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WORKSHOP ON CSDP DATA NEEDS FOR THE BACA GEOTHERMAL FIELD: A SUMMARY

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WORKSHOP ON CSDP DATA NEEDS FOR THE
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WORKSHOP ON CSDP DATA NEEDS FOR THE BACA GEOTHERMAL FIELD: A SUMMARY

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June 1984

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INTRODUCTION

This is an Executive Summary of the Workshop on Continental Scientific Drilling Program (CSDP) Data Needs: Baca Geothermal Field, held at Lawrence Berkeley Laboratory on December 2, 1983, with 42 scientists attending and participating in the meeting. The purpose of the Workshop was to discuss the data needs of the CSDP community and to introduce to the researchers involved in the program the available geological, geophysical, geochemical and reservoir engineering data of the Baca geothermal field, Valles Caldera, New Mexico. These data needs for CSDP have been reviewed also in a brief report, "A Review of Lessons Learned from the DOE/Union Baca Geothermal Project and their Application to CSDP Drilling in the Valles Caldera, New Mexico" (Goldstein and Tsang, 1983), reproduced below as a part of this Summary.

The Baca cooperative geothermal project (USDOE, 1979) was jointly sponsored by U.S. Department of Energy (DOE), Union Oil Company, and Public Service Company of New Mexico (PNM). Union had already done basic exploration work in geology, geophysics, etc. and had drilled 11 wells before the cooperative agreement between DOE, Union and PNM began in July, 1978. The project then produced a considerable body of scientific and engineering data before being terminated by mutual agreement in January, 1982. An overview of the main technical work of the project and a brief analysis of the results are contained in the "Final Report of the Department of Energy Reservoir Definition Review Team for the Baca Geothermal Demonstration Project", (Goldstein et al., 1982). Most of the data are from the wells drilled by Union Geothermal Company (including those drilled prior to July, 1978), made available through the DOE-Union-PNM cooperative agreement. The data have been collected in the Baca Data Base available from the Earth Sciences Division at Lawrence Berkeley Laboratory, and are comprehensively cataloged in an attachment to this report entitled "Listing of Scientific Data on the Baca Geothermal Field: A Compilation of Available Geological, Geophysical, Geochemical and Reservoir Engineering Data" (Spencer and Tsang, 1984).

The participants at the Workshop were able to review the data and reference material in the data base and request copies. Reproduction of any of the materials in the Baca Data Base are available to any interested researcher from the Reservoir Engineering and Hydrogeology Group--Baca Data Base, Earth Sciences Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720.

Co-chairmen of the Workshop were J. Hermance of Brown University and C. F. Tsang of Lawrence Berkeley Laboratory. An overview of the Workshop goals was given by J. Hermance who reminded participants that this Workshop is a continuation of earlier CSDP meetings on data needs, and stressed two points: (1) the goals of CSDP will strongly dictate which data must be required before and during deeper drilling, and (2) the Baca geothermal field provides a crucial large data base for beginning to understand the thermal environment of the Valles Caldera. This Executive Summary is intended to contribute to the discussion of CSDP data needs by drawing on the available slides and viewgraphs of the 17 presentations made during the Workshop. Its organization is as follows. First the review paper of Goldstein and Tsang (1983) is reproduced, and then the Workshop program with its list of speakers. Following this is a collection of the presentation materials from each talk, where they were available, for both the CSDP data needs and the review of the various kinds of scientific data obtained from the Baca field. The captions to some of the figures, diagrams, etc. were supplied for this report by the editors in the interest of identifying the material. A list of all the scientists that participated in the Workshop is given at the end.

The editors gratefully acknowledge the assistance of S. Vonder Haar and C. Doughty in the preparation of portions of this report.

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A REVIEW OF LESSONS LEARNED FROM THE DOE/UNION BACA GEOTHERMAL PROJECT AND THEIR APPLICATION TO CSDP DRILLING IN THE VALLES CALDERA, NEW MEXICO

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November 1983

INTRODUCTION

Geothermal trade papers and the general press have called attention to the Baca Project--a joint project of the U.S. DOE, Union Geothermal Company of New Mexico, and Public Service of New Mexico--and particularly to the lack of sufficient steam that caused cancellation of the planned 50 MWe demonstration plant. The authors of this paper, together with other scientists from DOE offices and laboratories, universities and industry, were empaneled to advise DOE when it became apparent in 1981 that Union was encountering difficulty in obtaining the expected steam rate from its new production wells. The Baca Reservoir Definition Review Team closely followed activities until the principal parties mutually agreed in January 1982 to terminate the project. The review team issued its final report later that year (Goldstein et al., 1982)

In contrast to the negative outcome of the project, the less newsworthy but beneficial scientific aspects of the project may have been largely ignored except by interested specialists in industry and research. Some of the lessons and information coming out of the project have been noted by members of the Thermal Regimes Panel of the National Academy of Sciences Continental Scientific Drilling Committee (CSDC) and particularly by scientists investigating the Valles Caldera as a site for deep drilling into an active hydrothermal-magmatic system (Reicker, 1983). It is significant and interesting that the Mexican national utility, Comisión Federal de Electricidad (CFE), is currently drilling a geothermal system in the La Primavera Caldera, which is geologically similar to the Valles Caldera. While no two systems are totally alike, preliminary indications from Mexico are that CFE may be experiencing some of the same problems encountered by Union Geothermal at the Baca Project site (Domínguez and Lippmann, 1983).

Space does not allow us to review the regional geology and exploration activities in the Jemez Mountains and the Valles Caldera. That material is contained in several excellent papers (Smith and Bailey, 1966, 1968; Doell et al., 1968; Bailey et al., 1969; Dondanville, 1978; Laughlin, 1981). In this paper we first review the more significant lessons for geothermal developers. Next we discuss the implications of the Baca project to the intermediate to deep drilling proposed in the Valles Caldera for scientific purposes under the Continental Scientific Drilling Program (CSDP).

Lessons for Geothermal Developers

Drilling in the Redondo Creek area revealed that a surprisingly large thickness, as much as 1.8 km, of Bandelier Tuff (ignimbrite) fills the medial graben on the flank of the resurgent dome. Because of the low permeability of the tuff, major graben-bounding and low-angle faults and their intersections within the tuff were considered to be the principal controls on fluid flow (Behrman and Knapp, 1980). Recognition of a three-dimensional fault pattern was believed to be the key to finding hot water entries and developing a viable reservoir. According to a later analysis, the pattern of normal faults mapped in detail at the surface (Behrman and Knapp, 1980) and fracture orientations obtained from dipmeter logs in Redondo Creek wells were considered to be unreliable guides to hot fluid entries at depth for two principal reasons (Hulen, 1982; Hulen and Nielson, 1982):

1. Some faults predicted by surface mapping and subsequently intersected by drill holes were found to be non-productive, presumably sealed by hydrothermal minerals.
2. Some of the fluid entries, initially believed to be steeply dipping faults, are actually discontinuous, permeable stratigraphic zones of tuffaceous sandstones and non-welded tuffs within the Bandelier Tuff.

Despite the 23 well completions, together with information from geological and geophysical logs and well tests, the conceptual model for the reservoir and its geological controls remains a point of debate. Union Geothermal (Union, 1983) believes that neither the steeply dipping faults of Behrman and Knapp (1980) nor the stratigraphic zones identified by Hulen (1982) and Hulen and Nielson (1982; 1983) are the features primarily responsible for high-temperature, hot-water production. Instead, they attribute production to a discontinuous, permeable contact zone at the base of the Bandelier Tuff and at the top of the Paliza Canyon Formation; this zone has been dislocated by faulting into separate cells that communicate hydraulically only weakly.

Regardless of which interpretation is correct, one conclusion seems inescapable: despite the number of holes drilled, logged and tested, geologists and reservoir engineers have not established a complete and verifiable geological explanation for the reservoir. Whether the bulk of the reservoir permeability is a coarse fracture network or in a confined stratigraphic contact zone has not been conclusively determined (Garg and Riney, 1982; Union, 1983). If there are geological lessons to be learned from the development activities in the Bandelier Tuff, they might include the following:

1. The tuff was far thicker and much lower in permeability than one might have surmised from studies on outcrops outside the caldera.

2. Detailed studies of volcanic stratigraphy based on well cuttings were important for understanding the structure within the project area and for indentifying higher-permeability stratigraphic zones.

In addition, the work seems to reinforce the argument that better high-temperature well-logging instrumentation, well-log analyses and well-testing techniques are needed.

Secondary (i.e., deeper) reservoir targets below the Bandelier Tuff proved equally difficult to find and develop for various geological reasons. The only productive intervals that could be developed in rocks older than the Bandelier Tuff were in the underlying Paliza Canyon Andesite (Pliocene). In addition to the contact zone, fluid entries may include faults and fractures.

Stratigraphically below the Paliza Canyon Andesite are sandstones logged as the Abiquiu Formation (Oligocene) and the Santa Fe Sandstone (Miocene). Both units are regarded to be too unconsolidated to support production (Behrman and Knapp, 1980).

Disconformably below the Abiquiu/Santa Fe is the Abo Formation (Permian "red beds" of interbedded arkosic siltstones and sandstones). While this formation may be a good aquifer, it presented severe lost-circulation problems and yielded no fluids. Formation damage due to drilling muds is one explanation for the lack of fluid extracted from the Abo.

Finally, the underlying Madera Limestone (Pennsylvanian) and Precambrian granite proved to be too tight where intersected by two deep wells at ~ 2.7 km below surface. Since the probability of finding permeable rocks tends to decline with increasing rock age and depth of burial, the findings from the deep wells cannot be considered unexpected.

How much more could have been learned or anticipated about low-permeability conditions prior to and during drilling from detailed surface geophysical investigations may never be known. While adequate geophysics (gravity, magnetics, electrical/electromagnetic) was performed in the exploration stages, little detailed geophysical follow-up was done in the Redondo Creek project area. There seem to be two reasons for this decision: (1) access within the topographically steep project area is limited, and (2) the early drilling results were so encouraging that additional expenditures for geophysics did not seem prudent or necessary. If exploration and development were starting today in Redondo Creek, it is likely that additional methods such as self-potential and controlled-source EM methods would be tried to help find areas of fluid convection and higher porosity (Wilt et al., 1982). The EM is particularly intriguing because magnetotelluric (MT) sounding interpretations (Wilt et al., 1982) revealed several interesting features that correlated with drilling results; namely, (1) the generally high resistivities (100-200 ohm-m) obtained for the Bandelier Tuff are characteristic of low-porosity, low-salinity conditions; (2) a low-resistivity zone (70 ohm-m) within the Bandelier Tuff correlated with the concentration of known hot-water entries; and (3) the presence of a steeply dipping electrical discontinuity may indicate a reservoir boundary. Even though we now possess better methods of data acquisition and interpretation, the Valles Caldera experience reinforces the fact that industry still lacks downhole geophysical techniques and instruments that can be used in high-temperature environments to help map major fracture zones.

Geochemistry of produced fluids provided useful information. The data not only indicated local boiling around the wells but verified the existence of a broader two-phase zone of interest to reservoir engineers. Geothermometer temperatures based on the Na-K-Ca method (Fournier and Truesdell, 1973) applied to well fluids were substantiated by means of direct downhole measurements. More important, the chloride-enthalpy relationship showed that there was little fluid convection within the reservoir rocks and that these rocks are conductively heated from below (Delany and Truesdell, 1982).

Drilling problems were more numerous than at other geothermal areas for which comparable data are available (The Geysers-Clear Lake and Imperial Valley). These problems added to well costs (Kelsey, 1983) and detracted from the acquisition of potentially useful geologic information. The problems, tabulated by Pye (1981), Molloy and Laughlin (1982), and Union (1983), were due to lost circulation, lost fish and stuck pipe. Although these problems occur in all geothermal areas, the severity of the problems at Baca can be attributed to specific geological conditions, mainly lost circulation. Because they encountered many lost-circulation zones and underpressured reservoir conditions, Union initially used aerated water as a drilling fluid. This severely accelerated corrosion of drill pipe and casings, increasing the likelihood of stuck pipe and twist-offs. The corrosion rate was substantially reduced by adding caustic, Unisteam and ammonium hydroxide to keep the pH above 10.5 (Pye, 1981; Molloy and Laughlin, 1982). Union also found it necessary to cement off many lost-circulation zones. Not only is this process costly but various factors make it difficult to carry off successfully (Pye, 1981). However, cementing casing and liners was found to be a relatively simple procedure. Drilling problems also arose because Union sidetracked five of the 24 wells in the hope of finding better fluid entries and bypassing lost fish. It was in drilling the deviated legs that problems frequently occurred. Additional mechanical stresses on the drill pipe, together with thermal stresses and stress corrosion cracking, contributed to the twist-offs and lost fish. Directional drilling was done with mud motors and turbines. Both approaches had notable success and failure. Union concluded that the difference between success and failure is more a function of the organization doing the drilling than the equipment (Pye, 1981).

Large hydraulic fracturing treatments were carried out in two wells. In each well a previously non-productive interval with a shut-in temperature of about 500°F was fractured (Morris et al., 1982). Although the hydraulic fractures did not intersect any major zones of natural permeability, and hence did not result in high productivity, the work demonstrated that hydraulic fracturing can be done under high-temperature conditions.

At the time Union and DOE initiated the Baca project, the state of the art in geothermal reservoir assessment consisted of two approaches. On the one hand, because the early success of geothermal power production at The Geysers, Wairakei, Cerro Prieto and Larderello, the common practice was to apply conventional petroleum engineering methods for estimating geothermal reservoir productivity. Methods included single-phase well-testing analyses, even though a system might be two phase (steam and water). There was also the implied belief that all in-place hot fluids could be produced. On the other hand, modeling techniques that accurately accounted for two-phase reservoir conditions had been developed for porous media. These newer techniques were in an early stage of development and use, and were being extended to fractured, low-permeability rocks. The Baca project provided the first practical opportunity to put these numerical methods to a stringent test. Many lessons were brought to light as a result (Bodvarsson et al., 1982).

1. The importance of a careful, non-isothermal, two-phase well-testing program was emphasized. Because the fluid in a petroleum reservoir has a high energy density, the tolerable margin of uncertainty can be relatively large. This is not the case for a geothermal reservoir, where one must make a careful determination of the transmissivity and the storativity, as well as boundaries. Recent developments in two-phase flow in fractures also provided the basis for new well-test methodologies.

2. The conventional method of equating hot fluid in place with the resource potential was found not applicable, especially in a low-permeability, fracture-controlled reservoir system, such as Baca. Up to the time of the Baca project, the producing capacity was

usually estimated by what is known as the lumped parameter model, in which the reservoir is represented by a rock volume of uniform pressure, temperature and liquid water saturation. This assumption is safe so long as there is a very high permeability within the volume. The reservoir engineering study of the Baca project focused on the necessity to use a "distributed parameter model" in which the above-named parameters vary over the reservoir region. The sharp drop in the pressure of the two-phase fluid near the well field turned out to be a controlling factor in the producing capacity of the Baca geothermal field.

3. The usefulness of modeling geothermal reservoirs numerically was also demonstrated by the Baca project. A conventional view was that if detailed reservoir information is sparse, a detailed numerical modeling study is not justified. The Baca example showed that because of the strong non-linearity of two-phase phenomena, even a simple case with only a few reservoir parameters given (usually by well testing) requires the use of detailed numerical modeling investigations. Some very crucial information can be obtained only in this way.

4. The Baca project also provided impetus for an accelerated study of fracture flow phenomena. The importance of fracture and channel flow is clearly noted in the Baca reservoir. Considerable progress has been made recently in the well testing and modeling of fractured reservoirs, ranging from new understanding of heat and fluid flows in discrete fractures to the recent development of the MINC (Multiple Interacting Continua) representation of fractured-porous media (Pruess and Narasimhan, 1982).

Implications for CSDP Drilling

Although the Baca project wells were concentrated in a relatively small area (Redondo Creek) of the Valles Caldera, the information gained can be applied to the siting and drilling of additional intermediate to deep drill holes within the caldera.

The wealth of temperature data from shallow and deep Union wells have been re-examined and reprocessed recently by Swanberg and Li (1982). Their analysis indicates a component of heat from a cooling magma body, but the most they can say about the depth of such a body is that it could be "shallow." The consensus of other geophysical data indicates that there is a good possibility for magma at < 12 km depth (Reicker, 1983) and perhaps as shallow as 8 to 10 km. The Redondo Creek area appears to have the highest near-surface temperatures encountered within the caldera. Temperature gradients in the deeper sections of the Union wells indicate that at 10,000 feet (~ 3 km) the subsurface temperatures should be < 350–375°C; i.e., roughly at the limit of the depth-temperature conditions presently considered drillable at reasonable costs (Kelsey, 1983, personal communication). Assuming one were available, reopening and deepening an existing Union well in Redondo Creek to 10,000 feet might be a feasible CSDP endeavor, but it might not yield much new scientific information. A better course of action is to drill dedicated holes in a "cooler" part of the caldera. This would provide geologic and thermal information in another part of the hydrothermal system and reduce temperature-related drilling and logging problems. Because of its smaller diameter, a CSDP hole should be inherently faster and cheaper to drill than a geothermal production well. However, the CSDP hole might also be subject to potential problems associated with lost circulation zones as encountered by Union in Redondo Creek. Union's drilling and cementing experience could help reduce costs and risks. Perhaps, and more importantly, a hole sited away from the underpressured and badly faulted conditions within the medial graben might encounter fewer and less serious lost-circulation zones. However, drilling experience by the Comisión Federal de Electricidad in the La Primavera Caldera showed lost circulation to be a serious problem in the Tala Tuff both near the center of the caldera and within the ring fracture zone bounding the caldera (Domínguez and Lippmann, 1983). This suggests that careful geophysical surveys should be conducted prior to drilling to help assess subsurface conditions.

In addition to the standard geological, geophysical and geochemical measurements that would be made in a CSDP well, various thermal, chemical and hydraulic tests should be made both during and after drilling. It is expected that at greater depths, the permeability will be low and probably fracture controlled. On the basis of lessons learned in studying the Redondo Creek wells and other geothermal sites, a number of tests can be designed to obtain key parameters, such as fluid enthalpy, fracture permeability and chemical characteristics. Discussions of some possible tests for CSDP wells are recently summarized in a report by Witherspoon et al. (1983).

Acknowledgements

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WORKSHOP ON

CSDP DATA NEEDS:

BACA GEOTHERMAL FIELD

(December 2, 1983)

Program of the Workshop on CSDP Data Needs: Baca Geothermal Field

Friday, December 2, 1983
Lawrence Berkeley Laboratory
Berkeley, California 94720

8:30-8:35	Welcome--T.V. McEvilly, P.A. Witherspoon / LBL
8:35-8:45	Objective and Scope of Workshop--J. Hermance / Brown University

8:45-12:00 Morning Session--Chairman: J. Hermance / Brown University

Continental Scientific Drilling Program--Data Needs

8:45-9:05	Geology--J. Aldrich / LANL
9:10-9:30	Geophysics--P.W. Kasameyer / LLL
9:35-9:55	Geochemistry--A.F. White / LBL
10:05-10:25	Thermal Transport Modeling--H.C. Hardee / SNL
10:30-10:40	Coffee Break

Baca Data

10:40-10:50	Overview of DOE Demonstration Project--M.W. Molloy / DOE-SAN
10:55-11:10	Regional Geology of Valles Caldera--R.A. Bailey / USGS - Reston
11:15-11:30	Geophysics--M.J. Wilt / LBL
11:35-11:45	Lithology--S. Vonder Haar / Pacific Energy Consultants
11:50-12:00	Structure and Permeability--D.L. Nielson / UURI
12:05-1:30	Lunch

1:30-4:00 Afternoon Session--Chairman: C.F. Tsang / LBL

1:30-1:40	Well Logging--S.E. Halfman / LBL
1:45-2:00	Geochemistry--A.H. Truesdell / USGS - Menlo Park
2:05-2:25	Well Testing/Conceptual Model--S.K. Garg / S-Cubed
2:30-2:45	Reservoir Capacity/Generating Capacity--G.S. Bodvarsson / LBL
2:50-3:05	Fracture Stimulation Experiments--C. Morris / RGI
3:10-3:25	Coffee Break
3:25-3:40	Baca Review Team Summary--N.E. Goldstein / LBL
3:45-4:00	Baca Data Base--R.K. Spencer / LBL

4:00-5:00 General Discussion--Chairman: J. Hermance / Brown University

4:00-4:55	Use of Data for CSDP--Further Data Needs
4:55-5:00	Workshop Closing--C.F. Tsang / LBL

9:00-12:00 Saturday Morning

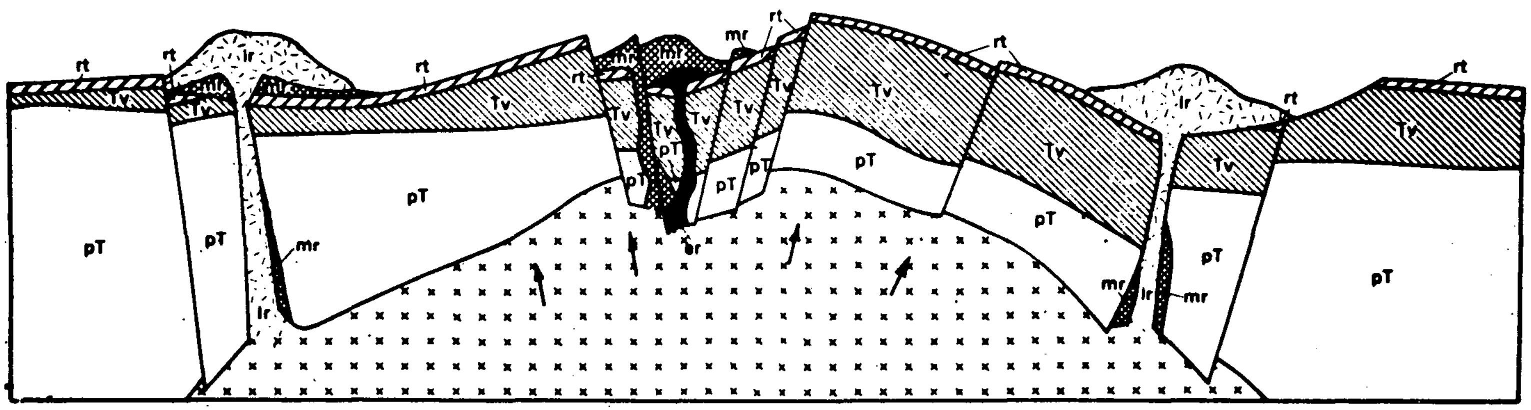
Data and reference materials are available for review by participants. Limited xerox facilities will be available. Interested participants should notify either chairman in advance.

PRESENTATION MATERIALS

FROM WORKSHOP SPEAKERS

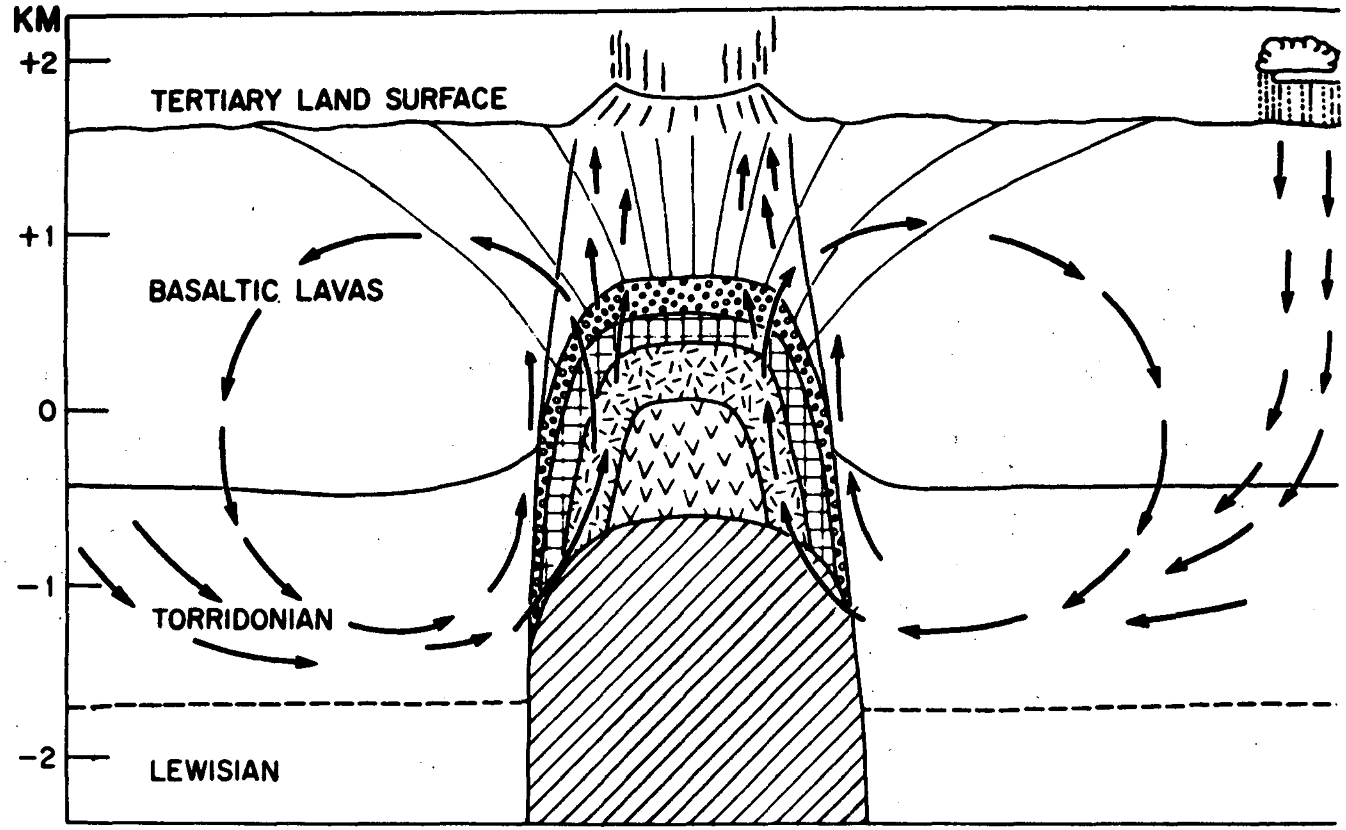
OBJECTIVE AND SCOPE
OF THE WORKSHOP

JOHN HERMANCE
BROWN UNIVERSITY



XBL 8312-4831

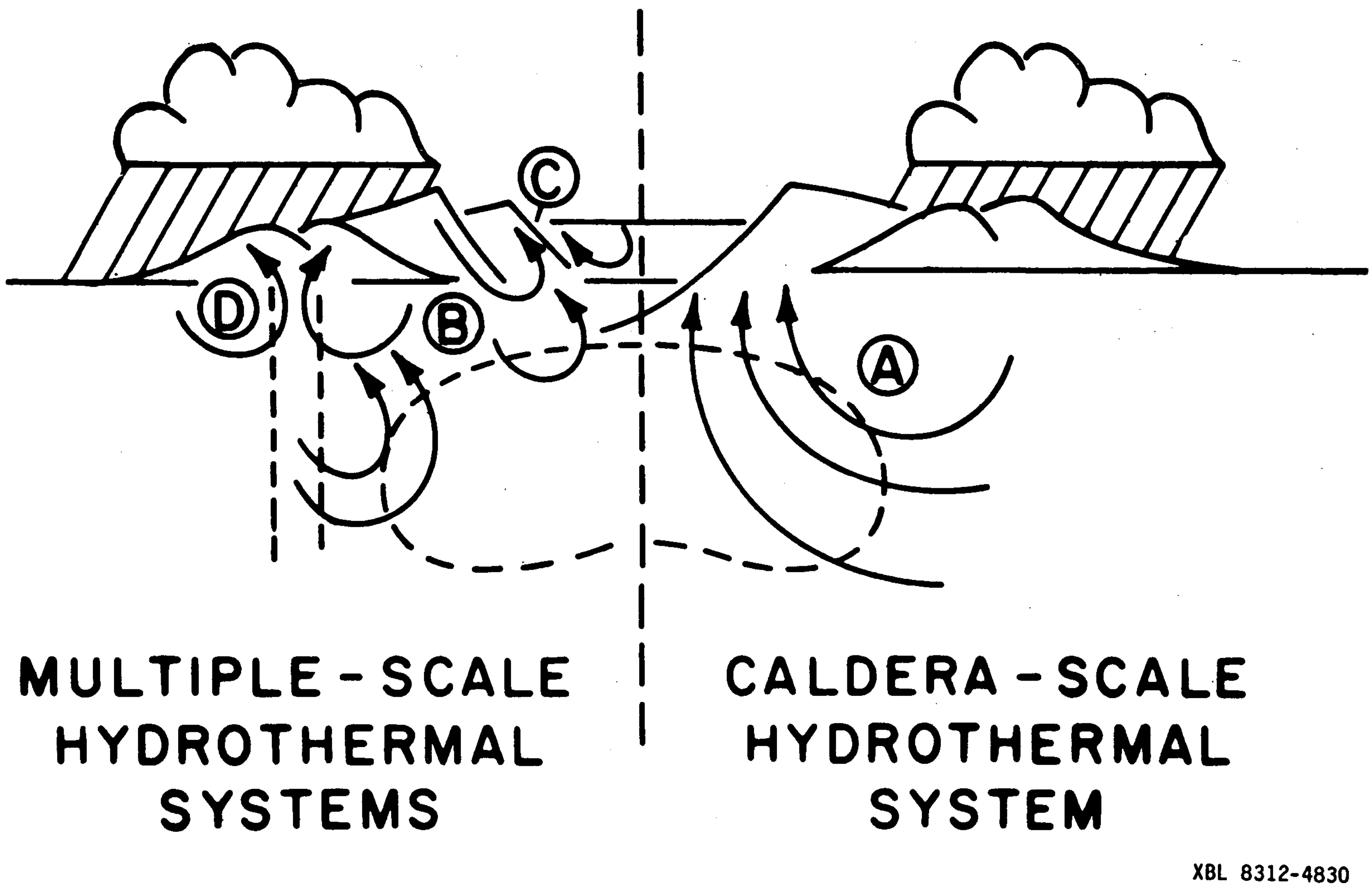
1. Cross-section of Caldera in relation to a deep magmatic body.



