GL00640
DOE # 006

Proposal Copy # 4 / of 5

Submitted to the Department of Energy
Idaho Operations Office

SOLICITATION FOR COOPERATIVE AGREEMENT PROPOSALS
SCAP No. DE-SC07-80ID12145

CHARACTERISTICS OF WATER-ROCK INTERACTION IN GEOTHERMAL SYSTEMS

Dept. of Geology, Stanford University
Name of Organization (including Branch, Title, if any)

Stanford, California 94305
Address of Organization — Zip Code

Investigation of Water-Rock Interaction in Geothermal Systems of Japan and Taiwan
Title of Proposed Project

Funding Requested from DOE $ 96,717 Total Project Cost $ 97,684 *

Proposed Duration (in weeks) 104 Proposed Starting Date Dec. 1, 1980

Name of Principal Investigator J. G. Liou

Position and Title Associate Professor

Telephone (with area code) (415) 497-2716

Approval ______________ ______________
Signature — Title

______________ ______________
Name (Typed) — Date

* - This amount does not cover the cost for research done by the Japanese Investigators on this project.

# FEDERAL ASSISTANCE

**1. TYPE OF ACTION** (Mark appropriate box)
- [ ] PREAPPLICATION
- [x] APPLICATION
- [ ] NOTIFICATION OF INTENT (Opt.)
- [ ] REPORT OF FEDERAL ACTION

**2. APPLICANT'S APPLICATION** a. NUMBER: b. DATE: Aug. 4 1980 (Year month day)

**3. STATE APPLICATION IDENTIFIER** a. NUMBER: b. DATE ASSIGNED: 19 (Year month day)

Leave Blank

## SECTION I—APPLICANT/RECIPIENT DATA

**4. LEGAL APPLICANT/RECIPIENT**
- a. Applicant Name : Stanford University
- b. Organization Unit : Sponsored Projects Office
- c. Street/P.O. Box : 320 Galvez
- d. City : Stanford
- e. County : Santa Clara
- f. State : CA
- g. ZIP Code: 94305
- h. Contact Person (Name & telephone No.) : Yrrah Piffero - (415) 497-2537

**5. FEDERAL EMPLOYER IDENTIFICATION NO.** 94-1156365

**6. PROGRAM** (From Federal Catalog) a. NUMBER: b. TITLE:

**7. TITLE AND DESCRIPTION OF APPLICANT'S PROJECT**

"Investigation of Water-Rock Interaction in Geothermal Systems of Japan and Taiwan"

(See attached for description)

**8. TYPE OF APPLICANT/RECIPIENT**
A–State, B–Interstate, C–Substate District, D–County, E–City, F–School District, G–Special Purpose District, H–Community Action Agency, I–Higher Educational Institution, J–Indian Tribe, K–Other (Specify):

Enter appropriate letter: I

**9. TYPE OF ASSISTANCE** Co-operative Agreement
A–Basic Grant, B–Supplemental Grant, C–Loan, D–Insurance, E–Other

Enter appropriate letter(s): E

**10. AREA OF PROJECT IMPACT** (Names of cities, counties, States, etc.) Not Applicable

**11. ESTIMATED NUMBER OF PERSONS BENEFITING** Not Applicable

**12. TYPE OF APPLICATION**
A–New, B–Renewal, C–Revision, D–Continuation, E–Augmentation

Enter appropriate letter: A

| 13. PROPOSED FUNDING | |
|---|---|
| a. FEDERAL | $ 96,717 .00 |
| b. APPLICANT | 967 .00 |
| c. STATE | .00 |
| d. LOCAL | .00 |
| e. OTHER | .00 |
| f. TOTAL | $ 97,684 .00 |

**14. CONGRESSIONAL DISTRICTS OF:** a. APPLICANT: 12 b. PROJECT: 12

**15. TYPE OF CHANGE** (For 12c or 12e)
A–Increase Dollars, B–Decrease Dollars, C–Increase Duration, D–Decrease Duration, E–Cancellation, F–Other (Specify):

Enter appropriate letter(s):

**16. PROJECT START DATE** (Year month day) 1980-12-1

**17. PROJECT DURATION** 24 Months

**18. ESTIMATED DATE TO BE SUBMITTED TO FEDERAL AGENCY** (Year month day) 1980-8-6

**19. EXISTING FEDERAL IDENTIFICATION NUMBER**

**20. FEDERAL AGENCY TO RECEIVE REQUEST** (Name, City, State, ZIP code) Dept. of Energy, Idaho Operations Office, Rm. HQ 117, 550 Second St., Idaho Falls, Idaho 84301

**21. REMARKS ADDED** [ ] Yes [x] No

## SECTION II—CERTIFICATION

**22. THE APPLICANT CERTIFIES THAT**
a. To the best of my knowledge and belief, data in this preapplication/application are true and correct, the document has been duly authorized by the governing body of the applicant and the applicant will comply with the attached assurances if the assistance is approved.

b. If required by OMB Circular A-95 this application was submitted, pursuant to instructions therein, to appropriate clearinghouses and all responses are attached:

| | No response | Response attached |
|---|---|---|
| (1) | [ ] | [ ] |
| (2) | [ ] | [ ] |
| (3) | [ ] | [ ] |

**23. CERTIFYING REPRESENTATIVE** a. TYPED NAME AND TITLE: Edward C. Barrera b. SIGNATURE: c. DATE SIGNED (Year month day): 19

## SECTION III—FEDERAL AGENCY ACTION

**24. AGENCY NAME**

**25. APPLICATION RECEIVED** (Year month day) 19

**26. ORGANIZATIONAL UNIT**

**27. ADMINISTRATIVE OFFICE**

**28. FEDERAL APPLICATION IDENTIFICATION**

**29. ADDRESS**

**30. FEDERAL GRANT IDENTIFICATION**

**31. ACTION TAKEN**
- [ ] a. AWARDED
- [ ] b. REJECTED
- [ ] c. RETURNED FOR AMENDMENT
- [ ] d. DEFERRED
- [ ] e. WITHDRAWN

| 32. FUNDING | |
|---|---|
| a. FEDERAL | $ .00 |
| b. APPLICANT | .00 |
| c. STATE | .00 |
| d. LOCAL | .00 |
| e. OTHER | .00 |
| f. TOTAL | $ .00 |

**33. ACTION DATE** (Year month day) 19

**34. STARTING DATE** (Year month day) 19

**35. CONTACT FOR ADDITIONAL INFORMATION** (Name and telephone number)

**36. ENDING DATE** (Year month day) 19

**37. REMARKS ADDED** [ ] Yes [ ] No

**38. FEDERAL AGENCY A-95 ACTION**
a. In taking above action, any comments received from clearinghouses were considered. If agency response is due under provisions of Part 1, OMB Circular A-95, it has been or is being made.

b. FEDERAL AGENCY A-95 OFFICIAL (Name and telephone no.)

# INVESTIGATIONS OF WATER-ROCK INTERACTION IN GEOTHERMAL SYSTEMS OF JAPAN AND TAIWAN

By

J. G. Liou, Associate Professor
Stanford University, Stanford, CA 94305

## ABSTRACT

The Department of Energy is asked to provide two years of support for the continuation of detailed mineralogical-petrological-geochemical investigations of drill hole core samples from the geothermal areas of Onikobe and Hakone (both in Japan) and Tatun (in Taiwan). On-going research has been supported by a Guggenheim Fellowship (9/1/78-8/31/79), and the U.S.-Japan project funded by the National Science Foundation (4/1/78-8/31/80). These geothermal areas were selected for detailed investigation because geological-geochemical-geophysical information and a nearly complete set of drill hole core samples are available to the principal investigator.

The purposes of the investigation are to determine:

1. The paragenetic sequence of formation of secondary minerals in the geothermal system and metamorphic reactions related to their formation;
2. The physico-chemical conditions of their genesis deduced from phase equilibria and isotopic fractionation of coexisting phases and their comparison with recorded and analyzed conditions;
3. The spatial patterns of hydrothermal alterations and their relation to the flow of hydrothermal solutions;
4. The source of the hydrothermal fluids responsible for the alteration;
5. The effective water-rock ratio in the geothermal system;
6. The attainment of chemical and isotopic equilibrium in the coexisting minerals; and
7. The change of isotopic and fluid compositions and temperature of geothermal fluids as a function of time as recorded in the changes of mineral assemblages.

All these will contribute to a better understanding of the genetic conditions and processes causing chemical and mineralogical changes during the rock-water interactions in a geothermal system. This, in turn, will aid in future exploration and assessment of geothermal potential for these and other areas. Our results have been tested in the Onikobe geothermal area, where a new producing well was drilled by the Japan Electric Development Cooperation in accordance with our recommendation.

# TABLE OF CONTENTS

APPENDICES

## STATEMENT OF WORK

Our basic premise is that the changing composition and temperature of geothermal fluids as a function of time will be recorded by the paragenesis, compositions and isotopic properties of the associated mineral assemblages, and that the latter can be used to reconstruct the evolution of a geothermal system.

We propose to continue detailed mineralogical-petrological-geochemical investigations of drill hole core samples from Onikobe and Hakone (both in Japan) and the Tatun geothermal area (in Taiwan). These geothermal areas were selected for detailed investigation because they are recognized as classic examples and because geological-geochemical-geophysical information and a nearly complete set of drill hole core samples are available to the principal investigator. All three of these geothermal areas are in volcanic arcs and are largely andesitic, but they differ from one another in the varieties of andesitic and other rocks present, and they differ somewhat in water types; hence, secondary mineral assemblages and mineral parageneses are different. Table 1 lists geological and mineralogical information on these three geothermal areas.

The differences in mineral parageneses among the 3 sets of core samples which are from drill holes up to 1500 meters deep are significant. For example, in the Onikobe geothermal area, Ca-Al silicates change with depth as follows:

mordenite → laumontite → yugawaralite → wairakite → prehnite → epidote.

Pyrite and magnetite are ubiquitous. However, in the Tatun geothermal area, depth zones of laumontite → wairakite → epidote are poorly developed, mordenite and other calcium zeolites and prehnite were not found, and carbonates, anhydrite (+ gypsum), pyrite and hematite are very common. Apparently the hydrothermal fluids in the Onikobe area must have lower activities of $CO_2$, $SO_4$ and oxygen compared with those at the Tatun area, inasmuch as temperature, pressure, and host rocks are very similar. The appearance of Fe-rich epidote at very shallow depths (see Appendix A) and the absence of prehnite in the Tatun geothermal area are consistent with this suggestion. However, both epidote and prehnite contain considerable amounts of $Fe^{+3}$ and their appearance is highly dependent on the $f_{O_2}$ of the hydrothermal fluid. Careful and systematic investigation of assemblages and compositions of the calcium aluminum silicates and clay minerals is necessary in order to fully understand the complex effects of rock-water interactions in geothermal systems.

The similarities and differences in mineral paragenesis and interactive modes determined from the proposed investigation of 3 geothermal areas could yield some principles relating to water-rock interactions in geothermal systems which might not be apparent from the investigation of a single geothermal area. Although the selected target areas are in foreign countries, the conclusions derived from these classic geothermal areas could be applied to many geothermal fields in the United States.

Specifically, the proposed investigations include:

(1) Examination of drill hole core samples by transmitted and reflected light microscopy in order to identify secondary minerals and their textural relations and paragenetic sequence;
(2) Identification of clay minerals by X-ray diffraction, differential thermal analysis and scanning electron microscopy (SEM) in order to establish their properties and parageneses in geothermal systems and their correlation with zeolitic mineral sequences;
(3) Microprobe analyses of carbonates, zeolites, clay minerals, prehnite, epidote and others in order to test chemical equilibrium and explain the parageneses and physico-chemical conditions of their formation;
(4) Detailed analyses of stable isotopes (C,O,H,S) of bulk rock and mineral phases in order to establish the source and nature of hydrothermal fluid and to estimate the temperature of equilibrium or near-equilibrium of the mineral species.

After completion of the data collection, the mineralogic-compositional characteristics of the hydrothermally altered rocks will be correlated with the chemical and isotopic compositions of the thermal waters. The experimental data on appropriate rock-water interactions will then be used to deduce the genetic conditions causing chemical and mineralogical changes during the rock-water interactions in geothermal systems.

The proposed studies will result in data applicable to both scientific and applied problems. The scientific aspects include processes related to metamorphism, rock alteration, ore genesis and geochemical cycling in hydrothermal systems. The practical aspects include developing a better basis for exploring for and exploiting geothermal resources. As a matter of fact, based on petrological-geochemical data accumulated thus far, a new, top producing well with a depth of 700 meters has been drilled recently in the Onikobe area under the recommendation of the Associate Principal Investigators Seki and Oki.

TABLE 1. Geological and Mineralogical Data of the Onikobe, Hakone and Tatun Geothermal Areas

| | Onikobe | Hakone | Tatun |
|---|---|---|---|
| Geologic Setting | Caldera | Volcano Caldera | Volcanic bedded sequence |
| Host Rock | Pleistocene dacite, andesite, tuffs & flows; Miocene volcanogenic sediments | Pleistocene basalt, dacite, andesite, tuffs & flows; Miocene volcanogenic sediments | Pleistocene andesitic lavas, tuffs & breccias; Miocene sandstone sediments |
| Thermal Waters | | | |
| Type | Meteoric, magmatic(?) | Meteoric, seawater(?) magmatic(?) | Meteoric, seawater(?) magmatic(?) |
| Composition | | Acid sulfate at the surface; bicarbonate sulfate and NaCl at depth | Acid sulfate chloride type |
| pH at surface | 2 - 5 | 3 - 8 | 1 - 3 |
| Temperatures | 60-225°C | 100-250°C | 50-250°C |
| Alteration Minerals | | | |
| Ca-Zeolites | Abundant; vary according to depth | Rare; vary according to depth | Rare; only laumontite and wairakite |
| Illite | Abundant | Rare | Abundant |
| Kaolinite | Abundant in shallow part | Rare | Abundant in shallow part |
| Smectite-Chlorite | four types according to depth (see p. 11) | | |
| Gypsum-Anhydrite | Common | Not common | Very common |
| Alunite | Very rare | Rare | Very rare |
| Carbonates | Common | Common | Common |
| Pyrite | Common | Rare | Common |
| Iron Oxides | Magnetite | Magnetite | Magnetite-Hematite |

## TECHNICAL REQUIREMENTS

### Introduction

Japan and Taiwan provide excellent examples of active geothermal systems in geologic terrains which are well understood. Development of geothermal power has been greatly emphasized in these countries because it is potentially a major energy resource in active volcanic areas. Exploration of geothermal energy in Japan and Taiwan began in the early sixties, and many exploratory holes have been drilled up to 2000 m in depth. Drill hole cores have been sampled, thermal waters have been analyzed chemically and isotopically, and many other geological data (e.g., temperature gradient, flow rate, permeability) and geophysical data have been collected. A geothermal power plant of 25 MW was successfully installed in Onikobe in 1975.

This project on low-temperature rock-water interaction in geothermal systems was initiated under a U.S.- Japan Project and a Guggenheim Fellowship. Since April 1, 1978, the NSF has sponsored a joint U.S.- Japan project on coordinated studies of rock-water interactions in geothermal systems utilizing experimental and field approaches. At Stanford, the principal investigator and his associates have studied the interaction of andesitic-basaltic rocks with seawater and meteoric waters from 200°C to 400°C in order to determine the kinetic and equilibrium modes of interaction of rocks with solutions chemically, isotopically and mineralogically. As a Guggenheim Fellow, the principal investigator spent his sabbatical year (September 1, 1978 to August 31, 1979) in both Taiwan and Japan. He joined our Japanese colleagues, Professor Yotaro Seki of Saitama University and Dr. Yasue Oki of Hakone Hot Springs Research Institute in studying the properties of drill hole core samples and the field aspects of rock-water interactions in the Onikobe, Hakone and Tatun geothermal areas. (See Fig. 1 for localities.) The field studies include petrological-mineralogical-geochemical examinations of drill-hole core samples and their correlation with the chemical and isotopic properties of thermal waters. The collective specific aims were, and are: (1) to determine the mineralogical, chemical and isotopic characteristics of the hydrothermally altered rocks in these geothermal areas, (2) to deduce the sequence of chemical, mineralogical and geological events that have affected the mineral assemblages of the altered rocks, and (3) to determine the kinetics and equilibrium reactions attending the alteration. The conclusions and problems posed by the field data are to be correlated with and interpreted by the experimental data, to better our understanding of the genetic processes in geothermal systems.

