CIRCUM-PACIFIC ENERGY AND MINERAL RESOURCES CONFERENCE

HEARINGS

BEFORE THE

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OF THE

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CIRCUM-PACIFIC ENERGY AND MINERAL RESOURCES CONFERENCE

TUESDAY, AUGUST 27, 1974

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON MINES AND MINING
OF THE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
Honolulu, Hawaii.

The subcommittee met, pursuant to notice, at 2 p.m. at the Sheraton Waikiki Hotel, Hon. Patsy T. Mink (chairwoman) presiding.

Present were Representatives Mink, Kazen, Vigorito, and Burton. Also present were Norman Williams, staff consultant; Charles Leppert, Jr., minority consultant; and Miss Elizabeth Medeiros, clerk.

Chairwoman MINK. The subcommittee will come to order. We will proceed. We are very pleased to welcome this afternoon as our first special guest, Dr. Richard Bowen, who is the economic geologist of the Department of Geology and Mineral Industries, State of Oregon, and he is, of course, one of the key participants at the Circum-Pacific Conference which is currently ongoing here in Honolulu at the Hilton Hawaiian Village. We are delighted that he would take the time away from the conference to give us a firsthand summary and opportunity to ask questions on the paper that he is presenting at the conference on the subject of environmental effects of geothermal energy development. The committee has jurisdiction over this subject area and we do have a couple of bills that have been introduced which are pending before the subcommittee. So, we are enormously grateful to you, Dr. Bowen, for agreeing to come here to give us the benefit of your research and your studies.

We do have a copy of the paper which you presented to the conference here. Without objection from my colleagues, I would ask that the paper be inserted at this point in the record.

[The paper follows:]

ENVIRONMENTAL EFFECTS OF GEOTHERMAL ENERGY DEVELOPMENT*

(By Richard G. Bowen**)

An appraisal of the environmental effects of geothermal development should do more than just list potential insults to the environment; it should also weigh the benefits to mankind and scale these insults and benefits against those from other energy sources.

Possibly the best way to compare these effects is to look at the total cycle of power production. The geothermal plant is unique in that all of the steps in the fuel cycle are localized at the site of the power-production facilities. At the other end of the power spectrum is the nuclear-reactor plant, in which the actual

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*Presented at Circum-Pacific Energy and Minerals Conference, Honolulu, Hawaii, August 26–30, 1974.

**Economic Geologist, State of Oregon Department of Geology and Mineral Industries.

power-production facilities are a small fraction of a cycle requiring a complex industrial-support system for each reactor. Intermediate in complexity and varying somewhat in rank with the type of fuel used, are the fossil fuel plants. Thus, for nuclear and fossil fuel plants, the environmental impact of the fuel cycle extends far beyond the bounds of the power-generating plant.

Like other thermal power plants, the geothermal plant involves the production and use of steam, expanding it through a turbine and condensing it at the turbine exhaust. The geothermal plant differs from the conventional fuel or nuclear plant in its method of steam production and the quality of its steam. At the geothermal plant the steam is produced in nature's own boiler by the natural circulation of water coming into contact with hot rocks in the depths of the earth. Depending upon conditions within the reservoir, the geothermal fluids may be in the form either of slightly superheated dry steam or of pressurized hot water. The condition of the fluid in turn controls the method of utilization. If the fluid is in the form of steam it can be passed through the turbine directly, if in the form of hot water it can be used directly by "flashing", or by means of heat exchangers the thermal energy in the fluid can be transferred to another liquid for expansion through a turbine. In all cases the energy transfer method is far simpler than that needed for the combustion of fuel or for containing a nuclear reaction.

The simplicity of the whole geothermal cycle contributes greatly to its reliability. With the geothermal system there are no complex mining, processing, and transportation steps. The system is not dependent upon vagaries, unreliable suppliers, strikes, or political decisions. To the extent that geothermal resources can be substituted for the more conventional fuels, both fossil and nuclear, the overall detrimental effects of energy production can be reduced.

DIRECT USE OF GEOTHERMAL ENERGY

The direct use of geothermal energy for space heating is well known and practiced in several parts of the world. The best known example of this has been at Reykjavik, Iceland, where a large district heating system provides nearly all the space heating for this city of 85,000. Extensive use is made of geothermal waters in Hungary, where in Budapest alone 5600 flats are supplied with natural hot water. Not only does this save fossil fuels but as Boldizsar (in press) reports, the heating costs are less than half those of conventional fuels. In the United States the largest utilization of natural hot water is in Klamath Falls, Oregon, where several hundred homes and numerous schools use geothermal waters. Several other cities in the West make some direct use of this energy source.

Utilization of geothermal fluids for space and process heating may involve little more than the drilling of a well and circulating the fluids through a radiator in the home. In some cases, heat exchangers are used, and in others it is necessary to make minor changes to the chemistry of the waters to keep minerals from plugging the pipes. The disposal of these fluids is handled in different ways depending upon the region and quality of the fluids; some are put directly into surface streams and some underground. Often the spent fluids are of sufficient quality to be used directly for irrigation or stock watering. If aquifer conditions are appropriate, there is no need to bring the geothermal fluids to the surface, as down-hole heat exchangers can be used and clean secondary fluids circulated to the surface installations. All of these techniques are practiced in some areas, and nowhere has it been necessary to resort to complex techniques of effluent capture and disposal.

The direct use of geothermal energy has been largely unheralded because it lacks the glamor and large revenue aspects of the production of electric power. However, the total amount of energy produced for direct use exceeds that for electric power production from geothermal resources today. The direct use of geothermal fluids for space heating is particularly attractive in areas of arctic and sub-arctic climatic conditions where winter heating is a major economic burden and where the winter high-pressure weather systems often create a pall of lingering smoke and fog from the burning of fossil fuels. There should be a major effort in those areas where geothermal resources are available to build district heating systems on the pattern of Reykjavik to lower the overall pollution and decrease the use of and dependency upon fossil fuels.

GEOTHERMAL ENERGY FOR THE PRODUCTION OF ELECTRICITY

The potential environmental insults arising from geothermal power developments are similar to those from any other industrial operation. The construction of roads, drilling of wells, and installation of pipelines and power plants all contribute to the changes in land-use patterns for the particular site. The effects on the land vary depending upon the type of fluid and utilization.

The two basic types of geothermal reservoirs, vapor-intensive or "dry steam" and liquid-intensive or "hot water," have been utilized for electric power production sufficiently to develop a history of environmental effects. The three productive "dry steam" fields, Larderello, The Geysers, and Matsukawa, all produce steam of similar thermodynamic properties (White, et al, 1971) but slightly differing chemical properties that reflect their individual reservoir rock character. The steam is made up dominantly of water vapor (from 90 to 99.9%) and varying amounts of non-condensable gases (carbon dioxide, methane, hydrogen sulfide, hydrogen, nitrogen, and ammonia). This indicates that other "dry steam" fields that may be found will probably have similar characteristics and can be handled in a manner similar to that presently developed, and will have predictable environmental effects.

The characteristics of liquid-intensive or "hot water" fields are much more variable, both in thermodynamic and chemical character. Temperature ranges from slightly above ambient to 388°C (Mercado, 1969) and chemical content from very low to the saline brines of the Salton Sea sump with minerals in solution totaling up to 25% of the mass. Production of electricity from the liquid-intensive field, therefore, utilizes more different techniques, and it is in this area that the greatest efforts are being expended on new mechanical methods for harnessing the energy.

The amount of land needed to be dedicated to productive fields, pipeline rights-of-way, and power production facilities also varies. At Wairakei, the steam field supplying the plant of 192–Mw capacity is less than a mile in area, and the plant and pipelines located about a mile from the field take up only ten or twenty acres making the total amount of land involved only about a square mile. At Cerro Prieto, approximately a kilometer is used for plant and production facilities for 75 Mw. At Larderello, the field covers many square miles, but the density of development is so low that numerous other productive activities are carried on within the geothermal field making the total amount of land dedicated to electric power production quite small. Larderello is an outstanding example of multiple land use, for within the bounds of the producing field is a diversified agricultural economy with many farms, orchards, and vineyards interspersed among the wells, pipelines, and power plants. Figures 1 and 2 are views of the Larderello field. The Geysers field, which may be typical of geothermal fields yet to be discovered and developed, is presently being developed with plants with 110 Mw capacity spaced about a mile apart, each supplied by a steam field about a mile in diameter. In this case, the total area occupied by the geothermal field that produces 1000 Mw approximates 10 square miles.

The amount of land dedicated to a nuclear or fossil fuel power plant of similar size varies from a minimum of around 100 acres to several thousand if plant-site fuel storage facilities and cooling ponds or lakes are needed. Fossil fuel and nuclear plants require extensive off-site facilities to mine, process, transport, and in some cases guard waste disposal. By contrast, all of the production facilities of the geothermal plant are located at the site, thus the total amount of land dedicated to the production of electricity from a geothermal power plant is less than other types of thermal plants. Not only is this important in these days of increasing competition for diminishing space, but the simplicity of the geothermal system with its minimum of outside dependence increases its reliability.

ENVIRONMENTAL INSULTS

The specific environmental insults and potential insults that are most widely believed to be associated with geothermal power plants are water resource degradation, noise, air pollution from the release of hydrogen sulfide, subsidence due to the production of large amounts of fluids, the induction of seismic activity from fluid re-injection, and climatic modification from the release of vapors from cooling towers. I believe it is best to take these insults one by one to try to put them in their proper perspective.

Water resource degradation

Two questions are often raised about geothermal power developments: (1) What is its potential to contaminate surface and ground waters? and (2) To what extent would waters drawn from geothermal reservoirs deplete presently developed aquifers?

In the early days of geothermal exploration and development, several improperly cased wells blew out during drilling or after abandonment, allowing the geothermal fluids to enter nearby streams and shallow aquifers. In the Salton Sea region extremely geothermal saline brines, which contains up to 33% dissolved solids after flashing, constitute a hazard if allowed to mix with the irrigation water in the region.

True, contamination of useful waters would be a serious deterrent if it could not be prevented, but with use of modern drilling, casing, and completion practices there is no reason to believe geothermal production presents any more of a hazard than does petroleum production. In many parts of the United States and in other countries, drillers routinely drill through fresh water aquifers to produce petroleum from underlying zones. By casing through these zones and then firmly cementing the casing into place, drillers can effectively isolate the aquifers from the deeper production zones. This isolation of thermal waters is necessary for the protection of both the aquifers and the geothermal system.

Allowing geothermal fluids to run into surface streams would possibly degrade stream quality. This practice, however, is prevented by law in the instances where the surface waters contain fewer contaminants than the geothermal fluids. Even accidental discharges of brines from a geothermal well into surface waters is not a serious hazard. In most parts of the world, the geothermal fluids are potable or range to the salt content of ocean waters. They can in no way compare to such substances as petroleum brines, chemical plant effluent, and municipal wastes, all of which are routinely handled and contained.

In some instances, a geothermal fluids can be added to surface waters because they are equal to or better in quality than the existing water resources. Geothermal developments may in some areas be a significant source of useful waters because the cost of producing them will be borne mostly by the power production facilities. The production of electricity, minerals, and usable water at the U.S. Bureau of Reclamation project in the Imperial Valley, as outlined by Laird (*in* Kruger and Otte, 1973), is an example of several beneficial uses from this resource. Many areas within the Circum-Pacific region could benefit by this type of multipurpose installation.

Arguments have been made that development of geothermal reservoirs may deplete existing developed aquifers. It is true that within a given area or basin there is only a certain quantity of water in storage. Aside from surface waters, the most useful waters and those of most concern, are the shallow aquifers ranging in depth from a few feet to at most a couple of thousand feet. In contrast, geothermal water brought up to the surface as steam is a new and previously untapped source of water coming from depths of as much as 9,000 feet.

All thermal power plants require water for the cooling process. Geothermal plants use these same geothermal waters; whereas the other types of plants require the use of conventional sources such as rivers, lakes, or ground-water reservoirs.

The fact that geothermal "dry steam" reservoirs are isolated from the groundwater aquifers can be shown by their very low reservoir pressures, which are about 500 psi even at depths of over 9,000 feet where hydrostatic pressures (pressures when the water is connected to the surface) would be about 4,500 psi (White, et al, 1971). Such extremely low pressures can only be explained by isolation—therefore there is no reason to believe that production of steam from a vapor-dominated system would have any effect upon overlying aquifers. The experience with the vapor-dominated systems, The Geysers, Larderello, and Matsukawa, show there has been little or no change in shallow-water zones. Surface spring and fumaroles at The Geysers have shown no changes since production began in 1960 (EIS, vol. II, p. v54).

In liquid intensive or "hot water" fields such as Wairakei, withdrawal of the geothermal fluids from depths could accelerate the depletion of shallow aquifers; in fact, since production began in the 1950's at Wairakei there has been a decrease in flow of the surface springs, and it is attributed to the withdrawal of large volumes of fluid for power production. As there is always a possibility of intercommunication between aquifers, the establishment of monitor wells in regions

where geothermal resources are being produced could show if aquifer communication were present.

In summary, each geothermal project has to be considered within its geologic environment. In some cases, existing water uses will be affected, but blanket prohibitions against development would be short sighted. In most cases geothermal development will not affect existing water uses; but where effects can demonstrate the higher value of the water when used as the medium for transporting the geothermal energy will allow it to pay for what displacement it causes. And this potential for displacement of existing uses has to be weighed against the potential to develop newer deeper sources of useful water from geothermal projects.

Noise from geothermal operations

Drilling operations in a geothermal field are comparable to construction activities in noise impact and are equally episodic in nature. The noise problem is associated mainly with drilling operations and steam escape during testing. Once the field is in production the noise level declines to that of other power plants. The drilling of dry-steam wells requires special techniques; at the present time, drilling into the production zone uses air, rather than mud, for the circulating fluid that removes the drill cuttings from the hole. This results in a "controlled blow-out" of the well during the time the steam zone is penetrated, amounting to only a few days out of the total drilling time. There is no danger involved because the pressures are relatively low and the blow-out can be quenched at any time by pumping water down the drill string. When the well is completed it must again be allowed to blow until the accumulated dust and rocks are removed from the bore hole. This constitutes the clean-out period, and until it is completed the wells can only be partially muffled. The silencers now in use at The Geysers field during drilling and testing operations have significantly lowered the noise level in the field, and new developments promise further decline of the noise levels.

During the early days of the development of The Geysers field, and other geothermal fields in the world, it was common practice to let wells blow for long periods of time and even to open them up for visitors to show the spectacular demonstration of energy exhibited by a blowing well. This has now changed and developers make every effort to keep the wells muffled.

Again, to get the true perspective of noise from geothermal operations it must be compared to that from fossil fuel and nuclear fuel cycle operations. Both require continual mining operations with blasting, operating of heavy machinery, and railroad or truck transportation of the fuels and waste products—far more individual sources of noise per unit of power than from the geothermal cycle.

Air pollution from hydrogen sulfide

Gases are rejected to the air from each type of thermal power plant. But because the geothermal plant operates without combustion, the volume of noxious gas produced is far less and is of a different nature than that from a fossil fuel plant. The natural steam is predominantly water vapor; that at The Geysers, for example, yields 99.5% water vapor. The noncondensable gases present in the steam are about 80% carbon dioxide, with lesser amounts of methane, hydrogen, nitrogen, ammonia, and hydrogen sulfide (Bruce, 1971). Of these, hydrogen sulfide presents the most serious environmental problem. At The Geysers, hydrogen sulfide runs about 2 to 6% and averages 1.5% of the noncondensable gases from the producing wells (Goldsmith, 1971, p. 31), or about 225 parts per million of the steam.

Because of the remoteness and the relatively small size of the power plants at The Geysers, and because of the lower release per unit of power than from fossil fuel plants, the hydrogen-sulfide emission has not caused the producers much concern. However, with expansion of the field and increasing awareness of the necessity for minimizing all releases, the power company and the steam producers are making efforts to lower the hydrogen-sulfide emission. Field studies and testing have shown the hydrogen sulfide can be removed either by the addition of a metal catalyst to the circulating cooling waters or by burning the H_2S to sulfur dioxide then scrubbing it out. Long term tests have shown that these methods will remove about 75% of the hydrogen sulfide. Hydrogen sulfide abatement equipment is being added to Unit 11, due for operation in October 1974 (Allen and McCluer, 1973).

Hydrogen sulfide released from geothermal power plants is a nuisance, but only on rare occasions does it become of sufficient concentration to be a hazard.

Fossil fuel power plants release far more gases and aerosols than do the geothermal plants per unit of power produced; and although gaseous emissions from nuclear power plants are minimal, other steps in the fuel cycle cause the gases released per unit of power to exceed those of a geothermal plant (Bowen, 1973). It appears that in geothermal plants utilizing hot water, particularly if a binary fluid system is used, the hydrogen sulfide release can be lowered from that of existing "dry steam" plants.

Subsidence in geothermal fields

Subsidence can occur whenever support is removed from beneath the ground. It has been noted in oil fields, in mines, and in areas being pumped for subsurface waters. In most cases subsidence is caused by the removal of ground waters pumped from a relatively shallow depth. In oil fields, the fluids have come from greater depths and subsidence occurs only under special conditions; i.e., when the fluids being removed are at greater than normal pressures for the depth of the reservoir. These conditions constitute an "over-pressured" reservoir, the fluids providing support to the overlying column of rock. Removal of this support may lead to subsidence. Injection of water around the periphery of the field replaces the petroleum with water, thus alleviating the problem.

Because of the geologic circumstances under which dry-steam fields develop, subsidence should not be expected to occur. The production reservoir of a dry-steam geothermal field consists of fracture zone, solution channels, or other permeable cavities filled with vapor at pressures much lower than normal hydrostatic. Because this vapor does not add support to the overlying rocks, subsidence has not been a problem at any of the "dry steam" fields in the world.

Hot-water fields, by contrast, could behave more like an unconsolidated petroleum reservoir, and unless pressures are maintained by fluid return there may be subsidence. Indeed, this has occurred in Wairakei, New Zealand (Hatton, 1970), where the water is not returned to the resorvoir. Much has been learned about subsidence from the exploitation of petroleum reservoirs, and with the proper understanding and practices, any geothermal area where this could be a problem can be established.

The hazard of subsidence from geothermal developments is minor compared to the total subsidence produced by other thermal plants. Where coal is mined underground the danger of subsidence is well known. In open pit mining, whether for coal or uranium, the abandoned mines, some with pits hundreds of feet deep, are testimony to another form of surface subsidence that must also be considered a part of the electric power production cycle. If ground water is utilized by the power plant for cooling, the possibility of subsidence arises, because most subsidence is related to ground-water production from shallow aquifers.

Induction of seismic activity from fluid reinjection

In relating the exploitation of geothermal resources to seismic hazards it must be considered that the unstable conditions in the earth's crust leading to the presence of geothermal phenomena are also those conditions producing faults and earthquakes. Thus, geothermal and seismic phenomena are geographically inseparable. In fact, the presence of high seismic incidence is one of the exploration clues used in the search for geothermal reservoirs (Clacy, 1968). However, the intensity of individual shocks within the thermal areas and associated with volcanic activity (the source of geothermal heat) is usually of a relatively low order, much lower than that associated with major crustal movements along faults (Ward, 1972). There is much to be learned about the interrelationship of thermal and seismic phenomena, and the drilling and exploitation of geothermal fields should add new information to this field of knowledge. But there is no evidence that geothermal production has increased the seismicity of an area.

Concern over seismic hazards arises in part from the process of reinjection of the spent geothermal fluids. Incidents of seismic activity relating to the injection of fluids in waste-disposal operations, such as that at the Rocky Mountain Arsenal near Denver (Evans, 1966), and to water-flooding operations to repressurize declining oil fields (Raleigh, et al, 1970, 1971), have involved injection at pressures exceeding hydrostatic. In such instances, reinjection could open and lubricate pre-existing fractures and zones of weakness or extend the fracture pattern causing increased seismic activity and perhaps structural damage. But geothermal reservoirs are at subnormal pressures and the return of fluids merely maintains pre-existing pressures in the reservoir and would not cause the increas-

ing seismicity noted in other conditions. The low pressure existing in geothermal reservoirs facilitates the reinjection of fluids into the field in two ways: first, because reservoir pressure is less than hydrostatic, the water's weight produces sufficient head to ensure its entry into the formation without pumping; and second, the returning water seeks the area of lowest pressure, thus minimizing the chances of geothermal fluid migrating into other aquifers.

Climate modification from the release of vapors at the cooling tower

This has been one of the points raised by the Sierra Club in opposing geothermal developments (Hess, 1972). It is pointed out that geothermal power plants because of their lower thermodynamic efficiencies use more water per unit of power than do either fossil fuel or nuclear plants, and that this water vapor could cause more fogging than presently existed in the region or could cause other climatic alterations.

The possibilities of climate modification from the discharge of cooling waters into the atmosphere by evaporation from thermal power-plant cooling towers should be considered from another perspective—the beneficial effects gained by adding moisture to the air. The general activities of man through agriculture, construction, logging, urbanization, etc., all tend to increase the amount of surface water runoff and lower the natural evaporation. It may well be that the extensive urbanization, logging, and farming along the high rainfall belt of the Pacific Coast have sufficiently reduced the natural evapo-transpiration, thereby lowering the water available for rainfall in the Rocky Mountains and Midwestern United States. Thermal power plants in regions where water is relatively abundant may proved needed moisture to those downwind. More investigation should be made on this subject.

NET EFFICIENCY OF POWER PLANTS

The term "efficiency" when related to the production of electricity or to power plants has come to be generally understood to mean the energy input: output ratio of fuel to electricity. The natural thermodynamic constraints placed on any electric generating machine require the rejection of 60 to 80% of the total energy input leaving only 40 to 20% of the energy available to do useful work. In the past when cost of fuel was the main variable in the price of electricity, every effort was made by designers and engineers to increase the thermodynamic efficiencies of power plants because over the life of the plant a small increment of efficiency could amount to savings or losses of millions of dollars. Consequently there has been great interest in maximizing the efficiencies of power plants, and because thermodynamic efficiencies have been the main variable, plant efficiency has become nearly synonymous with thermodynamic efficiency.

A large factor now entering into the picture is the cost difference between types of power plants, which varies more widely than in the past. And also important is the fact that different steps of the electric power cycle are performed at localities other then the power plant. Therefore, to get a truer picture of the efficiencies of electric power production, it is necessary to consider more than the thermodynamic efficiencies of the generating plant. One must look beyond to include the off-plant part of the power cycle. It is the net efficiency that gives a true measure of the power cycle (Odum, 1972), and in all cases the more complex the conversion system the lower is the net efficiency.

Recently in Oregon, the staff of the Governor's Office of Energy Research and Planning made a detailed study of the net efficiencies of several modes of electric power production including geothermal steam, mine-mouth coal, natural gas, oil, and nuclear fission. This study measured energy inputs at all steps of the cycle: exploration, development and exploitation of fuels, transportation systems, construction of power plants, and transmission of the electricity. Although this system is recognized as being imperfect because of the great number of variables involved, it puts the different cycles on a basis that can be compared. From these data two significant energy input factors have been quantified: first, the total energy input to achieve an output of 1000 Btu's of electricity; and second, the amount of fossil fuel as secondary inputs at various stages in the cycle to achieve this 1000 Btu's of electricity. Table 1, adopted from the Office of Energy Research and Planning studies, shows these relationships for coal, nuclear, and geothermal power systems. The relative high net efficiency of the coal plant shows why its use has been so widespread and why it will continue to be the major source of electricity for many years.

A factor little considered when all forms of fuel were thought to be abundant is illustrated in the amount of external fuel subsidy for each of the systems. This represents the direct energy inputs in the construction, mining, processing, and transportation to build and operate the three types of power plants. Here the simplicity of the geothermal system is apparent as it needs less than a tenth of the fossil fuel subsidy required by the more complex systems to produce electricity.

It is obvious from this study that the thermodynamic efficiency of the power plant is only one part of the cycle and that the complex high technology systems require substantial subsidies of fossil fuels in order to construct and operate them. Another point that has been illustrated by this study has been the high net efficiencies obtainable by the direct use of geothermal energy for space or process heating and of direct heating by utilizing solar collectors.

An understanding of the net efficiencies of the various methods of power production and conversion should cause a re-evaluation of the priorities for energy development which are presently dominated by the proponents of high technology. An example is Japan, where the 1974 research budget for development of geothermal and solar energy is 2.3 billion yen ($7 million) vs. a nuclear research budget of 67 billion yen ($230 million) (Mukaibo, 1974). Similar ratios exist in other "advanced" countries. If the energy crisis is to be solved, this ratio should be reversed.

HAZARDS TO THE PUBLIC

Equally cogent to a discussion of environmental effects is a consideration of hazards to the general public from accidents or unplanned incidents during some phase of the cycle associated with the various methods of electric power production. Every type of device utilized by man has at some time failed unexpectedly, many times causing widespread death and destruction. There is no need to list the number of dams that have washed out, bridges that have collapsed, boilers that have exploded, storage tanks that have burst, mines that have become death traps, and tankers that have collided. Every act in life and every machine contains a potential for failure and hazard to the user or bystander. This factor must be weighed and if the hazard to the public is great, even though the odds of a disaster are low, there should be no further development.

Again, the simplicity of the geothermal cycle limits the number of potential hazards—there is no mining, no transportation of inflammable or dangerous fluids, no wastes to be guarded. The maximum hazard from geothermal developments comes from well blow-outs or spillage of the brines. But to put the blow-out of a geothermal well into perspective, the fluid blowing out in a mitxure of steam and water—there is no fire hazard and the water pollution hazard is minimal. The unexpected blow-out of a geothermal well is hazardous to workmen on the rig but not to the general public.

CONCLUSIONS

The environmental impact of any power-production system is reflected in the number and complexity of the steps in the fuel and production cycle. Because geothermal power plants utilize the energy occurring naturally in geothermal fluids, they need no complex generating equipment or extensive mining, processing, storage, or transportation facilities as do other thermal power plants.

The energy captured from geothermal fluids, whether it is utilized directly for space or process heating or is converted to electrical power, will in effect cause an improvement in the environment to the extent that it displaces energy from other more polluting sources.

The use of geothermal energy has a long history of successful operation. Seventy years of operating experience at Larderello and 20 years at Wairakei have shown geothermal systems to be economically and environmentally successful. It is known that geothermal energy exists in vast quantities; its resources base is second only to solar energy. But how much geothermal energy is sufficiently concentrated to be utilized economically is not known, and can only be answered by serious exploration to locate and develop geothermal reservoirs. Delays and harassment are causing environmental degradation and rapid depletion of the world's store of valuable fossil fuels that should be used for purposes other than boiler feed. Geothermal energy could provide an important supplementary source of clean energy.

ENERGY CONSUMPTION AND NET EFFICIENCY

	Btu input for 1,000 Btu electric power output (293 watt-hours)					
	A. Primary resource	B. External resource	C. Total energy	Loss processing and conversion	Percent net efficiency (1,000 over C)	Percent external fuel subsidy (B over 1,000
Mine mouth coal	3,478	464	3,942	2,942	25.4	46.4
Nuclear fission	8,333	560	8,893	7,893	11.2	56.0
Geothermal steam	6,547	44	6,591	5,591	15.2	4.4

Source: Preliminary report by the Office of Energy Research and Planning, Governors Office, State of Oregon.

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STATEMENT OF DR. RICHARD G. BOWEN, ECONOMIC GEOLOGIST, DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, STATE OF OREGON

Chairwoman MINK. Dr. Bowen, it is my privilege to welcome you here this afternoon, and you may proceed in any manner that you would like, I might suggest that you summarize your paper, remembering that we are laymen and not scientists, and we would like at the conclusion of your summary to have an opportunity to ask questions which might relate to our interests.

So if you will proceed, we will appreciate it very much.

Dr. BOWEN. Thank you very much, Mrs. Mink. It is my privilege to discuss geothermal energy with you. This is a subject that has become of great interest in recent years, because of the realization that geothermal energy is a prime source of energy and can be utilized by man in many different ways. We are concerned about the environment—about the environmental effects of geothermal energy, and to appraise this, we should have more than just a listing of what the problems are. We have to have a listing of what the benefits from the development of geothermal energy is, and I sincerely believe that every energy source has its potential environmental impact. There is nothing that is free. We have to recognize this. Wherever there is an action, there is a reaction. We have to take this into effect. The thing about geothermal is its overall simplicity cuts down on the number of potential areas, where there may be environmental impact. The big difference on geothermal is it is localized at the site. It doesn't have the mining, the transportation, the expense of processing involved in other energy sources.

So this localization cuts down on the overall environmental impact. Another very important thing to consider, when we are considering the environmental impact from electric power production, is what are the hazards to the public from this? And also, what are the hazards to the workers from this? I believe that overall the hazard from geothermal is far less than it is from the other types of energy production. The specific insults, environmental insults related to geothermal energy production, the list is very long depending upon which experts you are talking to. If the expert happens to be with the Sierra Club or is very active in environmental things, then their list is noise, smell, intrusion into an area, potential to contaminate water. If the person, who is making the question, is from a technical field like utility, their usual questions are efficiency. Geothermal is believed to have a low efficiency, but I think I can point out to you that it has a high efficiency utilization. Other potential problems are the—one thing we hear very much about is the potential force subsidence from the production of fluid. Also, the reinjection of this fluid in the ground may cause—may trigger earthquakes. This has been discussed quite a bit, but I don't believe it is a problem of great importance. Earthquakes are of great importance, but the potential for geothermal development to trigger earthquakes, I believe, is very minor.

One of the other problems we hear very much of on geothermal is the air pollution problem, the hydrogen sulfide gas, with the steam associated with the geothermal production. Every geothermal area in the world has this hydrogen sulfide associated with it. It is actually

a very minor part, as a rule, of the gases. The important thing on the hydrogen sulfide is, when you consider per unit of power how much pollution from the geothermal, you get far less than from fossil fuel or even from nuclear fuel, when you consider the total cycle involved. Another possibility that is raised is climate modification. To make a geothermal powerplant run, you have to evaporate a lot of water to cool the steam after it goes through the turbine to get the maximum efficiency. This process of cooling the steam evaporates a great deal of water. Many of our energy resources, the development of our energy resources, are limited by the availability of water. Geothermal is an exception on this in that the development of geothermal energy produces its own cooling water.

When you find the steam, you have your cooling water and do not have to develop an auxiliary source of cooling water. The advantage in this is that if you have a thermal powerplant, whether it is cool power or whether it is nuclear power, this water that you have to use to cool the condenser is a competing use. Other—if this is agricultural water or if this is domestic water, this is industrial water, and water that is going to be used in other areas and going to be used to cool the condenser. With the geothermal, we have a geothermal steam. You condense that and you circulate that water back for your recooling power. I believe this is one of the most important single points on the development of geothermal energy is it brings water into the system that is not being utilized today and would not be utilized under normal conditions.

I believe the biggest single environmental problem with geothermal is possibly potential land use conflicts. Because geothermal is there, you can't decide you want to develop geothermal here, because this would be a nice place to put it. You have to accept where it is and develop it in that area. I feel that the way this—the only way this conflict is going to be resolved is that early in the game, we should specifically say that certain areas are too useful for other purposes than for the development of geothermal energy. Where we have high use recreation areas, then we just take that away and we do not plan on developing anything there.

Actually, geothermal energy, the environmental impact of geothermal energy is not as bad as I sometimes make it sound. For example, we have one city in Oregon that has a geothermal field right in the middle of it. You wouldn't know that you were in the middle of a geothermal field unless you happened to go into some of the homes and see the wells, where they were using this hot water from the geothermal field to heat their homes, businesses and schools within the city. So, this is a very important use, and if you see the pictures of, say, the geysers field like I will be showing here, this is only one type of geothermal field, but all geothermal fields don't look alike.

My first slide—

Mr. KAZEN. Pardon me, doctor. Could I ask you a question right there. You are talking about individual homes being heated from individual wells. This heat comes direct from the wells themselves? They have made their own powerplant?

Dr. BOWEN. They use the hot water that is down in the ground in these wells and they range in depth from a hundred feet to a thousand feet, and that is the way about five hundred homes and schools and

businesses are heated. In some cases they have individual home wells. In other cases four or five homeowners will go together and drill a joint well, and, generally, the businesses will have one well for the business, but this provides all the heating.

Mr. KAZEN. Is that in pipes throughout the house?

Dr. BOWEN. Yes. The water is circulated in these pipes. I will go into that in a little more detail.

Mr. KAZEN. I see.

Dr. BOWEN. If I could have the first slide, I will show whether they—this is a geyser geothermal steam field in northern California. This slide was given to me by a good friend, who is the Sierra Club representative to the Geothermal Resources Council in northern California, and it points out the intrusion that a geothermal development does make in an area. You have to build roads, you have to grade well sites, you have to build powerplants, you lay pipelines. No question, this is a noisy, smelly intrusion into what was once an isolated valley. Prior to becoming a geothermal field, it was used for grazing of cattle and for deer hunting.

Mr. KAZEN. Well, whom does it disturb, doctor?

Dr. BOWEN. It disturbs cattle, I guess, although not very much because the cattle are still there. But its presence, just the presence of something where somebody used to come here and go hunting and fishing, now this field is there and it has pretty well precluded the hunting and fishing activity. This is the kind of intrusion you cannot escape from. This is what geothermal does. The important thing is all the activities in the production of power is all right there. There are no mines. You don't have to process any fuels or wash any coal, transport anything. The steam flows out of the ground, flows into the powerplant. The electricity is produced. Most of the steam is evaporated in the cooling tower and a certain amount of it is returned. So, not only does it localize the environmental impact, but an extremely important factor is reliability.

It is not dependent upon somebody turning the key off in Saudi Arabia and saying, "We are not going to supply you with any oil." It is not dependent on railroad strikes. It is not dependent upon supplier strikes. Its overall simplicity adds greatly to its reliability.

Mr. KAZEN. Is there any residual that needs to be disposed of?

Dr. BOWEN. Yes. About 20 percent of the steam that comes out of the ground is evaporated and comes in—about 80 percent of the steam is evaporated. Twenty percent is left as a condensate. This condensate at the geyser is rejected back into this—through the producing reservoir and it has actually extended the life of the field because it goes back, is reheated, and comes to the surface again.

Mr. KAZEN. Do you force injection?

Dr. BOWEN. No, it is not necessary to force injection, because of the weight differentials of hot fluid and cold fluid. The cold fluid, when it is rejected, is a lot heavier than the hot stuff down in the field. So it supplants—so it supplaces it and goes to the bottom, where it is heated and recirculates again.

As you can see, this is a major industrialization of this area. During the development, you can't escape that, but after the construction of the field stabilizers, you go to a different period, and this slide shows the Larderello field in central Italy, where they have been producing

geothermal energy for 70 years now in this area, and I use this to illustrate the compatibility to other land uses to geothermal development. It does not displace other things; for example, the—the prime example is the mine. Well, that displaces other things for many years until it can be restored. I am sure you have heard a lot about this, but here the wells, the pipelines use only a small percentage of the land, of the geothermal area, and as you can see, there is a diversified agricultural economy with farms, orchards, and vineyards right in the geothermal field. This has been going on for 70 years. On an intense basis, for, maybe, 20 years back in this area geothermal production has been going on.

This is the other side of the hill from that last slide I showed you, showing the cooling towers of one of the plants at Larderello and, generally, how it again illustrates the compatibility with other land uses from geothermal development.

To understand how power is produced, we have to look beyond the powerplant and look at the entire cycle. Everybody is familiar with the coal mining cycle. You mine the coal, you transport it to the powerplant, sometimes thousands of miles and sometimes only a few thousand feet. You burn the coal there, and then you dispose of the waste material.