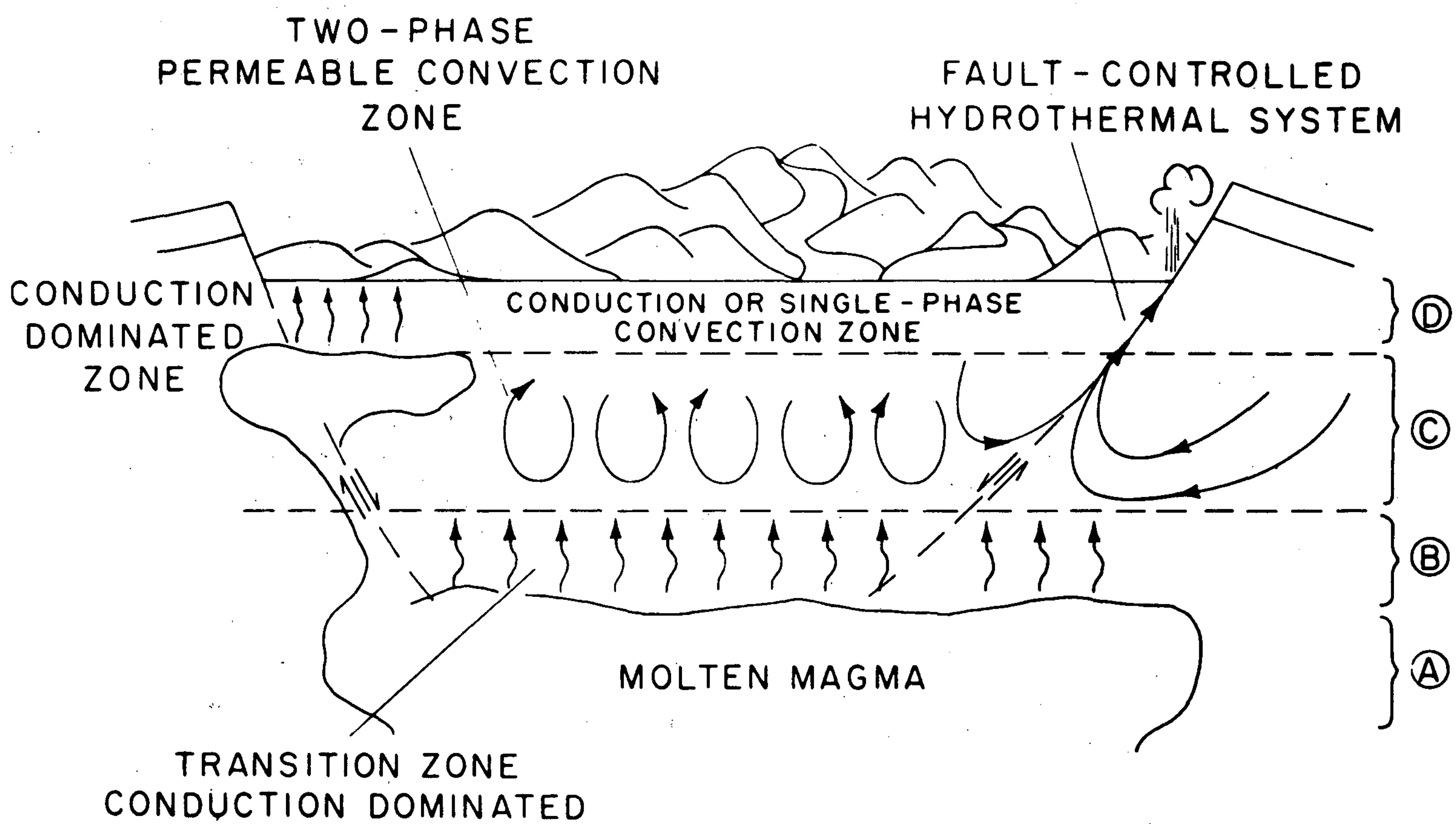
Generalized geologic section through a typical ring-dike complex at Skye (modified after Thompson, 1969). The various checked patterns indicate a series of ring dikes above a gabbro pluton. Cone-sheet fractures are shown extending upward to the caldera and the Tertiary land surface. The vertical scale is exaggerated relative to the horizontal. The heavy arrows show schematically how meteoric ground waters would be set in motion by the heat emanating from the hot igneous rocks and magmas (see text). The circulation is in reality undoubtedly much more complicated than that shown, and in addition there is probably some penetration of ground water into the Lewisian basement gneiss. With certain modifications in the thicknesses of the plateau lavas and Mesozoic sediments, and the absence of Torridonian and the presence of Moine schists, the diagram also applies to Mull and Ardnamurchan.

XBL 8312-4833

2. Model of convection about a ring dike.



3. Caldera-scale and multiple-scale hydrothermal systems.



XBL 8312-4832

4. Hardee's two-phase convection system with a fault-controlled hydrothermal system.

CONTINENTAL SCIENTIFIC DRILLING PROGRAM

DATA NEEDS: GEOLOGY

JAMES ALDRICH

LOS ALAMOS NATIONAL LABORATORY

Jim Aldrich   Geology

I. CSDP Drilling Needs at Valles

1. Need continuous core
   -at minimum "detailed" cores

2. Oriented cores from different depths

3. Deep core samples are essential
   -they are a "Major Goal of Drilling"

4. Hole must reach deep magma-related features
   -especially the pluton margin

II. Synthesis Report on Caldera System is Essential

-will tie together what has been done to date on Calderas

-intent is to develop an adequate predictive model

III. Additional Geologic Studies Needed:

1. Bandelier Tuff

   o Petrology

   o Geochemistry

   (CSDP Hole should penetrate thick section of Bandelier to provide information on zoned tuffs and magma chambers)

2. Pre-Caldera Rocks

   -Stratigraphy

3. Structure

   o Deep structure as indicated by regional picture

   o Fault Kinematics and Dynamics (recent work indicates Jemez Lineament has had significant strike-slip component in NE part of Jemez Mtns. Focal mechanism solution at Fenton Hill recently done is strike-slip solution)

4. Hydrothermal Alteration

    3 Episodes (?)

    - Bland Mining District
    - Topographic Rim of Caldera - especially at South and North Parts of Rim
    - What is now forming

5. Detailed Geologic Map of Redondo Peak

CONTINENTAL SCIENTIFIC DRILLING PROGRAM

DATA NEEDS: GEOPHYSICS

PAUL W. KASAMEYER
LAWRENCE LIVERMORE NATIONAL LABORATORY

DIFFERENT DRILL HOLES WILL HAVE DIFFERING GEOPHYSICAL DATA NEEDS

* NEEDS DEPEND ON OBJECTIVES

* NEEDS DEPEND ON THE ENVIRONMENT

MANY LISTS HAVE BEEN COMPILED

PRESENT TWO EXAMPLES

* GHOST RANCH REPORT, 1975-GENERAL

* UC/IGPP/CALIFORNIA UNIVERSITIES AD HOC COMMITTEE,1983-SPECIFIC

OBSERVATIONS ABOUT DATA MANAGEMENT OPTIONS

GEOPHYSICAL DATA SHOULD RELATE TO OBJECTIVES

* EXPLORATION
  USE BOREHOLE TO ADVANTAGE IN EXPLORATION

  * SURFACE MEASUREMENTS COLLECTED AT ANY TIME ARE ACCEPTABLE

  * COULD GENERATE EXTENSIVE LIST OF GEOPHYSICAL OR LOGGING TECHNIQUES

* EXPERIMENTATION
  TEST A HYPOTHESIS
  OR
  PROVIDE SAMPLES OR UNIQUE ENVIRONMENT

  * SURFACE GEOPHYSICS REQUIRED TO DEFINE HYPOTHESIS

  * SURFACE GEOPHYSICS REQUIRED TO PICK SITE

  * BOREHOLE GEOPHYSICS REQUIRED TO TEST HYPOTHESIS

* VALIDATION

  BOREHOLE GEOPHYSICS TO VALIDATE METHOD

* DRILLING SUPPORT
  USE GEOPHYSICS TO PREDICT DRILLING CONDITIONS

GEOPHYSICAL DATA NEEDS DEPEND ON OBJECTIVES / EXAMPLE

DRILL HOLE THROUGH APPALACHIAN OVERTHRUST SHEET WHERE SEISMIC REFLECTION IS OBSERVED

POSSIBLE OBJECTIVES

* EXPERIMENTATION / TEST HYPOTHESIS THAT SEDIMENTS WILL BE FOUND AT DEPTH

  ANALYZE UNCERTAINTY IN SEISMIC DATA BEFORE DRILLING BEGINS

  VSP DURING DRILLING TO LOCATE REFLECTION MORE ACCURATELY

  SAMPLE FROM HOLE TESTS HYPOTHESIS

* VALIDATION / WHAT CAUSES SEISMIC REFLECTION?

  ANALYZE UNCERTAINTY IN SEISMIC DATA BEFORE DRILLING BEGINS

  IN HOLE VSP TO LOCATE

  SET OF LOGS TO CHARACTERIZE

  STRESS MEASUREMENT

* EXPLORATION / WHAT IS THE NATURE OF THE ROCKS AT 6 KM. BENEATH THE APPALACHIANS?

  FULL SUITE OF SURFACE GEOPHYSICS

  FULL SUITE OF BOREHOLE GEOPHYSICS AND WELL LOGS

GHOST RANCH WORKSHOP, 1975 REPORT CONTAINED A "PARTIAL LIST OF MEASUREMENTS DESIRED"

SAMPLES	STRAIN	HEAT PROD.
S-VELOCITY	STRESS	THERMAL COND.
P-VELOCITY	POROSITY	TEMPERATURE
DENSITY	PERMEABILITY	
ALL ROUTINE LOGS		THERMAL GRADIENT

THIS LIST CONCENTRATED ON MEASUREMENTS IN THE BOREHOLE

UC/IGPP/CALIFORNIA UNIVERSITIES PANEL
RECOMMENDATIONS FOR GEOPHYSICS RELATED TO DEEP HOLE IN SALTON SEA GEOTHERMAL FIELD (DRAFT)

* FIELD EXPERIMENTS TO CHARACTERIZE THE GEOLOGIC OR TECTONIC SETTING

IDENTIFY BASEMENT

SEISMIC	GRAVITY	HEAT FLOW
MAGNETICS	EM/RESISTIVITY	
GEODETICS	SEISMICITY	

LITHOLOGY/STRUCTURE/ROCK PHYSICS

VSP COMPLETE SUITE OF LOGS
LONG-BASELINE ELECTRIC LOGS
ACOUSTIC EMISSION

* FIELD EXPERIMENTS TO UNDERSTAND MAGMA-HYDROTHERMAL SYSTEM

TEMPERATURE RESISTIVITY
BOREHOLE GRAVITY PRESSURE
STRESS TELEVIEWER
BOREHOLE SEISMIC AND MAGNETOMETER

* PETROPHYSICAL STUDIES ON CORE

* THEORETICAL MODELING

* OPPORTUNISTIC MEASUREMENTS NOT SPECIFICALLY RELATED TO THE GEOTHERMAL FIELD

CSDP PROJECTS ARE LARGE ENOUGH TO INVOLVE MULTIPLE INVESTIGATORS AND COMMITTEE DECISIONS

- NEED TO ENHANCE COMMUNICATION AND INTERACTION
- IDENTIFICATION OF POSSIBLE HOLES OF OPPORTUNITY
- LOGISTIC SUPPORT MAY BE REQUIRED
    - COMMON BASE MAPS
    - ACCURATE RELATIVE LOCATIONS
    - JOINT OCCUPATION OF EXPERIMENTAL SITES
- ACCESS TO RAW OR PROCESSED DATA IS REQUIRED FOR JOINT INVERSIONS OR INTERPRETATIONS BY MORE THAN ONE INVESTIGATOR

GEOPHYSICAL INTERPRETATION INVOLVES MANY STEPS

RAW DATA

* PROCESSING

PROCESSED DATA

* INVERSION

MAP OR CROSS SECTION OF PHYSICAL PROPERTY

* INTERPRETATION

GEOLOGIC MAP OR CROSS SECTION

INTERPRETATION OF THIS DATA BY MORE THAN ONE INVESTIGATOR REQUIRES CLARITY ABOUT:

* MEASUREMENT CONDITIONS
* ASSUMPTIONS AND PARAMETERS
* LIMITATIONS OF INVERSION AND INTERPRETATIONAL MODELS
* UNCERTAINTY AND NON-UNIQUENESS

MANY PANELS HAVE RECOMMENDED THE ESTABLISHMENT OF DATA-HANDLING PROCEDURES

* LOS ALAMOS WORKSHOP, 1978

  ESTABLISH NATIONAL DRILLING OPERATIONS COMMITTEE TO

  * CO-ORDINATE CATALOG SYSTEMS FOR LOGS

  * ESTABLISH A DATA MANAGEMENT SYSTEM

  * ALERT SCIENTIFIC COMMUNITY TO POTENTIAL DOWNHOLE RESEARCH OPPORTUNITIES

FCCSET, 1977 AND GHOST RANCH 1975

  ESTABLISH AN INFORMATION AND DATA MANAGEMENT UNIT TO

  * PROVIDE INFORMATION ON SOURCES OF DATA PERTINENT TO EACH PROJECT

  * ARRANGE SYSTEM FOR STORAGE AND MANAGEMENT OF PROJECT-AQUIRED DATA, USING EXISTING FACILITIES WHERE FEASIBLE

????HOW MUCH SHOULD DATA BE MANAGED????

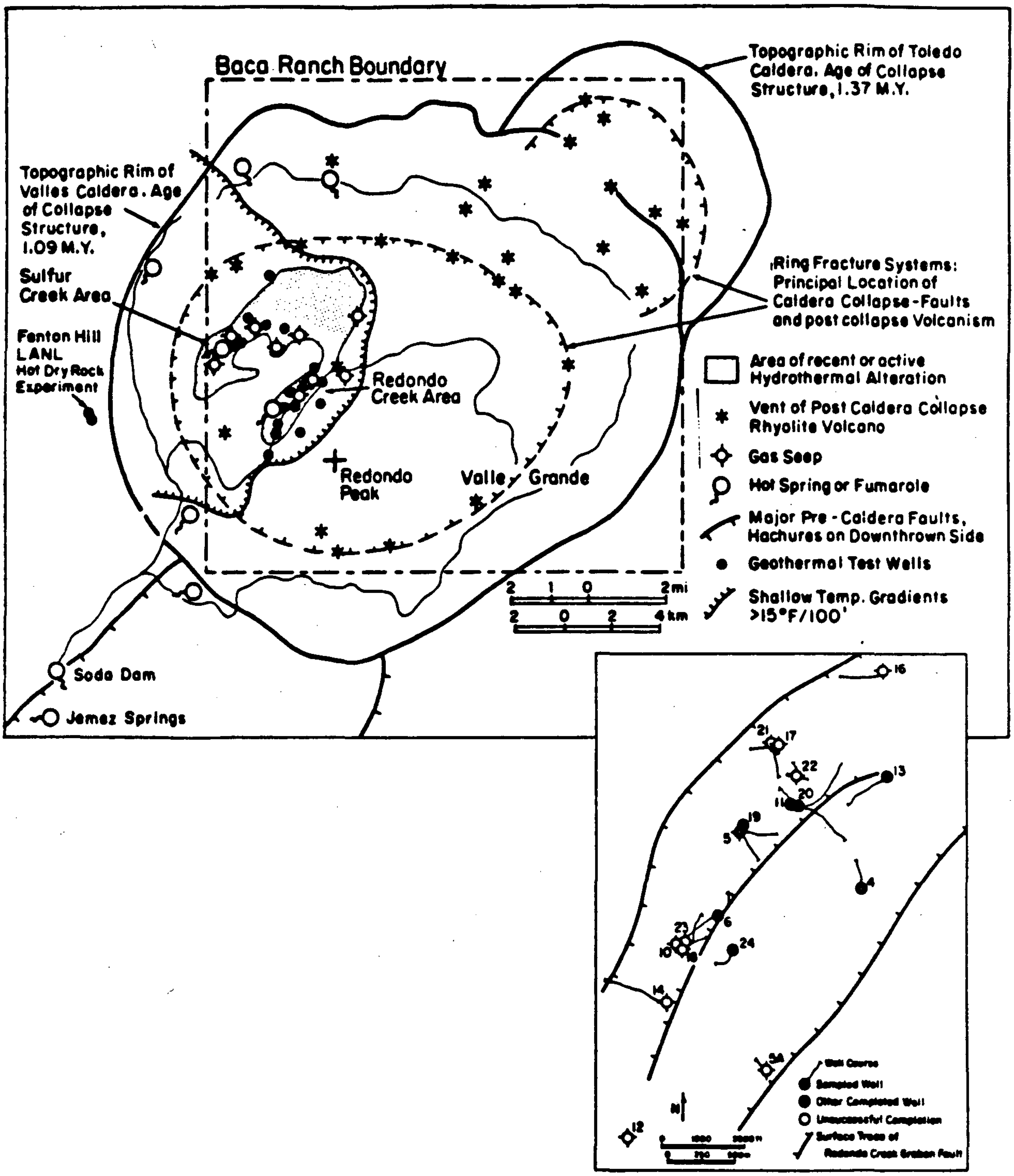
????TREAT INVESTIGATORS DATA DIFFERENTLY THAN PROJECT DATA????

CONTINENTAL SCIENTIFIC DRILLING PROGRAM

DATA NEEDS: GEOCHEMISTRY

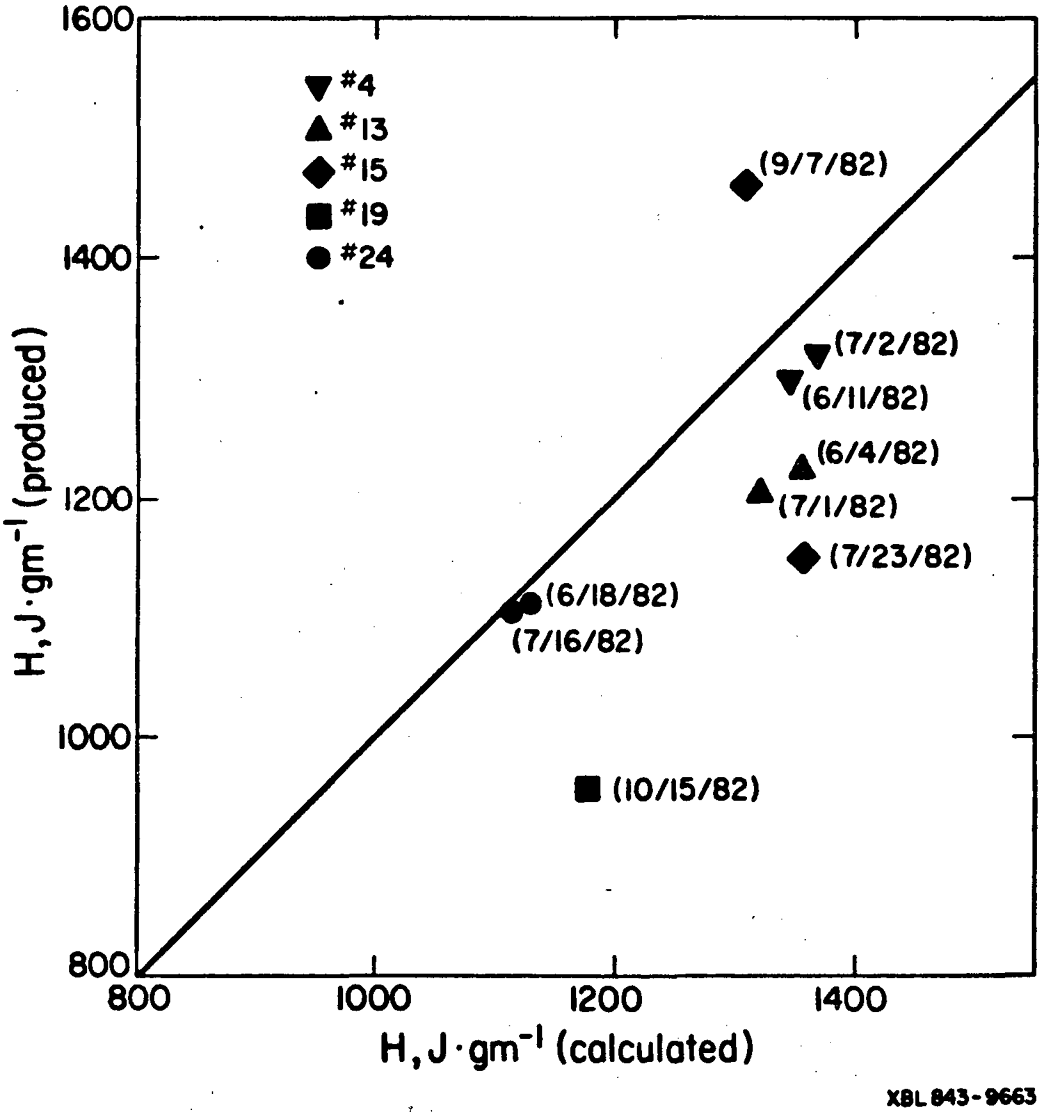
ARTHUR F. WHITE

LAWRENCE BERKELEY LABORATORY

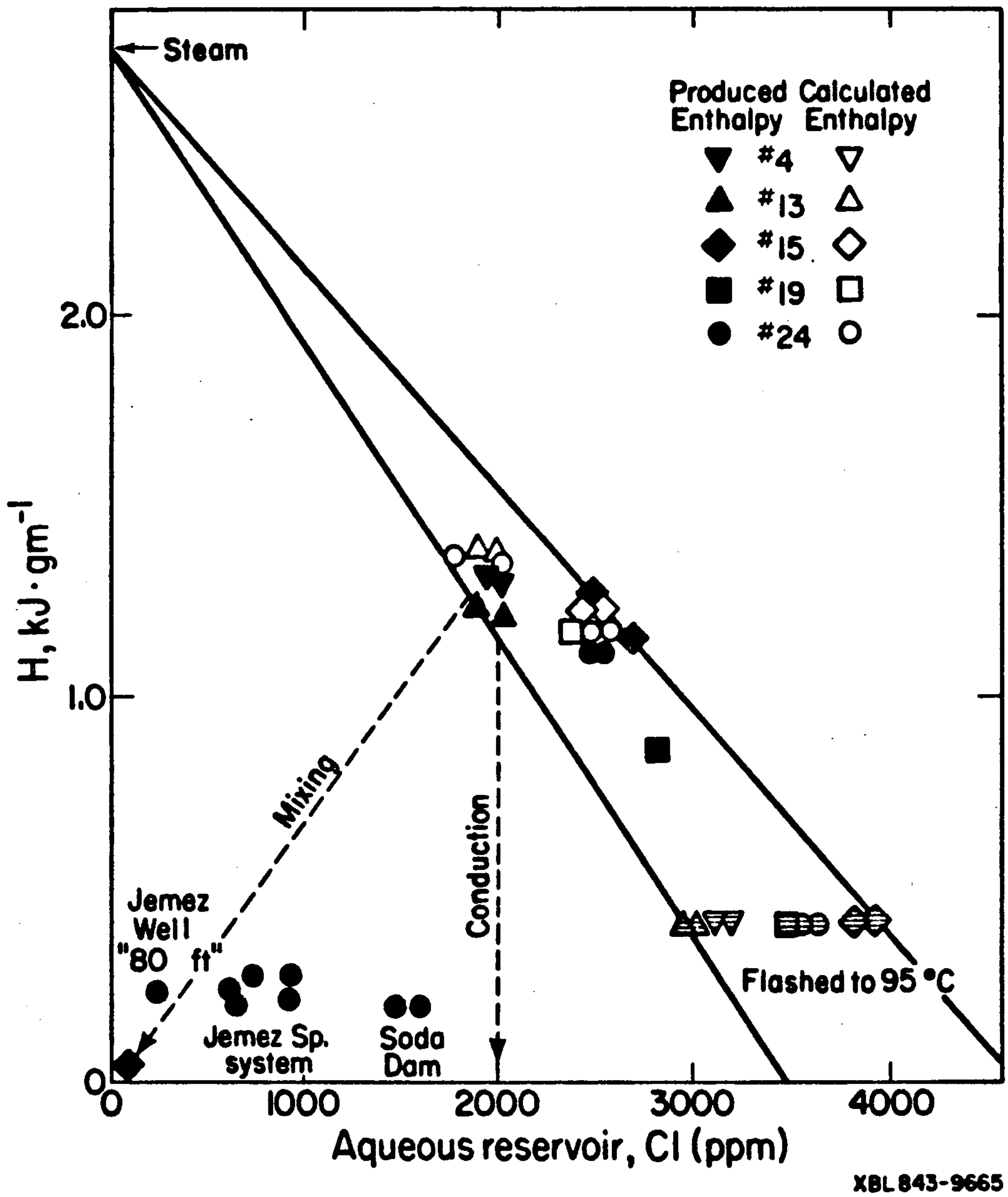


XBL 824-2116A

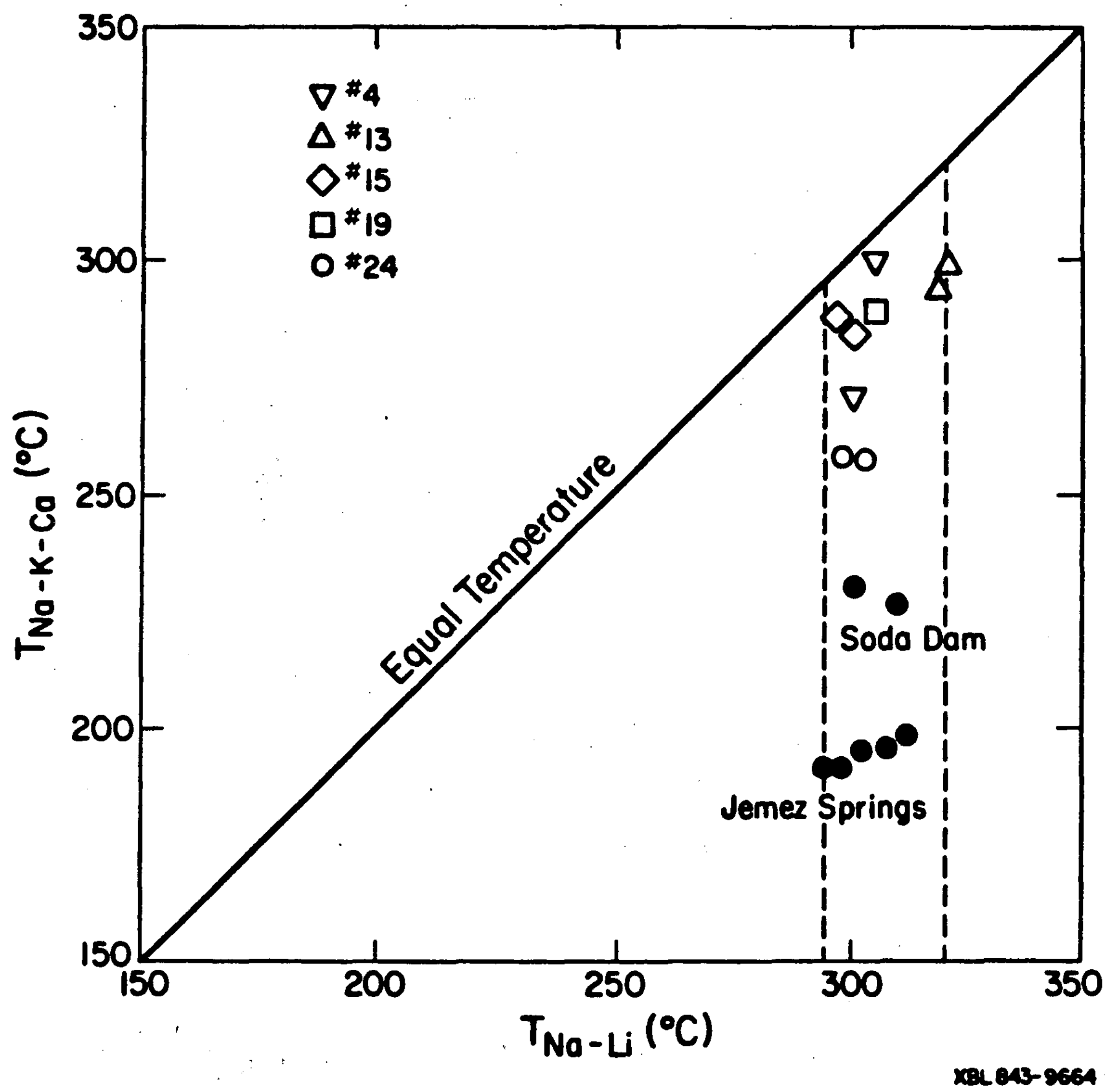
1. Map of the Valles Caldera area and locations of the Baca wells and hot springs.



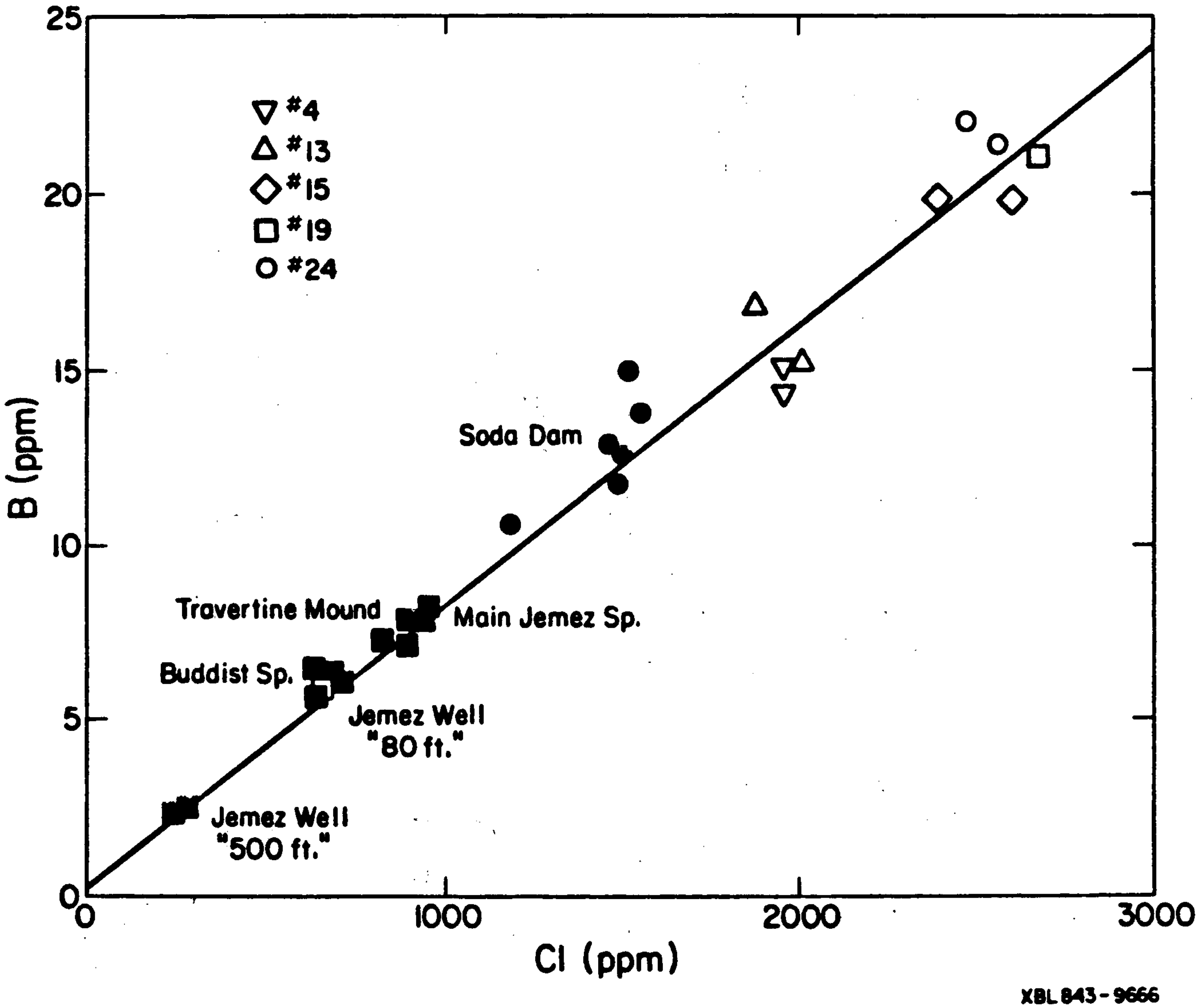
2. Comparison of produced enthalpies and calculated enthalpies assumig single phase hot water at Na-K-Ca geothermometer temperatures.



