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A GUIDE TO THE
SALTON SEA SCIENTIFIC DRILLING PROJECT

from

The Institute of Geophysics and Planetary Physics
University of California
Riverside, CA 92521

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Co-Principal Investigator: L. H. Cohen (714) 787-5029

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Abstract

We propose to perform an "add-on" experiment to a commercial geothermal well to be drilled this spring in the Salton Sea geothermal field in the Imperial Valley of California. By deepening it to 18,000 ft we would be able to study the deepest, and hopefully the hottest, geothermal well in the world. One aim of the experiment is to try to reach pressures and temperatures where "super-convection" may exist, i.e., zones where extremely high flow rates of very hot fluid are postulated to occur. If successful this would increase the potential of geothermal resources enormously.

Brines produced from this field contain unusually high contents of metals. Therefore this study is also important to understanding the formation of hydrothermal metal ore deposits similar to those known to be forming at the recently discovered submarine hot springs on mid-ocean spreading centers.

1.0 SUMMARY OF THE AIMS AND BENEFITS OF THE PROJECT

We plan to drill the deepest geothermal well in the world in the hottest geothermal field so far discovered in North America. The Salton Sea geothermal field is one of a series of geothermal fields in the Salton Trough, at the head of the Gulf of California, whose origin appears to be due to processes similar to those which give rise to high-temperature hot spring (hydrothermal) systems in ocean rift systems (sea-floor spreading centers). The geologic setting of this geothermal field in this zone of rifting, earthquakes and faults, where the earth's crust is being pulled apart, presents the only opportunity in North America to study processes akin to sea-floor spreading on land. There are obvious cost advantages to doing so.

In this environment, the rifting of the continental crust is accompanied by intrusions of molten rock (magma) from below. Such intrusions are the most likely explanation of the high temperatures already measured in geothermal wells in the Salton Sea geothermal field which exceed 690°F at 7,000 ft. For more than a decade many earth scientists have enthusiastically discussed the concept of deep drilling to penetrate such bodies of molten rock and the zones of convecting groundwater above them. Penetrating such hydrothermal-magmatic systems could unlock enormous sources of energy. However an experiment to drill into an actual magma chamber at depth would require extensive technological improvements to drill into such a hostile environment (temperatures exceeding 2,000°F at more than 25,000 ft depth). Some preliminary cost estimates suggest that to successfully drill into a deep magma chamber, even in a favorable environment such as a young volcanic terrane, might cost more than $100 million and require ten years of development work.

Our proposal is a modest preliminary step on the way to that long term goal. In the spring of this year Republic Geothermal, Inc. will drill a geothermal well to 12,000 ft in the eastern part of the Salton Sea field. We are requesting funds to study this well and deepen it to 18,000 ft. Situated as it is towards the flanks of the known geothermal field, we do not expect this well to reach a large magma chamber at only 18,000 ft depth. We aim to explore closer to the heat source in the roots of a hydrothermal system to look for possible zones of recharge where colder water is descending to be heated by the magma at greater depth, and to obtain samples of rock and water which will be used to interpret geophysical data obtained at the surface. These data will be used to model the three dimensional structure and hydrology of the whole field. This in turn will help us to better define future deeper exploration targets in the center of the field. The experiment will also help develop the necessary technology and experience of drilling and producing steam from wells which are deeper and hotter than those currently drilled by the geothermal industry.

The first 12,000 ft of the well will yield more samples and data to the public domain than are available from any commercial geothermal well yet drilled. Deepening the well to 18,000 ft will provide samples from a unique pressure/temperature environment never before investigated directly anywhere in the world. We would be exploring for permeable zones at depths and pressures never before explored in geothermal systems. We would also test the possiblity of creating fractures artifically and propping them open to generate permeability in the indurated rocks believed to exist at depth. Although such drilling is considerably more expensive than drilling to the more usual shallower depths, if successful, it may enter zones of "superconvection." According to a recent theory, at the appropriate (supercritical) high pressures and temperatures, fluid flow rates should be many times greater than those possible in less extreme conditions. Thus the speculation is such deep wells, although more expensive to drill, could yield much higher power output than wells drilled to lesser depths, because of the expected effect of higher pressure and temperature on flow rates.

A further important aim is to explore more deeply one of the most saline geothermal fields in the world, where brines contain more than 25% of the dissolved salts. Salinity-controlled density gradients permit very high temperature gradients because they tend to inhibit thermally-driven convection. These brines contain very high metal contents and are actively precipitating copper, lead, zinc and silver ores. Their study should provide considerable insight into ore genesis in hydrothermal systems. We plan to pay particular attention to the content of naturally-occurring radioactive elements in the rock and brine samples we will obtain from this well. One geological situation which is a likely candidate for the host rock for a mined repository for hot nuclear waste is salt, which occurs as beds or domes in various sedimentary basins in the USA. The temperatures found in the Salton Sea geothermal field equal or exceed those predicted to occur in such a waste repository. With this in mind the Office of Nuclear Waste Isolation has funded us to study geothermal fields as analogs of possible behavior around a waste repository. We are studying the extent to which radioactive elements are transported by the movement of hot brines in sedimentary rocks. Thus the samples obtained by the drilling discussed here will be an invaluable addition to this study of possible radionuclide migration in and near future nuclear waste repositories in salt mines.

