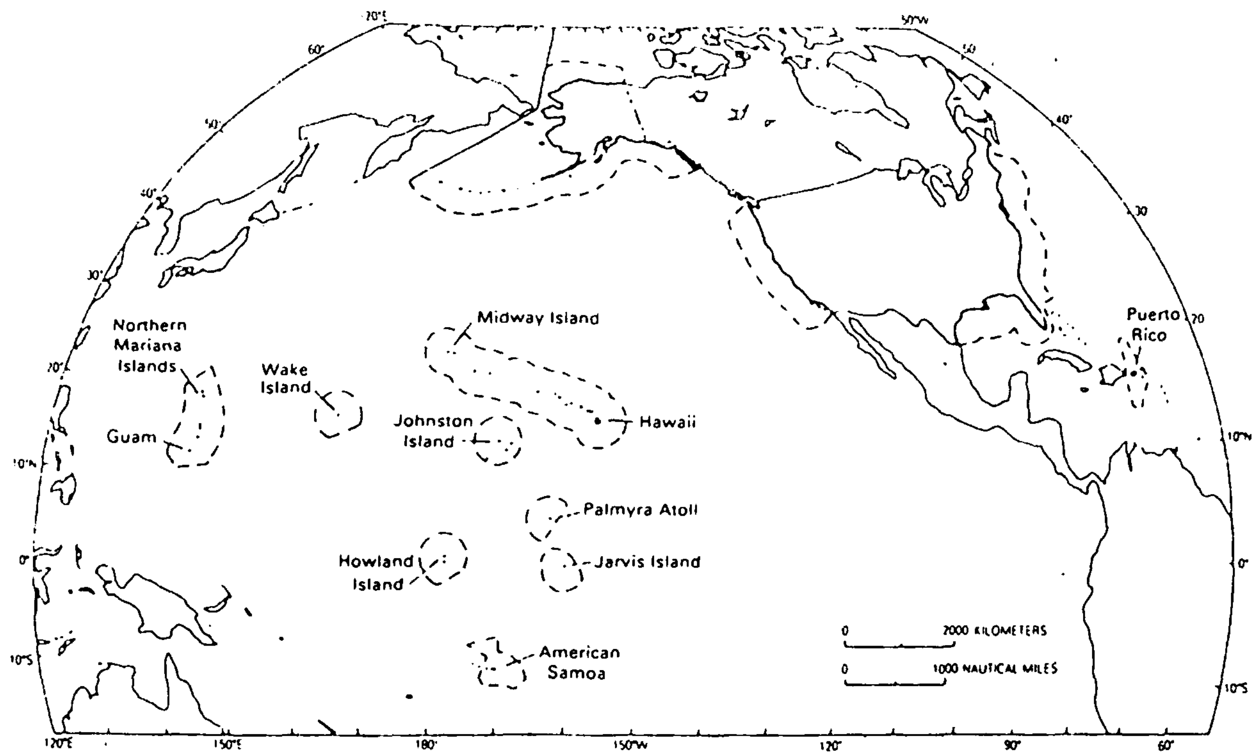
2. Anomalies in seawater temperature $<0.1°C$ within 10-30m of vents

3. Anomalies in He are at background within 10-100m of vents

4. Ocean ridge system is in 1000-4000m of water

HYPOTHETICAL
OFFSHORE RESOURCE ASSESSMENT





Exclusive Economic Zone (EEZ) of the United States, Commonwealth of Puerto Rico, Commonwealth of the Northern Mariana Islands, and the United States overseas territories and possessions (outlines of map are approximate).

EXCLUSIVE ECONOMIC ZONE MINERALS

Geothermal Resources	Gorda, Juan de Fuca Ridge Systems, Alaska, Pacific Islands
Polymetallic sulfides Zn, Cu, Cd, Ag	Gorda, Juan de Fuca Ridge Systems
Placer Deposits	Alaska , Pacific NW coasts
Phosphorites	CA, FL, S. Atlantic coasts
Crusts Co, Ni, Mn	Gorda, Juan de Fuca seamounts, Pacific Islands
Manganese Nodules Mn, Co, Ni, Cu	S. Atlantic Coasts, Pacific Islands

CONCLUSIONS

1. 0.3% of worlds ridge system explored in detail -- 5 high temperature resource areas found

2. Known occurrences of polymetallic sulfides indicate hydrothermal phenomena throughout geologic time

3. Temperatures of 300 - 350°C are typical

4. Typical heat flux is 2000 - 3000MW per vent system

5. System lifetimes 30 - 100 years

6. More exploration and improved techniques needed to quantify resource base

7. System in Guymas Basin known to be naturally distilling hydrocarbons

EARTH'S ENERGY PICTURE

1. TOTAL HEAT LOSS FROM INTERIOR OF EARTH

	10^6 MW
CONTINENTS	9.0
OCEAN BASINS (except spreading centers)	17.0
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(FOSSIL, NUCLEAR)

4. ESTIMATED 20% SPREADING CENTER HEAT LOSS DUE TO HYDROTHERMAL CONVECTION 3.3

Smaller Cutting

somewhat bigger cutting

KNOWN OCEANIC HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS

GALAPAGOS RIDGE 86°W

EAST PACIFIC RISE 12°N

EAST PACIFIC RISE 21°N

GUYMAS BASIN
(East Pacific Rise) 27°N

JUAN DE FUCA RIDGE.

GENERAL DESCRIPTION

1. KNOWN HIGH TEMPERATURE FIELDS (+250°C) CONFINED TO SPREADING AXES

2. EACH FIELD COMPOSED OF 3 - 5 VENT SYSTEMS SEPARATED BY ± 2 KM

3. EACH VENT SYSTEM COMPOSED OF 6 - 12 VENTS (CHIMNEYS) THAT ISSUE HOT WATER

4. VENTS ALIGNED ALONG FRACTURE ZONE OVER AREA 200 - 500 M WIDE BY ±1 KM LONG

5. VENTS 10 - 30 M HIGH

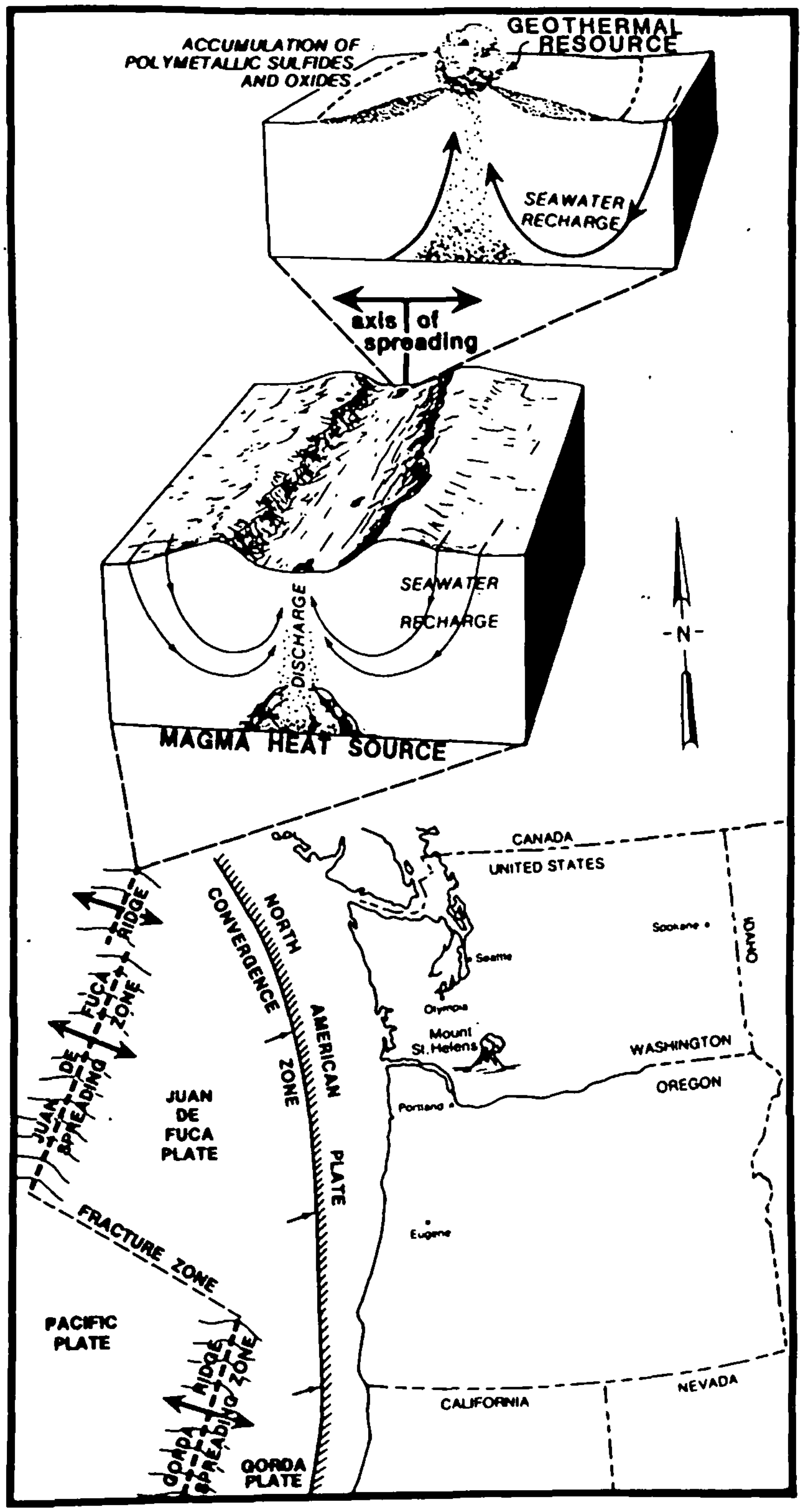
    BLACK SMOKERS : 350°C +
    metallic sulfides precipitating

    WHITE SMOKERS : 100 - 300°C
    silica, sulfates precipitating

7. DEPTH TO MAGMA POSTULATED ± 2 KM ON GEOPHYSICAL EVIDENCE

6. POSTULATED LIFETIME OF VENT SYSTEM 30 - 100 YEARS

8. SYSTEM AT 21°N EMANATING ± 11,800 MW.



GEOTHERMAL RESOURCE
ACCUMULATION OF POLYMETALLIC SULFIDES AND OXIDES
SEAWATER RECHARGE
axis of spreading
SEAWATER RECHARGE
DISCHARGE
MAGMA HEAT SOURCE
N
CANADA
UNITED STATES
Seattle
Olympia
Mount St. Helens
WASHINGTON
OREGON
IDAHO
Portland
Eugene
CALIFORNIA
NEVADA
NORTH AMERICAN PLATE
CONVERGENCE ZONE
JUAN DE FUCA RIDGE SPREADING ZONE
JUAN DE FUCA PLATE
FRACTURE ZONE
PACIFIC PLATE
GORDA RIDGE SPREADING ZONE
GORDA PLATE

TYPICAL CHARACTERISTICS OF VENT FLUIDS

TEMPERATURE:	Black Smokers	350°C+
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	Juan de Fuca	1300 m water
CHEMISTRY:	pH	4
	SiO	saturated
	major ions relative to sea water	
	Mg, SO_4	depleted
	Ca, K	enriched 2-4x
	Na, Cl	enriched 10%
	Li, Rb, Ba, Mn	enriched
	Contains: H_2S, Fe, Cu, Zn., other base and precious metals	

GUAYMAS BASIN (27°N EPR)

1. IN GULF OF CALIFORNIA

2. 315°C FLUIDS OBSERVED

3. 0.5 KM SEDIMENTS DEPOSITED BY COLORADO RIVER OVER SPREADING AXIS

4. LIGHT, MOBILE HYDROCARBONS OBSERVED BEING DISTILLED FROM CARBONACEOUS COMPONENTS OF SEDIMENTS

EXPLORATION ASPECTS

1. ONLY ±150KM RIDGE EXPLORED IN ANY DETAIL

2. FIVE HIGH TEMPERATURE AREAS DISCOVERED, ALL ON FAST SPREADING RIDGES (6 - 18 cm/yr)

3. 53,700 KM TOTAL RIDGE LENGTH, ±30 % FAST SPREADING

4. SOME EVIDENCE THAT EPR HYDROTHERMAL CENTERS OCCUR EVERY 100 KM ON RIDGE AXIS

5. HYDROTHERMAL PROCESSES AT SPREADING CENTERS ARE KNOWN TO HAVE BEEN ACTIVE FOR LAST ±2 BILLION YEARS DUE TO POLYMETALLIC SULFIDE DEPOSITS FORMED

6. NO OCEANOGRAPHER DOUBTS EXISTENCE OF VERY LARGE HYDROTHERMAL RESOURCE

EXPLORATION PROBLEMS

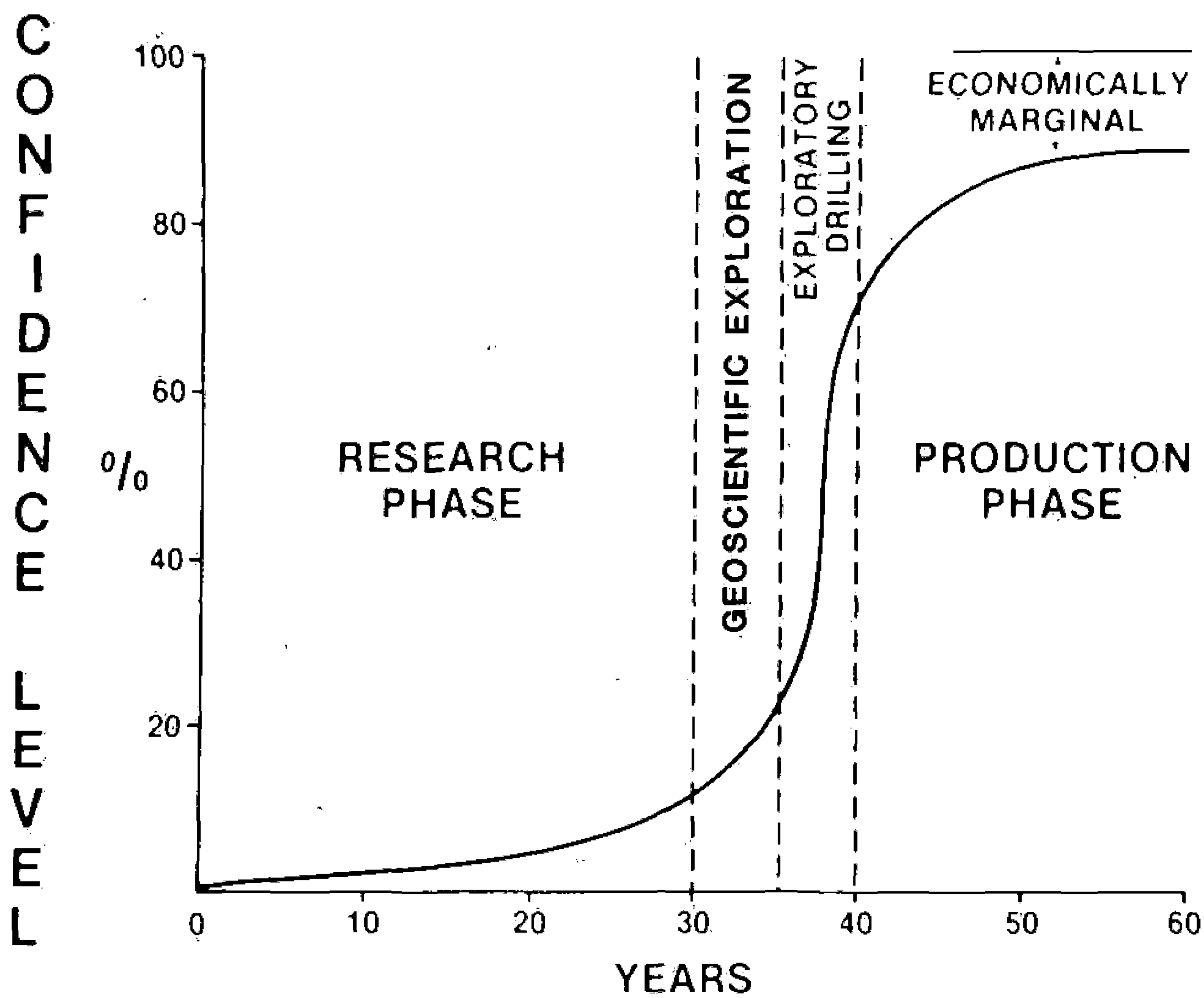
1. NO KNOWN GEOPHYSICAL EXPRESSION OF VENT FIELD

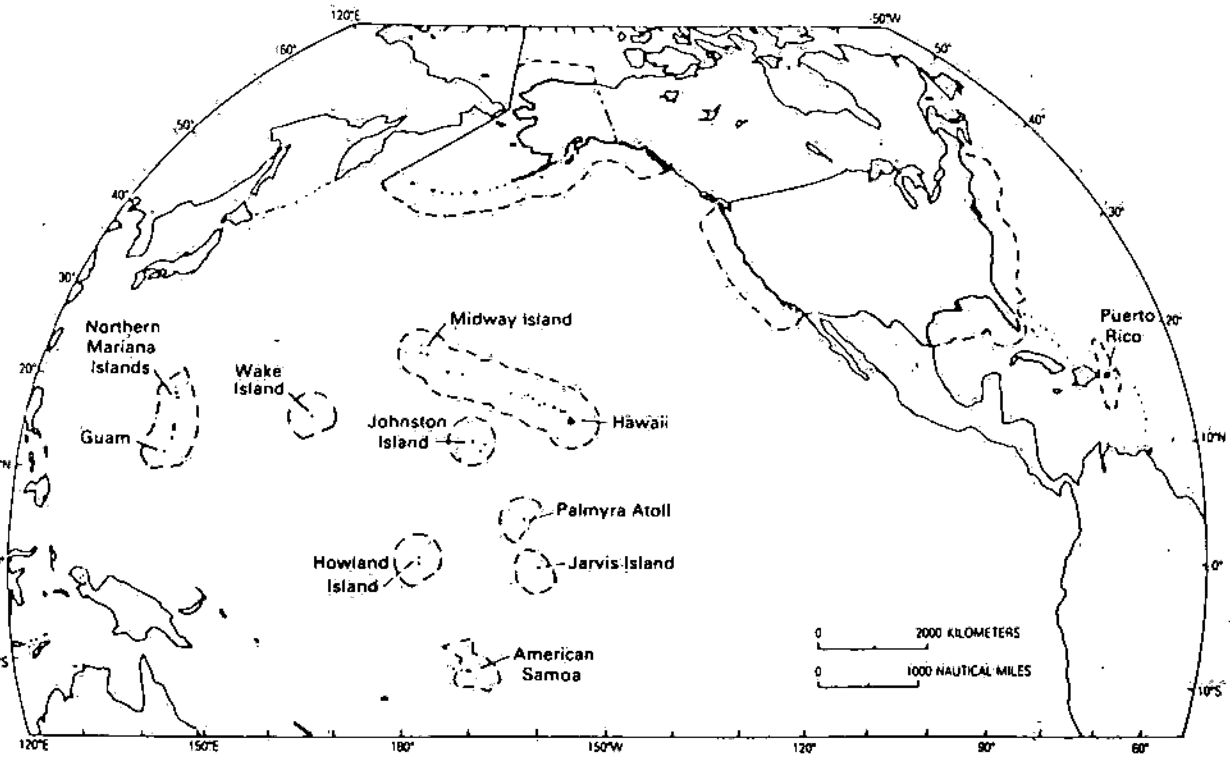
2. ANOMALIES IN SEAWATER TEMPERATURE $<0.1°C$ WITHIN 10–30 M OF VENTS

3. ANOMALIES IN He BACKGROUND WITHIN 10–100 M OF VENTS

4. OCEAN RIDGE SYSTEM IS IN 2000–4000 M OF WATER

HYPOTHETICAL OFFSHORE RESOURCE ASSESSMENT





Exclusive Economic Zone (EEZ) of the United States, Commonwealth of Puerto Rico, Commonwealth of the Northern Mariana Islands, and the United States overseas territories and possessions (outlines of map are approximate).