This slide illustrates some work done by the State of Oregon and its research and planning staff. I will spend a little time on this to show you how energy flows, and I am talking about the coal fire electrical mining mount plant in this case, and in order to get 1,000 Btu's of usable energy out of this part of the plant, these are the energy inputs that you have to make in that system in talking about the coal cycle. You have to start off with about 3,500 Btu's at the very beginning here, as the total amount of energy input at this point; and as you can see, you have energy input and exploration. Extraction, transportation, the cleaning and washing of the coal, the transportation, and then you have a large energy output at the conversion, where your coal is converted into electricity. This is your main point, where your energy is lost. Here you lose about almost twice as much as you get out of the end.

I have three slides here showing this for coal plants, geothermal plants, and nuclear plants. It is all normalized to a powerplant with the same transmission losses. So this shows the necessary energy inputs to get a given amount of electricity out of the ends here.

Now, a very important part of this and something that generally has not been considered in the past, but this group in Oregon has been doing it, is how many additional fossil fuel inputs are required to get this 1,000 Btu's of energy out the end. In addition to the coal, the 3,500 Btu's of coal here, there is also energy that goes in an exploration in each one of these steps. Energy in the form of coal, in the form of gasoline, in the form of natural gas, in the form of oil. They have summarized these energy inputs in this figure right here [indicating]. What they call this is external resource required to get this 1,000 Btu's of usable energy down here. It points out in different points in this cycle that it takes 206 Btu's of coal, 56 Btu's of natural gas, and about 200 Btu's of oil. So a total of extra energy subsidy of about 464 Btu's for 1,000 Btu's output. This gives an idea when you talk about efficiency, that there is more to it than just a powerplant.

I am sure everybody hears about efficiency of powerplants, but there are also other energy inputs, other energy losses, and extra energy inputs needed by the systems. This slide summarizes it. To discuss the geothermal system, the steam flows out of the ground at the wellhead here. It has a simple process—a simple centrifugal separator, where as the steam travels very rapidly coming out of the ground, it is expanding and it comes into this separator at very high speeds. The separator has a series of fixed vanes in there. The steam hits these fixed vanes, causing it to swirl; and as the steam comes out of the ground, it erodes. So this steam is carrying a small amount of finely divided rock particles, which you have to keep out of the turbine. This centrifugal separator causes these to thin out to the size, where they are rejected here at this point there. They fall down to the ground and are thrown out by a little bit of steam. From there it is directly connected to the powerplant, where the steam flows into the turbine through the condensers, to the cooling tower, where it is cooled. It circulates back into the condensers for more cooling, and the excess is rejected back into the producing reservoir. This is the entire geothermal system. It does not go beyond the bounds of the field. That, I feel, is a very important concept.

I have a few diagrams here of different types of geothermal systems that I will discuss very shortly. This is the kind that we are all looking for, but there probably isn't as much of this as of some of the others. This is the geothermal steam system and, again, the steam comes out of the ground, goes through the turbine, is condensed in a condenser and circulated to the cooling tower, where it is cooled. It circulates back and the excess is disposed of. This is the dry steam geothermal system.

The next geothermal system is the wet steam. The main thing here is a separator is necessary to separate out the—when I say wet steam, it is actually a mixture of very high temparture hot water and of steam. You make a separation here, take the steam out and run the steam through the system the same way as a normal geothermal powerplant. This is the system that exists in Wairakei, New Zealand. This is just the way it works. The extra problem that it has is its disposal of much larger amounts of the geothermal fluid. Having to dispose of larger amounts of geothermal fluid, there is question whether or not they can put this back in the reservoir without cooling. So, in New Zealand, they do not. They discard it into a nearby river.

Another system that we have been hearing quite a bit about and I am sure you are somewhat familiar with is the so-called binary fluid. This is by utilizing a heat exchanger and it transfers the energy from the geothermal fluid into a different type of fluid, where it in turn is expanded through the—expanded through the turbine. It is actually a double loop. This is the loop of the secondary fluid that goes through the turbine. This is the loop of the geothermal fluid. It is also reinjected there. These are the three types of geothermal systems that are most discussed right now.

This diagram shows the energy uses for geothermal steam electric system and how to get, again, 1,000 Btu of useful electricity out of the end. The total amount of energy input into the system, now, as you can see, for the geothermal system, to get this 1,000 Btu out, you have to reject a lot of waste heat through your energy input here. This is

in the form of geothermal steam. It is about 6½ times what you get out. But that has made up for other factors in that you don't have other losses in this system. You don't have all the transportation losses. You have the one major loss on waste heat, but most importantly on a geothermal development is this secondary energy input.

You will recall from the coal cycle, where it took about 416 Btu's of subsidiary energy to produce 1,000 Btu of—to deliver 1,000 Btu of electrical energy, the geothermal system does not require nearly as many subsidies as that does. As you can see, it takes about 14 Btu. This takes in the total amount of construction, the steel required for the pipelines, the steel required for the powerplant, the steel required for the drilling. They have analyzed the entire system. What is necessary to get to the powerplants. So, in producing that steel, you need a certain amount of coal, but to give you an idea here, it takes about 14.6 Btu of coal through this system, about 9 Btu of natural gas, and about 20 Btu of oil input to get this 1,000 Btu of electric energy output. As you can see, this is an order of magnitude differential energy input than the coal system. So, this conserves resources that we would utilize on the other—if we utilized coal and uranium resources.

This is a diagram in the steps of the supply of atomic fuel. I won't go into very much detail, but the idea of showing this slide is the complexity of the system necessary to get the uranium into this powerplant here at this point. First, you have to mine the uranium here and it is generally not understood just how much is involved. In order to keep this powerplant going for 1 year, using about 1,000 MW powerplant, which is the range most of the new ones are being built at, you have to mine at this point somewhere in the neighborhood of 120,000 to 150,000 tons of uranium ore per year. That has to go through all the steps. Milling, refinement, conversion, fabrication and then you wind up with something like 30 tons left over, but you have to start over here with a very large amount of mining and then all of these other steps.

So, what I am trying to point out in all of my lectures here is that when you are looking at a powerplant, you have to look beyond that to see really what the environmental impact is. There is a lot more to it than the powerplants. This is only a very small part of it except on the geothermal. On the geothermal, when you see a powerplant, you see almost the whole thing. But, in general, on the geothermal powerplants, you do have a larger impact at that site than you do from a nuclear powerplant. A nuclear powerplant is a nice, clean thing. There is no smoke coming out of it, but when you look beyond this, then you see these other steps that are not necessary in the geothermal system.

Of course, after the fuel comes out of the powerplant, it goes into reprocessing and the waste storage facilities necessary. This diagram shows the number of energy steps necessary, again, to get a thousand Btu's of usable electrical energy out the end. Also, the amount of fossil fuel subsidies required to get this 1,000 Btu's. You start off with about 8,000 Btu's of uranium energy here and then you process that. You have a major loss of the gaseous diffusion plant and then you have several losses at the conversion stage before you wind up with this, but very importantly are these numbers here, the fossil fuel subsidy to keep that plant going, and there is a major amount of energy

inputs. Here it takes 435 Btu's of coal. About 70 Btu's of natural gas, and 65 Btu's of oil for each 1,000 Btu's of electricity, for a total subsidy of 560 Btu's.

I have summarized those numbers on this slide and to recapitulate showing the mining mouth's coal plant, you start off with about 4,500 Btu's of coal. It requires an external resource of 464 Btu's here giving you 392 and you have a total loss of 2,900 Btu's to get a net efficiency of the cycle. Dividing 1,000 into this loss, you come up with a total net efficiency of about 25.4 percent. Very importantly is that 46.4 percent of that energy is a fossil fuel subsidy. Nuclear fission, you can see the numbers there. The net efficiency is quite a bit lower than the coal, because of the number of processing steps, the number of energy inputs at those processing steps and the external fuel subsidies, as you can see, is 56 percent.

Geothermal, because of its lower temperature, low pressures, you do have to make more of the geothermal steam at the beginning to get your given amount of power out. You have a net efficiency of somewhere in the neighborhood of 15 percent, but your external subsidy is one-tenth of what it is on the other fuel sources.

Now, these numbers were worked out by a group at the Governor's office in the State of Oregon. They are not perfect. Nothing in this life is perfect, as we all well recognize, but there are ranges of about what the energy inputs are. One thing they have not been able to do, they have not been able to get a handle on what is the energy input required to maintain the nuclear waste for a long period of time. So, that is not in these calculations. The AEC has not developed a definite system that they are going to be using. You can't quantify it until it is spelled out what it is. That is why that particular point is not in there.

This is another example of a geothermal field. This is Climate Falls, Oreg. In this zone right here, there are in the neighborhood of 500 geothermal wells. By geothermal wells, it isn't what you normally think of. Many of these are individual home wells drilled from 85 feet to 1,500 feet in depth. They produce hot water at temperatures of 140° to 212°. It heats a large part of Climate Falls. It heats about eight or nine schools and it heats one large college campus. This campus right here, the Oregon Institute of Technology, gets all of its heat from one hot water well and with the rising price of natural gas, oil, that has become a very important factor.

I believe there is potential in many other areas in the West, where this type of energy could be utilized. I think of people thinking of geothermal energy, they usually think of the production of electricity, but very possibly this kind of use is going to be just as important as the production of electricity 20 years from now. We need to look for other substitutes, perhaps of valuable fossil fuels, and we need to look to renewable energy sources such as geothermal and solar.

For this committee's hearings, I just put in a little bit more than the work that the staff on energy research and planning has been doing on energy uses. I thought you might be interested in this solar-heated home. This is a study of an actual home in Coos Bay, Oreg., which is on the Oregon coast. If any of you have ever been to the Oregon coast, you realize that if solar energy works there, it will work any place in the world. They just don't get any sunshine there. It has something like 300 days of clouds in this particular area, but there is

still enough radiation coming through. This particular home is able to utilize solar energy for about 80 to 85 percent of its house heating and for its heating of domestic water.

Mr. VIGORITO. Coming right through the clouds?

Dr. BOWEN. Yes. It comes through the clouds. What they have is a series of solar collectors, pipes, with water in them on the roof. This absorbs the heat and they circulate it down into the house. It works very well.

Putting this on the same basis as the other energy diagrams that I showed you, because of the loss of transfer of that solar energy hitting the collectors, you have to put in about 3,333 Btu's to get 1,000 Btu's out the end. Most of that is lost at that point. You have an efficiency, maybe of one-third, but again very importantly there is the external resource required and what is calculated in here is the logging of the lumber to build the house. Excuse me, they didn't go into the house but into the system. The well, the storage tanks, the solar collectors and it took an overall energy input to construct this system off about 170 Btu's for this 1,000 Btu's out.

Mr. KAZEN. A one-time expenditure?

Dr. BOWEN. This is a one-time expenditure, yes.

This is another diagram of this same type. This shows the Reykjavik, Iceland, geothermal heating system. The city of Reykjavik, as I am sure many of you are familiar, is heated with geothermal energy, and they did a study of that, and it shows the high efficiency obtainable by direct use. For 1,000 Btu's out the end, the total input here of hot water is only about 1,250 Btu's. So, you have extremely high efficiency. The total input of external energy resources for this 1,000 Btu's is only about 109 Btu's, so it would have a very low subsidy in comparison, for example, to electric heating or any other forms. This is an existing system. That is the city of Reykjavik, Iceland.

Those are all of my slides. I just wanted to summarize and emphasize this factor that in the development of any energy resource, what is the hazard to the person on the job developing this energy resource, what is the hazard to the general public. Somehow this is a very difficult question that will have to be answered by the people in general. It will have to be answered by our legislatures on their priorities. I won't go into the number of dams that have failed. Hydroelectric power is—we are very proud of our hydroelectric power in the States of Oregon and Washington. We are also aware that around the world a lot of dams have failed. So, there is a potential for hazard from hydroelectric. From oil we know the tankers collide. Wells blow up. From nuclear power, we hear about the potential hazards there of many ways. With geothermal, the only real hazard is in case a well blows up. If a well blows out and you are sitting on it, it would be very uncomfortable and dangerous, but it is not a hazard to the general public.

One of the best known blowouts in the United States is Old Faithful in Yellowstone. It blows out every hour. This is essentially what a geothermal blowout is. It is steam, gas, water coming out of the ground. If it does happen and it has happened in every geothermal field in the world at one time or another. They get these blowouts. You can contain these in various ways and generally, they can be stopped. Now, there is one still blowing at the geysers, which you may

be aware of, that has been erupting since 1957. It is a waste of a lot of energy, but it is no hazard to the public. Nobody has ever been burned by it. Nobody has ever been hurt by this blowout in the geothermal field. So, that is another thing that has to be considered.

Mr. KAZEN. How do they contain a blowout for these individual homes? What happens if there should be a blowout in one of those wells?

Dr. BOWEN. They are generally at such low temperatures that the only time they blow out—they do often on the drilling—but really there is not any hazard. The well drillers know this is going to happen and you can kill it with cold water. So, all you have to do to kill a blowout is take a hose and pump cold water. That causes the steam to condense and the whole thing collapses. This happens, oh, every once in a while, when they are drilling at Climate Falls, but it is never—it rarely gets serious. It just really is not a problem.

Mr. KAZEN. What about base subsidence?

Dr. BOWEN. Subsidence will be a problem in some types of geological environments. In the dry steam fields of Larderello of the geysers, you are producing this fluid out of a rock. If you think of rock as being solid and the steam is contained in cracks in that rock, so when you produce that steam out of there, because the rock is solid, it does not collapse. The other type of field, where you make it subsidence, is in the Imperial Valley, for example, where you are producing out of a sedimentary reservoir and the water in that field is actually adding to the strength of the rock. You remove that water and you get the subsidence.

We really have a lot of experience in subsidence in the petroleum industry and they have learned how to handle this. Actually, most subsidence comes from the shallow production of ground waters. For example, in the San Joachim Valley in southern California in the flush of ground waters, it has subsided up to 35 feet in some places. It is the shallow water that causes subsidence.

Going to geothermal, in some cases, you will get subsidence. If it looks like it is going to happen, you can probably compensate for it by reinjection of the water. In many areas of the western United States, subsidence wouldn't make any difference. In eastern Oregon, if the ground went down in some cases 10 feet, nobody would ever have any idea, because the only thing there is grazing and this kind of thing. Where subsidence is a problem is where—the Imperial Valley, where you have this extensive irrigation district. Then you just can't live with subsidence. In other areas you can live with it.

Another thing that you might consider on subsidence is how much subsidence do you get from the mining of coal? That is another thing that is part of the coal cycle. How much subsidence winds up from that uranium mine that is drilled out? You get subsidence from all of these things, and geothermal subsidence is only one part of it. Also you get subsidence when you produce water, cooling water for a nuclear plant or for any other type of thermal powerplant. There is more of a potential for subsidence in the production of cooling water if they utilize ground water than there is from a geothermal field.

Yes, sir?

Mr. BURTON. Would you spend a few minutes on the utilization of the water in these various energy-producing mechanisms as you

have used Btu measurements. Have there been studies as to what is the—for the lack of a better way to put it, the ongoing amount of water necessary for fossil fuel energy, nuclear energy, and other kinds of energy? Oil shale, for example.

Dr. BOWEN. There have been studies of specific points of the cycle. On nuclear powerplants, there has been a study of the water usage at the powerplant, which uses—to give you some comparisons, the water evaporated in the cooling tower from a 1,000 megawatt nuclear plant is about 25,000 acre-feet a year. In a coal plant the same size, at the powerplant it evaporates at about 15,000 acre-feet per year. In a geothermal plant the same size, it evaporates at about 40,000 acre-feet per year. That is 15,000, 25,000, 40,000. The geothermal does evaporate more water than other powerplants, but let me point out that one, geothermal does not use water in other steps of the cycle; and two, geothermal water is produced as the geothermal fluid, so it does not compete with other water uses.

Mr. BURTON. We have been led to believe, or I have been led to believe by some opinion that is presumably well informed, that in moving ahead with this energy field, and oil shale has been particularly brought to my attention, we may be having to make an absolute trade-off of water needed for agricultural purposes, or for the purposes of those of us living in cities as we normally use it, for the development and production of energy. I would like to have you walk around that a little bit for me.

Dr. BOWEN. I am convinced that this is true. That these high technology systems such as home conversion, such as oil shale, require tremendous water inputs at the point, where you convert. Oil shale to whatever it is converted to—to oil or coal, when you convert that coal to natural gas or to coal gas, there are large water requirements at those points in addition to the water requirements at the powerplants. So the general consensus, I believe, of scientific opinion, and maybe I shouldn't speak for—I can't speak for science in general, but it has been pointed out that, for example, the Rocky Mountain coal, you can decide what you want to do. You can mine the coal. There is enough water for that, and probably rehabilitate the land, but you cannot mine the coal, rehabilitate the land, produce the power, and make any coal gas quotation for those sites. You can do one of these things, but you can't do two or three. There is just not enough water. And I am sure it is the same for shale oil. Any of these high technology systems just require large amounts of water input for various steps of cooling along the way. Does that answer your—give you my idea of what your question was, Mr. Burton?

Chairwoman MINK. Could I expand on that? Have there been any studies similar to this which you have produced showing Btu's vis-a-vis energy consumption in its production of 1,000 Btu's. Relating that to the consumption of water in specific area sites? Is there any study that we could have the benefit of reviewing? Just exactly the quantity of water required for each type of production at various locales, realizing, of course, that the requirements would be different at different sites, but I think that would be interesting to see what the water demands are. One of the big questions that we have had to face, in the whole examination of our national coal leasing policy, is the demand for water. Each of the development proposals that have been sug-

gested, we have had to counterbalance that with the demand for water in that basin for agriculture and for other human requirements. This is something that has been of overriding concern to us. In considering the environmental impact, I would assume that before a geothermal plant was actually authorized, particularly if it was sited in Federal land, there would have to be an evaluation, a geologic evaluation, of the relative value of going geothermal or coal or oil shale or whatever it might be, vis-a-vis water. That is our interest in trying to evaluate the different systems.

Dr. BOWEN. The only study that I am aware of and you may be also is the AEC about 2 years ago did a study of water in the nuclear fuel site, where it talks about the amount of water required in the mining. The water required in the milling and the various steps in the nuclear cycle. This is the only report that relates to this that I am aware of.

Mr. BURTON. We are in the process of weighing a realinement of the House of Representatives' committee jurisdictions, and one of the primary bases of our concern about placing all the energy and environment matters in the same monolithic committee was the question of whether we will find that water use, particularly in all the West, will be the tail on the dog of energy development. We didn't just suddenly wake up and find ourselves almost out of business in terms of putting water to agricultural use, and now there is the possible dramatic negative impact on the industrial and urban use as well. It was for this reason that I wanted to raise the question, because I only have the vaguest kind of feeling. It is quite important, and I have not been able to particularize it well in my mind.

Mr. KAZEN. This is true in areas where water is very scarce and the question is, is it worth the expenditure of whatever amounts of water you have for the ultimate production of x number of British thermal units? Which is more important at the final end, and considering everything else along the way, environmental impact and everything else.

Dr. BOWEN. But who is going to make the decision how this resource is going to be distributed? This is the question.

Mr. KAZEN. Well, I think in line with what my colleagues have brought out, we need to have that type of study and the input of that precious water fuel, because I know down in my area, in Texas, water is more valuable than oil. We can always get power one way or the other and life goes on, but if we don't have water, that—water is life.

Dr. BOWEN. What you have to think about on geothermal water is that this is deep water. Like at the geysers, it is 9,000 feet.

Mr. KAZEN. Yes, I understand the geothermal process as you have discussed it. We were just wondering what input in the other types of energy producing systems, how much water production would be needed there?

Dr. BOWEN. Well, in the environmental survey put out by the Interior Department a couple of years ago, they pointed out that although the—they compared the geothermal with nuclear and coal. The geothermal evaporated more water at the cooling tower, at the tower plant than the others did, because it did not make use of water in other parts of the cycle. It appears to be less consumptive use of water in the geothermal system than from nuclear or coal systems.

Mr. KAZEN. Yes, but that water was not available for any other purpose except it is inherent in itself——

Dr. BOWEN. Yes.

Mr. KAZEN [continuing]. In the process itself. You are not using water from other purposes, taking it away from other uses to produce this kind of power.

Dr. BOWEN. This is the benefit of geothermal——

Mr. KAZEN. That's right.

Dr. BOWEN [continuing]. It is new water that would not be utilized otherwise. It does not take water that is concurrently being used for industrial or agricultural uses.

Chairwoman MINK. Can I take issue on that?

Dr. BOWEN. Yes.

Chairwoman MINK. That statement bothers me, because it seems to me that in whatever form water exists whether in the form of simple heat or steam or whatever, this provides a hydrologic source of water in some form, and if you take it out in whatever form you take it out. Do you not then diminish almost as a matter of logic, diminish the resource, and does that in some way not affect the ability of that area to utilize the water in some other form, because of the removal of hydrothermal steam?

Dr. BOWEN. You have to consider this geothermal steam and its hydrothermal water down there; it generally, in most areas, it is going to be as a brine, highly salient waters, and it would not be useable for normal purposes. It may be utilized for special purposes. So, this—in general the quality—this is not always the case—in Climate Falls, our geothermal you can drink, but I think this is going to be the exception. In most areas of the world——

Chairwoman MINK. Does the extraction of that have any relevance whatsoever in the ground water supply that is utilized for other purposes, drinking, industrial, and so forth in the area?

Dr. BOWEN. I am sure it does, but you put it into geological perspective. In the perspective of geological time. In the hundreds and thousands and millions of years it takes water to migrate. It migrates very slowly. So, water taken for industrial, residential use up at this horizon here doesn't have much effect. Now, it is going to have some effect if you produce water down here. For example, in Texas, they extensively produce oil from this area here. Going through these water zones, these very heavily used water zones up here, case them off, and have—I won't say they have no effect. They have some effect. Everything we do has some effect, but the effect is minor. There is a certain amount of draw—as you lower the pressure of this down here, there is a certain amount of draw down causing that over long periods of time to move down. But the question is, is this moving source—we are getting down here—worth this draw down here [indicating]? It is a matter of trace. So, we have to——

Chairwoman MINK. In Klamath Falls, for instance, how long will that supply last to provide heat for that particular school building for the children?

Dr. BOWEN. The heat will last for thousands of years. The life of the geothermal field is dependent upon the amount of water. If they utilize this; now, they are utilizing what is called Downey cold heat exchang-

ers. In using a heat exchanger, they do not take the water out of the ground. In most of the Climate Falls utilizations, they put pipes down into this hot water well, circulate the domestic water down, and it works just like your hot water radiator. The heat is sent down here. It rises to the radiator, it is cooled and sinks again. It is just a system like this. So, they are not removing—in 90 percent of the wells, they are not removing any water. So, this makes a very long-life system. Now, what would happen if everybody was pumping this water out and wasting it, the water level would go down. The heat would still be there, but people would have to deepen their wells to get something useful. This is the kind of thing we learned.

Chairwoman MINK. What numbers of people in the United States could be serviced by geothermal heat in this method that you have just described?

Dr. BOWEN. Five or ten percent maybe. Something like this. But I think the important thing here, Mrs. Mink,——

Chairwoman MINK. They are all in California?

Dr. BOWEN. They are all in California, Oregon, Washington, and Nevada.

Mr. BURTON. Hawaii and the Big Island.

Chairwoman MINK. We hear that hydroenergy—to give you an example, hydroelectric power provides about 6 percent of the electric power in the United States, which is not very important, but in Oregon and Washington, it provides 90 percent of the power. So, it is very important there. This is the way—the position that geothermal will be in. In these areas, where the geothermal energy is utilized, it will be very important. In other areas it won't be.

Mr. BURTON. I believe it was 2 or 3 years ago we changed the bidding procedure on public lands. I had doubts and questions about the change but I didn't have time to pursue it. Can you tell us—do you have any critical views of our current bidding procedures? Who is permitted to bid and the terms of the bids? Do we find that our bidding arrangements are structured in a manner that gives those who control most of the energy resources of our country a tilt, if you will, a favorable tilt in the bidding from this geothermal——

Dr. BOWEN. Unfortunately what has happened, the Federal Government in an effort to maximize the resource for geothermal development has added charges and put this bidding all the way through. Everything you do, you have to pay a large amount of money to get in to play the game.

Mr. BURTON. In other words, it is a cash bid and not, for lack of a better word, a royalty arrangement?

Dr. BOWEN. It is a front end thing. You have to put all the money up at the beginning before you can get started. This, unfortunately, is—the only ones that have this money are the present people in the area. In many ways it has closed off the independent——

Mr. BURTON. Well, for example, do you have any source documents that you can recommend that we look to? Do you happen to recall which particular business organizations have tended to dominate this bidding arrangement?

Dr. BOWEN. Well, you can look at the bidding at the Federal lands on the geysers. It was the major oil companies that dominated, because they could afford to do it, where the others couldn't. That is the way

the game is structured. Unfortunately, and even in the State agencies, it moved that way by adding on all these charges. The only ones that can pay the charges are the major oil companies. It doesn't affect them. They are happy to pay it, because they know it squeezes independents out, which I think is a real mistake.

Mr. KAZEN. Doctor, what are the economics of the geothermal development? Isn't it capital intensive?

Dr. BOWEN. It is capital intensive, but the amounts of capital for geothermal are, when you compare it—I have been keeping track for the last several years of clippings in the Wall Street Journal what it costs to build a powerplant for nuclear, for coal, for geothermal. Using the example of the geysers in California, they are putting up powerplants now for about $135 per kilowatt of installed capacity. This is a capital investment in the powerplant.

Mr. KAZEN. How much?

Dr. BOWEN. $135 per kilowatt. If it is a thousand kilowatt plant, it would be $135 million dollars. Excuse me, if it is a million kilowatt plant, it would be $135 million dollars it would cost comparably for that size geothermal powerplant. Now, let me point out that they are not building geothermal plants that big. They are building them in smaller units. So, I have converted this into dollar per kilowatt of capacity and compared it on that basis. Using coal with the requirements for pollution control on coal, your costs there are running around $300 to $350 per kilowatt capacity. Your nuclear plants, just for the powerplants alone, are now costing $500 to $700 per kilowatt capacity. A million kilowatt nuclear plant costs from $600 to $700 million. So, it is about three to four times as much as for geothermal.

Now, the reason for that is with the geothermal plant, you don't have to build the fuel handling and you don't have to build the boiler. Your boiler reactor system is the most expensive part of the nuclear powerplant. You use nature's own boiler, where with the other types you have to build your boiler. That is why they cost so much.

Mr. KAZEN. Just one more question.

In existing geothermal plants, is the electricity produced utilized as baseload power or peaking power?

Dr. BOWEN. Baseload power.

Mr. KAZEN. Baseload power exclusively?

Dr. BOWEN. Baseload power exclusively.

Mr. KAZEN. Thank you.

Dr. BOWEN. Certainly.

Mr. BURTON. If you had to name two or three outstanding public interest people in this geothermal field including, if you can, those who have some technical expertise in the area of the bidding practices, who would they be?

Dr. BOWEN. Joseph Aidlin.

Mr. KAZEN. How do you spell that name?

Dr. BOWEN. A-I-D-L-I-N.

Mr. BURTON. Where does he work?

Dr. BOWEN. He is an attorney in Los Angeles. He is the attorney for the Magma Power Co. Magma Power is the developer of the geyser—they are the discoverers and the developers of the geyser field. They are small, independent and have been involved in this since it started in the United States.

Another one is Sammy Eisenstad.

Mr. BURTON. How do you spell that?

Dr. BOWEN. E-I-S-E-N-S-T-A-D. I can give you the spelling of that. I can send it in, if you would like.

Mr. BURTON. That would be useful. Where does he work?

Dr. BOWEN. In New York City. He is a lawyer in New York City and has been writing articles on geothermal taxation and geothermal ownership questions. He sees this happening. Those are the only two that I can think of right now that are working on this particular problem. Perhaps Dr. Shupe can be of help.

Dr. SHUPE. Dave Anderson is the one in the State of California who is extremely knowledgeable, particularly on the licensing on this.

Mr. BURTON. You passed over the problem of the energy expense for the nuclear waste phase of the nuclear energy area. Will you expand on that? Tell us what is the state of the art, and do we also have a water expense in addition to an energy expense? Additionally, what source material might we look at, if any? What questions should we keep in mind in terms of regulating the siting of nuclear waste disposal as it relates either to the more commonly feared radiation and energy and water utilization?

Dr. BOWEN. Your question, Mr. Burton, is very difficult to answer because the AEC has not come up with a method they feel is long-term disposal. They are just using short-term disposal. Short-term disposal as being used today, for example, at Hanford, Wash., where they put it in tanks and transfer the tanks every 20 years or something like that. This has a major effect on ground water, because those tanks leak. Maybe it isn't going to hurt you or me, but that stuff is leaking all the time, and is getting down there further and as more leaks happen, it just continues to work down and sooner or later this is going to start affecting the ground water in that area. Maybe in 10 years, maybe in 200 years. This is one way it is being affected—where it is being permitted today.

Another thing is these nuclear wastes have to be cooled; and possibly in the process of cooling, they are going to require water for evaporation. This is an extremely difficult technology, and I don't really feel capable of going into it very much.

Chairwoman MINK. If my colleague will yield, do you generally agree with the statement that was issued by a group of atomic scientists who met over the weekend, I believe, in Chicago, where they issued a statement saying that in their opinion, doomsday was much closer as a result of our rather negligent policy in dealing with nuclear energy and nuclear waste materials?

Dr. BOWEN. I would ascribe to that conclusion also; yes.

Chairwoman MINK. So it would seem, then, the real responsibility of this committee in looking for so-called clean energy sources is extremely urgent?

Dr. BOWEN. I believe so and renewable energy resources such as geothermal and solar. I have one other thing I wanted to mention in my talk, which is the funding. How funding is going. Not only in the United States. For example, in Japan, I think their funding for development of nuclear energy is something like 60 times what their funding is for geothermal and solar energy. This is repeated in so-called developed countries. They are all doing this, going big

into nuclear and forgetting about these other things. I am sure you are well aware that the reason for this is because of the tremendous vested interest, the tremendous number of people who are employed by this system. With geothermal and with solar, the only people that are employed are a few hippies that are building the solar collectors and a few nuts that are trying to push geothermal. There just is not the bulk of people doing this.

Chairwoman MINK. What percentage of our geothermal energy is now developed, would you say? How far along are we? One percent?

Dr. BOWEN. No.

Chairwoman MINK. Not even 1 percent?

Dr. BOWEN. One-hundredth of 1 percent.

Chairman MINK. One-hundredth of 1 percent. What kind of monetary investment do you feel is necessary in order to bring this up to a realistic development stage in the next 10 years?

Dr. BOWEN. I believe something like, maybe, Mr. McCormick's bill, where he has a $50 million a year on geothermal and I believe $50 million a year on solar on the loan fund, and on the direct aid to municipalities, for cities, and so forth that want to set up geothermal. Plus the funding in the NSF, and I am not sure of the level, but I believe that you can only put so much money in at a time. You can't absorb too much efficiently. We are getting to the point now, where we are starting—where they are getting a lot of—what is going on today in geothermal is a lot of intelligent people are coming from other areas that have not been through geothermal at all, and they are seeing different applications than those of us who have been talking about this for years have not seen yet. I believe this is very important. If it will broaden the scope of the utilization, and in broadening the scope of utilization, it is going to cut down on the amount of oil, electricity, and nuclear power in other areas.

Chairwoman MINK. Which countries in the world have done the most in the area?

Dr. BOWEN. Italy has been the leader almost unrecognized in the United States, but they have done an excellent job for 70 years now. Next is New Zealand and then probably the United States. And Japan. Japan is very—is active on geothermal development but not——

Mr. KAZEN. Why is it that we have been so slow in the United States?

Dr. BOWEN. Because we have had an unlimited amount of coal. We have had an unlimited amount of oil and natural gas. Geothermal energy was way out there someplace, so why bother when we could mine the coal here, move it into town, burn it, get the electricity at the load center. Now, that has changed. You can't mine the coal out here, take it into New York City, and burn it at the load center. So that has completely changed the economics of electric power production. This is what has made geothermal attractive.

Mr. KAZEN. Is it also a fact that geothermal fields are so isolated, so that fewer people will benefit from it?

Dr. BOWEN. In comparison to energy needs, you can talk about nuclear power that is providing less useful energy than the burning of wood in the United States. Look how much money we funnel into that.

Mr. KAZEN. But you can see at the end in the future a lot more utilization of that type of power than you would geothermal, wouldn't you?

Dr. BOWEN. You can see it if everything works right. If something fails along the way, then you can see disaster down at the end. That is what I see. This geothermal, if something fails, well, it really doesn't matter. It may be a waste, but we are not going to wipe out the operation.

Chairwoman MINK. I have one final question. You mentioned weather modification being associated with the evaporation of waste steam. Has there been any study to determine that this represents a serious local hazard?

Dr. BOWEN. There hasn't been any study in this, and I think this is an area, where there should be studies, and where I am convinced, Mrs. Mink, that this is important not only on geothermal power, but every sort of cooling power evaporates a lot of water, and a lot of people are saying, "Well, this will have local effects." But there is another effect you have to consider in that these cooling towers are located, for example, along the Pacific coast, in the belt of high rainfall. This belt of high rainfall, high utilization, where this is taking place. All of our activities, our building of cities, our farming, our mining, our logging industry takes away evaporation transpiration and makes runoff. Surface runoff. So, what civilization, the building of civilization has done, it has cut down the amount of water evaporated and directed runoff into the ocean and rivers. It is not being utilized. So, I feel that somebody should look into the beneficial effects of evaporating large amounts of water in various types of cooling downwind. For example, are we in our increased industrialization and logging of the Pacific coast, are we robbing water from the Rocky Mountains in the Midwest? That water is not being evaporated. It goes straight into the ocean. I think this is something that should be considered on all sorts of——

Chairwoman MINK. There are no studies that you know of?

Dr. BOWEN. I have never seen anything like that.

Chairwoman MINK. What about the matter of reinjecting the fluid and the possibility of triggering earthquakes? Are there studies on this?

Dr. BOWEN. Yes. The Geological Survey has been doing a study for about the last 4 or 5 years on injection in oil fields, and it is essentially the same system. You remove the fluid and you replace it with another fluid. What they found is—and they have correlated this very well—that as they pump this water back down in the ground, they increase the earthquakes. This was known to happen in Colorado with the Rocky Mountain Arsenal. They pumped this down there. And it does happen when you inject under high pressure. This is where geothermal is different. Geothermal will return water down there and you are using very low pressure. The unique thing about geothermal is because of the high temperature and the thermal dynamic properties down in the ground, your pressures are very low. So when you put that water back into the field, you are only returning it and you are not overpressuring. So, triggering earthquakes from the injection of fluid is a problem if you don't understand the geology of the area and if you run at high pressure. If you run at low pressure, then it is not

a problem. They have actually started and stopped earthquakes in the range of the oil fields by varying the pressure of the pumps.

Chairwoman MINK. Well, we thank you very much, Dr. Bowen, for your very, very interesting contribution to our knowledge and understanding of this matter of geothermal energy. Thank you. We appreciate very much your willingness to come to this hearing.

Our next participant this afternoon is Dean John W. Shupe, who is the project director of the Hawaii Geothermal Project. He serves also as dean of the College of Engineering at the University of Hawaii. Dr. Yuen accompanies him. Dr. Yuen is the associate dean of the College of Engineering. We welcome you, Dr. Shupe and Dr. Yuen to these hearings. Would you like me to offer this summary for the record?

Dean SHUPE. Yes. Most of what I have to say will be based on that, Mrs. Mink.

Chairwoman MINK. The material entitled The Hawaii Geothermal Project, Overview of Phases I and II, August 27, 1974, will be inserted in the record at this point without objection. Dean Shupe, you may proceed in any way you wish.