Our estimated budget for the incremental costs of this project are approximately $6 million. The cost advantage of doing this as an "add-on" experiment to a well which is to be drilled anyway are obvious. Republic Geothermal, Inc. will have invested $15,000,000 in this site by the time development is completed. We estimate that the cost of acquiring a 40 acre site in the center of the Salton Sea field, paying for a lease, paying royalties, compensating the operators for loss of revenues from steam production, drilling a well to 18,000 ft, drilling a disposal well, building brine handling and pumping facilities, and operating this dedicated facility for five years would be in excess of $20,000,000. Costs of doing science in this facility would be additional to this estimate. We believe therefore that the plan we have proposed is exciting scientifically, technically feasible, and cost-effective. Furthermore we can begin immediately.

2. OUTLINE OF THE PROPOSAL

2.1 Introduction

Early in the spring of this year a private company, Republic Geothermal, Inc., will begin drilling a 12,000 ft (3.7 km) deep steam well, which will be the deepest well in the Salton Sea Geothermal Field in the Imperial Valley of California. This well will be used to supply steam to a power plant to be built by Parsons Engineering in the fall of 1985. We propose to "piggy-back" on this commercial well and pay for deepening it to 18,000 ft (5.5 km) for scientific purposes. Our aims are to drill the deepest geothermal well in the world. We wish to explore the roots of this intense hydrothermal system where temperatures reach 665°F at 7,000 ft (365°C at 2 km), and thus explore a regime of pressure and temperature never before directly studied in nature.

By the time this well is brought into steam production late in 1985, Republic Geothermal, Inc. will have invested some $15 million in developing this site. We are requesting a further $6 million of government funds will cover the additional engineering and scientific costs of our proposed experiment. Our proposal to the National Science Foundation requesting the first $405,000, which must be committed in FY83 to fit the timetable of the operating company, is under consideration. However, before committing these funds the NSF needs some assurance that funding for deepening the well to 18,000 ft will be forthcoming. We anticipate that these funds could come in FY84 and FY85 from a consortium of government agencies including the Department of Energy, the United States Geological Survey, and the National Science Foundation and others. Appendix I, the proposal submitted to NSF, gives a fuller documentation of the proposed project.

2.2 Background to the Proposal

The report entitled "Continental Scientific Drilling Program", published in 1979 by the U.S. Geodynamics Committee of the National Research Council, outlined the scientific reasons for drilling the continental crust for scientific purposes. The Continental Scientific Drilling Committee (CSDC) was subsequently established by the National Research Council - National Academy of Sciences to provide communication, coordination, and advice concerning implementation of such a program.

Four major scientific objectives were identified in the report (U.S. Geodynamics Committee, 1979): (a) Basement Structures and Deep Continental Basins, (b) Thermal Regimes, (c) Mineral Resources, and (d) Earthquakes. Both the Thermal Regimes Panel and Mineral Resources Panel of the U.S. Geodynamics Committee specifically mentioned the Salton Sea Geothermal Field (SSGF) as a desirable target for continental drilling: (USGC Report, 1979, p. 97 and p. 118-119).

Thermal regimes are manifestations of the earth's internal heat, the energy source for earthquakes, volcanoes and geothermal areas. The USGC Report (1979, p. 11) states:

> "The Panel on Thermal Regimes identified two major objectives. The first is to produce three-dimensional understanding of heat sources and products of thermally driven processes and to improve the boundary conditions of predictive models. The second is to remove barriers to the understanding of high heat-flow geothermal systems."

Similarly, according to the Mineral Resources Panel (USGC Report, 1979, p. 11),

> "The essential path to finding mineral deposits is to understand how the ore-forming processes have operated in the crust...Many important mineral deposits are concentrations of valuable elements mobilized and transported with energy derived from hot magma (molten rock) driving reactions between aqueous fluids and rocks within the earth. Such centers of magma-geothermal activity may be sampled in depth by drilling in two types of situations: (a) Currently active systems of interest in connection with fundamental principles regarding sources of geothermal energy... (b) Ancient mineralized hydrothermal systems that have yielded significant ore deposits.

In discussing scientific drilling the USGC Report pointed out the advantages of drilling "dedicated holes", i.e., holes drilled solely for scientific purposes but also encouraged "maximum use of holes of opportunity (holes drilled for specific mission purposes)" (USGC Report, 1979, p. 9). Even though they are expensive the advantages of "dedicated holes" are obvious. The advantage of "holes of opportunity" is that the largest part of the costs are borne by the operator.

In October 1982 we became aware that Republic Geothermal, Inc. (RGI) was planning to drill the deepest well yet sited in the Salton Sea Geothermal Field, and that the company was sympathetic to allowing scientific experiments to be carried out on this well if the well was deepened. After consultation with the RGI engineers we proposed to the CSDC, at its meeting on October 22, 1982, a technically feasible and cost effective plan for "add on" experiments in this hole of opportunity. The CSDC responded favorably to our proposal and appointed W. A. Elders as chairman of a steering committee to implement and oversee the project (see Appendix I). On November 8, 1982, a proposal entitled "Salton Sea Scientific Drilling Project, Phase 1" was submitted to the National Science Foundation (Appendix I). This proposal was discussed at an open forum convened by the Thermal Regimes Panel of the CSDC held at the annual meeting of the American Geophysical Union in San Francisco on December 8, 1982.