EXCLUSIVE ECONOMIC ZONE MINERALS

Geothermal Resources	Gorda, Juan de Fuca Ridge Systems, Alaska, Pacific Islands
Polymetallic sulfides Zn, Cu, Cd, Ag	Gorda, Juan de Fuca Ridge Systems
Placer Deposits	Alaska , Pacific NW coasts
Phosphorites	CA, FL, S. Atlantic coasts
Crusts Co, Ni, Mn	Gorda, Juan de Fuca seamounts, Pacific Islands

CONCLUSIONS

1. 0.3 % OF WORLDS RIDGE SYSTEM EXPLORED IN DETAIL -- 5 HIGH TEMPERATURE RESOURCE AREAS FOUND

3. TEMPERATURES OF 300 - 350°C ARE TYPICAL

4. TYPICAL HEAT FLUX 2000 - 3000 MW PER VENT SYSTEM

2. KNOWN OCCURRENCES OF POLYMETALLIC SULFIDES INDICATE HYDROTHERMAL PHENOMENA THROUGHOUT GEOLOGIC TIME

5. SYSTEM LIFETIMES 30 - 100 YEARS

6. MORE EXPLORATION AND IMPROVED TECHNIQUES NEEDED TO QUANTIFY RESOURCE BASE

7. SYSTEM IN GUYMAS BASIN KNOWN TO BE NATURALLY DISTILLING HYDROCARBONS

Known areas: Galapagos Ridge

Exploration Problems, other Points

1. Only ~~perhaps~~ 100-200km of ridge crests have been explored out of total of 52,000km.
~~2.~~ In these areas, high-temp vents have been found in — areas (name)

2. Available Exploration tools ~~are~~ do not allow remote detection -- must get virtually right on top of a vent area to detect it --
   - no meaningful direct geophysical expressions
   - ~~water temp an~~ seawater temperature anomalies are small (< 0.1°C) at short distances (10's of metres) away
   - deep diving, ~~ut~~ manned submersibles such as the Alvin, have ~~gee~~ permitted the kind of exploration needed for discovery to date, but rate of exploration is slow and cost is very high.

3. Hydrothermal processes on the ocean floor have been going on throughout geologic time. They are not a transient phenomenon. The evidence is the many polymetallic sulfide bodies, some of which are now on land and being mined, from all geologic ages, some 2-3 By old.

T, HC

Galapagos Ridge · 86°W

other poss sites
32°N, 45°N, 20°S

2600 m = 260 bars

EPR 21°N — called RISE geoth field
high-temp vent fields found disc 1979
3 vent systems over 6.2 km — each sys + 35 vent fields each w 6+ chim

p26 in zone 200–500 m wide confined to zone youngest volcanism

EPR 12°N
vent animals + massive sulfides
@ 12°49'N a series of black smokers were discovered
in 1982 over 8 km of ridge + active
sulfide deposition

27°N

MTS 25 Guaymas Basin — 315°C solutions are extracting
up organic-laden seds from Colo River —
they crack the organics "up to lighter volatile
hydrocarbons"

Galapagos Ridge — depth 2600 m
350°C

p41 Sulfides known on Juan de Fuca Ridge

Juan de Fuca Ridge fast speed?
low temp, except that found this year
1300 m depth — should boil @ 380°C

(over)

Sea mounts — near (west of) 12°N black smokers

2096 hydro vent

1 watt = 0.239 cal/sec   1 cal/sec = 4.18 watt

Single black smoker chimney has heat flux of 6×10^7 cal/sec = 250 MW

vents are likely not steady state due to big heat loss -- lifetimes of 10 - 100 years predicted

0.5 my sea mount has 20% fluids

p28 Seismic work has indicated magma beneath EPR @ 21°N, 12°N and GSC @ 86°W depth little as 2 km beneath sea floor

p44 massive sulfides

ρ = 4.1 gm/cm³

			ppm
~~10%~~ S	40%	Se	350
Fe	38%	Co	250
Cu	6.5%	Mg	270
SiO	7%	Mo	181
Zn	1%	Pb	215
Mn	0.5%	As	45
Al	0.3	Ba	45
		Au	0.2 ppm
		~~Ag~~	~~2~~ 1 ppm

Chemistry

primary solution 350°C
qtz saturated @ that ~~T~~ P,T
in situ pH ≈ 4
6 mM H_2S
2 mM Fe
+ Cu, Zn, other ore metals

major ions much different than seawater
Mg, SO_4 depleted
Ca, K enriched 2–4 X
Na, Cl enriched 10%
Li, Rb, Ba, Mn present in high conc

@ 21°N – highest temp, flow rates found yet
1–5 m/sec

- black smokers = sulfide laden 350°C (100 + 300°C)
- white smokers @ ≥ 220°C appear to have lost sulfide burden and to precip Mg silicates and $BaSO_4$
- warm springs

- black smokers – chimn 10's of m in height
  mechanical instability – protruding from debris

- ^{3}He isotope work indicates that a volume of water equivalent to the whole ocean circulates ~~through~~ the ridge axes, ~~[illegible]~~ every 8 million years.

Sulfides –
about 50 sites of sulfides known

Hydrothermal plumes

Red Sea
Mid Atlantic Ridge
East Pacific Rise
Back Arc Basins

30 km Galap

Known Locations ~~High~~ Temp vents

86°W Galapagos ~~Spreading Center~~ Ridge

EPR 21°N   12°N   86°W Galap

EPR 20°S

Guaymas Basin, GC - undersides 315°C

Processes Active throughout geologic time

100 km explored in any detail

Law of the Sea Treaty discourages high-risk cap investment by industry --
Industry will not explore for these resources

MTS p 19

According to Ballard - best places to explore are along fast-spreading ridges which are long in length to avoid crossfold cooling effects near transform faults.

2008 - 16 cm/yr spreading rate

2.9
0.0 4.0×10^{12}

Total length of oceanic spreading centers
(BPG V56 p136) = 53,000 km ± 5%
2.74 cm/yr av spreading rate ± 5%

>50% lithosphere cooling in < 2 my old crust
40% of total is lithosphere cooling
total = 10.2×10^{12} cal/sec
total for seafloor spreading centers =

2.1 (2.8) Continents = 2.16×10^{12} cal/sec
4.1 (7.3) Ocean backgd = 4.06×10^{12} cal/sec
4.0 Spreading Centers = 3.98×10^{12} cal/sec ~~#~~ — not this precise
10.2×10^{12} total = 10.2×10^{12} cal/sec

hydroth convection believed to account for
20% of 10.2×10^{12}

total energy use (1974) ≅ 2×10^{12} cal/sec
tides = 0.2×10^{12} cal/sec

Solar heat 4×10^{16} cal/sec 4000 X s been for relatively shallow holes run out of gas in the next 2 years. illing depends a lot on demand, on of deregulation, and costs. The s industry was granted a number of se development awards for deep illing in the Gulf of Mexico. It will derable drilling effort to bring these production by 1989, the year they ie question now is whether demand ficient to provide the necessary

son that a 1986 crisis is predicted ut not all) natural gas company ex- id market analysts is that supply nd are expected to balance out by Shortages may begin early 1986. of natural gas is expected to rise en, owing to shortages and to the decontrol and deregulation of the The status of wells that may have iged due to high pumping rates in ay be a factor in 2 years. The re- f shut-down wells may be another

outcome of the present circum- at not only will gas prices rise in 2 higher prices will support imports MB

Undersea arch Unit

t cold-water activity under the Na- anic and Atmospheric Administra- AA) National Undersea Research vill begin in the Gulf of Maine in cording to NOAA Administrator yrne. The prime objective of the y will be to survey ocean dumping nd to study the productivity of the able fish resources. (The World rrently deciding on the fishing between the United States and and around the Gulf of Maine.) maps of dumpsites off Portland, d Boston, Mass., will be made, fol- n assessment of the effects dump- marine life. Dredge spoil is ffshore from Portland; a variety of from dredge spoil to munitions—is ff Boston.

undersea research unit will be op- NOAA by the University of Con-

cilities in NOAA's National Under- ch Program include the Hydrolab

patterns discovered in this study highly believable" (*Research and Development*, May 1984). A first finding of the model is related to the homogeneity question of the upper and lower mantle regions. Dziewonski said, ". . .at this point our maps show little continuity between the upper and lower mantles." Other findings of the new models involve the roots of continental structures, which in South America and Africa extend into the transition zone to depths of about 600 km.

The new models may be limited to previous compilations of the seismic properties of the mantle by Dziewonski and colleagues under the acronyms of PEM, PREM, etc. In PREM, which refers to the preliminary reference earth model, an attempt was made to develop a parameterized approach and, as in the field of geodesy, compare a reference model in analogy with the reference ellipsoid. The result has been met with broad acceptance. The analogy of attempting to parameterize normalized functions strictly holds true only in terms of seismic coefficients (Vp,Vs), and less so for (Qu,Qk). Radius must be obtained from geodesic models, and density must be fit to models of velocity gradient whose exactness varies, particularly at discontinuities where detailed data may be unavailable (A. M. Dziewonski and D. L. Anderson, *Physics of the Earth and Planetary Interiors, 25*, 1981). Among the revelations of PREM are interpretations that the low velocity zone in the upper mantle is probably due to anisotropy, the result of preferred orientation of mineral crystals (olivine and pyroxene). Thus, the low velocity zone may not be due to a heated zone as previously thought.

Anderson extended the model-making effort recently and called his approach "earth tomography" (See *Eos*, April 17, 1984, cover, and May 8, 1984, p. 346; also see *Science, 223*, 347–355, 1984). He described the analogy with medical practice as follows: ". . .technique similar to medical tomography being used for imaging with seismic body and surface waves." There is a departure from the PREM approach in that geochemical reasoning and calculated mineral properties were fed into the modeling procedure. A conclusion was drawn that olivine mineralogy (actually, olivine chemical component or stoichiometry) was not dominant in the earth as would be the result of having pyrolite model compositions in the mantle. According to Anderson, "The transition region, therefore, appears to be mainly garnetite, rather than olivine and its high pressure forms."

The consequences of this model and of depths in the mantle. Ground truth for these interpretations lies in extensive seismic data. Ground truth must also lie in valid mineral data for the intense conditions of the mantle. The newly emerging field of mineral physics will have to supply this truth.—*PMB*

Acid Rain Study in Gulf of Mexico

As part of the continuing investigation into the sources and mechanisms of acid rain, a research project sponsored by the National Oceanic and Atmospheric Administration (NOAA) will attempt this summer to find out if natural substances blowing inland from the Gulf of Mexico might be partly responsible for the acidic rain that afflicts the midwestern and eastern United States.

A research team flying a Beechcraft twin-engine airplane will sample air quality at various points offshore, along the Gulf Coast, and inland to measure concentrations of chemicals that are "acid precursors." These precursors—sulfate, sulfur-containing gases, and alkaline materials—form naturally in the Gulf, its estuaries and coastal wetlands, according to the project's principal investigator, Rudolf F. Pueschel of NOAA's Environmental Research Laboratories. The chemicals rise into the atmosphere and are carried inland by onshore winds; the NOAA study group would like to know more about their concentration as they move northward over the continent.

During periods in the summer when stalled high pressure areas in the Gulf and off the Atlantic coast of Florida are forcing air masses inland, the research airplane will fly sampling missions twice daily. The plane is outfitted for trace gas analysis, cloud and rainwater collection, and measurement of aerosol size distribution and elemental composition. The flights will run parallel to the coastline at a distance of roughly 30–50 km offshore, as well as along the coast and at various distances inland (depending on how long the winds blow onshore). Samples will also be taken from within offshore clouds to collect data on how these clouds accumulate chemical compounds from the water.

The flights will originate from points between Corpus Christi and Houston, Tex., and from Mobile, Ala., east across the Florida panhandle. "Selection of these areas [where onshore winds can blow for 2–3 days] followed examination of weather conditions in

June 14: Conference committee on the **Export Administration Act** reauthorization (S. 979). Capitol Building, Room S-207, 2 P.M.

June 25: Hearing on the National **Minerals and Materials Policy** Coordination Act (H.R. 3717) by the Mining, Forest Management, and Bonneville Power Administration Subcommittee of the House Interior and Insular Affairs Committee. Longworth Building, Room 1324, 9:45 A.M.

June 26: Hearing on legislation subjecting the **Coastal Zone Management** Act (P.L. 94–370) to federal consistency provisions (H.R. 4589) by the House Merchant Marine and Fisheries Committee. Longworth Building, Room 1334, date and time tentative.—*BTR*

Mapping the EEZ

A cooperative, multi-year program to map the largely uncharted Exclusive Economic Zone (EEZ), begun last month, has the potential for piggybacking scientific observations and research. On March 10, 1983, President Ronald Reagan proclaimed the mineral-rich zone as the area between the U.S. shoreline and 200 nautical miles outward. The United States has sovereign rights for exploration, exploitation, conservation, and management of all living and nonliving resources within the zone.

The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) will cooperate in the project that will map an area nearly twice the area of U.S. land. USGS responsibilities include definition of seafloor geology and definition of geological processes and resources, including sand and gravel, placers, phosphorites, manganese nodules, cobalt crusts, and sulfides (*Eos*, March 20, 1984, p. 105). NOAA, meanwhile, will be surveying, mapping, analyzing resources, and managing fisheries.

Mapping began in the Pacific near Cape Mendocino, Calif. The west coast will be surveyed this year and next, followed by Alaska in 1986, the Hawaiian Islands in 1987, and the trust territories after that. No schedules have yet been set for the east and Gulf coasts.

NOAA and the USGS are encouraging the piggybacking of observations and sampling in related areas during the data-gathering cruises. For additional information, contact Adm. John Bossler, National Ocean Service, NOAA, 6001 Executive Blvd., Rockville, MD 20852, or Terry W. Offield, USGS, 915 National Center, Reston, VA 22092.—*BTR*

News

Oregon Seismic Experiment

The United States Geological Survey (USGS), with support from the Geothermal and Hydropower Technologies Division of the U.S. Department of Energy, will be conducting an active seismic experiment in central Oregon using nine large explosions during the last week of August 1984. A major goal of this experiment is to detect kilometer-size magma chambers in the upper crust below Newberry Volcano (Figure 1). The planned experiment is a small-scale version of one type of seismic-imaging experiment proposed by the Program for Array Seismic Studies of the Continental Lithosphere (PASSCL). Because of the required density of the recording array, the USGS recording effort will be concentrated in and around the summit caldera and leave ample opportunity for additional recording of the large shots, by interested parties, to study the rest of the volcano and surrounding geologic provinces.

Newberry Volcano is situated in central Oregon 50 km east of the High Cascade Range axis at the intersection of several major geologic provinces (Figure 1). Rhyolites of Newberry Volcano are the northwestern, young end members of a westward progression of rhyolitic volcanism which has occurred in south-central Oregon during the past 10 m.y. MacLeod and Sammel (*Calif. Geol.*, *35*, 235–244, 1982) presented an excellent description of the geology of Newberry Volcano, from which the following brief description is abstracted. The volcano is a broad shield, about 1 km high and covering an area of 1,200 km². The flanks are veneered by hundreds of basalt and basaltic-andesite flows and cinder cones with carbon 14 ages as young as 5,800 years. A caldera, 6–8 km in diameter, is present at the summit; the recent volcanism inside this caldera, in contrast to the mafic volcanism on the flanks, is predominantly rhyolitic. The most recent rhyolitic volcanism occurred 1,350 years ago. The occurrence of young silicic volcanism and hot springs in the summit caldera makes Newberry Volcano a prime target for geothermal exploration. Drilling within the caldera has been conducted by the USGS and Sandia National Laboratories. Similar temperature profiles were determined in both holes, and a temperature of 265°C was measured at the bottom of the and the results have been published by Leaver, Mooney, and Kohler (*J. Geophys. Res.*, *89*, 3121–3134, May 1984). The other seismic-refraction line which runs east-west through Newberry Volcano (Figure 1) was shot in fall 1983 as preliminary work for the current USGS experiment. A station spacing of 0.5 km and a shotpoint spacing of 15.0 km were used to allow concentration of a detailed seismic-velocity cross section of the volcano. Interpretation of this refraction line is in progress.