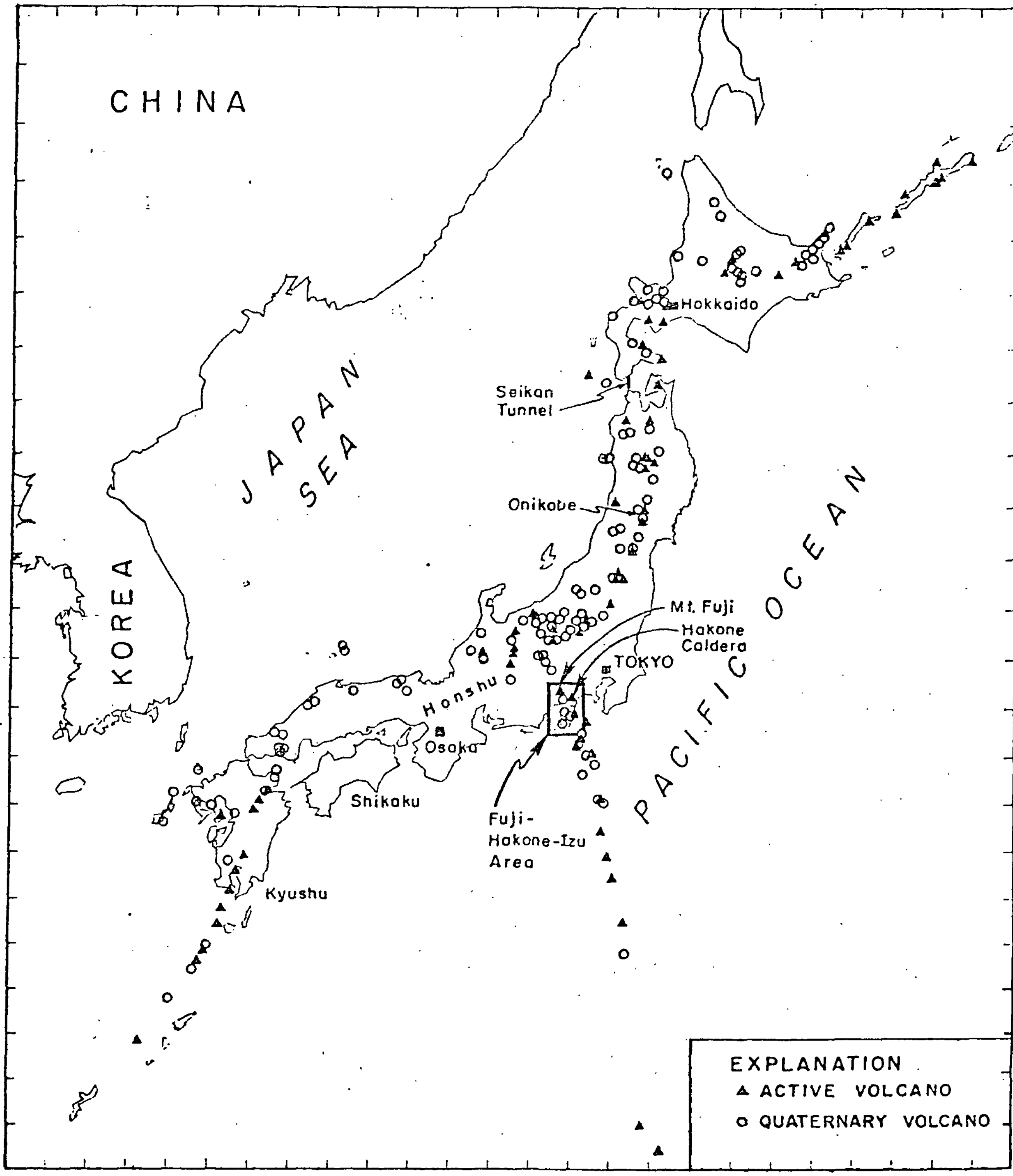



Fig. 1. Distribution of active and Quaternary volcanos in Japan. Also shown are the field areas such as Fuji-Hakone-Izu area, Seikan undersea tunnel, and Onikobe geothermal system for the cooperative project.

Thus far in this project, many experimental problems have been investigated at Stanford. The existing U.S.- Japan grant facilitated completion of andesite-water interactions carried out by graduate student Ray Guillemette and Visiting Professor Yishan Zeng of Peking University. The present proposal is being submitted because the mineralogical-geochemical- isotopic investigation of drill hole core samples from the Onikobe-Hakone-Tatun geothermal areas initiated by the Guggenheim Fellowship will require additional time and money for successful completion. Funds are requested from the Department of Energy to defray analytical expenses for this research. In addition, the principal investigator hopes to support two gradudate students who are currently engaged in Ph.D. research solely on this topic.

## Japan as a Source of Geothermal Data

### Geologic and Tectonic Setting

The Japanese island arc has experienced repeated volcanism, both terrestrial and sub-marine. Intensive volcanism that has continued since the early Miocene is believed to be intimately connected with the generation of fumaroles and hot-springs, development of high geothermal gradients, evolution of the Green Tuff tectonic belt, and intensive alteration of rocks at the surface and at depth in numerous existing geothermal areas, including the Hakone and surrounding region.

The zonal distribution of Quaternary volcanic rocks has been revealed by the classic studies of Kuno (1966, 1968), Katsui et al. (1974), Ishihara (1974) and Miyashiro (1974). The zones are, successively from the Pacific ocean side of Japan toward the west: an outer volcanic zone with tholeiite and calc-alkaline rocks containing relatively low $K_2O$ and $Na_2O$; an inner zone of tholeiitic and calc-alkaline rocks with higher $K_2O$ and $Na_2O$ contents; a westernmost zone characterized by tholeiitic, calc-alkaline and alkali rocks.

### Previous Investigations

Geochemical and geological investigations by Japanese workers have outlined the effects of large geothermal systems on the enclosing rocks (Seki et al., 1969; Seki, 1970; Oki et al., 1976). Studies of rocks from surface exposures and from drill holes show pervasive alteration of volcanic and sedimentary host rocks by hot fluids and gases. Lava flows and pyroclastic rocks such as tuffs and tuff breccias have been profoundly altered.

I. Thermal Waters: More than 150 thermal waters from 30 geothermal areas in Japan were analyzed for stable isotope composition (oxygen, hydrogen and sulfur) and for chemical components ($Cl^-$, $SO_4^{-2}$, $Na^+$, $K^+$, $Ca^{+2}$ and $Mg^{+2}$), by Sakai and his associates (Matsubaya & Sakai, 1973; Matsubaya, Sakai et al, 1973; Sakai & Matsubaya, 1974). Four types of Japanese thermal waters were recognized, according to their isotopic and chemical characteristics (Table 2).

Table 2. Isotopic and element chemistry of four types of thermal waters of Japan and related saline waters (after Sakai & Matsubaya, 1974)

| | | Isotopic ratios of: | | | | Chemical composition | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $H_2O$‰ | | $SO_4$‰ | | | | | | | | |
| No. | Thermal water[1] | $\delta^{18}O$ | $\delta D$ | $\delta^{34}S$ | $\delta^{18}O$ | Cl (meq.) | Na/Cl | K/Cl | Ca/Cl (meq. ratio) | Mg/Cl | $SO_4$/Cl | $HCO_3$/Cl |
| | "Coastal" waters | | | | | | | | | | | |
| 1 | Ibusuki | − 1.0 | −10.8 | +20.0 | + 7.6 | 307.3 | 0.808 | 0.039 | 0.117 | 0.015 | 0.057 | — |
| 2 | Fushime | − 0.9 | −10.7 | +16.3 | + 5.1 | 379.4 | —— 0.852 —— | | 0.148 | 0.002 | 0.003 | — |
| 3 | Shimogamo | − 2.5 | −22.4 | +18.0 | + 6.2 | 310.0 | 0.591 | 0.024 | 0.371 | 0.001 | 0.010 | — |
| | "Arima"-type waters | | | | | | | | | | | |
| 4 | Arima | + 6.5 | −27.8 | — | — | 1,090 | 0.745 | 0.092 | 0.166 | 0.004 | 0.000 | — |
| 5 | Yatate | − 1.8 | −39.7 | — | — | 222.8 | —— 1.150 —— | | 0.010 | 0.003 | 0.005 | 0.159 |
| 6 | Yashio | + 6.0 | −20.6 | +28.9 | +16.6 | 414.6 | 1.105 | 0.064 | 0.059 | 0.015 | 0.075 | 0.227 |
| | "Green Tuff"-type waters | | | | | | | | | | | |
| 7 | Tottori | − 8.8 | −55.5 | +24.3 | + 7.5 | 27.1 | 2.201 | 0.032 | 0.275 | 0.047 | 1.249 | 0.31 |
| 8 | Owani | −11.1 | −69.4 | +21.7 | + 6.9 | 43.4 | 1.002 | 0.037 | 0.294 | 0.032 | 0.342 | 0.015 |
| 9 | Moritake | − 4.7 | −34.2 | +29.0 | +11.0 | 373.0 | 0.650 | 0.017 | 0.342 | 0.008 | 0.015 | 0.103 |
| | "Volcanic" waters | | | | | | | | | | | |
| 10 | Tamagawa | − 7.7 | −57.9 | +28.4 | + 6.6 | 86.2 | 0.037 | 0.012 | 0.074 | 0.052 | 0.350 | — |
| 11 | Hakone | − 7.6 | −49.0 | − 4.2 | − 1.0 | ca. 0.0 | ——— | ——— | low chloride content | ——— | ——— | ——— |
| 12 | Beppu | − 5.0 | −47.1 | +24.4 | + 4.1 | 50.3 | 1.084 | 0.089 | 0.027 | 0.012 | 0.200 | 0.004 |
| | Other waters, for comparison | | | | | | | | | | | |
| 13 | Sea water | 0.0 | 0.0 | +20.3 | + 9.5 | 535.2 | 0.851 | 0.018 | 0.037 | 0.207 | 0.103 | — |
| 14 | Salton-Sea brine | + 3.3 | −75 | — | +13.7 | 4,366 | 0.502 | 0.103 | 0.329 | 0.001 | 0.0004 | — |
| 15 | Red Sea brine | + 1.2 | + 7.4 | +20.3 | + 7.2 | 4,395 | 0.916 | 0.011 | 0.058 | 0.014 | 0.004 | 0.0005 |
| 16 | Fluid inclusion | — | — | — | — | 1,662 | 0.702 | 0.039 | 0.510 | 0.109 | — | — |
| 17 | Fluid inclusion | — | — | — | — | 3,380 | 0.687 | 0.019 | 0.301 | 0.054 | 0.006 | — |

[1] Source of water, temperature, and pH, by sample number: 1. Ibusuki-5 (97°C, pH = 8.0), Kagoshima; 2. Fushime (95°C, —), Kagoshima; 3. Shimogamo No. 2 (100°C, 8.1), Shizuoka (Mizutani and Hamasuna, 1972); 4. Arima-1 (98°C, 5.3), Hyogo; 5. Yatate (31.8°C, 6.6), Akita; 6. Yashio (1°C, 6.7), Gunma (Takase, 1966); 7. Tottori-1 (48°C, 7.4), Tottori; 8. Owani (53°C, 6.8), Aomori; 9. Moritake No. 1 (61°C, 7.5), Akita; 10. Obuki (98°C, 1.2) of Tamagawa, Akita; 11. Ubako (50°C, 2.9) of Hakone, Kanagawa; 12. Beppu-Sumitomo (100°C, 7.3), Oita (A. Koga, unpub. data, 1973); 13. δS (Thode et al., 1961), δO (Longinelli and Craig, 1967); 14. $\delta H_2O$ (Craig, 1966), $\delta SO_4$ (Longinelli and Craig, 1967), chemistry (Helgeson, 1967); 15. Atlantis II Deep: $\delta H_2O$ (Craig, 1966), δS (Hartmann and Nielsen, 1966), δO (Longinelli and Craig, 1967), chemistry (Emery et al., 1969); 16. Sphalerite, Cave-in-Rock district, Ill. (Hall and Friedman, 1963); 17. Sphalerite, upper Mississippi Valley (Hall and Friedman, 1963).

These are: (1) Coastal thermal waters, which are mixtures of oceanic and meteoric waters, with $\delta O^{18}$ and $\delta D$ values intermediate between oceanic and local meteoric values. They are high in $Na^+$, $Ca^+$ and $Cl^-$ contents and low in $SO_4^{-2}$ and $Mg^{+2}$, and they appear to be the result of interactions between hot seawater and host rocks. The interactions were commonly accompanied by the precipitation of anhydrite. (2) Highly saline brines, significantly enriched in the heavy isotopes of oxygen and hydrogen. These are mixtures of as much as 80% of saline, $CO_2$-rich brines and local meteoric water. Deep brines may contain magmatic waters produced during pre-Tertiary granitic intrusive processes and metamorphism. (3) Waters of Green Tuff terrains, which are meteoric, of neutral Na-Cl-$SO_4$ type and Na-Ca-Cl-$SO_4$ type. These waters formed by reactions between the Green Tuffs and $CO_2$-rich meteoric waters at a time when the Green Tuff rocks were uplifted above sea level. (4) Volcanic thermal waters, associated with Quaternary volcanic rocks. These are almost purely meteoric in origin; chemically, they are either acid chloride-sulfate or acid-sulfate types.

II. <u>Secondary Minerals</u>: The minerals produced by the alteration depend on geologic position, composition of host rocks and chemical composition of the fluids. Near the surface, particularly in fumarolic areas, where vigorous boiling occurs and mixing with atmospheric oxygen is possible, the rocks alter to soft siliceous material containing clays, opaline silica, alunite, sulfur, and pyrite. At deeper levels, the mineral assemblages are different. Altered andesitic rocks collected in drill holes at depths of 100 to 200 m in the Katayama geothermal system near Onikobe (Seki et al., 1969) show alteration of mafic minerals to smectite and calcite and of plagioclase (along cracks and cleavages) to mordenite or laumontite, calcite and clay minerals (Fig. 2). Groundmass minerals or the tuffaceous matrix were nearly completely altered to laumontite, silica minerals, calcite, hematite, clay minerals and leucoxene. Rocks from levels deeper than 200 m were more extensively altered: mafic minerals were converted completely to chlorite, calcite and leucoxene; plagioclase was replaced by wairakite, albite, quartz and calcite ± epidote; and groundmass minerals were transformed to quartz, wairakite and lesser calcite, chlorite and pyrite. Amygdales of quartz and calcite were common. The three calcium zeolite minerals - mordenite, laumontite and wairakite - were distributed in zones according to increasing depth and temperature (Fig. 2). Fluids of this system are unusually low in $SO_4$ and $HCO_3$, and slightly acid with pH values of 6.5 to 5.1. Zonal distribution of zeolites in altered volcanic rocks have been reported for other areas, for example, the Kawaji damsite, central Japan (Seki, 1970), the Yugawara geothermal area, Japan (Oki <u>et al</u>., 1976), and the Wairakei geothermal region of New Zealand (Steiner, 1953; Coombs <u>et al</u>., 1959).

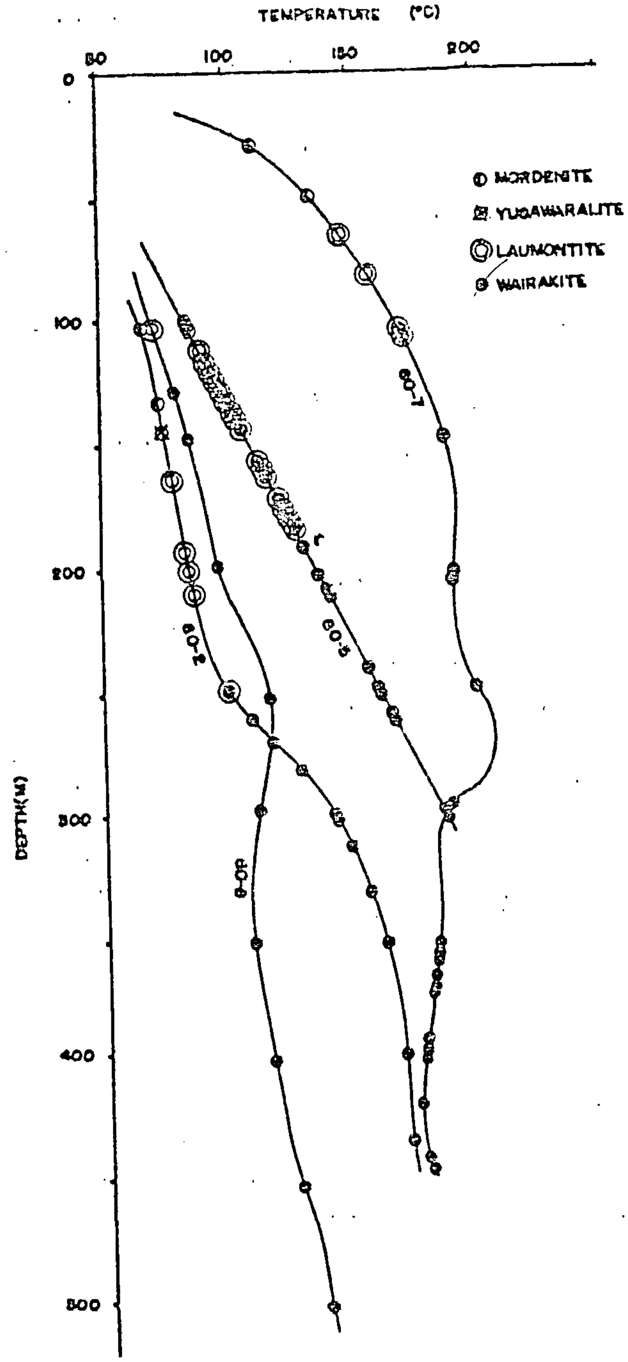



Fig. 2 . Geothermal gradients and zeolite distributions in deep holes drilled in the Katayama geothermal area, Onikobe, Japan (after Seki <u>et al</u>., 1969).