Approximately $225,000 of the funds requested in the Phase 1 proposal are the added costs of drilling the 12,000 ft deep hole at a larger diameter to permit deepening it to 18,000 ft. The remainder would be for sample collection and other studies in the first 12,000 ft of the well. **We now face the following dilemma:** the National Science Foundation is reluctant to commit the funds to drill the wider diameter hole to 12,000 ft unless funds to continue to 18,000 ft are to become available; on the other hand, unless we drill to 12,000 ft using the wider diameter bits and well casings, it will not be possible to continue below 12,000 ft. Thus, in order to get funds to begin our project, we must simultaneously obtain funds to complete it.

2.3 The Scientific Importance of the Salton Trough

By far the most important thermal regimes on earth are mid-ocean rift systems (sea-floor spreading centers) found in all of the world's oceans. Recent work suggests that the total heat flow through all the ocean rift systems amounts to about a quarter of the total internal heat flow out to the surface. The discovery of widespread intense outpourings of submarine hot springs on the East Pacific Rise is one manifestation of this activity. It is estimated that such hydrothermal circulation drives a volume of sea water equal to the total volume of the oceans through the mid-ocean rifts in about 10 million years. These hydrothermal systems at sea-floor spreading centers are important scientifically because they have profound effects on the chemistry of the oceans. Also we now recognize that certain kinds of economic metallic ore deposits, now found on land as the result of plate tectonic activity, were initially formed at such rifts.

Such oceanic hydrothermal systems are new and exciting targets for oceanographic research. However there are obvious cost advantages to studying these systems on land in the few rare instances where sea floor spreading centers affect land masses. The only opportunity for such a study in North America is in the Salton Trough, the landward extension of the Gulf of California (Figure 1). The Salton Trough appears to be in every way similar to the Gulf of California except that has been partially filled by the sedimentary deposits by the Colorado River. The Gulf of California is, in turn, a region transitional between the sea-floor spreading system of the East Pacific Rise and the southern end of the San Andreas Fault System. The Gulf contains numerous depressions such as the Guaymas Basin, where sea-floor spreading is occurring and submarine vents discharging hydrothermal brines at 650°F have been observed. These basins are connected by faults which continue north into the Colorado Delta and merge into the San Andreas Fault.

The Salton Trough is the site of numerous geothermal fields, now being developed for electrical power production (Figure 2). It also contains young volcanoes at Cerro Prieto, Mexico, and at the Salton Buttes, California, and is subject to frequent major earthquakes and earthquake swarms. These earthquake swarms are thought to be produced by intrusions of magma (molten rock) into the sedimentary section; indeed the most likely source of heat for the geothermal fields is igneous intrusions at depth. In several of the geothermal fields dike rocks, i.e., small solidified igneous intrusions, have been encountered in drillholes.

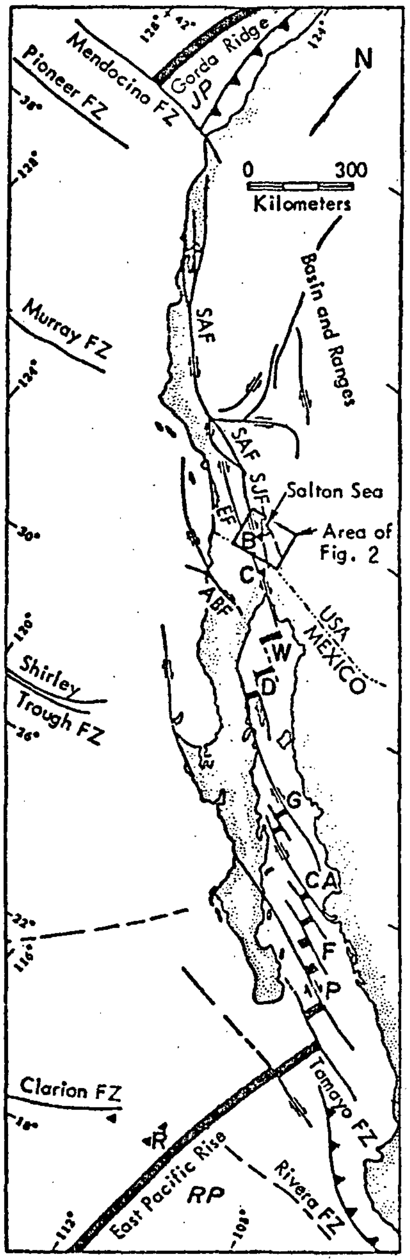

Figure 1. Gross tectonic environment of the Salton Trough. The Pacific Coast of North America is dominated by transform fault systems, which connect the Mendocino triple junction to the Rivera triple junction. Also shown are pull-apart basins between en echelon fault segments in the Gulf of California. Oceanic fracture zones (FZ) and continental faults (F) are solid black lines, dashed where uncertain. Other abbreviations: SAF = San Andreas Fault; EF = Elsinore Fault; SJF = San Jacinto Fault; ABF = Agua Blanca Fault; JP = Juan de Fucca Plate; RP = Rivera Plate; W = Wagner Basin; D = Delfin Basin; G = Guaymas Basin; CA = Carmen Basin; F = Farallon Basin; P = Pescadero Basin; ▲ = Holocene volcanoes; B = Salton Buttes; C = Cerro Prieto; and R = Revillagigedo. From Elders, et al., 1972.