The upcoming USGS experiment is similar to that performed at Le Mont-Dore Volcano, France, by Nercession, Hirn, and Tarantola (*Geophys. J. R. Astron. Soc.*, *76*, *307–315*, *1984*). *P* waves, generated by explosions distant from the volcano and reflected or refracted back toward the surface by the crustal velocity structure, will be used to illuminate, from below, the summit region of Newberry Volcano from many azimuths. The receiving array will consist of 120 portable analog recorders normally used in USGS refraction work and will cover a region, about 12 km in diameter, centered on the summit caldera, with an average station spacing of 1 km. Traveltime residuals will be inverted to obtain a three-dimensional *P* velocity model to a depth of about 5 km, with a spatial resolution of about 1 km. The distances from the array to the shot points were selected, after partial analysis of the detailed east-west refraction line through Newberry Volcano, to use two coherent impulsive and high-amplitude phases. Figure 2 illustrates ray paths for these two phases. Nine shot points are located at these two distances with as uniform an azimuthal distribution as possible (Figure 1). Here, 2,700 kg of explosives will be detonated below the surface at each shot point at scheduled times divided between two nights.

Because of the large number and sizes of the planned shots, many opportunities exist for recording reversed and unreversed refraction profiles (which will not be covered by the USGS) on Newberry Volcano and in the adjacent provinces, including the High Cascade Range, the Basin and Range, and the High Lava plains. Persons interested in utilizing these planned shots for such experiments should contact the author to obtain more information about the shots, the exact schedule, and possible coordination with other interested parties.

This news item was contributed by Douglas

CLAWS: Classify, Locate, Avoid Wind Shear. The operational program aims to develop procedures for using the information that Doppler radars can provide, establish the validity of microburst forecast techniques, and provide airplane pilots with the necessary real-time information.

CLAWS is the "natural consequence of the Joint Airport Weather Studies (JAWS) field research that took place at Stapleton during the summer of 1982 and our analysis of those findings," said McCarthy, who also directed JAWS. "It is vital for us to test our ultimate ability to transfer this information to the air traffic controllers who will, in turn, advise the pilots."

JAWS was designed by the National Center for Atmospheric Research (NCAR) and the

earth, the sun, and other stars, and in some planets of the solar system. Such fields are theoretically understood in terms of a dynamo mechanism that generates them in a manner related to the way in which commercial electricity is generated by electric dynamos. If the analysis holds, Morris said, the new discovery may be revealing the existence of a galactic dynamo.

"The importance of understanding the activity in our galactic nucleus lies in what it may imply about the much more intense activity seen in the nuclei of radio galaxies, quasars, and other varieties of active galaxies," the astronomer said.

Geophysicists

and Sammel, *Calif. Geol.*, *35*, 235–244, 1982). This high temperature and the occurence of young silicic volcanism suggest the existence of magma chambers within the shallow crust below the summit of the volcano.

Several seismic experiments have been conducted by the USGS in the vicinity of Newberry Volcano, including a teleseismic *P* residual study of the volcano, and two seismic-refraction lines. The teleseismic *P* residual study detected a column of high *P* velocity material, about 15 km in diameter, extending from within 10 km of the surface to 25 km depth beneath the summit, which is interpreted to result from numerous subsolidus mafic intrusions. One of the seismic-refraction lines runs along the margin of the High Cascade and Western Cascade provinces (Figure 1)

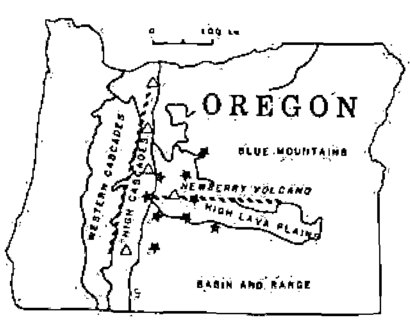


Fig. 1. Oregon, showing physiographic provinces (Baldwin, *Geology of Oregon*, 147 pp., 1976), major Cascade Range volcanos, including Newberry Volcano (triangles), existing USGS refraction lines (heavy dashed lines), and planned shots (stars).

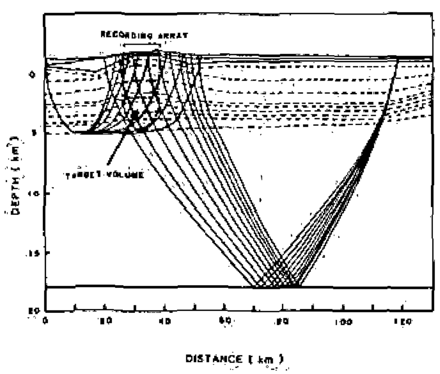


Fig. 2. East-west cross section through Newberry Volcano, showing ray paths for two phases to be used in the USGS experiment.

Park, Calif.

Upcoming Hearings In Congress

The following markup and conference committee have been tentatively scheduled by the Senate and House of Representatives. Dates and times should be verified with the committee or subcommittee holding the markup or conference; all offices on Capitol Hill may be reached by telephoning 202-224-3121. For guidelines on contacting a member of Congress, see *AGU's Guide to Legislative Information and Contacts* (*Eos*, April 17, 1984, p. 159).

August 7: Mark up legislation that would require federal **Coastal Zone Management** plans to be consistent with state management plans (H.R. 4589) by the House Merchant Marine and Fisheries Committee. Longworth Building, Room 1334, 10 A.M.

August 8: Conference on **ocean and coastal resources** block grants for fisheries programs and **deep seabed minerals resources** programs (S. 2463). Capitol Building, Room S205, time to be announced. (Note new date.)—*BTR*

Wind Shear Test

Techniques for forecasting and detecting a type of wind shear called microbursts are being tested this month in an operational program at Denver's Stapleton International Airport as part of an effort to reduce hazards to airplanes and passengers.

Wind shear, which can be spawned by convective storms, can occur as a microburst. These downbursts of cool air are usually recognizable as a visible rain shaft beneath a thundercloud. Sometimes, however, the rain shaft evaporates before reaching the ground, leaving the downdraft invisible. Although thunderstorms are traditionally avoided by airplane pilots, these invisible downdrafts also harbor hazards in what usually appear to be safe skies. When the downdraft reaches the earth's surface, the downdraft spreads out horizontally, much like a stream of water gushing from a garden hose on a concrete surface, explained John McCarthy, director of the operational program. Airplanes can encounter trouble when the downdraft from the microburst causes sudden shifts in wind direction, which may reduce lift on the wing, an especially dangerous situation during takeoff.

The test at Stapleton, funded by the Federal Aviation Administration, is dubbed

Bullard Fellowship

A research fellowship honoring the late Sir Edward Bullard has been established in his name at Churchill College in Cambridge, England.

Bullard received the AGU Maurice Ewing Medal in 1978 and the AGU Bowie Medal in 1975. His work was most recently described in *Eos* by Elizabeth N. Shor (*Eos*, February 28, 1984, p. 73). Bullard died April 3, 1980.

AGU members who would like to contribute to the fellowship are invited to do so through the American Friends of Cambridge University, P.O. Box 7070, Arlington, VA 22207. Please be sure to clearly identify all gifts as a contribution to the Bullard Research Fellowship. AFCU is a registered nonprofit, charitable organization; contributions are deductible for U.S. tax purposes.

Milky Way Gas

An enormous arc of hot gas protruding from the center of our galaxy has been discovered by astronomers near the center of the Milky Way. The existence of the arc could mean that stars are not being formed there at the high rate previously assumed. This assumption had been made because of the intense radio emissions rising there.

Discovered using the National Radio Astronomy Observatory's Very Large Array (VLA) in New Mexico, the structure resembles a solar prominence, which is a great streamer or column of glowing gas that often rises to great heights at enormous velocities about the sun's surface. The arc is 150 light years long and 30,000 light years from the earth.

"Among the unique characteristics of this unparalleled structure is its coherent organization on such a large scale, suggesting that its presence is linked to the structure of our galaxy," according to astronomer Mark Morris of the University of California at Los Angeles. Also on the research team making the discovery are Farhad Yusef-Zadah and Don Chance, both from Columbia University.

"The evidence now available, especially the detailed shape of the structure, implies that the arc of hot ionized gas is controlled by a magnetic field," Morris added. "While our galaxy has been known for some time to contain a magnetic field, this is the first indication of the existence of a substantial poloidal magnetic field, a field akin to the dipole field of a simple bar magnet."

Dipole magnetic fields are present in the

Otis B. Brown has been appointed acting chairman of the division of meteorology and physical oceanography at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. Brown succeeds ***Friedrich Schott***, who was chairman since 1979.

Mark Carle and ***Christopher G.A. Harrison*** of the Rosenstiel School of Marine and Atmospheric Science were commended recently by the National Aeronautics and Space Administration (NASA) for scientific use of scientific data. Each has studied the magnetic field over the ocean basins with data collected by the MAGSAT satellite. The commendation was presented by ***Gilbert Ousley***, leader of the NASA team responsible for the design, construction, and operation of MAGSAT.

Moustafa T. Chahine has been appointed as Chief Scientist of the Jet Propulsion Laboratory (JPL). He succeeds ***Arden Albee***, who will return at the end of August to his faculty position in the Division of Geological and Planetary Sciences at the California Institute of Technology. Chahine joined JPL in 1960 as a senior scientist specializing in atmospheric studies. He is currently manager of JPL's Earth and Space Sciences Division.

William S. Gaither, founder and dean of the College of Marine Studies at the University of Delaware, was selected as Drexel University's next president at the university's board of trustees meeting in May.

ry/Lunar Exploration), B. Burke (Astrono-y/Astrophysics), D. Anderson (Earth Sci-nces), E. Scarf (Solar/Space Plasmas), and L. argulis and S. Swisher (Life Sciences).

Objectives of the task groups during the ext year will be the continued definition and finements of the long-term space science ojectives and possible mission models on the sis of the expected positions of the various sciplines in 1995 as discussed in the past ard strategies. In the next year there will so be concerted efforts to discuss widely ithin the individual constituent scientific mmunities the activities of the task groups d the planning processes that are ongoing. here is every intent to involve as wide a ectrum of the scientific community as possi-e in order to ensure that the very best ideas e considered for the post-1995 space sci-ce objectives of the nation.

This news item was contributed by L. J. Lanzer-ti, *Bell Laboratories, Murray Hill, N. J.*

PEX: he Arctic Polynya xperiment

A field experiment has been initiated to ad-ress the mesoscale oceanographic, sea ice, d meteorological processes associated with polynya, or high-latitude area of semiper-anent open water and vigorous new ice owth. This experiment, called the Arctic lynya Experiment (APEX), is taking place and around the St. Lawrence Island Polyn-on the northern Bering Sea shelf. This po-nya was selected for study because it typifies any such features found throughout the rctic and Antarctic, is relatively accessible, d lies in a region that is of considerable in-rest due to projected resource develop-ent.

A polynya is an open water area which per-ts despite environmental conditions which

Nome, Alaska. The experiment is funded jointly by the National Science Foundation, the Office of Naval Research, and NOAA.

This news item was contributed by Robin D. Muench, *Science Applications International Corp., Bellevue, WA 98005* and Carol H. Pease, *Pacific Marine Environmental Laboratory, NOAA, Seattle, WA 98115.*

Exclusive Economic Zone

Following President Reagan's declaration of an Exclusive Economic Zone (EEZ) in March 1983, the National Advisory Committee on Oceans and Atmosphere (NACOA) undertook a study to begin sorting out what implications the proclamation would have on existing and future oceans legislation and policy. As a result of this proclamation and the Reagan administration's earlier decision not to sign the Law of the Sea (LOS) Treaty, much discussion has centered around whether or not the United States should attempt to formulate a comprehensive package containing all oceans-related legislation. According to the NACOA report "The Exclusive Economic Zone of the United States: Some Immediate Policy Issues," most experts argue against such a move. NACOA agreed, recommending that a comprehensive oceans package is not needed nor even desirable at this time. Instead, NACOA argues, emphasis should be placed on assuring that existing U.S. ocean policy is "consistent" with the nondeep seabed provisions of the LOS treaty. NACOA is a Presidential advisory committee that conducts ongoing reviews of national oceanic and atmospheric policy and reports directly to Congress and the President.

Another major NACOA recommendation called for a clearly defined system for dispute settlement, particularly regarding freedom of navigation through other nations' exclusive economic zones. In order to assure navigational freedoms, NACOA recommended that the United States should not implement any policy that goes beyond those provisions of the LOS treaty. Although disputes cannot be totally avoided, NACOA admits, a system of dispute settlements set up and agreed upon beforehand can help the United States reach timely agreements with other coastal nations. This may be particularly important, says NACOA, because existing treaties with coastal nations leave many gaps where disputes could develop.

A final major NACOA recommendation, now being acted upon, is to conduct a de-

entific and Engineering Personnel, JH 608-D3, National Research Council, 2101 Constitution Avenue, N.W., Washington, DC 20418 (telephone 202-334-2760).

Upcoming Hearings in Congress

The following hearing has been tentatively scheduled by the House of Representatives. The date and time should be verified with the committee or subcommittee holding the hearing; all offices on Capitol Hill may be reached by telephoning 202-224-3121. For guidelines on contacting a member of Congress, see *AGU's Guide to Legislative Information and Contacts* (*Eos*, August 28, 1984, p. 669).

October 10. Field hearing on U.S. ocean policy by the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the House Merchant Marine and Fisheries Committee, Versailles Room, New Orleans Hilton Hotel, 2 Poydras St., New Orleans, La., 9 A.M.—*BTR*

NASA Guest Investigators

The National Aeronautics and Space Administration (NASA) is now seeking guest investigators to participate in the International Sun-Earth Explorer (ISEE) and International Cometary Explorer (ICE) programs. The ISEE/ICE project is a joint NASA/European Space Agency (ESA) venture. A budget of approximately $500,000 to support the ISEE/ICE Guest Investigator Program is expected for fiscal year 1985, and a similar amount is expected for FY 1986.

Although NASA welcomes proposals at any time, proposals must be received by mid-October in order to be considered in the initial selection. Those arriving after mid-November may be held for another selection period.

NASA's objective is to extend and augment established ISEE/ICE programs. Participation and use of data may take several forms. Researchers may use data already collected or plan special operations for future data acquisition and interpretation using program instruments that are already operating. In addition, theoretical interpretive studies in support of specific experimental results from ISEE/ICE may be conducted, as well as comparative studies combining data from another source with ISEE/ICE data.

Questions regarding this guest investigator program should be addressed to John T.

Yews

ɹong-Range Space Objectives

At the request of the National Aeronautics ɪd Space Administration (NASA) the Na- ɪnal Research Council's Space Science ɔard has undertaken a special study of the ng-term (post-1985) objectives of U.S. re- arch in the space sciences. The study will ntinue over approximately 2 years and will volve two to three summer sessions as well disciplinary group meetings during the in- rvals between the summer sessions. This ecial study is intended to build upon and nsiderably extend the strategy reports in e various space science disciplines that the ɪard has been involved in formulating over e past few years.

In the first meeting of the entire study, ld at Woods Hole, Mass., August 20–29, ch of the disciplinary panels formulated a aft report on the present status of their sci- ces and the expected space science missions the year 1995. These expected missions e based upon the science strategies as con- ined in the reports of the several commit- es of the Space Science Board. The individ- l task groups also developed, in a very pre- ninary fashion, scientific objectives and ace science missions that might well be con- lered for implementation in the post-1995 a.

The study is organized around a steering oup and is being conducted by this steering oup plus six disciplinary panels, consisting approximately 12 individuals each. Present embership of the steering group includes M. Donahue (Chairman), University of ichigan; D. Anderson, California Institute Technology; R. Berliner, Yale; B. Burke, assachusetts Institute of Technology; A. G. Cameron, Harvard; H. Friedman, NASA; Hunten, University of Arizona; F. John- n, University of Texas, Dallas; S. M. Krimi- , Applied Physics Laboratory/Johns Hop- ns University; E. Levy, University of Arizo- ; F. B. McDonald, NASA; L. Margulis, ɔston University; J. Naugle, Fairchild In- ıstries; F. Scarf, TRW; E. Stone, California stitute of Technology; S. Swisher, Michigan ate University; J. A. Van Allen, University Iowa; and R. Weiss, Massachusetts Insti-

would seem to dictate formation of an ice cover. Such areas may be due to a variety of causes. The majority appear to occur, howev- er, when a physical barrier, such as a coast- line or a channel constriction, allows prevail- ing winds or currents to sweep newly formed ice away while at the same time preventing existing ice from moving into the area. The St. Lawrence Island Polynya occurs along the southern, or lee, coastline of St. Lawrence Is- land as the prevailing northerly winds sweep ice away toward the south. Polynyas are of oceanographic interest because they are sites for vigorous, continuous ice formation and are therefore sources both of new ice and of dense, brine-enriched water. They are of in- terest meteorologically because the associated strong sea-air heat fluxes modify the atmo- spheric boundary layer.

