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SALTON SEA SCIENTIFIC DRILLING PROGRAM

Report of the Third Quarter

FY 1987

January 1988

U.S. DEPARTMENT OF ENERGY
Office of Renewable Energy Technologies
Geothermal Technology Division

SALTON SEA SCIENTIFIC DRILLING PROGRAM

Eleventh Quarterly Progress Report:

Report of the Third Quarter
(April through June)
FY 1987

JANUARY 1988

U.S. Department of Energy
Office of Renewable Energy Technologies
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EXECUTIVE SUMMARY

The Salton Sea Scientific Drilling Program (SSSDP) was initiated by several federal agencies in 1985 as one of the first major undertakings in continental scientific drilling in the United States. Congress provided funding to the Department of Energy (DOE) Geothermal Technology Division (GTD) to drill and core this scientific research well; and National Science Foundation, U.S. Geological Survey, and DOE Office of Basic Energy Science funded additional research. As part of the first stage of activities, a borehole reaching a depth of over 3 km was made and a liner for the well was installed. From March to May 1986, numerous scientific measurements were taken downhole and 224 m of core samples were recovered for future scientific analysis. In May 1986, the liner of the well corroded and parted, preventing any additional scientific measurements from below the depth of 2000 m. The program's efforts since then have concentrated on finding ways to rehabilitate the well while planning both the successful conclusion of Stage I activities and the initiation of Stage II activities.

The progress of these efforts has been documented in a series of quarterly reports. This eleventh report covers the period from April 1 through June 30, 1987, the third quarter of fiscal year 1987. During this period, Stage I of the SSSDP officially came to a close with all the organizations involved in the program successfully fulfulling the terms of the original contract. Stage II of the SSSDP was initiated with the signing of a contract modification between the DOE and Bechtel National, Inc (BNI) for wellbore repair and for construction of facilities for a flow test and injection experiment. An agreement was also signed between Bechtel and Kennecott Australia, Ltd. for Kennecott to connect an injection well to the State 2-14 well site for the flow-test experiments. Kennecott implemented this task during this period.

Plans for repairing the State 2-14 well continued to be refined during the third quarter with Kennecott, DOE-GTD, and other related-SSSDP organizations exchanging final recommendations on repair techniques. However, no repairs were conducted during this period.

The first collective reporting of SSSDP results was conducted at a series of forums chaired by Wilfred Elders and John Sass during the spring meeting of the American Geophysical Union in Baltimore, Maryland on May 19 and 20, 1987. Participants covered a wide range of topics including geochemistry and vertical seismic profiling (VSP) data analysis.

Two key meetings were held during this reporting period. The first of these was held at Bechtel's San Francisco headquarters on June 2, 1987. Participants representing DOE's San Francisco Operations Office (DOE-SAN), DOE's Idaho Operations Office (DOE-IDO), Bechtel, University of Utah Research Institute (UURI), and Idaho National Engineering Laboratory (INEL) discussed Stage II Research and Development (R&D) coordination in general and Becthel's proposal in particular.

The second meeting was the program review session held at the end of the third quarter. Participants representing DOE-SAN, DOE-GTD, DOE-IDO, UURI, and INEL presented program updates and also discussed technical aspects of activities.

CONTENTS

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FIGURES

INTRODUCTION

Third quarter activities of SSSDP for fiscal 1987 focused on concluding Stage I of the program while planning and developing the basic infrastructure needed for implementing the flow test and injection experiment. The development of this infrastructure began with the signing of a contract modification between DOE-SAN and BNI.

Stage I of the program was concluded after a supplementary cost request submitted by the prime contractor Bechtel was approved by DOE-SAN. This put the final cost of Stage I at $7.5 million.

The statement of work for Stage II of SSSDP was formally announced on April 13, 1987. Five main task areas were identified for project completion:

1. Wellbore Repair
2. Construction of Flow-Test Facilities
3. Flow Test
4. Clean-up Activities
5. Utilities

Following clarification of the task areas, as requested by BNI, a contract effectively extending Bechtel's role as prime contractor was signed on June 30, 1987. Expenditures to complete the remainder of the project were expected to equal $1.150 million.

As part of an amended agreement between BNI and Kennecott, Task-2 activities involve a high degree of Kennecott participation. Included in this activity is Kennecott's responsibility for the drilling and completion of the injection well and the connection of this proposed injection well to the State 2-14 well for the flow test.