[The material follows:]

THE HAWAII GEOTHERMAL PROJECT

OVERVIEW OF PHASES I AND II, AUGUST 27, 1974

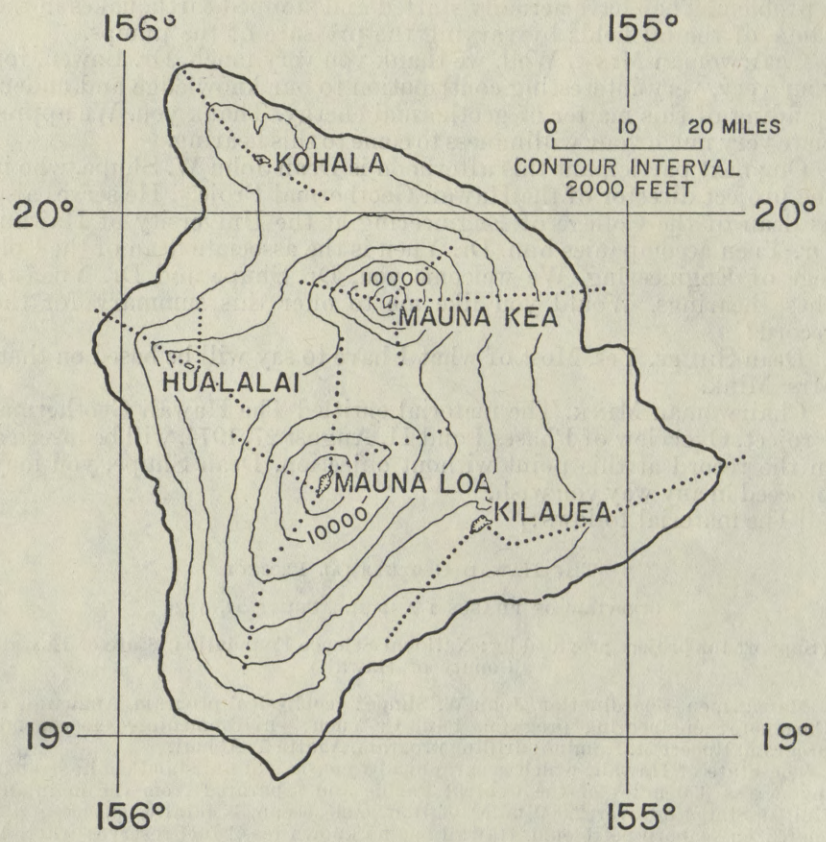
(Support for project provided by: National Science Foundation, State of Hawaii, County of Hawaii)

Management-Coordination, John W. Shupe; geophysical program, Augustine S. Furumoto; engineering program, Paul C. Yuen; environmental-socioeconomic program, Robert M. Kamins; drilling program, Agatin T. Abbott.

The State of Hawaii, which geographically consists of an island chain stretching across 350 miles of the Central Pacific and separated from the mainland United States by over 2,000 miles of that same ocean, is totally dependent for energy on seaborn petroleum. Hawaii has no known fossil fuel reserves; there is no coal coming into the State by rail; no natural gas by pipeline; and no regional electric grid to interconnect its electrical systems with those of other states or even with its separate islands. This complete lack of flexibility makes Hawaii particularly vulnerable to dislocations in the global energy market resulting from real or imagined shortages of petroleum. This is a travesty, since the State is generally endowed with a variety and abundance of natural energy resources: geothermal, solar radiation, ocean temperature differential, wind, waves, and ocean current—all potential non-polluting power sources.

The candidate from among these natural energy sources which shows the highest promise for early power generation at commercial levels is geothermal energy. In Hawaii there is an interesting variety of subsurface heat anomalies which may exist as: (1) molten magma, (2) hot dense rock, (3) hot porous rock, (4) geothermal steam, and (5) hot water. Any or all of these sources may occur in the proximity of 40°F deep-ocean water, adding to the flexibility in developing effective energy systems.

The Hawaii Geothermal Project (HGP) was organized to focus the resources of the University, the State, and the County of Hawaii on the identification, generation, and utilization of geothermal energy on the Big Island of Hawaii. Figure 1 shows the five volcanoes which form this largest island in the Hawaiian chain. Hawaii is also the youngest of the islands and is still experiencing growth from recent activity of the Mauna Loa and Kilauea volcanoes. Consequently, the Big Island was selected as the obvious site for initial geothermal exploration, but subsequent surveys will proceed up the island chain.



VOLCANOES & RIFT ZONES ON THE ISLAND OF HAWAII

FIGURE 1

The research program as developed by the HGP involves an interdisciplinary team of researchers from throughout the University system, which conduct scientific investigations on short-range exploratory and applied technology tasks to assist in the early development of any conventional geothermal resource—steam or hot water—that may exist on the Big Island, as well as long-range research studies of a more basic nature. The immediate goals and objectives of the HGP, many of which will contribute to the technology base for the recovery of energy from subsurface heat, no matter where it occurs, include:

(1) Improvement of geophysical survey techniques for locating underground heat resources.

(2) Experimentation with deep-drilling techniques for verifying and exploiting subsurface heat.

(3) Development of efficient, environmentally clean systems for conversion of underground heat resources to useful energy.

(4) Completion of socioeconomic and legal studies to assist in land use regulations and resource utilization.

(5) Establishment of environmental base lines with which to monitor subsequent geothermal development.

(6) Identification of potential geothermal resources, initially on the Big Island, but ultimately for the entire island chain.

(7) Development of a geothermal production field and prototype power plant on the Big Island, which will serve as a National Geothermal Energy Laboratory on technological development in power production and reservoir management of earth heat resources.

A long-range objective of the HGP is to develop techniques, materials, and components for the recovery of useful energy from molten magma. The nature of the basaltic lava flows on the Big Island make this an ideal location for the study of power generation from magma.

The HGP came into being when the 1972 Hawaii State Legislature allocated $200,000 for geothermal research—$100,000 to be administered through the County of Hawaii budget. This action was taken prior to the energy crisis and was a progressive step for a state governing body to take. Total support for the HGP through December 31, 1974, is as follows:

National Science Foundation (fiscal year 1973)	$252,000
Research applied to national needs (fiscal year 1974)	216,600
(Fiscal year 1975 committed)	118,700
State of Hawaii (fiscal year 1972)	100,000
(Fiscal year 1974 appropriated)	500,000
County of Hawaii (fiscal year 1972)	100,000
Other public and private funds	39,000
Total	1,326,300

Except for the $500,000 appropriated by the 1974 State Legislature for exploratory geothermal drilling—contingent on additional federal matching funds for a research drilling program—essentially all of the above funds will be expended by the end of this calendar year on completing Phase I of the project.

Phase I was organized into three separate programs, encompassing the following research tasks:

Geophysical program:
- Photogeologic (Infrared Scanning) Survey
- Electromagnetic Survey
- Electrical Resistivity Survey
- Microearthquake and Microseismic Surveys
- Geochemical Survey
- Thermal Survey of Wells

Engineering program:
- Reservoir Modeling
- Well Test Analysis
- Ghyben-Herzberg Lens Analysis
- Energy Extraction From High Temperature Brine

Environmental-socioeconomic program:
- Regulatory and Legal Aspects
- Land Use and Planning
- Economic Analysis
- Environmental Baseline Studies

The major emphasis of Phase I has been on the Geophysical Program, since the issue of *if* and *where* geothermal resources exist is crucial to the project. However, parallel studies were initiated in all supporting programs, so that some progress has been made in identifying and clarifying the technological, environmental, legal, regulatory, social and economic problems that could obstruct the development of geothermal power in Hawaii.

Although the completion of surveys and interpretation of field data will continue through 1974, it became obvious—both on the basis of preliminary results from Phase I and from complementary studies conducted on the Big Island over the past several decades—that an exploratory drilling program is essential to establish identity of the subsurface conditions predicted by the surveys. Phase II, the research drilling program, should verify interpretation of scientific data and determine whether conventional geothermal resources actually exist in Hawaii. A major proposal has been submitted to the National Science Foundation for total funding of the research drilling program. If insufficient federal funding is

forthcoming with which to complete this program, then a request will be directed to the Governor to allocate all or a portion of the $500,000 appropriated by the 1974 Legislature for exploratory geothermal drilling.

Referring again to Figure 1, tentative plans call for initial drilling in the Puna Area along the Eastern Rift of Kilauea, with other possible drilling sites along the Southwest Rift of Kilauea and Mauna Loa. The drilling program at each site will probably include a number of shallow holes a few hundred feet deep, three or four holes 2,000 feet or so in depth, and one deep hole that may extend to 6,000 feet. The exploratory drilling program will be under the direction of Dr. Agatin T. Abbott, with input provided by the Site Selection and Operations Committee, which he established to assist key decisions, both for preliminary planning and as drilling progresses.

Figure 2 is an organizational chart for Phase II of the HGP. Principal Investigator and Project Director is John W. Shupe, Dean of Engineering. A co-principal investigator is responsible for the planning and for the direct technical supervision in each of the four research programs: (A) Geophysical Program—Dr. Augustine S. Furumoto, Professor of Geophysics; (B) Engineering Program—Dr. Paul C. Yuen, Professor of Electrical Engineering; (C) Environmental-Socioeconomic Program—Dr. Robert M. Kamins, Professor of Economics; and (D) Dr. Agatin T. Abbott, Professor and Chairman of Geology and Geophysics.

The HGP Executive Committee consists of these five principal investigators, plus two additional members who assist the Project Director in assuring the necessary visibility and support throughout the academic community, as well as by the governmental and private sectors: (1) Dr. John P. Craven, Dean of Marine Programs at the University and Director of Marine Affairs for the State of Hawaii; and (2) Dr. George P. Woollard, Director of the Hawaii Institute of Geophysics and a member of the Governor's Science and Technology Advisory Committee.

To assure that the HGP has both local and national relevance, systematic evaluation and advice is provided to the Executive Committee and the P.I.'s from numerous sources: (A) the NSF Project Manager; (B) the National Liaison Board; and (C) the Hawaii Advisory Committee. The National Liaison Board (membership list attached) consists of the project leaders of other NSF-supported geothermal programs, along with a few of the national leaders in geothermal research and development. This Liaison Board meets annually in Hawaii to review program progress, to exchange current information on geothermal science and technology, and to advise on future planning and implementation for the HGP.

The Hawaii Advisory Committee (membership list attached) was established to provide interaction with key individuals from industry, government, and the scientific community, whose support is essential to the introduction of geothermal power in Hawaii. Included on this committee are the directors of the State Office of Environmental Quality Control and the Department of Planning and Economic Development; the president of the major electric utility company; Director of the County of Hawaii Office of Research and Development; a cross-section of business and industrial leaders of the community; and representatives of citizen groups. This committee meets semi-annually and supplements the Executive Committee in providing the necessary visibility for the HGP, both on and off campus, to assure public and private support for geothermal power in Hawaii.

In summary, the overall objective of Phase I and II of the HGP is to solve the problems and to answer the questions—geophysical, technological, legal, environmental, social, economic—relating to the development of a conventional geothermal resource. If such a resource is identified, it is the intent to carry this development to the proof of concept stage, through the construction of a 5- to 10-megawatt prototype geothermal power plant. This will be done in cooperation with the llocal electrical utility, which is expected to finance the basic cost of the plant and include it in the electric system for the Big Island. The HGP will endeavor to identify public funding in order to: (1) make the entire operation environmentally pure, as a demonstration of the non-polluting potential of geothermal energy; and (2) instrument both the wells and the plant sufficiently so that adequate operational data and reservoir characteristics can be obtained. This instrumented prototype power plant and geothermal field will form the

nucleus for a National Geothermal Energy Laboratory to be used by engineers and scientists from throughout the world to study reservoir characteristics and evaluate performance theories.

ORGANIZATIONAL CHART

HAWAII GEOTHERMAL PROJECT - PHASE II

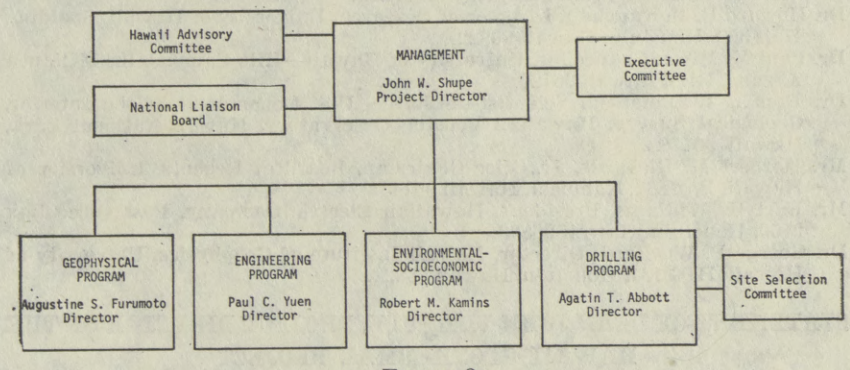


FIGURE 2

HGP NATIONAL LIAISON BOARD

Mr. David N. Anderson, Geothermal Officer, State of California Resources Agency, Department of Conservation, Division of Oil and Gas, 1416 Ninth Street, Room 1316, Sacramento, California 95814.

Mr. Ritchie Coryell, Program Director, Advanced Energy Research and Technology, National Science Foundation, 1800 G. Street, N.W., Washington, D.C. 20550.

Dr. George V. Keller, Professor, Colorado School of Mines, Golden, Colorado 80401.

Dr. George Kennedy, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, Los Angeles, California 90024.

Dr. James T. Kuwada, Rogers Engineering Company, Inc., 16 Beale Street, San Francisco, California 94105.

Dr. Henry J. Ramey, Jr., Professor of Petroleum Engineering, School of Earth Sciences, Stanford University, Stanford, California 94305.

Dr. Robert W. Rex, Republic Geothermal, Inc., 11848 East Washington Boulevard, Whittier, California 90606.

Dr. Donald H. Stewart, Battelle Pacific Northwest Laboratories, Post Office Box 999, Richland, Washington 99352.

Dr. Donald E. White, Geothermal Research Program, U.S. Department of the Interior, Geological Survey, Geologic Division, 345 Middlefield Road, Menlo Park, California 94025.

HGP ADVISORY COMMITTEE

Ms. Sophie Ann Aoki, Life of the Land (Environmental Program), 404 Piikoi Street, Suite 209, Honolulu, Hawaii 96814.

Mr. James Bacon, Executive Director, Congress of the Hawaiian People, Suite 351, Alexander Young Building, Honolulu, Hawaii 96813.

Dr. John P. Craven, Dean, Marine Programs, University of Hawaii, Holmes Hall 401, Honolulu, Hawaii 96822.

Mr. Robert F. Ellis, President, Chamber of Commerce of Hawaii, Dillingham Transportation Building, Honolulu, Hawaii 96813.

Mr. Robert H. Hughes, Senior Vice President, C. Brewer and Company, Ltd., Post Office Box 3470, Honolulu, Hawaii 96801.
Mr. Sunao Kido, Chairman of the Board, Department of Land and Natural Resources, State of Hawaii, Post Office Box 621, Honolulu, Hawaii 96809.
Mayor Shunichi Kimura, County of Hawaii, 25 Aupuni Street, Hilo, Hawaii 96720.
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Dr. Richard Maryand, Director, Governor's Office of Environmental Quality Control, 550 Halekauwila Street, Third Floor; Honolulu, Hawaii 96813.
Dr. Fujio Matsuda, Vice President, Business Affairs, University of Hawaii, Bachman Hall 211, Honolulu, Hawaii 96822.
Dr. Howard P. McKaughan, Director of Research, University of Hawaii, Spalding Hall 360, Honolulu, Hawaii 96822.
Dr. Paul M. Miwa, Chancellor, University of Hawaii—Hilo Campus, 1643 Kilauea Avenue, Hilo, Hawaii 96720.
Dr. Donald W. Peterson, Scientist-in-Charge, U.S. Department of the Interior, Geological Survey, Hawaiian Volcano Observatory, Hawaii National Park, Hawaii 96718.
Mr. Herbert M. Richards, Jr., Vice Chairman, Board of Regents, University of Hawaii, Box 837, Kamuela, Hawaii 96743.
Mr. Carl H. Williams, President, Hawaiian Electric Company, Post Office Box 2750, Honolulu, Hawaii 96803.
Dr. George P. Woollard, Director, Hawaii Institute of Geophysics, University of Hawaii, HIG 131, Honolulu, Hawaii 96822.

STATEMENT OF DEAN JOHN W. SHUPE, PROJECT DIRECTOR OF THE HAWAII GEOTHERMAL PROJECT

Dean SHUPE. Thank you, Mrs. Mink. I am quite pleased to have the opportunity to discuss the Hawaii geothermal project with the committee. Following the excellent overview of geothermal in general, I will be a little more specific than I intended, so it might seem a little provincial, but rather than repeat much of the discussion, the excellent discussion that you heard from Dr. Bowen, I will stick pretty much to the Hawaii geothermal project and realizing that the committee will understand that much of the technology spinoff in the application of the work that we are doing here will apply throughout the United States and throughout the world, for that matter.

I apologize for my husky voice. This is my third cold in 9 glorious years in Hawaii. If I lose my voice completely, Dr. Yuen will take over for what I intend to say.

Of all 50 States, Hawaii, of course, is the most vulnerable to any dislocations in the oil market. We have no fossil fuels at all. We have no coal coming by rail, no natural gas coming in by pipeline. We have no regional grid that ties us in to energy systems of other States or either interconnections to our various islands. So, we are totally dependent except for a small amount of bagasse or sugar cane waste that we burn. We are almost totally dependent on imported petroleum or energy. This complete lack of flexibility is somewhat of a travesty, because I am sure there is no other State and probably few other spots in the world that have the variety and abundance of natural resources that we have here in Hawaii. It is not only geothermal, but solar radiation, which we enjoy. Wind waves, ocean temperature differential, all of these are present, and we have a number of projects underway for trying to utilize these resources, because it has been brought out what potentially nonpolluting, renewable sources, but the one I have been specifically asked to speak on today, of course, is geo-

thermal, and also, I think as far as Hawaii is concerned, it probably is the leading candidate for developing energy at the commercial level in the very near future.

I think we will go directly to the slides and run rather quickly through those.

About a year ago the total production of geothermal power, and keeping in mind again, that this doesn't tell the total picture, was able to be brought out. There are many other uses of geothermal energy and home heating and space heating and processing. In Japan it is used in greenhouses and other types of industrial processes and construction. But as far as the energy, the geothermal energy, that is converted to electricity, the total capacity was 976 megawatts. To put that into perspective, the total power capacity on the island of Oahu is 1,015 megawatts. So, the point that I am endeavoring to make here is that although we have known about geothermal energy for 70 years, still, the total world capacity is less than we have on this island. We feel there is quite a bit more that still needs to be known about it.

Also, I will put in a slight defense for the U.S. technology. Since this chart was developed, they have put another 100 megawatts on line at the geysers, so it is approximately 400 megawatts now. So, the geyser is the largest geothermal field in the world and particularly the development in southern California that is coming along. I think there is a great deal being done in the United States, although, again, I would reinforce that we feel that more should be done. These, then, as of a year ago, were the nations that primarily had electric power, recognizing again that Iceland has many times that 3 megawatts in direct utilization in their hot water, in space heating, and material processing.

This is the Department of Interior table indicating the potential areas of under—subsurface heat in the western part of the United States, and it exists in a variety of ways. Either hot rock, hot water, or volcanic type of activity, and although technology might not be developed as yet for tapping all of these sources, it does indicate a rather broad coverage of the western part of the United States, particularly, as potential for it.

Here we are back to Larderello again. It wasn't a clear day or you are a better photographer than I am, or it may be both, but it is to illustrate, again, that here in the Tuscany Hills for 70 years they have been having geothermal development. Still it is very pleasant, if you discount the aesthetics of the cooling towers, but there is the grazing and the vineyards there. It is potentially a reasonable source.

This is the next-most successful. Again a dry steam. This is not an operational mode. This is of the geysers, as many of you will recognize. It is during—they have opened up all the valves and are running some blowdown tests, but it does illustrate the type of resource that exists there. Again, it is essentially dry steam that can be put through the turbine, as Dr. Bowen indicated.

This is down at New Zealand where here their resource, as was pointed out, was hot water to steam, and it can be used in this manner. So, when we have a geothermal resource existing as steam or hot water, we refer to this as a conventional resource, because the technology for utilizing these resources are reasonably well known and have been used for 70 years.

Here in Hawaii this is the resource as we know it exists and as we can see, molten magma bubbling. This leads us to suspect that there might be energy there and associated, then, with the volcanic activity, hopefully, there are then some of the conventional geothermal resources that can be identified and tapped with existing technology. So, we have developed, then, this Hawaii geothermal project concentrating primarily on the Big Island of Hawaii, where our early objectives will be to see if we can define and capture, display, if you will, a conventional geothermal resource, but a long-range interest of the project is ultimately to get to the direct utilization of molten magma. There is no NSF money in the molten magma search as yet, because it is pretty far down the line. Probably not as far as nuclear fusion, but much of the material development in that area will have spinoff or heat exchangers in the molten magma itself, but as in that last slide, you saw the magma was 1,200° C. Extremely high specific heat. From varying the cubic yard of that with a like quantity of steam, of course, they are many thousands of times the heat capacity of molten magma.

So, ultimately we hope to see developed, then, the utilization of this resource. If this does occur, it will be particularly interesting to the island of Hawaii, but also in other spots as well. The Big Island, the island chain was formed in a northwest to southeasterly direction and similarly, on the Big Island of Hawaii, the age is the same. Our older volcano, Kohala, Mauna Kea, Hualalai, Mauna Loa, and Kilauea, these are our most recent volcanoes. They are still active. The island is still growing. So, we felt that we would try to localize our search in this general area in order to find, then—see if we could identify the conventional source. We split this project up into three research programs across the bottom. The geophysical survey and exploration with Dr. Furumoto in charge. The engineering technology and utilization of the resource with Dr. Yuen in charge, and then our environmental and socioeconomic program with Dr. Robert Kamins, who is in charge at this period in time. I am listing in the management box. I am merely the coordinator of the program. We have a national liaison board with nine leading geothermal experts, many of them also affiliated with the National Science Foundation program, that gets together on an annual basis to interchange information and evaluate our program. Then we also have a 60-man advisory committee locally and representatives from Government and industry and environmental groups and others, so they will be aware of what is going on so this does not catch people by surprise.

In looking at our various research programs, this is kind of an overview of the Kilauea area with Mauna Loa in the background. This is a very complicated geological structure, and to try to find out if and where is the best place to drill, this does involve quite a bit in the way of geologic survey.

This is an air photo of an infrared showing up the various heat spots. There are gradations along the so-called Great Crack of the southwest rift of Kilauea in showing the heat variations. So, this is one of the types of surveys that were conducted. These were the various program that we worked up in the geophysical, the various types of surveys that we felt would identify if and where these resources exist. This was in our initial proposal that we developed.

Once the resource is identified, then the technology and the engineering of converting it is generally well-known. Again, this is Larderello

showing the cooling towers and the electric transmission system. Again, each system in both the geology and the resource itself is different. The earlier question on reinjection, for instance, there is apparently one site in Japan now that is potentially a very successful site, but it is in a park area, and they cannot find reinjection wells that they can discharge the material that is there. So, they are potentially very active wells that are sitting tapped, while they try to resolve the problem of what to do in the way of discharge. So, again, each project is different, although there are some similarities.

These are the turbines then at the geysers, which again are—look identical to any turbines. These happen to be Toshiba turbines, incidentally, which provide much of the power equipment in the geysers, because it is somewhat more competitive.

Mr. KAZEN. Is that the same type that is used in the Mexico plant?

Dean SHUPE. I don't know.

Mr. KAZEN. It is a Japanese plant. I have been there and I have seen it and I knew it was Japanese, but I didn't know whether they were competing within Japan.

Dean SHUPE. Yes. Mitsubishi has some development in the generators and all I am aware of, is that The Geysers' was Toshiba. The Mexican apparently are the same general—it is a very well designed unit. So, these were the projects that were established by Dr. Yuen and his group in the engineering program that we wanted to look into. These are the number of tests to help in the geophysical data. Then there are a number of nuts and bolts on transmission and energy extraction in some of these, but you will also notice there in the middle we do have some on the direct stats to magma energy, direct energy conversion.

Then down at the bottom the mechanical and electrical design of the pilot plant. What we would like to do with the Hawaii geothermal project is carry this on through to the proof on concept stage and set up, say, a 5- to 10-megawatt plant to indicate that the energy is there and can be recoverable. We are working with the public utility in this area, which I think would fund the base cost of the plant. What we will intend to do is to identify the public funding and to make the thing environmentally pure so that we can fully instrument it so that we continue to serve as a working laboratory.

In the environmental area, again, potentially it is environmentally sound, but some of the noise problems that have been mentioned before, these are the mufflers, the baffle mufflers that the geysers and other considerations, so that we do have an environmental group on this study unit, geotoxology, the environmental impact. Also, the legal and land use and regulatory aspects are quite important. Planning, economic analysis—if we find huge quantities of energy on the relatively undeveloped island of Hawaii, what impact will this have? The total capacity on that island is around seventy megawatts. If we find a 300- or 400-megawatt field, which is certainly not at all out of the realm of possibility, what impact will that have on that island? If we use it to refine manganese nodules, do you broaden your cane industry into pulp and this sort of thing. These are some of the economic considerations along with the byproduct research both on the resource itself and also if we tie this in to deep ocean water as a coolant, then we do have the potential of the nutrients there or converting deep ocean water to

purify it into other water or also into some of the other types of aquaculture things that can occur.

So, those represent a total list of the projects that we want to take on and Dick felt that we did have some expertise within the university within the State to look at them. As we try to get funding for this project, the State of Hawaii in the 1972 legislature put $200,000 into geothermal research. This was before the energy crisis had come along and I think it was a rather imaginative step for a State governing body to take. So, with the $200,000, the National Science Foundation out of fiscal 1973 put $250,000 with that. So, our phase I on our $450,000, we picked, then, these tasks that you see before you. Again, the majority of the funding has gone into our geophysical program, because, again, the engineering and the socioeconomic and the environmental are academic exercises unless we do find that resource there.

So, we have been trying to develop some of these in parallel to we felt it was essential to start looking into some of these other aspects, particularly the legal and regulatory aspects involved. Rather than doing these all in a series it would stretch out the timespan so greatly that possibly we all would lose interest in geothermal.

So, we have been trying to develop some of these in parallel to remove, in effect, all the obstacles and roadblocks to the development of geothermal power in Hawaii. So, for the first year of operation, which got underway in June of 1973, so we have been operating essentially a year and have made, in effect, progress on these various programs. We have received additional funding from the National Science Foundation of $340,000 to carry our operational program through the remainder of this calendar year. So, at the end of that time we will have completed the majority of our phase I tasks. What we would like to do then is to go directly to an exploratory drilling program.

This will still be a research drilling program, because, although we have all kinds of geophysical results that would predict what will occur where, until you actually punch a hole down there and determine if this really does exist at that temperature and this quantity, it is still somewhat speculation. So, we view this as a research goal in order to give us a little better idea of what we will be finding and we hope to start that program fairly early in 1975. The area that looks best for this which comes as no great surprise to any of us is along the Puna Rift or eastern rift of Kilauea. We have the majority of our tests there. The USGS has a great many tests. All of them favor the likelihood that this would be the best area for our preliminary drilling and we hope to start our program there. Other areas that look good were along the Great Crack or along the southwest. The South Point area also showed up some rather interesting hot spots in our infrared testing. But our initial drilling will be concentrated in that area along the Puna Rift. Again then coming back to our resource that is known there, our ultimate goal is to, of course, tap and develop this source, but in the interim, we would like to see if we can develop a conventional geothermal resource for Hawaii as well. I think that is about all I have, Mrs. Mink, as far as describing our general program.

Chairwoman MINK. Do my colleagues have any questions that they want to ask?

Mr. KAZEN. Is all of this area on Federal land or State land?

Dean SHUPE. We don't have any Federal known geothermal resources, to my knowledge in Hawaii. We are somewhat different from much of the western part of the United States, but there is—the land we are looking at is mixed ownership. Some State land. Much of it in small private developers. Some of it in some of our larger estates like the Bishop estate which have land.

Mr. KAZEN. No national park is involved?

Dean SHUPE. There is no national park involved in our program. There was funding for Dr. George Keller from the Colorado School of Mines. He received funding, again, from the National Science Foundation for an exploratory hole within the parks, which surprised all of us, but he did receive approval for this. He did drill an exploratory hole up close to that crater, which we saw. He started at 3,600 feet and drilled down to about 4,137 feet. So, he did get down below sea level. It seemed to verify his model for geothermal regime that was there and much of the scientific information from that hole will be helpful to us in planning our geothermal project. But one of the conditions of his drilling is that he did have to return that site to its pristine stage. So, he rearranged the boulders and if you drive over there now, it is really impossible to tell where the drilling did occur.

Mr. KAZEN. That was the only activity on Federal land?

Dean SHUPE. To my knowledge, yes.

Mr. VIGORITO. Most of the energy that Hawaii consumes now is primarily imported oil?

Dean SHUPE. Yes.

Mr. VIGORITO. Are you getting any electrical output now on geothermal?

Dean SHUPE. No.

Mr. VIGORITO. It is all experimental?

Dean SHUPE. Yes. We are still, in fact, in the exploratory state. We hope to drill our initial wells in early 1975, but these are not commercial wells. These are still research wells. If they are promising and we still have no guarantee that they will be. There are varying degrees of optimism among the various members. I am one of the most optimistic, which I am sure comes as no great surprise, but if we do find them, hot water or steam, with our experimental wells, then the next development would be to go to a commercial type well so that we could get sufficient energy from that to establish then a prototype plant. But if everything went well, if funding goes well, if the National Science Foundation—also the 1974 legislature earmarked $500,000 for the exploratory drilling. So this is in the CIP budget and it is contingent, again, on Federal matching. So, if we do receive money from NSF for ERDA, whoever might be funding at this time, we would also, if we are unable to complete our drilling program with Federal funding, we will request the Governor to release, then, enough funding from that $500,000 to complete our initial drilling program.

Mr. VIGORITO. Would you happen to know, are there any electrical transmission lines from island to island?

Dean SHUPE. No. This is another very real problem that we are looking into in our engineering program, is the transmission of electricity. To my knowledge, there are no undersea cables that go to the 6,500-foot depth that is in the channel between the big island of Hawaii

and Maui. So, it is unlikely that this sounds like a reasonable means of transmitting electricity from the big island on over toward Honolulu. We will be looking into conversion of hydrogen, if we find huge quantities of energy. Of course, you do have to go through an energy conversion cycle, which is rather inefficient. So, whether we go that route or not depends entirely on what we find. If, for instance, we should develop a procedure for extracting energy from molten magma, then I think we'd look into conversion to hydrogen or some other type of transmitting energy, because I think Hawaii then could very well be an exporter of energy either in product of processing or actual converting to hydrogen and shipping it out in ocean bottles.

Mr. VIGORITO. I never heard of underwater transmission of electrical power. I don't suppose there is anything like that?

Dean SHUPE. Yes. It has been done over greater distances than we would have between islands. Again I think close to Italy, and they have connected some of the islands off Sicily and some of these. So, I think the distance would not be a limitation. It is the fact that they have not developed the cables that will withstand the high pressures.

Mr. VIGORITO. At the different sea levels?

Dean SHUPE. Yes. And we have talked about neutrally buoyed cables with pyrogenic cooling and suspending them 200 or 300 feet below surface. The question always comes up, "What happens when the first German or Russian submarine runs into that? What type of problems?"

Mr. VIGORITO. They'd get electrocuted.

Dean SHUPE. There are a number of things that could be done, and again, if we do find huge quantities, then we would look more thoroughly. Of course, we would like to do all these things simultaneously, but again, until we develop the resource there, the problem in transmission is fairly far down the line.

There also is the possibility—It is our intent to come up the island chain, if we are successful on the big island, because again there are some of the geologists and geophysicists, who feel there might be a greater likelihood of a geothermal resource existing under some of the older volcanoes, because one theory is that when you do have molten magma at 1200° C. and you have ocean water and a porous island as we have here in Hawaii, that somewhere between those temperatures the water will flash to steam.

When it flashes to steam, it will then carry particulates in it and will deposit out silicates and calcites and zelites and you get then a self-sealing dome over the volcano. Then if you drill down to the self-sealing dome, then the steam comes out. One reason we might not find steam in Hawaii is that you need the three things. Like you have the geysers in Larderello. You need the heat, you need the water source, and you also need the cap rock that will confine the pressure. Then you drill down through the cap rock and the steam comes out. We have the heat and we have the water, but our volcanic lava is probably so porous that we do not have that cap rock.

So this is why my own feeling is we are much more likely to find hot water under pressure that can be converted to steam with either flash or through the binary system that Dr. Bowen discussed. But there always is the possibility that this self-sealing chamber exists and we might punch down through that and we might find dry steam. But

some of our consultants feel that that is a very strong likelihood, but I don't think too many people on our faculty here feel that that is a strong possibility.

Chairwoman MINK. What is the likelihood of finding geothermal fields on other islands?

Dean SHUPE. Well, probably if that self-sealing concept proves out, then I think there would be a real good likelihood because on Maui, for instance, there are warm water wells there indicating there is some recent activity. There are even two or three spots on Oahu, where warm water exists. Over in Waimanalo in the Great Swamp area and then over on the Waianae coast. So, there is a possibility that they would exist here as well, but we, again, felt that the likelihood of being successful was better in that area, so we thought we would start there and proceed up the island chain. This is another reason that the total research program is more than just wildcatting for geothermal energy.

The extensive amount of geophysical survey that we have, when we correlate that with our drilling program, hopefully, it will give us sufficient information and then we go and run sensitivity tests in some other location that has a similar geological formation, then it will improve our predictability as to whether we do or do not think that geothermal resources exist there.

So this is why, again, if we have our druthers, on where we would like to see a geothermal plant located on the big island, I would not choose the Puna area because that is a fairly highly developed area. It would be mixed ownership. I would prefer that we would be down south or even over on the Kona coast, because particularly if we could tie it in with some of the deep water access on the Kona coast and tie it in with desalted aquaculture and the whole bit, it would give us a somewhat broader potential on the total energy system, which is really what we are looking at for Hawaii.

Chairwoman MINK. What would be the waste product for your project? What kind of waste material are you talking about?

Dean SHUPE. Well, again, it would be the type of resource that Dr. Bowen was referring to. Probably we would reinject it as is our present plan. Again with the porous nature of our islands——

Chairwoman MINK. Would you have to reinject it at high pressure?

Dean SHUPE. I don't think we would have the problems that I referred to a little earlier, that this one group in Japan had, but we would have to have a better understanding of the geology than I have now. I am an engineer, not a geologist, but I do not think that the reinjection on the big island would be a major problem.

Chairwoman MINK. I would hate to have more earthquakes in the islands.

Down the road, how many years are you more or less assuming it is going to take to develop the background information and data to determine whether we have a commercially feasible amount of energy resource and can provide energy for the big island, at least?

Dean SHUPE. We would have a much better idea if our drilling program goes in next year. Of course, again, this will not tell us all the information that we need to know, because one hole identifying, say, a good hot geothermal resource at a given pressure and temperature isn't sufficient information to develop a whole geothermal field. But hopefully if our drilling program continues into the second year, I

would hope at the end of the second year we would have a much better feeling. I would hope that we would have that prototype plant on line still within this decade. Again, things would have to move rather rapidly for this to occur. I am still somewhat optimistic that we could get a 5- to 10-megawatt prototype on line before the decade is out.

Mr. KAZEN. Madam Chairman, I wonder if I could ask either Dr. Bowen or Dean Shupe to explain to me exactly how an earthquake is brought about by reinjection.

Dr. BOWEN. An earthquake takes place, when you have differential stresses within the Earth. This will tend to go this way. Something like this [indicating]. So, you have these rocks here tightly compressed together stressing this way. If you put fluid down there, it works into these fractures and cracks and lubricates them it it goes like that [indicating]. That's what happens. They have shown that these areas, where they are experimenting that there is continual movement along these fault zones and by putting pumps down in there and pumping the water out, it stops it. By increasing the pressure it starts it moving again.