Oceanographic goals of the APEX program include estimation of the mesoscale heat, salt, and momentum fluxes associated with a po- lynya and definition of the dynamics which affect these fluxes. These goals will be ad- dressed through time series current, tem- perature, and salinity observations obtained from oceanographic moorings. The data analyses will focus upon polynya-associated dynamics within the context of a coastal dynamics problem and will use descriptive analyses and simple analytic models. Goals of the APEX sea ice studies include estimation of ice formation rates and of the effects of the polynya on regional ice properties and dynamics. Field observations of ice motion will be obtained by using satellite-tracked drift buoys, and ice distribution will be ob- served with satellites. The analyses will inte- grate the observed ice distribution and mo- tion with oceanographic and meteorological conditions through a numerical model. Mete- orological program goals include estimation of mesoscale and boundary layer effects asso- ciated with the polynya. Meteorological con- ditions will be monitored by using remote re- cording and satellite transponding weather stations. The data will be analyzed in con- junction with computed regional winds to ad- dress the above goals.

The oceanographic moorings are presently in place, having been deployed in early Octo- ber 1984 from the University of Alaska vessel *Alpha Helix*. It is planned that these moorings will be recovered using the same vessel in

tailed "nuts and bolts" study to determine what implications the EEZ proclamation will have on existing U.S. legislation. The Outer Continental Shelf Lands Act of 1953 is a prime example. The Committee on Atmo- sphere and Oceans (CAO), a separate organi- zation, is in the process of completing this re- port, which is due sometime in November.

In related news, NACOA has received funding of $630,000 through the end of fis- cal year 1985, which began October 1. For the past several years the Reagan administra- tion has attempted to eliminate NACOA by cutting its funding, but Congress, as was the case this year, has always intervened.—*DWR*

NRC Associateships Available

The National Research Council (NRC) has announced that some 2500 new full-time as- sociateships will be awarded in 1985 for re- search in the sciences and engineering. Most of the positions are open to both U.S. and non-U.S. nationals and to both recent Ph.D. holders and senior investigators. Applications must be postmarked no later than January 15, 1985. The announcement of initial awards is expected in March and April 1985.

The associateships will be awarded on a competitive basis for research in chemistry, engineering, and mathematics and in the earth, environmental, physical, space, and life sciences. More than 20 federal agencies or re- search institutions located throughout the United States will participate.

Most of the awards will be made for 1 or 2 years. Applicants who have held doctorates for at least 5 years may request shorter ten- ures. Stipends beginning at $25,350 per year for recent Ph.D. holders will be awarded. A stipend supplement of up to $5,000 may be available to regular awardees who hold recog- nized Ph.D.s in disciplines which fall signifi- cantly below the current demand of U.S. graduate schools. Last year these disciplines included engineering, computer science, and space-related biomedical science.

Further information, including applica-

Lynch, Code EE, NASA Headquarters, Washington, D.C. 20546 (telephone: 202-453- 1676). Queries specifically regarding comet science only should be sent to William Brunk, Code EL, NASA Headquarters, Washington, D.C. 20546 (telephone: 202-453-1596).

Space Station Proposals

NASA has issued a request for proposals (RFP) for definition and preliminary design of a permanently manned space station. The station is to be operational in low earth orbit early in the 1990's. According to NASA, the station will "support scientific and commer- cial endeavors in space, stimulate new tech- nologies, and enhance space-based operation- al capabilities." Proposals are due November 15, 1984.

Intended to be operational for several dec- ades, the space station will include a number of pressurized modules and a power supply of 75 kilowatts, will support a crew of six to eight people, and will have two or more free- flying unmanned platforms.

The RFP includes four "work packages" covering preliminary designs of space station elements. Contracts to be let for each package are scheduled to begin April 1, 1985. The RFP also requires contractors to study the possibility of using automation and robotic technologies.

Final design and development of the sta- tion will begin in 1987. Overall system engi- neering and integration activities will be per- formed by NASA's Johnson Space Flight Center, Houston, Tex.

maintained for NASA to conduct state-of-the art science. Laboratory and experimental equipment used by NASA-sponsored researchers has also fallen into disrepair or become outmoded while limited funds have been spent elsewhere, according to the report, to the point where "many European and Japanese laboratories are equipped with instrumentation far superior to our own. It is important to the country's long-term technological well-being and to NASA's future in particular that this situation in universities be remedied."

Special JGR-B Issue: Mapping the Seafloor

JGR-B will publish a special issue in 1985 focusing on the results obtained by using a variety of new seafloor mapping tools (e.g., SEA BEAM, SEA MARC I and II, GLORIA, GEOS 3, and Seasat radar altimetry). Liberal use of color and large-format black and white figures is encouraged. Special reduced rates for color will apply. Papers describing results obtained by using these new techniques in a variety of tectonic environments (e.g., mid-ocean ridges, active margins, passive margins, seamounts) are solicited as well as papers describing instrumentation and data processing and interpretation techniques. Submission deadline is September 30, 1984. Publication is planned for July or August 1985. For further information contact Gerald Schubert, Editor of JGR-B, or Robert Detrick, Associate Editor for this volume.

Gerald Schubert, Editor
Journal of Geophysical Research
Department of Earth and Space Sciences
University of California
Los Angeles, CA 90024
(telephone: 213-825-4577 or 824-5665)

Robert S. Detrick
Graduate School of Oceanography
Narragansett Bay Campus
University of Rhode Island
Kingston, RI 02881

Flood

A Federal Interagency Work Group on Probable Maximum Flood Assessment is currently studying the problem of hydrologic design based on the probable maximum flood (PMF). Of particular interest are the calculation of PMF probabilities, the accuracy of such estimates, and the development of a standardized methodology for probabilistic assessment of severe floods.

In an effort to establish the state-of-the-art, the work group is interested in obtaining copies of papers or reports that are related to the subject. Please send relevant material to Richard H. McCuen, Department of Civil Engineering, University of Maryland, College Park, MD 20742.

Upcoming Hearings in Congress

Congress returns on September 5 from its recess for the Republican National Convention and the August district work period. Expect rapid changes in schedule during the next several weeks as the election approaches.

The following hearings, markups, and conference committees have been tentatively scheduled for the coming weeks by the Senate and House of Representatives. All dates and times have yet to be announced; the committee, subcommittee, or conference committee holding the hearing, markup, or conference will be setting schedules in the next few days. All offices on Capitol Hill may be reached by telephoning 202-224-3121. For guidelines on contacting a member of Congress, see *AGU's Guide to Legislative Information and Contacts* (*Eos*, August 28, 1984, p. 675).

TBA: Markup of **Safe Drinking Water** Act (P.L. 93-523) amendments (H.R. 5959) by

Scientific Event Alert Network. The complete bulletin is available in the microfiche edition of *Eos* as a microfiche supplement or as a paper reprint. For the microfiche, order document E84-008 at $2.50 (U.S.) from AGU Fulfillment, 2000 Florida Avenue, N.W., Washington, DC 20009. For the paper reprint, order *SEAN Bulletin* (giving volume and issue numbers and issue date) through AGU Separates at the above address; the price is $3.50 for one copy of each issue number for those who do not have a deposit account, $2 for those who do; additional copies of each issue number are $1. Subscriptions to *SEAN Bulletin* are available from AGU Fulfillment at the above address; the price is $18 for 12 monthly issues mailed to a U.S. address, $28 if mailed elsewhere, and must be prepaid.

Volcanic Events

Kilauea (Hawaii): Phases 22–23 of 1983–1984 E Rift Zone eruption.

Mount St. Helens (Washington): Deformation, seismicity, and SO_2 emission drop.

Arenal (Costa Rica): Lava production slows as strong tephra ejection begins.

Llaima (Chile): Dense columns of dark ash emitted from crater.

Rabaul (New Britain): Seismicity declines; deformation increases.

Manam (Bismarck Sea): Strombolian activity; frequent debris avalanches.

Home Reef (Tonga): Large pumice rafts in Fiji area from March eruption.

Etna (Italy): Lava production and strombolian activity continue from SE crater; strong explosions from central and NE craters.

Atmospheric effects: El Chichón aerosols persist in stratosphere.

Etna Volcano, *Sicily, Italy (37.73°N, 15.00°E). All times are local (= UT + 2 hours).*

The quoted material is a report from Romolo Romano.

"The southeast crater eruption that began April 27 was continuing in early August with more or less intense strombolian activity, accompanied at irregular intervals by violent expulsions of dark ash. This activity produced a scoria cone (about 50 m high) higher than the rim of the southeast crater. The ef-

... be estimated at around 8–10 x 106 m³.

"An increase in central crater eruptive activity was recorded in July. From the west vent (Bocca Nuova), violent expulsions of gray ash continued at irregular intervals, while on the floor of the vent, violent and continuous strombolian activity continued. At times, incandescent lava rose higher than the crater rim. The larger east vent (The Chasm) of the central crater, after showing activity similar to that at Bocca Nuova in mid-July, was the source of violent activity on July 19 between 1300 and 1700. Very violent strombolian activity ejected incandescent lava fragments about 1 m in diameter to 500 m from the crater rim. The southern and northern flanks of the central crater were most often impacted by the lava fragments (their average diameter was about 30 m, and they fell within an average radius of 300 m)."

The pilot of an aircraft flying near Etna at 1542 on July 19 observed an eruption cloud that reached about 6.5 km altitude. At 1613, the NOAA 7 polar orbiting satellite showed a plume extending 100 km east from Etna.

"After this, The Chasm remained obstructed until August 1, when it reopened (at 1900) with the expulsion of old material that fell outside the crater rim. On August 6, this vent was once again obstructed (around 1300) as the result of internal landslides.

"The northeast crater, inactive since February 1981, had a violent explosion that ejected old material on July 20 at 1715. Since then, strong emissions of vapor and gases occurred from the small vent that formed near the summit."

Information Contacts: Romolo Romano, Istituto Internazionale di Vulcanologia, Viale Regina Margherita 6, 95123 Catania, Italy; Michael Matson, NOAA/NESDIS, Room 510, World Weather Building, Washington, DC 20233.

Meteoritic Events

Fireballs: W Australia (two); N California, Oregon (two).

Earthquakes

Date	Time, UT	Magnitude	Latitude	Longitude	Depth of Focus	Region
July 5	0522	6.5 Ms	6.09°S	154.42°E	30 km	Solomon Islands
July 19	0656	4.9 mb Lg	52.91°N	4.20°W	20 km	United Kingdom

Information Contacts: National Earthquake Information Service, U.S. Geological Survey, Stop 967, Denver Federal Center, Box 25046, Denver, CO 80225.

OCEAN HYDROTHERMAL ENERGY UTILIZATION TECHNOLOGY PROGRAM

LIST OF CONTACTS

NAME	ADDRESS/AFFILIATION	PHONE	TOPICS OF INTEREST
Michael A. Hobart	Lamont-Doherty Geol Obs.	914-359-2900x331	hydrothermal processes
Kathleen Crane	Lamont-Doherty Geol. Obs.	914-359-2900x235	" "
J. M. Edmond	Mass. Inst. of Technology, Cambridge, MA		chemistry
Peter A. Rona	NOAA/Atlantic Oceanographic & Meteorological Laboratories/Miami, FL		mineralization, hydrothermal processes
David B. Duane	Marine Geol. Resources, Office of Sea Grant, NOAA - Shorter		research programs
C. G. Welling	Ocean Minerals Company, Mtn. View, CA		commercial mining
G. Ross Heath	College of Oceanography, Oregon State Univ.	503-754-4763	biology
Mel Peterson	Scripps Institution Oceanography	619-452-3500	general
Peter Lonsdale	Scripps Institution of Oceanography/Univ. of California/San Diego/Marine Physical Lab		general hydrothermal processes
F. N. Spiess	same add		instrumentation
Tom Simkin	Smithsonian Institution/Washington, D.C.		mineralization
David A. Clague	U.S. Geological Survey, Menlo Park, CA		mineralization
Randolph A. Koski	U.S. Geological Survey, Menlo Park, CA		mineralization
Janet L. Morton	U.S. Geological Survey, Menlo Park, CA		mineralization
William R. Normark	U.S. Geological Survey, Menlo Park, CA		mineralization
David L. Williams	U.S. Geological Survey, Denver, CO	303-234-2623	hydrothermal processes, geophysics

OCEAN HYDROTHERMAL ENERGY UTILIZATION TECHNOLOGY PROGRAM
LIST OF CONTACTS

NAME	ADDRESS/AFFILIATION	PHONE	TOPICS OF INTEREST
Jean Francheteau	Universite Paris 6, Paris, France/ Institute de Physique de Globe		hydrothermal processes, models
Ken C. Macdonald	Dept. of Geological Sciences & Marine Science Inst., Univ. California/Santa Barbara		geophysics
John E. Lupton	Dept. of Geological Sciences & Marine Science Inst., Univ. California/Santa Barbara		mineralization
James W. Murray	Dept. of Oceanography, Univ. of Washington/Seattle		mineralization
John R. Delaney	Dept. of Oceanography, Univ. of Washington/Seattle		mineralization, hydrothermal processes
H. Paul Johnson	Dept. of Oceanography, Univ. of Washington/Seattle		mineralization
~~John R. Delaney~~	~~School of Oceanography/University of Washington/Seattle~~		
Barbara A. Cosens	Dept. of Geological Sciences/University of WA/Seattle		hydrothermal processes
Rodey Batiza	Washington University/St. Louis, MO		mineralization
R. Von Hergen	Woods Hole Oceanographic Institution	617-548-1400	general, geophysics
Robert D. Ballard	Woods Hole Oceanographic Institution/Woods Hole, MA Dept. of Ocean Engineering		hydrothermal processes, ~~and~~ models
J. Frederick Grassle	Woods Hole Oceanographic Institution/Woods Hole, MA		biology

Shorten by more lines

Attendance List
Ocean Hydrothermal Utilization Program Review

Name	Organization	Phone
⇒ (or pass along a business card) ⇐		
Rayla Sala	DOE	252-8077
6 Marshall Reed	Consultant, Berkeley, CA	415-841-9410
5 Mike Wright	Earth Science Laboratory Univ of Utah Research Inst.	801-524-3422
→ 1 G. Ross Heath	College of Oceanography Oregon State University	503-754-4763
Ron Toms	DOE - Geo + Hydro Tech. Div.	252-5344
* 2 Mel A Peterson	Scripps Institution Oceanography Deep Sea Drilling Project	(619)452-3503 (619)755-2483 (home)
7 Deepak Kenkeremath	Meridian Corporation	703-998-0922
Martin W. Molloy	USDOE San Francisco Operations	(415) 273-7945
Dick Wood	DOE Idaho Operations	583-1432
Don Walter	DOE En. FRMUN Waste	252-6104
Susan Prestwich	DOE Idaho Operations	FTS 583-1147
John E Crawford	DOE San Francisco Operations	415-273-7944
→ 3 Michael A. Hobart	Lamont-Doherty Geol. Obs, Palisades, NY	914-359-2900 x331
→ 3 Kathleen Crane	Lamont-Doherty Geol. Obs. Palisades, NY	914-359-2900 x235
→ David L. Williams	U.S. Geological Survey Denver COLO	3032342623
→ 4 R. Von Herzen	WHOI Woods Hole MA	(617)548-1400 -2265

(continue on reverse)

ıase system, SELDADS II, has been procured ınd should be on-line by late 1985. Using a)ata General MV10000 computer, the system vill enhance SEL's capabilities to store and ınalyze the real-time data stream and will be ıble to run improved forecasting models.

The proposed budget reduction will impact ıpon SEL operations in a number of ways: Supporting technique development efforts 'or improving services will be lost; the preıent 24 hours per day forecast/warning ;chedule will be reduced to an 8 hour per day, 5 days per week operation; support for :he satellite systems will be decreased, with the possible loss of the solar X ray imager sysıem; the SELDADS II implementation will be delayed; and, the number of space environment products will be decreased, including a cutback in both the weekly "Preliminary Report and Forecast of Solar Geophysical Data" publication, and the space environment summaries on the WWV broadcasts.

This news item was contributed by William J. Brennan, *Public Affairs Officer, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Boulder, CO 80303.*

Ocean Drilling Suggestions

The Ocean Drilling Program replaces the recently completed drilling phase of the Deep Sea Drilling Project (DSDP). A new and larger deep sea drilling vessel with expanded capabilities including a longer drill string, bare rock spudin, enhanced logging, and the potential for riser drilling will replace the D/V *Glomar Challenger.* Drilling is scheduled to commence in January 1985, and planning is now underway for the tentative schedule shown below. The drill ship will then proceed to the Pacific Ocean and circumnavigate the earth at least twice during the 10-year program. Suggestions for drilling objectives, downhole experiments, etc., for all areas worldwide are now being solicited by JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling).

Suggestions for use of the drill ship are reviewed by the JOIDES science advisory structure, which includes three thematic and five regional panels and four service panels. The advisory structure is supplemented as required by specialized working groups and task groups. Approved objectives will be integrated into the drilling program by the Planning Committee under the direction of the JOIDES Executive Committee.

JOIDES is also seeking persons with scientific or technical expertise to serve on advisory panels for approximately 2 year terms. Anyone wishing to be considered should send his or her vita to the JOIDES office.

JOIDES is an international organization made up of ten U.S. academic institutions and the science agencies of other member countries which presently include Canada, France, the Federal Republic of Germany, Japan, and the United Kingdom. Support for the Ocean Drilling Program is provided by the U.S. National Science Foundation, the Department of Energy, Mines and Resources of Canada, the Centre National pour l'Exploitation des Oceans of France, the Bundesanstalt fur Geowissenschaften und Rohstoffe of the Federal Republic of Germany, the Natural Environment Research Council of the United Kingdom, and the European Science Foundation representing Italy, The Netherlands, Norway, Sweden, and Switzerland. Participation in the Ocean Drilling Program and science advisory structure is open to anyone, and is not limited to representatives of JOIDES institutions or member countries. Drilling suggestions and proposals should be submitted to the JOIDES office, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149 (telephone: 305-361-4168).