PROGRAM PLAN AND ACTIVITIES

Drilling and Engineering Program

Current and Planned Courses of Action for Stage II

As earlier summarized in the Introduction, the Statement of Work (SOW) for the Stage II contract was divided into five remaining task areas. The planned course of action for each of these tasks areas and any subsequent change to the planned course of action are detailed below.

Task 1. Wellbore (State 2-14) Repair

- Removal of temporary liner (about 812 ft of pipe)
- Removal of damaged 7-inch liner to the extent possible (maximum of approximately 4,000-ft of pipe)
- Installation of new 7-inch liner constructed in such a manner as to isolate the deepest possible production zone greater than 8,000-ft depth
- Side tracking the hole, if the daily damaged-liner extraction-rate is less than the estimated daily drilling rate of 75 ft per day.
- Making the (repaired) well available for acquisition of scientific data for 3 days

Task 2. Construction of Flow-Test Facilities

- Construct flow-test facilities, using DOE-supplied design and government-owned equipment
- Inspect and test government-owned equipment
- Repair and reconditioned government-owned equipment

Figure 1 shows the location of the State 2-14 site with respect to the proposed injection site, Imperial 1-13 well and the Wilson 1-12 well. Figure 2 shows the actual site layout for the State 2-14 well as designed by Bechtel. The pipeline needed to connect State 2-14 with Wilson 1-12 belonged to RGI, from whom it was purchased by Kennecott and installed. The installation was carried out by Kennecott to gain timely access to the State 2-14 brine-holding pend for containment of fluids expected to be produced by its short-term flow