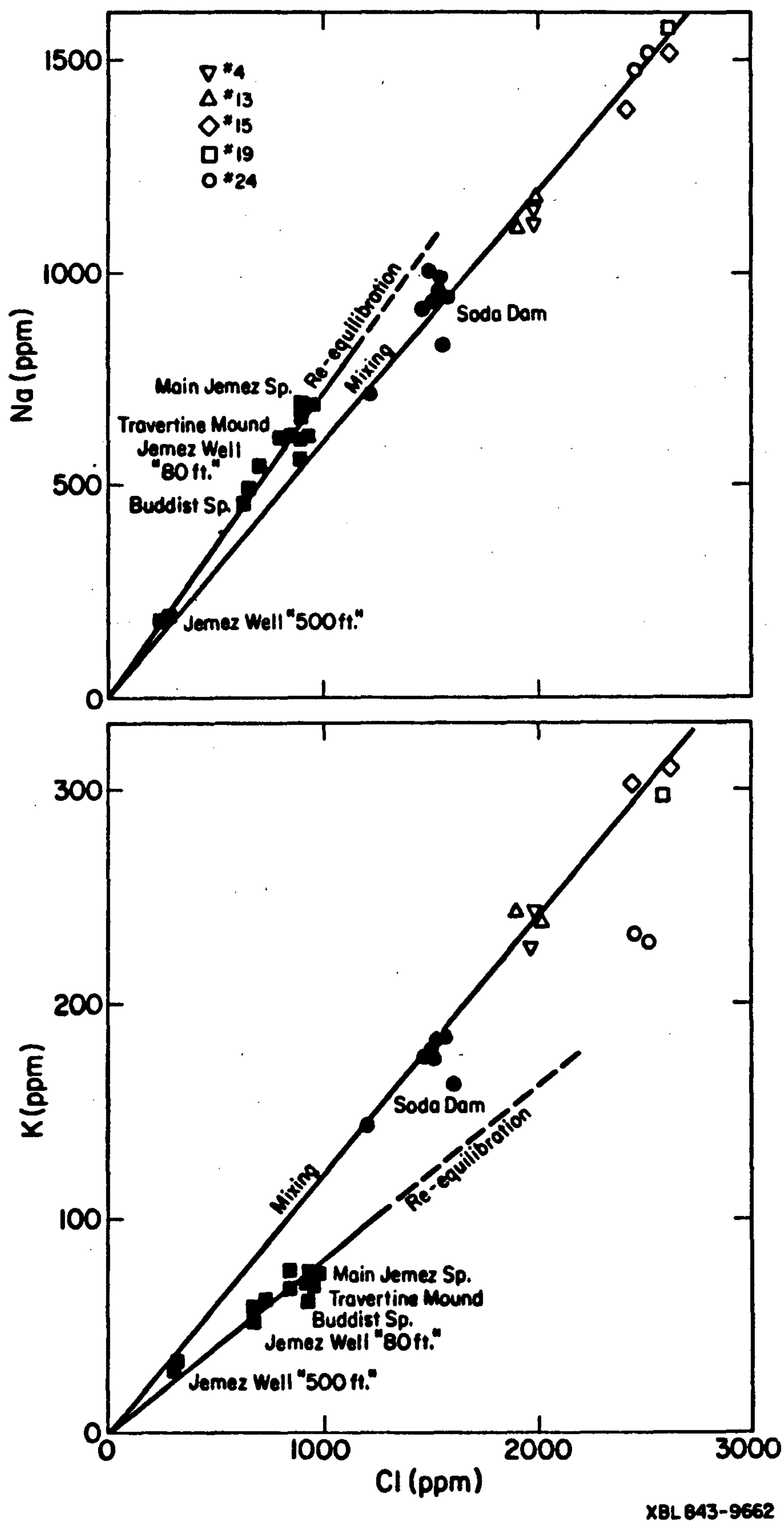
3. Enthalpy-chloride relationships for hot springs and Baca wells.



4. Comparison of temperatures of wells and hot springs calculated from Na-K-Ca and Na-Li geothermometers.



5. Boron and chloride distributions in wells and hot springs.



6. Sodium, potassium and chloride distributions in wells and hot springs.

TABLE 1

Well and Separator Characteristics

Well	Depth T.D. (m)	Production at line pressure (kg/km)	Well head pressure (psig)	Separator pressure (psig)	Water fraction (X^*fluid)
Baca 4					
6/11/82	1939	20,000	144	118	0.719
7/02/82			145	124	0.713
Baca 13					
6/04/82	2501	24,000	142	121	0.762
7/01/82			140	122	0.762
Baca 15					
7/23/82	1673	48,000	164	125	0.792
9/08/82			187	125	0.641
Baca 19					
9/08/82	1705	14,000	45	21	0.798
Baca 24					
6/18/82	3233	15,000	152	127	0.811
7/16/82			145	122	0.807

TABLE 2

Chemical analyses of liquid water from the separators ($mg.\ell^{-1}$)

	Baca 4		Baca 13		Baca 15		Baca 19	Baca 24	
	6/11/82	7/02/82	6/04/82	7/01/82	7/23/84	9/08/82	10/08/82	6/18/82	7/16/82
pH*	7.28	7.20	7.30	-	7.21	7.12	8.00	-	7.42
Li	21.1	21.2	22.5	22.7	24.9	24.0	26.6	24.1	24.0
Na	563	1607	1504	1533	1904	1867	1970	1867	1822
K	336	336	320	310	391	407	369	281	286
Mg	0		.049	0	0	.03	.02	0	.02
Ca	4.9	3.5	4.8	4.4	16.1	19.4	18.7	17.5	24.9
Al**	.09	.09	.13	.12	.14	.06	.12	.16	.22
Al^{3+}**	<.001	<.001	.003	.001	.003	.002	.002	<.001	.006
B	22	20	22	20	29	27	29	26	28
Si	376	380	335	333	341	322	294	309	317
SiO_2	804	813	717	712	730	689	629	661	678
NH_3**	2.2	2.8	2.0	2.2	--	1.8	1.5	.09	1.2
F	5.5	4.8	9.4	6.2	8.6	8.6	8.6	5.0	4.8
Cl	2770	2750	2489	2650	3328	3266	3356	3082	3046
Br	5.0	5.7	5.4	6.2	9.8	10.3	10.3	8.3	10.3
HCO_3**	215	190	221	236	89	75	139	89	90
CO_3**	0	0	0	0	0	0	4.8	0	0
SO_4	50	50	56	51	42.6	45.6	48.5	50	46.2
S^{2-}**	.35	.34	.21	.22	.45	41	.23	.04	.14
PO_4	.09	.31	.12	.15	0			.49	
As	1.9	2.6	2.1	3.2	3.5	3.6	4.0	5.0	3.6
Cr	.0016	.0008	<.0001	.0006	.0036	.0022	.0014	.0006	.0012
Cs	-	.4	-	.3	3.2	3.2	3.3	.4	3.6
Hg	.0048	<.001	.0015	<.001	<.001	<.001	<.001	<.001	<.001
Fe	0.22	0	.006	0	0	0	0		0
Mn	.0039	-	.0086	-	.0086	.0050	.0050	-	.018
Pb	<.01	<.01	<.01	<.01	<.001	<.001	<.01	<.01	<.001
Se	<.001	<.01	<.001	<.01	-	-	-	<.01	-
Sr	.158	0	.184	0	.2	.2	.2		.35
Zn	.012	<.01	.24	<.01	<.01	<.01	<.01	<.01	<.01

* measured in field
** measured at Fenton Hill Laboratory (LANL).

TABLE 3

Geothermometer temperatures (^oC)

Location	Sample date	$T_{measured}$	T_{SiO_2}	T_{Na-K}	$T_{Na-K-Ca}$	T_{Na-Li}
Baca 4	6/11/82	295	263	288	300	305
	7/02/82	295	264	283	271	301
Baca 13	6/04/82	295	254	286	299	320
	7/01/82	295	254	278	294	319
Baca 15	7/23/82	270	255	281	285	301
	9/08/82	270	251	290	287	298
Baca 19	10/08/82	-	244	267	288	304
Bacca 24	6/18/82	247	248	236	258	299
	7/16/82	224	250	242	257	302
Soda Dam	12/01/72	48	102	277	230	310
	1/04/79	48	102	278	226	301
Main Jemez Sp.	11/19/79	35	128	195	194	300
Travertine Mound	1/19/79	72	127	202	196	308
Buddhist Sp.	1/19/79	50	120	205	192	291
Jemez Well "80 ft"	1/19/79	68	118	201	192	296
Jemez Well "500 ft"	1/19/79	60	71	245	192	294

CONTINENTAL SCIENTIFIC DRILLING PROGRAM

DATA NEEDS:

THERMAL TRANSPORT MODELING

HARRY C. HARDEE

SANDIA NATIONAL LABORATORY

CSDP - DATA NEEDS

THERMAL TRANSPORT MODELING

EMPHASIS ON MAGMA BODY - ITS EVOLUTION AND ITS INTERACTION WITH THE HYDROTHERMAL SYSTEM

THERE ARE TWO AREAS OF INTEREST:

1. SURFACE AND SHALLOW THERMAL DATA THAT AIDS SITE SELECTION AND DRILLING.

2. DEEP DOWNHOLE DATA ONCE A DEEP HOLE HAS BEEN DRILLED AND THE MAGMA SOURCE APPROACHED.

- CSDP SITE ASSESSMENT: GEOPHYSICS REPORT (KASAMEYER, 1980) SUMMARIZED MODELS FOR VALLES AS OF 1980. "GEOPHYSICS DID NOT IDENTIFY ANY MOLTEN TARGET, MUCH LESS INDICATE DEPTH (TO ONE)". BASED ON HEAT FLOW THEY PLACE 600 C ISOTHERM AT 6-10 KM.

- HEAT FLOW IN CALDERA 4.5 - 6 HUF (REITER ET AL 1976). BACKGROUND HEAT FLOW IN THIS AREA OF THE RIFT 2-3 HFU.

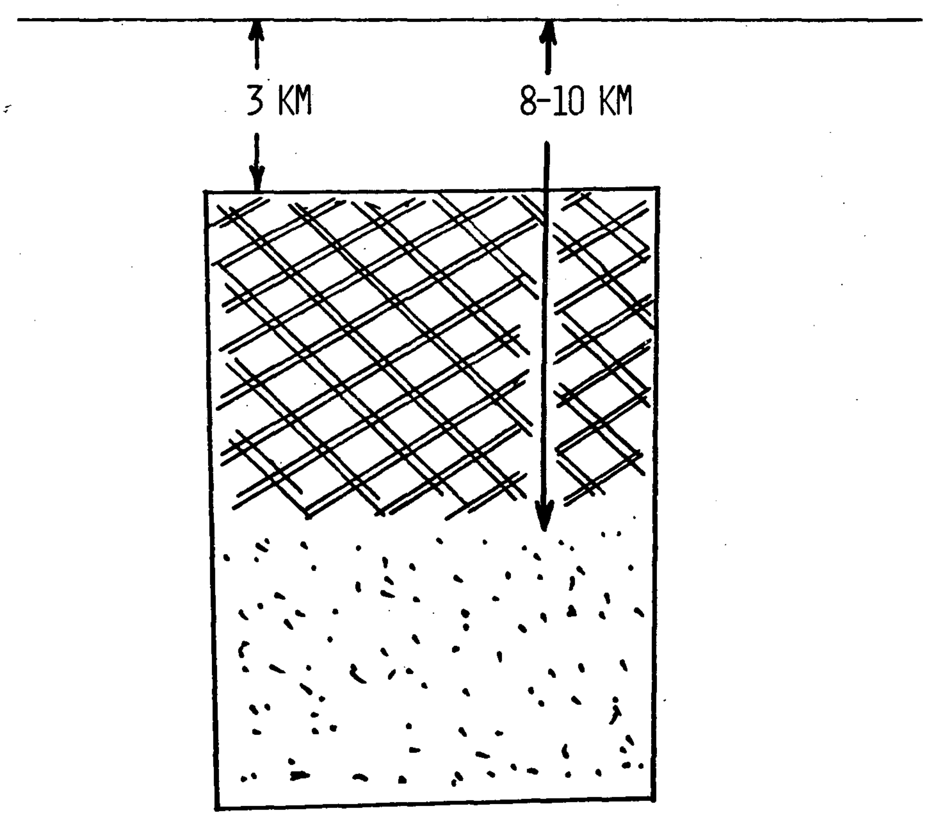
- KOLSTAD & MCGETCHIN (1978). PUBLISHED DEEPWELL TEMPERATURE DATA (200 C AT 3 KM GT-2) AND A MAGMA MODEL. THEY LOOKED AT NUMERICAL MODELS OF CYLINDRICAL PLUTONS SUDDENLY EMPLACED AT 1000 C 1 MY AGO WITH CONDUCTION COOLING. BEST MODEL REQUIRED 12 KM RADIUS, 20 KM VERTICAL EXTENT, PLUTON WITH TOP NO DEEPER THAN 3KM. 10 TO 30 PERCENT OF PLUTON SHOULD STILL BE MOLTEN.

SOLIDIFICATION DISTANCE

$$X = 2\lambda\sqrt{\kappa\tau}$$

$$X = 5 - 7.2 \text{ KM IN } 1 \text{ MY}$$

IF TOP OF ORIGINAL CHAMBER WAS ORIGINALLY AS SHALLOW AS 3 KM, THE DISTANCE TO THE MELT IS NOW 8 - 10.2 KM.



ASSUMING THAT HEAT FLOW IS CONTROLLED AT LATE TIMES BY CONDUCTION-DOMINANT SOLIDIFICATION CHANGE-OF-PHASE PROCESS (CARSLAW & JAEGER, 1959)

$$X = 2\lambda(\kappa\tau)^{1/2} \qquad \frac{c\,T_M}{\mathcal{L}\sqrt{\pi}} = 1.41$$

FOR INITIALLY COLD BODY ABOVE (CONDUCTION B.C.)

$$\lambda e^{\lambda^2}\,\mathrm{erf}(\lambda) = \frac{c\,T_M}{\mathcal{L}\sqrt{\pi}} = 1.41$$

$$\lambda = 0.86$$

FOR COLD SURFACE MAINTAINED COLD AT X = 0 (CONVECTION B.C.)

$$\lambda e^{\lambda^2}(1 + \mathrm{erf}\,\lambda) = \frac{c\,T_M}{\mathcal{L}\sqrt{\pi}} = 1.41$$

$$\lambda = 0.60$$

SURFACE HEAT FLOW

$$q = \rho\mathcal{L}\frac{dX}{d\tau} + q_{BK} \qquad \frac{dX}{d\tau} = \lambda\sqrt{\frac{\kappa}{\tau}}$$

$$q = \rho\mathcal{L}\lambda\sqrt{\frac{\kappa}{\tau}} + q_{BK} = 4.7 \rightarrow 6.0 \text{ HFU}$$

AFTER 1 MY

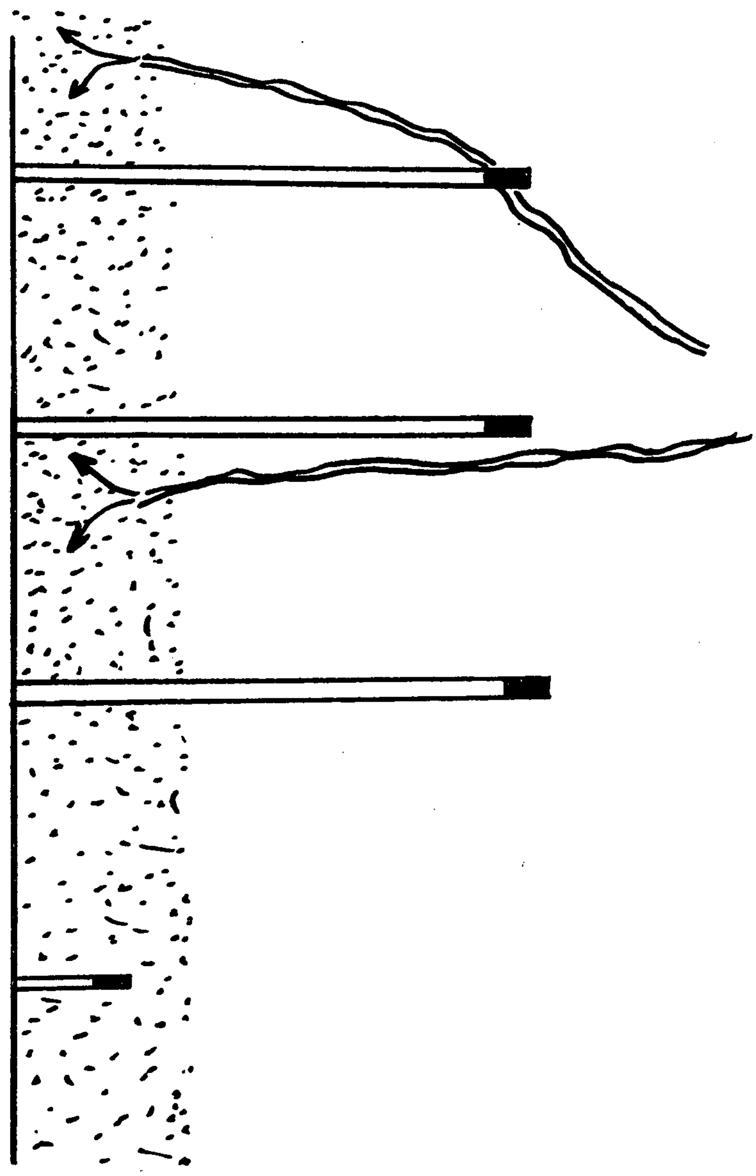
OBSERVED 4.5 - 6.0 HFU

DATA NEEDS

- SURFACE AND NEAR SURFACE HEAT FLOW - TOTAL HEAT FLOW (CONDUCTION AND CONVECTION). THIS INFORMATION VALUABLE FOR HEAT BUDGET AND RELATED MODEL CALCULATIONS. FROM THIS WE DETERMINE THE PRESENT STATE OF THE MAGMA TARGET SIZE, REMAINING MELT, ETC.

- RADIAL SURFACE HEAT FLOW PROFILES. THIS INFORMATION CAN SOMETIMES BE USED TO ESTIMATE AREAL EXTENT OF MAGMA BODY.

- DEEPHOLE TEMPERATURE GRADIENT OR HEAT FLUX MEASUREMENTS. USEFUL FOR STUDYING CURRENT STATE OF MAGMA BODY AND ITS INTERACTION WITH HYDROTHERMAL FIELD.



Sketch of energy flows up fractures to wells.

BACA DATA:
OVERVIEW OF
DOE DEMONSTRATION PROJECT

MARTIN W. MOLLOY

U.S. DOE, SAN FRANCISCO OPERATIONS OFFICE

BACA GEOTHERMAL FIELD

CONTINENTAL SCIENTIFIC DRILLING PROGRAM DATA NEEDS

- DECEMBER 2, 1983 -

- PROJECT DESCRIPTION
- CHRONOLOGY
- RESERVOIR PROBLEMS
- DATA & REPOSITORIES

BACA PROJECT DESCRIPTION

- 50 MW GEOTHERMAL POWER PLANT

- NORTHERN NEW MEXICO

- PARTICIPANTS:
  (50:50 COST SHARED COOP. AGREEMENT)

  UNION GEOTHERMAL CO. OF NM
  - STEAM WELLS: 900,000 LB/HR
  - PROD. & INJECT. PIPELINES

  PUBLIC SERVICE CO. OF NM
  - 50 MW POWER PLANT
  - TRANSMISSION LINE

  US DEPT. OF ENERGY (P.L. 9-410)
  - PROMOTE GEOTHERMAL DEVELOPMENT
  - ENVIRONMENTAL IMPACT STATEMENT
  - DATA DISTRIBUTION

- COSTS

COSTS		PLAN	ACTUAL
UNION	}	\$ 68 M	\$ 24 M
PNM	}		\$ 2 M
DOE		\$ 65 M	\$ 47 M
TOTAL		\$ 133 M	\$ 73 M

BACA PROJECT CHRONOLOGY

- 1960	OIL EXPLORATION (Westates Pet.) HIT GEOTHERMAL STEAM
- 1963	GEOTHERMAL EXPLORATION (Baca Land & Cattle Co.)
- 1970	REDONDO CREEK GEOTHERMAL DISCOVERY WELL (BL&CC)
- APRIL 1971	UNION LEASED 100,000 ACRE BACA LAND GRANT
- END 1973	TOTAL 6 UNION WELLS: EST. >300 MW/30 YEARS
- 1976	TOTAL 11 UNION WELLS: EST. > 220-385 MW/30YEARS

- - - - - - - - - - - - - - - - -

- SEPT. 1977	DOE ISSUED PROGRAM OPPORTUNITY NOTICE
- JAN. 1978	PNM/UNION PROPOSED BACA PROJECT TO DOE: EST. >410 MW/30 YEARS
- JULY 1978	DOE SELECTED PNM/UNION PROPOSAL
- JUNE 1979	PNM PETITIONED NM PUBLIC SERVICE COMMISSION
- JULY 1979	DOE ISSUED DRAFT ENVIRONMENTAL IMPACT STATEMENT
- JULY 1980	PNM PETITION DISMISSED; ORDERED TO CEASE CONSTRUCTION
- AUG. 1980	WATER RIGHTS TRANSFERRED TO UNION BY NM STATE ENGINEER
- SEPT. 1980	PUEBLO APPEALED WATER RIGHTS TRANSFER IN DISTRICT COURT
- JAN. 1981	INDIAN RELIGIOUS PRACTICES LAWSUIT AGAINST DOE BY 18 PUEBLOS
- MAY 1981	UNION NOTIFIED PNM/DOE OF INSUFFICIENT STEAM DOE FORMED RESERVOIR REVIEW TEAM UNION STARTED DEEP DRILLING AND WELL HYDROFRAC PROGRAM
- JAN. 1982	CERTIFICATE OF NON-VIABILITY SIGNED BY DOE/PNM/UNION
- AUG. 1982	UNION PURCHASED WELLFIELD EQUIPMENT & TERMINATED PROJECT
- IN PROGRESS	PNM SELLING POWER PLANT EQUIPMENT TO TERMINATE PROJECT

DOE/Molloy
1/9/83

RESERVOIR PROBLEMS

DRILLING IN FRACTURED, VOLCANIC ROCK (11 LOST WELLS)

	WELLS	%
- DRILL PIPE STUCK, TWISTED-OFF (LOST, SIDETRACKED)	8	26
- CASING & LINER WORN, CORRODED, COLLAPSED	3	10
- EXTENSIVE FISHING	7	23
- JUNK IN HOLE	1	3
- STEAM/WATER ENTRIES	3	10
- BAD SLOUGHING	6	19
- CASING & LINER BREAK, STUCK	1	3
- PRODUCTION ZONE DAMAGED BY FISHING	1	3
- BRIDGED WELLBORE	1	3
- WELLBORE SCALING	3	30

DRILL TARGETING MODELS

1) FRACTURES IN BASAL BANDELIER TUFF ALONG FAULT ZONE
2) " " " " " " " " INTERSECTIONS
3) UNDERLYING ANDESITE (TOP); BASEMENT GRANITE (TOP & FRACTURES)
4) (VOLCANIC SEDIMENTS & COLUMNAR JOINTING IN BANDELIER TUFF)

- INCOMPLETE GEOPHYSICAL, STRATIGRAPHIC & GEOCHEMICAL ANALYSES
- UNPREDICTABLE "STEAM" FRACTURES
- LOSS OF CRITICAL INFO FROM WELL FAILURES (ABOVE)

LOW RESERVOIR PERMEABILITY/TRANSMISSIVITY

FAILURE OF 2 WELL STIMULATIONS

BACA DATA & REPOSITORIES

MOST THOROUGHLY DOCUMENTED U.S. FRACTURED VOLCANIC GEOTHERMAL RESERVOIR

- RAW DATA (LOGS, CUTTINGS, DRILLING REPORTS, WELL TESTS, ETC.)
- UNION REPORTS (EXPLORATION & DEVELOPMENT)
- S-CUBED & LBL RESERVOIR ANALYSES
- DOE REVIEW TEAM REPORT
- UNION & PNM FINAL REPORTS
- OTHER (ENVIRONMENTAL, LEGAL, ETC.)

DATA REPOSITORIES:

- LAWRENCE BERKELEY LABORATORY
- LOS ALAMOS NATIONAL LABORATORY (FENTON HILL - HOT DRY ROCK)
- OAK RIDGE NATIONAL LABORATORY (ENVIRONMENTAL & LEGAL)
- UNIVERSITY OF UTAH RESEARCH INSTITUTE

BACA DATA:

GEOPHYSICS

MICHAEL J. WILT

LAWRENCE BERKELEY LABORATORY

PURPOSE OF STUDY

- DESCRIBE THE GEOPHYSICAL CHARACTERISTICS OF THE VALLES CALDERA AND REDONDO CREEK RESERVOIR.
- DELINEATE STRUCTURAL CONTROL TO THE SYSTEM.
- TRY TO ASSIGN FIELD BOUNDARIES FOR RESERVOIR ENGINEERING SIMULATIONS.

GEOPHYSICAL DATA USED

GRAVITY

- REGIONAL
- BACA RANCH (BACA LIBRARY)

MAGNETICS

- REGIONAL

GEOPHYSICAL WELL LOGS

- BACA RANCH (BACA LIBRARY)

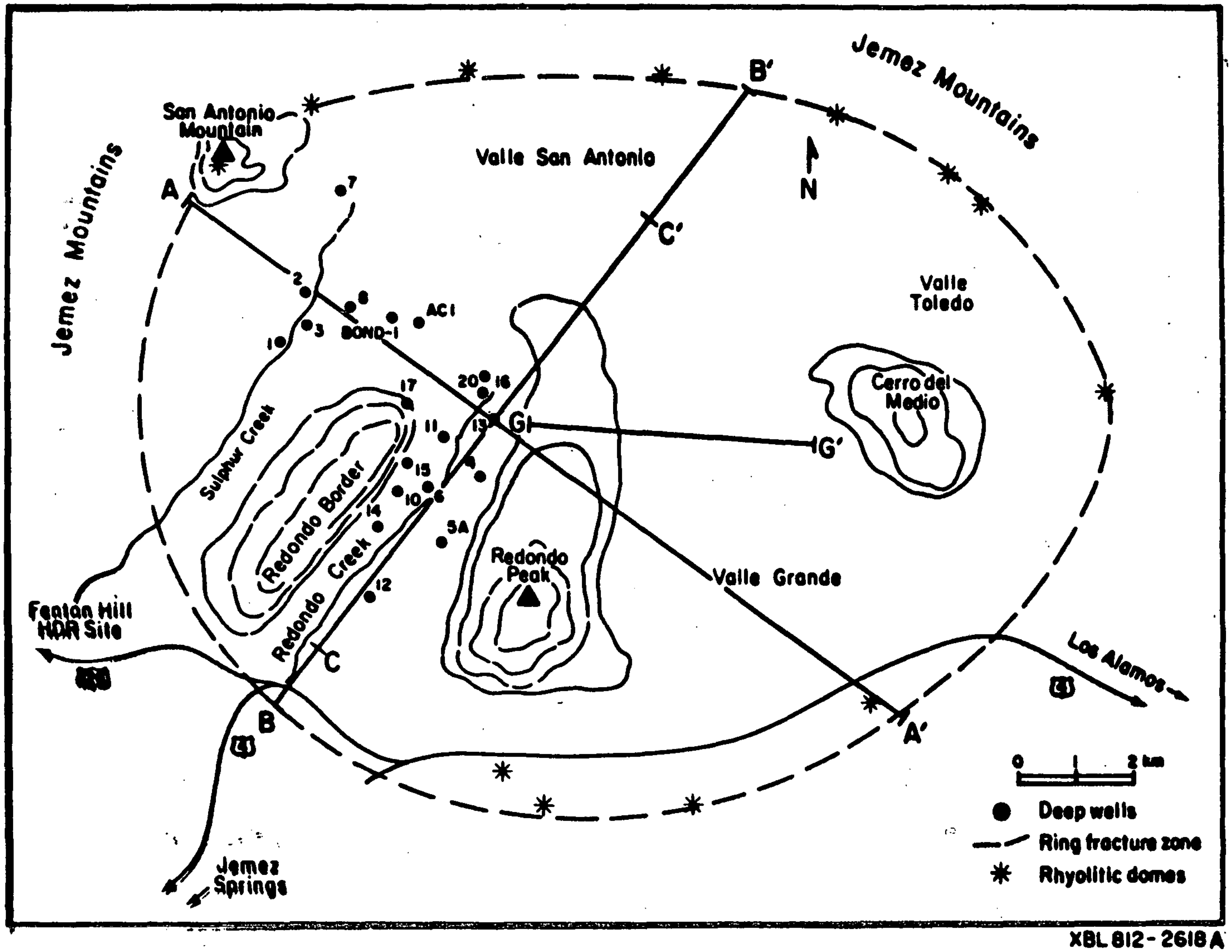
ELECTRICAL SURVEYS

- RECON. RESISTIVITY
- TDEM
- TELLURICS AND MT

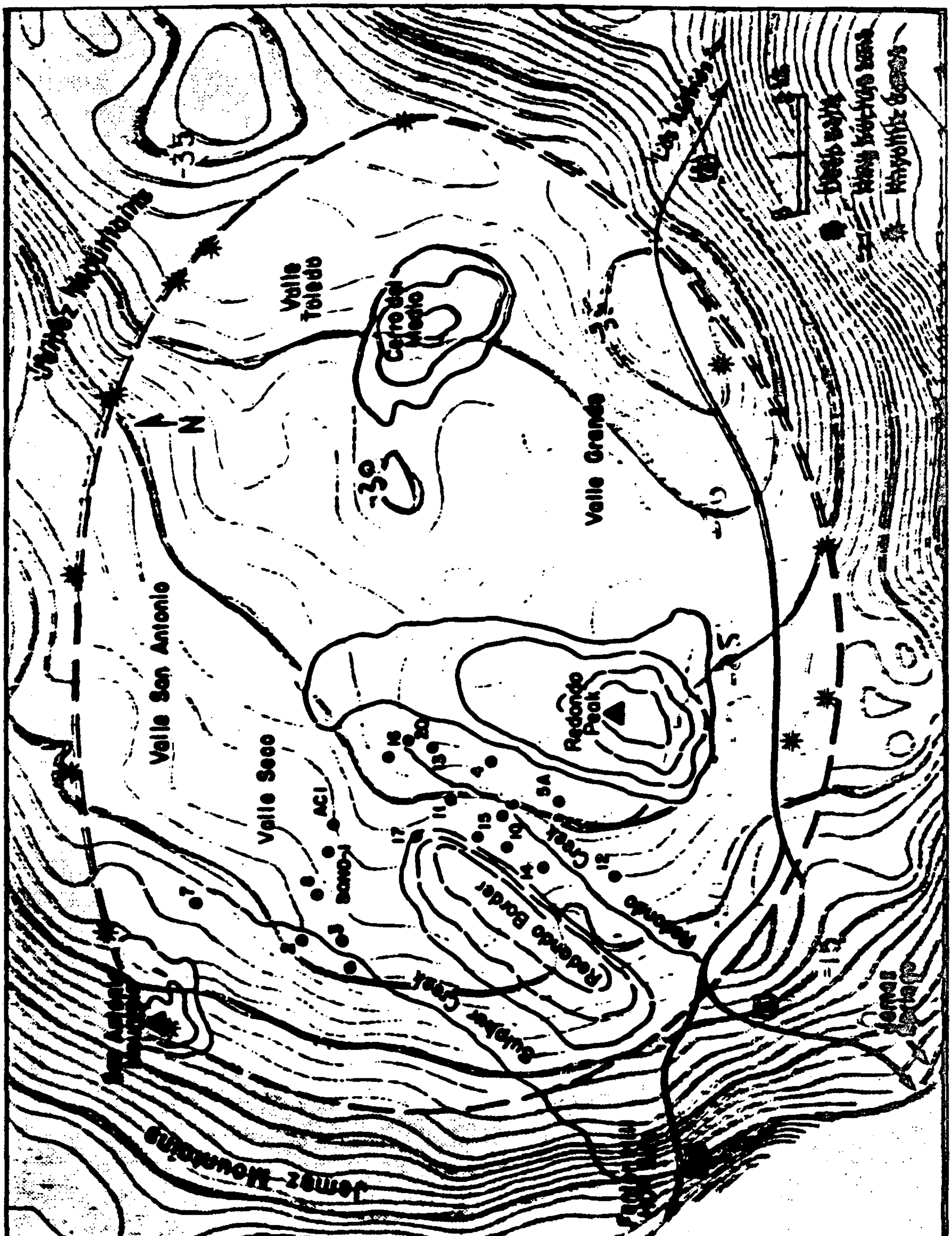
} BACA LIBRARY

- RESISTIVITY
- TELLURICS AND MT

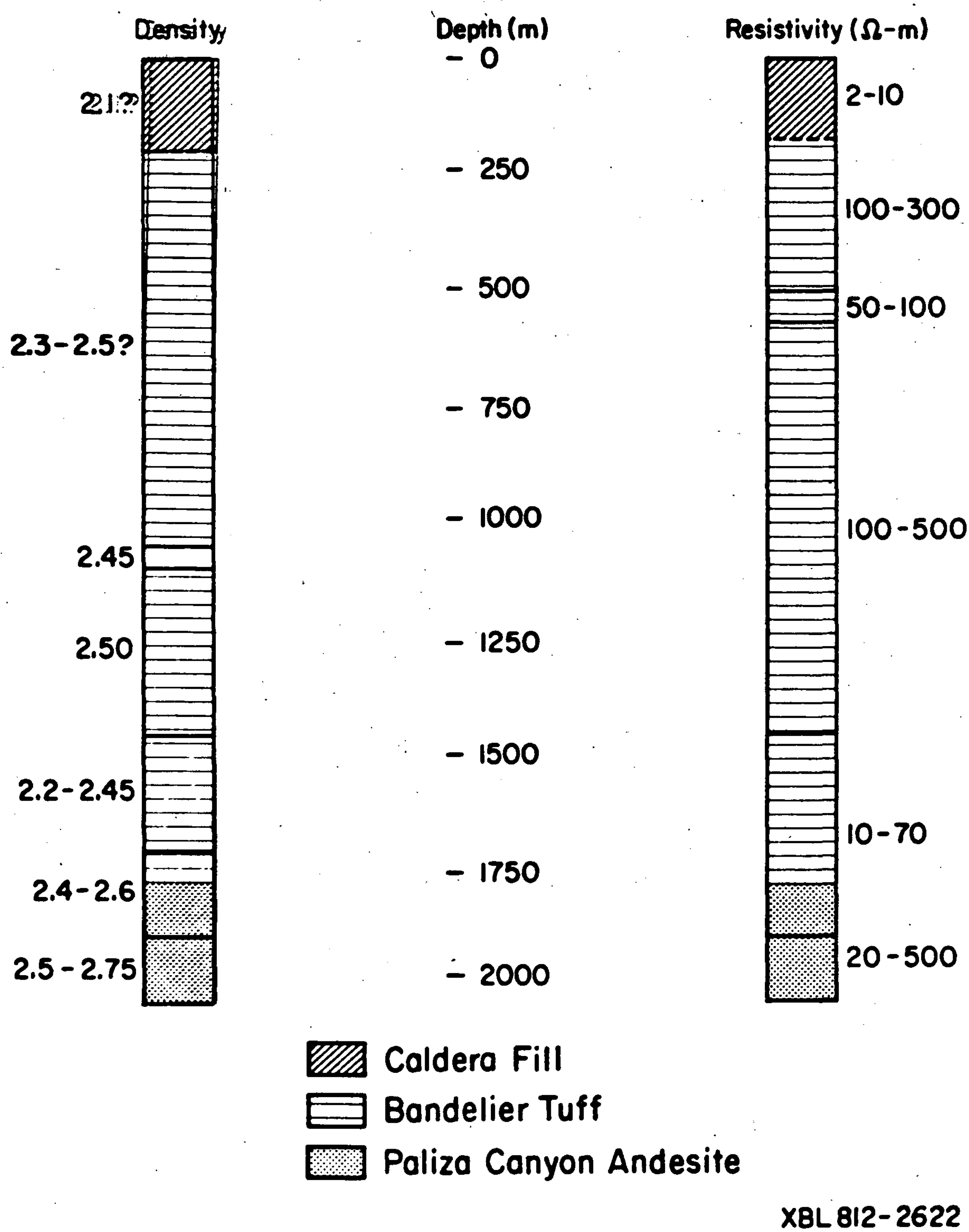
TEMPERATURE DATA (BACA LIBRARY)