This news item was submitted by Donald S. Marszalek, *JOIDES Science Coordinator, Miami, Fla.*

signed for such an effort. So, the Committee has had to improvise, or, in other words, maintain a record of the individual investments as best we can at little or no cost to the investor. We did ask the master system to produce sets of mailing labels for the full membership; that is, one set for each Section. Each computer printout fold contains 48 of these sticky labels. An investment record is maintained on a 4" x 6" card, with a pulled label attached for identification and for alphabetic filing, a file for each Section. A beautiful byproduct of this manual system is the hard copy residue of the unpulled labels (i.e., those who have not been able to invest).

This particular feature—the record of nonparticipants—gives us much concern. We know that many of the younger members and some of those enjoying retirement are not able to help; however, when we look at the labels still on the master printout we see names of many members who have benefitted and continue to benefit from their membership in AGU. They are receiving dividends—even compounded—by virture of their many years of membership. For those of you whose labels we have not pulled and are able to help, we ask that you look again at your relationship with AGU and reconsider your role in this program.

A few of our members are employed by corporations that practice matching gifts of their employees. We extend a double thanks to those members who have asked their employers to match. One corporation double matches, so a triple thanks is due. If you are employed by a corporation that contributes to educational institutions, endeavor to convince them that AGU merits support for its program of continuing education.

Those of us who are U.S. citizens recently submitted statements to the IRS identifing dividends and contributions along with other related information. Through the personal deduction process for contributions—or those "investments in AGU"—the federal government becomes a participant in the GIFT program with a form of matching. In the same way, many of the state governments are also participating. It is simple: The greater your deductions, the greater their participation. So the bottom line is, What you "invest in AGU" will bring multiple dividends, a greater financial reserve for the Union and lower taxes for you. Thank us, not Paine-Webber.

Charles A. Whitten
Co-Chairman
AGU GIFT Fund
Steering Committee

AGU-GIFT Program as of April 16, 1984

tal	$1–10	$11–20	$21–30	$31–99	$00–499	$500–999	Over $1000	Avg.	Percent Participation	Non-contributors
155	194	124	129	33	29	1	2	41	44	665
168	110	63	57	13	7	3	5	94	42	358
149	163	94	81	7	5		3	46	47	397
173	528	278	207	52	17	3	3	27	38	1,785
452	413	213	164	22	19	2	3	28	35	1,524
342	134	63	68	14	4	2	1	29	40	426
559	307	203	156	16	17	1	1	25	40	1,034
749	336	243	218	21	23		2	27	46	987
712	320	166	128	24	17	1	3	36	38	1,058
493	304	166	126	23	8	1	3	29	35	1,183
719	180	80	51	3	1	1	1	24	36	575
100										
200										
791	2989	1693	1385	127	247	15	27	33	40	9,992

Tethered Satellite Opportunity

The National Aeronautics and Space Administration (NASA) and the Piano Spaziale Nazionale of the Consiglio Nazionale Delle Ricerche of Italy (PNS/CNR) are inviting researchers to participate in the first three flights of the Tethered Satellite System (TSS) on the space shuttle. The Tethered Satellite, a joint Italian/U.S. project, will deploy experiments in space at a distance of up to 100 km from the shuttle orbiter. Science instruments will remain tethered either upward or downward from the vechicle for approximately 16 hours at a time before being "reeled" back in. The first three missions, scheduled between 1987 and 1990, will conduct experiments primarily in the areas of space plasma, atmospheric, geomagnetic, and earth gravity physics.

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OCEAN HYDROTHERMAL ENERGY UTILIZATION TECHNOLOGY PROGRAM
TELEPHONE INTERVIEW FORM

1. Purpose of Call - To fill you in on current status of project from DOE viewpoint - two factions--one in favor, one not in favor - program review 8 August--resource questions uppermost - small effort FY 85 - $200K level

2. Perceptions of 24 April 1984 Meeting?

3. Perceptions of potential for energy development?

4. Workshop
   (a) Purpose - to discuss potential for energy development
   - to discuss a possible DOE program

   (b) Who - names of 5 people who should attend + overview speakers

   (c) Length - 2 days - first day invited review papers, second day aspects of DOE program

   (d) Attendance - limited or open?

   (e) In association w/other national meeting? which?

   (f) Level of formality

   (g) Screen papers?

   (h) Best location

   (i) Best time of year

   (j) Would people generally have their own travel funds?

Kathleen Crane

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2. Perceptions of 24 April 1984 Meeting? – good start -- address nitty gritty – obvious lots of unknowns –

3. Perceptions of potential for energy development? not realistic in short run – but may be in long run. we know there is a lot of energy there, but don't know where. could start right away in Gulf of Calif. -- needs coring, etc.

4. Workshop
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   (b) Who - names of 5 people who should attend + overview speakers

   (c) Length - 2 days - first day invited review papers, second day aspects of DOE program – ok

   (d) Attendance - limited or open? – limited –

   (e) In association w/other national meeting? which? – AGU ⇒

   (f) Level of formality – informal

   (g) Screen papers?

   (h) Best location – west coast in January

   (i) Best time of year – go out all times of year – prob best time January

   (j) Would people generally have their own travel funds? – no.

France/US – EPR 400km portion – 14°N to 10°N
size magma chambers – continuity, etc. hydro systems –
geophysics, geochem, biology –

– 5 year efforts –

NOAA – Juan de Fuca +
Gorda Ridge – within US Exclusive Zone – –
– bad weather has influenced progress
– looks hopeful
— new fields

Better to take about this

Dick Van Herzen

Mike Pardy ext. 2826
ext. 2265

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   (e) In association w/other national meeting? which? — prob not -- big meeting have lots going on anyway —

   (f) Level of formality

   (g) Screen papers?

   (h) Best location — anywhere — SLC or San Diego

   (i) Best time of year — winter —

   (j) Would people generally have their own travel funds? ⇒ yes !

In WHOI, lots of thoughts in research -- not much in energy utilization -- ideas are far out.

not sure how to focus - need broad spectrum people - Biologists, engineers, etc.

Brainstorming this - firm conclusions not possible in workshop -

OCEAN HYDROTHERMAL ENERGY UTILIZATION TECHNOLOGY PROGRAM
TELEPHONE INTERVIEW FORM

1. Purpose of Call - To fill you in on current status of project from DOE viewpoint - two factions--one in favor, one not in favor - program review 8 August--resource questions uppermost - small effort FY 85 - $200K level

2. Perceptions of 24 April 1984 Meeting?

3. Perceptions of potential for energy development?

4. Workshop
   (a) Purpose - to discuss potential for energy development
   - to discuss a possible DOE program

   (b) Who - names of 5 people who should attend + overview speakers

   (c) Length - 2 days - first day invited review papers, second day aspects of DOE program

   (d) Attendance - limited or open?

   (e) In association w/other national meeting? which?

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Ocean Hydrothermal

23 May 88

How do you make something big happen?

Strategies
(a) Follow-up of people @ WDC meeting
(b) work w/ OBES -
- propose to OBES based on a workshop
- have to be careful about how much has already been done
(c) Clay said universal interaction is "don't want to see EG&G in oceanography" - Jack says they will work only on measures we will have this trouble, too.
(d) we will have to tie in w/ an "in" group. Jack wants us to decide who this year.
(e) How do we proceed? How do we orchestrate
(f) excuse to begin contacts - letter of ~~support~~ to Jack.
→ (g) Guy from Oregon said that Sandia has run a workshop on oceans -- find out about this.
(h) letter: 35-40 people @ workshop
5 ± papers - topics / authors
(i) Contacts: Marshall Reed
Dick Von Herzen
Mel Peterson
Cathy Crain - Mike
Ross Heath

2. Clay/Mock - $Zook for next year -

3. Jocks program - comments -- not sacred

Hinschberger (Russell), Crockett, consultants

Site Study

① Do preliminary investigation into site possibilities and most viable theoretical site.

a) develop site criteria
b) identify possible sites
c) match criteria to possibles in chosing "best" theoretical site

② Establish the legal international aspects of deep ocean processing. Effects on site recommendation.

③ Environmental aspects of deep ocean processing

a) identify pertinent regulations that apply
b) identify problems that may result

Spreading Center Assessment

(1) From literature search and "expert" consultants develop a theoretical working model of the O.S.C. physical character for use in the process studies.

a) Model and flow character of O.S.C. hydrothermal systems

b) Life cycle of O.S.C. and recommendation for optimum age of utilization

c) Estimated well flow - will it be artesian or are pumps needed?

d) Estimated temperatures available

e) Develop or identify technology for identification of prime areas for locating wells in O.S.C.s

1) look at possibility of this technology being eased ~~by~~ with the use of submersibles vs drill ships.

OCEAN HYDROTHERMAL ENERGY CONVERSION

TASK	FUNDING	PLANNED ACCOMPLISHMENTS
1. Accumulate Resource Data	$ 30,000	A comprehensive accumulation of the data available on ocean spreading centers will be conducted. Government and university personnel will be contacted, consultants will be hired and an extensive survey of the literature will be conducted. The primary needs in this area are: 1) a theoretical model of spreading center hydrothermal systems and 2) a means to locate the various hydrothermal systems. The specific problems associated with operating in this environment and other areas of research that need to be undertaken will be identified.
2. Laboratory Studies	$ 15,000	The objective of this task is to determine if kelp can be converted to fuel oil by reductive formulation at ocean spreading center environmental conditions. The spreading center environment will be simulated using a Barnes type autoclave. The influences of salt water and polymetallic sulfides on the conversion will be assessed.
3. Support Technology	$ 6,000	Drilling in deep ocean hydrothermal areas, handling of fluids and utilization of the energy in processes will require support technology. As concepts are designed, support technology and research needs will be identified. The first task will be a preliminary estimate of the present cost of drilling a well and getting the available energy to surface ans subsurface locations. A prediction of how this cost is expected to change with time will be determined.

TASK	FUNDING	PLANNED ACCOMPLISHMENTS
4. Process Studies	$ 25,000	Chemical, energy conversion and energy intensive processes that are considered as possible candidates for the utilization of energy available in spreading centers will be identified. The categories for potential use of spreading center energy will be 1) energy conversion to transportable forms and 2) in-situ energy utilization. The conversion of kelp to a liquid fuel by reductive formulation will be used as a baseline study to identify the potential problems of operating in the ocean environment.
5. Economic Analysis	$ 8,000	The processes studied will be analyzed to determine the competitive value of the products produced. Parametric analyzes will be conducted to determine the factors which most significantly affect product value. The future economic feasibility will be forecast based on the current believes of how the basic costs will change with time. These analyses will be used to prioritize DGHT research needs.
6. Year End Report	$ 8,500	The results of the above tasks will be combined and published as a final report. Recommendations for needed research will be presented.

Ocean Hydrothermal Project Review — 2 Ap 84

Jack Ramsthaler → See Handout

Positive Considerations

1. Large source of energy – 20K years worldwide consumption
2. Renewable
3. High quality – 350–1100°C
4. Drilling technology advancing rapidly
5. Remote technology advancing rapidly

(others are spending $ to develop these areas – gvt and industry)

6. Unique environment

Negative considerations

1. Very very expensive

- most alternate sources of energy are dilute, low-grade sources. Ocean systems may be concentrated
- Unique environment: the high pressure and temperature are used to convert coal, biomass to high quality liquid fuels in the lab -- the ocean systems could offer that environment cheaply -

Unknowns

1. How large is the resource? -- the accessible resource
2. what are resource characteristics?

Utilization Technology

60 concepts ~~at~~ considered, 10 studied, 2 selected

work going on @ INEL

1. Reductive formulation - conversion of growing biomass
2. Bioconversion - high flux bacteria

Suggestion - ocean floor also is a high-pressure refrigerator -- might make gas @ site, ~~ate~~ move to cold area, compress, tow deeply in tank to utilization site, lift to surface to convert to gas again using ~~oo~~ heat of upper layers to gasify again.

Tans – Kelp is not an economic feedstock for any system -- conclusion of biomass people

Ray L. – hammered away on
- to what extent is production of fuels important to concept?
- why are not unknowns listed as negatives? What are they? why "innovative"?
- Why not use avail process technology & stop there?

Economics

kelp $140–170 M/yr converted to diesel
algae $280–900 M/yr " " "

Suggested objective DOE Program
Assess conversion to transportable fuels

WBS
1. Resource Assessment – models needed – identify research needs
2. Process Technology – innovative processes needed
3. Support Technology – use present industry – research needs
4. Economics – assess cost of utilization processes –

Ray L. – how many $ on resource assessment
how much on process tech: $20K resource assess, $30–40K plants; $15K economics, etc.

Ron Toms suggests that we concentrate on the innovations that can make significant / the largest cost reductions.

Ted Stock -

- ERAB committee gave gt a failing grade because of misperception of us having access of electricity --
- This is a new, non-electric use, which is good.
- Cautioned people that new ideas are fragile, easily killed: especially hybrid ideas, because can't get 2 groups in DOE to cooperate. So wants to keep project in geothermal -- also be careful.

Ron Toms

- $90M spent on geopressure] still don't know where
  $110M spent on HDR] we stand re economics
- doesn't want to go into one of these if we don't know where we are -

Comment: 1. Energy costs will grow, perhaps metals costs will not in near future.

Dave Danbard - believes that legal and environmental considerations should be crowded in @ outset.

Dr. Beverly — *Biomass*

- GRI (gas research institute) report - abandoned the study. They did a mid-ocean experiment that failed. Lost the equipment to a storm. Could not get the *yields* ~~b/c~~ of upwelling in mid-ocean.
- Kelp resource will not be available
- For credibility need to look hard at *yields*.

Anerobic digestion @ zero pressure will be very hard to beat, cost wise. It has very high yields of methane (85%). This high efficiency allows one to do a lot of product w/out pricing one out of the market.

- Big study in oil from wood. Study in Albany Oregon -- study turned off — poor quality oil @ great expense
- Bioconversion now talking near shore

Kathy - topo variations along ridge crests ~~show~~ show correlation of hot spots.

Dick UH - On ridge crests there are systems that could be sealed

Mike - on ridge crests systems are open, heat is dissipated very fast

- need to find a sed-flooded area - Gulf of Calif Juan de Fuca area, pretty much it. Gorda Ridge

Kathy showed study to show association of nodes up domes. Only two surveys - Temp difference does not propagate upward or outward far. See Reed traced -- density layers -

- 350°C seems to be an upper limit because of:
(a) density @ 350°C @ bottom pressures is 0.8, but @ 370°C goes to 0.2.
(b) Silica content is such that hotter systems will plug quickly.

Comments

1. Energy costs will grow -- this is long lead-time research -- fits DOE charter quite well
2. Should spend some time on legal aspects
3. Program badly needs to be coordinated w/ other programs working along ~~sea~~ complementary lines
   - deep sea drilling - NSF
   - Other studies ocean floor -
   - Industry studies for exploration -- industry modest
   - Law of the Sea Committee
   - biomass / fossil conversion
   - this is DOE's responsibility
4. Big problems -
   - resource uncertainties (size, location, chemistry), esp within U.S. territory
   - how to tap the resource -- can't afford missed wells @ $20-40M/well
   - how to convert the resource
   - who owns the resource
   - how to protect the environment

Syntactic foam - for thermal insulation on Alvin
glass beads bonded w/ plastic

Ross - Suggested a workshop
→ asked each of us to list 5 keynote speakers
and workshop composition.
next September
Subjects + people

5. I believe biggest problem is how best to use
energy - we have enough info that resource
exists for the first year of effort. This year,
mostly uses + economics are needed. We need
good use ideas, conceptual stage engineering
then cost viability, and be able to show a
viable use if the resource exists.

JC. - He isn't satisfied. He thinks ~~that~~ not nearly enough is known about the resource. He equated the ~~occurrence~~ program as being like Baca, where the thing went down the drain because of resource.

He questions that EG&G is the co to do the work. What do they know about ocean work?

He says that if we don't have enough $ to do the job right, we should not do it at all.

At EG&G —

Sept 84

OBES Strategy
Office of Technology Assessment
then OBES
then Donna Fitzpatrick - interested
then Adv Research & Tech Develop - Fossile guy
Kaiser will follow up USBoM - minerals aspects -

1. 1[30] - 3[00] meeting Engineering Concepts -
Malone Stevenson

Assumptions
1. Design temp 350°C used
2. Useful flow amounts available
3. life of Systems ≥ 20 years
4. want to do energy conversion to form transportable hydrocarbons

1. Kelp - not enough productivity in kelp farm
100K acres not economic
40% ash in kelp
2. algae - can theoretically get productivity
10% ash - not bad
more carbon -
- have nutrient probs - deep water too dilute

Bernie - @ 13 at, French are doing -- basalt, no seds - see light oil plume over field due, they think, to pyrolized bacteria that are unable to live there

3. MSW - municipal solid waste
30 million population -- Wash, Ore, California -
process into cellulosic pellets: paper, plastic in; metals, glass, etc out
- 40-50 lbs/ft³ density
- 36-45% C by weight, 60% cellulosic -
- 34 M bbl/year oil from 30 M pop, at 50% efficiency of C conversion; rest of C in gases + solid residue -
- contamination: metals, sulfur etc -
- sewerage sludge + crop waste residues are also good sources -
- formate 20¢/lb - large price --
11 MT Na formate needed -- so better process needed
- looking into use of hydrogen directly -
- 60K tons/day MSW would be brought in -

Bernie believes that the first use of the hydrothermal systems will be waste disposal -- low level nuclear, PCB, etc -- under those conditions most things pyrolize.

$\frac{8}{30}$ .3

- MSW is discounted 15% below coal, -- still can't sell it.

Bernie - oil spills are best left alone and let the microbes work on it -

Economics -
looks like 16 yr. payback now
$4.7B plant costs

Concepts for BES Proposal

First pass will be to Policy Makers -
10 page briefing, half hour max. -

w/ Sue

1. Elizabeth - wants to take $20K ocean + $26K inj to start new contract -
- money will not go away at year's end. -

Questions for Jack

1. what of other oceanographic schools?
   will they be riffed?
   will we need their support?