Mr. KAZEN. Thank you, sir.

Dean SHUPE. In Hawaii, for instance, I do not feel that injection is a real problem as far as the earthquakes are concerned because again of the porous nature that we have, most of that area is saturated. I do not anticipate that we'd have to go to high pressures for injection. So, I think it is highly unlikely that reinjection in Hawaii would have any impact at all on earthquake potential.

Chairwoman MINK. What kind of water resource areas do you have to find in order to—say you have made a rich geothermal strike?

Dean SHUPE. In quantities of water?

Chairwoman MINK. Yes.

Dean SHUPE. Paul, do you have any feeling on what it would take? Possibly you are the better one for this than I.

Mr. YUEN. It is something on the order of 1 or 2 million gallons of water per day in order for the megawatts——

Chairwoman MINK. Of water going through a very intense heated area? Losing the steam? Is that the layman's view of what you are talking about?

Mr. YUEN. Water saying about——

Chairwoman MINK. I thought the area you were talking about has no water at all?

Dean SHUPE. No; this isn't true.

Chairwoman MINK. You are talking about Kona?

Dean SHUPE. The areas that I was referring to, once you get below sea level, you run into water. Our drilling program that we contemplate will start probably no more than 500 feet above sea level and penetrate well below sea level. We anticipate probably 2,000 to 3,000 feet down. So, we will be well below sea level in a saturated area. This hole that George Keller punched down in Kilauea starting at 3,600 feet, he hit a water table at 600 feet that was 2,000 feet below sea level. It was continuous all the way down. To, the porous nature and the high amount of rainfall, particularly when you get down below sea level—in fact, this is one concern that some people have about Hawaii. That we might have too much water and because of the porous open nature of this, that do we have enough opportunity for the temperature to build up or do we have so much circulation that maybe the natural

conduction will take it out? So, we will not have any difficulty at all. It might not be fractured when we get there. We feel that it will. I think there will be at the levels that we will be drilling. We will be drilling at the saturated area.

Chairwoman MINK. To develop up to the stage of getting the prototype plant constructed, what would be the dollar investment required?

Dean SHUPE. It is kind of hard to speculate on that, Mrs. Mink. Again, it depends on how involved a drilling program that we go into. For instance, if we are talking about, say, a million dollar drilling program in 1975, which is the figure I will pick out of the air, which we probably will not have that, but maybe a 2- or 3-year program of that nature, could develop then, if we are successful in finding a source and a location, maybe that could continue for about a 3-year period. Maybe—what are we talking about? At least three wells, I would imagine.

Two producing wells and one injection well for a 5- to 10-megawatt prototype plant. Those might be in the neighborhood of $400,000 to $500,000 each. Using your figure of what? Two hundred dollars per megawatt? What are we talking about? Per kilowatt? We'd be talking about $2 million a plant. So, we might be talking about in the neighborhood of another $5 million, at least in the way of development costs to get a prototype plant there. As I indicated before, I would hope again that the utility—the Hawaiian Electric Co. owns the Hilo Electric Power Co. and one possibility of developing this—this is about the size unit.

They have a 70-megawatt system on the big island and about a 10-megawatt unit would be a size that would be quite compatible with their expansion program. So, one possibility if there is not a Federal or public funding available for the total program would be to request then the Hawaiian Electric Co. to underwrite the basic cost of the powerplant. As I indicated, I will try to get additional funding to make it environmentally pure as an example of what can be done with powerplants. So, probably $5 million of public funding might be a reasonable estimate.

Mr. BURTON. What would the investment of the power company be?

Dean SHUPE. It depends again—It might do as the geysers did. It is my understanding the first turbine they put on line there was an old turbine that they had scrapped and sold. It was an old low pressure steam turbine. Then when they found low pressure steam, they found that that would be the most efficient.

So, they had to buy it back at a great deal more than they had sold it for scrap. Conceivably, the electric power company might have some of the large old turbines that they had at the sugar plantation areas, where these would adapt very well to probably the low pressure system that we have been working with. So, again, if they were starting from scratch, it might be a $2 million investment for a 10-megawatt plant. If they pull some of the other units offline, it could be somewhat less than that.

Mr. BURTON. What, if any, provision do you have for the fruits of the technological spinoff—that is exactly the word that I am looking for. Do they remain in the public domain, because of the public investment?

Dean SHUPE. Completely. We have Federal funding through the National Science Foundation, and State funding and county funding, so everyone is looking over our shoulders, and we are pleased that they are, because we are trying to make this information as readily available—as I indicated in our advisory notes through our National Liaison Board——

Mr. BURTON. This is explicitly NSF funding that the fruits of the research remain in the public domain?

Mr. RITCHIE CORYELL. Absolutely.

Mr. BURTON. Is it a condition of the State participation as well?

Dean SHUPE. Yes, it would be.

Mr. BURTON. Why would the State, if it is going to invest $5 million, then seek——

Dean SHUPE. I am hoping part of the $5 million—I refer to that as a—I didn't indicate that would be the State participation. I would hope there would be some Federal funding available for some of the exploratory work and surveys, because we are still in a developmental area, and as I indicated with the first slide, although there is a uniqueness to each installation and each geographic facility, still there is a spinoff to the technology base that our scientists and engineers are contributing to, and we would hope that the Federal Government will continue to underwrite a portion of that from the overall contribution.

Mr. BURTON. If the public investment is going to be in this order, five-sevenths or thereabouts, why would you have the private utility in this act at all? What would the rationale be?

Dean SHUPE. Frankly, the rationale, Mr. Burton, again, is to get funding to develop the program.

Mr. BURTON. I understand that.

Dean SHUPE. What my responsibility as project director is, is trying to scrounge funding from every area that is available and pull together Federal, State, county, industry, and university in trying to develop this resource in Hawaii. If we could get this total funding from ERDA, from NSF; if your bill 4920 goes through, which provides loans and support; then we would not have to go through this other direction at all, and it would be, again, much more comfortable for me as project director; but I have heard, but I have not seen those huge quantities of——

Mr. BURTON. I could understand the encouraging industrial consumers of energy to participate, because hopefully this would provide not only a supplemental source, but perhaps, even a lower per unit cost source of energy to them. But I just wondered why the—well, I think you have answered my question.

Dean SHUPE. Let me talk about that low unit cost. Again, this certainly would be our very real intent. Of course, PUC has some regulatory——

Mr. BURTON. Because you see, the taxpayers pay for all the investment anyway, or the energy consumers, I should say, pay, in any event, for this private utility.

Dean SHUPE. I agree with you completely. If we could get public funding for this, we all would be somewhat more comfortable. In the absence of public funding, since the utility needs to put a 10-megawatt unit on line, if they could help us achieve our goals, this was the reason

I have mentioned this as a possibility. Also, it is the type of encouragement that the Federal funding agencies encourage us to work with industry. I am thinking in terms of——

Mr. BURTON. I would agree with that. I would agree with working with the energy consuming industry.

Dean SHUPE. The geysers, for instance, the development of the geysers has been a cooperative venture first with Union Oil and then a variety of oil companies, but all that steam so far has been sold to P. G. & E.

Mr. BURTON. That is my point. That is exactly my point.

Dean SHUPE. OK. And that is a concern.

Mr. BURTON. Well, yes.

Dean SHUPE. Another alternative that we will be looking into—I don't think this is a decision that the university project can make on the ultimate utilization of that resource. What we are trying to do is to carry it through to the proof of concept stage. If we can get Federal funding for it, great. Again, if there are other potential sources of funding, which would make no long-term commitments to utilization of the resource, then this effect is where——

Chairwoman MINK. I would like to follow through on that. Suppose you do get all the Federal funds you need to bring it to the development stage to prove that it can be a commercially useful way of producing energy. What would you do after that? Once that stage is reached? How would you then go through the distribution?

Dean SHUPE. What would the State do, I think, is really what the question is, because I think many of the things that we have been doing on the project really don't have too much business being concentrated in a university, but no one else is doing it. So as a result——

Chairwoman MINK. No, I don't mean you in the sense of the university, but I mean you in the sense of the public entity.

Dean SHUPE. There are a variety of alternatives that I am sure will be considered in the Department of Planning and Economic Development, in DONR by our legislature as to how this resource should be utilized. The 1974 Hawaii Legislature enacted the first regulation on identifying geothermal energy, and it was identified by a bill presented to the Department of Land and Natural Resources as a mineral, of which I am sure you are aware. Your colleagues might not be. A mineral in Hawaii then belongs to the State. So by enactment of that legislation, this does identify ownership of the geothermal rights in Hawaii to the State of Hawaii.

So that is a first step. I am sure as the project develops since we have representatives on our advisory committee from DPED, from the Attorney General's Office, from DONR, and others, that these will develop in parallel various alternatives as to how this resource will be utilized, and again, we will in our socioeconomic area, Dr. Kamins and his group has written one paper on legal and public policy issue, which spells out a number of alternatives all the way from private ownership to complete public ownership of the resource. So we will be presenting these alternatives. Again I think it is the State's responsibility, and this is why we have a good liaison with them in maintaining it.

Chairwoman MINK. It seems to me you would have to leave the matter involving the private sector quite fully open at this stage of the game.

Dean SHUPE. It is.

Chairwoman MINK. If you are going to consider other long-range alternatives of going into public power or some other method of distribution, because if you make a decision at this level to involve private power in reaching your development stage, then you have no alternative but to turn over the power developed to the private company. Then you would close out your alternatives in the future.

Dean SHUPE. We certainly don't intend to close out the alternatives. As I say, the proof of concept stage, it is my concern, and I think the State of Hawaii would be best served to develop this to the proof of concept stage as rapidly as possible. I do not yet see public financing developed that will take it in that direction. If it does, it would certainly be welcome, and it would simplify the project. If we do go the other route, the option would be kept open so it would not put Hawaiian Electric Co., the Hilo Electric Light Co., any private group—I think you know the State much, much better than I do, and this is why I toss it in. The fact that our State legislature has already taken action to protect the ownership of the resource, and we certainly won't let that occur.

Chairwoman MINK. The geothermal field that is located on the big island, is it classified as a potential resource or as a known resource?

Dean SHUPE. It is not on Federal land, so no one has to bother about classifying it. It does not have the formal designation of the——

Chairwoman MINK. You said that twice now. I don't understand what you mean by it is not on Federal land. What is not on Federal land?

Dean SHUPE. Most of the known geothermal resources, as I understand them, in the western part of the United States——

Chairwoman MINK. No, I mean on the big island. What is not on Federal land on the big island?

Dean SHUPE. Well, the areas we are interested in——

Chairwoman MINK. Well, I am not talking about that. I am talking about the field. The geothermal field.

Dean SHUPE. We don't know where the field is, Mrs. Mink.

Chairwoman MINK. So it has not been identified?

Dean SHUPE. No, this is the stage that we are in right now. We know that there is heat under the national park. That is where the one hole has gone.

Chairwoman MINK. Going back to that beautiful map you had, when you had all those black dots, would we have a black dot on the big island is really my question.

Dean SHUPE. No.

Chairwoman MINK. We won't?

Dean SHUPE. The whole big island will be a black dot.

Chairwoman MINK. Oh, the whole thing.

Dean SHUPE. There is subsurface heat under the whole island.

Chairwoman MINK. So it is a potential insofar as the classification is concerned?

Dean SHUPE. Right.

Chairwoman MINK. With regard to your project, you are not interested in Federal land, but insofar as a long-range potential, the big island is included as a potential geothermal——

Dean SHUPE. Very much so.

Chairwoman MINK. What about the other islands? Are these all black dots, too?

Dean SHUPE. Of course, as we come up the island chain, Maui looks like the next best and probably is where we would next do our geophysical—but certainly I think it would have to be classified as potential as would, say, our hot water wells.

Chairwoman MINK. You see, I feel very neglected that the chart you have did not include the 50th State.

Dean SHUPE. So did I, but the Department of Interior—I think you have more influence there than I.

Chairwoman MINK. No, I have very little influence with the Department of Interior. It has only been 15 years, you know, that we have become a State, and we can't even get on the map. So I have to ask these embarrassing questions.

Mr. KAZEN. Dr. Bowen, are geothermal resources considered minerals?

Dr. BOWEN. In general, the Western States are writing legislation considering the geothermal sui generis. This is the word that they are using. This is a legal term meaning distinct in itself. It is not described either as a water resource or a mineral resource, but it is geothermal energy. This is what we are going after. This is what the royalties will be paid on. So, they have gotten away from deciding whether it is water or mineral. Sui generis. It is in itself.

Mr. KAZEN. We are very interested in the leasing procedure of Federal lands and in most instances, we reserve the minerals. I was just wondering how this particular resource was classified and what we would have to do as we progress in this field. What we would have to do in the way of changing our leasing procedures, if any, if they are not considered as minerals?

Dr. BOWEN. Possibly I can bring you up to date if you are not familiar with what has been happening in this field. There has been a court case on the ownership of the geysers of the steam at the geysers, which is the producing field. This relates to the 1916 Homestead Act, where the Federal Government retained ownership of all minerals. The court decision was that the—this resource, this geothermal resource was not meant to be withheld by Congress. Therefore, it belongs to the owner of the land and not to the owner of the mineral resources. Now, this was held in the first two steps and it is on its way to the Supreme Court to decide whether or not the surface owner or the mineral rights owner owns the geothermal resource. So far it has been the surface owner.

Mr. KAZEN. Well, this would be right where you are dealing with private property.

Dr. BOWEN. Yes.

Mr. KAZEN. I am talking about the Federal lands and the effect of leasing surface as to whether or not the owner of the surface lease also owns the geothermal resources below that land.

Dr. BOWEN. I think what the Congress should do in this matter, Mr. Kazen, is like the States and realize that geothermal is not something else. It is not water. It is not mineral. It is geothermal energy and the law should be written specifically to geothermal energy.

Mr. KAZEN. Well, is it any different than petroleum?

Dr. BOWEN. Yes, because this is the natural heat of the Earth.

Mr. KAZEN. Isn't petroleum the natural product of the Earth?

Dr. BOWEN. It is the product, but you can't produce petroleum without taking it out of the ground, and you can produce usable energy from geothermal without taking it out of the ground. This is one thing that comes into it.

Mr. KAZEN. Without taking it out of the ground?

Dr. BOWEN. By using heat exchangers. This heat radiates out of the ground all the time. You could take water—you could drill a well, circulate it down there, and take this heat energy out of the ground. Now, you are removing nothing from the ground except heat energy. Btu's. Now, how would you classify that except as being separate and distinct?

Mr. KAZEN. In other words, it is a renewable resource?

Dr. BOWEN. It is a renewable resource.

Chairwoman MINK. Why would geothermal be more mineral than water?

Dr. BOWEN. Well, I don't know that it would, Mrs. Mink.

Chairwoman MINK. I have some constituents who maintain it is water.

Dean SHUPE. Yes. I think it is the heat aspect. There is another court case that you are probably aware of in which a depletion allowance came up with regard to resources and it was enacted favorably in one court and I think it is still being appealed as to whether there should be a depletion allowance in geothermal resource.

Mr. BURTON. You could follow unwise conservation practices, could you not? Rather than this recycling?

Dr. BOWEN. Waste resources? Certain things like that?

Mr. BURTON. If I may, extending that tax wise, then, the closer you come to being eligible for depletion allowance, so, in a manner of speaking, you could be encouraging unjustified development from the conservation point of view, in the energy preserving sense.

Dr. BOWEN. There is a depletion allowance on steam, but you have to consider, you have to look at geothermal resources as something on the order of, say, for example, trees. You can produce them for a certain amount of time and then it is depleted. But it returns in another 2 or 3 generations and you have it back again. Like the geyser reservoir, which is apparently full of steam.

After x number of years, 50 years, 30 years, that steam is going to be gone, but if we wait another three or four generations, another 75 years, there's probably enough leaking down in that reservoir that 75 years from now that will be recharged and reproduced again. That is the way geothermal is a renewable resource in that you use it up and it is gone. You abandon it and water will leak back in. You won't be taking the heat out. You are only taking the water out. You are only getting a fraction of the heat available. The water comes back in and you can go back and produce that again. That is the way geothermal is renewable.

Mr. BURTON. Can you make an unconditional statement that in all respects, where you have this geothermal structure, you are better to go this recycling route, or is this a statement that is simply inaccurate?

Dr. BOWEN. It would be hard to make that as a general statement. It works very well at the geysers. In other areas, you would have to do more studying. This is an unknown.

Chairwoman MINK. Do we have any project where we artificially inject the water and create the steam from the heat that is located in the rocks?

Dr. BOWEN. Yes, ma'am.

Chairwoman MINK. What do you do with the water then under the circumstances?

Dr. BOWEN. They recycle it.

Chairwoman MINK. In and out?

Dr. BOWEN. In and out. Yes. This is the idea. This is the Los Alamos—in the New Mexico lab they are doing the study on this and the idea is that you—this is the hot dry rock theory where they reinject water down there, flash the steam, it comes back, then you just——

Dean SHUPE. It stays water. They keep it heavily pressured and you circulate it as water is what they hope to do.

Chairwoman MINK. That is for electrical energy or just hot water production?

Dr. BOWEN. Electrical energy.

Chairwoman MINK. Electrical energy.

Dean SHUPE. The proof of concept is still a good many months away. They are down to their first hole and have started the so-called hydrofracturing. If you recall, they were going to do this with nuclear devices. It wasn't very popular. Now they have a hydraulic fracturer and a technique where they force water down by high pressure and break up the rock in this manner and then punch down another hole and recirculate it around. It is an interesting possibility and it very well could work, but there are serious questions on the rock dust that you will end up with. And some of the sediments that are there and the variety of other heat transfer concerns. So, it has not been proven as yet to my knowledge any place in the world.

Mr. BURTON. Is there any relationship between the famous Johnson mole hole and the purpose of this conference this week? Is there any relationship at all? Do you know what I am talking about?

Dean SHUPE. Yes.

Mr. BURTON. The Brownen route mole hole.

Chairwoman MINK. The relationship of that to this?

Dr. BOWEN. There may be some in that——

Dean SHUPE. This was a drilling down through the end of the earth's crust. I think most of the drilling technology that was developed there was helpful and will assist in the deep drilling that comes along at a later date, but that did not progress to the point, where the data from that was extremely helpful.

Mr. BURTON. Was that aborted?

Dean SHUPE. Yes.

Mr. BURTON. Should it have been continued?

Chairwoman MINK. The House killed it.

Dean SHUPE. Again, I think that there was some justification. Here in Hawaii we were particularly sensitive to it, because one of the—Dr. Woollard in the Hawaii Institute of Geophysics was one that worked quite strongly on this, but the estimates—I'm afraid it was not costed out adequately to begin with. Again on our geothermal and other related programs, I think technology is a little bit more sophisti-

cated and not telling Congress that we can do this for a shoestring and request 10 and 20 times the amount of money.

Mr. BURTON. What was the stated purpose for that project?

Dean SHUPE. This was listed as basic research to contribute to the understanding of the mantle, the thickness of the crust, the formation of the continents. So it was billed as a basic project that would have given a tremendous amount of basic information but also was developed sufficiently far along that it has contributed to drilling technology for the undersea oil wells and these things have all profited from what was developed in that. We would like to drill a similar hole over the Big Swamp on Oahu. There is a magnetic anomaly over there that suggests something very interesting about 12,000 or 13,000 feet below Kailua. It could be a very interesting geothermal type of program.

Chairwoman MINK. Are there any further questions? If not, we thank you very, very much, Dean Shupe, for your contributions here today and for giving us a better understanding of your project. We wish you much success in our pursuit of the $5 million you need to complete this project.

With that we will adjourn the meeting. Thank you very much.

[Whereupon the proceedings ended at 4:20 p.m.]

CIRCUM-PACIFIC ENERGY AND MINERAL RESOURCES CONFERENCE

THURSDAY, AUGUST 29, 1974

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON MINES AND MINING
OF THE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
Honolulu, Hawaii.

The subcommittee met, pursuant to notice, at 2 p.m. at the Sheraton Waikiki Hotel, Hon. Patsy T. Mink, (chairwoman) presiding.

Chairwoman MINK. The Subcommittee on Mines and Mining will come to order. I would like to introduce my two colleagues. To my left, Congressman Phillip Burton of California and on my right, Congressman Abraham Kazen of Texas. We will be joined, I am sure, momentarily by our colleague, Congressman Vigorito from Pennsylvania.

We are here to attend the Circum-Pacific Energy and Mineral Resources Conference, and in conjunction with attending the conference, have set up these two meetings with participants at the conference on subject areas that the subcommittee was particularly interested in. And Tuesday we heard from two distinguished scientists on the geothermal question.

This afternoon we are very pleased, first of all, to welcome Dr. Geoffrey P. Glasby of the New Zealand Oceanographic Institute, Department of Scientific and Industrial Research, Wellington, New Zealand, who has prepared a paper for presentation to the Circum-Pacific Conference on Exploitation of Manganese Nodules in the South Pacific, and we are most delighted that he accepted our invitation to attend this session with the subcommittee to give us a brief summary of his research paper and to respond to questions that the subcommittee members may have.

We have a copy, Dr. Glasby, of your paper entitled Exploitation of Manganese Nodules in the South Pacific, and this paper will be received for the record and with the unanimous consent of my colleagues, I would request that the staff be authorized to include that portion of it, which can be inserted in the record of these hearings. Without objection, so ordered.

[The paper follows:]

EXPLOITATION OF MANGANESE NODULES IN THE SOUTH PACIFIC

(By G. P. Glasby, New Zealand Oceanographic Institute, Department of Scientific and Industrial Research, Wellington, New Zealand)

ABSTRACT

A series of seven charts showing the distribution and metal content of manganese nodules and the distribution of metal-rich sediments in the South Pacific has been prepared. Manganese nodules are shown to occur mainly in the following

regions: In an elongate belt approximately 1000 km wide beneath the Antarctic Circumpolar Current; the Southwestern Pacific Basin; the Peru Basin; the Chile Basin; and the mountain region bounded by the Cook Islands and Tuamotu Islands. Mn-Cu-Ni rich nodules are shown to occur dominantly in ocean basins and Fe-Co rich nodules in elevated regions. Metalliferous sediments occur dominantly along the crest of the East Pacific Pise where nodules are largely absent. The distribution patterns suggest that the formation of manganese nodules and metalliferous sediments is mutually exclusive.

A cruise of the R.V. *Tangaroa* has revealed a belt of nodules showing almost complete coverage of the sea floor southwest of the Cook Islands. Future surveys for economic concentrations of manganese nodules in the South Pacific should be restricted to the deep ocean basins.

INTRODUCTION

To date, exploration for manganese nodules of economic grade has centered mainly on the North Pacific, particularly in the red clay and siliceous ooze areas south of Hawaii. As a result, comparatively little work has been carried out on the distribution and metal contents of manganese nodules in the South Pacific. This somewhat unfortunate since certain regions of the South Pacific do have a potential for the commercial recovery of manganese nodules and this would have a beneficial effect on the economies of adjacent islands. In this paper, I discuss the distribution and metal contents of manganese deposits in the South Pacific, present a brief discussion on the results of a recent New Zealand Oceanographic Institute cruise to the Southwestern Pacific Basin, and make some assessment of the economic potential of manganese nodules from this region.

REGIONAL SETTING

In general terms, the South Pacific may be considered to consist of a mid-ocean ridge system (the Indian-Antarctic Ridge, the Pacific-Antarctic Ridge and the East Pacific Rise) bounded by oceanic crust of progressively increasing age away from the axis of the ridge (Winterer 1973, p. 270, fig. 5). This is bounded in the east by the South American continent and the west by the New Zealand Plateau, The Tonga-Kermadec Trench and its northward extension. Sediment distribution in the South Pacific has been described by Krasny and Bezrukov (1970), Lisitzin (1970) and Goodell et al (1973). Red clay is the dominant sediment type in deep sea basins such as the Southwestern Pacific Basin, the Peru Basin, the Chile Basin and the Southern Tasman Sea. Siliceous ooze is dominant in a belt stretching around the Antarctic continent. Carbonate sediments occur in elevated regions such as the East Pacific Rise and New Zealand Plateau (Lisitzin 1970, p. 102, fig. 9 and p. 112, fig 14.).

NODULE DISTRIBUTION

The following account of the distribution of manganese nodules in the South Pacific Ocean is based on a recently published chart of the New Zealand Oceanographic Institute (Glasby and Lawrence 1974a). This chart represents a compilation of all previously published data on the occurrence of manganese nodules in the South Pacific, much of which is stored in the Scripps Data Bank (Frazer and Arrhenius 1972; J. Z. Frazer pers. comm.). The data is plotted on the Soviet bathymetric chart of the region (Udintsev 1963) in order to show the relationship between nodule distribution and bathymetry. No attempt is made to show either the concentration of nodules at the sediment surface or the morphological features of the nodules. Because of the nature of oceanographic sampling, it is expected that some bias may occur in the data. The relatively high abundance of nodules in the Southern Ocean may, for example, reflect to some extent the substantial work of the U.S.N.S. *Eltanin* in that region whereas the relative absence of nodules in other regions may reflect the lack of sampling in deep-water areas far from land. A second problem is one of compilation. Much of the data in the manganese nodule literature has been used by a number of authors as is the case with the *Eltanin* and *Challenger* data. Because of this, it is not always easy to verify whether nodules discussed by different authors represent the same dredge haul. This may have resulted in assigning more

than one symbol for a given dredge haul in certain instances and hence an apparently higher nodule abundance at this site. In spite of these limitations, it is felt that the large numbers of samples collected in the South Pacific enable a generalised picture of nodule distribution in this region to be drawn.

From the data presented by Glasby and Lawrence (1974a) it is apparent that manganese nodule distribution in the South Pacific can be classified into three major categories; in basin-type environments such as the Southwestern Pacific Basin, Peru Basin, Chile Basin, South Tasman Basin (these are dominantly red clay areas); in the circumpolar belt approximately 1000 km wide (this is dominantly a siliceous ooze area); and in the mountain region bounded by the Manihiki Plateau, Society Islands, Tahiti and the Tuamotu Archipelago (*see also* Horn *et al* 1972a, 1972b, c, 1973a; Bezrukov 1973, Winterer *et al*, in press). In addition, limited quantities of nodules are found in plateaux and seamount environments such as the Campbell Plateau and Tasman Seamounts, although these represent only localised deposits of no commercial significance (*cf.* Glasby and Summerhayes, in Press). Significantly nodules are largely absent in elevated regions such as the East Pacific Rise where carbonate tests form the dominant sediment type.

From previous studies, it is probable that the sedimentation rate is the dominant factor controlling nodule distribution throughout the South Pacific, nodules forming preferentially in regions of low sedimentation such as the submarine basins where red clay forms the dominant sediment type and the siliceous ooze provinces around Antarctica. The paucity of nodules in the Tasman Basin may, in fact, reflect its shallower depth and relative proximity to sources of terrigenous sediment compared with other basin environments. The resultant higher sedimentation rate effectively limits the occurrence of nodules in this region. Nodules are also far less abundant in elevated regions above the carbonate compensation depth where the accumulation of calcareous sediments increases the sedimentation rate and prevents the formation of conditions favourable to manganese nodule growth. The occurrence of manganese deposits in elevated regions such as the Campbell Plateau most probably reflects the fact that the phosphorite nuclei on which the nodules form is a lag deposit which has been swept clear of sediment by bottom currents. This has created local conditions favourable for nodule formation and is analogous to the situation on the Blake Plateau (Glasby and Summerhayes, in press).

The occurrence of extensive deposits in the circumpolar region of Antarctica also reflects on a number of other factors including bottom current velocity, sediment substrate and availability of potential nucleating agents on which the manganese nodules can accrete (*cf.* Goodell *et al* 1971; Watkins and Kennett 1971, 1972; Conolly and Payne 1972; Payne and Conolly 1972). It is also probable that the siliceous ooze substrate is conducive to nodule formation as in the siliceous ooze province south of Hawaii. The efficacy of siliceous ooze as a substrate for nodule formation is probably a function of the open pore structure of the ooze which permits facile migration of trace metals through the interstitial waters of the sediment (*cf.* Horn *et al* 1973a). Finally, the presence of glacial erratics to serve as nodule nuclei is an important factor controlling nodule morphology in high latitudes (*cf.* Glasby 1972). Watkins and Self (1972) note a steady decrease in the percentage of manganese nodules in a dredge haul with increasing latitude as the Antarctic continent approached (Watkins and Self 1972, p. 69, fig. 9a). This reflects a dilution of nodule abundance by glacial erratics.

The origins of the manganese nodules in the mountain region of the central South Pacific are complex. Bezrukov (1973), for example, points out that in the Manihiki Plateau region nodule distribution is very heterogeneous. Sediments in this region are dominantly calcareous above the carbonate compensation depth, red clays at greater depths, and are strongly influenced by volcanic processes. It is probable that availability of potential nuclei may play some role in controlling the distribution of nodules in this region but other factors such as sediment type and the influence of bottom currents may also be important (*cf.* Heezen *et al* 1966; Hollister *et al* 1974). According to Horn *et al* (1972a), nodules in this region occur on the flanks and deeps of intermountain basins. Associated sediments are detrital carbonate on submarine slopes and red clays in adjacent deeps.

Finally, an interesting feature is the fact that the limited nodules so far recovered at depth in JOIDES Deep Sea Drill Cores in the South Pacific are often found away from the main areas of nodule occurrence. This is particularly true of the lag deposit of manganese nodules and pebbles recovered at a depth of 91.7 m from JOIDES drill hole 274 (68°59.81′ S, 173°25.64′ E, 3326 m), immediately north of the Antarctic continent. It is suggested that this deposit was formed at the sediment surface further north of its present position in the siliceous ooze province of the Antarctic circumpolar region and has subsequently been buried and migrated south during the migration of Antarctica from the Australian continent. Since the nodule horizon is dated approximately as early Pliocene to mid or late Miocene (5–12 myrs), the nodule would have formed originally some 130–300 km further north (assuming a half spreading rate of Antarctica from Australia of 2.6 cms/yr, Weissel and Hayes 1971, 1972). If this hypothesis is correct, it is clear that buried nodule provinces do not necessarily lie beneath present-day nodule provinces but may be displaced from them by a considerable distance. This trend has already been shown in the North Pacific (Horn *et al* 1973a).

As mentioned previously the chart of Glasby and Lawrence (1974a) shows only the occurrence of manganese nodules in individual dredge hauls and gives no indication of nodule morphology or abundance. As shown in underwater photographs, the distribution can be very high in certain regions (*cf.* Hollister and Heezen 1967, Jacobs *et al* 1970, 1972; Heezen and Hollister 1971; Payne and Conolly 1972; S.E. Salvert, pers. comm.). Skornyakova and Andrushchenko (1970) have previously presented a chart showing variations in nodule density throughout the Pacific. Comparison with the present results indicates that this chart can be regarded only as a generalisation based on over extrapolation of data.

METAL CONTENTS OF NODULES

The contents of certain metals of economic significance, notably Mn, Fe, Cu, Ni and Co, in South Pacific manganese nodules are shown in a series of recently published charts (Glasby and Lawrence 1974b–f). Each chart represents the compilation of all available data drawn from a number of publications, most of these data being stored in the Scripps Data Bank (Frazer and Arrhenius 1972; J. Z. Frazer, pers. comm.). Each data point represents the mean of up to 12 analyses carried out by different analysts on different samples in different laboratories using different sampling and analytical techniques. Some of the analyses were carried out almost a century ago (Murray and Renard 1891). The data are therefore uneven in quality. Variations in metal content within a single dredge haul can vary by more than an order of magnitude (Fig. 1).[1] Such variations may represent either genuine differences in composition between nodules from a given locality or differences in sampling and analytical techniques. Although no distinction can be made between the various sources of compositional variation on the basis of the present data, it does indicate the need for extreme caution in the interpretation of regional trends shown in these (and previous) charts and the need for further detailed study on the origin of localised variations in nodule composition on the sea floor (*cf.* Cronan and Tooms 1967; Grant 1967; Hubred 1970; Glasby *et al.* 1971; Glasby 1972). In addition, interpretation of regional trends for individual elements is complicated by the fact that nodules from adjacent stations often show marked differences in composition. In spite of these limitations, it is felt that the charts give a useful generalized picture of regional variations in nodule composition and in particular permit areas of obviously high metal content to be selected for further investigation as sites of potential economic importance.

Manganese.—Nodules containing high manganese contents (>25%) are generally found in oceanic basins, such as the Peru Basin and the oceanic basin N. of Tahiti. Lesser concentrations occur in elevated regions such as the mountain region between the Cook Islands and Tahiti and the Nazca and Chile Ridges. Lower contents of manganese are also found in the siliceous ooze province around Antarctica, particularly in the Drake Passage-Scotia Sea region where the lowest manganese contents are recorded (generally <10%). Excluding nodules from seamounts, banks or similar topographic highs, there does

[1] See chart on p. 57.

appear to be a decrease in manganese content of basin-type nodules away from the eastern margin of the Pacific toward the southwestern Pacific as indicated by Price and Calvert (1970). Nodules from the Southwestern Pacific Basin tend to be intermediate in composition (in the range 7.9–23.0%).

Iron.—The iron content of nodules is on average lower than that of manganese and shows almost the opposite pattern of distribution. Highest values occur on elevated regions such as the mountain region between Tahiti and the Cook Islands and the Nazca and Chile Ridges and in the siliceous ooze province around Antarctica. Nodules from the Drake Passage-Scotia Sea area, in particular, are much more iron-rich than manganese-rich. Concentrations in the oceanic basins are generally lower than in the elevated regions.

Nickel.—Nickel is the most abundant of the three trace metals studied here. Its distribution closely follows that of manganese. Highest values (>1.5%) are found mainly in the oceanic basins, particularly in the Peru Basin and the ocean basin N. of Tahiti. In elevated regions, the nickel contents are lower (generally <0.5%).

Copper.—Copper occurs in much lower concentrations than nickel but follows the same pattern of distribution. Concentrations of 0.7% are more common for oceanic basins, although values as high as 1.3% are observed. In elevated regions, values <0.2% are common.

Cobalt.—Cobalt has much the lowest concentration of the three elements studied here and tends to follow the distribution of iron. High concentrations (2.23%) are found in the mountain region between the Cook Islands and Tahiti. These are, however, rare. Most values are <0.4%.

Interelement Relations.—Visual examination of the element data presented by Glasby and Lawrence (1947b–f) indicates a positive correlation between Mn–Ni–Cu and between Fe–Co and a negative correlation between Mu and Fe Graphical plots of inter-element relations reveal a more complex situation (Figs. 2a–e;[1] *see also* Price and Calvert 1970). Mn shows a positive trend with respect to both Ni and Cu (Figs 2a, b) but in both cases there is a wide scatter of data. Ni and Cu, on the other hand, show a marked degree of coherence (Fig. 2c). This situation is analogous to that found for nodules from a limited area in the Indian Ocean (Glasby *et al*, in press) and emphasises the greater similarity in chemistry between Ni and Cu than between Mn–Ni or Mn–Cu in nodules. Considering the possible sources of analytical and sampling errors, the trend between Ni and Cu is remarkably linear, with an approximate grandient No=2.1 Cu. Fe and Co show a weakly developed positive correlation and Mn and Fe a poorly-defined negative correlation. In both cases, there is a wide scatter of data. Interestingly, Ostwald and Frazer (1973) report a positive correlation between Mn and Co in nodules from a single dredge haul south of Australia. This is not observed here.