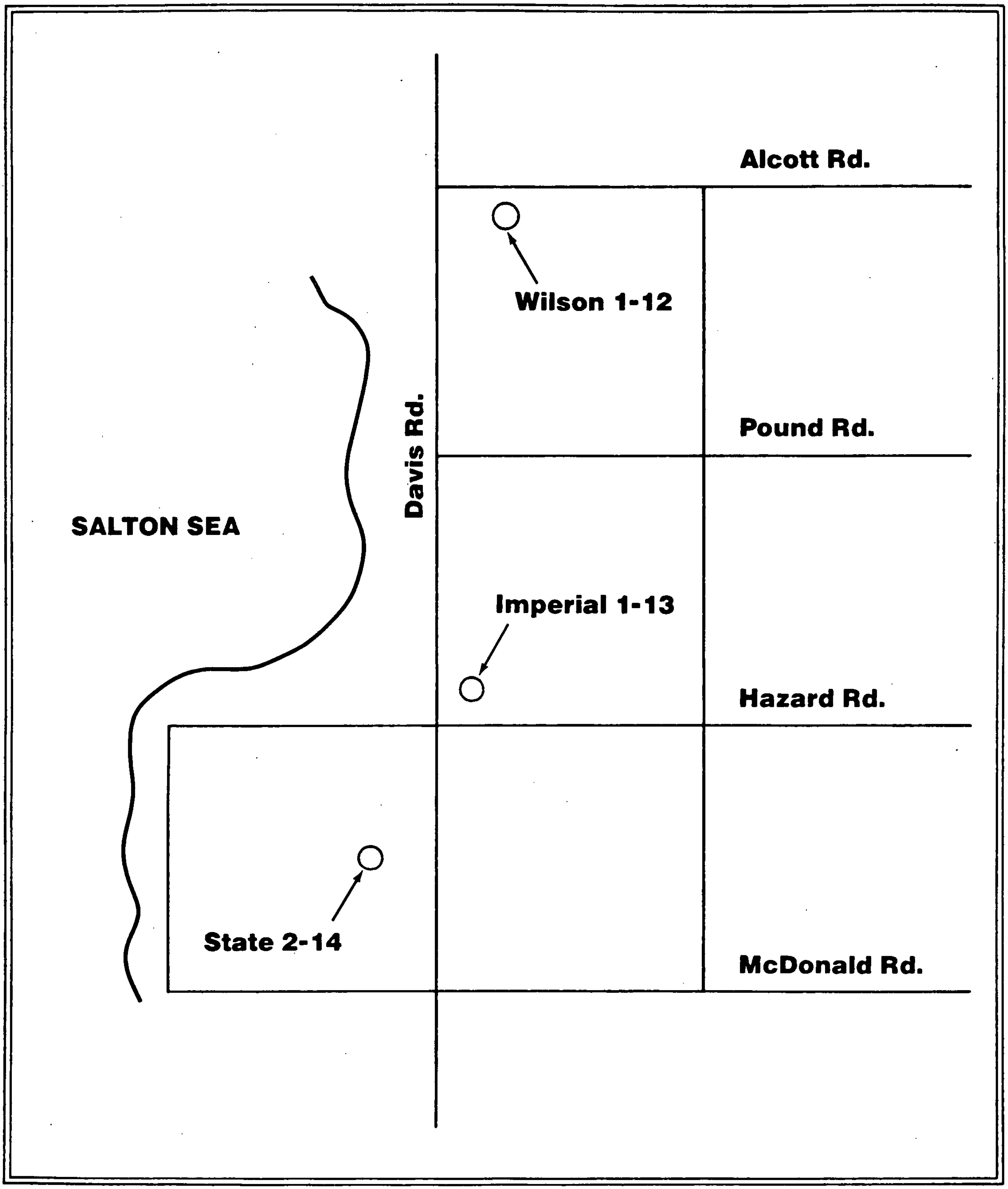

Figure 1. The SSSDP Wells

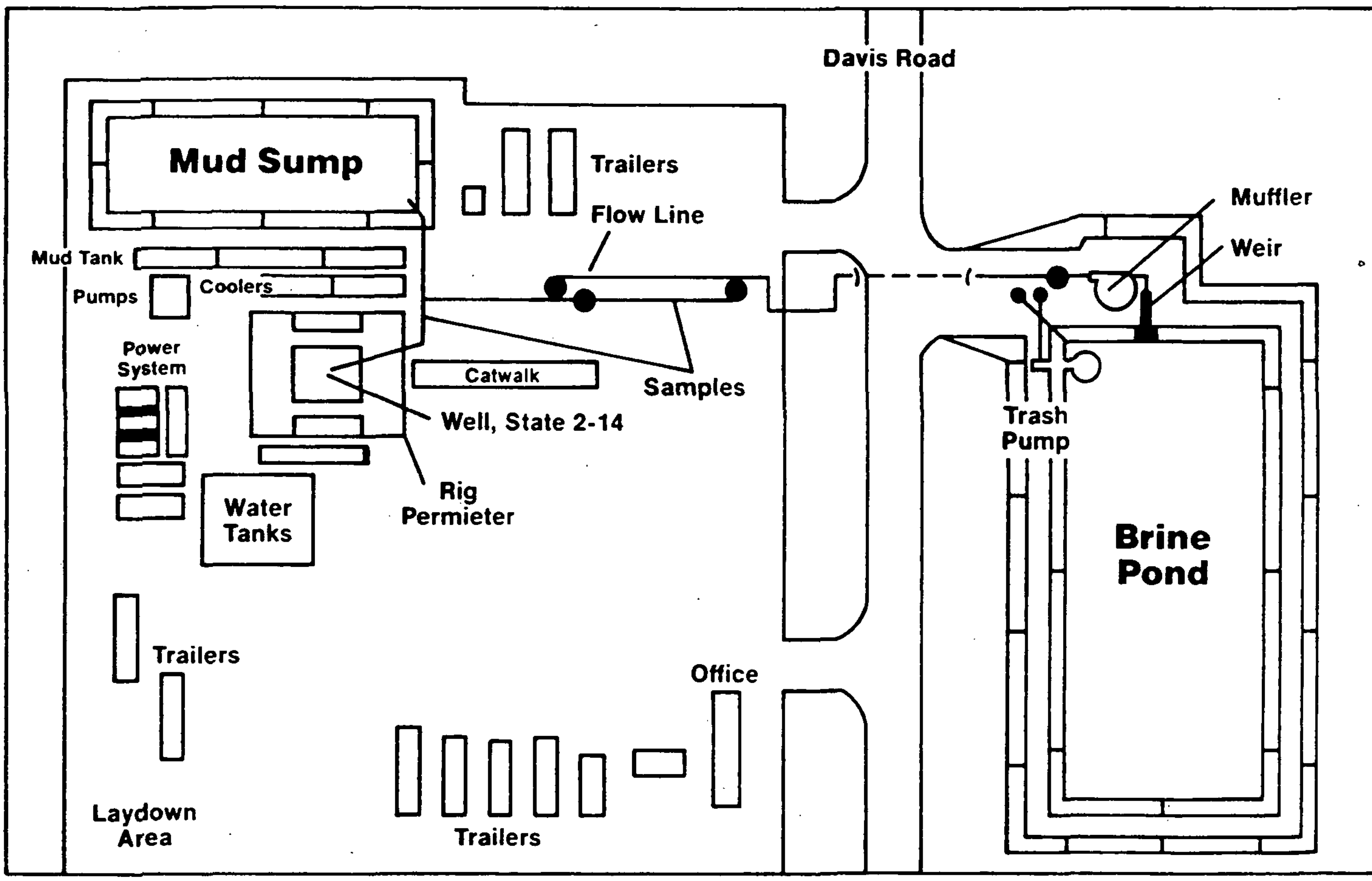

Figure 2. State 2-14 Site Layout for the LTFT

test of the Wilson 1-12 well. Most of the remaining government equipment was successfully obtained by auction from the defaulted CU-I loan guaranty program and to be reconditioned for use in Stage-II.