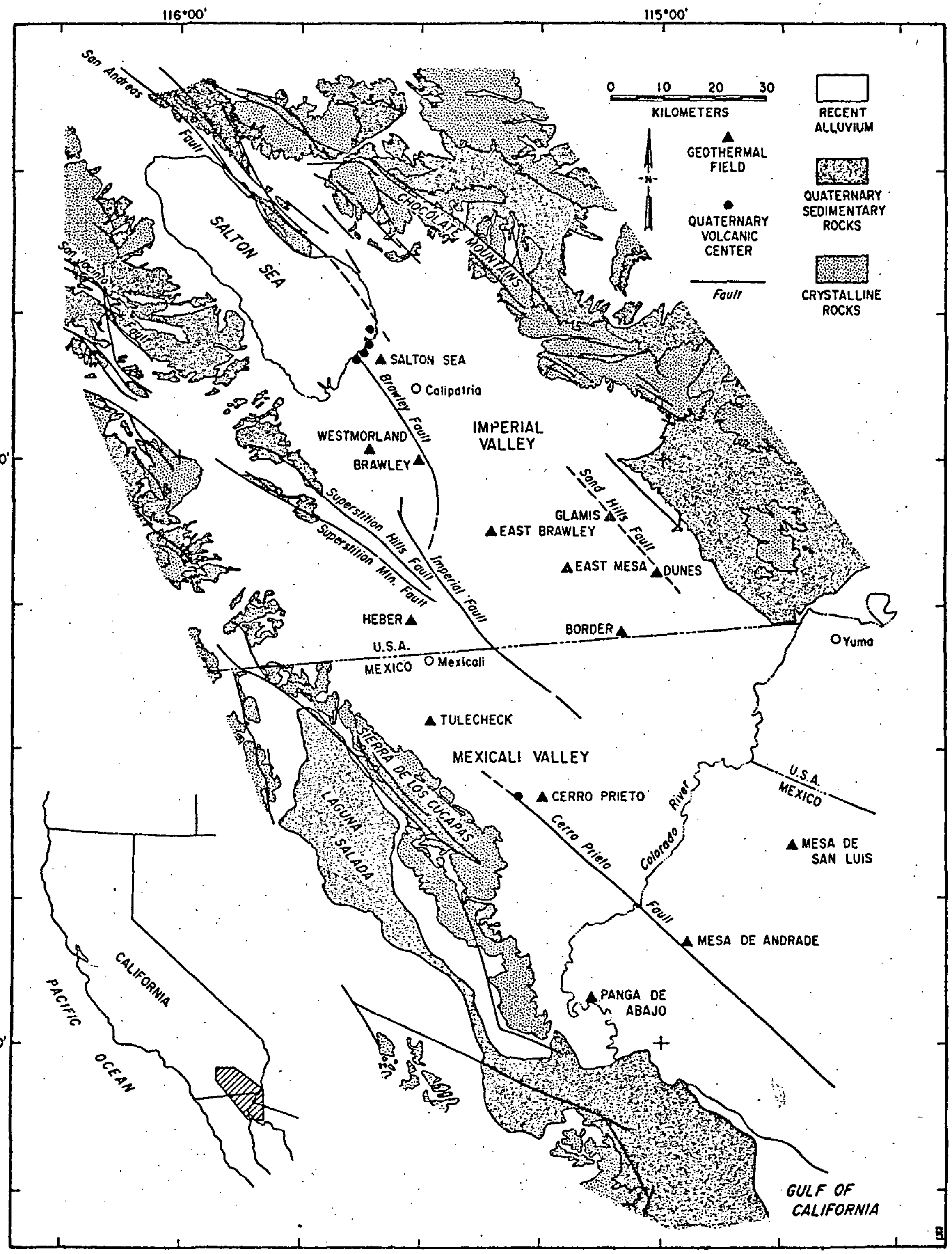

Figure 2.

Geothermal fields of the Salton Trough.

2.4 The Salton Sea Geothermal Field

The Salton Sea Geothermal Field is the largest of the series of geothermal fields so far explored in the Salton Trough (Figure 2). At least 32 wells deeper than 3,300 ft penetrate the system, making it the most extensively explored field in the Trough north of the international border (Figure 3). Since the summer of 1982 an electrical generating plant of 10 MWe has been in operation by Southern California Edison, with steam supplied by Union Geothermal Inc. Two plants of approximately 50 MWe each with steam to be supplied by Republic Geothermal, Inc. and Magma Power Company are planned.

The Salton Sea field exhibits the highest temperatures so far recorded in any geothermal field in North America, 690°F at 7,070 ft. Such high temperatures would cause pure water to boil even at the pressures encountered at depth. However the reservoir is occupied by hot brine rather than steam, because boiling is inhibited by the high salt content of the brine (up to 25 weight per cent of salt). These salts are themselves a potential resource as they contain high concentrations of ore-forming metals such as lithium, zinc, copper, lead and even silver. Ore minerals are abundant in cores and cuttings taken from these wells.

It is estimated that the value of the dissolved solids in the hot brine necessary to supply steam to a 50 MWe power plant for a year would have a value of more than $1 million. Since economic methods of recovery are lacking, the salt content of the hydrothermal fluid is at present more of a liability than an asset. Expensive brine-handling facilities are required both to produce clean steam for power generation and to inject the spent brine into disposal wells so that the power generating system is non-polluting.