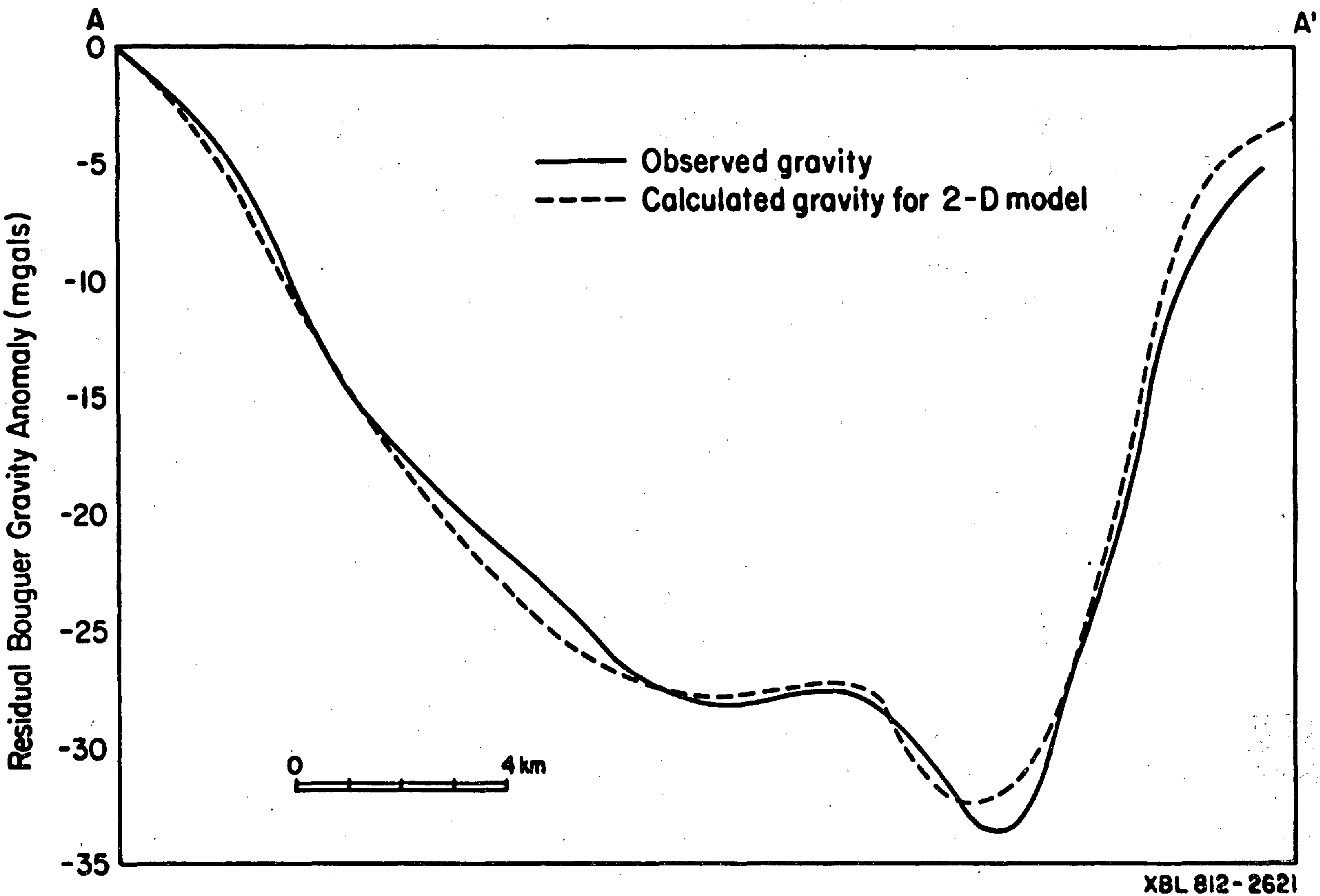
1. Location map for cross-sections AA', BB' and CC'.



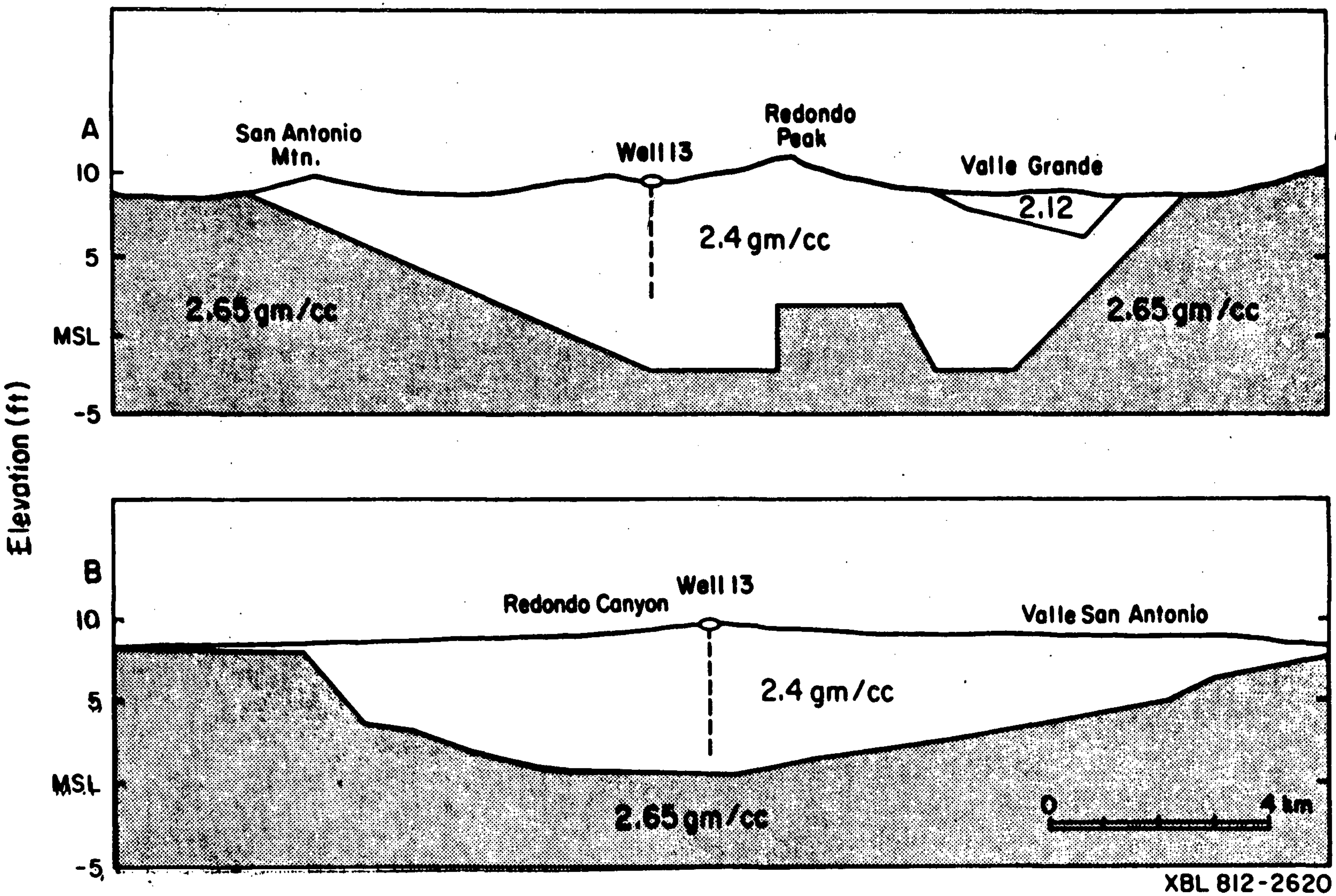
2. Gravity map of Valles Caldera.



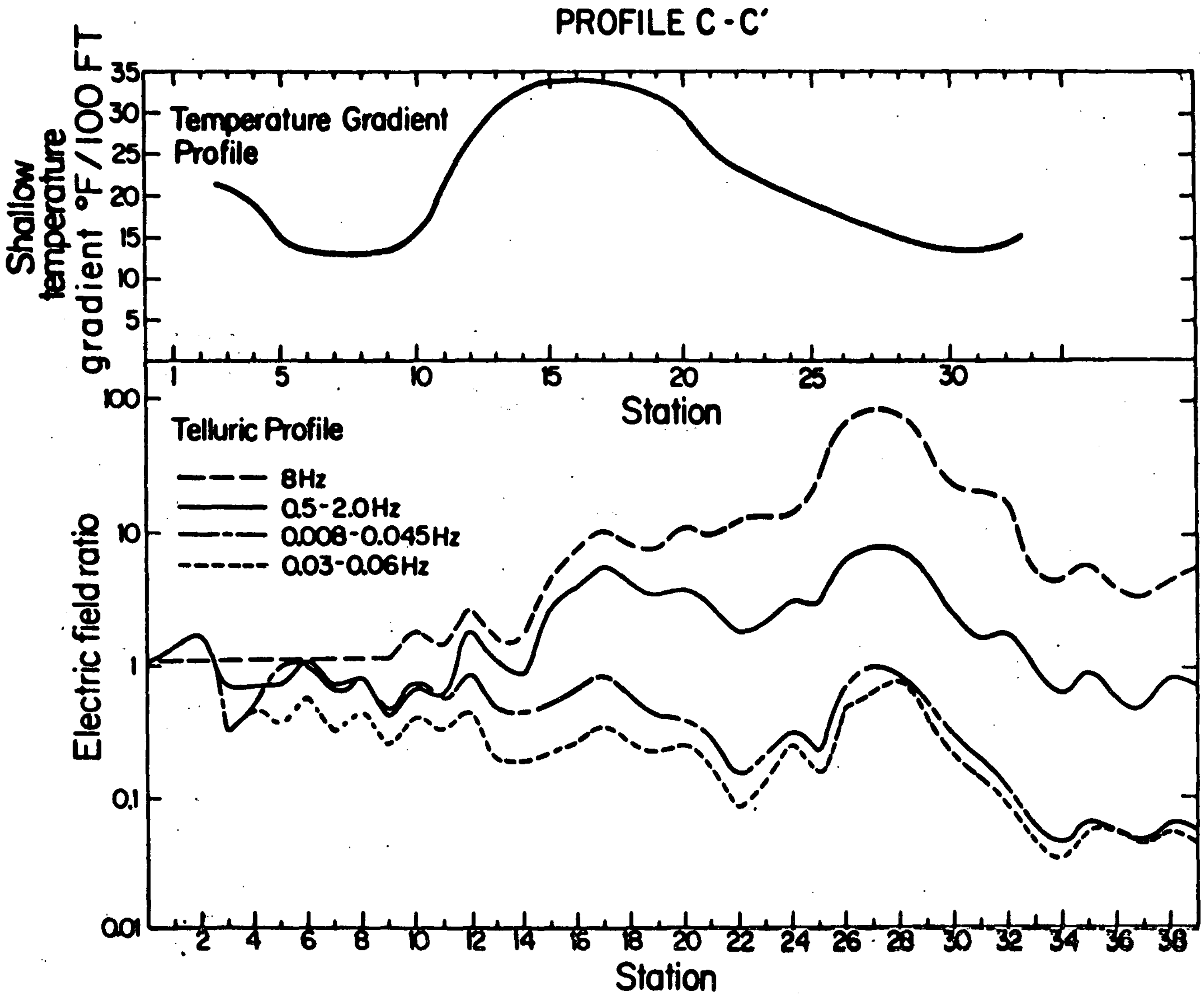
3. Generalized geophysical well log for the region near Baca well 13.



4. Fit of two-dimensional model for gravity to observed data along cross-section AA'.

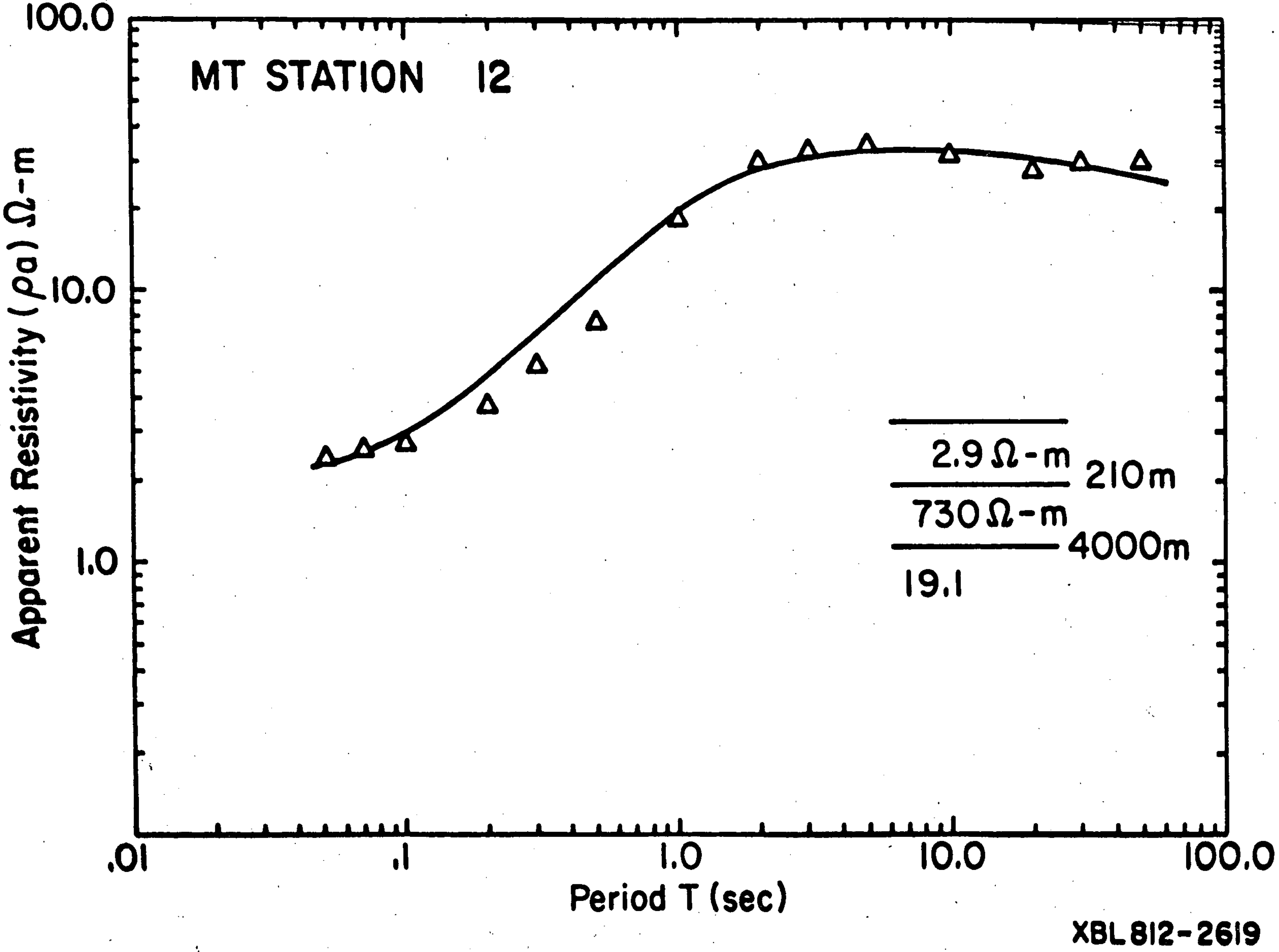


5. Density cross-sections for AA' and BB'.

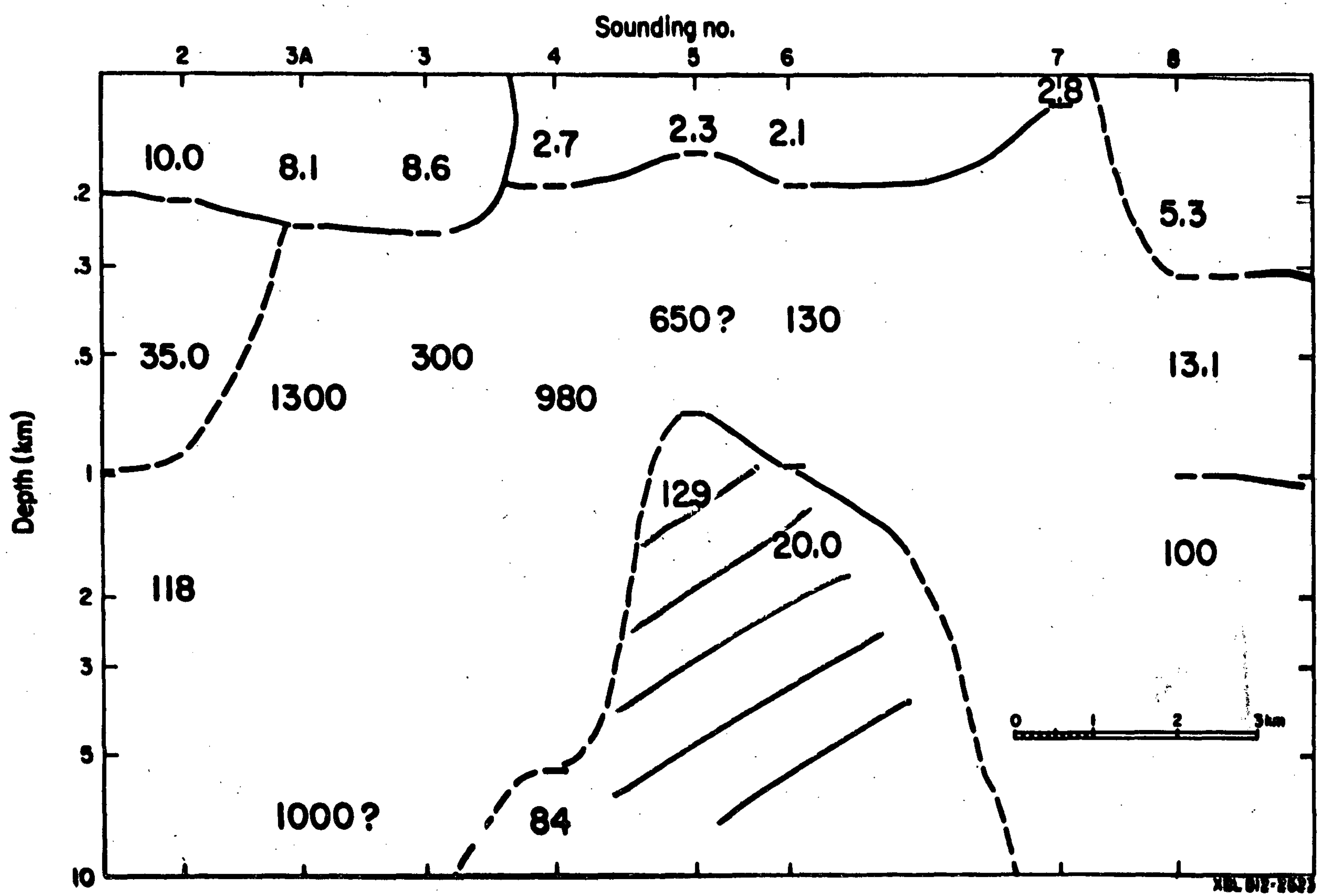


XBL 7912-13350A

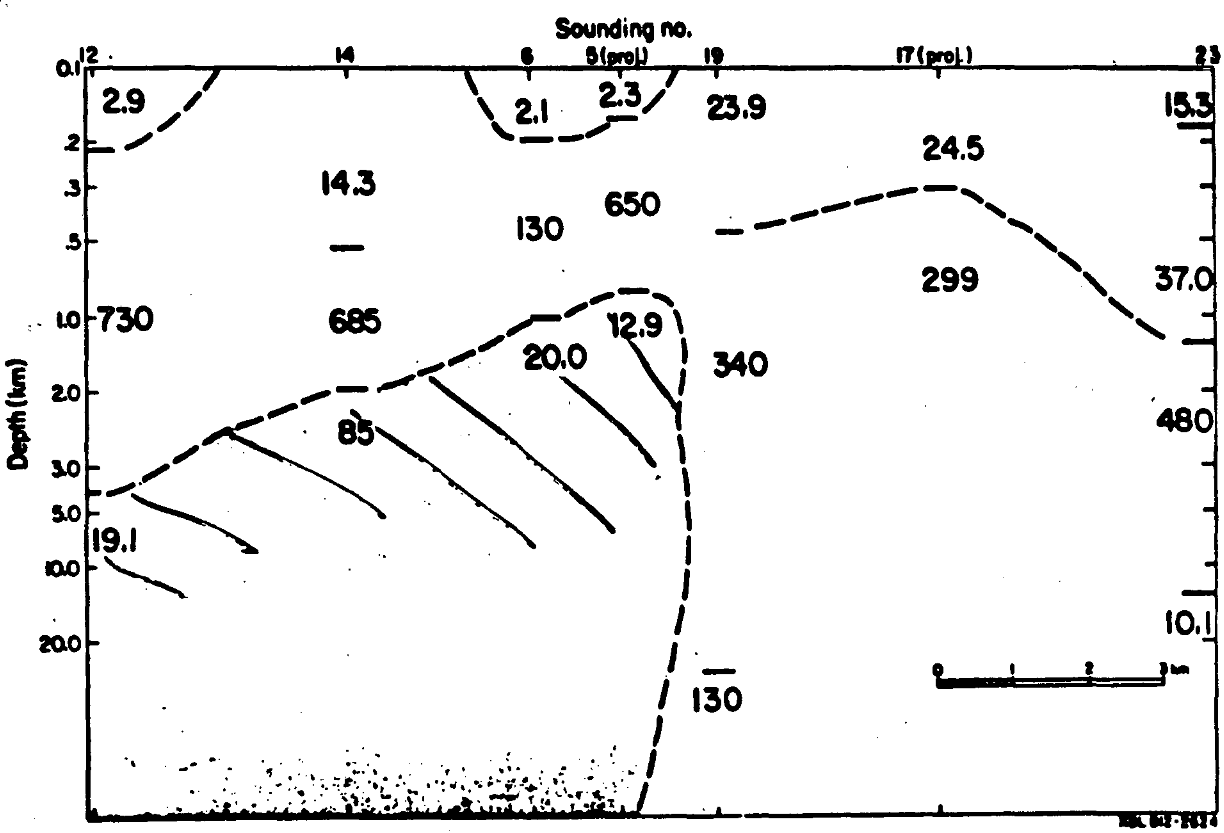
6. Profile CC', showing temperature gradients and telluric voltage ratios (J-values). Station spacing is 300 m.



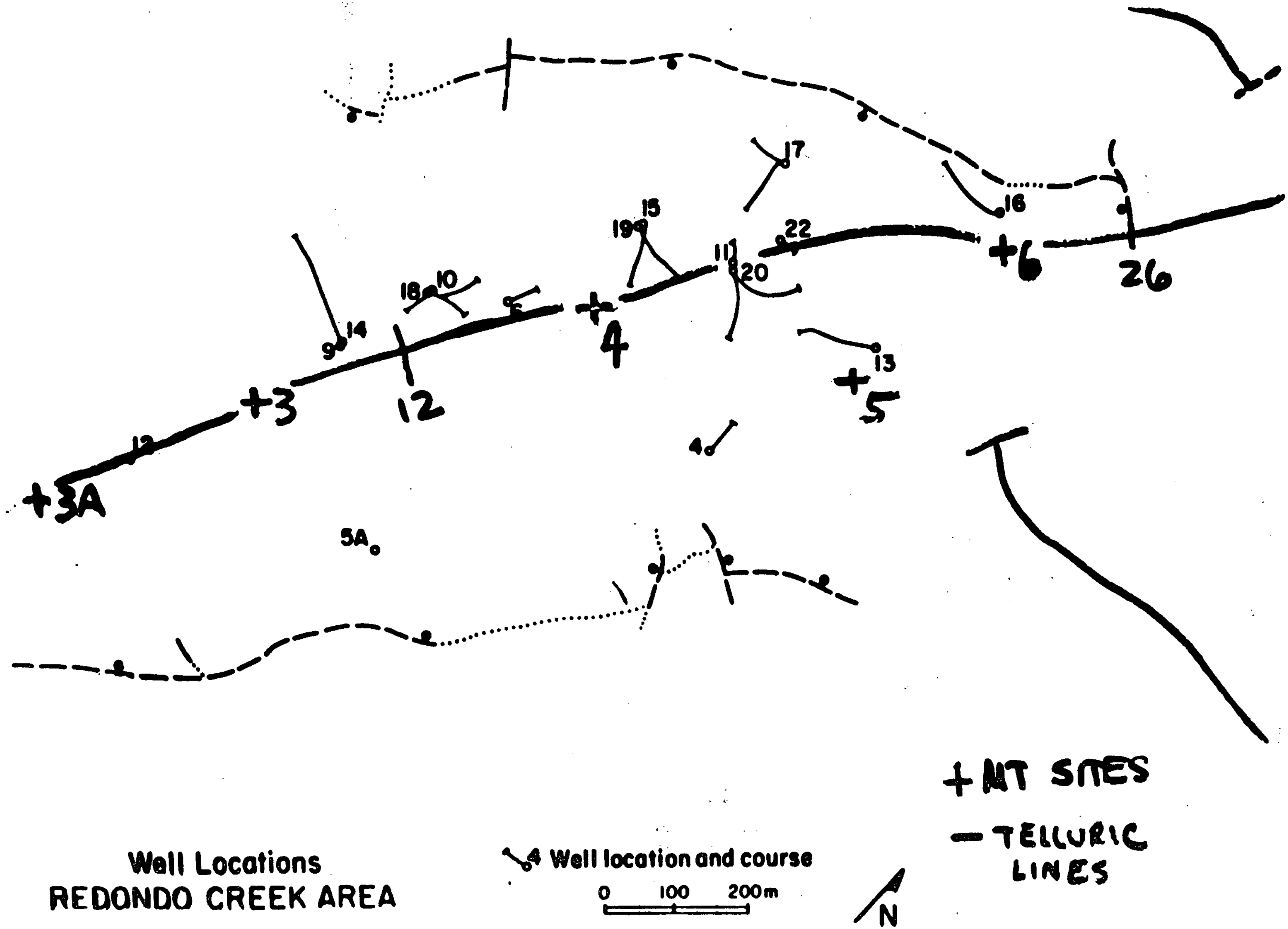
7. Apparent resistivities observed and calculated for MT Station 12 and layered model.