The DOE preliminary design for the brine-treatment facility is shown in Figure 3. The production brine passes through a number of meters to measure pressure and temperature before and after it flows through a series of separators. The exiting brine next passes through a series of media filters and polishing filters before it is metered and injected.

<u>Task 3. Flow Test</u>

- Provide a term of 30 days for research team to perform long-term flow test
- Test plans and operational procedures for the flow test to be developed by others (DOE)
- Personnel for operating test, equipment maintenance, and data gathering to be supplied by others (DOE)

<u>Task 4. Clean-Up Activities</u>

- Perform site clean-up activities as agreed with leaseholder.
- Prepare final report on well repair and flow-test activities

<u>Task 5. Utilities</u>

- Supply all utilities for the test center (see Figure 2 for site layout)

Bechtel's preliminary schedule for completing the five tasks is shown in Figure 4. The figure includes the completion of Stage I (Part A) on June 30, 1987 and the projected completion of Stage II (Part B) by mid-January 1988.

<u>The Wilson 1-12 Well</u>

The Wilson 1-12 well became an integral part of the Stage II contract in general, and Task 2, in particular. Kennecott management agreed to allow its use as an injection well, after completion and testing, but later withdrew the offer.

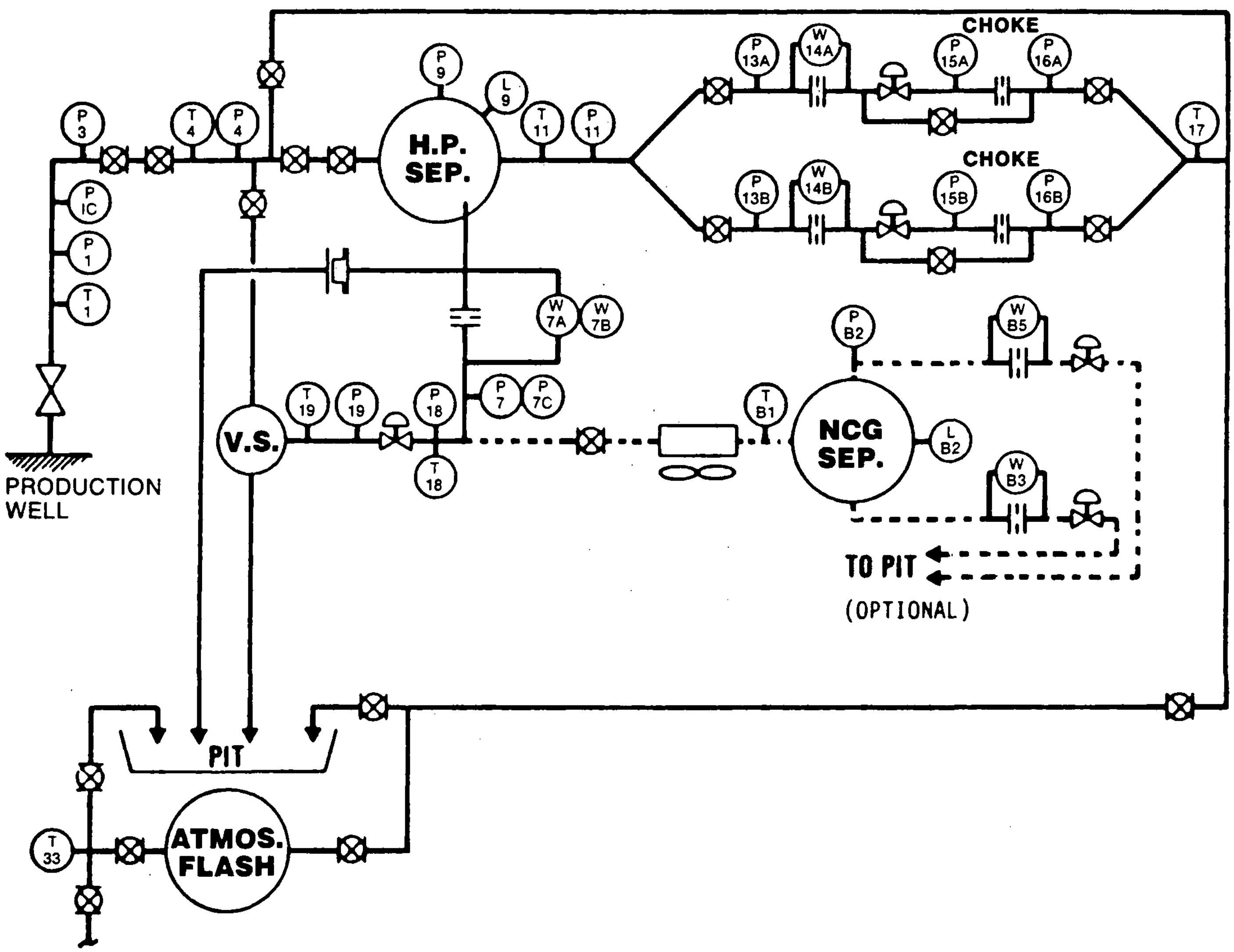

Figure 3. Preliminary Design for the LTFT

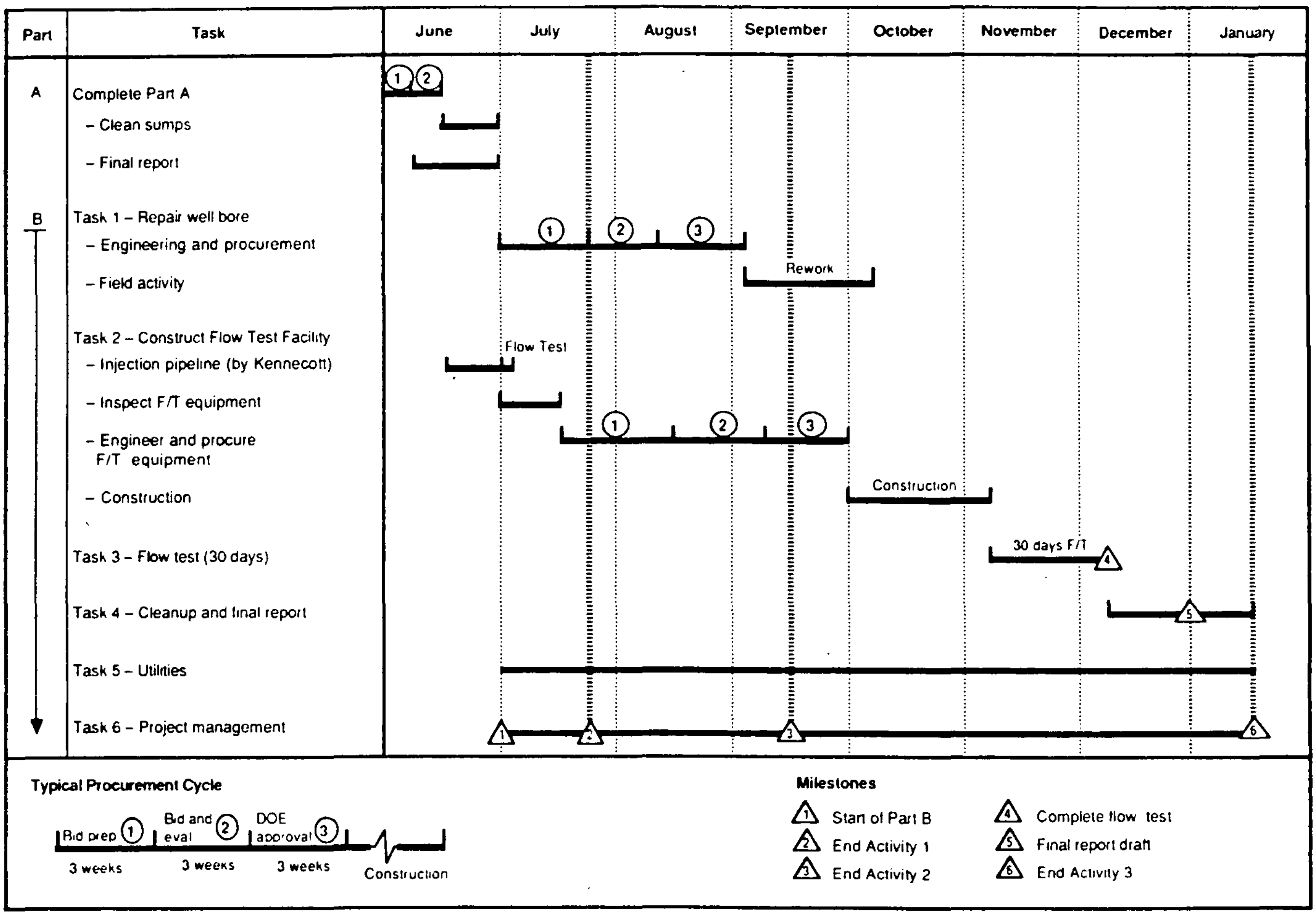

Figure 4. Schedule for Stage II of the Salton Sea Scientific Drilling Project

Results of Scientific Experiments

Several reports detailing preliminary results of scientific experiments were presented at the American Geophysical Union's (AGU) spring conference held in Baltimore, Maryland on May 19-20, 1987. These reports were the first formal presentation of SSSDP scientific research and provided the scientific community with the opportunity to not only study the geological characteristics of the Salton Sea area, but also to compare Salton Sea data with data from other geothermal resource areas.