Although no definite conclusions can be drawn regarding the nature of these inter-element relations, it is of interest to speculate on their origin. For both Mn—Ni and Mn—Cu, there appears to be a well-defined upper boundary of Ni and Cu contents in nodules for a given Mn content (*see* dashed lines Figs. 2a, b). This value possibly represents the maximum theoretical concentration of Ni and Cu that can be incorporated into manganese nodules for a given Mn content and therefore may represent the equilibrium concentration of these metals that can be absorbed from seawater onto manganese oxide minerals under ideal conditions. Lesser concentrations of Ni and Cu than these maximum values may therefore indicate some process capable of either enriching the nodule with Mn or inhibiting the deposition of Ni and Cu. Two factors which may be considered here are the diagenetic enrichment of Mn relative to trace metals in the sediment column (Ku and Glasby 1972) and the role of mineralogy in controlling the Ni and Cu contents (Cronan and Tooms 1969). Certainly, the points in the lower right-hand corners of Figs 2a and b represent extreme situations where extensive remobilisation of Mn has taken place in the sediment column in regions close to land leading to a marked separation of Mn from Ni and Cu. Intermediate values may represent situations where this effect is less pronounced.

Mn and Fe show a weakly defined antipathetic relation. This reflects the fact that the authigenic phase of manganese nodules represents an intermediate between Mn-rich and Fe-rich end members. Because of the cryptocrystalline nature of the oxide phase of manganese nodules, the end members never form discrete

[1] See charts on pp. 58 to 62.

phases but can be observed in individual nodules under the electron microprobe (Dunham and Glasby, in press). The gross relationship between Mn and Fe is, however, complicated by the fact that nodules represent a three-component system consisting of a manganese oxide phase, an iron oxide phase and a detrital mineral phase. These detrital minerals show large variations in abundance between nodules and thus tend to obscure any simple antipathetic relationship between Mn and Fe. There does, however, appear to be a well defined upper limit of Fe content for a given Mn content in the nodule (see dashed line Fig. 2d).

Finally, Fe and Co show only a weakly defined positive correlation with a wide scatter of data. Here, the distribution suggests two mechanisms of incorporation of Co in nodules; one where Co is associated directly with the iron oxide phase, Fe, the other where Co is appreciably enriched in the nodule relative to Fe. This latter situation occurs only in nodules from regions of strong topographic contrast and presumably reflects the oxidation of Co to the trivalent state (Cronan and Toms 1969).

It is of interest to calculate the maximum contents of Ni, Cu and Fe for a given Mn content. For 20% Mn, the ratio (in percent) is—

$$Ni_{max} : Cu_{max} : Fe_{max} : Mn$$
$$1.55 : 1.7 : 26.5 : 20$$
$$\text{or } 0.77 : 0.085 : 1.32 : 1$$

This compares with the concentrations of these elements in seawater (in $\mu g/l$) (Riley 1965)—

$$Ni : Cu : Fe : Mn$$
$$0.07\text{–}7 : 1\text{–}20 : 10\text{–}100 : 0.5\text{–}3$$

Thus, the ratio of the maximum theoretical concentrations of Ni, Cu and Fe with respect to Mn is lower in nodules than in seawater. Sorption processes need not therefore be particularly efficient to adsorb the required concentrations of Ni, Cu and Fe onto nodules. Interestingly, the ratio of Ni to Cu in nodules is much higher than in seawater. This is somewhat surprising since, at low pH values at least, Cu is more readily adsorbed on manganese oxides than Ni (Murray *et al.* 1968).

Regional Trends.—Regional trends in element composition of manganese nodules from the South Pacific have previously been documented by Mero (1965), Cronan and Tooms (1969), Price and Calvert (1970), Goodell *et al.* (1971) and Cronan (1972). From the present data, it is clear that the regional patterns for the South Pacific presented by both Mero and Cronan and Tooms are based on too few samples to be a meaningful reflection of the true distribution of metal contents in this region. The actual distribution of element contents is far more complex than shown by these authors and their contours can only be taken as a first approximation to the actual distribution of metal contents. The distribution of element ratios shown by Price and Calvert is based on more samples but unfortunately the data have been contoured across the East Pacific Rise where there are no nodules.

Goodell *et al.* (1971), on the basis of a detailed statistical analysis of the geochemistry of nodules from the Southern Oceans, divided the region into three major geochemical provinces; a manganese suite of element (including copper and nickel) dominating the Southwestern Pacific Basin, an iron suite (including cobalt) dominating the Albatross Cordillera, centered about 60° S, 160° W, both suites occurring in the third province, the Chile Rise. The manganese suite is taken to be associated with an abyssal plain and the iron suite with a mid-ocean ridge-rise system. Although these trends are essentially correct, it is surprising that these authors did not emphasise the extreme iron-rich manganese-deficient nature of nodules from the Drake Passage-Scotia Sea region nor the fact that nodules from the elongate abyssal plain running S.E. of the Albatross Cordillera are iron-rich.

From the data presented here, there appears to be a general trend between Mn, Cu and Ni and between Fe and Co. In general, the Mn-Cu-Ni rich nodules are associated with oceanic basins, particularly the Peru Basin and the oceanic basin N. of Tahiti where red clay is the dominant sediment type. The Fe-Co rich nodules are generally found in elevated regions where calcareous sediment dominate. Surprisingly nodules from the siliceous ooze province around Ant-

arctica are not greatly enriched in Mn-Cu-Ni. This differs markedly from the situation south of Hawaii. (*cf.* Horn *et al.* 1973a, b, c) where the Cu and Ni contents of nodules from the siliceous ooze province are significantly higher than in nodules from the adjacent red clay region. The presence of siliceous ooze does not therefore necessarily lead to the formation of Cu-Ni rich nodules.

The origin of the Mn-Cu-Ni enrichment in basin-type environments is not well understood. Cronan and Tooms (1969) have noted the enrichment of Cu and Ni in manganese nodules with increasing water depth and attributed this to the variation of nodule minerology with depth; todorokite-rich nodules being enriched in Cu and Ni and being found at greater depths than birnessite-rich nodules. A second factor which may be important, however, is the productivity of the overlying water and the nature of the sediment substrate. Greenslate *et al* (1973) have indicated the importance of biological factors in accounting for the Cu-Ni rich nodules in the equatorial N. Pacific (see also Graham 1959; Graham and Cooper 1959). According to this hypothesis, deposition rates of Cu and Ni in sediments from this region are controlled by the productivity of the overlying waters. Post-depositional migration of copper and nickel through the open pore structure of the sediments permits the incorporation of these elements into the nodules throughout the entire growth history of the nodule and leads to the high contents of these elements in the nodules. If this proves to be the case, it may explain the lower contents of these elements in the basin nodules of the South Pacific since the surface waters of a large region of the South Pacific (associated with the subtropical anticyclonic gyre) are of very low productivity (Bieri 1959; Reid 1962, 1973; Bogorov 1967; Warren 1970). This is reflected in the low amorphous silica contents of the sediments expressed on a carbonate-free basis for this region (1–5%) compared with those for the equatorial belt of the N. Pacific where nodules occur (10–30%) (Jousé *et al* 1971; Lisitzin 1971). Interestingly, a tongue of high productivity water extends off the coast of Peru over the Peru Basin where the highest Mn-Cu-Ni nodules of the South Pacific are found.

The importance of the productivity of the surface water in controlling nodule composition lies in cycling trace metals from the surface waters to the sea floor. Lisitzin (1971) notes that "silica acts as a transport medium, delivering large amounts of elements and compounds to the depths. After the frustules (the compounds) are dissolved, elements and compounds associated with them pass into deep waters and sediments". It is probable that the solution of biological silica accounts for the bulk of silica in interstitial waters of sediments from productive regions. In barren areas, the lower interstitial concentrations may be regulated by clay-mineral equilibria (Fanning and Schink 1969; Schink *et al* 1974). Since marine organisms are known to contain appreciable contents of trace metals (Goldberg 1957; Krinsley and Bieri 1959; Nicholls *et al* 1959; Arrhenius 1963; Wangersky and Gordon 1965; Martin 1970; Boothe and Knauer 1972; Knauer and Martin 1973; Turekian *et al* 1973), this may be a factor in accounting for the higher copper and nickel contents of nodules from basin environments. Greenslate (1973) notes a decrease in the Mn, Fe and Ni concentrations in sediments from high productivity zones, suggesting that these elements do in fact migrate from the sediment into manganese nodules in these areas (*see also* Cronan and Tooms 1969; Price and Calvert 1970).

Whether the dissolution of calcareous tests leads to enrichment of copper and nickel in nodules from basin environments is more debatable. Goldberg and Arrhenius (1958) accepted the idea of Correns (1941) of the possibility of the biological extraction of manganese from sea water into foraminiferal tests. At the partial dissolution of these after deposition, manganous ions are released in the pore water of the surface layer of the sediment. Evidence supporting this hypothesis has recently come from Greenslate (1974) who discovered smaller tubular structures of deep sea foraminifera on the surface of selected nodules from all parts of the Pacific. Nodules are therefore shown to be the home of many protozoan organisms (see also Harada and Nishida, in press). Decay of such organic materials may lead to the release of metallic ions and their subsequent incorporation into nodules (G. Arrhenius in Hammond 1974). This idea is supported by the observation of Berger (1971) that even in "well-preserved" calcareous sediments, considerable solution takes place. This must have a considerable effect on interstitial water composition and therefore possibly on nodule

composition. Further, Burns and Brown (1972) have noted the role of foraminifera in the initial precipitation of iron oxides in certain manganese nodules. An interesting feature of this hypothesis, however, is the role of the carbonate compensation depth. The equatorial Pacific siliceous ooze-red clay province (where Greenslate has mainly worked), the Peru Basin and the ocean basin N. of Tahiti lie at depths close to, or just below, the carbonate compensation depth. Here, dissolution of calcareous tests on the ocean floor would seem a reasonable source of trace metals in manganese nodules. By contrast, nodules from the Southwestern Pacific Basin are found at depths of the order of 5000 m, approximately 1000 m below the carbonate compensation depth. In this region, dissolution of calcareous tests would take place in the water column several hundred metres above the ocean floor. Incorporation of trace metals from the dissolution process would not therefore be possible. This factor may account for the lower contents of Mn-Cu-Ni in nodules from the Southwestern Pacific Basin compared with those in nodules from the other ocean basins. Thus, not only is the productivity of the waters overlying the nodules field important but also the water depth relative to the carbonate compensation depth. Whatever the mechanism, there is clearly need for a greater understanding of the flux of siliceous and calcareous material in pelagic sediments so that a quantitative assessment of this effect on nodule composition can be calculated.

A second factor which is important in controlling the compositions of nodules is diagenesis. This has been well documented for the Pacific by Price and Calvert (1970). As previously indicated, the present data support the contention of Price and Calvert of a decrease in the manganese content of basin-type nodules (excluding nodules from seamounts, banks or similar topographic highs) away from the eastern margin of the Pacific toward the Southwestern Pacific. However, both copper and nickel show a similar trend to manganese reflecting the coherence of these elements with manganese rather than their separation from manganese. Thus, although diagenetic processes may be an important factor in controlling the enrichment of manganese in nodules from the eastern margin of the Pacific as suggested by Price and Calvert (1970), they do not lead to extensive separation of this element from copper and nickel as in shallow marine environments (Ku and Glasby 1972).

Finally, the Fe-Co rich nodules are generally found in elevated regions. Previous studies have suggested that advection of oxygen over seamounts may be responsible for the high Co contents of these nodules (e.g. Cronan and Tooms 1969). These elevated regions are, however, above the carbonate compensation depth. Nodules from the Drake Passage, for example, are associated with light coloured foraminiferal ooze (Goodell et al. 1971; Herb 1971; Echols 1971). Perhaps this association with calcareous sediments rather than deep-sea clays may be partially responsible for the formation of these Fe-Co rich nodules in elevated regions. Interestingly, the low Mn-Cu-Ni contents of these nodules from elevated regions where calcareous sediments predominate suggest that extensive solution of calcareous material would be required to account for the increased Mn-Cu-Ni contents of basinal nodules and that it is the dissolution of, rather than association with, calcareous material that leads to high Mn-Cu-Ni contents.

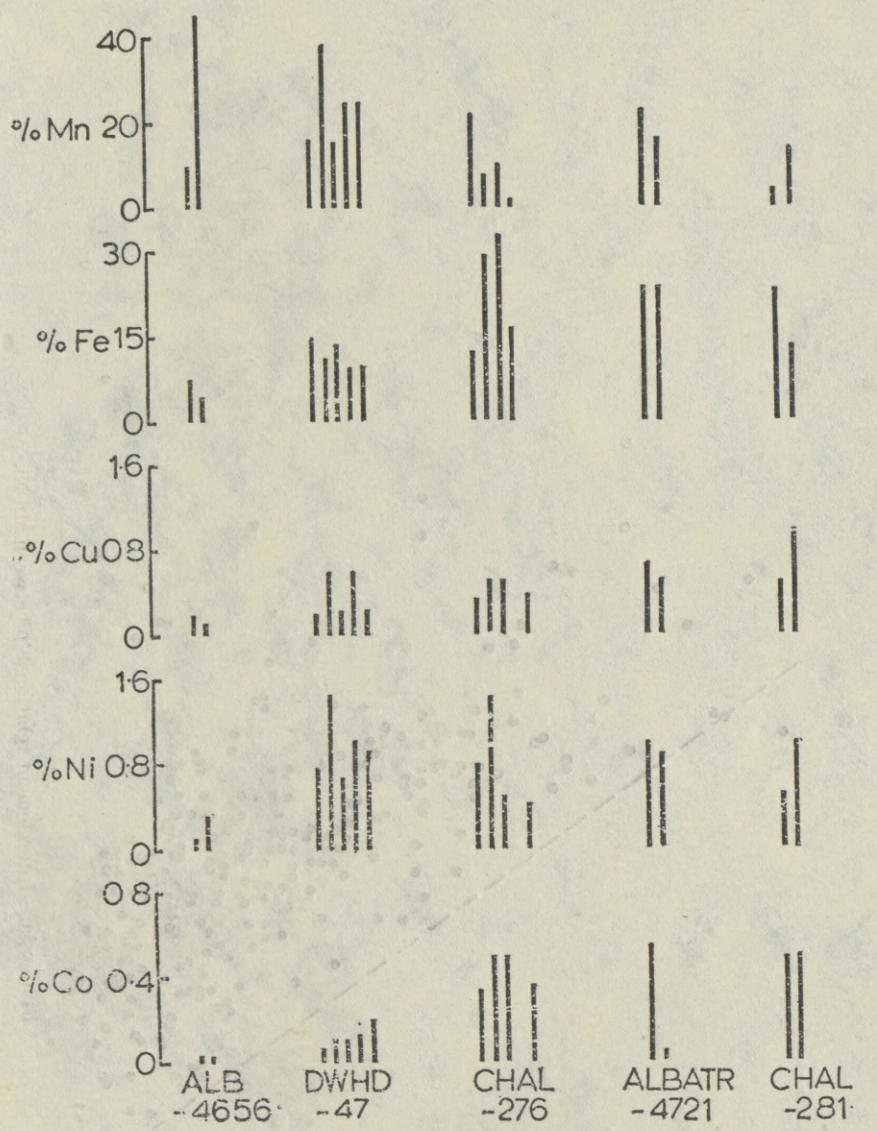

FIGURE 1.—Variation in element content at a series of stations.

FIGURE 2a.—Interelement relationship between Mn-Ni.

FIGURE 2b.—Interelement relationship between Mn-Cu.

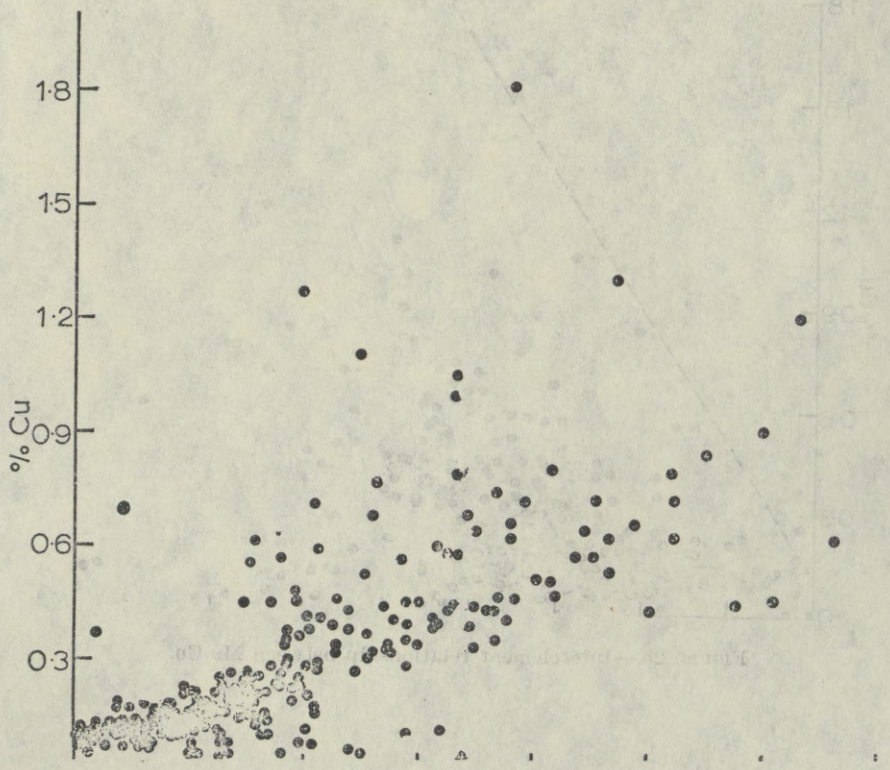

FIGURE 2c.—Interelement relationship between Ni-Cu.

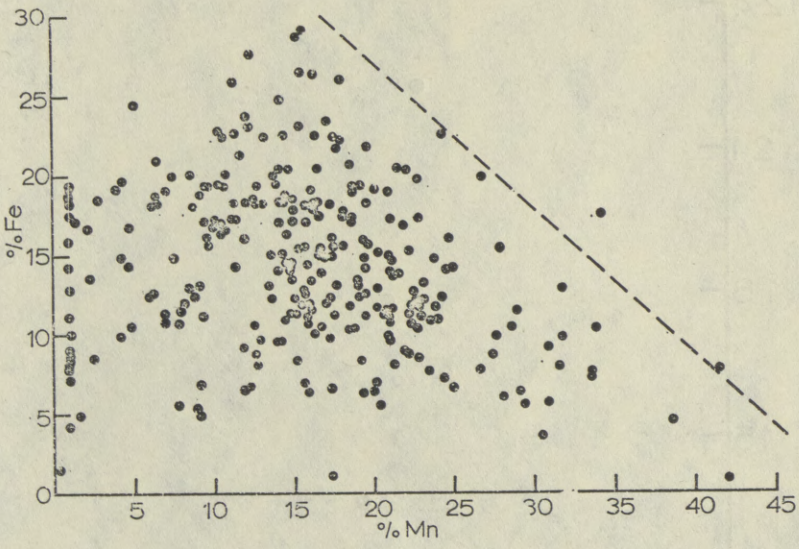

FIGURE 2d.—Interelement relationship between Mn-Fe.

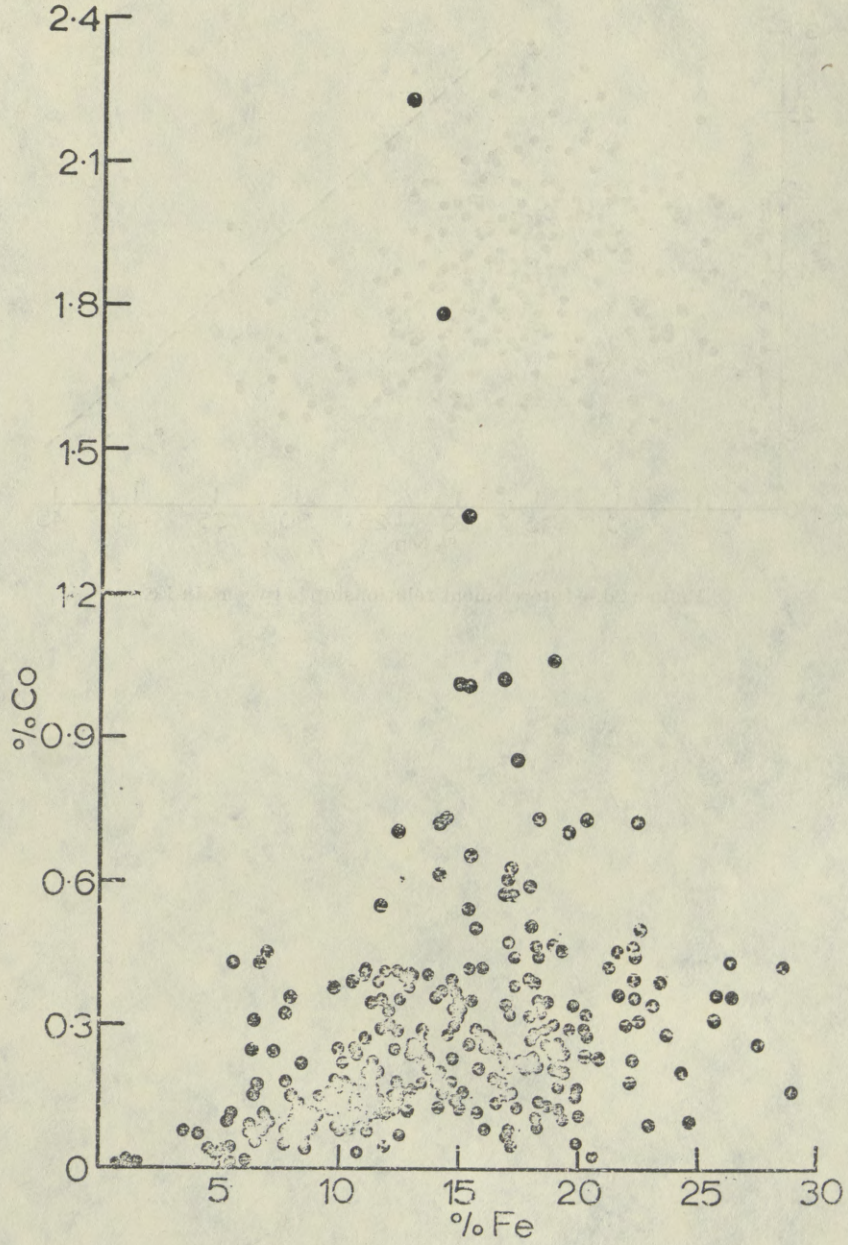

FIGURE 2e.—Interelement relationship between Fe-Co.

METALLIFEROUS SEDIMENTS

The occurrence of metalliferous sediments in the South Pacific has been reported by a number of authors (Boström and Petersen 1966, 1969; Boström et al. 1969; Horowitz 1970; Bischoff and Sayles 1972; Sayles and Bischoff 1973). As shown by Glasby and Lawrence (1974g), moderately to highly metalliferous sediments are concentrated almost exclusively in the vicinity of the East Pacific Rise where manganese nodules are largely absent as a result of the high rates of carbonate sedimentation. This absence of nodules in the region of metalliferous sediment occurrence suggests that the formation of manganese nodules and metalliferous sediments are mutually exclusive and that different processes contribute to their formation (cf. Bonatti et al. 1972; Glasby 1973, in press). If this is so, one possibility is that volcanogenic processes dominate the formation of metalliferous sediments whereas manganese nodules form largely from seawater. This conclusion is in agreement with the observations of Blissenbach and Fellerer (1973) that the formation of these mineral deposits reflects stages of continental drift; metalliferous muds being formed during the early stages of rifting whereas manganese nodules are generated on abyssal plains formed in the advanced stages of continental drift. Because of their relatively high metal contents and the ease of handling fine-grained sediments, some authorities (Greenslate et al. 1973) have suggested that metalliferous sediments from regions such as the Bauer Deep in the equatorial Pacific may be an alternative commercial source of metals to manganese nodules. However, metal contents of these sediments are at least an order of magnitude lower than those of manganese nodules of economic grade (Max. conc. of metals in bulk sediment Mn 6.5%, Cu 0.01%, Ni 0.16%, Sayles and Bischoff 1973). The increased transportation and handling costs of the greater bulk volume of material per unit of metal produced would effectively prevent their commercial exploitation.

SOUTHWESTERN PACIFIC BASIN

Because of the current interest in manganese nodules as a potential commercial resource, the New Zealand Oceanographic Institute has recently undertaken a reconnaissance cruise to the Southwestern Pacific Basin aboard the R.V. *Tangaroa*. The track chart is shown in Fig. 3.

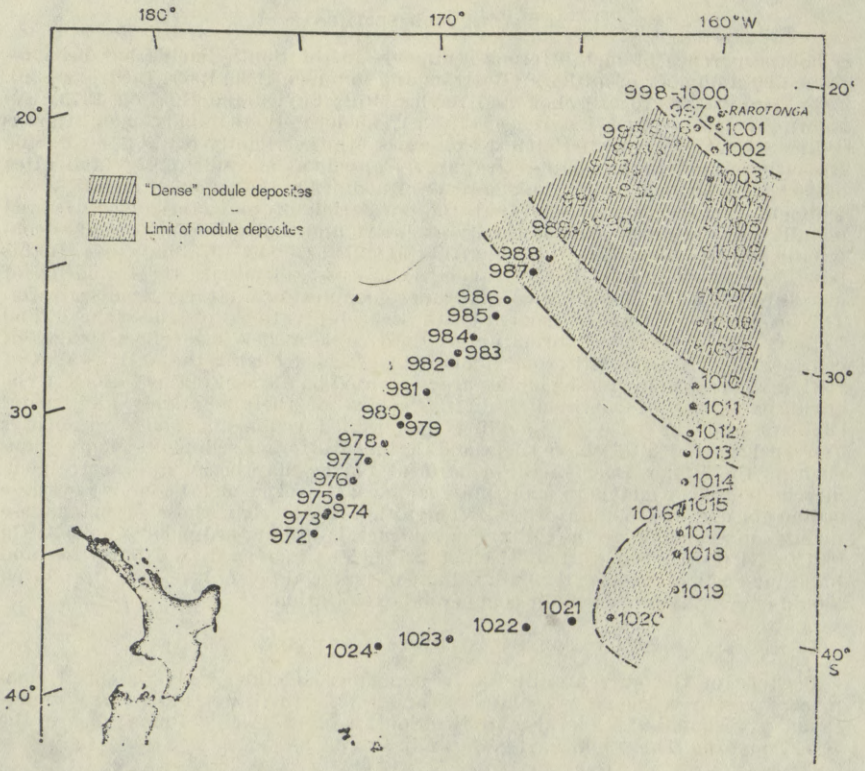

FIGURE 3.—Cruise track of the R.V. *Tangaroa* showing the distribution of managenese nodules in the Southwestern Pacific Basin.

The results of this cruise show that an extensive field of manganese nodules exists in a belt at least 300 miles wide southwest and south of Rarotonga, comparable in density to that of the nodule deposits of the siliceous ooze province southeast of Hawaii (Fig. 4). Nodule density varies from widely scattered (especially near the edges of the belt) to an essentially complete coverage at places within the belt. Nodules range in size from about ½ cm to 11 cm, and nodules from certain stations vary in size by an order of magnitude. Nodules from southwest of Rarotonga are spheroidal, while nodules from the field just south of the island are generally either tabular-discoidal (especially larger nodules) or spheroidal (especially smaller nodules). Nodules from the most southerly field are either "botryoidal" (shaped like a bunch of grapes) or "polys" (intergrown spheroids). The predominate surface texture of nodules from the cruise area is

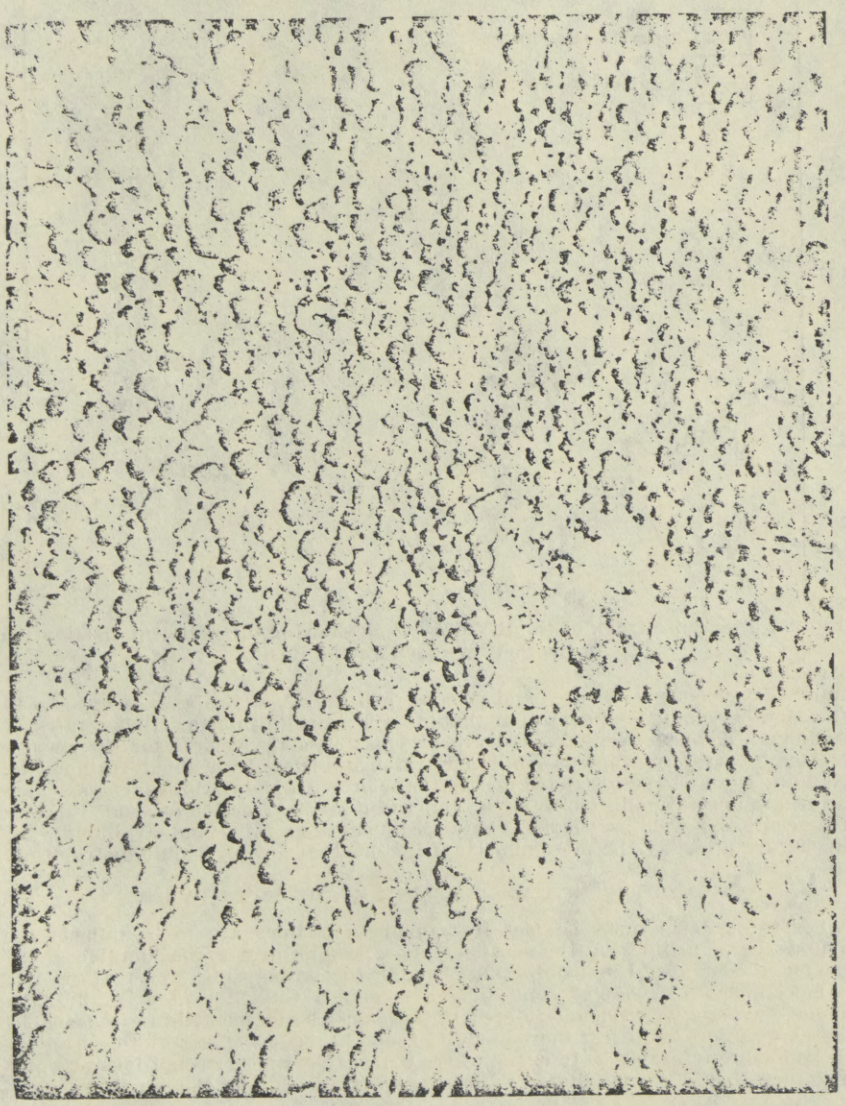

FIGURE 4.—Underwater photograph from Stn G992 showing almost complete coverage of the ocean at a depth of 5,400 m southwest of Rarotonga.

granular, but many larger nodules from the field southwest of Rarotonga display a cavernous microbotryoidal surface on one side.

Silty clays are the most important sediment type in the Southwestern Pacific Basin. In the cruise area they vary in colour from light brown (near New Zealand) to dark brown (near Rarotonga) (Fig. 5). This probably reflects a higher

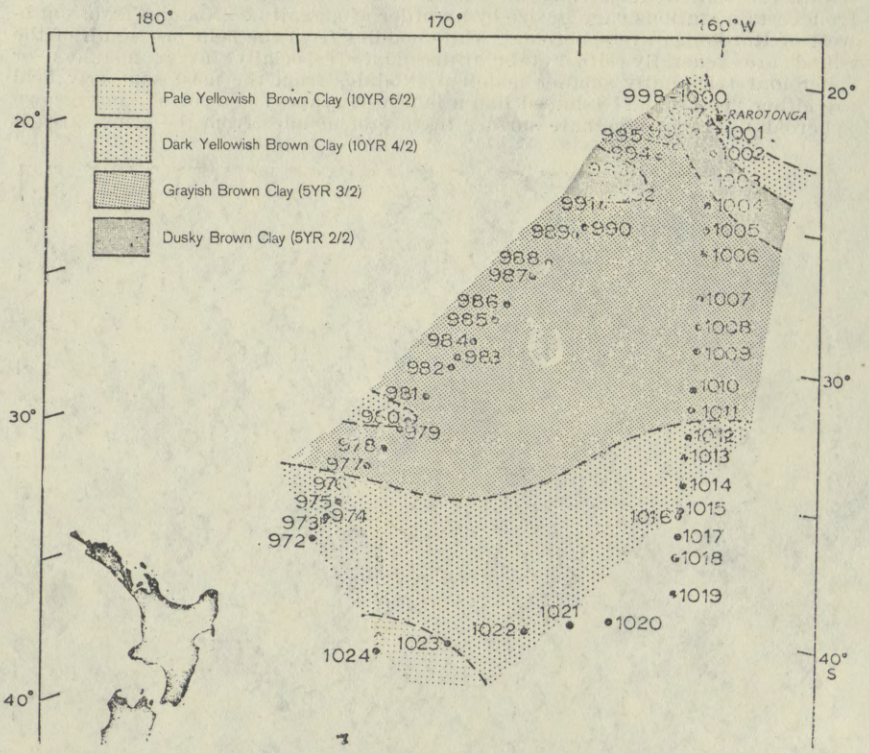

FIGURE. 5.—Cruise track of the R.V. *Tangaroa* showing the sediment distribution in the Southwestern Pacific Basin.

input of terrigenous silicates and volcanic ash near New Zealand, as opposed to the slower pelagic sedimentation that occurs near Rarotonga. Higher rates of sedimentation near New Zealand are probably also responsible for the smooth bottom topography, whereas south of Rarotonga a rugged volcanic terrain exists. Nodules appear to be restricted mostly to the brown and dark brown clays, which are characterized additionally by an important coarse fraction of small volcanic fragments, as well as sharks' teeth. Sedimentation rates and availability of nuclei are probably the most important factors that govern nodule distribution.

ECONOMIC POTENTIAL OF NODULES IN THE SOUTH PACIFIC

Several criteria must be met if manganese nodules are to be mined; the abundance of nodules on the sea floor must be high over a considerable area; the metal content of the nodules must be high (according to K. Meyer, Hawaiian Symposium, 1973, nodules containing a combined Cu+Ni content of 3% are defined as being of economic interest); they must be found within a reasonable distance of port facilities; they should be found in regions of smooth topography; they should preferably be in azone where reasonable weather conditions prevail; and they should not be diluted by other rock fragments on the sea floor.

Probably the most extensive manganese deposits in the South Pacific are found in the circumpolar siliceous ooze province. These are of no real economic interest because of their relatively low metal contents, their dilution by glacial erratics, their great distance from land and the unfavourable weather conditions in this region. More promising are the basin-type manganese deposits. These are known to occur at least locally in high abundance, have high metal contents in certain regions, are generally within reasonable distance of land, are found in regions of smooth topography, and are not subject to prolonged periods of adverse weather conditions. Further, it is probable that higher contents of metals (notably Cu and Ni) in nodules from these environments than are reported here have been found by commercial companies but have not been released for proprietary reasons. Because of the previously mentioned inter-relation between element content of nodules and depth (Fig. 6), it would seem logical that higher Cu and Ni contents would be found in the poorly surveyed deep-water regions further from land.

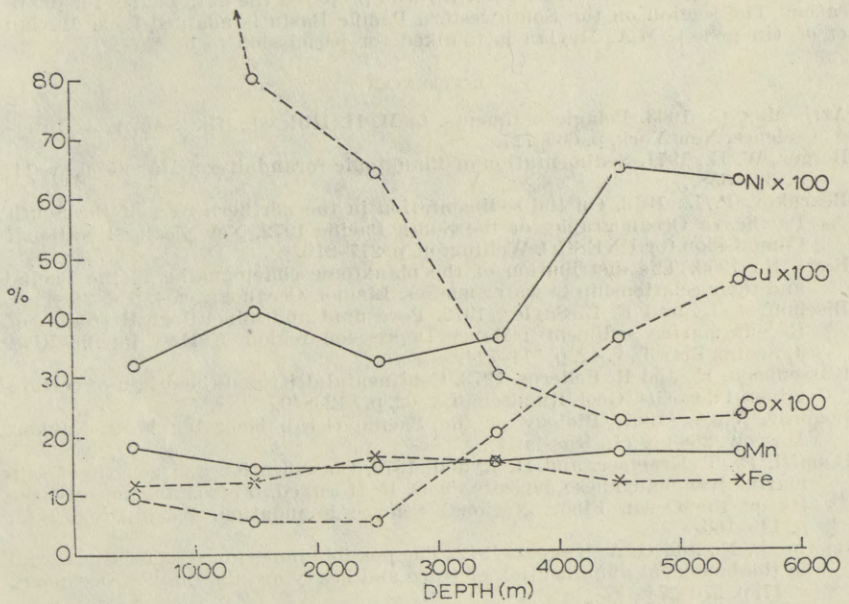

FIGURE 6.—Variation of element content with water depth. Data taken from Cronan and Tooms (1969, p. 340, table 5).