These potential ore-forming fluids are of great interest to students of the genesis of hydrothermal ore deposits. Currently the University of California-Riverside is funded by the Office of Nuclear Waste Isolation to study the migration of naturally-occurring radio-active elements in these hot brines as analogs of possible behaviors in the near field of a nuclear waste isolation facility in salt. In both a geothermal field and a nuclear waste repository hot concentrated solutions may cause migration of dissolved chemical elements.

Recently suggestions have been put forward that at high enough temperatures and pressures a "superconvecting regime" may exist. According to this hypothesis, near the critical point of water, where the distinction between water and steam disappears, the physical properties of water are discontinuous (Figure 4). Specifically it is postulated that the ratio of the driving force for convection (buoyancy) to the forces resisting fluid flow (viscosity) increases by a factor of a thousand. The implication is that this would cause very high fluid flow rates and efficient heat transfer. Such "superconvection", if it exists, would have a revolutionary impact on the economics of geothermal power production. As an example, deepening a well in order to reach supercritical fluid at several times the cost of a conventional well would be economic if it produced at a rate considerably greater than that of the conventional well.

Superconvecting regimes have not yet been encountered in nature. However the temperatures and pressures in the Salton Sea geothermal field come closer to the critical point of water than in any other field known to us. The critical point is of course elevated in temperature and pressure by the high salinity. However the steep temperature gradient in the Britz #3 well

Figure 3. Location of existing and proposed geothermal wells in the Salton Sea and Westmorland geothermal areas (from Geothermal Resources Council, 1981).

- ⓫ Geothermal wells for which samples and/or logs exist at UCR
- O Other geothermal wells
- ✳ Proposed well Fee #7

# on map	Well name
1	Britz #3
2	River Ranch #1
3	Sportsman #1
4	I.I.D. #1
5	I.I.D. #2
6	State of California #1
7	Elmore #1
8	Magmamax #3
9	Magmamax #2
10	Magmamax #1
11	Woolsey #1
12	Sinclair #4
13	Sinclair #1
14	Sinclair #3
15	Landers #1
16	Landers #2
17	Dearborn Farms
18	Kalin Farms
19	Fee #1

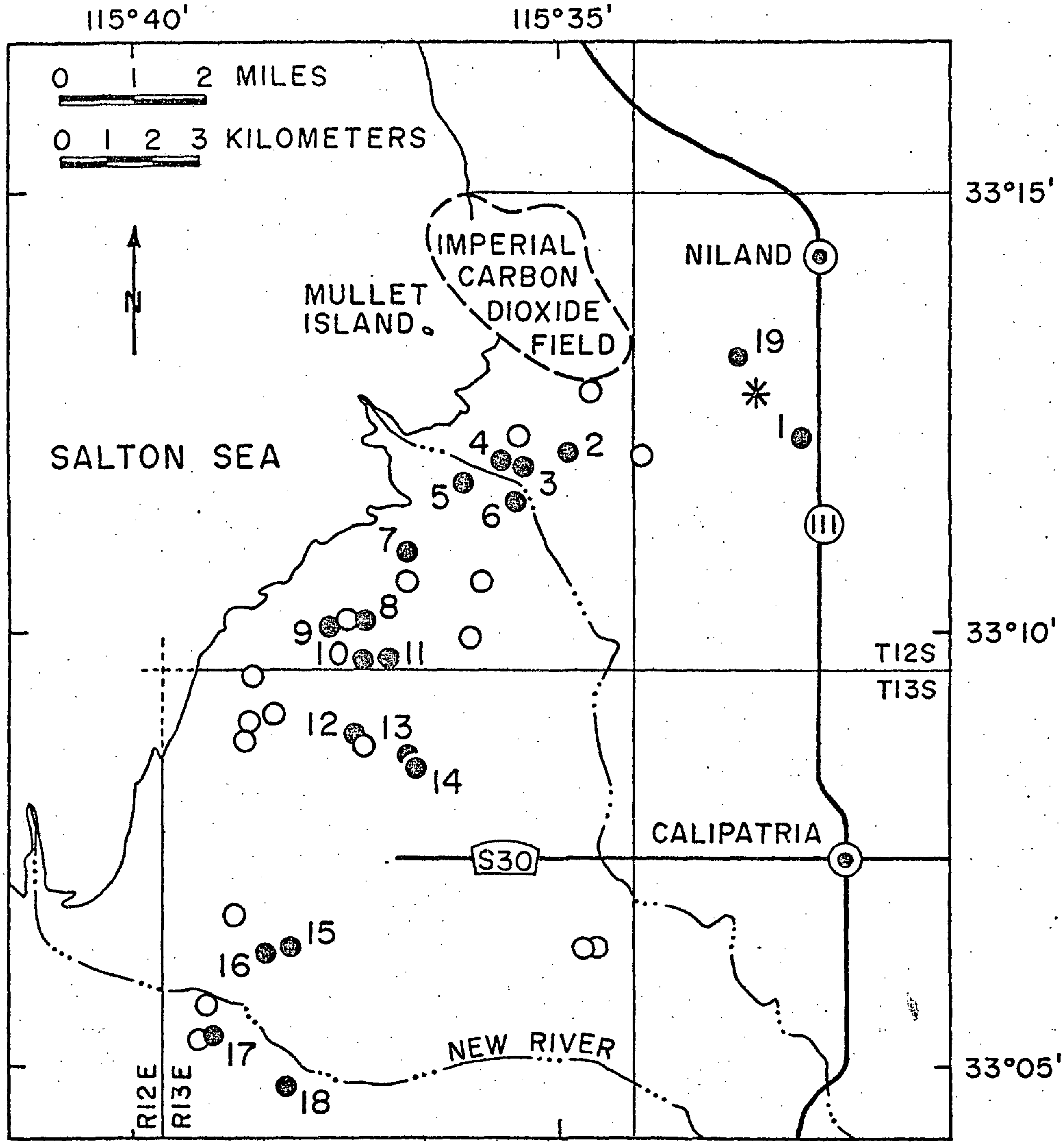
115°40'
115°35'
0 1 2 MILES
0 1 2 3 KILOMETERS
33°15'
33°10'
33°05'
N
IMPERIAL CARBON DIOXIDE FIELD
MULLET ISLAND
NILAND
SALTON SEA
111
T12S
T13S
CALIPATRIA
S30
NEW RIVER
R12E
R13E
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Figure 3.