Some of the scientific results contained in these reports are summarized below as presented in EOS, the transactions journal of the AGU. All are listed in the bibliography section of this report.

Fluid Inclusions in SSSDP Core: Preliminary Results Authors: Roeder, Edwin, and Kevin W. Howard, USGS

Eighty-six fluid inclusions were examined in calcite, quartz, and anhydride from thin (~1mm) veinlets crosscutting the SSSDP core, from 1983-7400 ft (605-2256 m) depth in the Salton Sea geothermal field, California. Preliminary data were obtained on the homogenization temperatures (Th; all in liquid phase), melting of ice (Tm), and eutectic melting (Te). No daughter minerals were seen, and no clathrates were recognized on freezing. Most inclusions adequate for both Th and Tm range in Th from 217 to 350°C and vary widely in salinity (as indicated by Tm, -0.7 to -268°C), suggesting a complex history of fluid circulation in the past. Te values are all in the range -40 to 62°C (mean approximately 51°C). The data are too few for correlation with inclusion origin or host mineral.

Extensive speculation on the origin and nature of these various fluids is premature, but several points are noteworthy: 1) with one exception, all inclusions with highly saline brines (i.e., Tm below -15°C, >18.8 wt% NaCl eq.) were from >1700-m depth; 2) very low-salinity fluids (Tm -0.7 to -2.4°C, 1.2 to 4.0 wt% NaCl eq.) circulated as deep as 1939 m; 3) the Te values almost certainly require $CaCl_2$ as a major component; 4) on a plot of Tm vs. Th, most of the data points are clustered, suggesting a series of discrete fluids. The data obtained can be explained by combinations of the processes suggested by other workers (e.g., McKibben, and Oakes & Williams, ACROFI, 1987) on the basis of fluid inclusion and other studies from other wells in the Salton Sea geothermal field. These processes include thermal metamorphism of evaporates, local igneous intrusions or fracturing of deep over-pressured zones, and mixing of water from dehydration of gypsum with partly evaporated Colorado River water.