From the trace metal data so far available (Glasby and Lawrence 1974b–f), it would seem that very few nodules satisfy the basic economic criterion of having a Cu and Ni content exceeding 3%. Although nodules having nickel contents in excess of 1.5% are relatively common in basin environments, being observed in the ocean basin N. of Tahiti, the Peru Basin, the Chile Basin and to a lesser extent in the Southwestern Pacific Basin, no nodules have a copper content approaching this value. In fact, only three nodles, all of which occur in the ocean basin N. of Tahiti, have a copper content in excess of 0.8%. Since copper is the major element of interest from a commercial standpoint, this is a severe limitation of the region as a potential source of economic grade nodules. Nodules having cobalt contents in excess of 1.5% are found in the intermountain region between the Cook Islands and Tahiti. These nodules are deficient in copper and nickel and occur in regions of steep topography. For these reasons, they are of no economic interest. In the deep ocean basins, the content of cobalt is much lower (generally less than 0.4%). Thus, cobalt is only of marginal interest from a commercial standpoint.

On the basis of the presently available metal contents, only the deep ocean basin N. of Tahiti appears to have definite potential as a source of economic grade manganese nodules. The Peru Basin, Chile Basin and Southwestern Pacific Basin all appear to be of marginal interest. It must be emphasized, however, that extremely high surface concentrations of manganese nodules have already been discovered in the Southwestern Pacific Basin comparable with those of the red clay-siliceous ooze province south of Hawaii and that many of the deep water areas further from land (where Cu-Ni rich nodules may be found) are largely unexplored. Thus, the region does have a potential for nodules exploitation, with the proviso that future studies be restricted to the deep ocean basins.

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Chairwoman MINK. Dr. Glasby, we welcome you to these meetings. They are informal. You may proceed any way you choose. The paper will be part of our record. If we might hear from you, thank you very much.

STATEMENT OF DR. G. P. GLASBY, NEW ZEALAND OCEANOGRAPHIC INSTITUTE, WELLINGTON, NEW ZEALAND

Dr. GLASBY. Mrs. Mink, Congressmen, ladies and gentlemen, it is a great privilege to be asked to testify before your committee.

At the New Zealand Oceanographic Institute, we have recently become interested in the distribution of the metal content of manganese nodules throughout the South Pacific and so far I have adopted a two pronged attack to this problem.

Firstly, I have produced a series of charts showing the distribution of the metal content of manganese nodules throughout the South Pacific.

Secondly, I have recently led a cruise aboard the research vessel, *Tangaroa* to the Southwestern Pacific Basin to look for manganese nodules and this is to assess whether they are of a commercial grade. This cruise was an international effort with representatives of the University of Hawaii and the Valdivia Research Group of West Germany abroad.

What I have done, then, is to prepare a series of seven charts showing the distribution of the metal contents of the manganese nodules throughout the South Pacific. This chart [1] on the upper lefthand shows the distribution of nodules. There are two major limitations in the interpretations of this chart.

First, it shows only the currents of manganese nodules on the sea floor as recorded in the literature and, therefore, it gives no indication of the surface density of nodules on the sea floor.

[1] Chart has been placed in subcommittee file.

Second, there is a problem of sample biasing. For example, a considerable amount of work is being done by a U.S. Navy ship in the Antarctic region, whereas relatively little work is being done in the deep ocean basins far from land. As a result, there are far more denser points around the Antarctic than in the deep ocean basin, but in spite of this limitation, I think there is enough data to give a generalized picture of nodule distribution throughout the South Pacific.

Well, basically, there are three major types of areas, where nodules are found in the South Pacific. Here we can include this Peru Basin here, the Chile Basin, which is down in this region here [indicating], this basin the north of Tahiti here and the Southwestern Pacific Basin here. These are essentially red clay areas and the reason that the nodules are found here is because it is a low sedimentation regime so that the nodules aren't rapidly buried by sediment.

We also have this thousand kilometer wide belt stretching right down the Antarctic Continent here and here nodules are set in siliceous ooze and this is a very favorable substrate for nodule formation and the region is also one of very strong bottom currents that sweep the sediment away creating conditions favorable for nodule formation.

And the third major area in the South Pacific is the Summary Mountain Belt bounded by Tahiti in the Cook Islands and here nodules are found associated with carbon sediments on the plains of seamounts and with red clays in the depressions. So, it is a very mountainous region, but luckily very high concentrations of nodules are recorded here.

Professor Bezrukov of the Soviet Union recovered over 6 tons of manganese nodules of one dredged basin of the Manahiti Plateau.

Now, nodules do occur in other regions in the South Pacific. For example, they occur in the Campbell Plateau in New Zealand and, in certain seamounts of the Tasman Sea, but these really are thin encrustations of manganese phosphorites and certainly of no commercial significance.

I would like to draw your attention to the fact that there are virtually no nodules on the crest of the East Pacific Rise. This reflects the fact that it is an elevated region covered by carbonite sediments and this is essentially a dilute—a high sedimentation regime and so nodules can't form there, because they would be buried too rapidly. That also applies to the South—the Central Tasman Basin here, where you get input of tergilent (sic) from Australia and New Zealand.

Further south we have what is known as the Tasman-Manganese Pavement and here currents are sweeping away the sediment to create a regime favorable for nodule growth.

Coming now to metal content, this shows the manganese content.[1] What I have done is I have plotted a series of dots and I think you will have difficulty seeing these, but the very small dots here represent naught 5 percent manganese. Going up to the very large dot, that would be these greater than 30 percent manganese. The actual metal content is in parenthesis. Well, there is a major limitation in interpretation in the fact that these are taken from the literature, and if you will look at repeat in our seas from a given dredge hole,

[1] Chart has been placed in subcommittee file.

you will note that there is quite a considerable variation of an order of magnitude and extreme—between repeats in our seas. So, this does mask any real regional trend and you find that nodules from adjacent sites do show quite a lot of variability in composition.

However, the overall trend is that manganese is highest in the basin. We have 30 to 40 percent figures in the Peru Basin and the Chile Basin. It is lower—I'm sorry. In the Basin north of Tahiti. It is somewhat lower in the Chile Basin in the Southwestern Pacific Basin and generally quite a bit lower in the other regions such as around Tahiti and the Cooke Islands.

It is also somewhat lower around Antarctica, particularly in this direct passage region, where values less than 5 percent are common.

Coming now to iron, iron shows a different trend from manganese.[1] Iron is very much enriched in elevated regions like the submarine mountain growth in Tahiti and the Cook Islands. It depletes it in the Oceanic Basins and it is also tied in somewhat in the region around Antarctica. Particularly in this direct passage region, these nodules are really iron rich nodules rather than manganese rich nodules. But these two elements are probably of no commercial significance. They are what we could consider ore elements. The ore elements really are copper and nickel and this shows the distribution of nickel. Now the scale has changed so that they go from 0 to 0.25 percent in increments up to greater than 1.5 percent and that is the big dot.

The reason I have chosen this scale is because certain industrial authorities have suggested that 3 percent copper and nickel content is required for economic exploitation of nodules. So, nickel is highest in the basins, particularly the Peru Basin and the basin north of Tahiti and here values in excess of 1.5 percent are quite common.

It is somewhat lower in the Chile Basin and in the Southwest Pacific Basin and lower still in the other basic regions around here. It is also quite low in the region around Antarctica. Coming now to copper, copper tends to show the same trend as nickel, but it is generally present in about half the concentration of nickel.[1]

So, whilst the deep basin shows the same enrichment of copper relative to the elevated regions like the submarine mountain belt, the copper content is now quite a bit lower. So, here you get figures of, say, 1.2 percent occasionally, but quite often these values are less than 0.9 percent in both the basin north of Tahiti and the Peru Basin. They are even lower in the Chile Basin and the Southwestern Pacific Basin.

Again, they are lower still in the region around Antarctica and in this region here [indicating]. So, if we take this criteria, that 3 percent copper plus nickel as being an amount required for nodules mining, we can say that the only real places to look are this basin north of Tahiti here and perhaps the Peru Basin and the basin such as the Chile Basin in the Southwestern Pacific Basin may be of peripheral interest and we can, perhaps, ignore the submarine mountain belt around this region and the Antarctic nodules.

I should point out that various workers have shown that copper and nickel increase with depth in the oceans. It is exactly these deep oceanic areas which are the least studied. So, it would seem to me that

[1] Chart has been placed in subcommittee file.

with really detailed studies of these regions, one could well get higher values than I have shown.

Also, C.N.E.X.O., a French company has done work around here and not released its data for proprietary reasons. So, again, I think that these charts could probably be regarded as giving conservative values for the actual metal contents present.

Coming now to cobalt, cobalt shows a totally different trend from copper, nickel, and manganese.[1] Cobalt is more associated with iron. It shows its greatest enrichments in the submarine mountain belts around here [indicating]. In fact, values as high as 2.23 percent are recorded here [indicating]. In the basins, cobalt values become very low and values as low as .006 cobalt are recorded in these basins here. So, if we are going to take copper and nickel as being our primary targets, it follows that we must look in these two basin regions here.

In these regions, the cobalt content is so low, that we could probably regard it as being of very peripheral interest from the mining standpoint. The highest cobalt contents are found in the submarine mountain belt, but it is debatable whether they would ever be mined, because most mining operations require a region with a very smooth topography in order to operate.

It would not be advisable to mine in the mountain belt. So, the possibility of mining for cobalt rich nodules, I think, is nil. OK. I think we have left that chart.

Could I have the slides, please?[1]

To change the subject, now, in May of this year I led a cruise aboard the research vessel, *Tangaroa*, to the southwestern Pacific Basin to try and assess the commercial importance of nodules from this region.

This is the research vessel, *Tangaroa*, from which the cruise was carried out. Next slide, please.

This is just to show our cruise track. This is Wellington in New Zealand going up to Raro Tonga in the Cook Islands. This distance here is about 2,000 miles. Once in the southwestern Pacific Basin, we were sampling at an interval of roughly 50 to 100 miles in this region. So, we went on the northeast tract to Raro Tonga, came back south across to New Zealand. This gives an indication as to the nodule currents.

Nodules have a relatively thin cover around these two regions here and have very high densities in this region here. Particularly in this region 140 to 400 miles southwest of Raro Tonga, we have got extremely high densities of manganese nodules. It exceeded 20 kilograms per meter square sitting at the surface. There is almost a complete coverage of the sea floor. But they were generally in the size range of 1 to 6 centimeters.

They were spheroidal to ellipsoidal in shape with a granular surface texture. Very uniform in appearance. So these looked like a very promising yield. Now, south of Raro Tonga, we got an extremely wide variation in nodule morphology. We got manganese crust. We got botchurial nodules. We got spherical nodules with equitorial skirts. A very wide range in morphology is here, but our opinion was that these were, perhaps, of much less significance from the commercial

[1] Chart has been placed in subcommittee file.

standpoint. So, this is our main area that we discovered and I just found out that Dr. Hollister from Woods Hall has found nodules in the Samoan passage, which is essentially the elongate region of this, so I suspect we can go from here right at this channel into the Samoan channel to find extensive regions of nodules.

If I could have the next slide, please.

This shows the sediment color through this region. It goes from a light brown clay here through gradations of brown until we come to the dark brown clay just around Raro Tonga. These are going from—yes, these are going into a true abissel red clay around Raro Tonga. Essentially, the reason for this is that the sediment coming up from the New Zealand Continental Shelf is spreading out this way. It is only here that the sedimentation rate is low enough for manganese nodules formation.

So. it is the input of sediment from the New Zealand Continental Shelf which is prohibiting nodule formation in this western region of the southwestern Pacific Basin.

Next slide.

Just to show some cause, you see there that these are fairly light brown cores. You see, we are away from New Zealand. This is New Zealand here and we are going to, say, half way around to Raro Tonga. These are fairly light brown cores with no nodules. Next slide.

Now we are coming to Raro Tonga. We can see the cores are getting much browner in texture until we are getting to really brown cores here. The nodules are embedded in the surface. At the maximum, we got four nodules at the surface of one core 3 inches in diameter.

Chairwoman MINK. Could you point out the nodule?

Dr. GLASBY. I will be showing some more slides of this in a minute. This is the nodule. This is granular surface texture here. You can't really see them well, because they are a surface phenomenon. Next slide.

I think this will show it a bit more clearly. You see, there are three nodules on this one and one nodule here and they are restricted to the surface. Next slide.

Well, this is to give some idea of the distribution of nodules in the region southwest of Raro Tonga. You see it almost completely covers the sea floor. These are in the size range of about 1 to 6 centimeters. Next slide.

This is from the same site. This is a camera weight here to give you some indication of the distribution. Next slide.

Again, this is from the same site.

Chairwoman MINK. What depth, Dr. Glasby, are these?

Dr. GLASBY. These are at the depth of 5,400 meters, which was approximately 3 miles. So, they are a very deep deposit. Next slide.

Now, you see we are going out of the region of very high concentration of manganese nodules. Next slide.

And now we are almost completely out of this. Could we have the lights, please?

Chairwoman MINK. Would it be disruptive if we interrupted with questions as you went along?

Dr. GLASBY. I was just going to conclude very briefly. Several criteria must be met before manganese nodules can be exploited commercially. You must have a very high surface density on the sea floor.

You must have a very high metal content and here we take a copper and nickel content of greater than 3 percent as, perhaps, being appropriate.

They must be found near suitable port facilities for shipping. They must be found in regions of clement weather throughout most of the year and they must not be diluted on the sea floor by other rock fragments.

In the three areas we have been considering, the Antarctic seems to be of little interest because the copper and nickel contents are not sufficiently high. The weather would not be good—at least southerly latitudes throughout most of the year and there will be considerable dilution of the nodules on the sea floor by glacier rapids.

Similarly, the submarine mountain belt between Tahiti and the Cook Islands is of no interest from a commercial standpoint, because the copper and nickel contents are far too low. Perhaps the most promising regions are the deep ocean basins far from land.

In particular the Peru Basin and the basin north of Tahiti are being shown to have high copper and nickel content approaching the 3-percent level necessary for exploitation.

Similarly, as we have shown in this cruise, parts of the Southwestern Pacific Basin are extremely high in surface densities and manganese nodules comparing in density with the siliceous ooze province south of Hawaii. Unfortunately, these nodules have not yet been analyzed chemically.

Well, in conclusion I would just like to say that in my opinion, the South Pacific does have a potential for nodule exploitation with a proviso that future studies be restricted to the deep ocean basins far from land.

Chairwoman MINK. Thank you very much. Do my colleagues have any questions?

Mr. BURTON. What, if any, role have you or others been able to determine these nodules play in place that might disrupt the sea bed environment or balance of forces if removed?

Dr. GLASBY. Well, we have not done any work. The only work that I know of that is being done is at the Geological Observatory in New York. And they were of the opinion that actually moving these nodules from the floor of the ocean would not have a disruptive effect provided certain precautions were taken.

For example, in order not to depopulate the community, one might use strip mining, so one might mine 80 percent of the sea floor and leave 20 percent as the strip so you can have repopulation of the sea floor.

They concluded that the effect of bringing up water from the deep oceans, cold nutrient rich water, which would stimulate plankton blooms is not a major factor, so the turbidity and the high nutrient contents from this effect aren't important.

What people haven't talked about is the discharge of waste from the mining operation. For example, to leach out the copper and nickel, you have got to use extensive amounts of some sort of acid. Probably sulfuric acid and where are you going to dump this? Are you going to keep your operations at sea or at land?

Also, there is a problem that when you mine nodules, you are mining 3 percent of the nodule, so you have got 97 percent as waste. So,

you will have to come up with some answer, which tells you to do something reasonable with that 97 percent waste.

Mr. KAZEN. What is the method of mining?

Dr. GLASBY. Well, there are two major methods, which are being tested at the moment. The first is a continuous line bucket dredge system and I think what they are trying to do here is use a two-ship operation and have buckets going in a continuous line, say, 100 yards apart. These will go from the ship, down to the sea floor, pick up the nodules, come up, deposit the load on the ship and just go in a continuous bucket——

Mr. KAZEN. This is all surface mining?

Dr. GLASBY. Yes, they are purely a surface phenomenon. So, the idea is to scoop up the nodules. That is one method. And, you need two ships, because if you have one ship, you have got about 100 yards maximum that you could have between your buckets and the surface and it is 3 miles down to the sea floor.

Now, the other method, which is the one that Hughes is using is to suck the nodules up using some hydraulic suction system. So, you have—he has got an airlift pump, which fits into something the size of an aircraft hanger. He is going to place that under the Hughes Glenmar Explorer and use this as a suction pump to suck up the nodules. But the details of that aren't released.

Mr. KAZEN. Do we know the average size of these nodules?

Dr. GLASBY. Well, if you were going to mine them, you would know the average size distribution, because it would be very necessary to look at this in considerable detail before you started your mining operation. You would have to know your area very well.

So, yes, you would. Even on our recognizance surveys, you know roughly that nodules are going to be in the size range 1 to 8 centimeters and so, you would make necessary adjustments to your apparatus. You wouldn't mine if you knew you were going to get manganese crust.

Mr. KAZEN. Now, what density of nodules in any particular area is necessary before you classify it as commercial?

Dr. GLASBY. Well, this is an economic problem. I mean mining means you have got to be able to recover them and get more money for getting them up and for putting all your equipment down. This is a matter for economists, but, I would say that the highest density you could have would be on the order of 40,000 metric tons per square mile. Something of that order.

Mr. KAZEN. And we have the technology available to be able to survey this proposition?

Dr. GLASBY. Yes. We certainly have got the capability to survey regions in detail. This is being done. What is less known is how to recover them in the concentrations that they are talking about. I mean conservative estimates, say, a million tons of nodules a year, I think. A million a year or a million a day? A million a year.

Mr. KAZEN. A million?

Dr. GLASBY. A million tons of manganese nodules will be required to be recovered per year to break even, you see, because you are only really trying to get out copper and nickel, so you are only really talking about 3 percent of that as your recoverable ore.

Chairwoman MINK. Why is the manganese of no value? Why wouldn't you want to extract the manganese while you are at it?

Dr. GLASBY. Well, the trouble with manganese nodules is that their element ratios are not the same as the ratios of consumption in the world metal markets. So, if you would produce manganese for commercial exploitation, you would find that you would swamp the world market. That is if you are going to get reasonable copper and nickel contents out.

The other thing is I think it is a relatively cheap metal. Another factor is that the main use of manganese are in uses in steel production and battery production. For battery grade manganese dioxide you need very high purity manganese dioxide. These are highly contaminated by other metals and to get out the manganese and then reprecipitate out pure MnO_2 would, in fact, mean a very expensive extraction process. So, I think there are those reasons. They probably would extract manganese on a small operation.

Once you got into a really big operation, then it would not be worth mining manganese except as, perhaps, part of the operation.

Chairwoman MINK. What percentage of the nodule is manganese?

Dr. GLASBY. This varies greatly, but the highest it can go up to is 40 percent, but usually these nodules would not have high metal content. The lowest content might be 10 percent. Ten to 40 percent.

Chairwoman MINK. Are there any other questions?

Has your department done any surveys with regard to the northern part of the Pacific?

Dr. GLASBY. Not at all, no. That wouldn't be considered within our group.

Chairwoman MINK. Would you have any basis for making any statements with regard to the extent of deposits and so forth?

Dr. GLASBY. Well, it is accepted that the best deposits for manganese nodules lie in the belt that runs between California and south of Hawaii. These generally occur in the siliceous ooze red clay area south of Hawaii. I think it is generally accepted that if nodule mining is going to occur, it will occur here first. These have high copper and nickel contents.

Chairwoman MINK. In relation to the best deposits that you described this afternoon in the South Pacific, what would be the ratio of percentage compositions in the best deposits between Hawaii and California?

Dr. GLASBY. Well, certainly, I think it is a difficult question to answer, because most of the data in the Pacific is company data and, therefore, it isn't released. So, it is difficult to say.

Chairwoman MINK. Company data, you mean private?

Dr. GLASBY. Yes, private enterprise like Kennecott Copper.

Chairwoman MINK. Which companies are engaged in—that you know of?

Dr. GLASBY. All right. The main ones in the United States are Hughes, which comes under the name of Suma Corp., Kennecott Copper, Deep Sea Ventures from Virginia and I think those are the main American companies. In Europe there is the Valdivia Research Group of West Germany. Then France is doing some work under its group, CNEXO, and the Japanese Research Vessel was in port this

week and we went to look over that and they are obviously doing a very big survey program. They are just starting on a brand new vessel. So, the Japanese have got an interest in this too.

Chairwoman MINK. The Japanese vessels that are doing exploratory work in the north Pacific use the bucket method?

Dr. GLASBY. I think that is what they are working.

Chairwoman MINK. Do they have the buckets on the ships?

Dr. GLASBY. No. This is just an exploration vessel, but they said that this was an exploration vessel mainly to be used by the geological survey of Japan. What they are going to do is to build an exploitation vessel to test the system. Everybody is testing the systems with regard to exploitation. Nobody can actually mine these in quantities required at the moment.

Mr. KAZEN. Not even Hughes?

Dr. GLASBY. That information is just not made available to the academic world. So, I couldn't answer that question.

Chairwoman MINK. Do you know of any governments that have exploratory vessels that are strictly government research efforts and therefore information is generally available for the public?

Dr. GLASBY. There is New Zealand. Well, in the United States it is not being done through the Government. It is being done through groups like the University of Hawaii, but the trouble with the manganese nodules work is it contains a lot of proprietary information, so most of the data is either—for example, it is impossible to get any data at all out of Hughes. Almost the same applies to Kennecott. It is slightly better with, say, Valdivia Research Group in West Germany. In France, the CNEXO Group will not tell you a thing. I don't know what the Japanese will tell you. They have not produced any substantial work so far.

Mr. KAZEN. What information is it that they will not divulge? What are we talking about?

Dr. GLASBY. Well, we are talking about charts showing the distribution of nodules. We are talking about charts showing the metal contents of the nodules. I mean it just wouldn't be possible to get hold of it.

Mr. KAZEN. Well, this data could be available to other governments and to organizations such as yours?

Dr. GLASBY. No.

Mr. KAZEN. It wouldn't?

Dr. GLASBY. For example, the Valdiva Group of West Germany made part of its data available. Say, there was a conference here in Hawaii last year and they did prepare charts, but what they did is they left off their coordinates, so you could get some indication as to what they were actually doing, but they have entered into an agreement with Kennecott Copper and so what they are trying to do is form a consortium and, the restriction of the American firms is that Kennecott will not enter into data swapping agreements with European firms if the European firms make their data available.

So, the Valdivia Group is being forced into a situation where it could not release any of its data. So, because these consortia are forming, it means that nobody in the industrial world can release any information at all.

Mr. KAZEN. What I am driving at is that information is out there and available to anyone who wants to get it himself, is it not?

Dr. GLASBY. Oh, yes. If you take your ship, yes, it is.

Mr. KAZEN. What is the cost, for instance, of a reconnaisance trip like the one you made and just showed us?

Dr. GLASBY. Well, that is a difficult question, because we don't finance things in the way that you do, so we don't really have a monetary system as such. We just have a ship. Ours was a 30-day cruise. It might be $2,000 a day. It might be $60,000 worth of ship time. I mean, a $100,000 might be the minimum you could get away with to do a cruise like we did. That is not paying for staff to work up the data and get a chart production like that. So, it might be quite an expensive process, but we don't cost it, you see.

Chairwoman MINK. Is the New Zealand Government working on the environmental impact then of this type of exploration?

Dr. GLASBY. No, our studies are very preliminary. Indeed, the New Zealand Government would not exploit the nodules. We are in the same position as, say, the U.S. Geological Survey in advising the Government, rather than in actually exploiting the sources.

Chairwoman MINK. I am talking about the environmental impact that would come about as a result of exploitation. It would seem to me that that would be a unique governmental responsibility as to what happens and what the consequences are in the environment if there should be a commercial exploitation.

Dr. GLASBY. Well, in New Zealand we would regard nodules mining even if the Southwest Pacific Basin does prove to be mineable, to be at least a decade away. So, it would be premature to do extensive work on the enviornmental impact without even knowing that we have got a resource at all.

I mean, before we get any chemical analysis out of this cruise. When we get those out, we will be able to come to a more realistic assessment as to whether we have got a resource or not.

Chairwoman MINK. How did you obtain your nodules? The bucket method?

Dr. GLASBY. Oh, there is a difference between exploration and exploitation. In the exploration programs, you can use all sorts of things. We used dredging, coring, underwater cameras. This sort of thing, but we weren't trying to get vast quantities.

Chairwoman MINK. I see. In terms of displacement of the surface of the ocean floor, if you were to—just without knowing all the details of the two methods, which do you think would cause the most dislocation of the surface area? The bucket method, which goes along and scrapes up the bottom or the suction method?

In other words, really, the question I am asking is how are these nodules placed? Is it a simple matter of sucking them up or must you take up huge quantities of other materials at the same time?

Dr. GLASBY. I don't know, but clearly it is an inefficient system that brings up a lot of sediment with the nodules. The ideal thing would be to bring up nodules without any sediment. I am sure the engineers will try and do that, but as for environmental impact, we will really have no access to any data apart from the—I really couldn't answer that question.

Chairwoman MINK. Do you have any information as to the areas of the Pacific that the Japanese research vessels have been working in?

Dr. GLASBY. Well, they had a chart on their boat and I think, as I said, the Hawaiian Islands does—is that southwest of Hawaii? They

have a little chart in a region southwest of Hawaii and as I said that is where they were working.

Chairwoman MINK. How about West Germany?

Dr. GLASBY. I think they are working mainly south and southeast of Hawaii. But essentially they are all following the same belt of nodules. So, this is—it is just an east-west belt that comes off the west coast of the United States and south of Hawaii. It is this belt that more or less everybody is looking at.

Chairwoman MINK. So, the explorations really have not come down into the South Pacific, the Chilean and Peruvian areas, and Tahiti that you have described?

Dr. GLASBY. The only people, who are doing any work at the moment, I think, are CNEXO and, obviously being a French organization, they would like to operate out of either New Caledonia or Tahiti. So, they have been doing work north of Tahiti and also around New Caledonia. I would get the impression that they found some interesting nodules around Tahiti.

Then we have done some work in the southwestern basin.

Chairwoman MINK. The volume that has to be brought up, is it possible to do the very basic refining process on the vessels? I notice you mentioned that they could do it at sea or on land. Does this mean that a great part of it could be done at that very site and the sediment then just pumped back in to the ocean?

Dr. GLASBY. I really—I am talking a bit out of my field of speciology on this here, but I would suspect that what they might do is have another ship and a series of barges and the barges would then transport the nodules from, say, a port and refine there. But quite how, I don't know.

Chairwoman MINK. Are there any other questions? Mr. Burton?

Mr. BURTON. To get you further afield from the area of your specialty, would you have any thought on what kind of political or legal arrangements would be desirable in this area?

Dr. GLASBY. Well, that really is well outside my field of interest, yes.

Mr. BURTON. You are probably as much of an expert on that as we are in the area we are trying to educate ourselves about this afternoon. I would be interested in whatever thoughts you have in that regard.

Dr. GLASBY. Well, I think there is a certain amount of movement toward an international seat with some U.N. authority to cover all mining operations, but I understood that the U.S. Congress was not happy about the progress being made and was thinking of passing a U.S. mining bill, which would give protection to U.S. vessels that would be mining. So, I understood that if there was no international agreement set up, some sort of body to cover deep sea mining, that the U.S. Congress may unilaterally give U.S. ships some protection. That is my understanding of the situation.

As I say, you would know more about that than I.

Mr. BURTON. This thought occurred to me, in part, because you made some reference to the possible desirability of having a checkerboard kind of mining or extraction setup rather than taking everything in front of the sweep of whatever process you use. If there

aren't any mandated ground rules, the problems are there will be no ground rules observed. I was just wondering if you had——

Dr. GLASBY. The size nodules, where you have a distribution of 40,000 tons a square mile, then you would require 25 square miles to get a million tons. So, if you are mining, say, 80 percent of the area, you would require something like, say, 30 or 40 square miles to get 1 million tons of mineable nodules, which is what? Seven miles square. In other words, 7 miles square may satisfy a year's mining operation.

So, when I was talking about mining, we are not talking about mining vast areas. I mean, what Fermus (phonetic spelling) would be trying to do would be pinpoint good areas and then work on those. So, you are, in fact, taking the Pacific as a whole working on very small areas from the commercial standpoint.

Mr. BURTON. In the absence of some kind of international agreement, there is not any writ that any nation can construct that will run beyond its own national territory. You have a no man's land in the absence of some international—or multinational, at least, arrangement.

Dr. GLASBY. I can tell you what the 1964 New Zealand Continental Shelf Act says and that says that New Zealand will claim to mine—to exploit down to the 200 meter limit or to any depth thereafter, which is exploitable. So, consequently, it could strictly claim to, on a median line principal, to whatever—to Chile, we could match ourselves with Chile, say. But this is impractical. So, I would think that some sort of international agreement has to be obtained.

Mr. BURTON. You say Chile. How about Hawaii?

Dr. GLASBY. Yes. We could split it. We have a problem in New Zealand in that the Cook Islands are independent internally, but not externally. Because we found manganese around Raro Tonga within 14,400 miles of Raro Tonga, the Cook Islands have been suggesting that they should become fully independent in order that they can claim all these manganese nodules to be their own.

So, the 1964 New Zealand Continental Shelf Act, which also covered the Cook Island, would have to be amended in order to give the Cook Islands jurisdiction over their nodules. But even then, you see, mining companies would mine outside. You know, if you say—well, say the new U.N. law goes out the 200 miles. A mining company like Kenicott could come around the 200 miles outside their territorial jurisdiction. Nobody could stop them in such cases.

Mr. KAZEN. In your opinion how far are we from commercial mining of nodules?

Dr. GLASBY. I wouldn't really know, but at least 5 years and, perhaps 10. I don't know.

Chairwoman MINK. Any other questions?

[There were none.]

Chairwoman MINK. Thank you very much. We certainly appreciate your time and testimony here today. It is a matter that has given the subcommittee and, in particular, the chairman of the subcommittee a good deal of concern and we appreciate your giving us the benefit of your research. We will be following it with a good deal of interest. Thank you very much.

I would like to ask Dr. Andrews, chairman of the department of oceanography, from the university to speak next. Is he here. If you

have no objections, we would like to incorporate in the testimony just completed, copies of these charts that you have made available to us.

Dr. GLASBY. Fine, please.

Chairwoman MINK. Without objection, these will be added to the record. And, such other additions to the testimony as will clarify the explanations of the charts, which I noted are also referenced in the prepared paper that Dr. Glasby has submitted. Is Dr. Andrews here?

We welcome you, Dr. Andrews and realize the enormous responsibilities you have had to coordinate the Circum-Pacific conference from Hawaii and appreciate your taking the time to also take on this chore of educating this committee about manganese nodules. You may proceed in any way you wish.

Dr. ANDREWS. I thought what I would do would be to speak to the North Pacific area and also speak specifically to the program, which is presently being carried out by the University of Hawaii and several other universities under an IDOE National Science Foundation program to examine the origin distribution of manganese nodules in the—well, in the world oceans, but at the present time with specific reference to the North Pacific and the areas that may be exploited economically in the near future.

So, perhaps we could put on the first slide, which is a good one. The points raised by Dr. Glasby about the distribution of the nodules in the Pacific Ocean. This is a chart which actually shows distribution of sediment types, but the sediment types also tend to outline these nodule areas. Here is Hawaii. There is California, Baja, California, Mexico, and there is a belt indicated through here. The belt indicated through here marked as siliceous biogenic ooze on this slide, which is the general area of the presently recognized copper and nickel rich nodules. It is bounded more or less by two fracture zones. Here and here and extends—well, the good nodules from somewhere in the neighborhood of 125 over to at least 150 something.

The Japanese ship is looking at this little area over here beyond the Line Islands.

Chairwoman MINK. Where are we?

Dr. ANDREWS. We are right here [indicating]. Here is Oahu. Here is the big island. So, the nearest point in the work that we have been doing or that the Valdivia group has been doing is roughly 500 miles south or southeast of Hawaii.

Mr. BURTON. What is the light blue area that looks almost from here as if it is a lake or something?

Dr. ANDREWS. These are sediments which are related to the volcanic islands or volcanic seamounts. They in some part outline the areas which Dr. Glasby mentioned that would be more cobalt rich. You could find more volcanic type sediments here related to the fact that you have more volcanic structures.

Chairwoman. MINK. Can you walk by that again as to why the nodules occur where they do occur in the copper, nickel content?

Dr. ANDREWS. Well, that is one of the goals of the IDOE program.

Chairwoman MINK. Sorry about that.

Dr. ANDREWS. I can give you some of our thoughts on the matter. There are several possibilities. First of all, one distinct possibility is that the siliceous oozes are very much more porous than the red clays or the calcareous oozes on either side of them, so there is a greater

potential for interstitial water in the sediments to migrate and to influence growth of nodules.

Chairwoman MINK. Would you state that in English?

Dr. ANDREWS. These sediments contain much more water than these sediments or these sediments [indicating].

Chairwoman MINK. I see.

Dr. ANDREWS. Having more water, there is more room for that water to migrate within the sediments as the sediments accumulate slowly and there is one line of suggestion that this influences strongly what happens to nodules growing on the surface.

Another thought is that the zones of high biological productivity in the ocean lie along the equator and along about 10 degrees north related to the equatorial currents and it is thought that the organisms growing here may accumulate materials, particularly copper, into some of their body materials and that these go into the sediments and may influence the enrichment of the nodules.

Another possibility is that there is a relationship between hydrothermal activity, volcanic activity related to some of the factor zones here. A third possibility is as Dr. Glasby mentioned Antarctic bottom water coming north and through the Samoan passage. It turns across here, so this is also an area, which is scoured by Antarctic bottom water. Whether that water itself or the scouring activity may have some influence is also open to question. There are several theories that we are trying to explore as to why you should find—in fact, a fairly narrow line, if you wanted to get specific, you could almost draw a line that is the highest enrichment of copper and nickel and it would go something like this [indicating] in the data that is available in the published literature.

Just why that should be is, as I say, a major question. The people involved in this program, perhaps I should outline, are the University of Hawaii, Scripps Institute of Oceanography, the University of Washington, Washington State University, Columbia University through Lamont Geological Observatory, University of Rhode Island, University of Wisconsin, and the University of Michigan. So, it is a nationwide group.

The main area right now—in fact, we have just completed last month our first cruise in this program going down through this area and ending up in San Diego. The scientists at the university here are due to go back to San Diego in about 3 days time to bring the ship back again through this zone to extend these studies.

Outside of this area of rich nodules, there are nodules throughout particularly the red clay area of the Pacific, but again the copper-nickel values are rather low and are not such that they would be immediately attractive to mine. I do have one copy of this map that I can leave here. I was not able to locate any more than that, but there are more copies available.

Chairwoman MINK. Yes. Without objection, that will also be included in the record, if it is possible to reproduce at this point.

Mr. KAZEN. I want to make sure about this word "mine." It is more or less a harvesting, isn't it? There will be no actual violation of the crust or of the bed of the ocean, will there?