Metamorphism of the andesitic rocks of some of the Green Tuff Formation of Japan, by fluids with moderate to high $CO_2$ contents, to a propylitic assemblage of calcite, chlorite and sericite ($\pm$ albite, quartz and epidote) took place over about the same temperature interval as zeolite facies metamorphism, $150^{o}$ to $350^{o}C$ (Seki, 1973). The absence of zeolites in the Green Tuff areas probably reflects the high $CO_2$ contents of the metamorphosing fluids, which causes calcite to take the place of calcium zeolites, prehnite and pumpellyite (Seki, 1976).

## Water-Rock Interactions in Geothermal Systems

From the foregoing summary of findings in Japan, it appears that the presence or absence of calcium zeolites as alteration products of rocks of geothermal areas is controlled in part by solution components, such as $CO_2$ and $SO_4$, which tend to react with Ca to form insoluble carbonate and sulfate minerals.

In essence, mineralogic and petrologic investigation of hydrothermally altered and low-grade metamorphic rocks by the associated Japanese investigators has outlined the effects of geothermal solutions on the enclosing rocks (e.g., Seki *et al.*, 1969b; Seki, 1970; Oki *et al.*, 1976). Studies of rocks from surface exposures and drill holes show pervasive alteration of volcanic and sedimentary host rocks. The minerals produced by the alteration depend on temperature and pressure regimes, composition of host rocks, and chemical composition of geothrmal fluids. The new minerals include members of the silicate, carbonate, sulfate and sulfide groups. Careful studies on mineral paragenesis and hydrothermal solutions in many Japanese geothermal areas and elewhere in the world have yielded significant correlations between mineral assemblage and solution chemistry (e.g., Coombs *et al.*, 1970; Browne, 1970; Liou, 1971; Zen and Thompson, 1974; Seki, 1976; Oki *et al.*, 1977; Elders *et al.*, 1978). However, the alteration processes involving water-rock interations are not fully understood.

The petrological studies of rocks from drill-holes imply that alteration of volcanic rocks at temperatures of $100^{o}$ to $400^{o}C$ by hydrothermal solutions proceed by multi-step processes, accompanied by progressive bulk chemical changes in solids and solutions, and recrystallization. Knowledge of the mineral parageneses, particularly zeolite-prehnite-epidote vs clay-carbonate-anydydrite, and the solution parameters, particularly $CO_2$, $SO_4$, $f_{O_2}$ and $f_{S_2}$, is needed to understand hydrothermal and low-grade metamorphism.

## RESEARCH IN PROGRESS

A. Mineralogic-petrologic-geochemical investigations of waters and hydrothermally altered rocks in the Onikobe-Hakone geothermal areas, Japan.

We have taken the Onikobe and Hakone geothermal areas as on-going subjects for the U.S.-Japan program. Prior to 1975, many geochemical and petrological data of these two areas were collected by the Japanese members of the group, but only limited data have been published to date. In the Onikobe area, except for reconnaissance study on zeolite distributions in 4 drill hole cores (Seki et al., 1969), detailed mineral parageneses with respect to depth and their correlation with chemical compositions of the geothermal fluids have not been investigated. On the other hand, in the Hakone area, only the thermal waters have been analyzed and characterized according to chemical compositions (Oki and Hirano, 1970, 1974). The rocks from the Hakone drill holes have been studied only in reconnaissance fashion. Consequently, there still remain the mineral parageneses to be studied thoroughly and altered minerals with solution types and underground temperatures to be correlated. Such systematic studies are now in progress. Two sets of drill-hole core samples were collected respectively from the Onikobe (Nos. 123 and 124) and Hakone (M-112 and M-116) areas during the summer of 1978. Petrographic studies of these rocks and characterization of clay minerals have been completed (see Section C). Compositions of zeolites, prehnite, epidote, clay and other secondary minerals are being analyzed by the electron microprobe at Stanford. Compositions of solutions and O-H-S isotopic data for solutions, and for pyrite and calcite, will be collected. After completion of the data collection, the chemical and isotopic compositions of the solutions will be correlated with the mineralogic characteristics of the hydrothermthermally altered rocks. The experimental data on appropriate rock-water interactions will then be used to deduce the genetic conditions causing chemical and mineralogical changes during the rock-water interactions in nature.

B. Investigation of Drill Hole Core Samples from Tatun Geothermal Area, Taiwan.

The Tatun geothermal area of northeastern Taiwan, about 3 x 18 km in size, is covered by a thick sequence of Pleistocene andesitic lavas and pyroclastics. Spring waters with $40^\circ$ to $120^\circ C$ temperatures are mostly the acid sulphate chloride type and have extremely low pH values ranging from 1 to about 3. Many pilot holes up to 1300 m have been drilled; temperatures as high as $250^\circ C$ and their variations with depth have been recorded. Core samples from 6 drill holes were selected for detailed investigation in order to understand their mineral parageneses of hydrothermal alteration and to compare them with those from Hakone and Onikobe, Japan.

Three alteration zones based on the occurrence of kaolinite, Ca-zeolites and epidote were recognized. Zone 1, restricted to a near surface region of about 200 m or less, is characterized by the presence of kaolinite, gypsum and cristobalite. Zone 2, the intermediate zone between about 200 to 500 m, is characterized by the sporadic occurrence of laumontite and wairakite together with abundant smectite-chlorite, anhydrite, quartz, pyrite and hematite. Zone 3, below about 500 m, is characterized by the appearance of epidote in addition to chlorite, anhydrite and pyrite. Calcite is ubiquitous at depths below about 200 m and its frequent occurrence indicates that thermal fluids at great depth are not so acid as those in the surface zone. The rare occurrence of calcium zeolites and other calcium aluminum silicates, and the abundance of calcite and anhydrite suggest that the hydrothermal alteration in this area must have taken place at high activities of $CO_2$ and $SO_4$ and temperatures of $100^{o}$-$250^{o}C$.

A summary of this study was presented at the Water/Rock Interaction Symposium in Edmonton, Alberta, Canada, July, 1980. An extended abstract is attached here as Appendix A.

C. Properties, correlations, and implications of clay and chloritic mineral associations in geothermal systems of Japan and Taiwan.

Mineral associations of the clay-chlorite group show systematic variations with depth and temperature, correlateable with Ca-zeolites and other minerals, in cores from the geothermal systems of Onikobe and Hakone, Japan, and Tatun, Taiwan. Detailed petrographic, XRD and DTA studies of hydrothermally altered andesitic to dacitic rocks from depths up to 1300 m revealed abundant clay-chlorite minerals associated, in order of increasing depth, with: mordenite, clinoptilotite and dachiardite; laumontite; and wairakite. Occurring locally are prehnite, epidote, calcite, gypsum, anhydrite and other minerals. Characteristic features of four types of phyllosilicate mineral associations are as follows:

| Type | Association | Cu-Kα 2θ (001) | Cu Kα 2θ EG(001) | DTA Endothermic T, $^{o}C$ |
|---|---|---|---|---|
| I | alk. smec. | 7.0 | 5.0 | 70,150,650 |
| I' | smectite | 6.0 | 5.0 | 70,150,650 |
| II | chl.-smec. | 3.0,6.0-6.2 | 3.0,5.6-5.9 | 70,150,550 |
| III | chlorite | 6.0-6.1 | 6.0-6.1 | 550 |

Fig. 3 shows the relation between the basal spacings of air-dried clay minerals from drill hole cores and the same minerals treated by ethylene glycol. Four fields of alkaline smectite (Type I), Ca-Mg-Fe smectite (Type I'), chlorite-smectite mixed layer minerals (Type II) and chlorite (Type III) are apparent. From our detailed examination of clay minerals and their associated zeolite minerals in the Tatun, Onikobe and Hakone areas, we consistently found that Type I and Type I' clay minerals occur commonly with mordenite and clinoptilolite, Type II smectite-chlorite with laumontite and Type III chlorite with wairakite. Identification of phyllosilicate minerals in geothermal drill hole cores according to this classification is useful for evaluating the temperatures of formation of mineral assemblages of hydrothermally altered rocks.

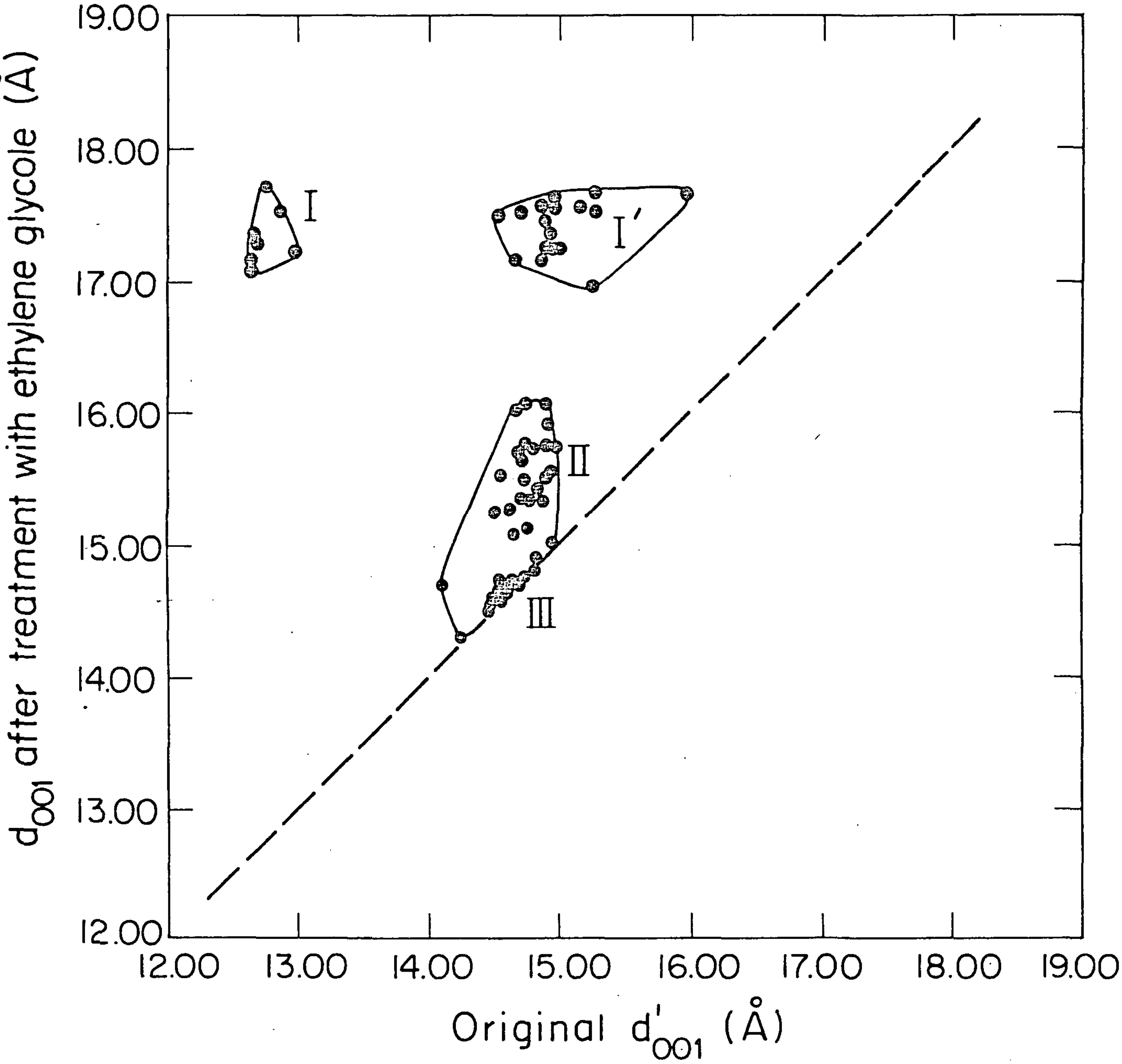



Fig. 3. Plots of $d_{001}$ (dry) vs $d_{001}$ (ethylene glycol treatment) relationships of clay minerals from drill hole core samples of the Tatun geothermal area, Taiwan.

# APPROACH AND INNOVATION

## The Research Group - Background and Strength

The research described here is a continuation of an on-going project: "Low-temperature studies of rock-water interactions in geothermal systems." This project brought together five scientists - two from the U.S.A. and three from Japan. They are listed below along with their institutions.

### Principal Investigator

J. G. Liou, Department of Geology, Stanford University, Stanford, CA 94305
"Petrological-mineralogical-geochemical studies of rock-water interactions in geothermal systems."

### Associate Principal Investigators

Yotaro Seki, Hydroscience and Geotechnology Laboratory Saitama University, Urawa, Japan
"Petrological-mineralogical-geochemical studies of rock-water interactions in geothermal systems, with emphasis on the Onikobe area."

Yasue Oki, Hot Springs Institute, Hakone, Kanagawa, Japan
"Petrological-mineralogical-geochemical studies of rock-water interactions in geothermal systems, with emphasis on the Hakone area."

Hitoshi Sakai, Institute for Thermal Springs Research, Okayama University, Misasa, Japan
"Isotopic and geochemical studies of rock-water interactions in geothermal systems."

### Associate Investigator

Ray Guillemette, Department of Geology, Stanford University, Stanford, CA 94305.
"Microprobe and SEM Investigations of drill hole core samples in geothermal systems".

It should be emphasized that the funds requested from the DOE are only for the Principal and Associate Investigators and their associates at Stanford University. The associate principal investigators in Japan have been funded by their own organizations.

The group has great expertise in the investigation of low-grade metamorphism and hydrothermal alteration in geothermal system. The Principal Investigator, J. G. Liou, and his associates at Stanford have been actively working on low-temperature rock-water interactions and the mineral paragenesis of low-grade metamorphic rocks from both experimental and field approaches. Because of his work on low-grade metamorphism, Dr. Liou received the Mineralogical Society of America Award in 1977.

Professor Y. Seki, a noted low-grade metamorphic petrologist, has been working on the mineralogic-petrologic problem of the Onikobe area since 1965 (Seki et al., 1969). Seki has long been interested in geological, mineralogical and petrological problems of low-grade diagenetic and hydrothermal alteration of volcanogenic rocks. Dr. Oki at Hot Springs Research Institute has gained wide recognition for their studies of the chemistry, mineralogy, and geology of volcanic rock-water systems in and around the Hakone volcanic region (Oki and Hirano, 1970, 1974). His major research for the last 10 years has been on water-rock interactions in hydrothermal metamorphism in both the Green Tuff region and some active geothermal areas in Japan. Prof. Sakai has achieved international recognition for his research on the isotopic properties of Japanese rock-water systems and his contributions to the theory of isotopic fractionations (e.g., Sakai and Matsubaya, 1974; Sakai and Dickson, 1978).

The Principal Investigator and his Japanese associates have an excellent record of identifying the Ca-zeolites by the use of polarizing microscopes (e.g., Seki, 1970; Oki, et al., 1976; Liou, 1978). These Ca-zeolites commonly constitute less than 5% of the rock as replacement of Ca-plagioclase and as vein and amygdaloidal minerals, and bulk X-ray diffraction analysis (e.g., Ehlers et al., 1979) may not detect their presence. Their occurrence in the geothermal system provides excellent control in estimating P-T conditions as well as the activities of $CO_2$ and $SO_4$, since their stabilities have been previously well determined by the Principal Investigator (Liou, 1970, 1971a,b,c,&d).

During the last two years, the group has been effectively working on "The interactions between Miocene Volcanogenic rocks and seawater-meteoric water mixtures in the Seikan Undersea Tunnel, Japan" and a number of other projects. Publication of a book on the Seikan results is underway (Seki et al., in press).

Procedures and Cooperation

I. Plan of the Project: Selection of the Onikobe and Hakone geothermal areas for the cooperative research targets was made three years ago, since their basic geology and hydrologic-geochemical information of their thermal waters are available and the Associate Principal Investigators Seki and Oki have been working on these geothermal areas for a number of years. The Tatun geothermal system was added to our project for comparison with the Japanese systems and because of its potential economic importance. The group (in part or as a whole) met several times during the 1976-78 period to discuss and define the basic role of each investigator. A set of interesting scientific questions was drawn up, and alternative target areas in Japan and Taiwan were proposed.

II. Field Study and Sample Collection: The group met in Japan during the summer of 1978 and visited many geothermal areas there. At the Onikobe caldera, the power plant was visited and rock types, geologic structures and flowing springs were examined. Two drill hole cores with depths down to 350 m (Nos. 123 and 124) and one down to 1300 m (GO-11) were selected for detailed petrologic-geothermal studies. Their stratigraphic relations and temperature gradients have been constructed by Seki (e.g. see Fig. 2).

Core samples were collected at every 10 to 20 m and were separated into three portions: one to Seki and Oki for petrographic and clay mineral identification, one to Sakai for isotopic study, and one to Stanford for petrographic, microprobe and SEM investigations. The group also visited the Hakone caldera and examined geologic features and thermal springs. Two drill-hole cores up to 500 m in depth (Nos. M-112 and M-116) with known stratigraphy and temperature gradient were collected according to the same procedures as those for the Onikobe samples. In the same summer, Liou visited the Tatun geothermal field in Taiwan, collected core samples from drill holes (see Appendix A for detail) and made a parallel study.