Analysis of VSP Data at the Salton Sea Scientific Drilling Program

Daley, Thomas M., Thomas V. McEvilly, and Ernest L. Majer, Lawrence Berkeley Laboratory

As part of the Salton Sea Scientific Drilling Project, a three-component vertical seismic profile was conducted with P-wave and Shear-wave vibrator sources at both a zero-offset and a far-offset. The use of cross-polarized shear sources, along with careful rotation of the recorded geophone-motion into radial and orthogonal transverse components, allowed study of the in situ material properties and seismic response of the area surrounding the well.

Velocity models developed from zero-offset, first-arrivals show a zone of low Poisson's ratio around 2500' and a zone of anomalously high-P and low-S velocities (high Poisson's ratio) around 3000 ft. The velocity data extend from the surface to the deepest geophone location at 5500 ft. A strong reflection is observed on both P- and S-wave profiles from an approximate depth of 6800 ft.

By rotating the recordings from the two polarizations of shear sources, which were in line and normal to the direction to the well (termed "SV" and "SH" sources here), into separate SH and SV arrivals, we measured velocity anisotropy as a travel-time difference between SH and SV waves as a function of depth. This anisotropy was also observed as a shear-wave splitting, which leads to complicated particle motion within the first arrival wavelet. Comparison of particle motion between SH and SV waves shows the anisotropy. The shear wave splitting is seen strongly with the SH source, whereas waves generated with the SV source are mostly unaffected, maintaining a linear polarization at depths where the SH source produces circularly polarized waves.