8. Redondo Canyon cross-section: apparent resistivities in a series of layered models, stations 2 to 8.

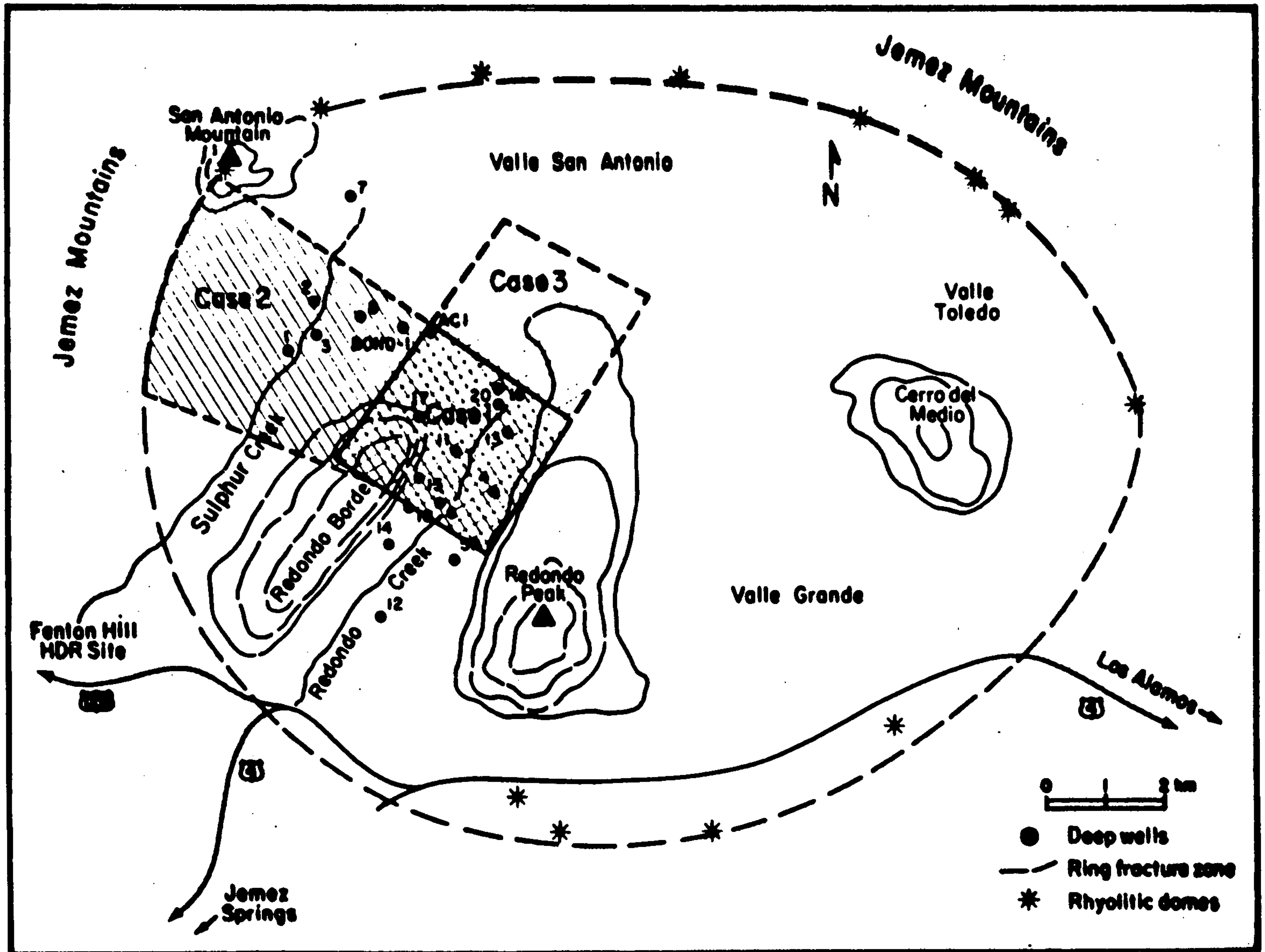


9. Further cross-section with apparent resistivities in a series of layered models, stations 12 to 23.



XBL 819-11672

10. MT sites and telluric lines on a map of well locations in the Redondo Creek area.



XBL 812-2618B

11. Reservoir definition for 3 cases in Valles Caldera.

CONCLUSIONS

THE REDONDO CREEK RESERVOIR REGION IS ASSOCIATED WITH A LOW RESISTIVITY ZONE AT DEPTH. LOW RESISTIVITY ZONES ALSO FOUND IN VALLE SECO AND AT DEPTH IN SULPHUR CREEK.

GRAVITY DATA SUGGEST THAT BASEMENT IS 3-5 KM DEEP WITHIN THE CALDERA. THERE ARE STRONG NE AND NNE TRENDING LINEAMENTS WHICH INTERSECT AT THE NORTHERN END OF REDONDO CANYON. THE CALDERA IS TIPPED TOWARDS THE SOUTHEAST.

THE MOST LIBERAL ESTIMATES OF RESERVOIR DIMENSIONS RANGE FROM 10-30 KM^2. REAL DIMENSIONS PROBABLY LESS.

A DEEP LOW RESISTIVITY ZONE IS PRESENT AT A DEPTH OF 15 KM BENEATH THE CALDERA. ONE SOUNDING LOCATED AT THE WESTERN BOUNDARY SHOWS A LOW RESISTIVITY ZONE AT A DEPTH OF 4-5 KM.

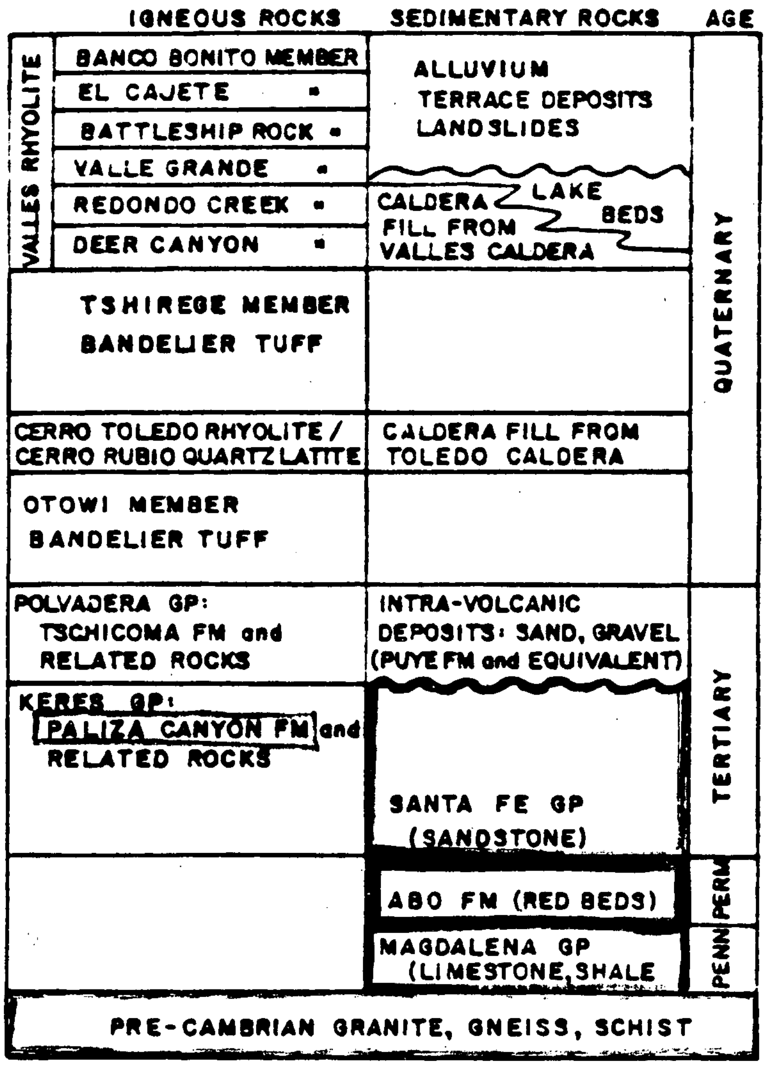
BACA DATA:

LITHOLOGY

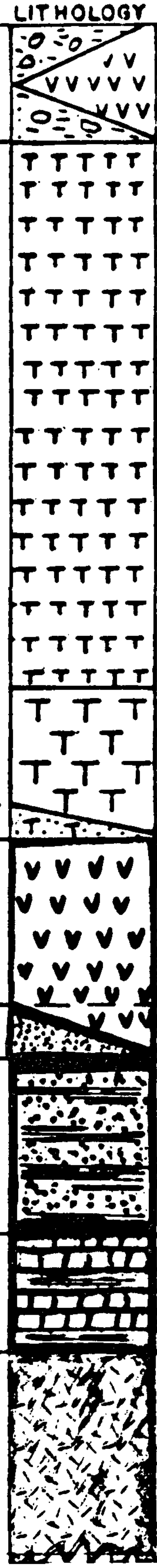
STEPHEN VONDER HAAR

PACIFIC ENERGY CONSULTANTS

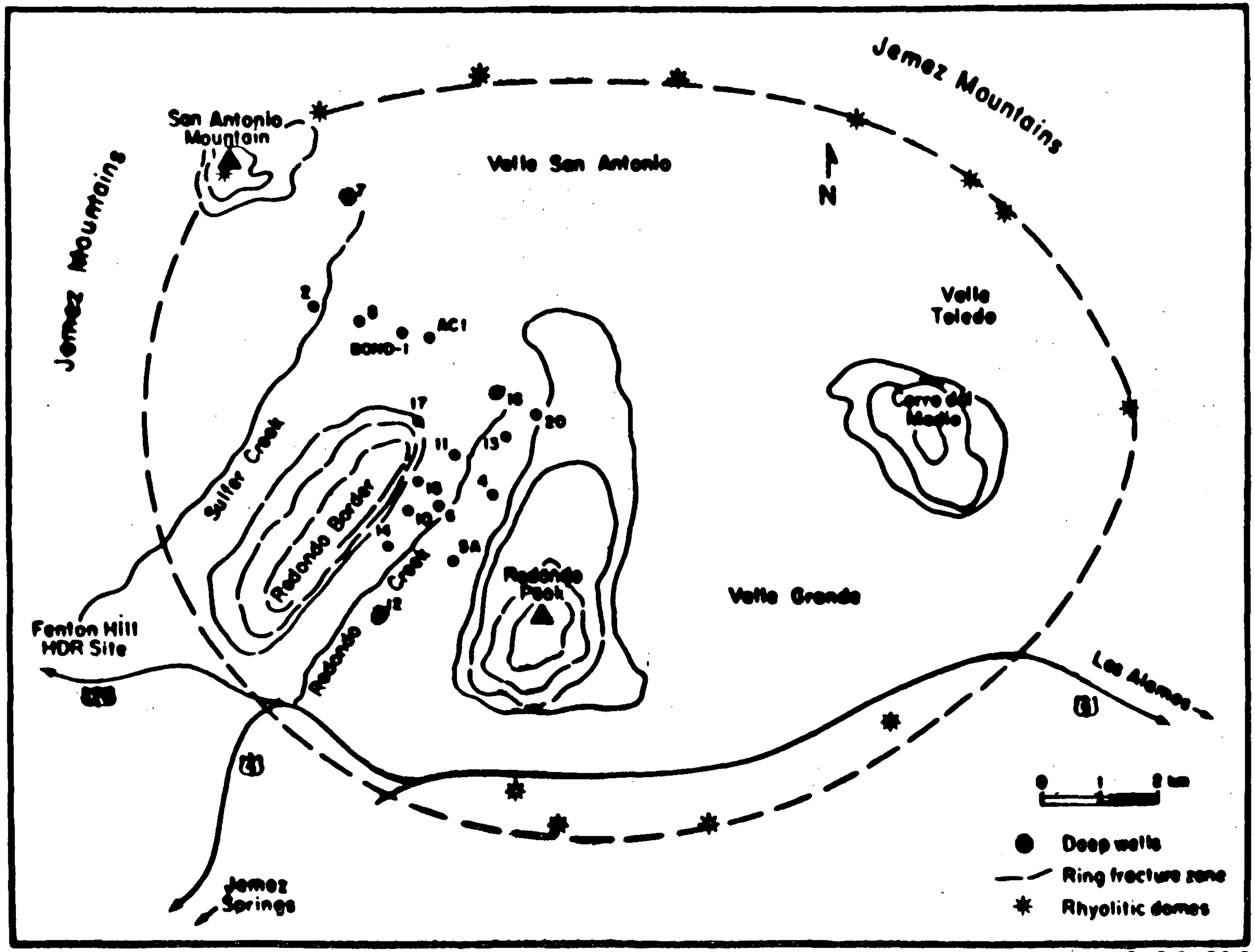
GENERALIZED STRATIGRAPHIC SECTION
VALLES CALDERA
after U.S.G.S. MAP I-571



COMPOSITE STRATIGRAPHIC SECTION
REDONDO CREEK WELLS

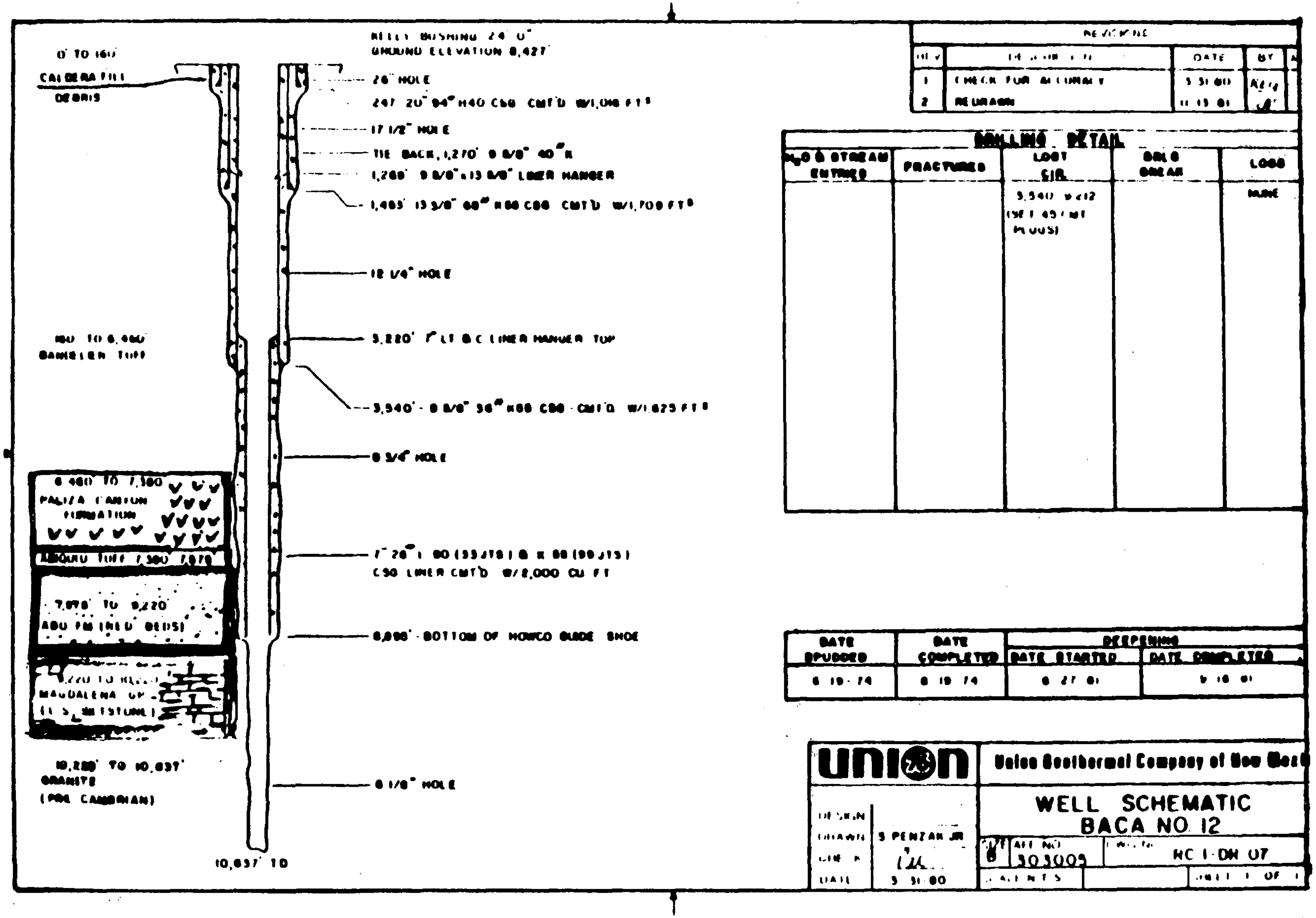


MAP SYMBOL		DESCRIPTION	APPARENT VERTICAL THICKNESS-FT.
Qcf	Qcf 2	CALDERA FILL: LANDSLIDE DEPOSITS, COARSE BRECCIA, GRAVEL, CLAY	0 - 500
	Qvrc	REDONDO CREEK RHYOLITE: RHYOLITE FLOWS. BIOTITIC, AMYGDULAR, Qtz -FREE	0 - 500
	Qcf 1		
Qb		BANDELIER TUFF: WELDED RHYOLITE ASH FLOWS	4200-6300
	QbA	ZONE A: VERY DENSELY WELDED NO APPARENT PUMICE	3700 - 4750
	QbB	ZONE B: MODERATELY TO DENSELY WELDED. HIGHLY VARIABLE TEXTURE. PUMICE EVIDENT	300 - 750
	QbC	ZONE C: BASAL PUMICE. NON-WELDED.	0 - 120
Tp		PALIZA CANYON FM: ANDESITE FLOWS. MINOR AMOUNTS DACITE, TUFFS	300 - 2400
Tsf		SANTA FE GP: SANDSTONE. Poorly consolidated, very fine, occasionally tuffaceous. Includes Abiquiu tuff ? (Tab ?)	0 - 500
Pa		ABO FM: RED BEDS. CONSOLIDATED FINE CALCAREOUS SANDSTONE AND SILTSTONE	1600 ±
IPm		MAGDALENA GP: LIMESTONE, SAND AND SHALE PARTINGS. OCCASIONALLY FOSSILIFEROUS	1000 ±
p€		GRANITE: MEDIUM GRAINED. SUBHEDRAL. MINOR BIOTITE	



XBL 812-2618

Map of Valles Caldera with Baca well locations identified.



Well Schematic for Baca well 12.

WELL BACA 22 REDRILL 2

MARKER NAME	DEPTH TO MARKER TOP			APPARENT VERTICAL THICKNESS	HORIZONTAL CO-ORDINATES FROM SURFACE LOCATION
	MEASURED	VERTICAL	SUBSEA		
REDONDO CR. RHYOLITE	0	0	9270	236	
CALDERA FILL	260	260	9034	360	1N 1W
BANDELIER TUFF	620	620	8674	4649	6N 0E
PALIZA CANYON FM	5280	5269	4025	724	103S 226E
TD	6006	5994	3300		61S 253E

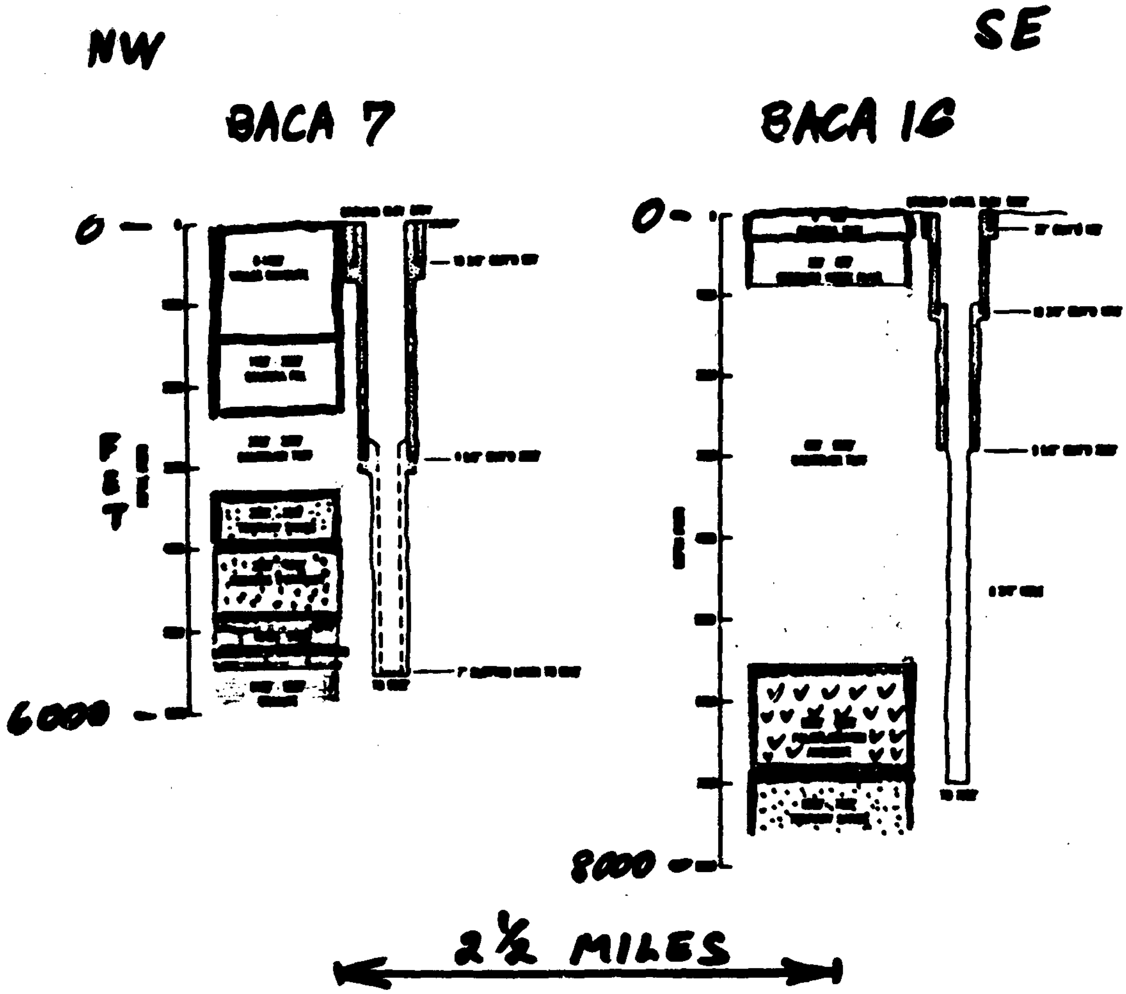
WELL BACA 22 REDRILL 3

MARKER NAME	DEPTH TO MARKER TOP			APPARENT VERTICAL THICKNESS	HORIZONTAL CO-ORDINATES FROM SURFACE LOCATION
	MEASURED	VERTICAL	SUBSEA		
REDONDO CR. RHYOLITE	0	0	9270	236	
CALDERA FILL	260	260	9034	360	1N 1W
BANDELIER TUFF					
ZONE A	620	620	8674	3908	6N 0E
ZONE B	4540	4528	4766	759	136S 93E
ZONE C	5300	5286	4008	97	186S 95E
TOTAL BANDELIER				4764	
PALIZA CANYON FM	5397	5383	3911	1362	187S 94E
ABIQUIU TUFF?	6760	6745	2549	239	158S 59E
SANTA FE Gp	7000	6984	2310	647	148S 43E
ABO FM	7650	7632	1662	965	113S 2W
MAGDALENA Gp	8620	8597	697	225	53S 73W
TD	8846	8822	472		39S 89W

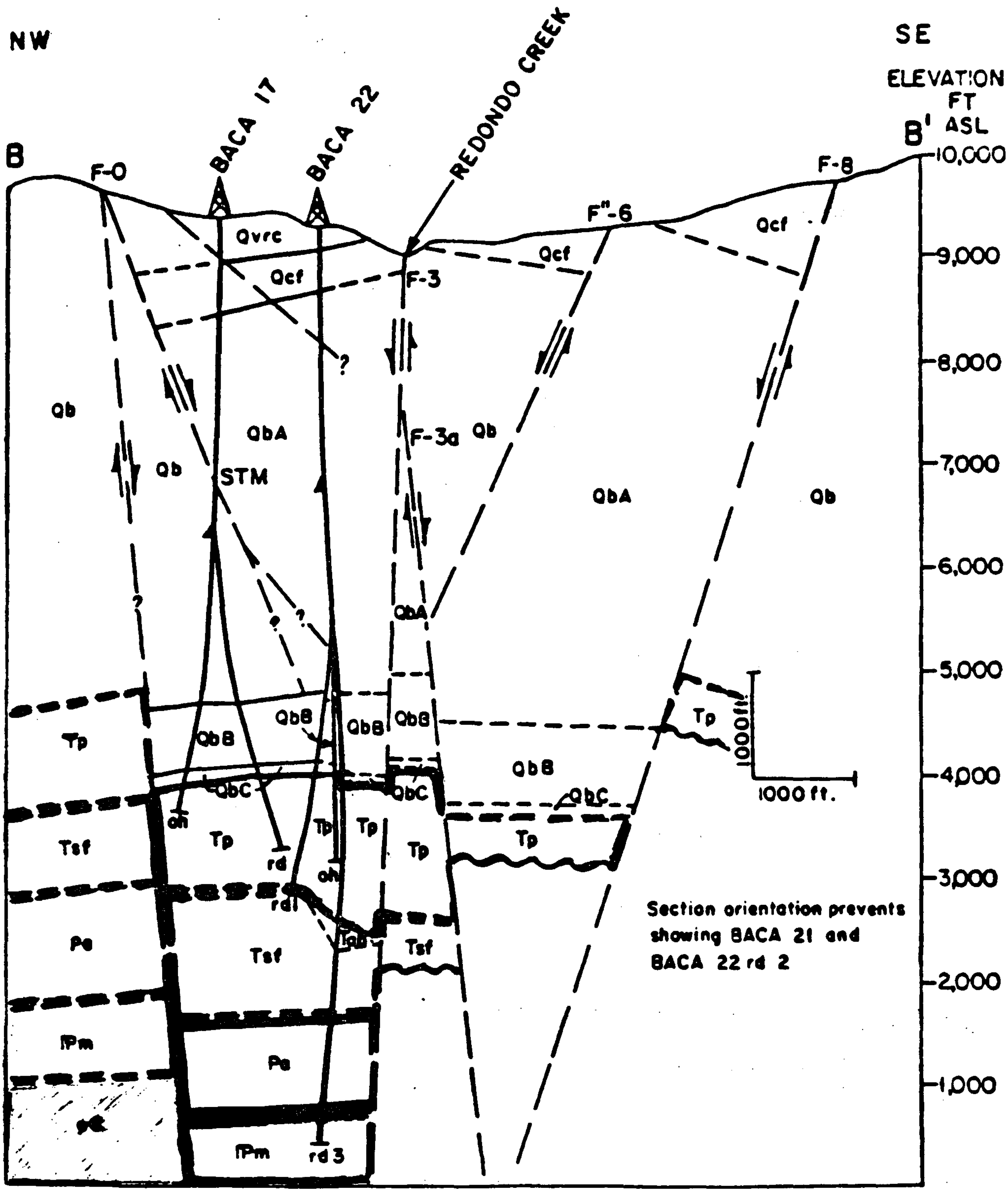
ALL DEPTHS, THICKNESSES AND DISTANCES IN FEET

ALL THICKNESSES CALCULATED FROM DIRECTIONAL DATA

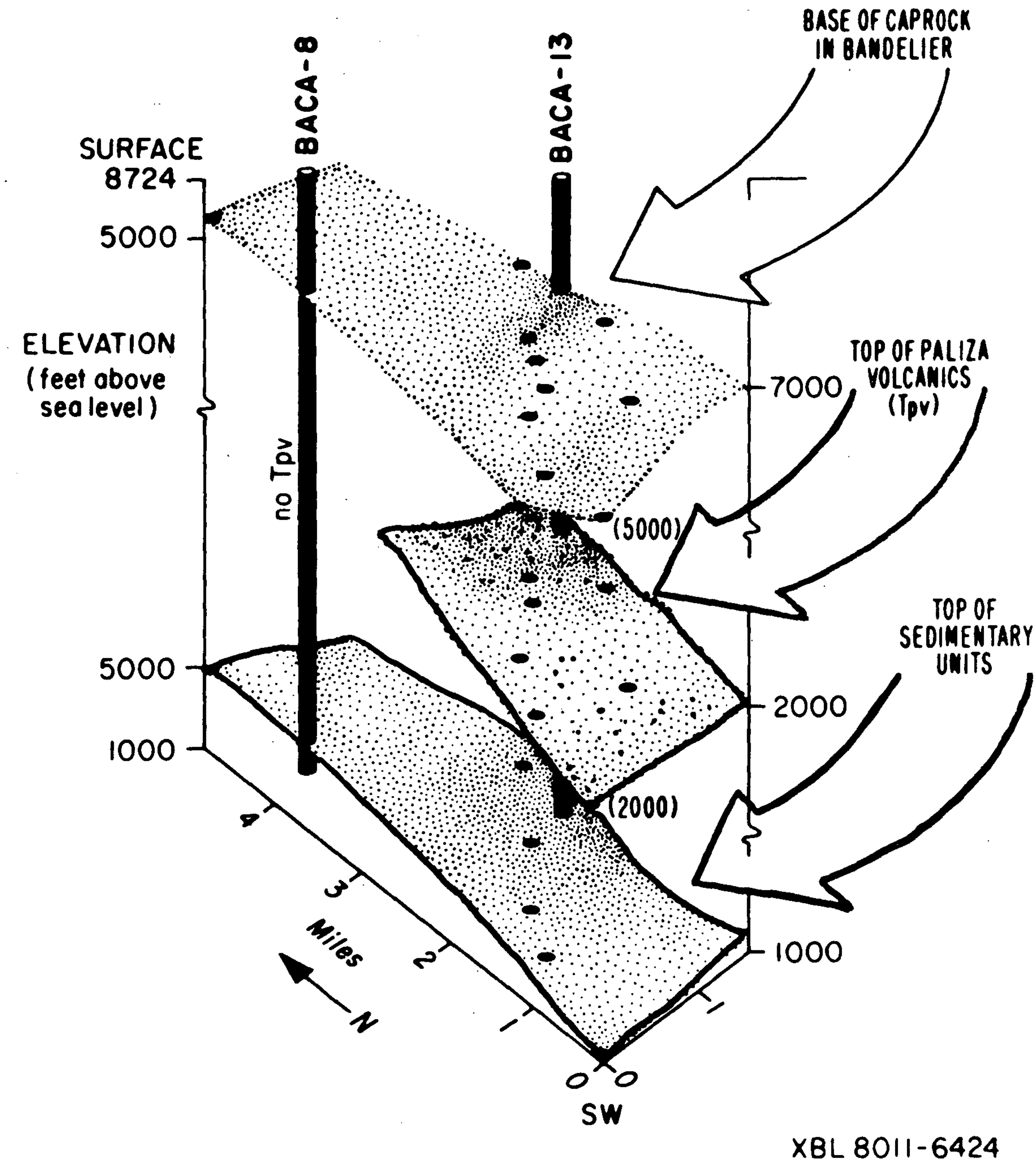
Stratigraphic data for Baca-22, second and third redrills.



Stratigraphic sections for Baca well 7 in the Sulfur Creek area and Baca well 16 in the Redondo Creek area.



Northwest-Southeast cross-section of Baca wells 17 and 22 and vicinity.



Three stratigraphic horizons in the Baca field.

CONCLUSIONS

1. Stratigraphy is relatively uniform.
    a. Some units of $\leq$ 1000 ft thickness missing over horizontal distances of 2 to 5 miles.
    b. Lithologic variability within units over 1 mile.

2. Steeply dipping faults common -- vertical offsets of ~1500 ft.

3. Deepest well penetration 10,600 ft. in B-12; 420 ft into Precambrian granite.

4. Data base: Complete and excellent for stratigraphic/ lithologic picks.
    a. Refinements in progress.
    b. Data highly accessible.

BACA DATA:

STRUCTURE AND PERMEABILITY

DENNIS L. NIELSON

UNIVERSITY OF UTAH RESEARCH INSTITUTE

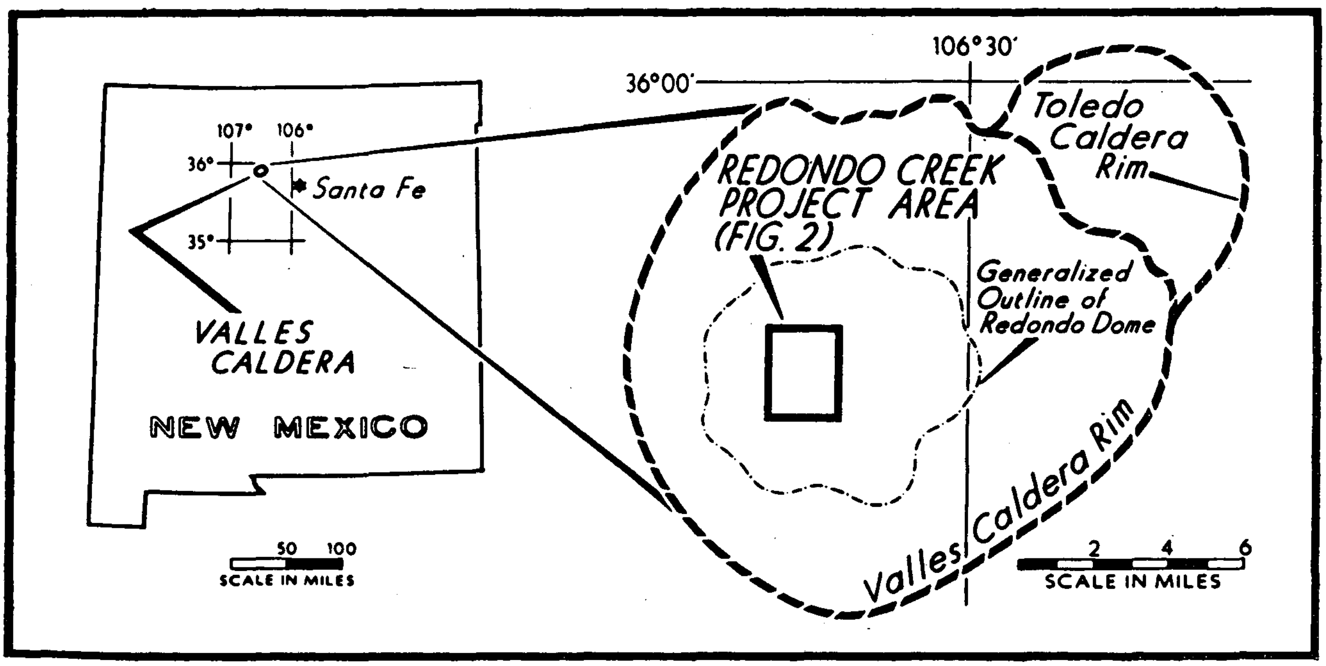


Figure 1. Location map showing position of the Baca geothermal system, Redondo Creek project area, in the Valles Caldera, New Mexico.