In September, 1980, the Associate Investigator, Guillemette, will visit the Onikobe and Hakone geothermal areas and collect core samples from a newly drilled hole (No. 134) in Onikobe. This hole was drilled under the recommendation of Seki and Oki based on our petrological-geochemical data, and this has been the best producing well in the area.

III. Petrographic Study: During the sabbatical year (September, 1978 to July, 1979), the Principal Investigator, Seki, and Oki studied the thin sections of drill-hole core samples from the Onikobe, Hakone and Tatun geothermal areas. Minerals identified include Ca-zeolites (mordenite, stilbite, epistilbite, heulandite, yugawaralite, laumontite and wairakite), analcime, prehnite, epidote, albite, K-feldspar, gypsum, anhydrite, alunite, carbonate, kaolinite, illite, smectite-chlorite clay minerals, pyrite, magnetite, hematite and others. Their paragenetic sequence and depth zonal distribution were delineated; examples are shown in Figure 1 of Appendix A.

IV. X-ray Diffraction and SEM Study: By using X-ray diffraction together with Differential Thermal Analyses (DTA), we have identified 4 types of smectite-chlorite clays in these geothermal areas as described in p.11 . Systematic study of these clay minerals by Scanning Electron Microscopy (SEM) will be undertaken at Stanford in order to determine (1) morphology and crystallinity of the 4 types of clay minerals; (2) textural relationships and paragenesis among the clay minerals and other silicates, and (3) compositions of these fine-grained clay minerals. These data are significant for our interpretation of rock-water interactions in geothermal systems, as these clay minerals are ubiquitous and abundant in most drill-hole core samples.

V. Microprobe Analyses: Microprobe analyses of silicates, clay and carbonate minerals are underway at Stanford by graduate student Ray Guillemette and the Principal Investigator. It is well known that most Ca-zeolites have extensive compositional variations. For example, wairakite ($CaAl_2Si_4O_{12} \cdot 2H_2O$) and analcime ($Na_2Al_2Si_4O_{12} \cdot 2H_2O$) form a nearly complete solid solution (e.g., Seki and Oki, 1969), yet only the end-member stabilities have been determined (Liou, 1970, 1971c). Therefore, depending on the Ca-Na substitution, wairakite minerals may form at temperatures much lower than those experimentally determined. Both epidote and prehnite from geothermal areas may contain substantial amounts of ferric iron; a previous experimental study by Liou (1973) and studies on natural paragenesis by Seki (1971) and Liou (1979) suggest that Fe-rich epidote may form at very low temperatures in a very oxidized environment.

Therefore, compositions of those Ca-Al silicates are important in deciphering the physico-chemical conditions of their formation.

Our recent study on carbonate minerals from the Seikan Undersea Tunnel has yielded a significant paragenetic sequence of carbonates from calcite $\rightarrow$ dolomitic carbonate $\rightarrow$ sideritic carbonate in response to the changes in circulating fluids (Liou and Seki, 1980). Similar variations and paragenesis of carbonate minerals may have occurred in the geothermal areas inasmuch as the circulating hydrothermal fluids are mixtures of seawater and meteoric water.

Polished thin sections were prepared for most drill hole core samples and each section was carefully examined. Individual mineral grains selected for probe analysis were sketched and photographed before being coated with carbon in preparation for microprobe analysis. Microprobe analyses of carbonate and clay minerals require highly polished carbon-coated surfaces. Slight imperfections caused by cleavage, fracture and impurities can significantly affect the analytical results. Moreover, carbonate, clay and zeolite minerals are readily damaged by high electron-beam currents of the small beam diameters used during the microprobe analysis (e.g., Macqueen and Ghent, 1970; Bickle and Powell, 1977; Matsumoto, 1978; Liou, 1979). Therefore, special precautions were necessary to ensure that the data were reliable.

VI. Isotope Studies: Concurrent with the mineralogical-petrological and compositional investigations, stable isotopic studies will be made on selective drill hole core samples and their mineral separates including carbonates, sulfates, sulfides and silicates by Sakai in his laboratory. The isotopic compositions (C, O, H, S) will be carefully defined and the data utilized to establish the source and nature of the hydrothermal fluids and to estimate the temperatures of equilibration of the mineral species.

Isotopic fractionation factors between co-precipitated mineral pairs such as quartz-carbonate, or sulfate-sulfiode are functions of temperature. The fractionation factors of oxygen isotope ratios among carbonates and silicates have been commonly used as geothermometers. Those of sulfur isotopes have been experimentally destermined by Sakai and Dickson (1978) and by Sakai et al. (1980) as part of the U.S. - Japan Cooperative project. During the next two years, waters from rain, river, shallow and deep wells in the Onikobe geothermal area will be collected periodically and analyzed for deuterium and $O^{18}$ contents. These data, together with the isotopes of many Japanese geothermal waters and meteoric waters (e.g., Matsubaya and Sakai, 1973) will be used to determine the origin of present-day geothermal fluids in the Onikobe. The carbon and sulfur isotopic ratios of carbonates and sulfur minerals from the drill-hole core samples reflect whether the geothermal fluids are magmatic, meteoric or brines or mixtures of these. Furthermore, once the temperature of a fossil fluid is determined, the oxygen and hydrogen isotope ratios of the fluids will be estimated. Hence, the source and origin of the fossil geothermal area will be evaluated and compared with the present active geothermal system and evolution of a geothermal system will be better understood.

VII. Interpretation: When the mineralogical-petrological-isotopic data are accumulated, the interaction modes between andesitic rocks and hydrothermal solutions will be addressed for the Onikobe, Hakone and Tatun geothermal areas independently. The similarities and differences between them and many other geothermal areas elsewhere will be compared and explained. The experimental data on andesite-water (+$CO_2$) presently undertaken at Stanford will be utilized to explain the genetic conditions and processes causing chemical and mineralogical changes during the rock-water interactions in the geothermal system.

VIII. Specific Goals and Anticipated Results: In conclusion, we are interested in the following questions:

1. The paragenetic sequence of formation of secondary minerals in the 3 geothermal areas and metamorphic reactions related to their formation.
2. The physico-chemical conditions of their genesis deduced from phase equilibria and their comparison with recorded temperatures, depth, pH and analyzed solution compositions.
3. The spatial patterns of hydrothermal alterations and their relation to the flow of hydrothermal solutions.
4. The source of the hydrothermal fluids responsible for the alteration.
5. The effective water-rock ratio in the geothermal system.
6. The attainment of chemical and isotopic equilibrium in the coexisting minerals.
7. The change of isotopic and fluid compositions and temperature of geothermal fluids as a function of time as recorded in the changes of mineral assemblages in these geothermal areas.

The comprehensive and cooperative study described above will address the above and other questions which are necessary for our better understanding of the evolution of a geothermal system. This, in turn, will aid in future exloration and assessment of geothermal potential for other areas, as we have successfully recommended that a production well be drilled in the Onikobe area. The results of our cooperative research will be summarized into 3 comprehensive reports and many scientific papers.

## REFERENCES


Bickle, M. J., and Powell, R., 1977, Calcite-dolomite geothermometry for iron-bearing carbonates. Contr. Mineral. & Petrol. 59, p. 281-292.

Browne, P. R. L., 1970, Hydrothermal alteration as an aid in investigating geothermal fields. Geothermics, Special Issue 2, p. 564-570.

Coombs, D. S., Ellis, A. ., Fyfe, W. S., and Taylor, A. M., 1959, The zeolite facies, with comments on the interpretation of hydrothermal syntheses. Geochim. Cosmochim. Acta 17, p. 53-107.

Elders, W. A., Houghland, J. R., Olson, E. R., McDowell, S. D., and Collier, P., 1978, A comprehensive study of samples from geothermal reservoirs: petrology and light stable isotope geochemistry of twenty-three wells in the Cerro Prieto geothermal field, Baja California, Mexico. Institute of Geophysics & Planetary Physics, Riverside, California, 264 p.

Ishihara, S., 1974, Magmatism of the Green Tuff tectonic belt, Northeast Japan, in, Geology of Kuroko Deposits (Eds., Ishihara et al.), Mining Geology, Special Issue No. 6, p. 235-249.

Katsui, Y., Oba, Y., Ando, S., Nishimura, S., Masuda, Y., Kurasawa, H., and Fujimaki, H., 1974, Petrochemistry of the Quaternary volcanic rocks of Hokkaido, North Japan. Japanese-Soviet Seminar, Tokyo, Geodynamic Project, p. 1-36.

Kuno, H., 1966, Lateral variation of basalt magma type across continental margins and island arcs. Bull. Volcanol. 29, p. 195-222.

Kuno, H., 1968, Origin of andesite and its bearing on the islnd arc structure. Bull. Volcanol. ser. 2, 32, p. 141-176.

Liou, J.G., 1970, Synthesis and stability relations of wairakite, $CaAl_2Si_4O_{12} \cdot 2 H_2O$. Contr. Mineral. Petrol. 27, p. 259-282.

Liou, J.G., 1971a, Synthesis and stability relations of prehnite, $Ca_3Al_2Si_3O_{10}(OH)_2$. Amer. Mineral. 56, p. 507-531.

Liou, J. G., 1971b, P-T stabilities of laumontite, wairakite, lawsonite and related minerals in the system $CaAl_2Si_2O_8$-$SiO_2H_2O$. Jour. Petrol. 12, p. 370-411.

Liou, J. G., 1971c, Stilbite-laumontite equilibrium. Contr. Mineral. Petrol. 31, p. 171-177.

Liou, J. G., 1971d, Stilbite-laumontite equilibria. Lithos. 4, p. 389-402.

Liou, J. G., 1973, Synthesis and stability relations of epidote, $Ca_2Al_2FeSi_3O_{12}$ . (OH) . Jour. Petrol. 14, p. 381-413.

Liou, J. G., 1979, Zeolite facies metamorphism of basaltic rocks from the East Taiwan ophiolite. Amer. Mineral. v. 64, p. 1-14.

Liou, J. G., and Y. Seki, 1980, Parageneses of carbonate minerals from volcanogenic rocks interacted with sewater and meteoric water in the Seikan Undersea tunnel, Japan. Proc. 3rd Internat. Symposium on Water-Rock Interaction, Edmonton, Canada, p. 151-152.

Macqueen, R. W., and Ghent, E. D., 1970, Electron microprobe study of magnesian distribution in some Mississippian echinoderm limestones from western Canada. Canadian Jour. Earth Sci. 7, p. 1307-1316.

Matsubaya, O., and Sakai, H., 1973, Oxygen and hydrogen isotopic study on the water of crystallization of gypsum from the Kuroko-type mineralization. Geochem. Jour. 7, p. 153-165.

Matsubaya, O., Sakai, H., Kusachi, I., and Satake, H., 1973, Hydrogen and oxygen isotopic ratios and major element chemistry of Japanese thermal water systems. Geochem. Jour., 7, p. 123-151.

Matsumoto, R., 1978, Occurrence and origin of authigenic Ca.Mg.Fe carbonates and carbonate rocks in the Paleogene coalfield regions in Japan. Tokyo Univ. Fac. Sci. Jour. Sect. II, 19, p. 335-367.

Miyashiro, A., 1974, Volcanic rock series in island arcs and active continental margins. Amer. Jour. Sci., 274, p. 321-355.

Oki, Y., and Hirano, T., 1970, The geothermal system of the Hakone volcano. U.S. Symp. on Development and Utilization of Geothermal resources, Pisa, 1970, 2, p. 1157-1166.

Oki, Y., and Hirano, T., 1974, Hydrothermal system and seismic activity of Hakone volcano. The Utilization of Volcanic Energy, Proceedings of U.S.-Japan Cooperatiove Science Seminar, Hilo, Hawaii, p. 13-40.

Oki, Y., Hirano, T., Suzuki, T., 1976, Hydrothermal metamorphism and vein minerals of the Yugawara geothermal area, Japan. Proc. First Internat. Symposium Water-Rock Interaction, IAGC, p. 209-222.

Sakai, H., and Dickson, F. W., 1978. Experimental determination of the rate and equilibrium fractionation factors of sulfur isotope exchange between sulfate and sulfide in slightly acid solutions at $300^{\circ}C$ and 1000 bars. Earth and Planetary Sci. Letters, v. 329, p. 151-161.

Sakai, H., and Matsubaya, O., 1974, Isotopic geochemistry of the thermal waters of Japan and its bearing on the Kuroko ore solutions. Econ. Geol. 69, p. 974-991.

Sakai, H., Takenaka, T., and Kishima, N., 1980. Expermental study of the rate and isotope effect in sulfate reduction by ferrous iron oxides and silicates under hydrothermal conditions. Proc. 3rd Internat. Symposium on Water-Rock Interaction, Edmonton, Canada, p. 75-76.

Seki, Y., 1970, Alteration of bore-hole cores in mordenite-bearing assemblages in Atosanupuri active geothermal area, Hokkaido, Japan. Jour. Geol. Soc. Japan 76, p. 605-611.

Seki, Y., 1973, Metamorphic facies of propylitic alteration. Jour. Geol. Soc. Japan 79, p. 771-780.

Seki, Y., 1976, Comparison of $CO_2$ and $O_2$ in fluids attending the prehnite-pumpellyite facies metamorphism of the central Kii Peninsula and the Tanzawa mountains, Japan. Proc. 1st Internat. Symposium Water-Rock Interaction, p 230-235, Prague.

Seki, Y., Onuki, H., Okumura, K., and Takashima, I., 1969, Zeolite distribution in the Katayama geothermal area, Onikobe, Japan. Japan. Jour. Geol. Geography, Vol. XL, p. 63-79.

Seki, Y. and Oki, Y., 1969, Wairakite-analcime solid solutions from low-grade metamorphic rocks of the Tanzawa Mountains, central Japan. Min. Journal, 6, p. 36-45.

Seki, Y., Liou, J. G., Dickson, F. W., Oki, Y., Sakai, H., Hirano, T., in review. The interactions between volcanogenic rocks and seawater-meteoric water mixture in the near coast undersea part of the Seikan Tunnel, Japan. Tokyo Univ. Press.

Steiner, A., 1953, Hydrothermal rock alteration at Wairakei, New Zealand. Econ. Geol., 48, p. 1-13.

Zen, E-An and Thompson, Alan B., 1974, Low-grade regional metamorphism: Mineral equilibrium relations. Annual review of Earth and Planet. Sci., vol. 2, p. 179-212.

## PROPOSED TIMETABLE AND RESEARCH ACTIVITIES

We request the starting date of this prject be December 1, 1980, and suggest a two-year duration. As described in previous sections, the geologic setting, petrographic and X-ray studies of drill hole core samples from the Onikobe, Hakone and Tatun geothermal areas were examined by the Principal Investigator and his associates during his sabbatical year of 1978-79 in Japan and Taiwan. Table 3 lists the data collected thus far and the responsibilities of each individual of the research group. Research activities of the Principal Investigator and his associates at Stanford are chronologically listed below along with their allotted time:

| Date & % Of Effort of Principal Investigator | Research Activities at Stanford |
|---|---|
| September, 1980 | 1. The Associate Investigator, Ray Guillemette, to visit Onikobe and Hakone, (a) studying the geologic setting and (b) collecting more core samples for detailed study. |
| December, 1980<br>10% time | 1. Continue petrographic and X-ray study of drill-hole core samples.<br>2. Completion of microprobe analyses of minerals from Onikobe.<br>3. Begin examination of clay minerals by SEM. |
| January, 1981<br>10% time | 1. The Principal Investigator to meet Drs. Seki and Oki in Taiwan (a) to examine the geologic-hydrologic setting of the Tatun geothermal area, and (b) to discuss results and write a first draft on the Onikobe geothermal system. (The Principal Investigator and Drs. Seki and Oki have been invited to attend a U.S.- China Symposium in Taiwan).<br>2. Continue research |
| February-June, 1981<br>10% time | 1. Continue writing a report on "The Onikobe Geothermal System".<br>2. Continue examination of clay minerals by SEM.<br>3. Complete microprobe analyses of minerals from Hakone.<br>4. Prepare abstracts for the GSA Annual Meeting. |
| Summer, 1981<br>(July-Sept.)<br>30% time | 1. Complete 1st draft of "The Onikobe Geothermal System" report.<br>2. Meet Japanese Colleagues (Seki or Oki) at Stanford to exchange results.<br>3. Continue research, data processing.<br>4. Complete clay mineral examination by SEM.<br>5. Prepare an outline for a report on "The Hakone Geothermal System."<br>6. Task I Report to DOE on 8/11/81. |

| Date & % Of Effort of Principal Investigator | Research Activities at Stanford |
|---|---|
| Sept.- Oct., 1981<br><br>10% Time | 1. Revise "The Onikobe Geothermal System".<br>2. Complete microprobe analyses of minerals from Tatun.<br>3. Continue research, data processing, preparation of talks for the GSA meeting.<br>4. Report writing, "The Hakone Geothermal System." |
| Jan.- June, 1982<br><br>10% time | 1. Complete final draft of "The Onikobe Geothermal System".<br>2. Complete 1st draft of "The Hakone Geothermal System."<br>3. Complete all data collection.<br>4. Condense manuscripts of "The Onikobe Geothermal System" for publication.<br>5. Task II Report to DOE on Feb. 1, 1982. |
| Summer, 1982 (July Sept.)<br><br>30% time | 1. Meet Seki-Oki-Sakai in Japan and discuss work accomplishment.<br>2. Complete final draft of "The Hakone Geothermal System".<br>3. Start first draft of "The Tatun Geothermal System". |
| Sept.- Nov., 1982<br><br>10% time | 1. Complete first draft of "The Tatun Geothermal System".<br>2. Condense manuscript of "The Hakone Geothermal System" for publication.<br>3. First draft of over-view paper to compare the three areas studied with other geothermal areas.<br>4. Task III Report to DOE on Oct. 1, 1982. |
| Dec., 82 - June, 83 | 1. Complete final draft of "The Tatun Geothermal System".<br>2. Prepare papers for publication.<br>3. Final Report to DOE on Dec. 30, 1982. |
| Aug., 1983 | 1. Meet Seki, Oki, and Sakai in Japan to review the project accomplishments.<br>2. Attend and present papers at the 4th International Water/Rock Interaction Symposium in Japan (which Sakai is chairing).<br>3. Field trips to Hakone and Onikobe will be scheduled and led by Oki and Seki, respectively. |

TABLE 3. Accomplished data collection for drill hole cores from the Onikobe, Hakone and Tatun Geothermal Areas.

| | Onikobe | | | Hakone | | Tatun |
|---|---|---|---|---|---|---|
| | 123 | 124 | 134 | M-112 | M-116 | |
| Thin-section making | YS 100% | YS 100% | JL, YS | YS 100% | YS 100% | JL 100% |
| Petrography 80% | YS 80% | YS 80% | JL, YS | YS, JL | YS, JL | JL, YS |
| Bulk XRF | JL | JL | JL | JL | JL | JL |
| Bulk X-ray | YS 80% | YS 80% | YS | YS 80% | YS 80% | JL 80% |
| Clay Fraction | | | | | | |
| X-ray (dry) | YS 80% | YS 80% | YS | YS 80% | YS 80% | JL YS |
| EG | YS 80% | YS 80% | YS | YS 80% | YS 80% | JL YS |
| Electron Microprobe (EMX) | JL 40% | JL | JL, RG | RG 20% | JL | JL |
| Carbonate | | | | | | |
| X-ray | YS 100% | YS 100% | YS | YS 100% | YS 100% | YS 100% |
| EMX | JL | JL | JL | RG 100% | JL | JL |
| SEM | RG | RG | RG | RG | RG | RG |
| Isotopes | HS | HS | HS | HS | HS | HS |

JL - Liou, YS - Seki, YO - Oki, HS - Sakai, RG - Guillemette

Abbreviations: EG - ethylene glycol;
EMX - electron microprobe analysis of minerals;
XRF - X-ray fluorescence analysis of rocks;
SEM - scanning electron microscope.