5 Sept. 84

Bernd Seemonit -
organic geochemistry, Analytical organic chemistry
UCLA, Oregon State - educ curr -

1. Known Systems -
Marianas backarc

2. Hydroth Systems bypass long-time maturation -- instantaneous maturation

2. Guaymas Basin - Gulf Calif opened 3 m years ago

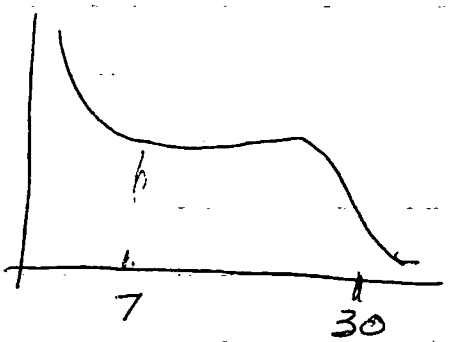
3. Maturation - Geothermal = slow; Hydroth = fast

Ancient Rocks
4. Gas - Bitumen Asphaltenes - Kerogen
classy in ancient seds
Seeps -
Gas (major) Bitumen (major) Asphaltenes (major) (Kerogen none

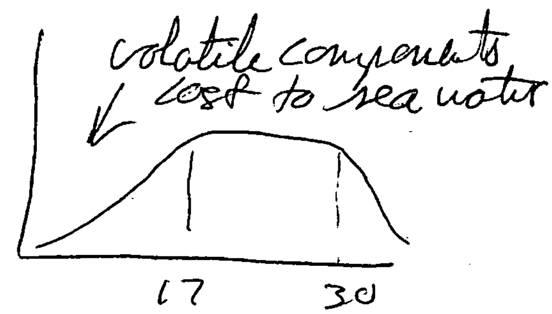
5. Guaymas Basin
(a) some parts exaggerated
(b) 1.5 axtl rift; 3 km wide, 20-400 m relief
30-50 m hydroth mounds -
dredging brings up stuff that smells like diesel fuel

5. Can use molecular markers such as steroids, etc that have resulted from living material to tell temp and alteration history because they eventually go to saturated hydrocarbons -

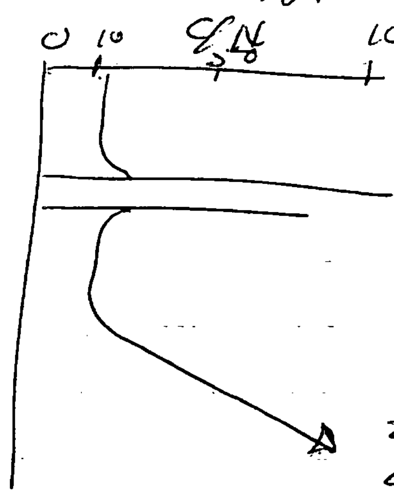
6. Petroleum Reservoir



Ocean Hydroth



7. C/N ratio



≥ N goes to 0 -- has been leached out. Temp to do this unknown, but > 400 °C - Prob due to magma chamber -

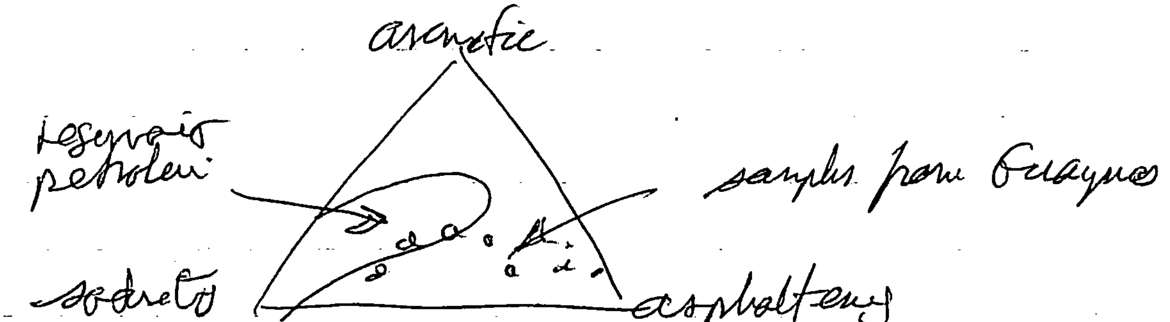
8. many vents are along dikes or faults where basalts have come up in a sill like a mushroom -

8. molecular markers
- indicate genesis
biogenic, geogenic, synthetic

- use mass spectra to tell structure
- straight c-chains
- large iron side chains
- rings

} all characteristic of geneses

9. yields: 2-30% hydrocarbons



means these hydroth petroleums are non-migrated, because many components that usually do not migrate far are still present -

10. Active petroleum genesis Guaymas
gasoline range
broad HC w/ hump
no C # preference
selective degradation

recharge		discharge
Seawater	⇒	geoth fluid
3°C		350°C
pH 8		pH 4
oxidizing		reducing
SO_4-rich		
metal dep		contains metals
Mg rich		Mg poor

Sed rate — radiocarb 5 m/1000 yrs
biostratig 1 m/1000 yrs

Sed depth — 400-500 m (seismic)
drilled to 240 m

Ages — oldest 150,000 yrs
top hydrotherm alt 50,000 yrs

Area 3 × 9 km = 27 km²
Hydro alt 120 m ⇒ 3.2×10^9 m³
organic carbon 2%
Conversion effic 50%

Potential yield 6×10^6 m³ = 30×10^6 bbls } potential only

10. 3 more dive cruises for next year

11. Sonar & side lookg
- show plumes seem high & low density material that must be hydrocarbons --
oil microdrops -

sulfides form an inversion layer --
oil plume penetrates sulfide inversion layer --

plumes occur in Kanyon fault areas
QEF -

12. In seds, chimneys are diff
-- seds - get lots of sulfates - barite, etc

basalt   seds -

13. Some bacteria may use H_2S and hydrocarbons
both or one or other -

14. *Vegetoa bacteria*
- sulfur rich -
- in tube worms, gills take in H_2S - bacteria in gut metabolizes it to elemental S, worm lives on metabolic products

15. -

5 Sept. 84
Tony Allen, Rich Diehl, Jack Rawsthoder, Bernie Simonet, Greg Stormberg =

1. - Dennis Kaine - excited about super critical mineral processing

- EG&G (Tony) wants to build reactor 500°C, 1000 atm, 50cc -- allows me to get into supercrit range -
- USBM asked EG&G to put in an Ocean Hydrate proposal for processing ores in place
- EG&G's strategic materials will go from 3M to 6M. -

2. Resource Aspects
FY 85 - workshop, etc
beyond - obtaining data to quantify resource
- difficult part -- to work w/ established infrastructure to do this

- workshop - put together papers from all contingencies

3. Scope of Work

Ocean Hydrothermal Clay Deposits
EG&G

- Marketing
- Exper Group Design
  - (Marketing and Exper Group Design: TDP)
- Mineral Assess (USGS)
- Energy Assess (OTA)
- ~~Process Tech~~ Feasibility Experiments (DGHT)

OTA milestones
1. workshop - to get
2. Resource Report
3. Conversion Report

w/ Clay, Susan

- Steve Oriel - published w/ Mobey -
- regional envirn
- well respected
- Denver -
- priestly, etc. - Less politic than Mobey -

5 Sept 84

meeting w/ Charles Gilmore, Clay Nichols, Sue Presfried -
Jack, Rich, Bernd, Dave.

1. Does petroleum conversion match w/ direction we're going - yes - it seems to be a good match.
2. Is OH still a viable prog? yes.
conversion
supercritical fluid experiments - people haven't been able to do these in the lab -

3. EG&G works w/ Bob Chaney in USBM -

EG&G Idaho, Inc.

Report No. RE-E-83-005

Date: September 29, 1983

INTERNAL TECHNICAL REPORT

Title: OCEAN SPREADING CENTER ENVIRONMENT UTILIZATION

Organization: Mechanical Engineering Experiment and Waste Branch

Author: Roger R. Piscitella
R. R. Piscitella

Checked By: John E. Conner

Approved By: J M Romsthaler

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TABLE OF CONTENTS

I. INTRODUCTION

In the last decade, discoveries in the area of plate tectonics have unfolded a new understanding of how the earth's surface is formed and destroyed. It is now known that the earth's surface is made up of finite plates which are in constant motion relative to each other. Some of the earth's surface is being consumed and deposited back into the earth mantle as a plate "dives" or subducts under an adjoining plate. The Pacific Plate subducting under the North America Continental Plate is an example of this. At the other end of the colliding plates, new earth surface is being formed as the plates move apart or spread. These areas are called spreading centers. An example of this situation is the Mid-Atlantic Rift which extends from Iceland to the Antartic.

Spreading centers are characterized by active volcanism. Magma raising up from the earth's mantle as the plates part give rise to land surface expressions such as hot pools, geysers, and active volcanos. Iceland which sets astride such a spreading center has well known hydrothermal fields which have been extensively developed for commercial uses. Seabed surface expressions of spreading center activity take the form of basalt pillow lava formations that are formed when lava extrudes out of the fissure and rapidly solidifes; hot water vents that are heavily mineralized and that support colonies of bacteria, tube worms, clams, and other organisms; and lack of a sea floor sediment layer. There are approximately 40,000 miles of spreading centers on the earth surface. 95% of these lie below the oceans of the world.

The ocean spreading centers represent a tremendous source of unexplored-untapped energy. A rough estimate of the amount of energy available in the spreading centers is 0.15×10^6 to 7.5×10^6 quads equivalent to 2,000-to 100,000-yr U.S. energy supply at the current annual total energy consumption rate of 75 quads.[(1)] It should be noted that this estimate is for energy available IN-SITU in the rift zones. As the tectonic plates spread, new magma flowing into these zones replenishes the heat that is lost. As long as tectonic plates continue to move and the earth's core remains hot, this heat source will be available.

With such a huge resource available, a logical question to ask is: "Why hasn't it been developed?" Part of the answer has already been given. That being the understanding of plate tectonic theory is relatively new --- developed in the last ten years. Actual viewing of mineralized hot water vents on the ocean spreading centers occurred as late as 1979. Another reason was the seemingly inhospitable environment. Since most of this resource is located 2.5 km below the surface of the world's ocean's it was easy to be overwhelmed by the technological difficulties in utilizing the energy. This inhospitable view of the environment also prevented people from looking at the spreading centers as being uniquely qualified for certain processes.

In this TDP task, we took a different view of the ocean spreading center environment. We viewed its high pressure, temperature, etc., as assets to be utilized to the maximum extent. A team of INEL personnel,

---

[(1)] "Final Report - Magma Energy Research Project", SAND 82-2377, October 1982, p. 8.

with the charge that the conditions in existence on the ocean spreading center would be uniquely beneficial to some process, was formed. The team "Brainstormed" for new process ideas. This effort was very successful. In parallel with the "Brainstorming" effort, the seemingly overwhelming technical difficulties were identified and it was found that recent work has elminated a lot of these obstacles. The remainder of this report presents our view of the spreading centers, discusses critical related technology, presents our new ideas for uses of the energy, and suggests work which should be done.

II. OCEAN SPREADING CENTER ENVIRONMENT

The ocean spreading environment is unique. This environment is viewed today in much the same way that space was viewed fifteen or twenty years ago. Space was seen to be a place of inhospitable extremes --- a vacuum with no air to breathe, deadly radiation exposure from the sun, the possibility of being killed by a meteor traveling at great speed and striking without warning, hot and cold temperatures extremes that would cook half of one's body while the other half froze, and no gravity which allowed one to float off into space with no way of getting back. View of space today is very different. All of these seemingly insurmountable obstacles have been overcome, and the environmental factors that appeared awesome are actually being utilized in different processes and systems to make products that are not possible on the earth's surface. The ocean spreading center environment also has the potential of being developed and utilized in ways only dreamed of today.

The following environmental conditions are those that exist on the ocean spreading center. These conditions are presented in a positive light with a concerted effort being made to find applications for the conditions. For easy reference, these conditions are summarized in Table 1.

<u>TEMPERATURE</u>: Thermal energy appears in a number of forms in the spreading center areas. Heavily mineralized water exiting vents has been measured at 350°C. Ambient sea water in the vicinity is 2°C. These two temperature extremes exist within a few meters of each other. In some areas, ocean currents supply a continuous flow of 2°C water. This large ΔT could be utilized for a number of process and power production applications. Magma, which is as close as a kilometer below the spreading center surface, has temperatures on the order of 1000° to 1200°C.

<u>PRESSURE</u>: Ambient pressure is on the order of 3500 psig. This pressure is due to the hydrostatic head of sea water that exists above the spreading center. High ambient pressures such as these allow processes to be conducted without the need of expensive heavy walled pressure vessels. It is interesting to note that the temperature (350°C) and pressure (3500 psig) of actual hot water plumes are very similar to those of an operating nuclear pressurized

water reactor. Some people consider "alternate energy" schemes as being low quality. This certainly is not the case here.

SPACE: Space for equipment and processes in the area of the spreading center is essentially infinite. Football field size or square mile size units would be completely acceptable. Real estate is very cheap. Large heavy components for process plants are usually layed out side by side on the earth's surface since stacking these components one on top of the other results is a large cost penalty for heavy support structure. Components on the ocean bottom can be made to remain suspended above each other by adjusting their buoyant force to equal their weight. Minimal cost is required for support and positioning.

TIME: Since there is no immediate demand for the space occupied by the process and since a process can be made to utilize - in a self contained way - the energy in the environment, the urgency to complete things fast disappears. Time for various processes can be expanded to months, years, and decades. Processes so slow, large, and inefficient that they become ineffective on the land become cost effective with a self contained system on the ocean bottom.

AQUEOUS ENVIRONMENT: The water environment affords many advantages. Water conducts heat better than air. Ocean currents can be used for forced convection heat transfer with the oceans thermal mass being essentially infinite. This adds up to the capability to easily eject waste heat from various processes and equipment. Thermal pollution, which is a problem on land base systems, will not exist on ocean spreading centers since the heat is currently being dumped directly into the environment. The electrical conduction properties of sea water along with the lack of light at this depth may also become advantages in targeted processes. Steel and other cheap structural materials may have an extended lifetime at these depths. Downward movement of large quantities of water into and out of the rift zones may be utilized in some processes.

PROXIMITY TO POPULATION AREAS: Ocean spreading centers have got to rank among the most isolated areas on the earth. Being on the ocean bottom far from shore a number of constraints on a process would no longer be applicable. Noise and visible pollution would not apply. Possibly some EPA limits on other pollutants could be relaxed.

TABLE 1

SUMMARY OF OCEAN SPREADING CENTER ENVIRONMENT

TEMPERATURE:	Water in Vents	$350^{o}C$
	Ambient Seawater	$2^{o}C$
	Magma	1000^{o} - $1200^{o}C$
PRESSURE:		~3500 psig
SPACE:		Infinite
TIME:		Infinite
ENVIRONMENT:	Aqueous (sea water); Area of high seawater flux both into and out of the sea floor.	
PROXIMITY TO POPULATION AREAS:		Remote

III. CRITICAL RELATED TECHNOLOGY DEVELOPMENT

Ocean spreading center energy exists in the form of hydrothermal systems and magma. Before this energy can be developed, a number of "critical" technologies must exist. These technologies are: Deep Sea Spreading Center Location and Exploration; Ocean Bottom Equipment; Drilling Technology on Ocean Bottoms; and Magma Drilling and Utilization Technology. In the course of this work it was found that all of these technologies have been developed to the point where they are no longer an obstacle to further progress. The following gives a more detailed discussion of each of these technologie and an assessment of their state-of-the-art development.

Deep Spreading Center Location and Exploration

The International Decade of Ocean Exploration (IDOE) which occured from 1972 through 1982 was the single largest driving force in developing new technology for sea floor exploration. The United States goals in this effort included "expand seabed assessment activities."[(2)]

Over $34 million was spent in seabed assessment activities by this country. In 1974 alone thirty dives were made by three submersibles in 2700 meters on the Mid-Atlantic Ridge. Instrumented sleds were built and towed behind ships to measure water chemistry, temperature, pressure, and to record on video tape the ocean bottom. More standard equipment such as air towed magnetometers and gravitometers were used successfully to locate sea floor anomalies.

(2) "Report of the Decade: The International Decade of Ocean Exploration", National Science Foundation, Division of Ocean Sciences, Washington, D.C., p.6.

More recently an oceangraphic satelite called "Seasat" has used a radar altimeter to make detailed measurements from satelite to sea surface. Because of gravity, sea surface topography reflects that of the sea floor. Mid ocean ridges and fracture zones are clearly visible.[3]

Although still not a simple task, ocean spreading centers can be located and explored with today's technology.

Ocean Bottom Equipment

In addition to the sleds and submersibles mentioned in the previous section, equipment designed to operate on the ocean floor has been developed. Crawler trencher mechanisms have been designed to dig trenches and bury cable on the ocean floor.[4] A number of private and government projects developed equipment to harvest manganese modules that are present on the sea floor. As part of IDOE, workshops were held on deep-sea mining technology. The U. S. Navy has funded a number of projects for living and working in a sub-surface environment. All of these efforts have yielded a good understanding of the equipment needed to operate on the ocean bottom.