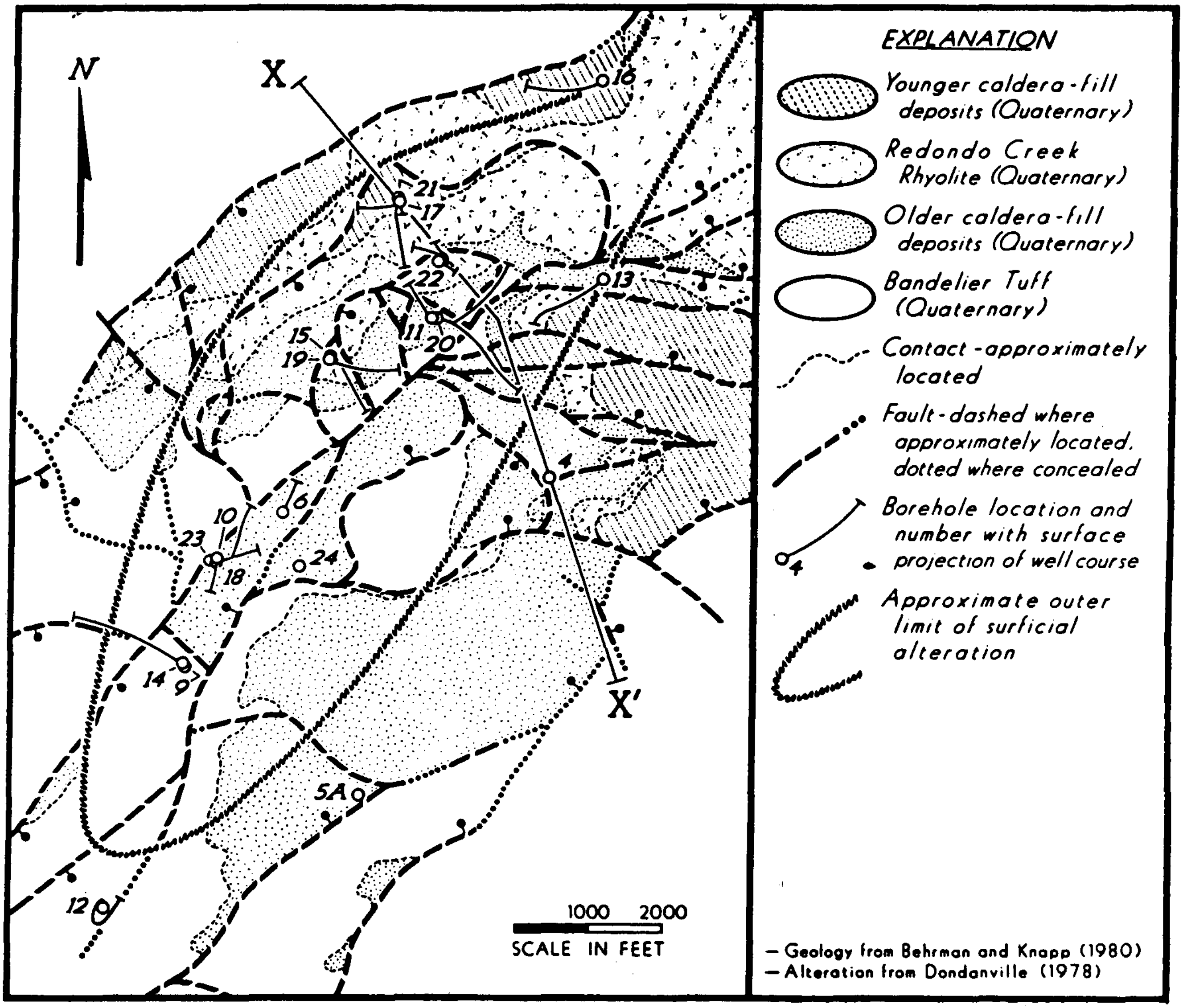


Figure 2. Geologic map of the Redondo Creek project area, Valles Caldera, New Mexico.

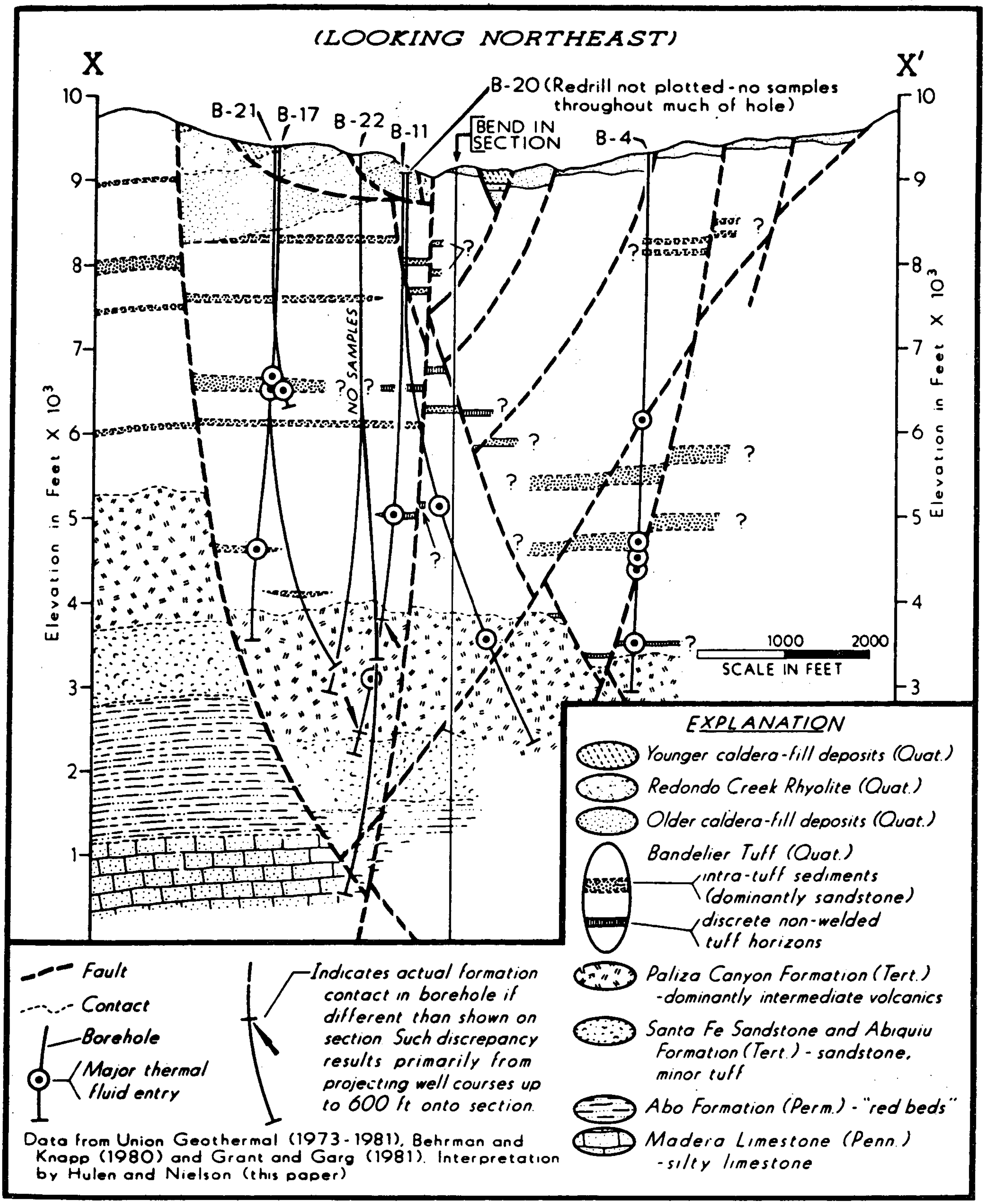


Figure 3. Geologic section through the Redondo Creek project area, Valles Caldera, New Mexico.

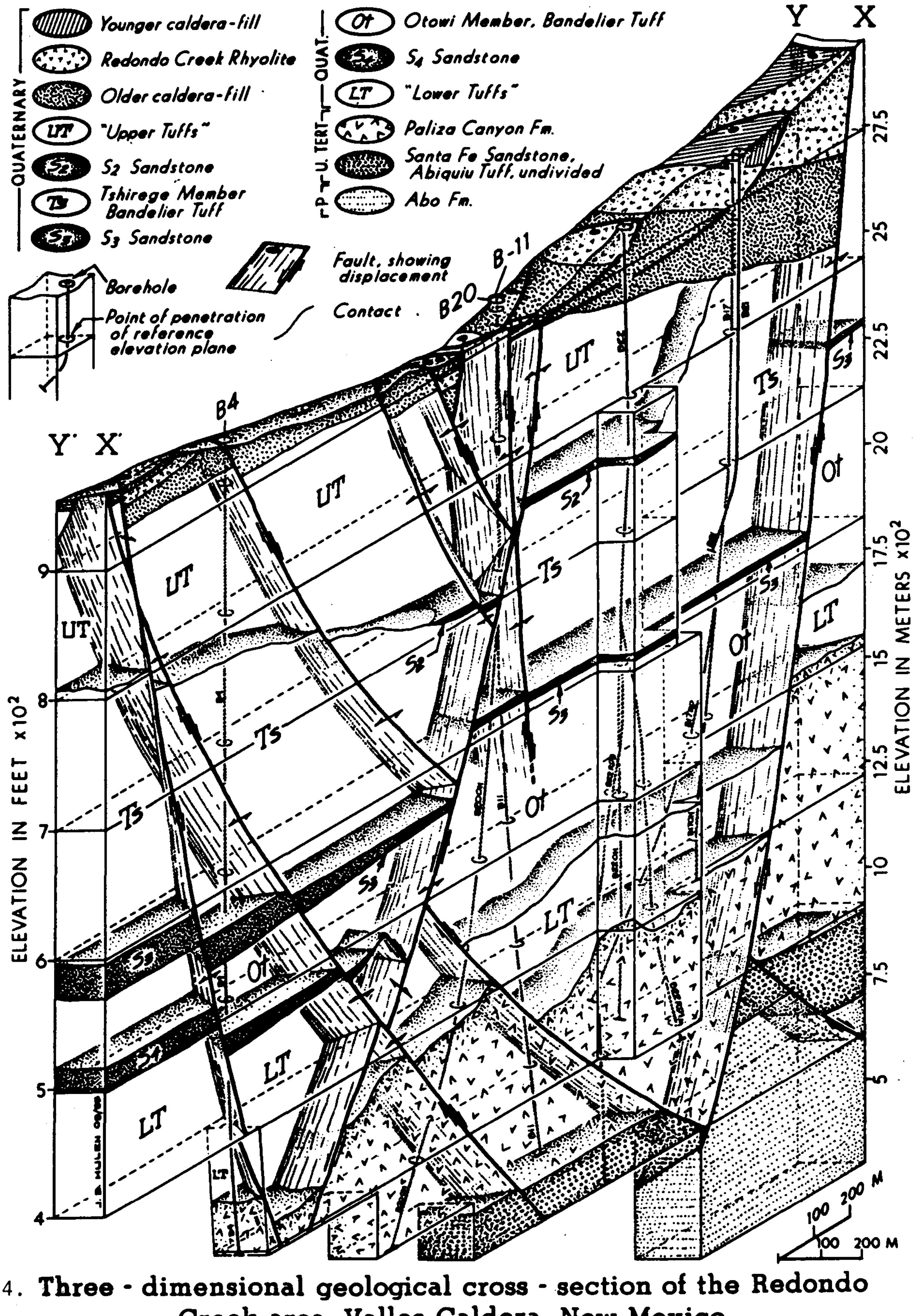


Figure 4. **Three - dimensional geological cross - section of the Redondo Creek area, Valles Caldera, New Mexico**

BACA DATA:

WELL LOGGING

SUSAN E. HALFMAN

LAWRENCE BERKELEY LABORATORY

Well Logging

Log Suites

Well Log Holdings

paper logs
digitzed logs

Well Log Picks

Fracture Identification

Log Suites

Resistivity

Neutron-Density

Temperature

Dipmeter

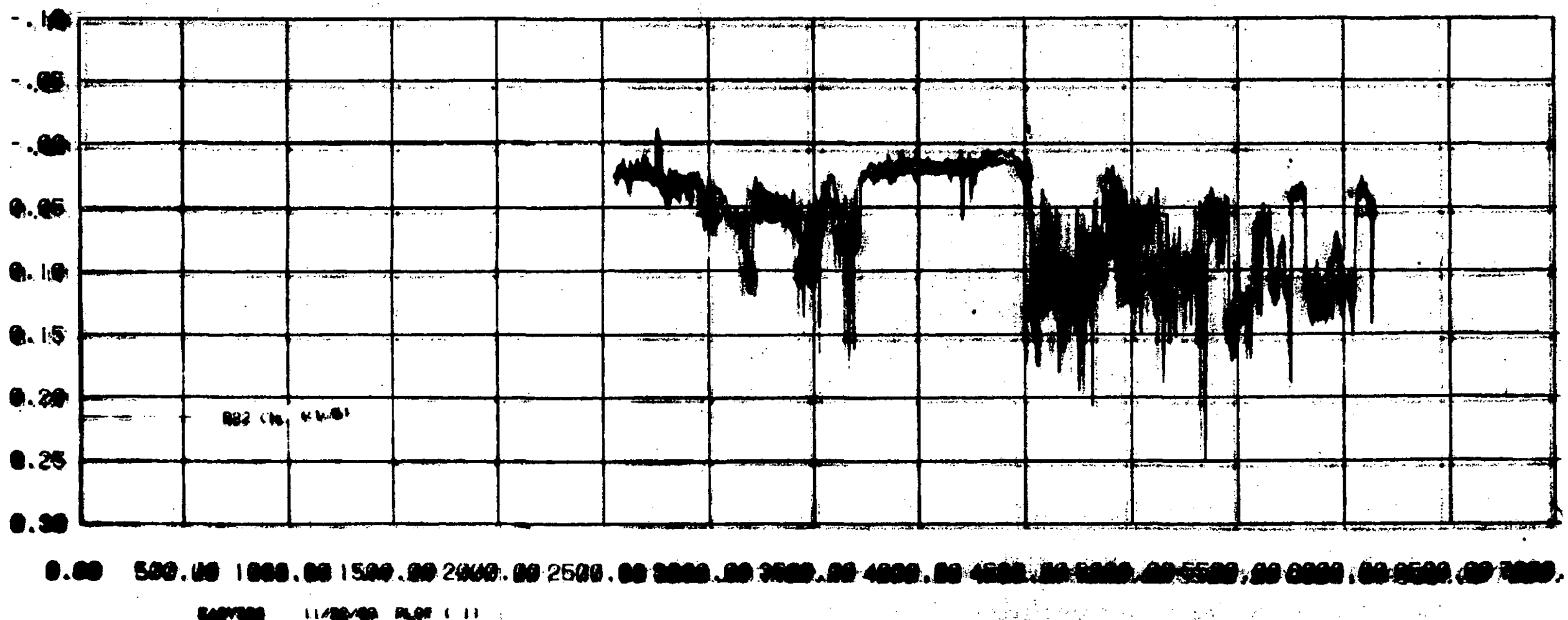
Sonic (optional)

	ALL8	BOND IND	BOND LOG	CABL SPD	CALI	CILD	CNL	DIFF THRM	FDC	GR	ITT	LL8	LLS
B4													
B5A													
B6													
B8													
B9													
B10			X							X			
B11													
B12													
B13				X	X	X	X	X		X	X	X	
B14					X		X			X			
B15													
B16													
B17	X	X			X	X				X		X	
B17 RD#1						X							
B18	X				X	X				X		X	
B18 RD#1													
B19						X				X	X		
B20					X		X	X		X	X		X
B20 RD#1					X				X	X			
B21					X	X	X		X	X			X
B22					X	X	X		X	X			X
B22 RD#1					X		X		X	X			
B22 RD#2													
B22 RD#3										X			X
B23					X	X	X		X	X			
B24										X			X

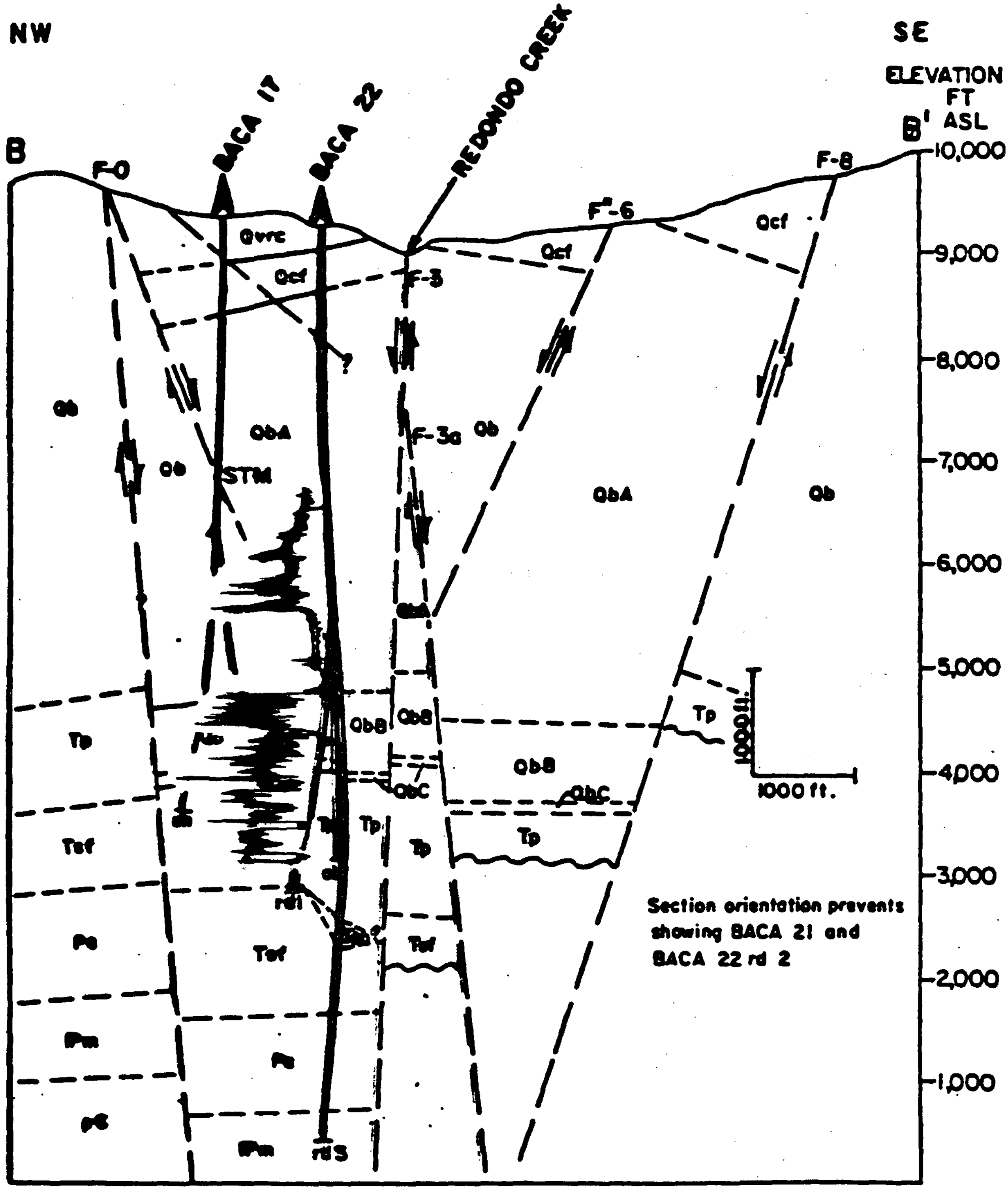
Well logs available for the different wells at Baca.

	LLD	RHOB	DEL RHOB	RIL	RILD	RILM	RLL18	SFL	SP	SPIN	TEMP	VDM	LITH	FIL
B4													X	
B5A													X	
B6													X	
B8													X	
B9													X	
B10											X		X	
B11													X	
B12											X		X	
B13		X	X		X	X	X		X	X	X	X	X	
B14											X		X	
B15													X	
B16													X	
B17					X	X			X		X	X	X	
B17 RD#1					X				X				X	
B18					X	X			X		X		X	X
B18 RD#1													X	
B19					X	X		X	X		X		X	
B20	X	X	X								X	X		X
B20 RD#1														X
B21	X	X	X		X	X		X	X				X	X
B22	X	X	X		X	X		X	X		X		X	X
B22 RD#1													X	
B22 RD#2		X	X										X	
B22 RD#3	X												X	
B23		X	X		X	X		X	X				X	X
B24	X										X		X	

Well logs available for the different wells at Baca.

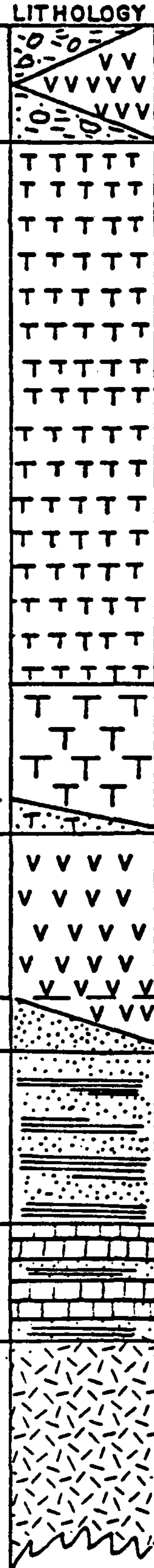


Example of a computer plot of a digitized well log.



A digitized neutron log superimposed on geologic cross-section B-B'.

COMPOSITE STRATIGRAPHIC SECTION
REDONDO CREEK WELLS



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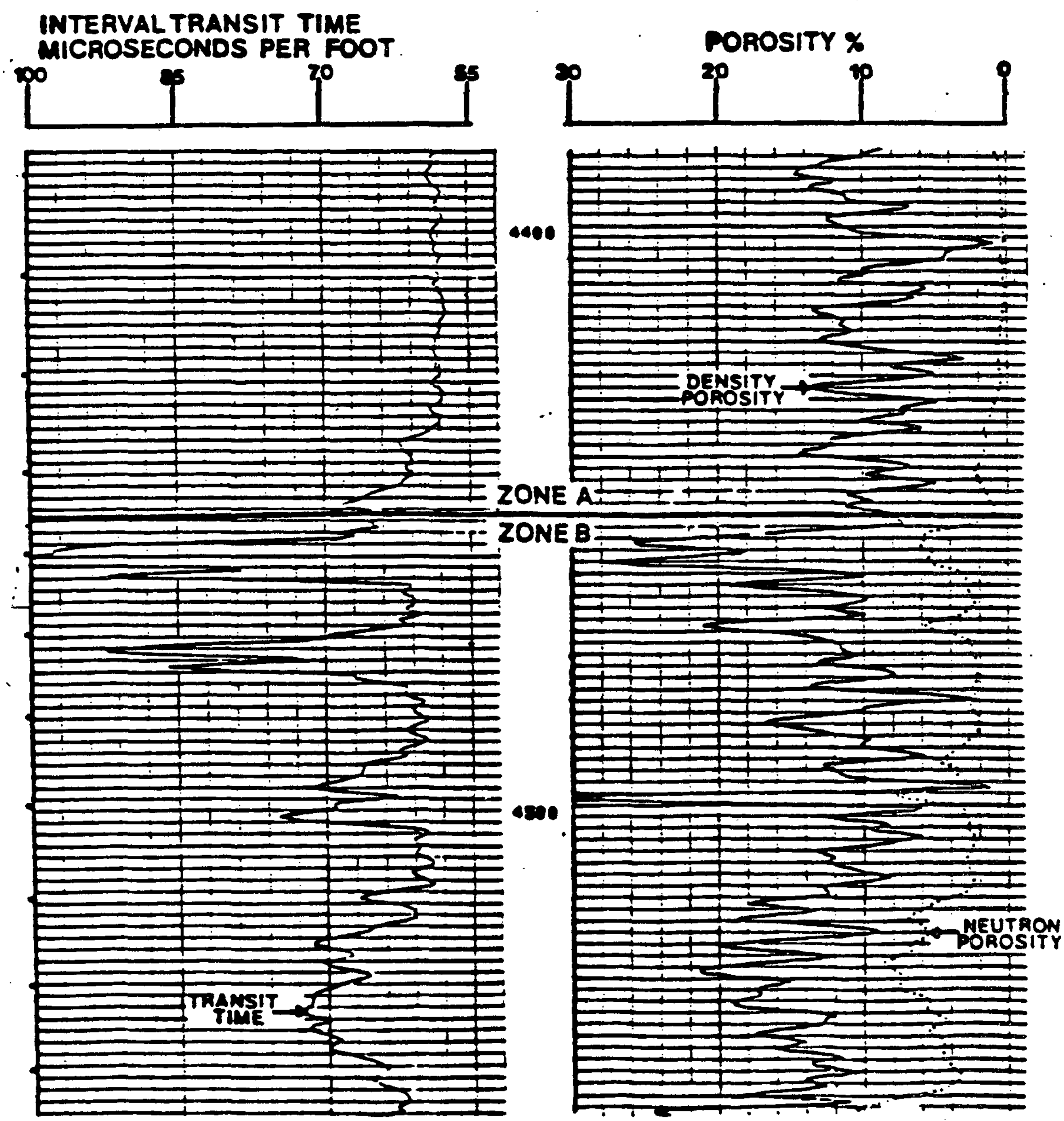
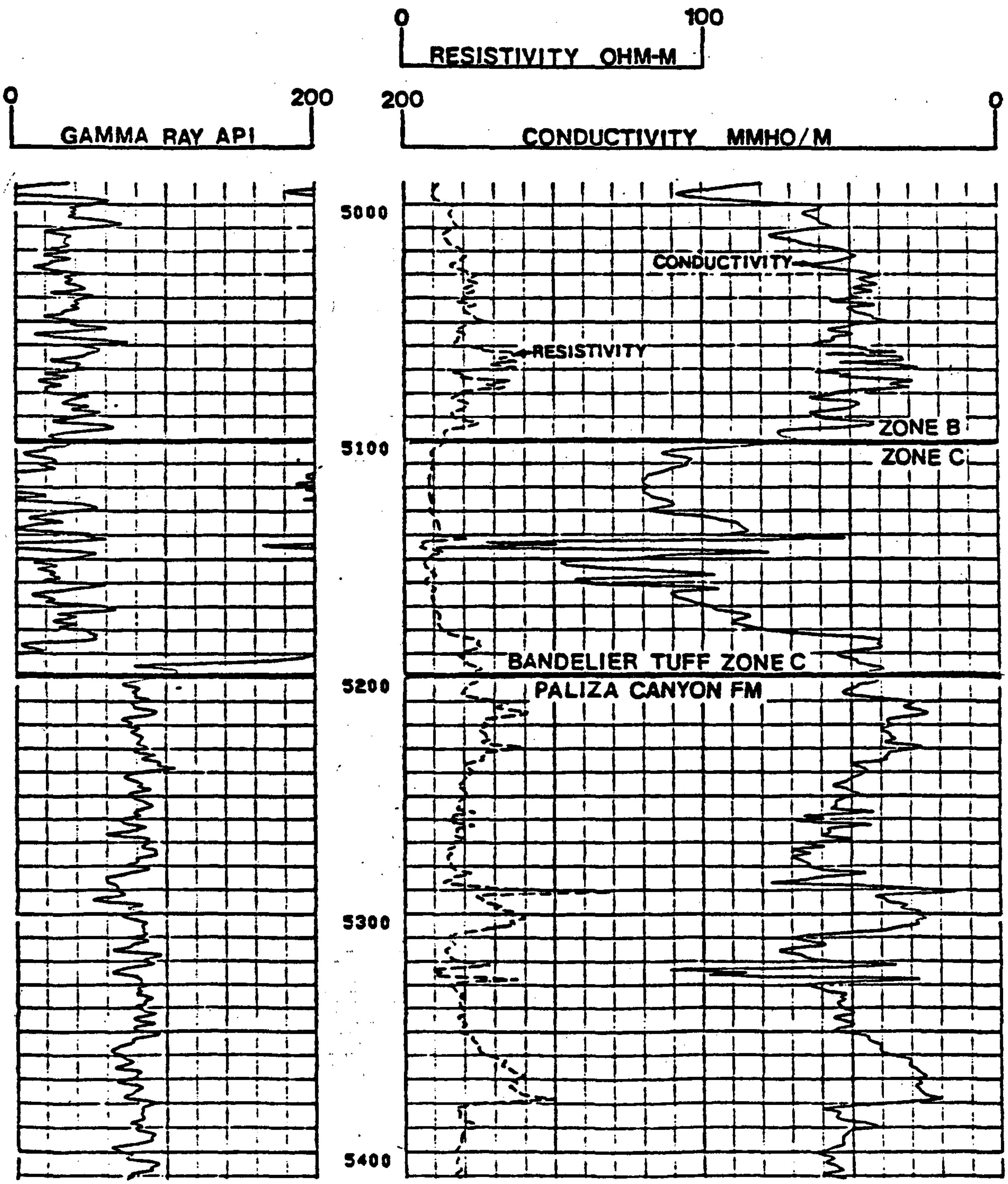
	Qcf I		
Qb		BANDELIER TUFF: WELDED RHYOLITE ASH FLOWS	4200-6300
	Qb A	ZONE A: VERY DENSELY WELDED NO APPARENT PUMICE	3700 - 4750
	QbB	ZONE B: MODERATELY TO DENSELY WELDED. HIGHLY VARIABLE TEXTURE. PUMICE EVIDENT	300 - 750
	QbC	ZONE C: BASAL PUMICE. NON-WELDED.	0 - 120
Tp		PALIZA CANYON FM: ANDESITE FLOWS. MINOR AMOUNTS DACITE, TUFFS	300 - 2400
Tsf		SANTA FE GP: SANDSTONE. Poorly consolidated, very fine, occasionally tuffaceous. Includes Abiquiu Tuff ? (Tab ?)	0 - 500
Pa		ABO FM: RED BEDS. CONSOLIDATED FINE CALCAREOUS SANDSTONE AND SILTSTONE	1600 ±
IPm		MAGDALENA GP: LIMESTONE, SAND AND SHALE PARTINGS. OCCASIONALLY FOSSILIFEROUS	1000 ±
p€		GRANITE: MEDIUM GRAINED, SUBHEDRAL. MINOR BIOTITE	