% shown here indicates the data collection accomplished thus far.

## QUALIFICATIONS AND CAPABILITIES

### Personnel at Stanford

Principal Investigator: J. G. Liou, Associate Professor, will spend about 10% time on the proposed research during the academic year and 40% time for four months during the summers of 1981 and 1982. For bibliography of J. G. Liou see Appendix B.

Associate Investigator: Ray Guillemette, a graduate student of the Stanford Geology Department, has been working on the project described in the proposal since 1978. He was a Principal Investigator on a ERDA-DOE grant to investigate clay minerals and zeolites in cores and cuttings from the Raft River geothermal area in Idaho. He will spend 100% time on the proposed research. For bibliography of Ray Guillemette, see Appendix C.

Visiting Investigator: Prof. Hyung Shik Kim of Korean University will be supported by his government at Stanford for advanced training in low-grade metamorphism during the period from August 1, 1980 to August 31, 1981. During his stay at Stanford, he will spend about 60% time on the research described in the proposal. Funds are requested to support some of the analytical expenses of his research. For bibliography of H. S. Kim see Appendix D.

Research Assistant: One half-time research assistant is requested. Currently, Rona Donahoe (a Ph.D. candidate) is doing research for her degree solely on the topics of this proposal.

### Personnel in Japan

Associate Principal Investigator: Yotaro Seki, Professor of Saitama University, will spend about 40% time on the proposed research. He has been working on low-grade metamorphism and hydrothermal alteration of Onikobe and other geothermal areas for years. His major effort is optical and X-ray identification of zeolites, clay and other secondary minerals in the drill hole core samples of the three geothermal areas. For bibliography of Yotaro Seki, see Appendix E.

Associate Principal Investigator: Yasue Oki, Director of Hot Spring Research Institute, Hakone, Japan, and his co-worker Tomi Hirano will spend about 20% time on the proposed research. They have gained wide recognition for their studies of the chemistry, mineralogy and geology of volcanic rock-water systems in and around the Hakone volcanic region. Their major effort is to analyze major and trace elements of thermal waters in geothermal systems and to determine their relations to the paragenesis of secondary minerals. For bibliography of Yasue Oki, see Appendix F.

Associate Principal Investigator: Hitoshi Sakai, Director of the Institute for Thermal Spring Research, Japan, will spend about 20% time on the proposed research. He has gained international recognition for his research on the isotopic properties of the rock-water systems of Japan. His major effort will be isotopic analyses (C.H.O.S) of thermal waters and minerals in geothermal systems.

## Facilities

Modern analytical facilities for geochemical, petrological, and mineralogical research are available in the School of Earth Sciences, Stanford University. In routine operation are an ARL electron-microprobe, an X-ray fluorescence spectrograph, emission and atomic absorption spectrographs, and laboratories for conventional wet chemical analyses.

Automation of the Stanford Electron Microprobe is underway. During the period of September, 1980 to August, 1982, the state-of-the-arts analytical facilities of the U. S. Geological Survey, Menlo Park, will be installed at the School of Earth Science, Stanford University because of reconstruction of their earthquake-safety building at Menlo Park. These facilities include 2 fully automated Wave Length Dispersive X-ray Spectrometers (Diano Type 8600) for both major and minor 30 element analyses and an automatic plasma spectrograph for minor and trace element analysis of solutions. They will be available to the Principal Investigator and his associates under an agreement signed in May, 1980. X-ray equipment includes standard powder and single crystal diffractometers and a Picker automated spectrometer. Many of these facilities are supported in large part by NSF. A thin-section laboratory and a machine shop are available to both investigators. A scanning electron microscope and computer facilities at Stanford can be used by appropriate arrangement.

Other analytical facilities for the proposed research include Standard X-ray equipment and a humidity controlled laboratory for separation and identification of clay minerals at Saitama University (Prof. Yotaro Seki) and a mass spectrometer for isotopic analyses (H, C, O, and S) at the Institute for Thermal Research (Prof. Hitoshi Sakai). The Associate Investigators, Seki and Sakai, are in charge of these laboratories.

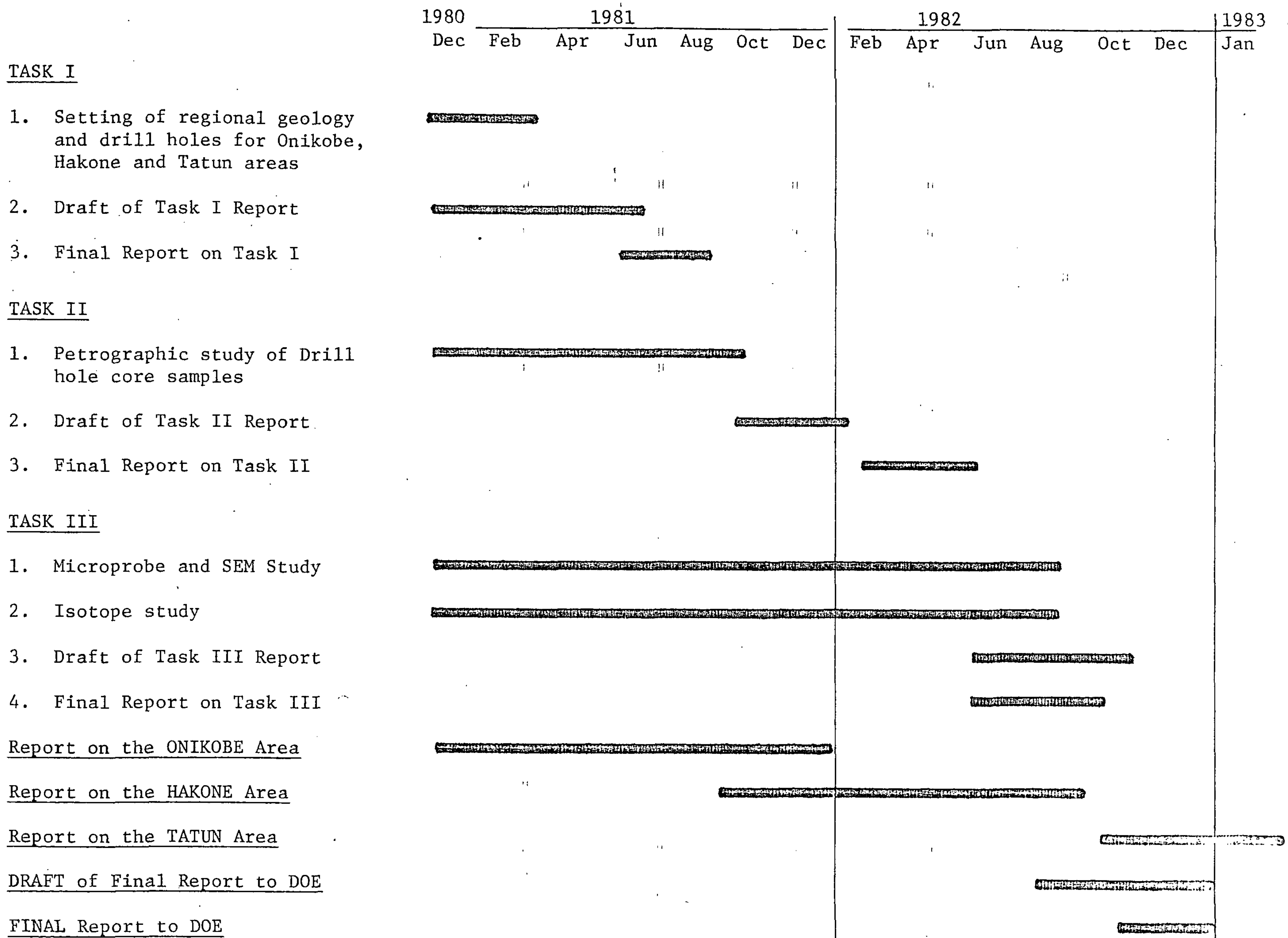
## OTHER CONTRACTS

The list below are other contracts by the Principal Investigator during the period from 1976 - 1982.

| Agency | Project Title and Contract No. | Amount | Period |
|---|---|---|---|
| NSF[1] | Stabilities and Element Distribution of Minerals under Hydrothermal Conditions, EAR 73-06520-A-02 | $ 70,000 | 4/1/76 - 8/31/79 |
| NSF[2] | Stabilities and Element Distribution of Minerals under Hydrothermal Conditions, EAR 79-09183 | $100,480 | 9/1/79 - 8/31/81 |
| NSF[1] | Petrology, Metamorphism and Tectonics of Some Gabbroic Intrusives and Conglomates in the Franciscan Complex, EAR 76-22650 | $ 64,600 | 1/1/77 - 12/1/79 |
| NSF[2] | Petrology, Metamorphism and Tectonics of Melange Terranes in the Franciscan Complex, California EAR 80-08527 | $ 75,200 | 4/1/78 - 8/31/80 |
| NSF[1] | Coordinated Studies of Rock-Water Interactions Related to Island-Arc Processes by Experimental and Field Approaches, EAR 77-23173 | $ 85,200 | 4/1/78 - 8/31/80 |
| NSF[3] | Petrologic, Structural and Tectonic Investigations of the Paired Metamorphic Belts and Ophiolite of Taiwan, EAR 77-23533 (With W. G. Ernst & John Suppe) | $ 94,000 | 7/1/78 - 6/30/80 |

[1]Geochemistry
[2]Petrology
[3]Geology

## TASK SCHEDULE*




* For details, see Proposed Timetable and Research Activities

# MILESTONES

| | Year | 1981 | | | | | | 1982 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MON. | 2/1 | 4/1 | 6/1 | 8/1 | 10/1 | 12/1 | 2/1 | 4/1 | 6/1 | 8/1 | 10/1 | 12/1 |
| | Quarterly Progress Reports | | | Δ | | | Δ | | | Δ | | | Δ |
| | | | | | | | | | | | | | |
| | Task I Report | | | | | Δ | | | | | | | |
| | Task II Report | | | | | | | | Δ | | | | |
| | Task III Report | | | | | | | | | | Δ | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | Draft Final Report | | | | | | | | | | | Δ | |
| | | | | | | | | | | | | | |
| | Final Report* | | | | | | | | | | | | Δ |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

REMARKS (Comment Briefly on Significant Items)

* The final report will include final draft for (1) the Onikobe and (2) the Hakone geothermal systems and first draft for the Tatun geothermal system.

PROJECT MANAGEMENT PLAN

Liou (P. I.)

Geothermal Areas

- Seki (A.I.) (Onikobe)
- Oki (A.I.) (Hakone)
- Liou (P.I.) (Tatun)

Operation and Data Collection

- Regional Geology, Setting of Drill Cores, Geothermal Potential, etc.
  - Seki (Onikobe)
  - Oki (Hakone)
  - Liou (Tatun
- Petrography, Lithology, Mineral Parageneses (Seki & Liou)
- Characteristics of Thermal Waters (Oki)
- XRD, Clay Minerals (Seki)
- XRF Rock Composition (Liou)
- Microprobe, Mineral Comp.; SEM Morphology (Liou, Guillemette)
- Isotopic (Sakai)

Preparation of Reports and Scientific Papers

(in charge)

- Onikobe (Seki & Liou)
- Hakone (Oki, Seki, Liou)
- Tatun (Liou)

Report to DOE
(Liou)

## PROPOSED BUDGET

| | 12/1/80 - 11/30/81 | 12/1/81 - 11/30/82 |
|---|---|---|
| A. SALARIES AND WAGES | | |
| J. G. Liou, Principal Investigator<br>10% each academic year, 1.8 mm | 3,277 | 3,507 |
| 30% each summer 1.8 mm | 3,277 | 3,507 |
| Research Assistant<br>(2) 50% time acad. year, 100% time summer | 10,500 | 11,236 |
| Secretary, 8% effort calendar year | 800 | 856 |
| | 17,854 | 19,106 |
| B. FRINGE BENEFITS | | |
| 12/1/80 - 8/31/81 @ 21%<br>9/1/81 -11/30/81 @21.6% | 3,883 | |
| 12/1/81 - 8/31/82 @ 21.6%<br>9/1/82 -11/30/82 @ 22.2% | | 4,270 |
| C. EXPENDABLE SUPPLIES AND EXPENSES | | |
| Xeroxing, phones, etc. | 1,000 | 1,000 |
| D. SERVICES | | |
| Thin section preparation for probe analysis<br>60 each year @ $10/ea | 600 | 600 |
| Electron microprobe at $40/hr w/o operator<br>50 hrs/yr | 2,000 | 2,000 |
| XRF analyses @ 20/hr, 40 hrs/yr | 800 | 800 |
| Scanning electron microscope, 25/hr w/o operator<br>40 hrs/year | 1,000 | 1,000 |
| E. TRAVEL | | |
| One round trip to Japan in summer, 1982 | | 2,500 |
| Domestic meetings | 600 | 600 |
| F. PUBLICATION COSTS | 500 | 500 |
| G. COMPUTER COSTS | 300 | 300 |

| | | 12/1/80 - 11/30/81 | 12/1/81 - 11/30/82 |
|---|---|---|---|
| H. | TOTAL DIRECT COSTS (A THROUGH G) | 28,537 | 32,676 |
| I. | INDIRECT COSTS (58% NTDC) | 16,551 | 18,953 |
| J. | TOTAL REQUESTED FROM SPONSOR | 45,088 | 51,629 |
| K. | UNIVERSITY COST SHARING PER YEAR* | 451 | 516 |
| L. | TOTAL COST OF PROJECT PER YEAR | 45,539 | 52,145 |

* - Cost sharing of $977.00 represents
3% of P. I. Annual Salary.

/agc

| CONTRACT PRICING PROPOSAL (RESEARCH AND DEVELOPMENT) | Office of Management and Budget Approval No. 29-RO184 |
|---|---|

This form is for use when (i) submission of cost or pricing data (see FPR 1-3.807-3) is required and (ii) substitution for the Optional Form 59 is authorized by the contracting officer.