Possible evidence of bulk-fracturing is seen as scattered P-waves energy generated at a depth of approximately 2950 ft by the far-offset source. We observed a variation in the polarization of shear-wave particle motion, which may be indicative of fracturing near the well. Distinct and consistent polarization directions can be followed over certain depth intervals, while other depths show varying polarization directions. The presence of fracturing near the well is also inferred from scattered P-wave energy within the first arrival wavelet of SH and SV waves.

Mineralized Fractures in SSSDP Well 2-14 Core Samples

Caruso, I. J., D. K. Bird, M. Cho, and J. G. Liou, Stanford University

Mineralized fractures in SSSDP Well 2-14 core samples, between 1400 m and 2960 m, were examined using optical and backscattered electron microscopy, and electron-probe microanalysis to characterize (1) their mineralogy and mineral paragenesis, (2) the texture and composition of vein minerals, and (3) the spatial relationships among fractures. Using progressive changes in fracture mineralogy and crosscutting relationships among fracture sets, the history of fracturing and fracture sealing was developed.

Epidote (Ep) and quartz (Qz) occurs throughout the entire sample depth interval; calcite (Cc), anhydride (Anh), K-feldspar (Ksp), hematite (Hm), chlorite (Chl), and actinolite (Act) occur in restricted depth intervals. In samples from depths less than 1860 m, Ep and Cc are the dominant fracture-filling minerals with minor Hm, Qz, sulfides, and Ksp. Ep is the first mineral to precipitate in these veins. It usually occurs as euhedral crystals growing on fracture walls or incorporated in later forming Cc and Hm. A few samples contain Cc veins crosscutting fractures filled with Ep±Hm. Veins in metasediments within the 1860-2746-m depth-interval are filled primarily with one or more of the following minerals: Ep, Ksp, or Anh. Lesser amounts of Qz, Hm, sulfides, and Chl, and trace-quantities of sphene, rutile, and allanite are also present. When Ep + Ksp + Anh occur in a single fracture (at 2226 m), Ksp is usually the first mineral to precipitate followed by Ep; Anh occurs, replacing Ep. In samples with two distinct fracture sets, one containing Anh and the other filled with Ep±Ksp±Hm±Qz, the Anh veins are always younger. At greater depths (>2226 m), Ep is the most abundant and, paragenetically, the earliest mineral to precipitate in fractures; Qz, pyrite, and Act may occur with Ep.

The iron content (X_{fe}+8=Fe^{+3}+ Al) of vein epidotes decreases systematically with increasing depth. Vein epidotes do not show the same irregular discontinuities observed in the compositional trend of the matrix epidotes. Compositional zoning, common in most vein epidotes, is defined by variations in X_{fe}+e or, to a lesser degree, in REE content, and ranges from a uniform pattern (i.e., core to rim) to a complex mosaic.

We conclude that metasediments from the SSSDP Well 2-14 underwent episode fracturing, infiltration of reactive fluids, and fracture sealing. The minerals that seal fractures exhibit significant temporal and spatial variations resulting from a hydrothermal fluid-chemistry that varied in time and space. Fracture sealing by mineral precipitation can act as an effective barrier to fluid flow; however, a single fracture set can provide pathways for several generations of reactive fluids.

The Lithostratigraphy of the Colorado River Delta in the Active SSGF Pull-Apart Basin, California

Herzig, and Charles T., James M. Mehegan (Both at Institute of Geophysics and Planetary Physics, University of California, Riverside, CA 92521)

The lithostratigraphy of the California State 2-14 well, located in the Salton Sea Geothermal Field (SSGF), Imperial Valley, California, records the history of the Colorado River Delta in the actively developing, SSGF pull-apart basin. The 10,564-ft drilled section consists of unconsolidated muds and sands to 1,100 ft. At greater depth, the rocks are 70 percent shale and siltstone. Other lithologies include sandstone, pebble conglomerate, and a volcanic tuff at 5,591 ft. Sedimentary bedding in cored intervals, cut by mm-cm scale normal offsets, dip 20-40^{o}. Two igneous intrusions occur at 9,440-50 ft. The deeper intrusion's lower margin was cored, exhibiting a brachiated and chilled contact with shales.