SONIC AND POROSITY LOG RESPONSES TO BANDELIER TUFF ZONES A AND B BACA 20 REDRILL

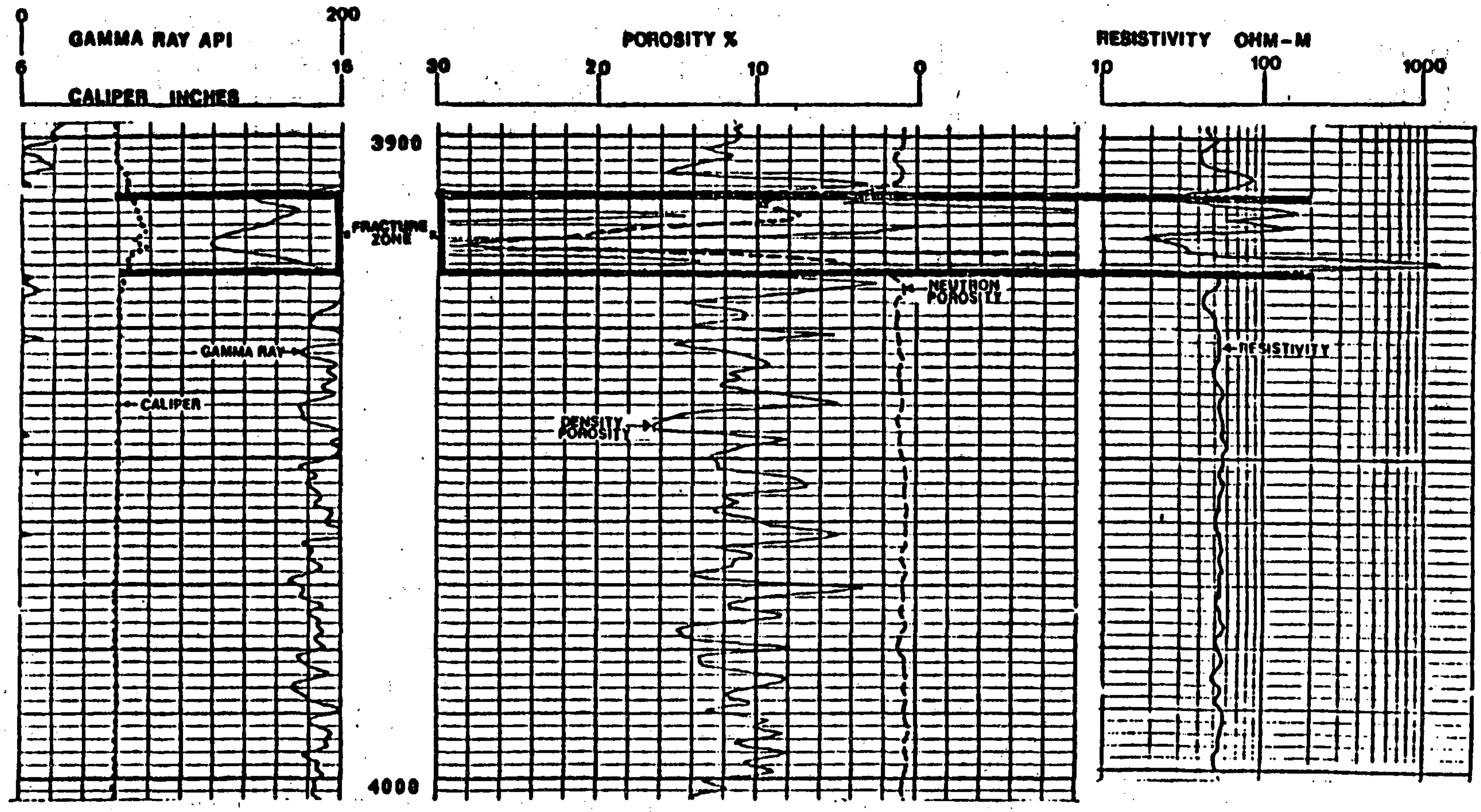


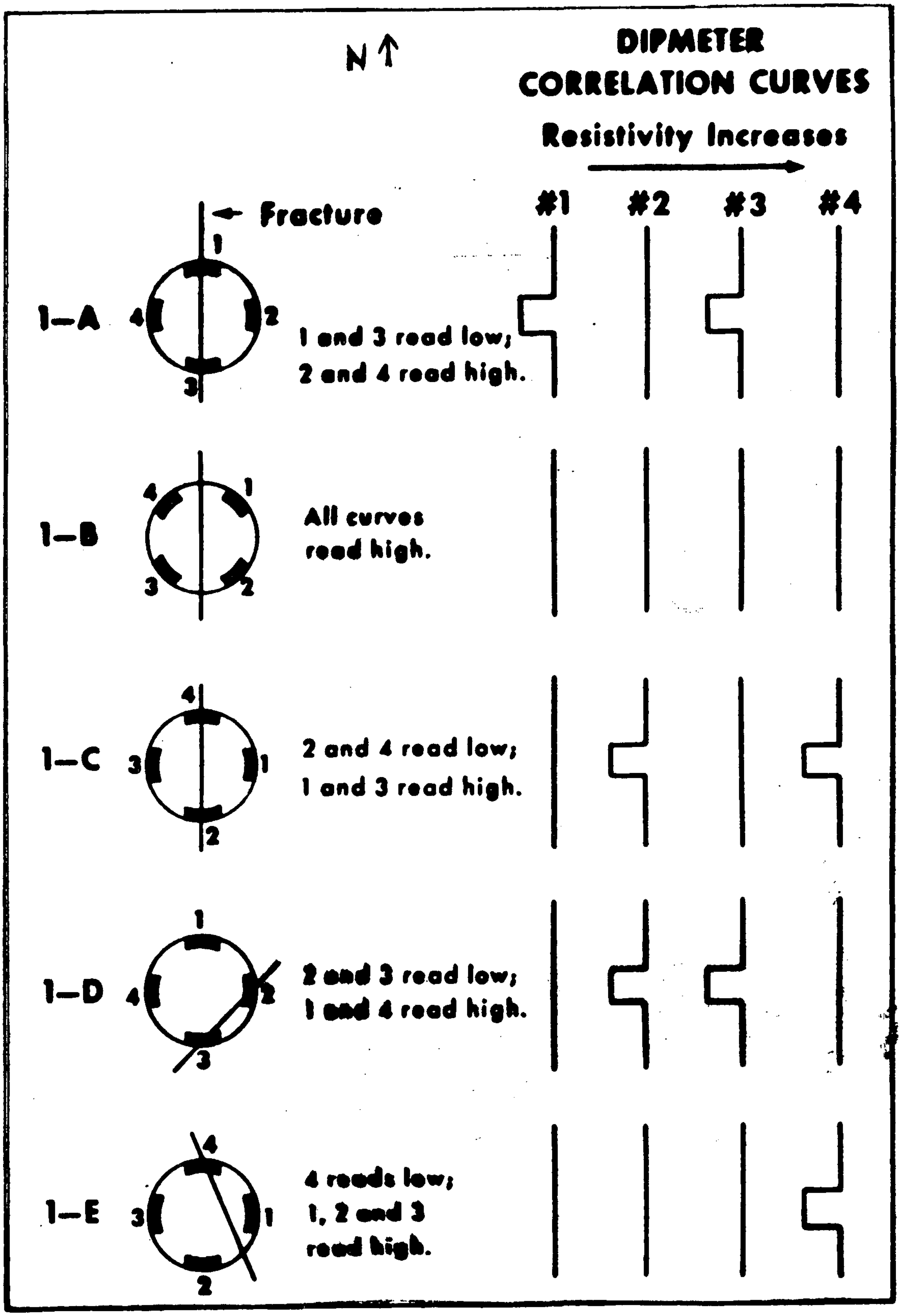
RESISTIVITY LOG RESPONSE TO
BANDELIER TUFF ZONES B AND C AND PALIZA CANYON FM
BACA 20 REDRILL



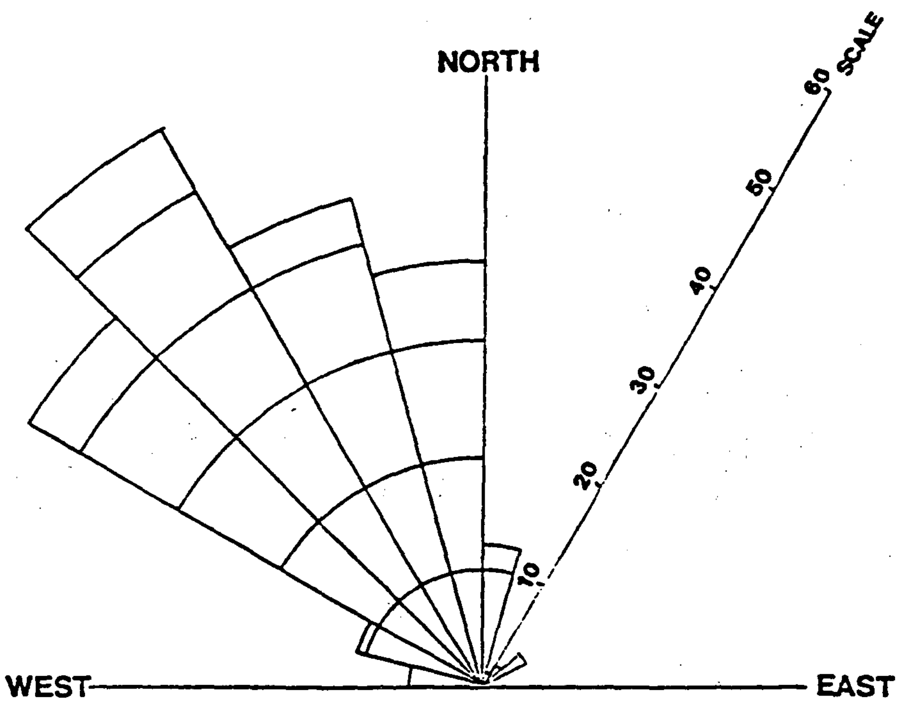
LOG RESPONSES TO FRACTURE ZONE

BACA 20 REDRILL





Responses of High-Resolution-Dipmeter correlation curves to vertical fractures (schematic).



FRACTURE STRIKES
ALL WELLS

Number of Fractures	220
Mean Direction	N31W
Std Dev.	27 deg

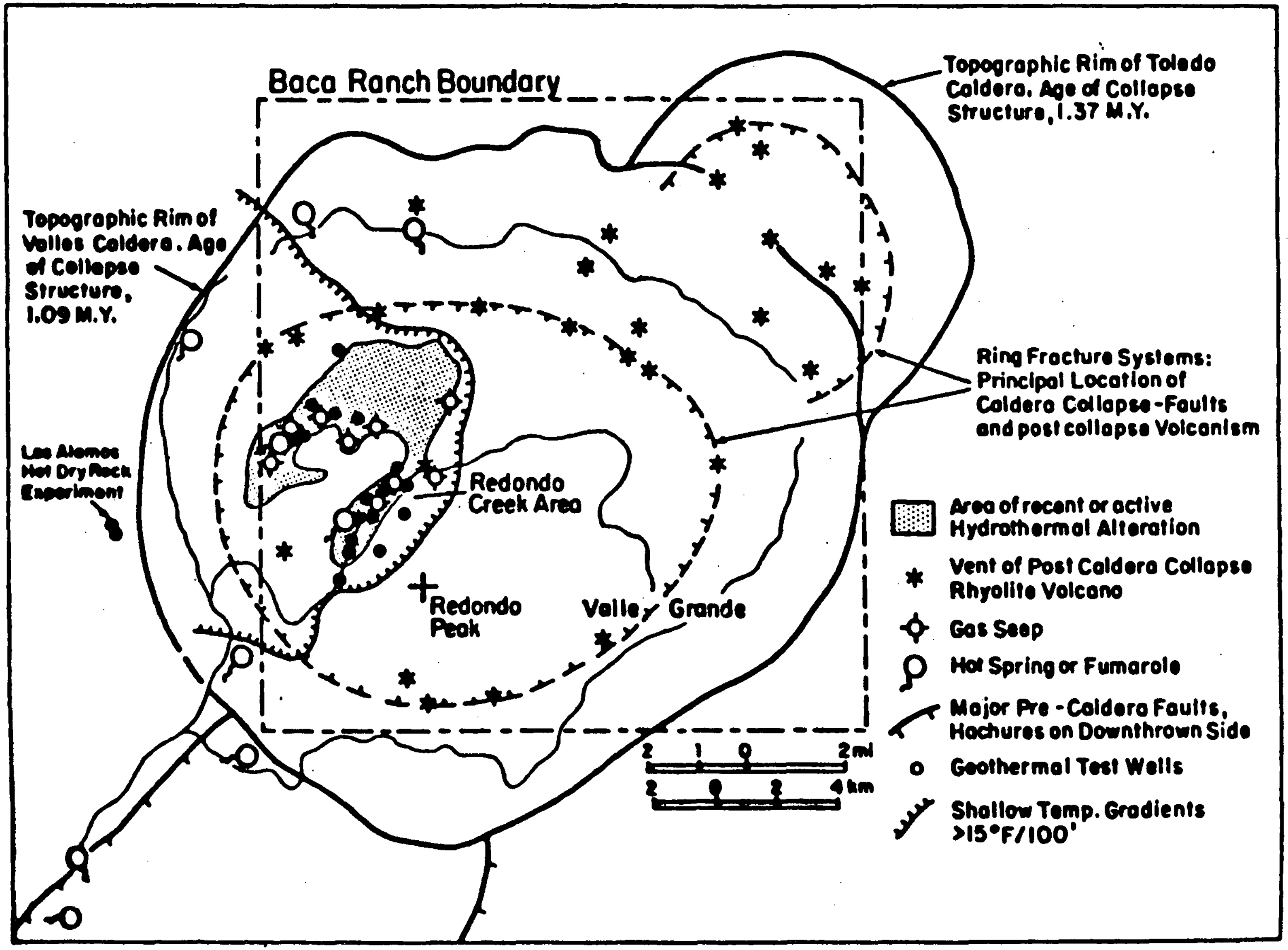
The mean direction of fractures at Baca.

BACA DATA:

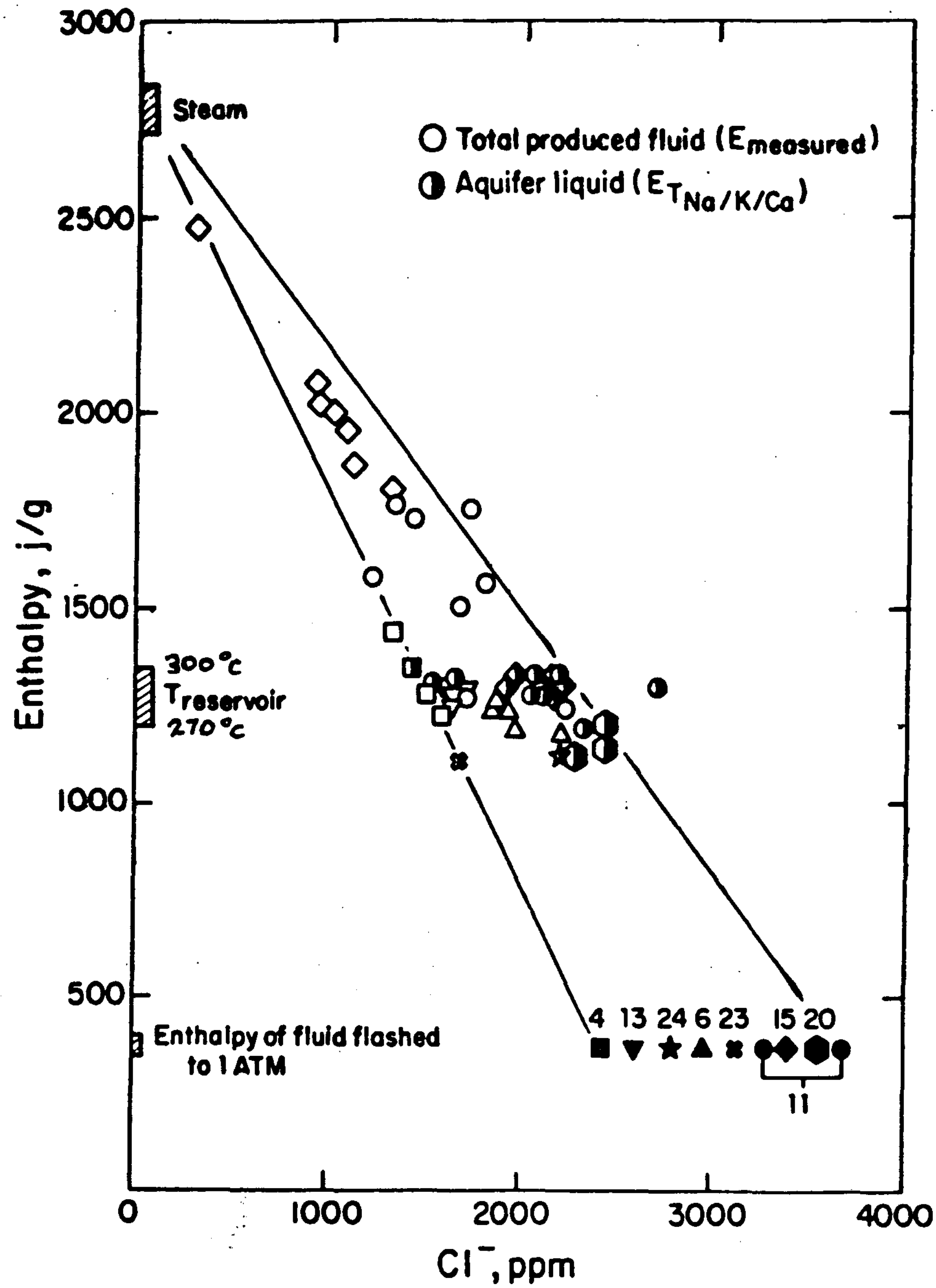
GEOCHEMISTRY

ALFRED H. TRUESDELL

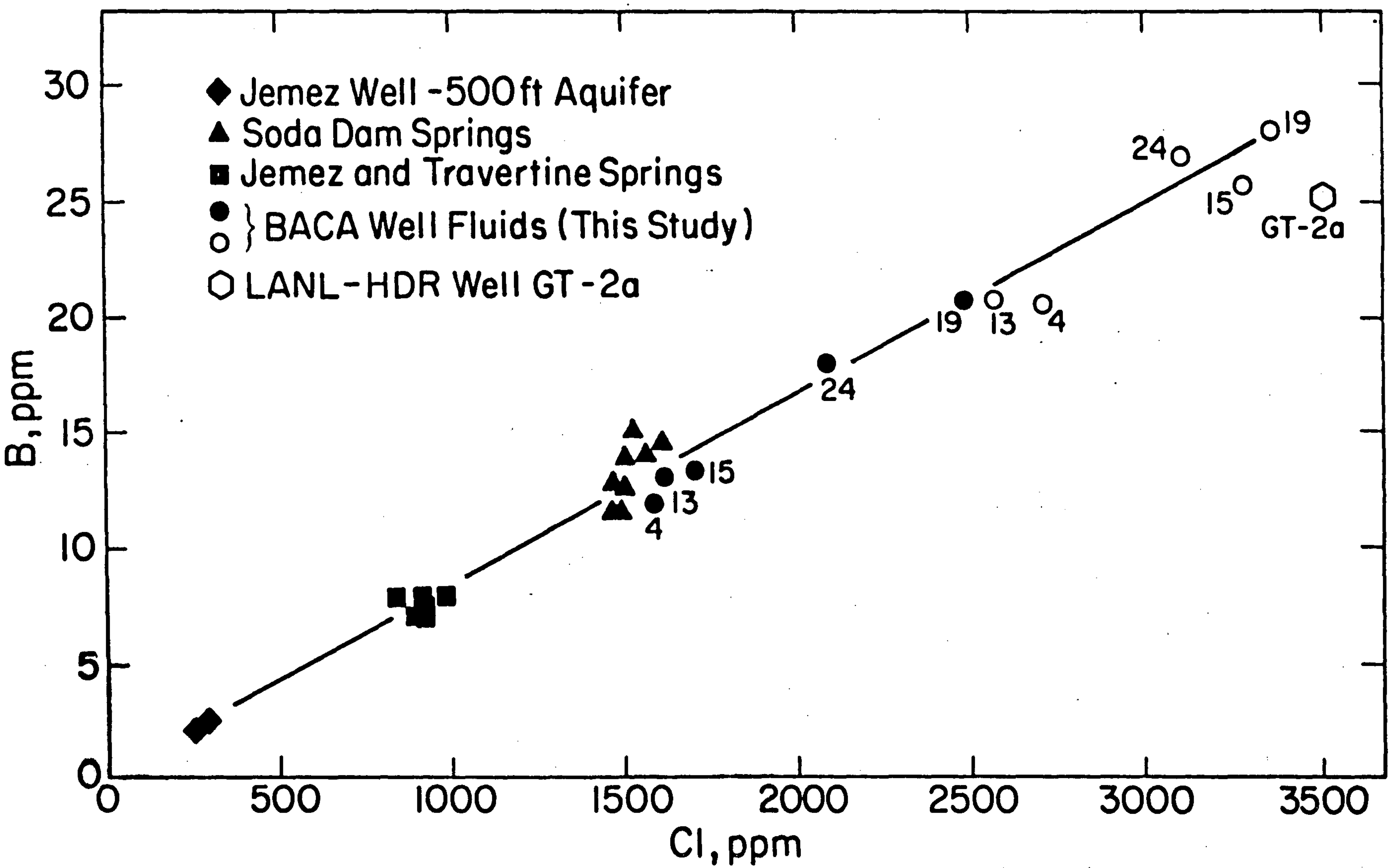
U.S. GEOLOGICAL SURVEY, MENLO PARK



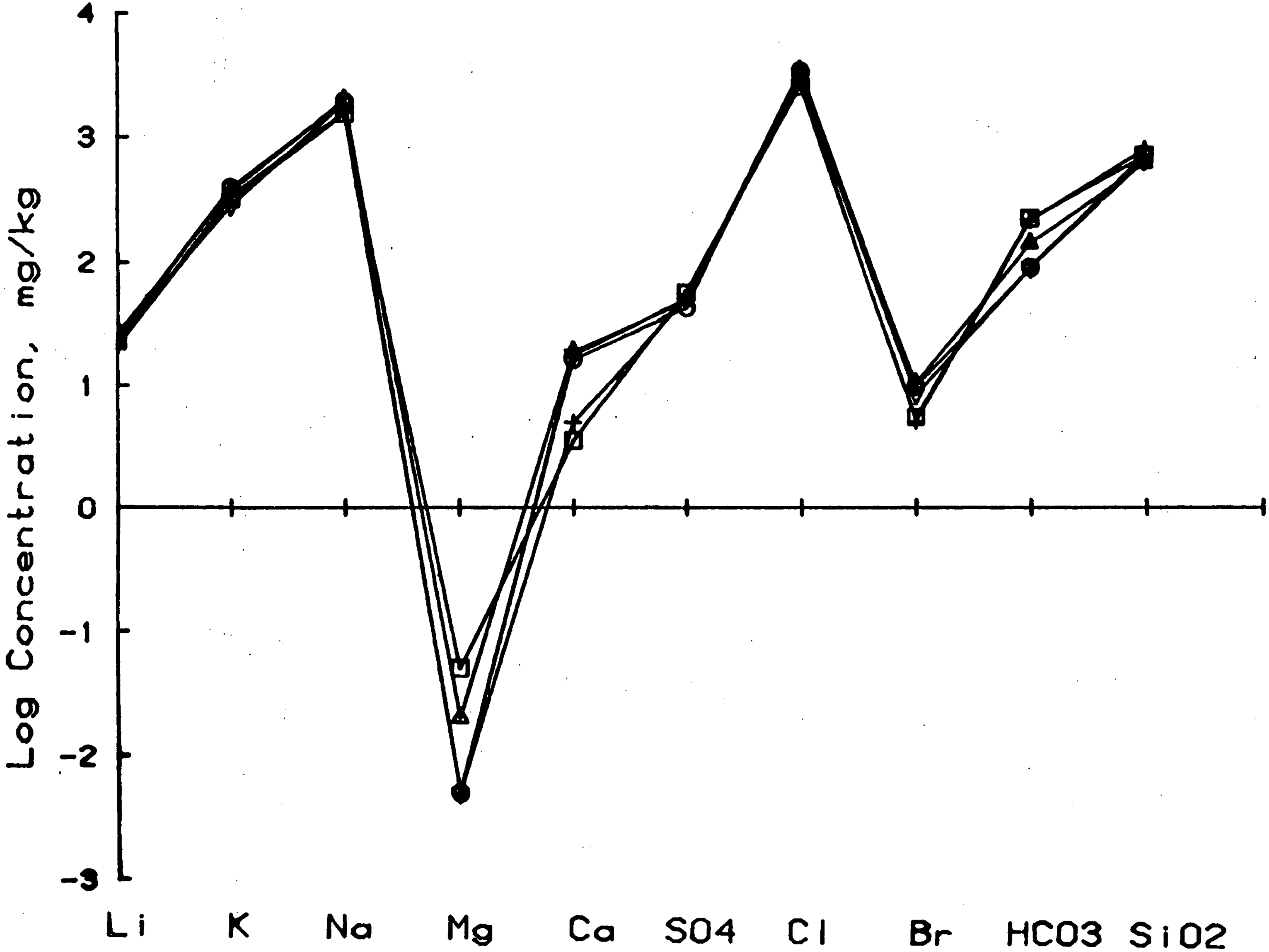
1. Map showing the Baca location in the Valles Caldera.



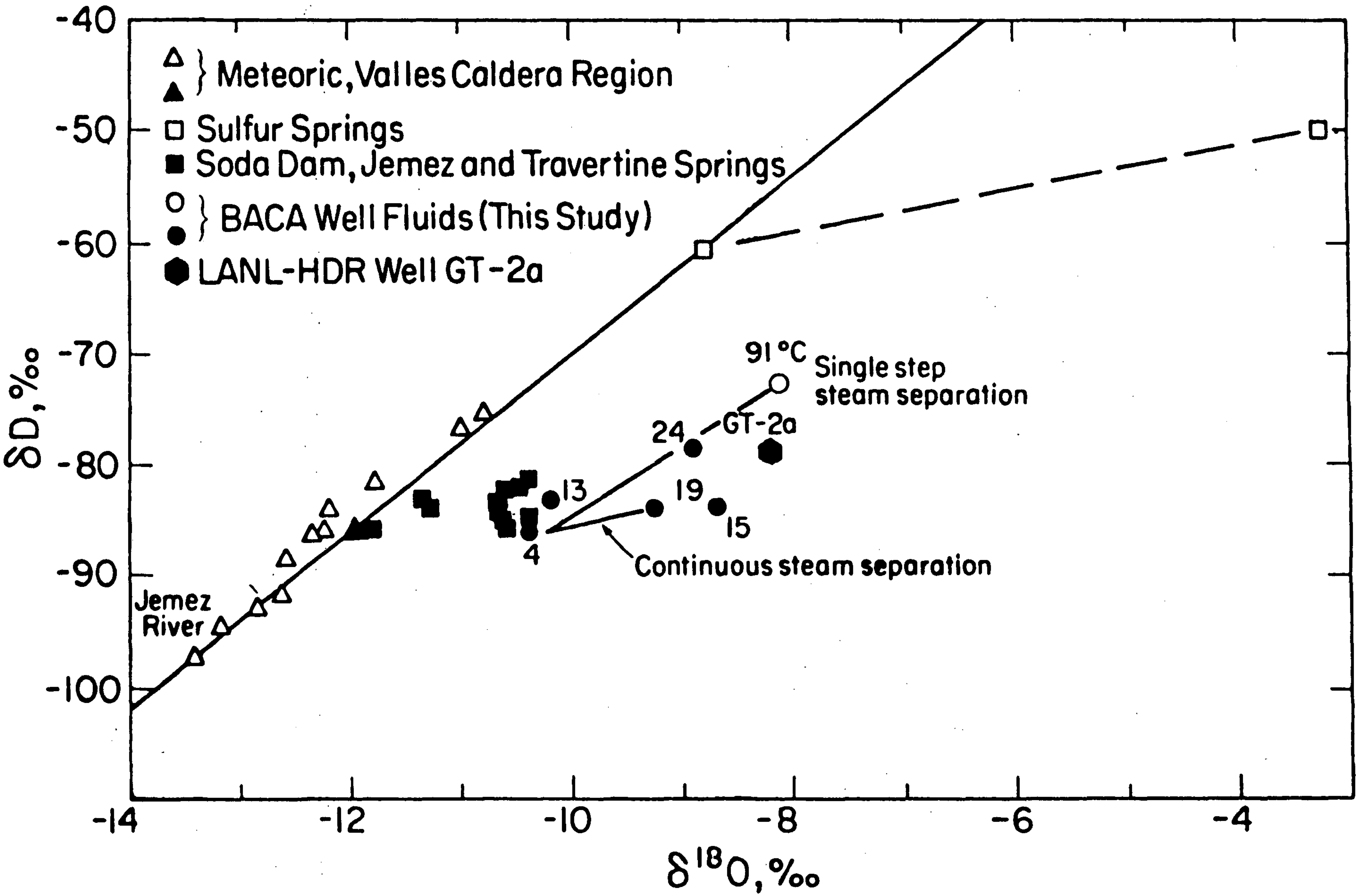
2. Enthalpy-chloride plot of steam from production wells in the Redondo Creek area. The variation in chloride content for wells 4, 6, 11, 13, 15, 20, 23, and 24 is shown by the solid symbols with an enthalpy value of ~400j/g for a fluid flashed to one atmosphere at an elevation of ~9000 feet. Aquifer chloride values (half-shaded symbols) were completed using the reservoir temperature ($T_{Na/K/Ca}$), and the total produced fluid values (open symbols) are shown plotted on a dilution trend toward pure steam.



3. Boron-chloride mixing line for certain Baca wells and for other waters in the Valles Caldera region.



4. Schoeller diagram of log concentrations (mg/kg) of some ions for certain Baca wells.



5. Deuterium-oxygen-18 isotope line for certain Baca wells and for other waters in the Valles Caldera region.

Well	4	13	15	19	24
T silica	282	272	274	251	265
T Na-Li	301	318	298	304	297
T Na-K	288	286	281	267	236
T NaKCa	300	303	285	276	259
T SO4-H2O	301	283	298	281	291
T enthalpy	297	279	323	227	261
T measured	>260	278	>260	-	>260
Cl aquifer	2090	1940	2590	2500	2470

6. Table of geothermometers for Baca wells 4, 13, 15, 19, and 24 with measured temperatures and chloride concentrations.

GAS ISOTOPES

	$F\ ^{22}NE$	$F\ ^{84}KR$	$F\ ^{132}XE$	R/RA
BACA 4	0.708	1.352	2.042	3.99
BACA 13	0.488	1.696	3.457	4.77
BACA 15	1.172	0.872	0.949	4.22
BACA 24	0.850	1.409	2.239	3.95

$$FI = (I/^{36}AR)_{SAMPLE}/(I/^{36}AR)_{AIR}$$

$$R/RA = (^{3}HE/^{4}HE)_{SAMPLE}/(^{3}HE/^{4}HE)_{AIR}$$

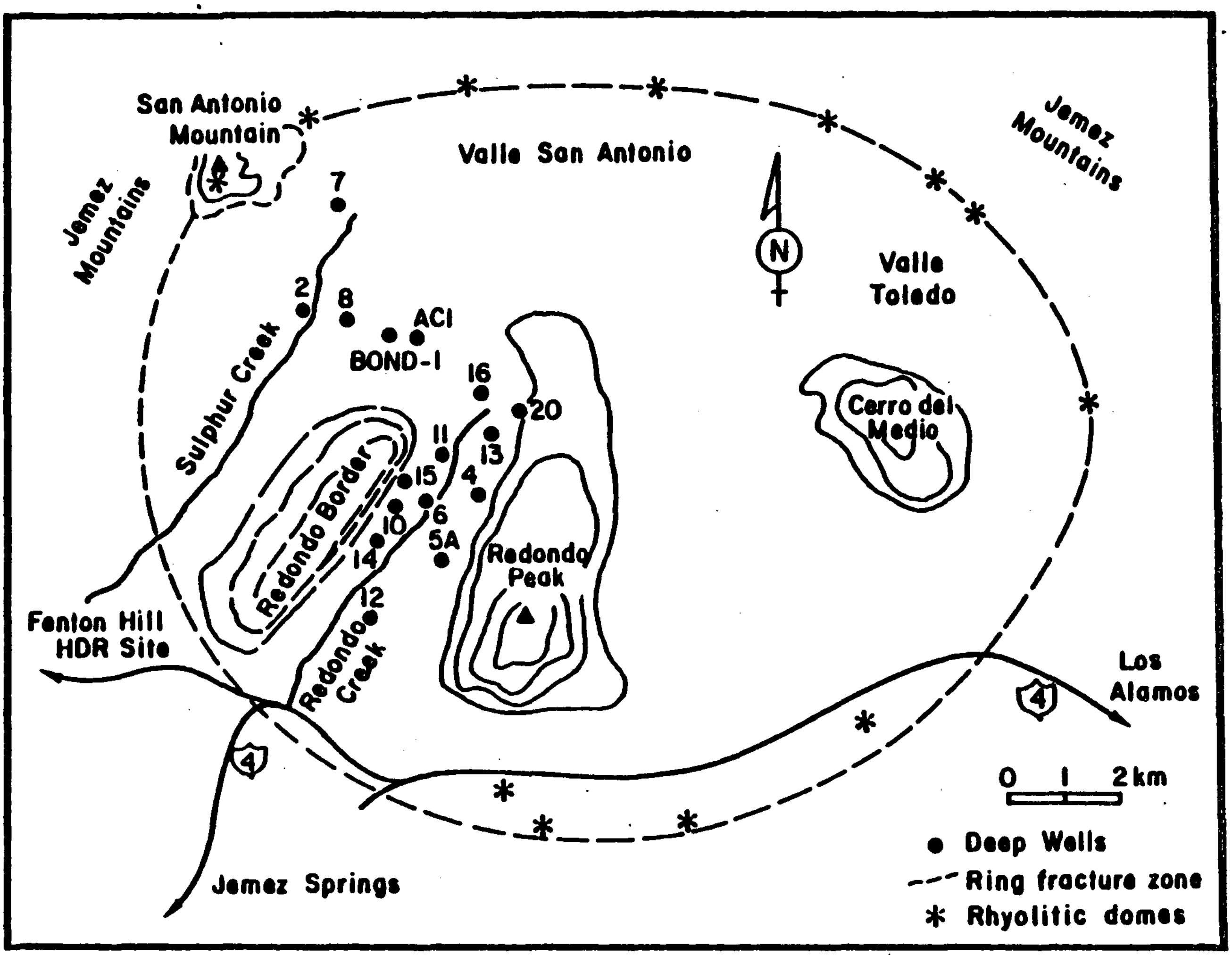
7. Gas isotopes for Baca wells 4, 13, 15, and 24.