PAGE NO. | NO. OF PAGES

| | | |
|---|---|---|
| NAME OF OFFEROR Board of Trustees of the Leland Stanford Junior University | SUPPLIES AND/OR SERVICES TO BE FURNISHED Title of proposal | |
| HOME OFFICE ADDRESS Sponsored Projects Office Stanford, CA 94305 | | |
| DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED Dept. of Geology | TOTAL AMOUNT OF PROPOSAL $ 97,684 | GOV'T SOLICITATION NO. DE-SC07-80ID 12145 |

## DETAIL DESCRIPTION OF COST ELEMENTS

| | | | | EST COST ($) | TOTAL EST COST[1] | REFERENCE[2] |
|---|---|---|---|---|---|---|
| 1. DIRECT MATERIAL (Itemize on Exhibit A) | | | | | | |
| a. PURCHASED PARTS | | | | -0- | | |
| b. SUBCONTRACTED ITEMS | | | | | | |
| c. OTHER—(1) RAW MATERIAL | | | | | | |
| (2) YOUR STANDARD COMMERCIAL ITEMS | | | | | | |
| (3) INTERDIVISIONAL TRANSFERS (At other than cost) | | | | | | |
| TOTAL DIRECT MATERIAL | | | | | -0- | |
| 2. MATERIAL OVERHEAD[3] (Rate %X$ base =) | | | | | -0- | |
| 3. DIRECT LABOR (Specify) | % effort" | RATE/HOUR | | EST COST ($) | | |
| See attached budget | | | | | | |
| TOTAL DIRECT LABOR | | | | | $36,960 | A |
| 4. LABOR OVERHEAD (Specify Department or Cost Center)[3] | O.H. RATE | X BASE = | | EST COST ($) | | |
| TOTAL LABOR OVERHEAD | | | | | 8,153 | B |
| 5. SPECIAL TESTING (Including field work at Government installations) | | | | EST COST ($) | | |
| TOTAL SPECIAL TESTING | | | | | Ø | |
| 6. SPECIAL EQUIPMENT (If direct charge) (Itemize on Exhibit A) | | | | | -0- | |
| 7. TRAVEL (If direct charge) (Give details on attached Schedule) | | | | EST COST ($) | | |
| a. TRANSPORTATION | | | | | | |
| b. PER DIEM OR SUBSISTENCE See attached | | | | | | |
| TOTAL TRAVEL | | | | | 3,700 | E |
| 8. CONSULTANTS (Identify—purpose—rate) | | | | EST COST ($) | | |
| TOTAL CONSULTANTS | | | | | -0- | |
| 9. OTHER DIRECT COSTS (Itemize on Exhibit A) | | | | | 12,400 | C,DFG |
| 10. TOTAL DIRECT COST | | | | | 61,213 | H |
| 11. "Indirect Costs" 58% of cost element Nos. )[3] | | | | | 35,504 | I |
| 12. ROYALTIES[4] | | | | | -0- | |
| 13. TOTAL ESTIMATED COST | | | | | 96,717 | J |
| 14. "Cost Sharing" | | | | | 967 | K |
| 15. TOTAL ESTIMATED COST AND FEE OR PROFIT | | | | | 97,684 | L |



OPTIONAL FORM 60
October 1971
General Services Administration

This proposal is submitted for use in connection with and in response to *(Describe RFP, etc.)*

DE-SC07-80ID12145

and reflects our best estimates as of this date, in accordance with the Instructions to Offerors and the Footnotes which follow.

| TYPED NAME AND TITLE | SIGNATURE |
|---|---|
| Edward C. Barrera,<br>Staff Associate | |

| NAME OF FIRM | DATE OF SUBMISSION |
|---|---|
| Board of Trustees of the Leland Stanford Junior University | |

**EXHIBIT A—SUPPORTING SCHEDULE** *(Specify. If more space is needed, use reverse)*

| COST EL NO. | ITEM DESCRIPTION *(See footnote 5)* | EST COST ($) |
|---|---|---|
| | ~~See attached budget~~ | |

I. HAS ANY EXECUTIVE AGENCY OF THE UNITED STATES GOVERNMENT PERFORMED ANY REVIEW OF YOUR ACCOUNTS OR RECORDS IN CONNECTION WITH ANY OTHER GOVERNMENT PRIME CONTRACT OR SUBCONTRACT WITHIN THE PAST TWELVE MONTHS?

[x] YES [ ] NO *(If yes, identify below.)*

| NAME AND ADDRESS OF REVIEWING OFFICE AND INDIVIDUAL | TELEPHONE NUMBER/EXTENSION |
|---|---|
| DCAA, 400 Cambridge Ave., Suite 404 Palo Alto, CA 94305 | (415) 327-8411 |

II. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

[ ] YES [x] NO *(If yes, identify on reverse or separate page)*

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

[x] YES [ ] NO *(If yes, identify.)*: [x] ADVANCE PAYMENTS [ ] PROGRESS PAYMENTS OR [ ] GUARANTEED LOANS

IV. DO YOU NOW HOLD ANY CONTRACT *(Or, do you have any independently financed (IR&D) projects)* FOR THE SAME OR SIMILAR WORK CALLED FOR BY THIS PROPOSED CONTRACT?

[ ] YES [x] NO *(If yes, identify.)*:

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN AGENCY REGULATIONS?

[x] YES [ ] NO *(If no, explain on reverse or separate page)*

*See Reverse for Instructions and Footnotes* OPTIONAL FORM 60 (10-71)

APPENDIX E

## REPRESENTATIONS AND CERTIFICATIONS

[Instructions: Check or complete all appropriate boxes or blanks.]

The proposer makes the following representations and certifications:

1. SMALL AND SMALL DISADVANTAGED BUSINESS CERTIFICATION

(a) The bidder or offeror certifies that it is ( ) is not (X) a small business concern as defined in accordance with Section 3 of the Small Business Act (15 U.S.C. 632).

(b) The bidder or offeror certifies that it is a small business [as set forth in (a) above] and is ( ) is not ( ) owned and controlled by socially and economically disadvantaged individuals. Such a firm is defined as one -

(i) which is at least 51 per centum owned by one or more such individuals or, in the case of any publicly owned business, at least 51 per centum of the stock is owned by such individuals;

(ii) whose management and daily business operations are controlled by one or more such individuals; and

(iii) which certifies concerning said ownership and control in accordance with section (c) below.

(c) The bidder or offeror certifies that it is ( ) is not (X) a minority individual(s) in accordance with (c)(i) below or that it is ( ) is not (X) socially and economically disadvantaged in accord with section (c)(ii) or (c)(iii). Socially and economically disadvantaged individuals are defined as:

(i) United States citizens who are Black Americans, Hispanic Americans, Native Americans, or other specified minorities;

(ii) any other individual found to be disadvantaged pursuant to section 8(a) of the Small Business Act (15 U.S.C. 637); or

(iii) any other individual defined as socially, and economically disadvantaged, for purposes relating to other sections of the Small Business Act.

2. CONTINGENT FEE

(a) It ( ) has, (X) has not, employed or retained any company or person (other than a full-time bona fide employee working solely for the bidder) to solicit or secure this contract, and (b) it ( ) has, (X) has not, paid or agreed to pay any company or person (other than a full-time bona fide employee working solely for the bidder) any fee, commission, percentage or brokerage fee, contingent upon or resulting from the award of this contract; and agrees to furnish information relating to (a) and (b) above as requested by the Contracting Officer. (For interpretation of the representation, including the term "bona fide employee," see Code of Federal Regulations, Title 41, Subpart 1-1.5.).

3. TYPE OF ORGANIZATION

(X) non-profit educational institution

It operates as an ( ) individual, ( ) partnership, ( ) joint venture, ( ) corporation, incorporated in State of ________________________.
A body having corporate powers under the laws of the State of California.

4. EQUAL OPPORTUNITY

It (X) has, ( ) has not, participated in a previous contract or subcontract subject to the Equal Opportunity Clause herein, the clause originally contained in Section 301 of Executive Order No. 10925, or the clause contained in Section 201 of Executive Order No. 11114; it (X) has, ( ) has not, filed all required compliance reports; and representations indicating submission or required compliance reports, signed by proposed subcontractors, will be obtained prior to subcontract awards.

5. AFFIRMATIVE ACTION COMPLIANCE PROGRAM

The offeror represents that (a) it (X) has developed and has on file, ( ) has not developed and does not have on file, at each establishment an affirmative action program as required by the rules and regulations of the Secretary of Labor (41 CFR 60-1 and 60-2), or (b) ( ) has not previously had contracts subject to written affirmative action program requirements of the rules and regulations of the Secretary of Labor because (check as applicable):

________________________ offeror does not have 50 or more employees

________________________ offeror has not had a Government prime contract or subcontract of $50,000 or more.

6. CERTIFICATION OF NONSEGREGATED FACILITIES

By the submission of this proposal, the offeror, applicant, or subcontractor certifies that it does not maintain or provide for its employees any segregated facilities at any of its establishments, and that it does not permit its employees to perform their services at any location, under its control, where segregated facilities are maintained. It certifies further that it will not maintain or provide for its employees any segregated facilities at any of its establishments, and that it will not permit its employees to perform their services at any location, under its control, where segregated facilities are maintained. The offeror, applicant, or subcontractor agrees that a breach of this certification is a violation of the Equal Opportunity clause in this contract. As used in this certification, the term "segregated facilities" means any waiting rooms, work areas, rest rooms and wash rooms, restaurants and other eating areas, time clocks, locker rooms and other storage or dressing areas, parking lots, drinking fountains, recreation or entertainment areas, transportation, and housing facilities provided for employees which are segregated by explicit directive or are in fact segregated on the basis of race, creed, color, or national origin, because of habit, local custom, or otherwise. It further agrees that (except where it has obtained identical certifications from proposed subcontractors for specific time periods) it will obtain identical certifications from proposed subcontractors prior to the award of subcontracts exceeding $10,000 which are not exempt from the provisions of the Equal Opportunity clause; that it will retain such certifications in its files; and that it will forward the following notice to such proposed subcontractors (except where the proposed subcontractors have submitted identical certifications for specific time periods):

NOTICE TO PROSPECTIVE SUBCONTRACTORS OF REQUIREMENT FOR CERTIFICATION OF NONSEGREGATED FACILITIES

A Certification of Nonsegregated Facilities must be submitted prior to the award of a subcontract exceeding $10,000 which is not exempt from the provisions of the Equal Opportunity clause. The certification may be submitted either for each subcontract or for all subcontracts during a period (i.e., quarterly, semi-annually, or annually).

7. PARENT COMPANY AND EMPLOYER IDENTIFICATION NUMBER

Each proposer shall furnish the following information by filling in the appropriate blocks:

a. Is the proposer owned or controlled by a parent company as described below? ( ) Yes (X) No. (For the purpose of this proposal, a parent company is defined as one which either owns or controls the activities and basic business policies of the proposer. To own another company means the parent company must own at least a majority (more than 50 percent) of the voting rights in that company. To control another company, such ownership is not required; if another company is able to formulate, determine or veto basic business policy decisions of the proposer, such other company is considered the parent company of the proposer. This control may be exercised through the use of dominant minority voting rights, use of proxy voting, contractual arrangements, or otherwise.)

b. If the answer to a. above is "Yes", proposer shall insert in the space below the name and main office address of the parent company.

Name of Parent Company: ______________________

______________________

Main Office Address (No., Street, City, State and Zip Code)

______________________

______________________

______________________

______________________

c. Proposer shall insert in the applicable space below, if it has no parent company, its own Employer's Identification Number (E.I. No.) (Federal Social Security Number used on Employer's Quarterly Federal Tax Return, U. S. Treasury Department Form 941), or if it has a parent company, the E.I. No. of its parent company.

Employer Identification Number of Parent Company: 94-1156365

______________________

8. CLEAN AIR AND WATER CERTIFICATION

(Applicable if the bid or offer exceeds $100,000, or the Contracting Officer has determined that orders under an indefinite quantity contract in any year will exceed $100,000, or a facility to be used has been the subject of a conviction under the Clean Air Act (42 U.S.C. 1857c-8(c)(1)) or the Federal Water Pollution Control Act (33 U.S.C. 1319(c)) and is listed by EPA, or is not otherwise exempt.)

The bidder or offeror certifies as follows:

(a) Any facility to be utilized in the performance of this proposed contract has ( ), has not (X), been listed on the Environmental Protection Agency List of Violating Facilities.

(b) It will promptly notify the Contracting Officer, prior to award, of the receipt of any communication from the Director, Office of

6. CERTIFICATION OF NONSEGREGATED FACILITIES

By the submission of this proposal, the offeror, applicant, or subcontractor certifies that it does not maintain or provide for its employees any segregated facilities at any of its establishments, and that it does not permit its employees to perform their services at any location, under its control, where segregated facilities are maintained. It certifies further that it will not maintain or provide for its employees any segregated facilities at any of its establishments, and that it will not permit its employees to perform their services at any location, under its control, where segregated facilities are maintained. The offeror, applicant, or subcontractor agrees that a breach of this certification is a violation of the Equal Opportunity clause in this contract. As used in this certification, the term "segregated facilities" means any waiting rooms, work areas, rest rooms and wash rooms, restaurants and other eating areas, time clocks, locker rooms and other storage or dressing areas, parking lots, drinking fountains, recreation or entertainment areas, transportation, and housing facilities provided for employees which are segregated by explicit directive or are in fact segregated on the basis of race, creed, color, or national origin, because of habit, local custom, or otherwise. It further agrees that (except where it has obtained identical certifications from proposed subcontractors for specific time periods) it will obtain identical certifications from proposed subcontractors prior to the award of subcontracts exceeding $10,000 which are not exempt from the provisions of the Equal Opportunity clause; that it will retain such certifications in its files; and that it will forward the following notice to such proposed subcontractors (except where the proposed subcontractors have submitted identical certifications for specific time periods):

NOTICE TO PROSPECTIVE SUBCONTRACTORS OF REQUIREMENT FOR CERTIFICATION OF NONSEGREGATED FACILITIES

A Certification of Nonsegregated Facilities must be submitted prior to the award of a subcontract exceeding $10,000 which is not exempt from the provisions of the Equal Opportunity clause. The certification may be submitted either for each subcontract or for all subcontracts during a period (i.e., quarterly, semi-annually, or annually).

7. PARENT COMPANY AND EMPLOYER IDENTIFICATION NUMBER

Each proposer shall furnish the following information by filling in the appropriate blocks:

a. Is the proposer owned or controlled by a parent company as described below? ( ) Yes (X) No. (For the purpose of this proposal, a parent company is defined as one which either owns or controls the activities and basic business policies of the proposer. To own another company means the parent company must own at least a majority (more than 50 percent) of the voting rights in that company. To control another company, such ownership is not required; if another company is able to formulate, determine or veto basic business policy decisions of the proposer, such other company is considered the parent company of the proposer. This control may be exercised through the use of dominant minority voting rights, use of proxy voting, contractual arrangements, or otherwise.)

b. If the answer to a. above is "Yes", proposer shall insert in the space below the name and main office address of the parent company.

Name of Parent Company: ____________________

____________________

Main Office Address (No., Street, City, State and Zip Code)

____________________

____________________

____________________

____________________

c. Proposer shall insert in the applicable space below, if it has no parent company, its own Employer's Identification Number (E.I. No.) (Federal Social Security Number used on Employer's Quarterly Federal Tax Return, U. S. Treasury Department Form 941), or if it has a parent company, the E.I. No. of its parent company.

Employer Identification Number of Parent Company: 94-1156365

____________________

8. CLEAN AIR AND WATER CERTIFICATION

(Applicable if the bid or offer exceeds $100,000, or the Contracting Officer has determined that orders under an indefinite quantity contract in any year will exceed $100,000, or a facility to be used has been the subject of a conviction under the Clean Air Act (42 U.S.C. 1857c-8(c)(1)) or the Federal Water Pollution Control Act (33 U.S.C. 1319(c)) and is listed by EPA, or is not otherwise exempt.)

The bidder or offeror certifies as follows:

(a) Any facility to be utilized in the performance of this proposed contract has ( ), has not (X), been listed on the Environmental Protection Agency List of Violating Facilities.

(b) It will promptly notify the Contracting Officer, prior to award, of the receipt of any communication from the Director, Office of

Federal Activities, Environmental Protection Agency, indicating that any facility which it proposes to use for the performance of the contract is under consideration to be listed on the EPA List of Violating Facilities.

(c) It will include substantially this certification, including this paragraph (c), in every nonexempt subcontract.

9. WOMAN-OWNED BUSINESS

Concern is ( ) is not (X) a woman-owned business.

A woman-owned business is a business which is, at least, 51 percent owned, controlled, and operated by a woman or women. Controlled is defined as exercising the power to make policy decisions. Operated is defined as actively involved in the day-to-day management.

For the purposes of this definition, businesses which are publicly owned, joint stock associations, and business trusts are exempted. Exempted businesses may voluntarily represent that they are, or are not, woman-owned if this information is available.

10. PERCENT OF FOREIGN CONTENT

The offeror/contractor will represent (as an estimate), immediately after the award of a contract, the percent of the foreign content of the item or service being procured expressed as a percent of the contract award price (accuracy within plus or minus 5 percent is acceptable).

Signed by ______________________________

Edward C. Barrera, Staff Associate
(Title)

Note: No solicitation may be properly considered without this certification and no award may be made without it being executed.