Dr. ANDREWS. No, except for a few inches, perhaps, or maybe a few feet, depending on the weight of the instruments involved. I suppose,

actually, since nodules, at least in some part of the ocean are still growing, you could call it harvesting in some sense. In some places they are going to be growing back. If they are going to be growing back with copper and nickel, it is debatable but, yes, it is skimming off a thin layer from the sea floor.

Mr. BURTON. What is the process by which these nodules grow or accumulate?

Dr. ANDREWS. I think if we could get the next slide it will answer that. Well, no, I have got a few slides that show——

Mr. BURTON. Just proceed and forget the question until you get to that point in your presentation.

Dr. ANDREWS. OK. I will come back to that. I have a series of slides from—mostly from the area we have been studying. These are photographs from cruises taken during the last 2 years showing more or less typical nodules from the equatorial area. Also illustrating one problem, here you see a moderate coverage of nodules. Perhaps on the order of slightly less than 10 kilograms per square meter, which would be just around 2 pounds per square foot.

You can, however, find widely variant nodules populations over short distances in this area. This is something which is not immediately visible in the data that Dr. Glasby had. There may be different kinds of deposits going on. He encountered very dense deposits over long distances.

Chairwoman MINK. What is the depth, the ocean depth of these deposits?

Dr. ANDREWS. These again are—this picture was about 5,100 meters depth and from the point of some of the questions that were asked regarding bentic life, you might note that there are here—I can't identify them for you, but there are things, which either are alive or are traces of things alive. Probably burrows. Areas where organisms have been actively processing sediment, but given that the area of this picture is probably something greater than 1 square meter, the density of organisms is not terribly great.

This is an item to keep in mind. Now, this is a picture in the same region a few miles from the last one and about the same depth. You can see here that the sea floor is quite different. There are a few fragments of volcanic rock, which are coated with manganese oxide to a small degree. A few nodules, a few organisms also, but a very much different picture than the last one.

Here is another area in the same region. A lot of sediment, where the camera hit. Here is a somewhat dense deposit, but small bare areas, where organisms have been active. So, one of the things that the investigators will have to—or that the mining operations ought to take into account is how these things are distributed on a small scale.

In other words, you don't want to pick an area that has more barren zones that has nodule rich zones.

Here is an even slightly denser deposit of nodules. That was one—I didn't know that Geoff would have his slides here. This was a picture taken on a Russian ship down toward the southwest Pacific in the Cooke Islands. I brought it just in case you weren't there, but, again, that is a very dense nodule coverage on the sea floor.

Now, to go back to your question about the origin of nodules, this is a—actually, it is an X-radiograph out of the section of the nodule

from the equatorial Pacific. You can see in this case there was a bit of volcanic glass and a series of concentric rings which have grown around the nodule. Not all of them go all the way around the nodule. It is not perhaps entirely clear here, but some of them are present.

For instance, this layer, which you can see—a boundary very distinctly here, and it doesn't go all the way around. So that in this case the attitude of the nodule on the sea floor it has presumably been changing with time and these layers have been accumulating either by precipitation of the material out of sea water, by accumulation of small particles formed in sea water, on the surface or alternatively migration materials through the sediments to add to the nodules.

It looks from the structure, from the number of nodules like this that they, in fact, grow mostly in contact with sea water, but you can still get a good argument on that point.

Mr. BURTON. What is the age of these nodules?

Dr. ANDREWS. The age of most of these nodules is probably—that is in this area where this one came from, would probably be in excess of 20 million years. They grow at rates that are on the order of a fraction of a millimeter to perhaps 10 millimeters per million years so that you have to have, for a nodule—which is in this case probably a diameter of about, I'd say about 5 centimeters this one was, you would have a period of at least 20 million years. Something like that.

This is a point that is not entirely clear, because original assumptions said that nodules grew slowly and continuously, but when you look at a picture like this that has bands of very distinct structures in it—in fact, the next slide, I think, shows it more clearly, where you can see structures that are—well, almost spherolitic. You can see all sorts of spherolitic kinds of structures around the sea and then a layer, which is very laminar and much denser in the X-ray and then an area, which is almost columnar.

It looks as though there may have been distinct kinds of episodes that affected the growth of the nodules. Microbe probe work that other investigators at the university have just completed at MIT has shown, in fact, bands like this may be significantly different in chemistry from bands on either side of them, which would suggest that something occurred at some point in time on the sea floor to change what was happening to the nodules. To change from a rather irregular looking growth pattern that may have been in fact slightly random, because the seed seems to be off center to a very well defined laminar growth pattern and then something else happened. So, whether changes in circulation of the deep water of the ocean or volcanic events, things like this, all may influence the growth.

We may be looking at a very discontinuous kind of program.

Mr. BURTON. You made the statement that in the area where you found the one nodule of which you have given us this cross section, that perhaps the nodule is older than or was in the process of reaching the stage, when you obtained it, of some 20 million years. You have devices, do you not, to measure the age of each of these layers?

Dr. ANDREWS. Within limits, yes. The technique most commonly used is uranium series dating, using some of the daughter products, ionium and thorium and these will permit you to date back to, perhaps, 700,000 or 800,000 years and perhaps a little bit more, so the technique is usually to try and scrape off at discrete intervals on the surface of

the nodule, measure the activities, try to establish whether or not the surface of the nodule was in an equilibrium with the sea water. Presumably these daughter products are not soluble in sea water and should precipitate into the nodule or the sediment, and to establish a series of points that you then extrapolate down to the center.

To date the material in the center of the nodule is usually fairly difficult, because if they are glasses, usually they are old enough to be altered entirely so that you can't use a technique entirely like hydration rhine dating except in some cases where, for instance, around the islands here, growth is very fast.

If there are basalt fragments or something like this, they also have been altered enough so that long-range radiometric techniques like potassium argon are not good, because the potassium has been leached out or the argon has been exchanged or something like this, but occasionally you find them growing on fossil material, which is readily identifiable.

There are good populations of sharks teeth in some areas, which can be occasionally dated. Also, occasionally, you find things growing artificially or enhanced artificially, because they are growing on spark plugs or old naval shells or something like this. This is a whole different set of problems.

Mr. KAZEN. What minerals are found in that nodule right there?

Dr. ANDREWS. A complex of manganese and iron hydroxides, really. This nodule here is from the North Pacific, the red clay zone and is relatively poor in copper and nickel compared to the equatorial ones. The mineralogy is very complex and people are beginning to think now that it may change as you bring them to the surface under pressure and they are cold and if you bring them up to the surface and let them dry out and lose moisture, that these things change so that some of the minerologists are not even confident that they know what they were growing as. They only know what they were being stored as.

We are trying now in this IDOE program to handle our samples very carefully, keep them frozen in sea water or refrigerated to perhaps find out what the original form was.

Chairwoman MINK. What is the temperature where these are growing?

Dr. ANDREWS. On the order of 2 degrees centigrade. Just slightly above freezing in this area. As you go farther south, it would be slightly colder. This was just one last slide from the same area, which I will be showing at the conference tomorrow, but just to indicate that in the same area, the same sequence of events is visible in the growth of a variety of nodules. You see the laminar zone, the columnar zone, and the inner zone and you can also find the time, when these two apparently came in contact and got—were cemented together by growth processes. I think that was the last slide.

Mr. KAZEN. Are the nodules solid or are they hollow?

Dr. ANDREWS. They are solid. In fact, I have here not a very good example of a nodule, because I picked it up in a hurry as I was leaving, but that is a nodule. It is relatively typical or atypical depending on how critical you want to be of it. Here are also fragments of another nodule, which did not totally survive the trip.

Mr. BURTON. What trip?

Dr. ANDREWS. The trip down here from the university. This was one which was growing on a piece of rock, so it was actually just a thin crust growing over it. Those, in essence, are manganese nodules. If you'd care to look at them, also, I have another collection of some photographs and so on. Just their occurrence on the sea floor.

Mr. BURTON. May we see them?

Dr. ANDREWS. Certainly. I would also point out that I don't have a complete set here and unfortunately most of the ones that I—we seem to be in the process of giving away charts almost as quickly as we make them, so I found the Atlantic charts, but not the Pacific charts that have been produced by people working in this idea we program and these are available from the National Science Foundation showing generalized distribution of metal in the Pacific Ocean.

The program that we are working on is pretty much in its infancy as far as a national program goes. It has only been operating for about a year and a half and has only had its first actual cruise during July and August of this year.

Prior to that there have been other investigations, but at least we do have a coordinated program beginning now.

Mr. KAZEN. Let me ask you something doctor. At what depth did you find this nodule?

Dr. ANDREWS. That one was only about 3,000 meters. Actually, that one is from near Hawaii, so that is not a copper-nickel rich nodule, but you can find them actually at almost all depths.

Mr. KAZEN. This was the original size of it?

Dr. ANDREWS. Yes. As you will see in the photographs, they run—the sizes can vary quite greatly, and even in the same area they can vary from having populations that are thumbnail size mixed in with nodules that may be several times as large.

Mr. BURTON. Most of these photographs are a couple of years old. Is there any significance in that?

Dr. ANDREWS. No; except that they were some of the clearer prints that I had from the cruise that we made to look at both questions of manganese distribution and also to try and see if there would be any environmental problems developed around mining tests. This was in 1972, and this was in this equatorial area.

Mr. BURTON. In the basement, in other words?

Dr. ANDREWS. Yes.

Mr. BURTON. Any particular part of the basement?

Dr. ANDREWS. Right where we were going to work. The only other significance was that they were the best pictures that I happened to have immediately available.

Mr. BURTON. How much money are we spending annually in this program of research in this area? Would you have any idea?

Dr. ANDREWS. I think the present grant to the program to these—whatever the total number of universities, the seven or eight universities, is about $600,000.

Mr. BURTON. Are these sea grant colleges that get this money?

Dr. ANDREWS. Some of them are and some of them aren't. I think the ones that are, are Wisconsin, Hawaii. I am not sure of the status of Rhode Island and Washington. Scripps and University of California sea grant program, but the money is not the sea grant, it is through the National Science Foundation.

Mr. BURTON. Do you have any view of what role, if any, organizations like Kenicott are playing or business organizations that are large consumers as distinguished from producers of, let us say copper, are playing, in terms of the level of funding that has been committed to the universities?

Dr. ANDREWS. Well, in an indirect sense, we do have an advisory council, which consists mainly of people working in the program, academic people and members from industry, who act in an advisory capacity to suggest what they would like to see us doing. They have made available at various times equipment or analytical services to the program. I can't speak for them, but I would suspect that they would enjoy seeing as much data gathered as possible so that there is better knowledge on what is going on.

Their main contribution on their part have been in kind in terms of loaning equipment and things like this.

Chairwoman MINK. We have often seen Government research data analyzed in terms of how many years supply is on hand either in storage or as a resource, a known resource in the field. If you had to describe the resource in the North Pacific in this rich zone area, how many years' supply would you say there would be of the two major minerals, copper and nickel?

Dr. ANDREWS. I would have to give that some thought. Dr. Glasby mentioned the fact that it would appear that you could use an area of relatively few square miles on an annual basis for mining, and the area you are dealing with is on the order of 600 miles by 1,500 miles, and I could do the calculation to see how many years that would come out to. The estimates have been there are quite significant reserves that would be on the order of more than 100 years. I don't remember the exact numbers of——

Chairwoman MINK. In terms of the current annual worldwide consumption of copper, there was a 100-year supply of copper in these nodules? In this band?

Dr. ANDREWS. I think that actually the numbers I have seen have been slightly more than 100 years.

Dr. GLASBY. You better not tell the governments and Chileans there that.

Chairwoman MINK. Would that be the same as to nickel?

Dr. ANDREWS. Yes. I think actually it is rather greater than that. If you are using, say, 10 square miles as an annual thing for a mine-site, you could have a mine operating successfully for several thousand years and several mines for several hundred years. Several mines there meeting the demands and if you went outside the rich area, and if you lower your aim a little bit—for instance, the mines in—it was reported at the meeting yesterday, I think, that many of the copper mines in Chile and Peru are running less than a percent in copper in the copper deposits that are being mined.

So once you have the system operating properly, then we presume that 200 years from now, you would be happy to mine eight-tenths of a percent copper instead of one-half percent copper, so the reserve is quite large.

Chairwoman MINK. So what kind of threat does this exploratory endeavor constitute for the land deposits of copper?

Dr. ANDREWS. You can get a variety of answers on that. Some people will say, "Well, you can save the world, because you can close down all the sulfide mines, which are polluting, when you try to smelt sulfides." Of course, that doesn't make the people at the sulfide mines happy, the copper sulfide people happy. Probably the answer is that the people, who are going to be exploiting it are in the minerals business at the present time and would probably not mine at a rate that would put themselves out of business someplace else, where you have already made your capital investments. At least, this would be my thought.

Chairwoman MINK. Is that the only safety valve we have for the control of the exploitation of these seabeds?

Dr. ANDREWS. At the present time, outside of having any either unilateral, bilateral, or U.N. type international agreement being reached, I would think, yes, probably enlightened self-interest on the part of the mining companies is the only thing.

Chairwoman MINK. Is there any commercial mining going on now of any of these nodules in either the Pacific or the Atlantic?

Dr. ANDREWS. No.

Mr. KAZEN. I assume the cost would be a factor, too, among these people? The cost of mining on land and the cost of sea mining?

Dr. ANDREWS. And at the present time, they are quite competitive and, if you find a reasonable political regime, it would look better, because you can build a mining ship and a refining facility and transportation lines. You don't have to develop a minesite and build railroads and towns and all this sort of thing and then worry about being nationalized at the same time.

Mr. BURTON. That works out better than you think. In Chile, the USAID program paid the Chilean government to pay Kenicott Copper for the nationalizing of the mines. So it isn't necessarily that burdensome.

Dr. ANDREWS. To the company?

Mr. BURTON. Yes. That is what happened. The government nationalized the mines in part and the aid program provided the money to the Chilean government to pay for the mines.

Dr. ANDREWS. At least we avoid that drain on the taxpayers, then, perhaps. I would make one other comment, also, in terms of enlightened self-interest. It has been—at least, to date and within limits, a practice of the companies to at least discuss actively or provide access in some cases to test for people doing environmental studies. When Deep Sea Ventures did their first test of the hydraulic lift system in the Atlantic 4 years ago, this was monitored and when the bucket line system was tested in the full scale prototype, this was also monitored. So, I think it is that probably people are fairly aware of the problems they might have.

Mr. KAZEN. Do we have a comparable study of the Atlantic?

Dr. ANDREWS. Only in a general sense. We do have some maps that have compiled existing data in the Atlantic and also in the north Pacific, but they are very, very general. They are based on materials drawn from archives at the various oceanographic institutes and there may be even some question as to the validity of all the data, because you don't know how the people did their analyses. In many cases you

don't know if they had dry weights or wet weights or what their errors might have been in the various things, but we do have some maps that are——

Mr. KAZEN. More work has been done in the Pacific area than in the Atlantic area?

Dr. ANDREWS. Oh yes, definitely. The Atlantic is not as rich in the nodules as the younger oceanic areas and it also has much more continental sedimentation. So the areas of nodule growth are much richer and much more restricted.

Chairwoman MINK. You just mentioned that some of these dredging activities, the bucket dredging and so forth that occurred were monitored. Who monitored them?

Dr. ANDREWS. Most of the sponsorship for the environmental monitoring has been through NOAA, through the National Oceanic Atmospheric Agency. In 1972 I think they still had in operation the tiberon, which was—do you remember the title of that—the mineral technology or something like this, center and now the group, who is proposing to carry this out further is associated with the Pacific Oceanographic Laboratory of NOAA in Seattle.

Chairwoman MINK. How do you mean monitor? Do they go around with these private venturers, that are doing the——

Dr. ANDREWS. In the case of the hydraulic lift system, the investigators from Lamont went on board the vessel and took water samples and observed sediment discharge and cultured bottom water that came up.

Chairwoman MINK. Went on board what vessel?

Dr. ANDREWS. The vessel that the Deep Sea Ventures had during the test.

Chairwoman MINK. Has anyone been permitted to monitor the Hughes operation?

Dr. ANDREWS. No. I am told that discussions are underway by people that know him, but I don't know if they have had any direct success in that.

Chairwoman MINK. Have there been any published reports on the monitoring of the Deep Sea Venture's vessel?

Dr. ANDREWS. Yes, there have been. Both that and the bucket line system tests have been published as reports at Columbia University.

Chairwoman MINK. Have you studied these reports so that you could give us a general summary? What about this matter of the enlarged plankton growth, when you bring the cold water up to the surface?

Dr. ANDREWS. This was actually something people thought might be helpful, because we could enrich areas in the sea surface, but it turns out that the dilution factors are so great that you would have to get something greater than 1 percent diffusion of bottom water into an average large area to influence productivity at all. This is what they found in culture studies.

And, the rates of dilution from discharge as they were studied were rapidly diluted well below 1 percent and would have very little effect, if any at all, on surface productivity.

Chairwoman MINK. What about the sediment problem?

Dr. ANDREWS. The sediment problem is not as clearly defined, because the area that that test took place was on the Blake Plateau,

where the sea floor tends to be a little bit harder. It is not—there is not as much extremely soft sediment as there is in the Pacific, and at that time there was a small sediment discharged around the ship again, which diluted very rapidly. This has not been examined in the kind of sediments that underlie these rich deposits in the Pacific, so it would be hard to say what would happen there.

Chairwoman MINK. Have there been any scientific research or monitoring of the actual floor that has been scraped off as to what happens there once these nodules are removed?

Dr. ANDREWS. We try to do that, but at the time we are not successful. Mainly because of limitations in navigation and controlling instruments on the sea floor or near the sea floor.

Chairwoman MINK. Is there any way you can pinpoint these areas that have been mined so that you could return to obtain the data later?

Dr. ANDREWS. Yes, you could. The problem is that in the—for instance, in the bucket line mining tests, there would be a path on the sea floor, perhaps as much as a quarter mile wide which would have been crossed by buckets so that you would get a set of stripes a quarter mile wide and the spacing of the stripes would depend on how fast we were running the system at the time.

If you run it very fast and the ship is drifting closely and they are close together—if your ship is drifting rapidly and you run the system slowly, then the stripes are going to be far apart. So, the major problem is not in locating an area where they did it, but in controlling the bottom instrument to systematically take a look at that. And also controlling your ship at the surface.

To do something like that you really have to put down acustic transponders on the sea floor and have very detailed navigation in an area that is only a few miles wide.

Chairwoman MINK. What about the quantity and quality and nature of the fish life at these depths?

Dr. ANDREWS. At depths it is very minimal. The sea floor at these depths is sort of the tail end of the food chain. Everything down there is essentially scavengers and a few predators living off the scavengers. Everything is growing in the upper 200 meters and then filtering slowly down through midwater populations till finally it hits the sea floor and enough organic material builds up in the sediments to support a small population of animals that just burrow around and digest the sediments.

Mr. BURTON. Apart from Members of Congress, what are the predators down there?

Dr. ANDREWS. Unfortunately, I don't have any photographs or documentation on the kinds of things—in fact, this is one area of biology that has relatively few investigators, just because there is relatively little and it is easier, for instance, to get grant support if you are going to study tuna fisheries or squid or coral reefs and sea cucumbers in the deep ocean 2,000 miles from anywhere have not generated a whole lot of interest so far.

Congresswoman MINK. So in your view, there would be no real impact on the food cycle?

Dr. ANDREWS. Not on the food cycle, no. Also as Dr. Glasby said if mining were—well, presumably it might even be very difficult to in fact make your tracts of your money systems such that they would

almost overlap. I would think you would have to leave some areas and these would probably repopulate the areas that you disturbed.

Mr. BURTON. Do you look forward with enthusiasm or concern to the prospect that we'll be mining seabeds?

Dr. ANDREWS. Well, I look forward with enthusiasm, I guess, because I have been studying the problem for about 7 or 8 years.

Mr. BURTON. How about your colleague?

Dr. GLASBY. Well it can certainly generate more interest in the scientific community. Yes. That is all I can really say.

Chairwoman MINK. Along with your oceanographic studies, is someone also looking into the economics?

Dr. ANDREWS. As far as our work is concerned, only very peripherally. That is it is fun to sit down in the evening and look at the assays and figure up the value.

Chairwoman MINK. How long have people known about the nodules?

Dr. ANDREWS. How long have people known about nodules?

Chairwoman MINK. Yes.

Dr. ANDREWS. Well they have known about the existence of nodules since about 1873.

Dr. GLASBY. They were found on February 18, 1873.

Dr. ANDREWS. I think people have discussed their potential as a mineral resource since the early midfifties. Since that time data has slowly accumulated to demonstrate where deposits are richest and what kind of things you could get at most easily.

Mr. BURTON. How would you account for Hughes apparently having the jump on everyone, the Government as well as private business organizations?

Dr. ANDREWS. They have the jump in one regard, which is the development of technology for mining and they have that, because they are in a position to make the kind of investment needed without worrying about answering to stockholders, whereas Kenicott will tell you, quite directly that they have a very large amount of data on the exploration side and they have probably areas that they know they will mine. They have not proceeded into building ships heretofore, because of the capital investment problem and the fact that they are answerable to the stockholders and boards. I think they would like to secure their investment with some kinds of international or national regime that would let them identify a mine site and then claim it for a period of years.

Chairwoman MINK. Mr. Leppert, do you have a question?

Mr. LEPPERT. Thank you, Madam Chairman, Dr. Andrews, you responded to a question from one of the members and I believe it was the chairman to the effect that the reserve here was approximately a 100-year reserve. Did your response indicate or do you distinguish in that response between an economically recoverable reserve as opposed to a total resource?

Dr. ANDREWS. Well actually that is sort of a minimum guess on economically recoverable. I think it depends by the time you get to the extent of this whether it was 100 years or maybe even 500 years, other things might look fairly recoverable and attractive because your systems were developed to the point where you could tolerate much lower grade ores.

So, in one sense you could just measure all the manganese nodules in the ocean and say that is the reserve, if you presume that the technology and need is going to make it profitable to mine lower grades later on.

Mr. LEPPERT. Ordinarily in mining they distinguish the reserves as an economically recoverable reserve as opposed to a resource. You are not doing the same thing here?

Dr. ANDREWS. Well I think that 100 years is certainly a reasonable estimate for the equatorial belt. I think then you can look at the question of what happens in the metals markets in mines that were closed down and were not economic 10 or 20 years ago and are being reopened now, because prices have reached the point where these things suddenly become profitable rather than just curiosity.

Mr. LEPPERT. You also said that the areas would be repopulated. How will they be repopulated?

Dr. ANDREWS. I think I was referring there to the question of the life on the seabed. If you move material out of a strip or if you disrupt the material in the strip, the animals living next to that strip actually are going to find some advantage, because this strip has been stirred up and organic material may have been too deep for them to get at before is now available and they are going to move across and occupy it.

Mr. LEPPERT. Is that an assumption or do you have data that shows that?

Dr. ANDREWS. Well, it has been demonstrated in a somewhat similar case in the case of movement of sediment off the Continental Shelf you get flows called turbidity currents, which are quite catastrophic, they break telephone cables and do quite a bit of the ordering of the sea floor. These things get repopulated very rapidly. In fact, almost preferentially, because they are moving in a new source of food for the bottom animals. This happens within a few tens to a few hundreds of years.

Mr. LEPPERT. Then would it be possible to classify the nodule as a renewable resource, or not in terms of the lifespan that you mentioned earlier in response to a question by Congressman Burton?

Dr. ANDREWS. Oh, you mean getting over into the growth of the nodule itself?

Mr. LEPPERT. That is right.

Dr. ANDREWS. Okay. The nodules are presumably growing or at least in some parts of the ocean they are actively growing, but the time scales are probably different enough so that you could not strictly class them as a renewable resource for exploitation. That is, you could probably exploit all of the nodules in the world's oceans in, I do not know, 1,000 years or 2,000 years or something like that, going everywhere you could and if they are growing at rates of millimeters per 1 million years, you have not regrown enough to replace it.

Mr. LEPPERT. I think Dr. Glasby said that nodules were first discovered in 1873. What kind of data was available from the time of discovery until the mid-fifties whenever there was some renewed activity in this area? Was there any data in this area?

Dr. GLASBY. Yes, there was. The major work—well, the nodules were discovered on the *Challenger* expedition, which went from 1872 to 1876.

Mr. LEPPERT. Which expedition?

Dr. GLASBY. The H.M.S. *Challenger* expedition, the British expedition and they went out and they discovered the nodules in the equatorial Pacific, for example, and from other regions. They circumnavigated the globe and then Agissiz, an American scientist went and did further with the equatorial Pacific so that belt was known in about the 1890's or early 1900's.

But then very little work was done from then on until the fifties, when oceanography really took off. So, you can almost say that in the mid-1950's the major work on the deep-sea manganese nodules were those of the *Challenger* and *Agissiz'*.

Mr. BURTON. How do you spell that second?

Dr. GLASBY. A-g-i-s-s-i-z.

Mr. LEPPERT. You said in the mid-1950's oceanography took off. What were the significant things that focused in on nodules?

Dr. GLASBY. Well mainly it comes down to one man, John Mero who was——

Mr. BURTON. How do you spell that name?

Dr. GLASBY. M-e-r-o. John Mero, who was a graduate student at California. He did some work on the various resources and he published a book in 1965, which drew attention to the potential of nodules as an economic resource. He had been writing smaller papers before the publication of this book, but really he was the only person up to 1965, who was talking about nodules as a resource and really, I think it is true to say that the firms, who are interested in nodule recovery did not really come to the scene until about 1970.

Dr. ANDREWS. I think John started working some of them earlier than that, because you could also go back to the 1950's as being the time bottom cameras and recording echo sounders and a variety of other things became available, generally, to research oceanographers and you suddenly got a picture like this and saw that you hadn't just happened on a few nodules, but here that they were really extensive.

Mr. LEPPERT. When did the major corporate activity begin?

Dr. ANDREWS. I think around 1965 or 1967. Somewhere around there.

Mr. LEPPERT. 1965?

Dr. ANDREWS. Something like that.

Mr. LEPPERT. Thank you.

Chairwoman MINK. Thank you very much. We heard that of the nodules, 3 percent is what we are interested in, is that correct?

Dr. ANDREWS. That would be the copper and nickel, yes.

Chairwoman MINK. So, 97 percent of that is waste. In addition to the problem of what happens to the sediment, when you are in the process of bringing this up, if there are no controls with regard to breaking this down and taking back to the plant, only that 3 percent; if there were no controls and the 97 percent of this was dumped over as tailings, what would then be the environmental consequence?

Dr. ANDREWS. It would depend on how you did it. Some of the companies looking at this problem feel that there are processing techniques which would leave fairly clean tailings that you might use as soil fill. Otherwise it might be just as——

Chairwoman MINK. Soil fill where?

Dr. ANDREWS. Wherever you happen to need landfill.

Chairwoman MINK. To build another island in our chain?

Dr. ANDREWS. Well I suppose if it was here in Hawaii I suppose you could use it to cover some of the lava fields, but perhaps the most direct route would be to take this back to the mine site and——

Chairwoman MINK. To the ocean?

Dr. ANDREWS. Yes and inject it back down to a depth, where it is going to get back to the sea floor and not interfere with the productive layers near the surface. Either that or find a very large spot to dump it in on land. You wouldn't want to dump it arbitrarily in the surface waters, because then there would be enough volume that you could possibly impede transmission of sunlight and production of——

Chairwoman MINK. What would be the consistency of the tailings? Would it be a powder? Or would the process require that it be in the form of a liquid? Or would it be like cement shale or what?

Dr. ANDREWS. Again it would depend on the process. The processes that have been discussed in the literature, some of them dissolve only portions. They grind up the nodules and dissolve portions of the metals out selectively and that leaves a powder or soil or a mud or whatever behind. Others would perhaps dissolve the whole nodule in which case you would be left with a liquid waste, which you would have to process somehow. Most of the processing techniques as Dr. Glasby mentioned have been centered on acid, leaching, and then removing the metals from solution mostly by electrical means. Beyond some publicity for Deep Sea Venture's leaching technique, which is the one that would produce a fairly clean soil type residue, these are fairly proprietary and have not been released extensively.

Chairwoman MINK. So the current research is to locate and to analyze the deposits, why they occur and so forth. We will have in the future then, a whole area of research in terms of the actual mining techniques that should be followed to safeguard the environment, to wit, the ocean as well as the land area, which might be involved in the recovery of the copper and nickel. Is that a fair statement of the state of art?

Dr. ANDREWS. I would think so. The areas that are being investigated by the academic community are, as you stated, the origin, distribution, and metal values of the nodules and the areas that are only beginning to be looked at are the environmental questions in deep oceans as the areas which have not been looked at at all, yet, are environmental and technical questions in the near shore areas, where you might have processing plants and transshipment facilities. Things like this.

Chairwoman MINK. Well, just a moment ago, we heard from Dr. Glasby that you could very well have two ships. One which would be in the processing and one on the recovery end.

Dr. ANDREWS. I think there would be a variety of possibilities. I would imagine that by the time this became a very sophiscated process in a couple of decades, that you might have at least preprocessing at sea and only final processing on land, but I would suspect in the present developments, that you would simply mine the nodules and return them to shore for processing there and then you would have your metal and your waste material at some shore site.

Chairwoman MINK. Are you acquainted with the UN law of the sea deliberations insofar as the kind of mechanisms that would be put

into place to also safeguard the environmental pollution of the oceans with mineral exploration and commercial developments?

Dr. ANDREWS. Not specifically, no.

Chairwoman MINK. Wouldn't you say that that would be an essential ingredient of any treaty?

Dr. ANDREWS. I would suspect that you would want to have a standard approach insofar as environmental limits are concerned. There are several ways that you could probably get at it.

Chairwoman MINK. We have heard that the nodule deposits around Hawaii are perhaps the richest in the Pacific areas. I assume that that is a correct statement?

Dr. ANDREWS. Yes, the ones south, southeast of Hawaii, yes.

Chairwoman MINK. Are these within the range of immediate commercial exploitation?

Dr. ANDREWS. Within the next 5 or 10 years I would imagine, yes.

Chairwoman MINK. What steps must the Government of the United States take to safeguard the ocean in the vicinity of the 50th State? If we are within 5 years of commercial exploitation, wouldn't you say we are within—really, we are almost too late to even be thinking what needs to be done?

Dr. ANDREWS. Well, there are existing clean water standards and things like this related to the near shore environment, which would, of course, be applicable to any land base facility.

Chairwoman MINK. I am not concerned if we can require them to bring it into land. I am concerned if we do not have such requirements.

Dr. ANDREWS. I don't think that the technology as such, that they will be able to avoid bringing it to land for processing for quite some time. A minimum time limit, let's say of 5 years, presuming that the international regime is reached or unilateral or bilateral agreements were made and people started mining, there is still the time necessary to construct the processing plants, which is going to be 2 to 3 years and to facilitate your mining so that using present technology——

Chairwoman MINK. If you had to put a dollar value on deposits that are within—where Hawaii would be the closest land base, where such processing could occur, what dollar value would you put on these deposits? Specifically, copper, for instance.

Dr. ANDREWS. Well——

Chairwoman MINK. Well, I have seen price tags. I am just interested in whether they are realistic prices.

Dr. ANDREWS. I think most of them are. If you are talking about mining 2 or 3 million tons of ore a year and 3 percent of that is copper, you are talking about a plant that is going to be making—a program that should be making——

Dr. GLASBY. About 60,000——

Dr. ANDREWS. It would be tons. So, you are going to have to be operating on a level of $200 or $300 million a year gross, I would think, at least. And the economic forecast—there was one published just recently in an engineering and mining journal, which suggested that by taking all sorts of environmental or economic factors into consideration, an investment of $300 million to $500 million to start the program would be paid off in 5 to 6 years and the rate of return would be 20 percent, and if you are talking about, then, gross products of.

say, a few hundred million dollars a year and you are talking about a large number of years of mining, however many years you apply to the reserve, if you apply 200 years to the reserve, then you have got several billions of dollars more. Estimates that go from hundreds of billions to, I guess, trillions, if you take the whole ocean basin.

Reserves probably aren't known accurately enough to get beyond a few hundred billion.

Dr. GLASBY. The trouble is that most people who know most about it are those who are least likely to talk about it.

Chairwoman MINK. With that kind of a figure and the extent of the reserves, you would think there would be hundreds of people out there scraping up the ocean bottom.

Dr. ANDREWS. Still, you have got to have the $300 or $400 million to invest in the first place.

Chairwoman MINK. We have heard that Mr. Hughes' interest is not in mining, but in developing the process so that he can patent it. Do you know if that is a true statement or not?

Dr. ANDREWS. I would imagine that he has several routes open at the present time. That is, I am sure if he developed an operating mining system, that he could sell as a package, that he could find quite a number of buyers, but I presume if he had something like that, he could also go ahead and mine it himself if it looks like that is also a profitable thing to do.

Chairwoman MINK. Who owns the patent on the bucket system?

Dr. ANDREWS. The patent on the bucket system is a Japanese design. I think the U.S. Patent Rights are owned by John Mero. John Mero and various other people have various patents relating to various types of hydraulic airlifts, waterlifts, pumping type systems.

Chairwoman MINK. Would you care to comment about the two methods? The bucket and the suction methods? Or do you think this committee ought to be concerned about one or the other or both?

Dr. ANDREWS. Well, they both have a potentially slightly different environmental impact, but I suppose the main difference between them is how effective they finally prove to be and also the capital cost. The bucket line system would be much cheaper, but you may not produce at quite as high a rate. The hydraulic system is quite expensive, but it may be somewhat more controllable because you have more rigid connection to the sea floor. It also depends on whether you are selling technology or selling manganese nodules. Which end you want to work away at. The expensive or the inexpensive end.

Chairwoman MINK. How do you divide up the ocean bottom among nations? Supposing four of you got to the same spot at the same time. How would you decide who could do it there?

Dr. ANDREWS. Well, if I can speculate not on how they would do it, but the fact that it has been announced in the press that Kenicott, for instance, has formed an international consortium with Consolidated Gold Fields, Miranda, Riotinta, Mitsubishi, and Deep Sea Ventures has formed a consortium with some other Japanese companies. You might find, if you leave it to the technologically developed nations, that they will form consortiums for capital investment purposes and reach internal agreements. I don't know. How else you divide it up, I am not sure.

Mr. VIGORITO. Do you know, doctor, has the Soviet Union been doing anything along this line?

Dr. ANDREWS. They are carrying out some investigations. They are not really looking at it as extensively as any of the other countries. Professor Bezrukov will be giving a paper tomorrow morning, I think the opening paper of the session, on some of their work. They did some work in the Pacific in 1972. And there is some work in the Indian Ocean in 1973. They haven't done anything in the Pacific since 1972.

Dr. GLASBY. Professsor Bezrukov told me that the manganese deposits in Russia are—they have got the most extensive manganese deposits in the world in Russia, and they will not be interested in manganese. They have got resources in Russia. So they are not too interested.

Mr. VIGORITO. Besides this subject matter, isn't the Soviet Union doing more research in the oceans than any other country? Are they leading the parade of all types of research in the ocean?

Dr. ANDREWS. That is a question that is difficult to answer. They have some very large and active research vessels. They have a more integrated national program, I guess. I really could not say whether they were ahead of us or behind us in that category.

Chairwoman MINK. I think Mr. Williams wanted to know if you had visited the Japanese ship last night.

Dr. ANDREWS. Yes.

Congresswoman MINK. Whether they extended an invitation. Do you care to comment on what you found interesting?

Dr. ANDREWS. Well, I felt very covetous, when I was on board.

Chairwoman MINK. Why? I'll make a careful note of that and send it on to the NSF.

Dr. ANDREWS. It is a very nicely equipped research ship and it is designed with a goal of geological exploration in mind. Comparing it to some of our ships, there is a different philosophy. It is a larger ship and it is more expensive to operate and I suspect that it is funded—the Japanese Government built it for the Japanese geological survey and it now becomes part of their line budget, that they operate the ship. Just like when you build a building, you plan that you are going to have to hire janitors and pay electrical bills.