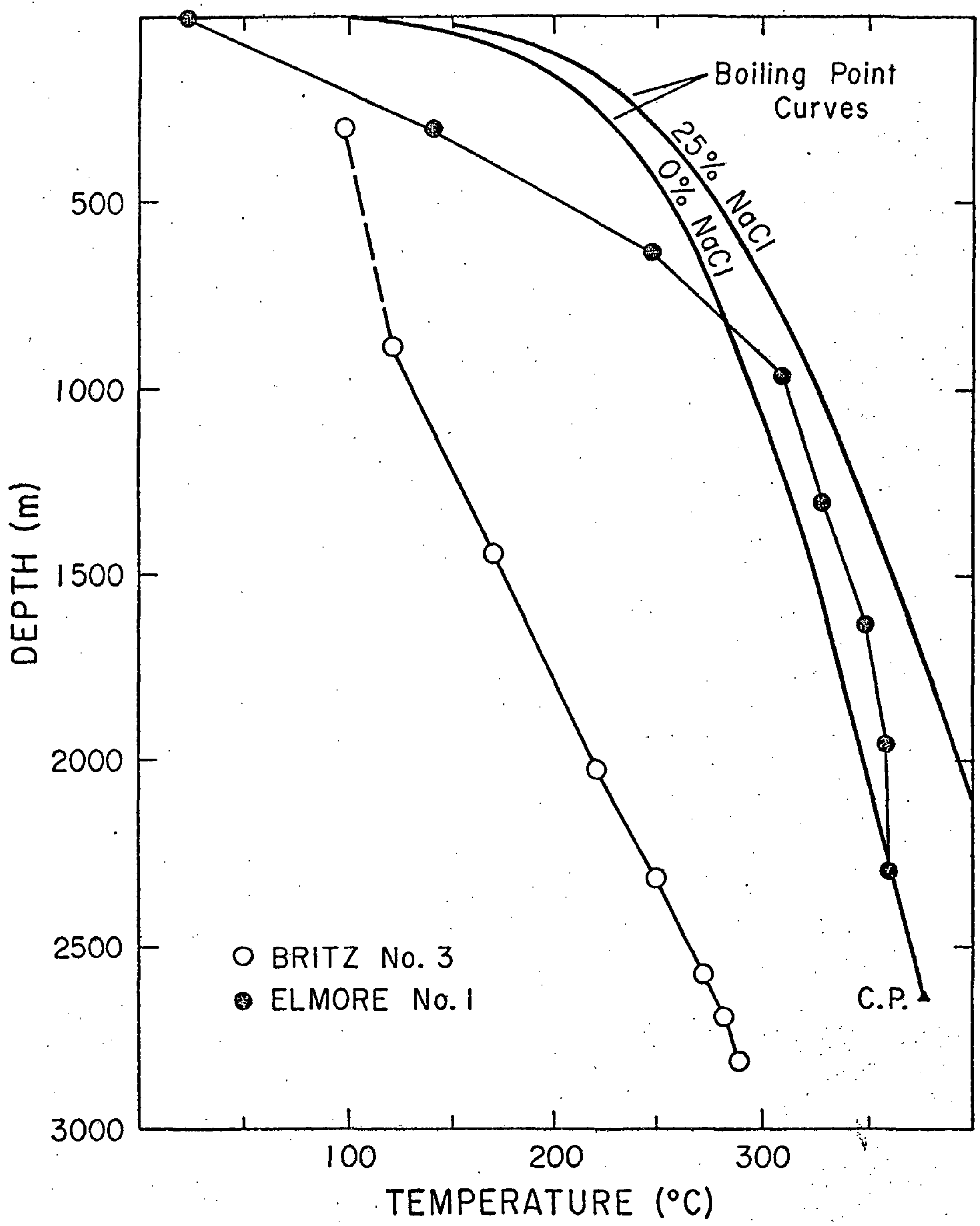


Figure 4. Equilibrium temperature logs for Elmore #1 and Britz #3 wells, together with the boiling point curves for pure water and a 25% NaCl solution (Ellis and Mahon, 1977). CP = critical point of pure water. For well locations see Figure 4.

adjacent to our proposed well (Figure 4) offers the exciting possibility that by drilling deeper supercritical conditions might be encountered for the first time in nature.