# Investigation of Drillhole Core Samples from Tatun Geothermal Area, Taiwan

C.Y. Lan, J.G. Liou*, and Y. Seki**

Mining Research and Service Organization; No. 1, Tun-Hwa South Road, Taiwan, ROC
*Department of Geology, Stanford University, Stanford, CA 94305, United States of America
**Department of Hydroscience and Geotectonics, Saitama University, Japan

The Tatun geothermal area of northeastern Taiwan, about 3 x 18 $km^2$ in dimension, is covered by a thick sequence of Pleistocene andesitic lavas and pyroclastics. The andesites belong to the hypersthene series and range in composition from mafic augite-hypersthene andesite to silicic biotite-hornblende andesite. The volcanic rocks are unconformably underlain by Miocene sandstones, conglomerates, and shales. The sandstones are coarse-grained and very permeable (with porosity greater than 10 percent) and have been suggested to be deep geothermal reservoirs with temperatures greater than 250°C and areal distribution greater than 20 $km^2$. Many hot springs and fumaroles occur, but those with the most impressive discharges of thermal fluids are concentrated within a NE-striking fault zone about 4 km wide and 18 km long. Spring waters with temperatures of 40°C – 120°C are mostly the acid sulfate chloride type and have extremely low pH values from 1 to about 3 (Chen, 1975). The acid nature is apparently restricted to surface zones where oxidation of volcanic gases such as $H_2S$ prevails. At depth, as discussed later, the pH of waters must be higher as evidenced by the ubiquitous occurrence of calcite. Secondary minerals resulting from near-surface water/rock interactions include various silica minerals (opal, cristobalite, tridymite, and quartz), alunite, kaolinite, allophane, montmorillonite, pyrite, sulfur, and others. The mineral assemblages are characteristic of high $S_2$ and $O_2$ fugacities, high $SiO_2$ and total dissolved sulfur contents in the hydrothermal fluids (Wang, 1973).

The geothermal exploration of the Tatun area began in 1965 and, thus far, 62 gradient holes and 20 exploratory holes have been drilled. The gradient holes, of 35 to 622 m in depth and 2 to 3 inches in diameter, are mainly for collecting data on geothermal gradients and geology, whereas the exploratory holes up to 1510 m deep and 8.5 inches in diameter are mainly for collecting information about variation in geology, mineralogy, temperature, flow rate, and composition of fluid with depth. Core samples have been collected and temperature variations with depth have been recorded. Core samples from five drillholes were selected for detailed investigation in order to understand mineral parageneses of hydrothermal alteration and to compare them with those from Hakone and Onikobe, Japan (Seki, *et al.*, 1969; Oki and Hirano, 1974). The secondary minerals identified, together with recorded temperature gradients, are plotted versus depth in figure 1. Because temperatures fluctuated with time, temperatures shown in the figure represent the most recent measurement. A maximum temperature of 290°C has been recorded at a depth of 1200 m.

Three alteration zones were recognized based on the occurrence of kaolinite, alunite, Ca-zeolites, epidote, and the types of smectite-chlorite. Zone 1, restricted to near-surface depths of about 200 m or less, is characterized by the presence of kaolinite, alunite, pyrite, and gypsum. The original textures of andesite are totally obscured, and primary minerals have been entirely replaced. Core samples were recovered with difficulty, and secondary minerals are very similar to those at the effusive areas of hot springs and fumaroles. Zone 2, the intermediate zone between about 200 to 500 m, is characterized by the sporadic occurrence of laumontite, analcime, and hematite, together with abundant smectite-chlorite, anhydrite, quartz, carbonate, and pyrite. Alunite, wairakite, Type III chlorite and secondary albite were not found. Primary textures and minerals of the andesitic rocks are well preserved. Plagioclase (An 42 to 68) was mainly replaced by carbonates and anhydrite and locally by laumontite, whereas both hornblende and pyroxenes were mainly replaced by smectite-chlorite, illite, carbonate, pyrite, and hematite. Zone 3, below about 500 m, is characterized by the appearance of epidote, wairakite, chlorite, albite in addition to anhydrite, illite, quartz, and pyrite. The hornblende-two pyroxene andesitic core samples within this zone (for example, E-205 and E-208) are extensively altered and veined by secondary minerals. The primary porphyritic texture is modified by aggregates of saussurite + carbonate + anhydrite pseudomorphs after plagioclase and chlorite + pyrite + magnetite + sphene after mafic minerals. Plagioclases (An 44 to 66) were locally replaced by wairakite and epidote. Major vein minerals are carbonates, quartz, and anhydrite; wairakite and chlorite are also present.

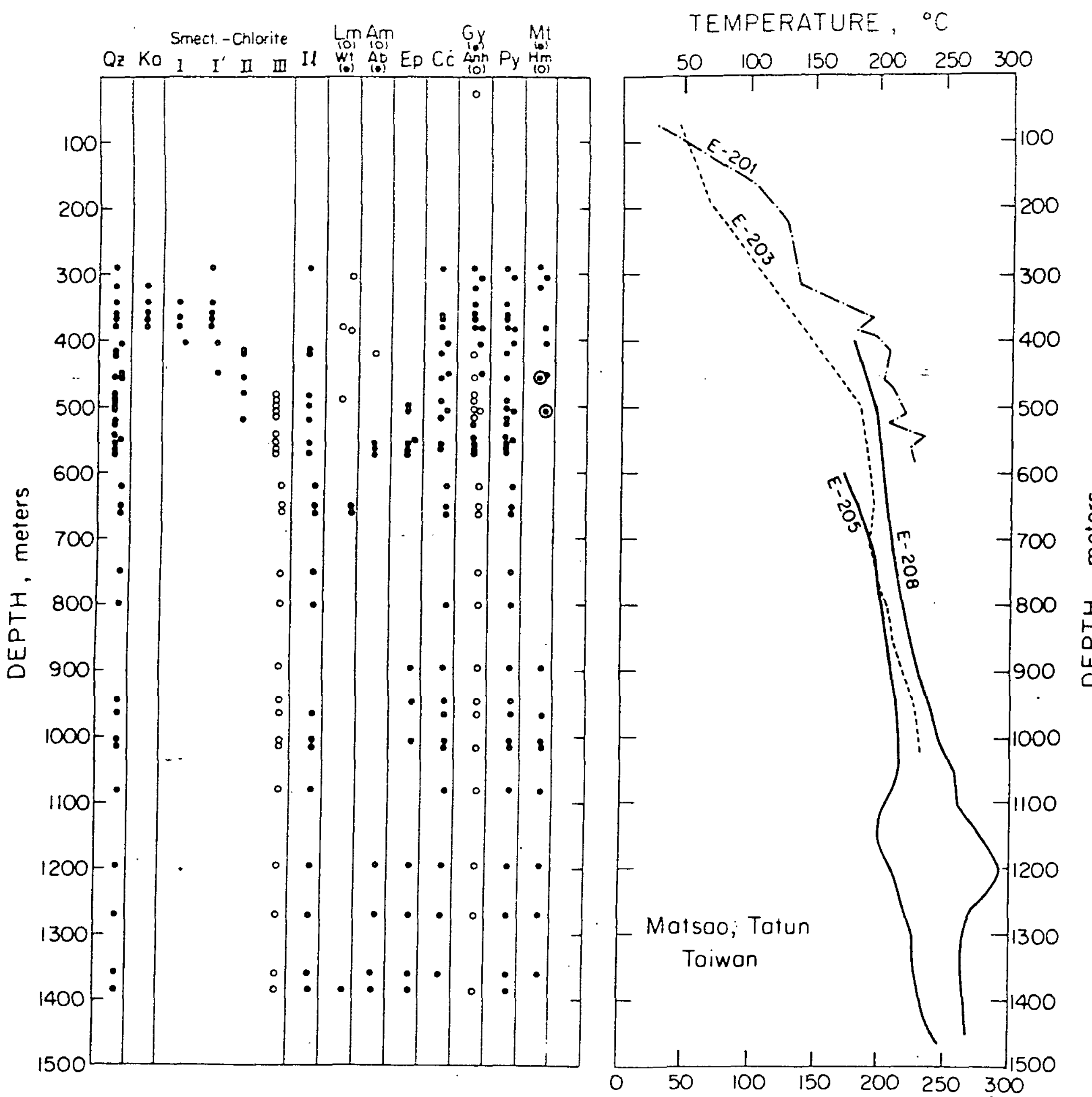



FIGURE 1. Variations of secondary minerals and temperatures with depths for exploratory drill holes E-201, 203, 205, and 208 from Matsao, Tatun Taiwan. Abbreviations for minerals: Qz-quartz, Ka-kaolinite, Il-illite, Lm-laumontite, Wt-wairakite, Am-analcime, Ab-albite, Ep-epidote, Cc-calcite, Gy-gypsum, Anh-anhydrite, Py-pyrite, Mt-magnetite, Hm-hematite.

The smectite-chlorite minerals of the altered andesitic rocks from the Tatun geothermal area and those from Onikobe and Hakone, Japan show systematic variations with depth and temperature. Detailed petrographic, X-ray diffraction (XRD), and differential thermal analysis (DTA) studies of the clay minerals reveal four distinct types, and their characteristic features are as follows. As shown in figure 1 together with the data from Hakone and Onikobe areas, Type I (alkaline montmorillonite) and Type I' (smectite) clay minerals are found commonly with mordenite and clinoptilolite, Type II smectite-chlorite with laumontite, and Type III with wairakite.

TABLE 1

XRD and DTA data on the four mineral associations, Tatun geothermal area

| Type | Association | CuKα2θ(001) | CuKα2θEG(001) | DTA Endothermic T, C |
|---|---|---|---|---|
| I | alk. mont. | 7.0 | 5.0 | 70,150,650 |
| I' | smectite | 6.0 | 5.0 | 70,150,650 |
| II | chl.-smec. | 3.0,6.0-6.2 | 3.0,5.6-5.9 | 70,150,550 |
| III | chlorite | 6.0-6.1 | 6.0-6.1 | 550 |

The smectite-chlorite minerals of the altered andesitic rocks from the Tatun geothermal area and those from Onikobe and Hakone, Japan show systematic variations with depth and temperature. Detailed petrographic, X-ray diffraction (XRD), and differential thermal analysis (DTA) studies of the clay minerals reveal four distinct types, and their characteristic features are as follows. As shown in figure 1 together with the data from Hakone and Onikobe areas, Type I (alkaline montmorillonite) and Type I′ (smectite) clay minerals are found commonly with mordenite and clinoptilolite, Type II smectite-chlorite with laumontite, and Type III with wairakite.

The parageneses of secondary minerals in the Tatun geothermal area is consistent with the recorded temperature-depth relations as shown in figure 1. However, it should be noted that calcite is ubiquitous at depths below about 200 m, and its common occurrence as a replacement of plagioclase and pyroxene and as fissure fillings indicates that thermal waters at greater depth must be less acidic than those in the surface zone. The rare occurrence of Ca-zeolites and other calcium aluminum silicates, and abundance of calcite and anhydrite (and gypsum) suggest that the hydrothermal alteration in this area must have taken place at high activities of $CO_2$ and $SO_2$ and temperatures of 100 to 300°C.

This paper represents research accomplished during the tenure of the U.S.-Japan (NSF EAR 77-23172) and the U.S.-China (NSF EAR 77-23533) scientific cooperative projects. We thank our colleagues Y. Oki, F.W. Dickson, and W.E. Dibble for informative discussion and review.

**References**

Chen, C.H. (1975): Thermal waters in Taiwan, a preliminary study; #119 International Association of Hydrogeological Sciences, Proceedings Grenoble Symposium, pp. 79-88.

Oki, Y. and T. Hirano (1974): Hydrothermal system and seismic activity of Hakone volcano. The Utilization of Volcano Energy; Proceedings of U.S.-Japan Cooperative Science Seminar, Hilo, Hawaii, pp. 13-40.

Seki, Y., H. Onuki, K. Okumura, and I. Takashima (1969): Zeolite distribution in the Katayama geothermal area, Onikobe, Japan; Japanese Journal of Geology and Geography, V. XI, pp. 63-79.

APPENDIX B

PRINCIPAL INVESTIGATOR: J. G. LIOU

Born: December 28, 1939, Taiwan, Republic of China

Degrees: B.S., National Taiwan University, 1962
Ph.D., University of California, Los Angeles, 1970

Positions: NSF Postdoctoral Fellow, University of California, Los Angeles, January to August, 1970
National Research Council Resident Research Fellow at MSC, NASA, 1970-1972
Assistant Professor, Stanford University, 1972 - August, 1976
Associate Professor, Stanford University September 1976 - present

Honors: Mineralogical Society of America Award, 1977
Guggenheim Fellowship, 1978-79
Fellow, Mineralogical Society of America, 1978
Fellow, Geological Society of America, 1979

Publications (exclusive of abstracts)

Juan, V.C., J.G. Liou, and B.M. Jahn, 1965, A preliminary study of minerals in the zeolite group in taiwanite from Taitung, Taiwan. Proc. Geol. Soc. China, No. 8, p. 85-89.

_____, 1967, Problem of the mode of occurrence of dolerite and taiwanite in the light of rock association. Proc. Geol. Soc. China, No. 10, p. 40-52.

Liou, J., 1970, Synthesis and stability relations of wairakite, $CaAl_2Si_4O_{12} \cdot 2H_2O$. Contr. Mineral. Petrol., v. 27, p. 259-282.

_____, 1971, Synthesis and stability relations of prehnite, $Ca_3Al_2Si_3O_{10}(OH)_2$. Amer. Mineral., v. 56, p. 507-531.

_____, 1971, P-T stabilities of laumontite, wairakite, lawsonite, and related minerals in the system $CaAl_2Si_2O_8$- $SiO_2$- $H_2O$. Jour. Petrol., v. 12, p. 370-411.

_____, 1971, Stilbite-laumontite equilibrium. Contr. Mineral. Petrol., v. 31 p. 171-177.

_____, 1971, Analcime equilibria. Lithos, v. 4, p. 389-402.

Liou, J.G., and W.G. Ernst, 1971, Zeolite equilibria in the system *$CaO \cdot Al_2O_3 \cdot 2SiO_2 - SiO_2 - H_2O$, the stabilities of wairakite and* laumontite. Invest. Akad. Nauk. USSR Earth Sci. Sect. v. I. Experimental investigation of mineral formations in systems with volatile components, p. 62-72.

Liou, J.G., 1973, Synthesis and stability relations of epidote, $Ca_2Al_2FeSi_3O_{12}(OH)$. Jour. Petrol., v. 14, p. 381-413.

_____, 1974, Mineralogy and chemistry of the glassy basalts, Coastal Range ophiolites, Taiwan. Geol. Soc. Amer. Bull., v. 85, p. 1-10.

_____, 1974, Stability relations of andradite-quartz in the system Ca Fe Si O H. Amer. Mineral., v. 59, p. 1016-1025.

Liou, J.G., S. Kuniyoshi, and K. Ito, 1974, Experimental studies of the phase relations between greenschist and amphibolite in a basaltic system. Amer. Jour. Sci., v. 274, p. 613-632.

Liou, J.G., C.O. Ho, and T.P. Yen, 1975, Petrology of the glaucophane schist and related rocks in Taiwan. Jour. Petrol., v. 16, p. 80-109.

Kuniyoshi, S., and J.G. Liou, 1976, Contact metamorphism of the Karmutsen Volcanics, Vancouver Island, British Columbia. Jour. Petrol., v. 17, p. 73-99.

Platt, J.B., J.G. Liou and B.M. Page, 1975, Franciscan blueschist facies metaconglomerates, Diablo Range, California. Geol. Soc. America Bull., v. 87, p. 581-591.

Liou, J.G., B.M. Jahn, and T.P. Yen, 1976, Petrology of East Taiwan ophiolites. Petroleum Geology of Taiwan, No. 13, p. 59-82.

Suppe, J., Y. Wang, J.G. Liou, and W.G. Ernst, 1976, Observation of some contacts between basement and Cenozoic cover in the Central Mountains, Taiwan. Proc. Geol. Soc. China, v. 19, p. 59-70.

Kuniyoshi, S., and J.G Liou, 1976, Burial metamorphism of the Karmutsen volcanics, Vancouver Island, British Columbia. Am. Jour. Sci., v. 276, p. 1096-1119.

Liou, J.G., C.Y. Lan, J. Suppe, and W.G. Ernst, 1977, The East Taiwan Ophiolite: its occurrence, petrology, metamorphism, and tectonic setting: Mining Res. and Service Oranization, Special Paper No. 1, 213 p.

Schiffman, Peter, and J.G. Liou, 1977, Synthesis and stability relations of Mg-pumpellyite. Proc. 2nd Internat. Symposium on Water-Rock Interaction, Strasbourg, France. August, 1977, P. IV, p. 157-164.

Jahn, B.M., and J.G. Liou, 1977, Age and geochemical constraints of glaucophane schists of Taiwan: Memoir, Geol. Soc. China, No. 2, p. 129-140.

Liou, J.G., J. Suppe, and W.G. Ernst, 1977, Conglomerates and Pebbly mudstones in the Lichi Melange. Memoir, Geol. Soc. China, No. 2, p. 115-128.

Suppe, J., C.Y. Lan, E.M. Hendel, and J.G. Liou, 1977, Paleogeographic interpretation of red shales within the East Taiwan Ophiolite: Petroleum Geology Taiwan, No. 14, p. 11-24.

Taylor, B.E., and J.G. Liou, 1978, The low-temperature stability of andradite in C-O-H fluids. Amer. Mineral., v. 63, p. 378-393.

Liou, J.G., 1978, Acceptance of the Mineralogical Society of America Award for 1977. Amer. Mineral. v. 63, p. 605-606.

Liou, J.G., and P.Y. Chen, 1978, Chemistry and origin of the chloritoid rocks from Taiwan: Lithos, v. 11, no. 2, p. 175-187.