I suppose that is the main difference between the U.S. academic community. When we get a ship, then we have to go to the National Science Foundation and the Navy each year to get funds to operate it. If we don't get them, we tie it to the docks, even though we still have an investment in the ship.

Chairwoman MINK. What is the name of the ship you use?

Dr. ANDREWS. The ship we used in 1972 was the *Kiana Keoki*, which belongs to the University of Hawaii and still does. The ship we used this year was a new one Egor 22, which was the *Moana Wave*, which was just built by the Navy for the University of Hawaii.

Chairwoman MINK. At what cost?

Dr. ANDREWS. I really don't know. I think it was on the order of $3 million.

Chairwoman MINK. How many scientists are onboard and how many provide the backup? The labor.

Dr. ANDREWS. On board the ship?

Chairwoman MINK. What is your total network of personnel?

Dr. ANDREWS. The manganese program?

Chairwoman MINK. Yes.

Dr. ANDREWS. Or at the university?

Chairwoman MINK. Yes. In the manganese program.

Dr. ANDREWS. Well, the shipboard complement on the *Moana Wave*, the way we were operating it was 13 scientists. It could be as large as 18 scientists, but then it limits your laboratory space. This included, on this last cruise three of the principal investigators in the program and on shore-based laboratories, there are another eight principal investigators with various technical support ranging from, perhaps, one graduate student at some places to two or three or four laboratory technicians and four or five graduate students at other places.

Chairwoman MINK. Does this mean you have contributing scientists from the seven or eight universities onboard at the same time?

Dr. ANDREWS. Yes.

Chairwoman MINK. May we ask for the names of the institutions these come from?

Dr. ANDREWS. Yes.

Chairwoman MINK. That could be provided for the record. I ask that this be inserted at this point.

[The information follows:]

PARTICIPATING INSTITUTIONS AND INVESTIGATORS—IDOE FERROMANGANESE RESEARCH PROGRAM

University of Hawaii:
- James E. Andrews [1]
- Dave Boylan
- Charles Fein
- Peter Kroopnick
- Stanley Margolis [1]
- Maurice Morgenstein
- Harry Zeitlin

Scripps Institution of Oceanography:
- Gustav Arrhenius
- James Greenslate

University of Washington: James Murray [1]

Washington State University: Ronald Sorem

University of Southern California: Richard Ku

University of Wisconsin (Madison): Carl Bowser [1]

University of Michigan (to be USGS—Reston, Va., Jan. 1, 1975): Edward Callender [1]

Lamont-Doherty Geological Observatory (Columbia University): Robert Gerard

University of Rhode Island:
- Michael Bender
- G. J. Schilling

MIT: Roger Burns

Others on board for Cruises Mn 7401 and 02:
- Michael Gauthier—CNEXO, Brest, France
- Wilton Hardy—University of Hawaii
- John Mero—Ocean Resources, San Diego

Other cruises participated in:
- New Zealand Oceonographic Institute: R/V Tangaroa. Wellington-Rarotonga-return.
- 1974 Maurice Meylan, University of Hawaii
- AMR—R/V Valdivia—Germany:
  - 1972 A. Abbott, University of Hawaii
  - 1974 J. Craig, University of Hawaii.

[1] Participation at sea on R/V Moana Wave.

Chairwoman MINK. If you had your way and you could ask the Government of the United States to provide this endeavor with what it could reasonably, rationably use for manganese nodules research, from all aspects including developmental, commercial development, environmental impact, what would you say would be the required budget for the next 5 years, taking your 5 years as the necessary time-span, because at that point it would be commercial.

Dr. ANDREWS. This would be including environmental research——

Chairwoman MINK. Yes.

Dr. ANDREWS. And so on?

Chairwoman MINK. Yes.

Dr. ANDREWS. It could have a sizable price tag over a 5-year period. Again, doing the calculation in my head on it would cost to equip and staff our program——

Chairwoman MINK. You are permitted to dream a little.

Mr. BURTON. This is what we promise, not what you are going to get.

Dr. ANDREWS. That is definitely understood. Well, over a 5-year period, you are probably looking at $20 or $25 million.

Chairwoman MINK. Pardon?

Dr. ANDREWS. Probably a minimum of $20 to $25 million.

Chairwoman MINK. That is very modest.

FROM THE FLOOR. Per year.

Chairwoman MINK. Oh, per year?

Dr. ANDREWS. Well, again, if you wanted to complete all these studies within the 5-year period, you would have to expand that considerably. I am just looking at the flushing out programs that I know are either proposed or are already existing. I tend to be fairly much on the lower end of monetary suggestions, too, most of the time, my colleagues tell me.

Chairwoman MINK. Dr. Craven doesn't look too happy in the back of the room. Twenty to twenty-five million per year for 5 years would provide this country with all it needs to know in terms of the commercial development aspects of manganese nodules so that we would be in a position to evaluate the commercial mining operations in these areas in the North Pacific, that would be the initial prime area that everybody would go to?

Dr. ANDREWS. I think that would.

Chairwoman MINK. Do my colleagues have anything else?

Mr. KAZEN. I want to come back to the 5- to 10-year period before we can go into this project in commercial quantities. It seems to me that unless there is something that we have not heard about, in order to be able to produce commercially within the next decade, we must have at least enough known areas, where there will be commercial quantities available. We must have the technology that is necessary to go into commercial production. We must have the equipment necessary and on line, and we must have the capital.

Now, does it seem possible to you that within 10 years we will be seeing commercial harvesting of manganese nodules?

Dr. ANDREWS. Yes, I think so.

Mr. KAZEN. We are that far advanced in all of these areas?

Dr. ANDREWS. I think we are at a point now, where if the legal climate was right, you would probably see the investments initiated to begin mining. That is, mining technology such as is being looked at on

the *Glomar Explorer*, the Hughes' ship. It is partly an outgrowth of techniques, for instance, developed by the deep-sea drilling project and operating the deep-sea drilling project is about $12 million a year, which would be a technology development cost.

There is enough known that you could identify several good mine sites. Not all good mine sites are known. The general area is known, but I think if the company were told that it could pick a thousand square miles of sea floor. If you told Kennecott that they could pick a thousand square miles of sea floor and feel safe in investing $500 million, that things would proceed fairly rapidly. That is my feeling on this.

Mr. KAZEN. And the ships could be built within that time frame?

Dr. ANDREWS. Yes. I think that the time frame on building the ship would probably be actually shorter than for building the processing plant. The processing plant, I think, would be at least 3 years to get it to a point where it would be functional and the ship you could probably do in 18 months or something like that.

Mr. KAZEN. But who is that far advanced that could start an operation within the next 5 to 10 years?

Dr. ANDREWS. All right. Hughes. Obviously they have a ship if everything tests out. Deep Sea Ventures with their consortium.

Mr. KAZEN. Wait a minute.

Dr. ANDREWS. Oh, I'm sorry.

Mr. KAZEN. Hughes only has the ship as far as we know?

Dr. ANDREWS. Yes.

Mr. KAZEN. They don't have the processing plants or anything else?

Dr. ANDREWS. No. They would have to start and build—well, everybody would have to build processing plants.

Mr. KAZEN. You say that takes around 3 years?

Dr. ANDREWS. I would think that would take around 3 years.

Mr. KAZEN. Starting from scratch?

Dr. ANDREWS. Yes. That is knowing what you were going to build of course.

Mr. KAZEN. Yes.

Dr. ANDREWS. Now, I don't know in the case of Hughes. I am sure Kennecott Copper and Deep Sea Ventures and probably International Nickel and a few others know exactly how they would build the processing plant.

Mr. KAZEN. All of these groups that you mentioned, you are satisfied that they do have the capital or will be able to acquire the capital?

Dr. ANDREWS. I would think so; yes.

Mr. KAZEN. Are any of the known areas now that you were talking about—you say there were several of them—what is their proximity to Hawaii, for instance?

Dr. ANDREWS. Well, again, for specific areas that are mine sites, I can't say, but for general areas that would be good for mine sites, I could say 500 to 700 miles would be the closest ones.

Mr. KAZEN. You were mentioning awhile ago that there are several known commercial sites now.

Dr. ANDREWS. I am sure the companies have maps, where they have little small dots that are very precise. We have broader maps, where we know that there are rich areas, but the kinds of surveys that we

have been conducting so far have, in fact, rather specifically not been directed to trying to assess whether this 10 square miles was of good mine site, but rather trying to assess how the nodules in this 10 square miles relate to this whole region and to local structures.

To try and determine why there should be nodules there that are rich.

Mr. KAZEN. We are then presuming that these companies know where these commercial mine sites are, but they are not talking about them?

Dr. ANDREWS. Yes. They have had exploration ships operating for 5 or 6 years.

Mr. KAZEN. Do we know from whatever information they have given us that there are these commercial areas and that they have been located, without telling us where they are?

Dr. ANDREWS. Yes.

Mr. KAZEN. Is this the type of information that they are withholding?

Dr. ANDREWS. It is quite common to ask a company for a sample if some worker who is not in an oceanographic laboratory wants to look at a nodule and they will be happy to send him a bag of nodules, but they won't tell him where they are from.

Mr. KAZEN. I see.

Dr. ANDREWS. It makes them a little bit less than totally useful for detailed study, because you have no idea, whether they came 5,000 meters or 2,000 meters or the Atlantic. Oh, they will tell you if they came from the Pacific Ocean.

Mr. KAZEN. This 5- to 10-year period you are talking about is general knowledge among your society, not specifically your estimate.

Dr. ANDREWS. Well, that is specifically my estimate based on my interpretation of what I have heard, but I think you would probably get the same kinds of numbers from—I think Dr. Glasby earlier said 7 years.

Dr. GLASBY. Well, somebody from Valdivia Research Group of Germany said that they would start mining by 1980 plus or minus 2 years. That is what he told me.

Mr. KAZEN. 1980?

Dr. GLASBY. Plus or minus 2 years.

Dr. ANDREWS. So, that is actually 3 to 10 years.

Mr. WILLIAMS. This would be in reference to the Ocean Dumping Act. I wondered if you had any experience at all with the effectiveness of the controls that the EPA Administration has through this act as it might apply to the disposal of wastes?

Dr. ANDREWS. No, I really don't. I am not sure how it would apply in international waters also. I think that this is one way that most people, who are pumping bilges or discharging wastes avoid these kinds of things by doing it on the high seas rather than within coastal waters. So, again you can probably police the coastal waters fairly well. It would be like an oil spill. It would be fairly obvious somebody did something and you would only have two or three or four or half a dozen people to go and put the finger on, but in the open ocean it might not be so apparent.

Chairwoman MINK. So, the key problem, as I see it—the key difficulty that private enterprise has in deciding to move ahead in this field is that rhetorical question you asked. If they could stake out 10 square miles of the ocean floor as theirs, then they would be prepared to put in a $200 million investment?

Dr. ANDREWS. This is what they have said.

Chairwoman MINK. And the question is how would such a staking be possible given the international legal situation? Isn't that really the issue? What has to be decided by the U.N. Law of the Sea Conference?

Dr. ANDREWS. The question, actually, the way the U.N. is looking at it, the way I can see it seems to be not only how you would issue this, but what kind of controls you would put with it. That is whether you were simply licensing them or whether you would in fact say, "I am subcontracted to you and I am taking the profits." Or whether you would say, "I am licensing you and I am expecting a royalty or we are going to apply an international tax to this rather than a national tax." Whatever might be done.

Chairwoman MINK. If my colleagues have no further questions, we thank you very, very much Dr. Andrews, for your contribution toward our understanding of this very complex matter and one which, of course, is exceedingly important to Hawaii specifically.

We thank you both for coming here and giving us the benefit of your knowledge.

Before we close, we have the luncheon address by President Cleveland inserted in the record at the conclusion of these hearings together with an introductory statement by Dr. McElvey, a statement, which he brought of the remarks of Secretary Rogers. So, without objection both of these will be appended to the hearing.

Thank you very much. The meeting of the subcommittee is adjourned.

[Whereupon the proceedings ended at 4:10 p.m.]

THE MACROPROBLEM OF MODERNIZATION

(By Harlan Cleveland, president of the University of Hawaii)

I

Each of us has now partaken of enough protein and calories to last an equivalent number of the world's disadvantaged people for two days or more. So we should be ready to face the world. And it's high time we do just that—face the world, not part of it, not one or another function or commodity or industry, but all of it at once.

I will make no apology for speaking today in the down-to-earth language of general theory. As practical men and women, there is nothing more practical for us to do today than to think comprehensively, inclusively, about the situation as a whole.

We humans are operators—we are very good at getting rapidly and efficiently to where we don't want to be when we get there.

Ten years ago, the focus of such a conference as this would have been the exploitation of resources and the production of energy. But the moral climate does not permit so narrow a focus in 1974. The key questions about Pacific energy and mineral resources are no longer just "How?" and "When?" and "How much?" but also "Why?" and "For whom?"

To build systems for the discovery and development of energy and minerals, in new forms and places including the deep-water ocean, will present a technical challenge of enormous complexity, at least as complex as the challenge of outer

space and advanced weapons systems. At the University of Hawaii we are launched on a major effort to find and package geothermal energy from volcanoes, and our Legislature has authorized a natural energy laboratory which will work to convert to human use the flood of energy we get here from our year-round sunlight. And because I am largely ignorant of the problems which the scientists and engineers among you will have to solve in developments like these, I am serenely confident that you will solve them.

But my profession is to conceive and build the institutions to divide up the wealth you produce, train the people you need, analyze the alternative choices your technical prowess makes possible, and formulate the values your energy and minerals will serve. And in this area, which I do know something about, it is harder to be confident that Man will learn in time how to harness his runaway power to a restraining purpose.

One of America's most thoughtful historians, the one who first dared to include the future as part of history, has recently produced a powerful and pessimistic prognosis. "Is there hope for man?" Robert Heilbroner asks, and gloomily answers his own question.

We are entering, says Heilbroner, an era "in which rapid population, the presence of obliterative weapons, and dwindling resources will bring international tensions to dangerous levels for an extended period. . . ." Human nature is quite unable to cope with the changes human beings have set in train. "Thus in all likelihood we must brace ourselves for the consequences . . .—the risk of 'wars of redistribution' or of 'pre-emptive seizure', the rise of social tensions in the industrialized nations over the division of an ever more slow-growing or even diminishing product, and the prospect of a far more coercive exercise of national power as the means by which we will attempt to bring these disruptive processes under control. . . . If then, by the question 'Is there hope for man?' we ask whether it is possible to meet the challenges of the future without the payment of a fearful price, the answer must be: No, there is no such hope."

We have on our agenda more urgent tactical issues, and more fascinating technical puzzles. But we have no more important mission at this conference than to consider how, in the great laboratory of the Pacific, we are going to prove Heilbroner wrong. And the agony of the historian's writing shows how badly Heilbroner would like to be proven wrong.

II

A good place to start is to look honestly at the changing assumptions, aspirations and attitudes that make the world's peoples so much more interdependent than their institutions, and their leaders' rhetoric, yet express. Each of the dozen elements I will mention is familiar to us in the abstract. But it helps to look at them all at once, as ten parts of the macroproblem of modernization:

1. Values once taken as basic are now in question. Long-time defenders of democracy are beginning to wonder, with Heilbroner, whether authoritarian government is the only way after all. In the "post-industrial" countries, quality of life is challenging quantitative growth as the central goal of national development. Charity turns out to be too fragile and unjust a basis for aid from the rich to the poor. Doctrines such as freedom of the seas and national control of communications are questioned as ethically and technologically obsolete. Those steadying institutions, the extended family and religious traditions, are enormously weakened—whether beyond repair is part of the macroproblem.

2. Concepts of the world as a biosphere, of different peoples as common residents of a global village, of future generations as possibly having no future if we don't act now, are taken seriously by many scholars and writers, if not yet by most statesmen and political leaders.

3. For the first time in history, barriers of prudence are seen as limiting what people can safely do to Nature, or to other people. Even if it cannot yet be defined, we sense now that there is an outer limit beyond which man cannot exploit resources without self-destruction; in the mastery of our environment, the costs are all too obviously catching up with the benefits. Nuclear weapons are likewise setting an upper limit to warfare; *guerre à outrance*, war to the uttermost, has so far been rejected in practice, if not always in theory, by every leader who acquaints himself with the potentials of nuclear conflict.

4. The "population bomb" is still ticking, and is no less dangerous now that the simultaneous equation of births and deaths is a staple of paperback literature. The least alarmist experts think the world's population will double by the year

2000 or shortly thereafter. In the last quarter of this century, the shelter and facilities requirements for all these people represents an enormous quantum of effort, equivalent (says the Club of Rome) to a thousand years of past construction. We can probably grow enough food for a world population of six or seven billion, but we have not yet demonstrated that we can get it past the institutional obstacles into malnourished and starving households. And climatologists are now warning that weather changes in the decades ahead may be adverse to food production as well.

5. The "soft" technologies of the biological revolution bid fair to do even more to change the world than the industrial/nuclear/electronics revolutions we have just been experiencing. Machines and drugs and procedures that can inspire or tranquilize people, alter human personality, raise or lower intelligence, enhance or impair memory and learning, make births more various or uniform, and extend the very frontiers of death present agonizing new choices for individuals, for families, and for public policy.

6. Each technological breakthrough thus adds to mankind's moral burden, by opening doors that used to be nailed shut, and making it possible to avert tragedies that could previously only be deplored. Now that many diseases are preventable and food for starving people can physically be produced and delivered, the act of *not* preventing, producing and delivering becomes suddenly outrageous. When weather can be modified at human command the ethics of changing other people's weather will raise a whole new set of reasons for international cooperation.

7. The revolution in communications and transportation connects peoples, and their leaders, with each other in ways that are inherently revolutionary. No violence is "local", no disruption one-of-a-kind, no fad or fashion limited by geography or culture if the mass media are looking on. No place need be remote that has a jet runway, direct-dial telephones, satellite radio and television, and terminals connected to a major computer; satellite exchange of data packages will make the world of information rounder than the world of coal and steel could ever be. The technologies that shorten time and distance are not necessarily "progress": they also make society's web more vulnerable to individual desperadoes or small groups of terrorists.

8. A proliferation of serious trade disputes, the breakdown of the dollar as the world's "key currency", and a new transnational pattern of inflation-with-unemployment, threaten to produce "a vicious cycle of competition, autarchy, rivalry and depression such as led to the collapse of world order in the Thirties (Secretary of State Henry Kissinger at the 1974 Washington Energy Conference). More workable rules of the international game, both for commerce and for money, are urgently needed.

9. The rich nations and the poor nations are overdue for a new, post-patronizing relationship. The coming struggles over resources, including energy, food, and metals will require ways of thinking and institutional arrangements which get beyond the postwar concepts of national development planning aimed at economic growth and supported by aid-as-charity. Again the moral issues are breaking through the surface of events. For example: "Why should the poor in the rich countries help the rich in the poor countries?" (Miriam Camps, in *The Management of Interdependence*).

10. In the years just ahead, minimum human needs threaten dramatically to out-distance the world's capacity to produce and deliver them. (Again the moral dimension is paramount: do the rich let enough of the poor die to relieve the population pressure in the Malthusian way, or do we rescue them whatever it costs? And if the starving are rescued, do we face what Heilbroner gloomily calls "the danger that the Malthusian check will be offset by a large increase in food production, which will enable additional hundreds of millions to reach childbearing age"?)

III

The interdependence of nations has long been a familiar litany. It must have been 20 years ago that the nationalistic American was first described as sitting in his Danish chair, wearing his Hong Kong suit, drinking Brazilian coffee out of an English china cup, writing a letter on Irish linen paper with a Japanese ball point pen. The letter is to his Congressman, and complains about too much gold going overseas.

Yet the nation-state has proven very durable indeed, as a focus of loyalty and a channel for political ambition. And in the United States at least, each international crisis strengthens in their resolve those who would limit our foreign entanglements.

The recent energy crisis was no exception: the rhetoric of Project Independence soon went beyond prudent conservation and active research on alternatives to fossil fuels, to put an overriding value on cutting off imports of energy by 1980. That goal is not only unrealistic—my impression is that by spending one-third of a trillion dollars we could only reduce our dependence from 18 per cent to 10 per cent or so by 1985—but almost certainly undesirable too. If America strives for autarchy at enormous cost, weaker more vulnerable nations will strive even harder to protect themselves. The resulting rivalries and the ugly scramble for scarce resources would surely bring the collapse of world order our Secretary of State warned against earlier this year.

Despite an occasional flourish such as Project Independence, the internationalization of the world economy is now so far advanced as to be an element in each nation's domestic politics. National political leaders live on the presumption that they can affect the destinies of the people they lead. Yet no thoughtful national leader can honestly claim that his government has under control the global trends that determine whether his constituents prosper or are impoverished, develop or stagnate, get sick or stay well, live or die. The determining factors are no longer "domestic affairs".

The very protection of "national sovereignty", not to mention the fixing of oil prices, requires collective action with other sovereignties.

Energy, pollution, human rights, racial tensions, education, science, technology, business, labor, food, transportation, population, culture, communication, terrorism, revolution, arms, drugs, religion, ideology—name a category and its international aspects are likely to outweigh its "domestic" aspects, now, or soon.

No nation now controls even that central symbol of national independence, the value of its money: inflation and recession are partly transnational. Because President Ford was addressing the American people the other night, he felt it necessary to diagnose these as domestic diseases, and set up all-American committees to prescribe for them. But inflation and unemployment are, of course, part of a global epidemic. The shortage of capital for investment in new resources, or new forms of energy, is worldwide. The status of many new resources—minerals from the seabed, protein from ocean waters—is uncertain, and can only be cleared up by governments working together. (Whether to divide the spoils or to place them under an international authority is the piece of our macroproblem which they have been fruitlessly debating at Caracas this summer.)

IV

For those of us who would bet on interdependence, there is a modicum of good news—some developments that may help mankind enhance control of its destiny.

For one thing, systems thinking has created new ways to help an individual encompass in a single mind "the situation as a whole". The fast computer, and the complex simulations it makes possible, become key tools for analyzing conflict, forecasting economic processes, assessing the future impact of present technologies, studying events as the interplay of many conditions, constructing decision models, and applying mathematical probability to social and political guesswork. These tools enable groups of human beings, drawn from different cultures and polities, to develop new comparative approaches to policy-choice analysis and make complex decisions in the more mindful knowledge of alternative futures.

Don't get me wrong. There are dangers in excessive dedication to systems analysis. Part of the tragic body count in Vietnam may be traceable to trying to quantify the tactics of war while neglecting the strategies of peace. Still, it is useful for the decisionmaker to be able to analyze what can be analyzed—as long as he remembers only to guess what can only be guessed at.

Don't we have a galaxy of public international organizations—regional alliances, common markets, and the U.N. family—to reflect and express the interdependence of nations? Yes, we do, but they are of course the subject of global dismay and disenchantment—and with some reason.

The United Nations Charter and other compacts of twenty-five or thirty years ago did not predict or provide for what we would now regard as gut issues in

"harmonizing the actions of nations": the distribution of energy, the pricing and distribution of food and other world resources, the management of inflation, the globalization of pollution, the explosion of population, the exploitation of the oceans and the seabeds, the limitation of strategic weapons, the spread of nuclear technology, the control of traffic in arms and in drugs, the modification of weather, the control of outer space. Some of these omissions have been partially filled in—some effective programs of development aid, a well-managed World Bank group, more than a dozen local peacekeeping operations, conventions to ban nuclear spread and bombs in orbit, bilateral talks about strategic weapons, conferences for international sensitivity training about population, pollution; and poverty. But the range and rhetoric of international cooperation has been simply no match for the pace of events.

Meanwhile, remarkably effective nongovernmental vehicles for transnational operations have been developing alongside the public international agencies, and in some degree beyond the reach of effective national regulation. In business especially, multinational enterprises (MNE) have solved many problems of communication, accountability, and staffing which organizations tied to national governments still find baffling. The world of interdependence they serve and reflect has rewarded them with an extraordinary rate of growth: MNE's now do nearly half a trillion dollars' worth of business, more than one-seventh of the gross world product, and are growing at something like ten per cent per year. It is seriously estimated that multinational corporations will account for one-half of the gross world product by the year 2000. There is obviously much to be learned about international cooperation from their successes, and excesses—and the important task ahead to reconcile their private purposes with their public responsibility.

Beyond the technical tools for the management of interdependence, our world environment of unglued values and threatened disasters defines an urgent requirement for world political leadership. But who are the contemporary leaders who presumed, as Churchill and Nehru and Betancourt and Paul-Henri Spaak and Hammarskjöld did, to address the human condition in its glorious and desperate entirety? Who in America is speaking, and is listened to, as Woodrow Wilson and Franklin Roosevelt and Adlai Stevenson were in their time? Try coming up with ten names. Three names. One name. See what I mean? The available political leaders—President Ford and the prime ministers, chairmen, monarchs and military politicians around the world—are talking to and for fragmented national constituencies. Who speaks for Man? Nobody?

The answer cannot be "Nobody", so it has to be us. We are gathered here because in one way or another we are or want to be leaders in thinking and acting about the future of the "circum-Pacific" area. If each of us merely says what he came to say and departs, we will miss a great opportunity. To match the macro-problem of modernization, we need to build a Pacific-wide consortium of the concerned, a community of continuous consultation about the purposes and values our miraculous technologies are going to serve.

If we miss this chance, here or soon, we who presume to leadership and are called President or Chairman or Director in our own communities, will deserve that devastatingly snide comment of Girardoux: "The privilege of the great is to watch catastrophe from a terrace."

STATEMENT OF HON. ROGERS C. B. MORTON, SECRETARY, U.S. DEPARTMENT OF THE INTERIOR, DELIVERED BY DR. V. E. MCKELVEY, DIRECTOR, U.S. GEOLOGICAL SURVEY

INTRODUCTION BY DR. MCKELVEY

Mr. Chairmen, Governor Burns, Mayor Fasi, Dr. Cleveland, ladies and gentlemen, I am doubly honored today—honored to have the oportunity to participate in the opening session of this most significant Conference on the energy and mineral resources of the Circum Pacific, and honored to speak on behalf of Secretary Rogers C. B. Morton. He had looked forward to attending this conference, but new duties just assigned to him by President Ford have prevented him from being here in person. When asking me to deliver his remarks to you, he also asked that I bring you his personal greetings, convey his regrets over not being able to be here in person, and make sure you know of his deep interest in and appreciation for the work you are about to do here.

I will now read Secretary Morton's address.

SECRETARY MORTON'S REMARKS

It is a pleasure to add my own warm welcome to those of Governor Burns, Mayor Fasi, and Dr. Cleveland. I am pleased beyond measure over the magnificent collaboration among the governments and scientists of the Circum Pacific countries in planning this conference and in jointly addressing themselves to examining the energy and mineral resources of this great region.

I am told that nearly 50 nations are participating in this, the first conference ever called to consider the total mineral resource potential of an entire region. The published transactions of this meeting will lay a foundation for the continuing effort to locate and assess the mineral riches of this enormous sector of the world.

I want especially to commend the ongoing effort to map the Pacific Ocean Area. Although it will be several years before the Circum Pacific Map Project will be completed, every increment that is published will have immediate usefulness to those who have some responsibility for providing the vital raw materials on which our countries must depend.

A major function of the ministry which I head is that of mapping the features of the United States, both natural and man-made. On the personal side I have an aviator's respect for maps and a firsthand knowledge of their critical importance to the user, and I am wholeheartedly in support of the effort to provide these vital navigation aids to explorationists who will be called upon to help us navigate efficiently to the mineral supplies of tomorrow. I wish success to all who are connected with this most important undertaking.

The United States has had close and enduring ties with the Pacific region since early in the last Century: from the China trade carried by the great Clipper ships; to Commodore Perry's mission to Japan; to the accession of Guam and Hawaii in 1898; to the present responsibilities it holds under the United Nations for the welfare of the Micronesian peoples residing in the Trust Territory of the Pacific Islands; and to friendly and mutually beneficial relations with Circum Pacific nations. More than 7,500 miles of the U.S.A. coastline borders the Pacific, and for more than thirty years the United States has been involved in close technical and scientific cooperation with other Pacific countries.

Scientists from my own ministry—the Department of the Interior—have worked in most of the countries represented at this conference, and worked jointly with many of their scientists. Contrary to the implications of its name—Interior—the Department has helped establish or strengthen earth resources agencies through major assistance programs in more than 20 Pacific countries.

The Interior Department and other U.S. agencies are involved in many major scientific research efforts in or adjacent to the Pacific region, including Antarctic mapping and research; the International Geological Correlation Program; and ocean exploration and drilling. The Pacific region is not only a major area to explore for resources. It is also the world laboratory for the study of active processes of geotectonics as they relate to the origin of energy and mineral resources.

By any measurement, the Pacific region is enormous. A billion people live along its shores. The Rim of Fire, in a giant arc from New Zealand to Patagonia, numbers more active volcanoes than all the rest of the world combined. The entire land area of the earth could easily be contained in the Pacific basin. To identify and assess the mineral wealth of such a region will be a formidable task indeed.

Precisely because of its gigantic proportions, the Pacific region must be explored for its ability to contribute to the rising needs of the world's people. The problem posed by these needs are themselves of giant proportions. There are at least 3.8 billion of us now and the experts expect the world population to be 7 billion by the turn of the Century. Not only will there be more people, but we can be sure they will not be content with today's level of living. Understandably and justifiably they will want something better.

"Something better" for 7 billion people means enormous new demands for materials of all kinds, especially minerals. This is not a conjecture on my part: it is an observation of trends already evident.

Twenty-five years ago, for example, the United States produced approximately half the world's minerals, by value, and consumed about the same share. Today it accounts for no more than 30 percent of consumption, and 25 percent of mineral production. The growth in demand for minerals by other countries has far exceeded that of the United States, and our share of the market has diminished accordingly.

The result of this large sudden increase in demand for materials of all kinds was to break the stable mold of long-term real prices of mineral commodities. Since 1963 these prices have been advancing—at first slowly, but lately very rapidly. A year ago the price of a pound of copper on the London Metal Exchange was 60 cents; today it is 86 cents. Lead has gone from 16 cents to 24 cents; zinc from 21 cents to 35 cents; and tin from $2.18 to $4.49 during the same interval. The price of steel scrap in the United States has almost tripled over the past year, and is currently about $145 a ton. The point here is not the prices themselves, but what they say about the outlook for future supply.

Let me cite the simple but critical example of food. The people of the highly industrialized nations eat well, and one of the primary features of their diet is its high content of animal proteins. But it's costly to "eat high on the hog," if I may use an American rural phrase, for this high-protein diet requires for its production about five times as much primary energy in the form of sunlight as does the average diet in Asia or Africa. To achieve a better quality diet for all peoples will require that a vast amount of additional crops and pasture land be put into use. The additional acreage will require tremendous amounts of fertilizer, water, pesticides, machinery, and all the other concomitants of efficient agricultural operation. The provision of these supplies will in turn demand enormous amounts of minerals and energy.

And speaking of fertilizer, one of the most severe problems to come out of the skyrocketing prices of petroleum over the past year has been their impact on the production of chemical fertilizers—which are critically important to the cultivation of the high-yield strains of wheat and rice which are the foundation of the Green Revolution.

Meanwhile, the population bomb ticks relentlessly on: 225 babies born every minute; 93 deaths every minute; seventy million people added each year, at a rate which would double the world's population by the year 2010. And I have only talked about one item—food!

I do not pretend to know what the world's demands for minerals will be as we enter the next Century, except that they seem likely to be multiples of what they are today. The exact numbers aren't important. What is important is that people everywhere come to realize that the provision of mineral supply, including the mineral fuels, will be the most important problem they have to deal with in the last quarter of this Century. Everything else depends on it, including the production of food and fibre. Mineral supply is now everybody's business, everywhere in the world!

As all of you know, there has been much argument in recent years over the question as to whether or not the earth's resources will soon be exhausted by the ever-increasing demands of people. Some talk about the future glut of energy and minerals as producers respond to higher prices and some see an urgent need to achieve zero growth in population and resource consumption.

The earth's carrying capacity, of course, will not for long sustain a doubling of the human population every thirty-five years, which is the implication of the present rate of increase. At some point, we shall indeed reach a point of equilibrium between population and resources, if not by design, then later of necessity.

But there is a world of difference between conceding and preparing for the ultimate arrival of a steady state between population and resources, and supinely resigning ourselves to some inevitable doomsday soon to come. The fact is that we have the capacity to create additional resources by discovery of deposits whose existence and location are presently unknown to us. And we can increase our ability to use the resources we have more efficiently. These are the processes by which men have satisfied their increasing needs for at least 8,000 years.

Our demands now are much greater than they have ever been before—but then so are our capabilities for meeting them if we are but willing to make the effort and apply ourselves to the problem with diligence and imagination.

Everything that we can infer about the presence of minerals in the earth's crust leads up to believe that vast resources remain to be discovered and developed. We have many recent reminders of this: the huge iron and bauzite deposits of Australia, discovered within the last 25 years in a continent that had been explored for more than two hundred; new discoveries of deposits of tin in the British Isles, where tin had been mined for 4,000 years; new deposits in the lead belt of my own country where lead had been extensively mined for two centuries. And here in Hawaii we are in the midst of a region that contains enormous deposits of metal-rich nodules on the sea floor, for which the recovery technology is now within our grasp.

It is true that we are now facing shortages in some energy and mineral commodities but I believe we still face a largely unexplored horizon, rich in opportunities to provide the resources the world needs. More of a problem than the adequacy of our potential is the problem of our attitude about what it takes to meet future needs. The spectre of scarcity has risen and been put to rest so many times in the past that there is a tendency to regard the present warnings as no more than passing annoyances.

But we can ignore these signals only at our great peril. New sources of yet-to-be-discovered minerals do not materialize overnight. There must be years of exhaustive exploratory and development effort, billions of dollars of investment, and a vast amount of patient, cooperative effort among nations to solve the political, technological, and economic problems that bar access to the new supplies. It takes time also to develop the technologies to use resources that are now too costly to produce and to significantly increase the efficiency of resource use so as to make them go further and last longer.

The essential ingredient—as yet largely missing—is a reservoir of popular support for the costly and difficult actions that must be taken by both government and private enterprise to assure that timely discoveries of new supplies are made and that conservation science and technology advance in a timely manner. At best, there is a long interval between the time when remedial actions are begun and the time when their effect begins to be evident in terms of increased supplies. Unless these actions are begun early, before urgency sets in, the likelihood is that their results will come too late to be of any real benefit. I am saying simply that the time to begin these actions is *now*.

This conference points in the true direction we should be travelling. It is a bold venture—to join together to examine the total mineral resource potential of half of the world's area.

It is a recognition of the essential interdependence of all the world's peoples, and the importance of working together to help solve world resource problems.

An adequate attack on these problems, including research to better techniques, requires joint government and private company efforts; the cooperation of national and international agencies; and mechanisms for articulating and implementing these cooperative actions. The Circum Pacific Conference and Map Project are prime examples of the kind of mechanisms that are so critically needed to develop new concepts and turn them into specific results.

To all of you here, I extend my best wishes for a successful meeting. To the sponsoring organizations and to Mike Halbouty, in particular, I want to take this opportunity to express my gratitude for assuming the burden and responsibility for arranging this vitally needed convocation at the geographic crossroads of the Pacific.

May this be the beginning of a long and friutful effort by the Pacific countries to develop the resources of this great region for the benefit of mankind.

Ladies and gentlemen, that concludes Secretary Morton's address. May I express my own appreciation and gratitude to the American Association of Petroleum Geologists, the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Area, the Pacific Science Association, other cooperating scientific associations and governments, and all those who organized and contributed to this conference for their dedicated and imaginative efforts in bringing us together to focus on the resource potential of the Circum Pacific region. And may I express also my belief that the international cooperation this conference involves and symbolizes will result in a successful attack on resource problems of concern to all of us.

Thank you.

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