3.0 THE SPECIFIC PLAN

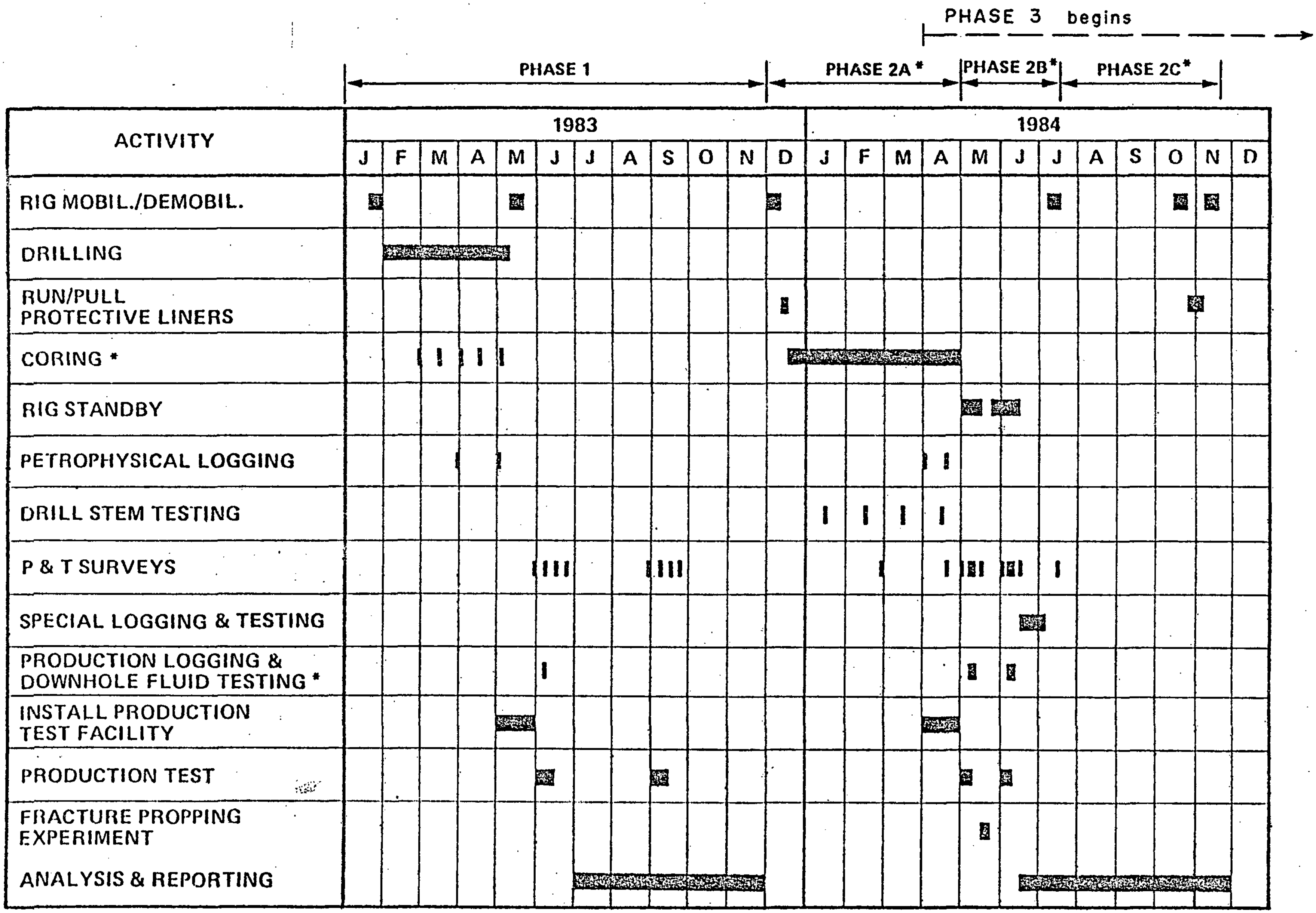
Republic Geothermal, Inc. has drilled the Fee #1 and the Britz #3 wells on their company-owned land in the eastern portion of the Salton Sea geothermal field to depths of 6,000 to 8,000 ft (Figures 3 and 4). They plan next to drill a new well, the Fee #7, between these two wells, to a depth of 12,000 ft. Their aim is to explore for higher temperatures and deeper steam zones than those found in the Fee #1 and Britz #3, where temperatures slightly less than 555°F were measured at 8,000 ft (Figure 4). It was originally planned to begin drilling Fee #7 in February 1983 but current planning suggests this will now begin in March or April. (Thus the dates in Figure 5 will be adjusted).

Given the willingness of RGI to collaborate with our scientific goals we proposed the following research plan and timetable (see Figure 5, the timetable we proposed in October 1982).

3.1 Phase 1

(1) Using funding requested from the National Science Foundation, we will obtain rock cores (five 30 ft long cores), water samples and temperature and wireline logs from the 12,000 ft well. The incremental costs for this would be $130,000. Geothermal developers do not normally recover rock cores. The 150 ft of core thus made available to the public domain will exceed the total amount of core currently available for study from the entire Salton Sea geothermal field. These samples will be by far the most important material available to the Office of Nuclear Waste Isolation study on radionuclide

Figure 5. Proposed timetable for Phases 1 & 2 of the SSSDP



* CONTINENTAL SCIENTIFIC DRILLING PROGRAM SPONSORED ACTIVITIES.

migration referred to above. In addition they will be available for petrophysical studies. Measuring the physical properties of these rocks will enable us to calibrate and help interpret both surface and downhole geophysical surveys, and so generalize the information obtained from this well into three dimensions across the field.