Bauder, J.M., and J.G. Liou, 1979, Tectonic outlier of Great Valley Sequence in Franciscan Terrain, Diablo Range, California. Geol. Soc. America Bull., v. 90, Part I, p. 561-568.

Liou, J.G., 1979, Zeolite facies metamorphism of basaltic rocks from the East Taiwan Ophiolite. American Mineral., v. 64, p. 1-14.

Liou, J.G., and W.G. Ernst, 1979, Oceanic ridge metamorphism of the East Taiwan Ophiolite. Contr. Mineral. Petrol. v. 68, p. 335-348.

Moore, D.E., and J.G. Liou, 1979, Chessboard-twinned albite from Franciscan metaconglomerates of the Diablo Range, California. Amer. Mineral. v. 74, p. 329-336.

Keskinen, M., and J.G. Liou, 1979. Synthesis and stability relations of piemontite, $Ca_2MnAl_2Si_3O_{12}(OH)$. Amer. Mineral. v. 64, p. 317-328.

Moore, D.E., and J.G. Liou, 1979, Mineral chemistry of some Franciscan blueschist metasediments from the Diablo Range, California. Geol. Soc. America Bulletin, parts I, p. 1089-1091 & II, p, 1737-1781.

Adib, D., and J.G. Liou, 1979, The Naragh meteorite: a new olivine-bronzite chondrite fall. Meteoritics, v. 14, p. 257-272.

Liou, J.G., C.Y. Lan, John Suppe, 1979, Field trip guide to the East Taiwan Ophiolite. ROC-ROK Workshop on Regional Stratigraphical and Structural Studies, p. 13-21.

Chen, P.Y., and J.G. Liou, in press. Chloritoid rock, a possible metamorphosed aluminous laterite deposit, from eastern Taiwan. Kingston Conf. Internat. Comm. for Studies of Bauxites, Alumina and Aluminum.

Moore, D.E., and J.G. Liou, 1980. Detrital blueschist pebbles in Franciscan conglomerates of northern Diablo Range, California. Amer. Jour. Sci, 4. 280, 249-264.

Moore, D.E., J.G. Liou and B.S. King, in press. Sedimentary Petrology and Source Terrains of Conglomerate Pebbles in the Franciscan Complex. Diablo Range, California. Jour. Sedimentary Petrology.

Schiffman, Peter, and J.G. Liou, 1980. Synthesis and stability relations of pumpellyite. Jour. Petrol.

Suppe, John, J.G. Liou, and W.G. Ernst, in press. Paleogeographic origins of the east Taiwan Ophiolite. Amer. Jour. Sci.

Suppe, John and J.G. Liou, 1979, Tectonics of the Lichi Melange and East Taiwan Ophiolite. Geol. Soc. China Memoir, No. 3, p. 147-154.

Liou, J.G. and Y. Seki, 1980, Parageneses of carbonate minerals from volcanogenic rocks interacted with seawater and meteoric water in the Seikan Undersea tunnel, Japan. Proc. 3rd Internat. Symposium on Water-Rock Interaction. Edmonton, Canada, p. 151-152.

Guillemette, R.N., J. G. Liou and F.W. Dickson, 1980, The effect of glassy vs. crystalline starting materials on andesite-water interactions. Proc. 3rd Internat. Symposium on Water-Rock Interaction, Edmonton, Canada, p. 168-169.

Lan, C.Y., J. G. Liou and Y. Seki, 1980. Investigation of drill hole core samples from Tatun geothermal area, Taiwan. Proc. 3rd Internat. Symposium on Water-Rock Interaction, Edmonton, Canada, p. 183-185.

Seki, Y., J.G. Liou, F.W. Dickson, Y. Oki, H. Sakai, T. Hirano, in review, The interactions between volcanogenic rocks and seawater-meteoric water mixture in the near coast undersea part of the Seikan Tunnel, Japan. Tokyo University Press.

Liou, J.G., W.G. Ernst, D.E. Moore and John Suppe, in press, Geology and petrology of some polymetamorphosed amphibolites and associated rocks in northeastern Taiwan. Geol. Soc. Amer. Bull. Part I and Part II.

APPENDIX C

ASSOCIATE INVESTIGATOR: RENALD N. GUILLEMETTE

Born: April 5th, 1949, Maine,

Degrees: B.S. in Geology, Rensselaer Polytechnic Institute, 1972
M.S. in Geology, Brown University, 1974
Ph.D. Candidate in Geology, Stanford University, in 1980

Professional Experience:

Aug. 1978 - To Present: Research and Teaching Assistant, Department of Geology, Stanford University
Ph.D. research in progress: "Experimental Investigations of Andesite-Water Interaction and Their Application to Island-Arc Systems."
Research Equipment Used:
Electron microprobe, scanning electron microscope with energy-dispersive analyzer, petrographic microscope, atomic absorption spectrometer, Dickson-type experimental hydrothermal apparatus.

Jan. 1979 - March 1979: Acting Instructor, Stanford University, teaching Igneous Petrology.

Jan. 1975 - July 1978: Research Associate and Instructor, Dept. of Geology and Geophysics, Boise State University, Boise, Idaho.
Research Activities:
Principal investigator on ERDA-DOE grant to use XRD to identify clay minerals and zeolites in cores and cuttings from the Raft River Geothermal Project in southeastern Idaho (1975-78). This grant also included the geochemical analysis of low-temperature geothermal waters in Boise, Idaho.

Sept. 1972 - Dec. 1974: Teaching and Research Assistant, Brown University, Providence, Rhode Island.

Publications:

Hess, P. C., Rutherford, M. J., Guillemette, R. N., Ryerson, F. J., Tuchfeld, H. A. (1975) Residual products of fractional crystallization of lunar magmas: An experimental study. Proc. Lunar Science Conf. 6th, p. 895-909.

Guillemette, R. N., Liou, J. G., and Dickson, F. W. (1980) The effect of glassy vs. crystalline starting materials on andesite-water interactions. Proc. 3rd Internat. Symposium on Water-Rock Interaction, Edmonton, Alberta, Canada, p. 168-169.

## APPENDIX D

## VISITING INVESTIGATOR: HYUNG SHIK KIM

Born: October 16, 1943, Korea

Degrees: M.S. in Geology, Seoul National University, 1967
Ph.D. in Geology, Seoul National University, 1972

Positions: Full Professor, Department of Geology, Korea University

Publications (selected)

Hyung Shik Kim, 1967, On the Replacement Texture of the Syenite in the Yangyang Mining District (English). College Review, Seoul National University, vol. 13, no. 1, p. 289-293.

Hyung Shik Kim, 1967, Formation of Perthite in the Syenite at the Yangyang Mining District (English). J. Geol. Soc. Korea, v. 3, no. 2, p. 289-293.

Hyung Shik Kim, and Sang Man Lee, 1968, Petrogenesis of the Syenite in the Kangwon Province, Korea (English). J. Geol. Soc. Korea, v. 4, no. 4, p. 199-214.

Hyung Shik Kim, 1970, Regional Metamorphism of the South-Western Part of Korea (Korean). J. Geol. Soc. Korea, v. 6, no. 2, p. 97-128.

Hyung Shik Kim, 1973, On Migmatites in the Jeonju-Mogpo Area, Korea (English). J. Geol. Soc. Korea, v. 9, no. 4, p. 207-234.

Hyung Shik Kim, 1975, Regional Metamorphism of the Gimcheon-Ulzin Area, Korea (Korean). J. Sciences and Technologies, Korea University, v. 12, no. 4, p. 189-206.

Hyung Shik Kim, 1977, Mineralogy and Petrology of the Precambrian Iron Deposits, Korea (English). J. Geol. Soc. Korea, v. 13, no. 3, p. 191-212.

Hyung Shik Kim, and others, 1979, Orbicular Gabbroic Rocks from the Hwangryeong Mountain District, Korea (English). J. Geol. Soc. Korea, v. 15, no. 4, p. 295-314.

Hyung Shik Kim, and others, 1980, Copper bearing Porphyry from Weolseong, Southeastern Part of Korea (Korean). J. Geol. Soc. Korea, v. 16, no. 1, p.

APPENDIX E

ASSOCIATE PRINCIPAL INVESTIGATOR: YOTARO SEKI

Born: September 24, 1925, Osaka, Japan

Degrees: Ph.D., University of Tokyo, Department of Geology, 1948

Positions: Dean, Faculty of Science and Engineering, Saitama University, 1974-1978
Visiting Professor, Smith College (by Senior Foreign Scientist Exchange Program of NSF), 1970-1971
Professor, Saitama University, 1964-
Research Fellow, University of California, Los Angeles, 1962-63
Assistant Professor, Saitama University, 1951-1964

Honors: Geological Society of Japan Prize, 1952
Hattori Prize for Scientific Contribution, 1953

Publications (selected):

Seki, Y. and Yamasaki, M., 1957, Aluminian ferroanthrophyllite from the Kitakami Mountainland, NE Japan. Amer. Min., 42, p. 506-520.

Seki, Y, 1958, Glaucophanitic regional metamorphism in the Kanto Mountains, central Japan. Jap. Journ. Geol. Geogr., 29, p. 233-258.

Miyashiro, A. and Seki, Y., 1958, Mineral assemblages and subfacies of glaucophane schist facies. Jap. Journ. Geol. Geogr., 29, p. 199-208.

Miyashiro, A. and Seki, Y., 1958, Enlargement of the composition field of epidote and piemontite with rising temperature. Amer. Journ. Sci., 256, p. 423-430.

Seki, Y., 1959, Relation between chemical composition and lattice constants of epidote. Amer. Min., 44, p. 720-730.

Seki, Y., Kato, C., Aiba, M., 1960, Jadeite and associated minerals in metagabbroic rocks in the Sibukawa district, central Japan. Amer. Min., 45, p. 668-679.

Seki, Y., 1960, Jadeite in the Sanbagawa metamorphic belt in central Japan. Amer. Journ. Sci., 258, p. 705-715.

Seki, Y., 1961, Calcareous hornfelses in the Arisu district of the Kitakami Mountains, NE Japan. Jap. Journ. Geol. Geogr., 32, p. 55-78.

Seki, Y., 1961, Pumpellyite in low-grade metamorphism. Journ. Petr., 2, p. 407-423.

Seki, Y. and Kennedy, G. C., 1964, An experimental study on the leucite-pseudoleucite problem. Amer. Min. 49, p. 1267-1280.

Seki, Y. and Kennedy, G. C., 1964, The breakdown of potassium feldspar, $KAlSi_3O_8$, at high temperature and high pressures. Amer. Min., 49, p. 1688-1706.

Seki, Y. and Takizawa, H., 1964, Finding of pebbles of lawsonite- and pumpellyite-bearing rocks in lower Cretaceous formation of the Kanto Mountains, central Japan. Jap. Journ. Geol. Geogr., 36, p. 81-87.

Seki, Y. and Kennedy, G. C., 1965, Muscovite and its melting relations in the system $KAlSi_3O_8$-$H_2O$. Geoch. Cosmoch. Acta, 29, p. 1077-1083.

Seki, Y., 1966, Wairakite in Japan. Journ. Assoc. Jap. Min. Petr. Econom. Geol., 55, p. 254-261, 56, p. 30-39.

Ernst, W. G. and Seki, Y., 1967, Petrologic comparison of the Franciscan and Sanbagawa metamorphic terranes. Tectonophysics, 4, p. 463-478.

Seki, Y., 1968, Synthesized Wairakites: their difference from natural wairakites. Jour. Geol. Soc. Japan, 74, p. 457-458.

Seki, Y., Oki, Y., Matsuda, T., Okimura, K., 1969, Metamorphism in the Tanzawa Mountains, central Japan. Journ. Assoc. Japan Min. Petr. Economic Geol., 61, p. 1-25, 50-75.

Seki, Y., 1969, Facies series in low-grade metamorphism. Journ. Geol. Soc Japan, 75, p. 255-266.

Seki, Y., Onuki, H. and Takashima, I., 1969. Zeolite distribution in the Katayama geothermal area, Onikobe, Japan. Jap. Journ. Geol. Geogr. 40, p. 63-79.

Seki, Y. and Oki, Y., 1969, Wairakite-analcime solid solutions from low-grade metamorphic rocks of the Tanzawa Mountains, central Japan. Min. Journal, 6, p. 36-45.

Ernst, W. G., Seki, Y., Onuki, H. and Gilbert, M. C., 1970, Comparative study of low-grade metamorphism in the California Coast Ranges and the outer metamorphic belt of Japan. Mem. 124, Geol. Soc. America, p. 1-275.

Seki, Y., Onuki, H. and Oba, T., 1971, Sanbagawa metamorphism in the central Kii Peninsula, Japan. Jap. Journ. Geol. Geogr., 41, p. 65-78.

Seki, Y., Oki, Y. and Odaka, S., 1972, Stability of mordenite in zeolite facies metamorphism of the Oyama-Isehara district, east Tanzawa Mountains, central Japan. Journ. Geol. Soc. Japan, 78, p. 145-160.

Seki, Y., Lower-grade stability limit of epidote in the light of natural occurrences. Journ. Geol. Soc. Japan, 78, p. 405-413.

Seki, Y., 1973, Metamorphic facies of propylitic alteration. Journ. Geol. Soc. Japan, 79, p. 771-780.

Seki, Y., 1973, Ionic substitution and stability of mordenite. Journ. Geol. Soc. Japan, 79, p. 669-676.

Seki T., 1976, Comparison of $CO_2$ and $O_2$ in fluids attending the prehnite-pumpellyite facies metamorphism of the central Kii Peninsula and the Tanzawa Mountains, Japan. Proc. Water-Rock Intelraction, Praha, p. 230-235.

Seki, 1977, Long-term seawater-rock interaction observed in Seikan Undersea Tunnel of Japan. Proc. Water-Rock Interaction, Strasbourg, p. 35-41.

Seki, 1978, Chemical characters of seawater-meteoric water mixtures interacted with Miocene volcanogenic sediments at low temperatures. Amer. Geoph. Union, Transact., 59, p. 1220.

APPENDIX F

ASSOCIATE PRINCIPAL INVESTIGATOR: YASUE OKI

Born: September 11, 1932, Kamisuwa, Japan

Degrees: B.S., Tokyo University of Education, 1955
Ph.D., University of Tokyo, 1962

Positions: Director of Hot Springs Research Institute of Kanagawa Prefecture, Japan, 1969-
Chief Geologist of Hot Springs Research Institute, 1967-1969
Senior Geologist of Hot Springs Research Institute, 1965-1967
Geologist of Hot Springs Research Institute, 1962, 1965

Honors: Kanagawa Prefectural Government, 1967
Hakone Prize for Cultural Contribution, 1978

Publications (selected)


Oki, Y., 1961, Metamorphism in the northern Kiso range, Nagano Pref., Japan. Japan Jour. Geol. Geogr., 32, p. 97-506.

Oki, Y., 1961, Biotites in metamorphic rocks. Japan. Jour. Geol. Geogr., 32, p. 497-506.

Oki, Y., Oki, S., and Shibata, H., 1962, The systematic analysis of silicate rocks using ion exchange resin. Bull. Chem. Soc. Japan, 35, p. 273-276.

Oki, Y., Ogino, K., and Hirota, S., 1966, A differential temperature logging technique. Jour. Eng. Mineral Springs, Japan, 4, p. 73-82.

Seki, Y., Oki, Y., Matsuda, T., Mikami, K., and Okumura, K., 1969, metamorphism in the Tanzawa Mountains, central Japan. Min. Petr. Econ. Geol., 61, 1, p. 25.

Seki, Y., and Oki, Y., 1969, Wairakite-analcime solid solutions from low grade metamorphic rocks of the Tanzawa Mountains, central Japan. Min. Jour., 6, p. 36-45.

Oki, Y., and Hirano, T., 1970, The geothermal system of the Hakone volcano. Geothermics, Special Issue 2, p. 1157-1166.

Kuno, H., Oki, Y., Ogino, K., and Hirota, S., 1970, Structure of the Hakone caldera as revealed by drilling. Bull. Volcano., 34, p. 713-725.

Seki, Y., Oki, Y., Onuki, H., and Odaka, S., 1971, Metamorphism and vein minerals of north Tanzawa Mountains, central Japan. Jour. Japan. Assoc. Min. Pet. Econ. Geol., 66, p. 1-21.

Seki, Y., Oki, Y., Odaka, S., and Ozawa, K., 1972, Stability of mordenite in zeolite facies metamorphism of the Oyama-Isehara district, east Tanzawa Mountains, Central Japan. Jour. Geol. Soc. Japan, 76, p. 145-160.

Oki, Y., and Hirano, T., 1974, Hydrothermal metamorphism and seismic activity of Hakone volcano. The Utilization of Volcanic Energy, p. 13-40.

Oki, Y., Hirano, T., and Suzuki, T., 1974, Hydrothermal metamorphism and vein minerals of the Yugawara geothermal area, Japan. Water-rock interaction, p. 209-222, Geological Survey, Prague.

Oki, Y., Suzukio, T., and Hirano, T., 1977, High pH groundwaters of the Tanzawa Mountains, Japan. Proceedings of 2nd Water-rock interaction symposium, Strasburg, Sec. 1, p. 1-14.

Iriyama, J., and Oki, Y., 1977, Thermal structure and energy of the Hakone volcano. Pure and Applied Geophysics, 117, p. 331-337.