Shale-siltstone intervals containing gastropods and ostrocods are up to 140-feet thick. Cross-bedded, subarkosic arenites, 1- to 36-feet thick, are inter bedded with the shale-siltstones. The pebble conglomerates contain sedimentary, volcanic, plutonic, and metamorphic rock fragments. Conglomerates were not observed deeper than 5,000 ft.

Rock texture becomes more hornfelsic with depth. Quartz, calcite, epidote, anhydride, montmorillonite, illite, chlorite, adularia, albite, sphene, white mica, and actinolite fill subvertical fractures, interstitial voids, and replace detrital grains. Hornblende occurs deeper than 10,300 ft. Ore minerals are galena, sphalerite, pyrite, chalcopyrite, pyrhotite, and specular hematite.

Geochemistry of Salton Sea Scientific Drilling Projects Hydrothermal Fluids and Comparisons to Red Sea Brines

Campbell, A.C., Edmond, J.M, T. S. Bowers, C. I., Measures, M. R. Palmer and E. T. Brown (Dept. of Earth, Atmos. and Planet, Sci., M.I.T. Cambridge, MA 02139)

Hydrothermal fluids from both flow tests of the Salton Sea Scientific well have been analyzed for all major and a number of minor elements. Many of the "minor" metals have solution concentrations 100-1000X higher than in vent-waters from ridge rest hydrothermal vents at 21~N. A more appropriate comparison may be made to the Red Sea brines (RSB) that, like the Salton Sea brines (SSB), have a high salinity due to the circulation of fluids through evaporite sequences. Both systems have very similar Cl concentrations (SSB - 4.314 M/kg and RSB - 4.40 M/kg) (Brewer & Spencer, 1969). The Na concentrations in SSB are 40 percent lower than in RSB (2.42 vs. 4.03 M/kg). Both K and Ca have higher values in SSB (10X and 5X, respectively). These differences may, in part, reflect differences in the evaporite compositions for the two regions. In addition, the reaction substrates and secondary mineral assemblages also must play a role in these differences. Some of the minor elements in the Salton Sea fluids, e.g., Zn, Cu, and Pb, are about 100X enriched relative to the Red Sea brines. Both areas have similar pH values (SSB - 5.2-5.4 and RSB - 5.5) (Shanks & Bischoff, 1977). The metal enrichments of the Salton Sea fluids may reflect greater availability of these elements in the reactions substrate.

Boron isotope measurements on fluids from the four sampling ports indicate a linear decrease in and ^{11}B, which can only be due to precipitation within the sampling system. This result, in conjunction with a concomitant decrease in silica, indicates that some sampling artifacts are present. Thus minor element values must be considered minimum numbers due to the possible effects of coprecipitation.

Reporting of SSSDP Results

Documentation and dissemination of SSSDP results continued in accordance with established protocol during this period. The first series of formal presentations of papers and posters detailing the activities of the SSSDP was conducted at the AGU meeting in Baltimore, Maryland on May 19. The full day of sessions was chaired by Wilfred A. Elders (UC Riverside) and John Sass (USGS) and included a total of 22 papers and 12 poster presentations on the program.

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SIGNIFICANT MEETINGS

Stage II/Flow-Test Planning Session

A meeting was held at Bechtel's San Francisco headquarters on June 2, 1987 to review coordination of SSSDP R&D with SSSDP operations. Attending the meeting were: John Crawford and Bettyanne Moore of SAN; Charles Harper, Sherman May, Neil Harlen, and Gus Benz of Bechtel; and Susan Stiger of INEL.

Discussed at length during the meeting was the view that the deletion of the media filters from the brine-treatment facility design could result in damage to the Kennecott well during injection of fluids. All parties were in relatively good agreement about the remaining proposed components of Stage II such as site-layout and set up of test equipment. It was also suggested that all experiments be carried out in the cooler, fall weather to reduce stress on personnel and equipment.

Additional discussions were held about Bechtel's contribution to the areas of site clean up, site abandonment, and final cost. An agreement was reached to complete all revisions to the proposal and sign the contract modification by the June 30 deadline.

Program Review Session

A second significant meeting finalizing the proposal was held during the program review session conducted at DOE-HQ, June 29-July 1. Present at the meeting were representatives of DOE/SAN, DOE/GTD, DOE/IDO, Lawrence Berkeley Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL), UURI, and INEL. A contract outlining the Scope of Work (Tasks 1-5) was signed between Bechtel and DOE--officially starting Stage II of SSSDP.