(3) "Satelites That Serve Us", September 1983, National Geographic, Vol. 164, No. 3, p. 282-283

(4) Procedures of the 1980 Off-Shore Technology Conference

Drilling Technology or Ocean Bottoms

Deep sea drilling technology has made rapid gains in the last few years. Geothermal development of sea floor resources were thought to be unattractive in 1981 because of the lack of technology for drilling at depth in the oceans. Shell Oil Company in July of this year started drilling in 6800 feet (2.1 km) of water off the New Jersey coast. Expected hole depth will be 7,700 feet (2.3 km). The previous water depth record was 5,624 feet (1.7 km) set last year.[5] This large step in capabilities is the result of using a highly computerized drillship controlled by a "dynamic positioning" system. Acoustic beacons located on the sea floor allow the ship's computer to accurately calculate its position and to make the appropriate corrections. Drill ships of this design now have the capability to drill into ocean spreading centers (average depth 2.5 km) and to tap the magma resource (approximately 1 km below the surface).

Magma Drilling and Utilization Technology

A 7-year research project conducted by Sandia National Laboratories assessing the scientific feasibility of extracting energy directly from buried magma sources was completed in 1981. High temperature drilling technology was developed and tested as part of this project. Water jet agumented core drill bits were designed which allowed bore holes to be

[5] "Shell Does It Deepest", The Energy Daily, July 18, 1983, p. 2.

made directly into molten rock. This unique device injected water out of holes located in the face of the bit causing the lava to harden and crack. The newly formed solid rock was then removed as cuttings and flushed from the hole. Water flowrate was sufficient to maintain a stable hole and to allow rapid drilling rates. Drilling rates up to 20 m/h were common in the Kilanea Ika lava lake field tests.[6]

Once it was demonstrated that bore holes could be drilled and maintained in lava, various tests were conducted to evaluate energy extraction potential. Single tube boilers were first tried and experienced a rapid build-up of lava crust. To circumvent this problem an open heat exchanger experiment was done that injected water directly into the magma. A large fractured area of permeable solidified rock was formed adjacent to the bore hole. Water under pressure was injected into this zone where it flashed to steam. 95% to 100% of the injected water was reclaimed as steam at the surface demonstrating that a sealed fractured rock chamber had been formed. Steady state (180 kw/m^2) and transient (950 kw/m^2) heat extraction rates were measured.

When magma resources on ocean spreading centers are compared to continental magma source, a number of advantages arise. The depth of the magma is a critical factor. On the continent, magma is thought to exist in the upper

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(6) "Final Report - Magma Energy Research Project", SAND 82-2377, Oct. 1982, p. 16

10 km of the earth's crust. This is not beyond the limits of drilling technology but does result in an expensive well. To hope to utilize this resource magma domes must be located where upwelling lava approaches the surface. These areas of upwelling lava are not known and may be difficult to locate. Once identified, a well on the order of 5-10 km must still be drilled to reach the resource. Ocean spreading centers on the other hand are easily identified---their location is known today. The narrow seams that form the line where the techtonic plates separate almost pinpint the area where magma is closest to the surface. To reach the magma the drill string needs to be lowered through approximately 2.5 km of sea water and a 1 km hole drilled.

It should be noted that the excellent work done by Sandia on this project was geared toward land based magma resources and although they did recognize the ocean spending center resource, it was not pursued.

The technological developments that were just discussed form a strong foundation upon which new ideas for utilization can be based. There no indication in the literature that any national laboratory or private company have recognized the potential of these areas. The tools are available now for utilizing the ocean spreading environment and the opportunity exists for EG&G Idaho to take a lead role in that development.

IV. INNOVATIVE IDEA GENERATION

As was mentioned in the previous section, the area of ocean spreading center utilization is new and undeveloped. This represents a great opportunity to break new ground with new ideas that have not been thought of before. To do this, innovation and creativity must be initiated, stimulated, nurtured, and focused on this new area. The process of setting up the environment for new ideas and the generation of those ideas is critical to the success of starting a new program of this type. Without this innovative environment, the search for new ideas regresses to a literature search and in this case that would yield nothing.

Since the environment is so important for innovative ideas, a short discussion will be given here on the techniques used to stimulate creativity on this project. A number of "brainstorming" sessions were held. People invited to these meetings came from all parts of the Company. Engineers, secretaries, drafters, chemists, procurement personnel, craftsmen, and safety people all participated. The only prerequisite being that they be willing to say anything that came to mind. The meetings were set up to operate in a atmosphere of trust. No "put downs" were allowed. People were encouraged to say any wild idea that came to mind. The idea was developed from the point of, "How can we make it work." Negative attitudes were discouraged. The meetings developed a synergism that allowed embryonic new thoughts to be tossed rapidly around the room, going through three or four permeations in a matter of seconds. The innovative/trusting atmosphere was encouraged outside the meetings also. Impromptu discussions held on the escalator, in the parking lot, over partitions in the restrooms all yield good ideas.

The techniques used were very successful. People involved in this project spent many hours on weekends and at nights thinking and coming up with ideas. Not because they had to but because they wanted to. Only one person out of the approximately fifty people that attended the brainstorming session asked for a charge number. An enormous amount of work was done for the monies available.

The results of these brainstorming sessions have convinced us that systems do exist that are uniquely suited to ocean spreading center environments.

V. HOT NEW IDEAS

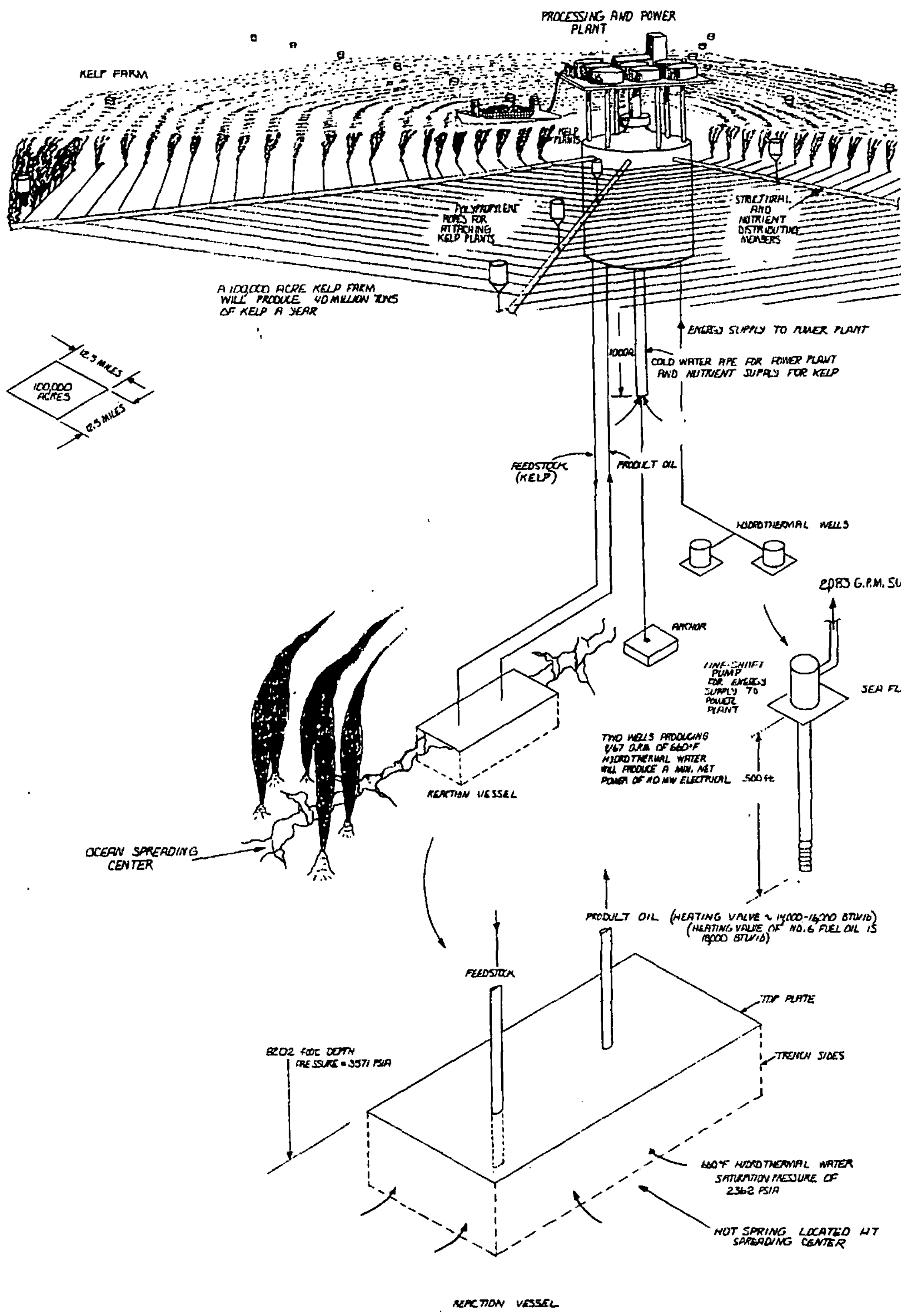
This section of the report will present the ideas which we developed that were judged to have high potential. All of the new ideas that were generate are included in Appendix 1 to this report.

SYNTHETIC OIL PRODUCTION FROM KELP IN AN OCEAN SPREADING CENTER ENVIRONMENT.

This idea combines a number of recent technical developments into an integrated system for synthetic oil production (see Figure 1). Kelp is grown on a floating kelp farm located over the ocean spreading center. This technology has been developed and tested through a research effort known as the Marine Biomass Program.[7] The kelp is grown on polypropylene ropes that form a spider web type of net around a central process plant hub. Cold nutrient-rich sea water is pumped from the ocean depths to fertilize the kelp. The remoteness of the spreading center allows this farm to cover large areas.....on the order of 100,000 acres.... without interferring with shipping channels or other human activity. The kelp is harvested in such a fashion to allow for a continuous supply to the process plant where it is slurried and pumped down to the reaction vessel. The reaction vessel is located on the ocean floor and straddles a spreading center. Conditions in the vessel are those of the spreading center..... 3500 psia, and 350°C. At these temperatures and pressures, the kelp is converted to oil...very similar to No. 6 fuel oil....by the

[7] "Seaweed Power - Renewable Energy from Off Shore Kelp Farms" Popular Science - 1981

Figure 1. SYNTHETIC OIL PRODUCTION FROM KELP IN AN OCEAN SPREADING CENTER ENVIRONMENT



process of reductive formylation.[8] The oil and non-converted solids are transported to the surface where they are separated and the oil taken to land based stations via a tanker.

The process of oil production has already been witnessed by explorers of ocean spreading centers. The submersible ALVIN had been noted to smell like diesel fuel after being exposed to the high temperatures and pressures on the spreading centers. The oily residue on the outside surface of ALVIN is thought to occur when algea decomposes to a hydrocarbon in this environment.

Energy requirements for the complex will come directly from the ocean spreading center and the sun. Hydrothermal wells as shown on Figure 1 may be used to pump hot water to a platform mounted electrical power station or process steam may be produced in a magma well similar to those drilled in the Kilanea Ika Lava bed. Heat into the reaction vessel will come directly from natural convective systems (i.e., hot springs) or may be supplemented by magma heat sources. The sun will supply the solar energy required to grow kelp. The production plant will be completely energy independent and will depend solely on renewable energy sources.

It is estimated that a 100,000 acre kelp farm would yield 40 million tons of kelp per year. The amount of dry biomass available for

[8] "Conversion of Organic Wastes to Oil by Reductive Formylation", Design and Management for Resource Recovery, Volume I., Edited by T. C. Frankiewiez.

conversion in this amount of kelp is 5.2 million tons. Assuming a conversion efficiency of 30%, approximately 11.0 x 10^6 barrels of oil per year would be produced. At a price of $35/barrel, the plant would generate $385 million per year income. The system was not developed to the point where initial capital cost and operating expenses could be estimated. However, the initial assessment of the idea seems very attractive and additional development is warranted.

SELECTIVE COMPLEXING COLUMNS FOR NOBLE METALS RECOVERY

Sea water is a vast resource for noble metals although present in extremely low concentrations. Complexing columns which contain resins that selectively capture noble metals may be an effective way of concentrating these materials. These columns would be located in areas of high sea water flux so that millions of gallons would continually be flushed across the resin material. Hot water leaving spreading center vents could be used as the motive force to drive such a process. Areas where large amounts of water move into the pillow lava formations on the ocean floor could also be located and complexing columns installed at these locations. The columns would not have to be highly efficient since they could be made large and left in place for long periods of time. The resins could be "mined" periodically and replaced with new resins.

Preliminary investigations have identified some possible resin materials. Glycidyl acrylate resins having episuffide or thiol group or crosslinked aromatic vinylpolyvinyl copolymers having thiol group were effective in separating gold from sea water. Styrenedivinylbenzene copolymers incorporating isothiourea functional groups showed a remarkable affinity for platinum group metals when in a chloride media.[9][10]

PERMEATION PROCESSES FOR VALUABLE ELEMENT RECOVERY

Permeation processes can be used to concentrate elements in environmental conditions similar to ocean spreading centers. This may allow the economic extraction of elements present in this environment.

Temperature and pressure conditions restrict the application of permeable membranes to metal, ceramic or glass, and exclude the use of polymeric membranes. Membranes constructed from these type of materials have proven to be effective in concentrating elements. Table 2 summarizes the elements which can be separated, the membrance material, and the temperature at which they operate.[11]

CONVERSION OF THERMAL CONVERSION OF MECHANICAL OR ELECTRICAL ENERGY

Many of the processes conceived to operate in ocean spreading center environments will require mechanical or electrical energy to operate support equipment. Pump work and electrical instrumentation are two examples of a wide range of components requiring energy. Many creative ideas were proposed that could generate this energy. Electrochemical fuel cells which utilize the high delta temperature available appear to be promising. Nitinol engines,

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(9) A. Warshowsky, M. D. Fieberg, P. Mihalik, T. G. Murphy, Y. B. Ras, "The Separation of Platinum Group Metals in Chloride Media by Isothiouronium Resins". Separation Purification Methods, Weizmann Institute Science, 3 Rehavot, Israel, 1980.

(10) Egawa, Hiroaki, "Separation and Recovery of Gold", Jpn. Kokai Tokkyo Koho, 1981

(11) <u>Membrane Separation Processes</u>, H. Strathmann

TABLE 2

ELEMENTS WHICH CAN BE SEPARATED BY PERMEATION

Element	Membrane Mat.	Temper. ^oC	D(CM^2/Sec.)
Cu	Au	300	1.5×10^{-13}
Zn	Cu	350	
α - Brass			5.8×10^{-11}
β - Brass			1.3×10^{-9}
Ag	Pb	220	1.5×10^{-8}
Au	Pb	300	1.5×10^{-6}
Ni	Pb	320	3.5×10^{-10}

that utilize the "memory" feature of some metals to return to their original shape when heated, may also be used.[12]

VI. CONCLUSIONS AND SUGGESTED FOLLOW-ON WORK

It is an overall conclusion of this report that the energy available at ocean spreading centers is sufficient to supply a major portion of the world's energy needs, and it is virtually inexhaustible. It presently is not considered a viable source of energy by private or government personnel because of its recent discovery, perceived technical problems, and anticipated prohibitive economics. It is our assessment that these perceptions are no longer valid with today's technology, and that economical processes can be conceived that will utilize this huge energy source.

As our extension of our current hydrothermal program, it is suggested that INEL vigorously pursue the development of spreading center energy in the following areas:

- o The effort to develop innovative uses of the environment should continue. This year's creative efforts have identified some attractive processes and have established the "positive" attitude that was a prerequisite for the work in this report.

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(12) Johnson "Nitinol Heat Engines", Tenth Intersociety Energy Conversion Engineering Conference, Newark, New Jersey, August 18-22, 1975, pp. 530-534

- This year's best ideas and the good ones created next year should be further developed in conjunction with an oceanographic institute. Ideas will be developed to the point where a reasonable economic assessment can be made of their feasibility.

- A proposal should be written to drill a well into an ocean spreading center. This well will yield valuable geological information and will confirm some of the assumptions made in our engineering and economic evaluations.

Being the first to realize the significant energy potential of ocean spreading centers places EG&G in a possible position of obtaining a major program in this area. The opportunity exists now and should be seized.

APPENDIX 1

NEW PROCESSES FOR OCEAN SPREADING CENTER APPLICATIONS

1. Utilize a fuel cell for process such as powering an omni beacon.
2. Propigate a mollusk farm.
3. Grow agricultural crops.
4. Hot water shields for sub or sonar antenna.
5. Utilize the lens effect ($\Delta T, \Delta P$) for transmitting signals or shielding strategic vessels.
6. Utilize an all mechanical turbine in the plume to pump fresh water ashore, utilize residual steam heat.
7. Obtain He.
8. Power generation by ΔT for a Nitinol engine.
9. Utilize a wave generator to collect oil globules.
10. Install a self powered organ to indicate the conditions in the vent environment.
11. Collect metals and materials over a very long time frame.
12. Sub recharging station for O_2 and fresh H_2O.
13. Utilize palladuim foil to extract H_2 by a heat induced permeation process.
14. Recover H_2/H_3 and utilize as an ocean floor energy source.
15. Utilize older spreading center locations as a geological clock.
16. Melt and quench metals, use in conjunction with permeation tubes and complexing columns.
17. Operate a super heated nuclear reactor without a pressure vessel containment.
18. Extremely large furnace for firing larger one piece ceramics.

Appendix 1 (Continued)

19. Make a water shocker (pressure/thermal cycles).
20. Instrument vents in order to assess and predict volcanos and earthquakes.
21. IEEE qualification laboratory.
22. Obtain basic chemical and physical measurements in order to properly assess potential applications.
23. Turbine wheel in plume to generate power.
24. Drill inlet holes into vent initiation area and introduce chemicals to induce exchange of precious metals, etc.
25. Steam generator/turbine assembly to generate electricity.
26. Extraction of chemicals and/or minerals.
27. Chemical analysis of plume-discover new isotopes, etc.
28. Mine ore deposits.
29. Build a structure for heating and directive plume by the addition of salt and its subsequent hardening.
30. Tap magma and utilize for producing building blocks.
31. Dissipate heat in large containers in order to grow agricultural crops or mollusks.
32. Generate light by a galvanic cell to be used in an underwater environment.
33. Grow a coral colony.
34. Generate electricity for process utilization by a thermal/magnetic cycle.