(2) The most crucial activity for the succeeding activities will be to pay the incremental costs of drilling this 12,000 ft well at a wider diameter and for using wider diameter casing. This is necessary in order that the well can be re-entered to deepen it to 18,000 ft in Phase 2. These added costs are estimated to be $225,000.

The total costs of Phase 1 including salaries, travel, overhead and the activities mentioned above will be $405,657. As can be seen in Figure 5, its total duration including analysis and reporting would be 11 months.

3.2 Phase 2

(1) In Phase 2A of the project, which could begin as soon as Phase 1 is concluded (probably in January 1984), RGI will deepen the well using funding from this project. If funds permit, this could go to the limit of the capability of the drilling rig, i.e., 18,000 ft. Because thermal effects indurate (harden) the rocks, this section would not need to be cased. Similarly because the rocks will be hard enough, drilling would be done with diamond bits and cored continuously. This avoids problems with lost circulation zones and provides the best kind of samples. The well would be logged using commercial logging services and repeated water samples would be taken. The cost of deepening the hole to the target depth, insurance, sampling and logging would be $3,280,000 and the estimated duration would be five to six months, thus it could be concluded by June 1984.

(2) In Phase 2B scientific studies in the well would be performed. These could run from June or July 1984 until the fall of 1985, i.e., between 1 and 1-1/2 years. Possibly the most important of these studies would be an attempt at fracture stimulation and propping. When hot rocks are encountered which lack permeability it is necessary to create artificial fractures by pumping fluids into the hole at pressures high enough to fracture the rocks. To these fluids sand-size grains of hard minerals are added. These enter the fractures and keep them open when the pressure is relieved. Such fracture stimulation is fairly common in certain oil fields and has been carried out in hot granites in the Fenton Hill, NM, hot dry rock project. It has not been attempted in the hot indurated sedimentary rocks of the Imperial Valley. We estimate the cost of this study to be $965,000.

We anticipate that there will be a number of different scientific investigations carried on in this hole by other interested groups. Fracture mapping, borehole televiewer surveys, downhole seismometry, downhole water sampling, etc., would be of widespread interest. We have not attempted to anticipate the costs of such activities at this time. However we expect that such costs could be partly borne by redirecting activities already programmed and funded by various agencies. We will invite the broadest possible participation consistent with the safety of the well and maximizing the scientific yield for the mutual advantage of all concerned. The steering committee will oversee the scheduling of these experiments during the 12 to 18 months available for Phase 2B.

At this stage, rather than preparing a detailed technical program plan and budget for these as yet unspecified experiments, we will simply invite suggestions for both experiments and funding by outside investigators. We will, of course, encourage and support these investigators in seeking funding, rather than our assuming responsibility for planning and funding all potential downhole experiments. We will, however, take responsibility for curation and distribution of the samples, and for administration of Phase 2B. Our estimated budget for this would be $276,000.

(3) Because RGI is drilling the Fee #7 as a steam production well, it will be necessary to prepare it for steam production by the late fall or end of 1985. The cost of such restoration to production status would be $440,000. However this cost could be reduced if the interval below 12,000 ft is a producing zone which does not need to be sealed off.

The experienced personnel of RGI believe that these proposed activities do not depend upon any advancements in the current state-of-the-art technology of drilling and testing geothermal wells. The total cost of Phases 2A, 2B and 2C including administration and overhead is estimated to be $4,970,000. However because all drilling activities are subject to uncertainties, equipment failures and delays, a contingency allowance of 20% would be desirable.

3.3 Phase 3

Phase 3 of our proposal comprises the analysis of the samples and data obtained in Phases 1 and 2 of the project and the interpretation and reporting of the results. Detailed geochemical, petrological and petrophysical studies of 6,000 ft (1,800 m) of cores, numerous water samples, downhole logs and other data may take several years. We propose, however, to perform a preliminary geochemical and petrological study at UCR and expect to conclude it in 1985-86. The costs of this two year study (including $200,000 for upgrading laboratory facilities) would be approximately $594,000. We confidently expect that these results of Phases 1, 2, and 3 will stimulate further surface geophysical and modelling studies of the field. However such costs are not included here. The total budget for what we have proposed is still subject to revision, negotiation, and improvement. It is summarized in Section 4.0 below.

4.0 ESTIMATED BUDGET FOR THE PROJECT

	Subcontractor $K	UCR $K	Total $K
Phase 1			
Coring, sampling, logging	130.0		
Mechanical modifications	225.0		
	355.0		
Salaries, expendibles, curation, administration, etc.		40.1	
Overhead		10.5	
		50.6	
			405.6
Phase 2			
2A Deepening well, etc.	3,280.0		
2B Fracture stimulation	965.0		
Curation, administration, salaries, etc.		201.0	
Overhead		75.0	
2C Restoring well to production	440.0		
	4,685.0	276.0	
			4,970.0
Phase 3			
Science, salaries, etc.		477.0	
Overhead		117.0	
			594.0
TOTAL PROPOSED COSTS			$5,969.6