Appendix 1 (Continued)

35. Generate a magnetic shield and utilize for strategic purposes.
36. Establish an underwater community.
37. Collect minerals and sell as a novelty item; i.e., Mount St. Helens volcanic ash.
38. Promote unique temp/press chemical reactions.
39. Isolate conditions by building a lava wall and utilize for a process plant.
40. Buoyant hot water collection tank.
41. Extract He to float work stations.
42. Remote manipulators for performing an undetermined process.
43. Utilize plume stringers (i.e., heat, minerals) to transfer electricity without wires.
44. Prevent catastrophic geological events (volcanoes, earthquakes, etc.) from occurring by modifying vents; i.e., pressure, temperature.
45. Selection complexing of inlet plume.
46. Collect minerals by flashing water to steam.
47. Modify plume conditions by controlling inlet plume.
48. Encapsulate rad waste by temperature process utilizing entrained silica.
49. Dispose of rad waste in undersea geological formations for infinitely long period of time, allowing enough decay that remaining waste can be neglects.
50. Single crystal formation in magma utilizing entrained silica under extreme conditions.
51. $\Delta T, \Delta P$ cycle performance, utilizing a reaction vessel constructed by water injection in magma.

Appendix 1 (Continued)

52. Use selective complexing columns to extract noble metals.
53. Use permeation tubes to extract valuable elements.
54. Use galvanic cells to produce electrical power.
55. Detoxify pollutants.
56. Utilize environment as a qualification testing ground for PWR conditions; i.e., seals, etc.
57. Electronic deposition of metals inherent to location - this may be coupled with the galvanic cell idea.
58. Create a semi-plug flow reactor, testing ground.
59. Entrain metals to surrounding water to enhance sports fishing environment.
60. Produce amorphous metals by high heat transfer to cold water.
61. Utilize environment for processing solid, porous waste into a liquid phase.
62. Utilize environment for processing plastics and synthetics; i.e., moldings, springs, ball bearings, etc.
63. Utilize environment for refining aluminum from Boxite.
64. By chemical processes obtain free hydrogen from H_2S.
65. Utilize environment as a research laboratory for kinetics of metallurgical reactions.
66. Utilize environment for the desalination of sea water.

EG&G Idaho

INTEROFFICE CORRESPONDENCE

date November 4, 1983

to H. R. Hilker

from J. H. Ramsthaler

subject PRELIMINARY PROGRAM PLAN OCEAN SPREADING CENTER HYDROTHERMAL TEST FACILITY [redacted]

Ref: Internal Technical Report RE-E-83-005, September 29, 1983, Ocean Spreading Center Environment Utilization

In the reference document, it was concluded the use of energy from ocean spreading centers is a potentially economical means to provide power for a number of unique chemical processes. A follow-on recommendation was to drill a hydrothermal well for use as a test bed to study the availability and usefullness of the resource. A number of pre-program activities and an outline of a program plan defining activities necessary to develop a test facility has been prepared. The following summarize key elements of the plan:

OBJECTIVE

The objective of the program is to obtain scientific data on the hydrothermal resources associated with ocean spreading centers by testing potential applications of the resource in field experiments. The key element to meet this objective is a hydrothermal well, cased, with control valves, and necessary plumbing and associated facilities to conduct a scientific test program.

PRE-PROGRAM ACTIVITIES

o Obtain EG&G Idaho Management Support

The Ocean Spreading Center Test Facility is a major undertaking with a price tag which will exceed 100 million dollars. It will be highly visible and will require extensive coordination with U.S. government politicians, government agencies, the scientific community and similar groups from foreign countries. To accomplish this task, EG&G Idaho must develop a versatile group of knowledgeable scientific personnel. This can only be accomplished with a commitment from EG&G Idaho management to support the work and in particular, to approve a significant new applications TDP task. We presently have a small ($20K) task and it will be proposed to expand this into a $200K new application effort.

o <u>Develop Technical Agency Support</u>

Deep ocean work is presently funded primarily by the National Science Foundation, but NOAA, the USGS and the Navy support considerable underocean scientific work. The scientific community currently working on undersea projects have in general concluded the current state of understanding is insufficient to launch into development activities. However, the Navy (China Lake) has convinced the SAN office of DOE and DGHT to propose a modest effort ($2M) which appears directed towards drilling a well.

Based on the reference report, we have concluded a large scale effort is justified and we need to find Washington support for the program. H. R. Hilker and J. H. Ramsthaler will visit DGHT during November and attempt to obtain their support in pursuing the program. If a positive reception is received, a strategy will be developed for interacting with other agencies who currently have an interest in undersea projects.

o <u>Develop Support from Laboratories Currently Involved in Undersea Scientific Projects</u>

There are currently several laboratories such as Scripps or Woods Hole who have the expertise necessary to accomplish the objectives of this program. In addition, there is a whole scientific community who would resent a major project which was planned in their area of expertise if they were not asked to participate. To prevent such a backlash and to assure we are not reinventing the wheel, it is necessary to obtain input from this community and to fund them to provide significant support work to the project.

Our current plan is to visit several of the major oceanographic laboratories using our TDP funds after we have developed our federal agency and political support.

o <u>Develop Political Support</u>

A major new program with potential to cost hundreds of millions requires congressional support. Senator McClure has already expressed an interest in supporting a modest exploratory effort ($300K), and he appears to be the ideal person to champion the entire program. During the visit to Washington November 1983, Marilyn Osterhout will be contacted and given a presentation on the entire project. Assuming she is willing to propose the project to the Sentator and he agrees to support the project, we will attempt to involve the supporting federal agencies, oceanographic labs, etc. from areas which the Senator feels will be most politically advantageous to accomplish the program objectives.

Ideally, we would like to develop a rapport where most of the significant program accomplishments are released through the Senator's office, or in a manner such that we obtain greatest political effectiveness.

WORK BREAKDOWN STRUCTURE

A proposed work breakdown structure for the program is shown on Figure 1. Seven major areas of work are defined and the following define the objectives and work to be accomplished in each area.

A. Project Management

The overall objective of this task is to promote, coordinate, and manage all of the activities necessary to meet the objectives of the program.

- Form Advisory Team

  A major undertaking such as the Ocean Spreading Center Hydrothermal Test Facility must have a formal means to obtain a quick feedback from the involved scientific community or it will quickly get into trouble. A scientific advisory committee will be picked and funded to critique all aspects of the program. The number of members, frequency of meeting and organization will be determined based on quiries of the involved scientific community, federal agencies and possibly potential industry participants.

- Question Industry

  There presently is no industry for using deep ocean hydrothermal energy. However, a portion of the objective of this work is to investigate processes with commercial potential. Industrial concerns who market applicable products will be contacted to assess their interest. The petroleum industry, of course, with their drilling expertise is mandatory to participate in the project. The overall objectives of this task are to develop a working relationship with potential industrial participants, to determine if ideas exist which are applicable to spreading center energy utilization and to stimulate industry to begin to think about potential applications.

- <u>Tech Transfer</u>

  The initial effort in tech transfer will be to convince the public that it is reasonable that the government conduct research on utilization of spreading center energy. There is a certain 'wow' factor when considering the mysteries of the deep but the first reaction of almost everyone is that it is ridiculous to consider using energy located on the bottom of the ocean a thousand miles from land. A careful release of information is required to convince the public that utilization of spreading center energy is environmentally benign, it is potentially economical, and it is an enormous source of energy with the potential to be a long-term solution to the world's energy problems.

  During the acquisition of background data and construction of the test facility (primarily well drilling) a steady release of articles and papers will be necessary to maintain public interest.

  After data are obtained from the test well/wells, assuming the results are positive, the tech transfer effort will concentrate on the economics of potential projects to stimulate industrial interest.

- <u>Project Management, Costs and Schedules</u>

  The test facility construction and operation will, hopefully, be a large project with parallel tasks in progress at all times. The project management function will maintain a master program plan which will be updated annually, and a management summary schedule which shows the status of each of the major subtasks for the anticipated life of the program. Critical path items for construction and operation of the facility will be delineated at all times.

  Rate of expenditures during each year will be tracked and required funds for following years wll be defined for the anticipated life of the project.

  RFP's for proposals will be prepared for tasks which are required but not initiated. Proposals for extensions of on-going work will be reviewed and recommendations made for acceptance, modification or rejection. Unsolicited proposals will be reviewed for potential application to the program. Assistance will be provided to DOE in writing work statements and contracts will be issued when requested.

B. <u>Select Drill Site</u>

The objective of this area of work is to accomplish the technical tasks which are necessary to select a drill site. The output will be a prioritized list of potential sites with the rational for selecting each site.

- <u>Review of Available Data</u>

  A review will be conducted of available data on ocean spreading centers. The review will include locations of known vents, chemical and biological analyses on effluents, geophysical studies on spreading centers, drilling history near centers and all pertinent geology data. A report will be proposed summarizing the data, recommending candidate sites and recommending follow-on work to aid in selecting the final site.

- <u>Conduct Pre-drilling Test Program</u>

  Recommendations from the data review will be funded from this work package. Types of work include additional geophysical surveys, additional samples, core samples (using NSF ships), geological work and site surveillance using submersibles.

- <u>Economic Analysis</u>

  The selection of the drill site will be affected by economic considerations such as the depth required, the distance to get to the drill site, the weather in the area to be drilled, and the needs of the potential experiments to be conducted using the test well. The studies to be funded from this work package will determine the cost of locating the test facility at the various locations which appear geologically desirable.

- <u>Site Selection</u>

  The object of this work package will be to integrate the information from the pre-drilling test program, the economic analyses, the experimental requirements, and the institutional and environmental considerations. A committee of scientists, industry and government personnel will be formed to review the data and select the candidate drill sites.

C. <u>Institutional and Environmental Considerations</u>

Ownership of the spreading center energy is an unknown and environmental problems which might arise from its use have not been studied. Resolution of these potential problems is equally important to the technical problems in establishing a spreading center test facility.

The objective of this task is to study environmental and institutional problems, conduct necessary research and undertake the activities which assure that the energy is developed in an environmentally and institutionally sound manner.

- <u>Biological Contamination</u>

  The ocean spreading centers are known to contain biological material with a life cycle which can only be speculated on at the present time. This biological system must be studied completely prior to drilling a test well. Initial studies will concentrate on health or environmental effects which might result from large quantities of this material being released into the ocean either on the ocean floor or at the surface. Since the biological material is unique to anything currently existing at the surface of the earth, studies will be conducted to assure that samples being distributed as a part of the sample program do not have adverse consequences.

  A final study will be conducted to assess the biological impact of large scale commercial utilization of spreading center fluids.

- <u>Thermal Contamination</u>

  The test well will have negligible thermal contamination of the ocean ecosystem but large scale commercial utilization could conceivably cause adverse effects. A scenario will be developed and possible problems analyzed.

- <u>Waste Disposal</u>

  Similar to thermal contamination wastes from the test facility will be insignificant as a means of ocean contamination. Large scale commercial development could cause problems and screening studies will be conducted to see if there are any obvious environmental problems.

- <u>Environmental Assessment</u>

  An environmental assessment will be prepared summarizing environmental considerations for the test well and for full-scale development of spreading center utilization. Comparisons with enviornmental effects of other major sources of energy will be made.

- <u>Legal Considerations</u>

  Studies will be made of various legal scenarios for development of spreading center energy. Recommendations will be made for options which the U.S. should champion for the world community to adopt.

o **Advisory Committee**

An environmental advisory committee will be formed with international representatives to review data and make recommendations for project action. Input will be provided to the site selection task, the experiment planning task and to test operations.

D. **Experiment Planning and Analysis**

The objectives of this area of work is to plan a test program for the hydrothermal well. To assure the test program can be successfully accomplished, well requirements will be established and necessary pre-test laboratory experiments will be conducted.

o **Biological Experiments**

It is known that the organisms which live in the spreading center fluids cause the formation of methane and hydrogen. These are useful forms of energy which can be economically transported from spreading centers and suggests there may be processes which might be based on ocean floor bioconversion.

A task will be funded to do basic research on the mechanisms by which the organisms exist and applied research will be conducted searching for potentially economical processes.

If it is determined that there is a need, experiments will be designed using the test well. Under this task, requirements for the experiments will be established, procedures will be written, test monitoring will be provided, data will be analyzed and analysis reports will be written.

o **Reservoir Definition**

The initial test program with the completed well will be to determine the magnitude of the reservoir. A reservoir engineering program will be planned to assess the reservoir. An important initial output of this task will be requirements for test equipment and instrumentation design. A second output will be test procedures to be used and a third output will be a test report. Technical support will be provided to test operations during the conduct of the well tests.

o **Process Evaluation**

The end use of the test facility is to determine if the energy available at the spreading centers can be used in processes which have commercial value. The objective of this work package is to conduct experiments designed to determine if calculated economic advantages can be obtained in the deep ocean environment. Processes to be studied include, but are not limited to, conversion of biomass (kelp) to diesel fuel, CH_4 and hydrogen, recovery of metals from the hydrothermal water, long-term extraction of noble metals from sea water and any unique chemical conversion processes which appear economical in the deep sea environment.

Work on this task will initiate with funded brainstorming efforts to visualize processes which are uniquely economic in the deep ocean environment. This is an extension of work which has been initiated at EG&G Idaho using in-house funds. The most promising concepts will be funded for laboratory exploratory and proof of principle experiments. The projects which prove feasible will be funded for pilot-scale experiments using the spreading center test facility. The funded experiments will define test requirements for construction of necessary equipment, review experimental designs, participate in the conduct of the tests, analyze the data and produce a data report.

- <u>International Participation</u>

  The ocean spreading centers are not presently owned by anyone. To help develop a spirit of cooperation, experiments by foreign scientists will be encouraged at the test facility. As a part of this work package, presentations will be made to foreign governments and experiments proposed by the international community will be screened. Funding will be available to support experiments by countries who cannot afford to participate on their own.

- <u>Experiment Review Committee</u>

  An experiment review committee will be formed to study proposed experiments from all areas of the program and prioritize the use of the test facility. The experiment review committee will consist of senior scientists from all portions of the program and will include international representatives.

- <u>Sample Acquisition</u>

  The scientific support work for the spreading center test facility will require extensive samples of spreading center hydrothermal fluids prior to drilling the test well. The objective of the work in this task is to obtain samples for the various scientific tasks. Large volume samples will be taken from vents thought to be representative of the range of fluids which may exist. Collection of the samples will require the design of special collection equipment. Requirements for preservation of samples will be obtained from the various scientific disciplines.

E. <u>Support Engineering</u>

Cost effective utilization of spreading center energy will likely require a minimum of human activity on the ocean floor. From the outset, a goal will be to have fully remote operated subsurface equipment. The technology for this goal will be generated in this work package. In addition to developing the deep ocean remote handling technology facility design and support engineering work will be accomplished in this area.

- <u>Material Studies</u>

  The deep sea environment and the composition of the spreading center hydrothermal fluid may present unique material corrosion problems which effect selection of well construction materials. Laboratory corrosion studies will be conducted to evaluate candidate materials. A report will be issued with recommended materials.

- <u>Well Plugging</u>

  Available information indicates spreading center hydrothermal fluids are high in dissolved solids and precipitates form when they contact sea water. Current literature indicates ocean floor vents have relatively short lives which suggests plugging will be a significant problem in the test well. Samples of vents will be taken and studies conducted to assess interactions with drilling fluids and general chemical characteristics which might affect the flow from a well. It will be necessary to determine how the fluids react to changes in pressure and temperature with and without contact with sea water.

- <u>Deep Ocean Technology</u>

  Work on deep ocean technology will initiate with a survey on the current state of the art on deep sea equipment utilization. Prototypes will be designed for any additionally needed equipment and a deep sea test program conducted. A close contact will be maintained with work in the well drilling and experiment planning work packages to assure the technology development program has developed the proper equipment.

- Experimental Equipment Design

  As experiments are approved by the experiment review committee specialized equipment will be designed and procured as required to facilitate conduct of the experiments. Technical support will be supplied to experimenters during the conduct of tests.

- Facility Design

  The test facility will be designed based on requirements established by the test facility operations group.

F. Well Drilling

The objective of this task is to drill the well/wells which will be used to support the test facility.

- Well Design

  Based on data obtained from the environmental, site selection, engineering and scientific work packages a well design will be formulated. The proposed well design will be reviewed and approved by managers from each of the aforementioned work areas.

- Drilling Contracts

  Contracts will be let for all aspects of drilling from this work package. The net output of the work from this area will be a well complete with all environmental and safety requirements. A remote acting valve will be supplied at the top of the well head for interfacing with the experiments to be conducted using the well.

G. Test Facility Operations

The objectives of this task are to set requirements for and fund the design and construction of the test facility and to operate it after it is constructed.

- Requirements

  The test facility will be fully mobile such that it can be moved from well site to well site. The design will include requirements for remote operation of subsurface equipment as well as the utilization of hydrothermal fluids at the surface. Support equipment will include a capability for personnel to work at bottom locations for short periods of time. The facility will include a complete data acquisition system and space for equipment to study processes for utilization of hydrothermal energy.

An operations group will be formed to prepare a complete set of requirements for the facility.

- <u>Construction</u>

  The groups intended to operate the facility will manage the procurement and integration of equipment for operating the facility.

- <u>Operations</u>

  A permanent group of people will be maintained for management, operation and maintainance of the facility. The permanent group will be augmented with technical support personnel from the design and experiment groups with these personnel changing as experiments are changed. The permanent personnel will have responsibility for the procedures for all tests.

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Figure 1.

WORK BREAKDOWN STRUCTURE

OCEAN SPREADING CENTER HYDROTHERMAL TEST FACILITY