BACA DATA:

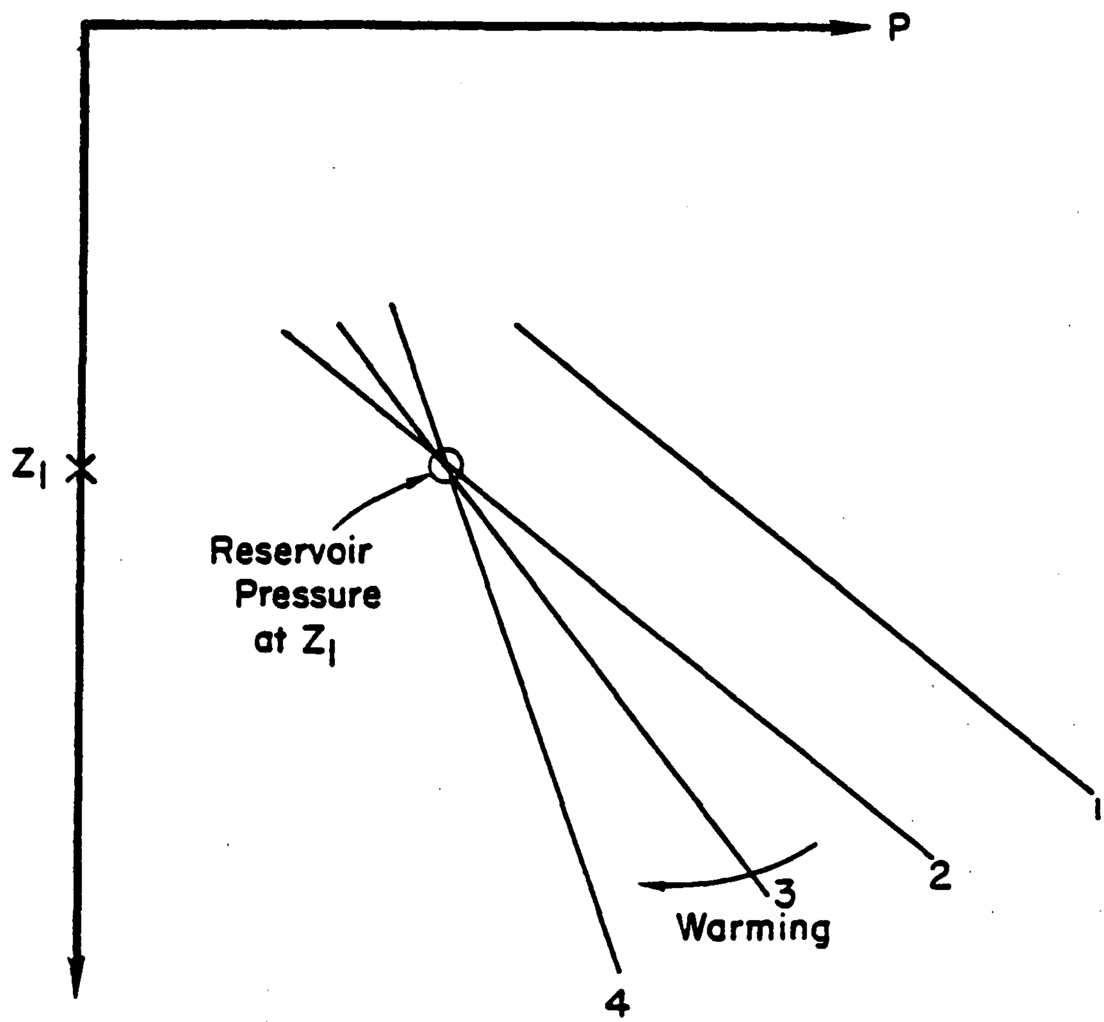
WELL TESTING/CONCEPTUAL MODEL

SABODH K. GARG

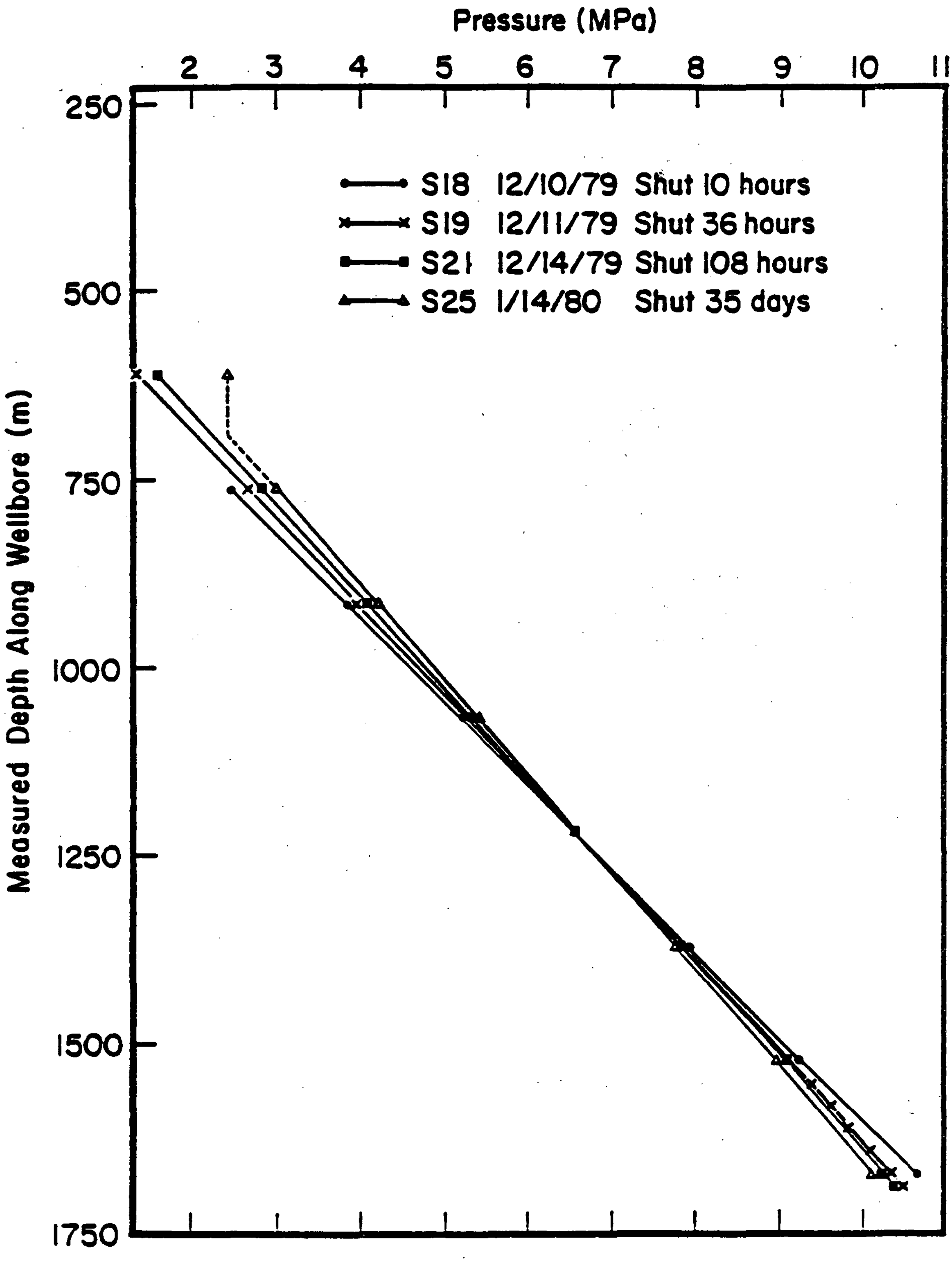
S-CUBED



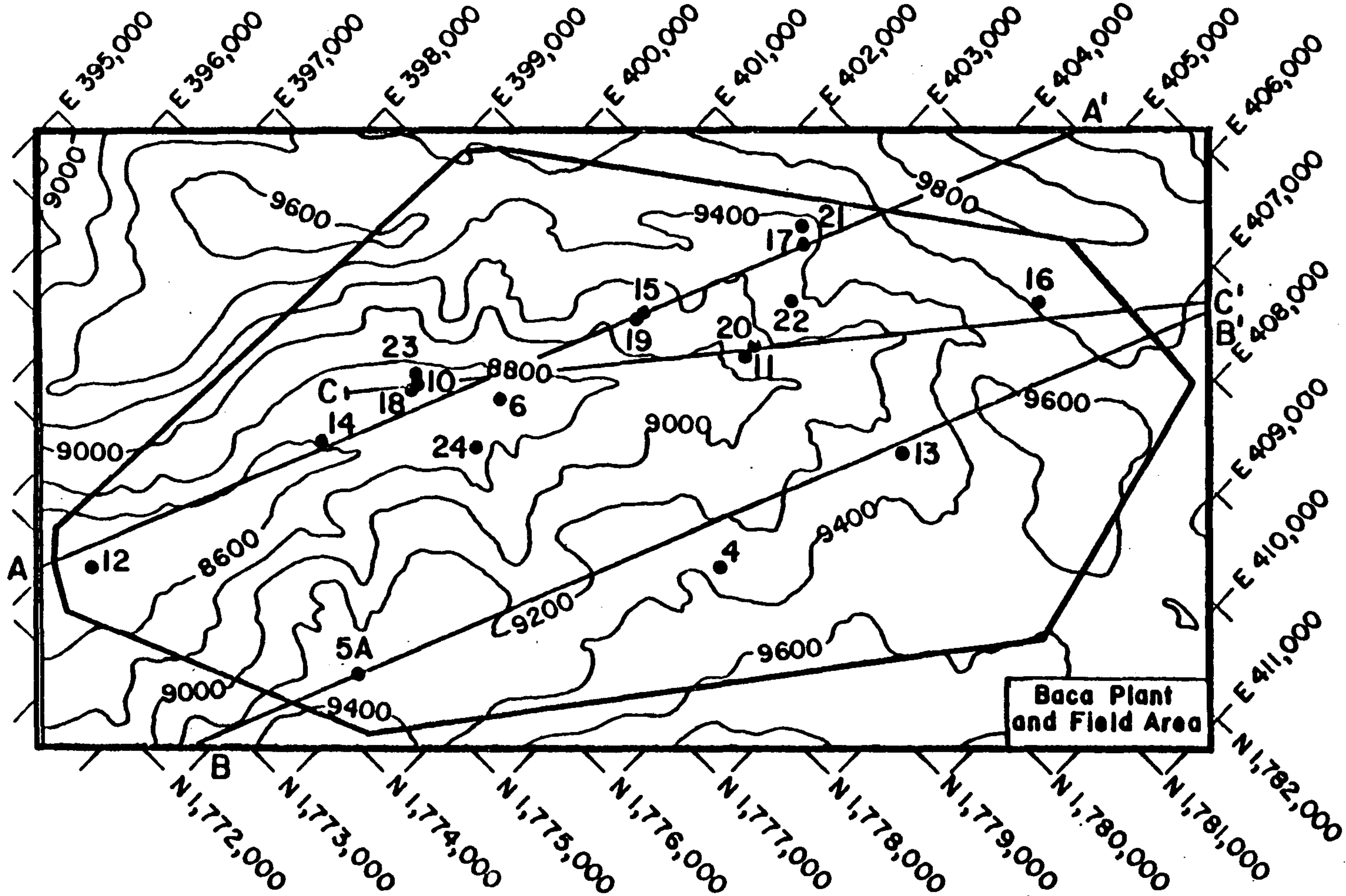
1. Map showing Valles Caldera with the locations of a number of the Baca wells.



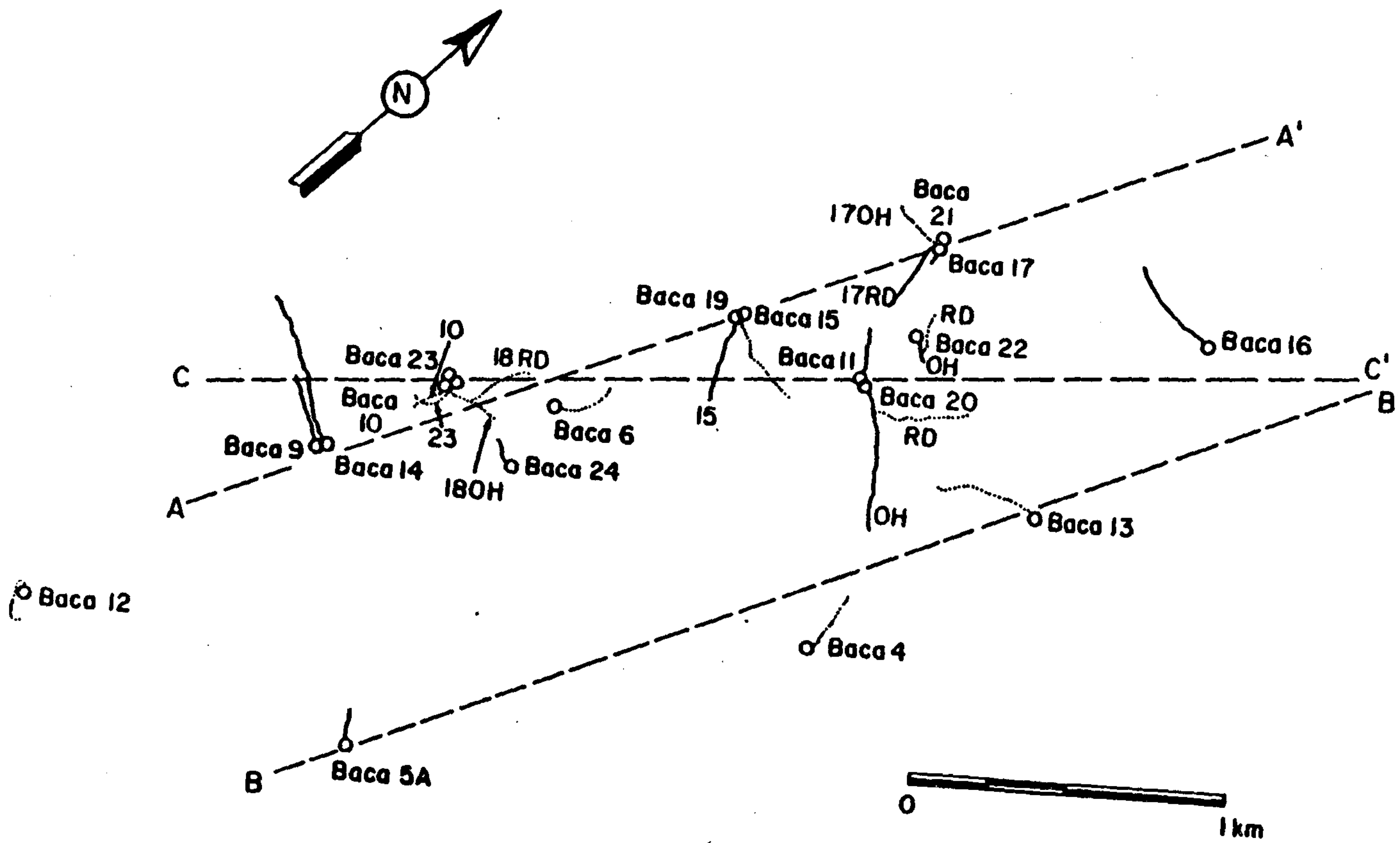
2. Schematic diagram of pressure-depth relationship with a warming trend in the well. Point Z_1 is a feedpoint.



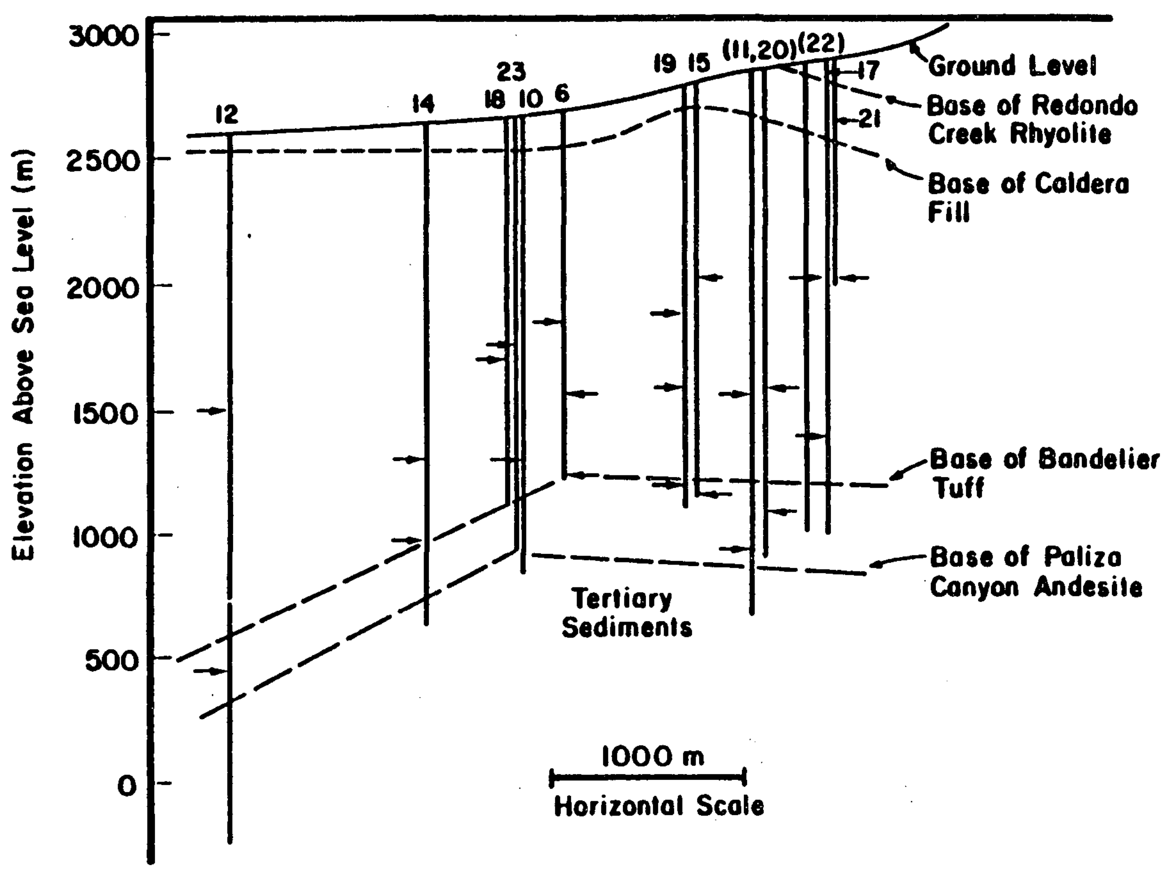
3. Pressure-depth curves for Baca well 19 for certain shut-in times, with an indication of a feedpoint.



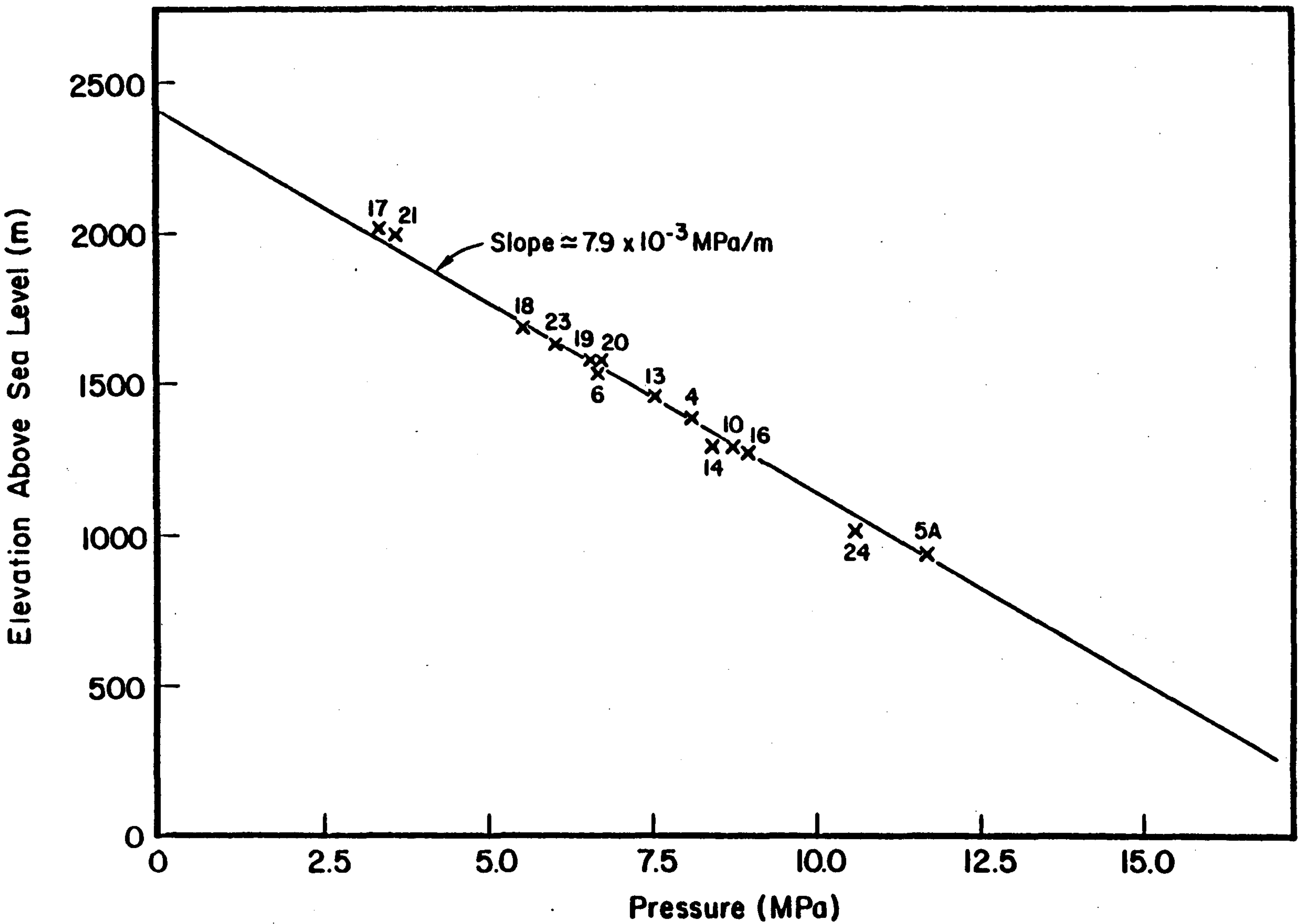
4. Map of Baca plant and field area with locations of lines AA', BB' and CC', and some well locations indicated.



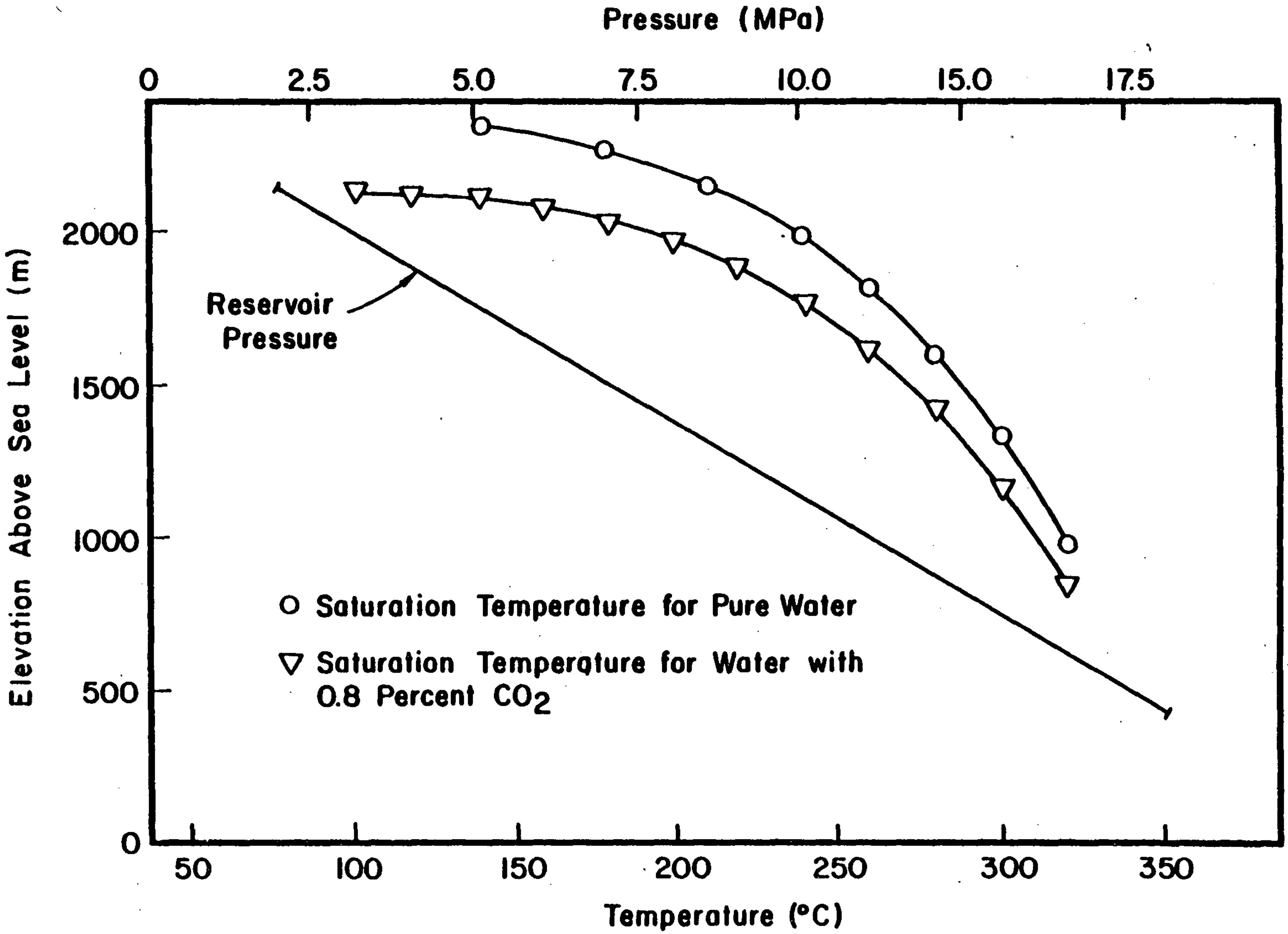
5. Map of Baca wells along lines AA', BB', and CC'.



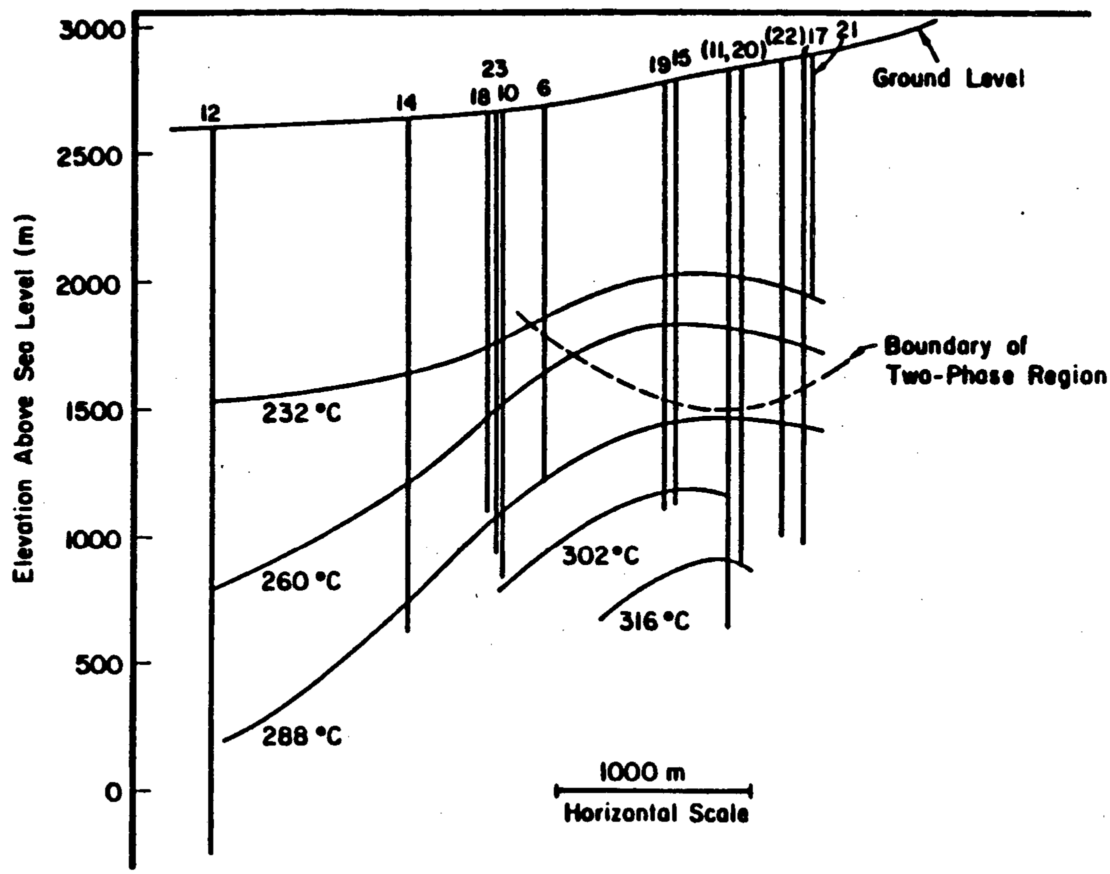
6. Cross-section of Baca wells along line AA' with sketch of stratigraphy and feedpoints (arrows) indicated.



7. Baca reservoir pressure versus elevation at a number of wells.



8. Baca reservoir pressure versus elevation and temperature with saturation temperatures for pure water and water with 0.8 percent CO_2 indicated.



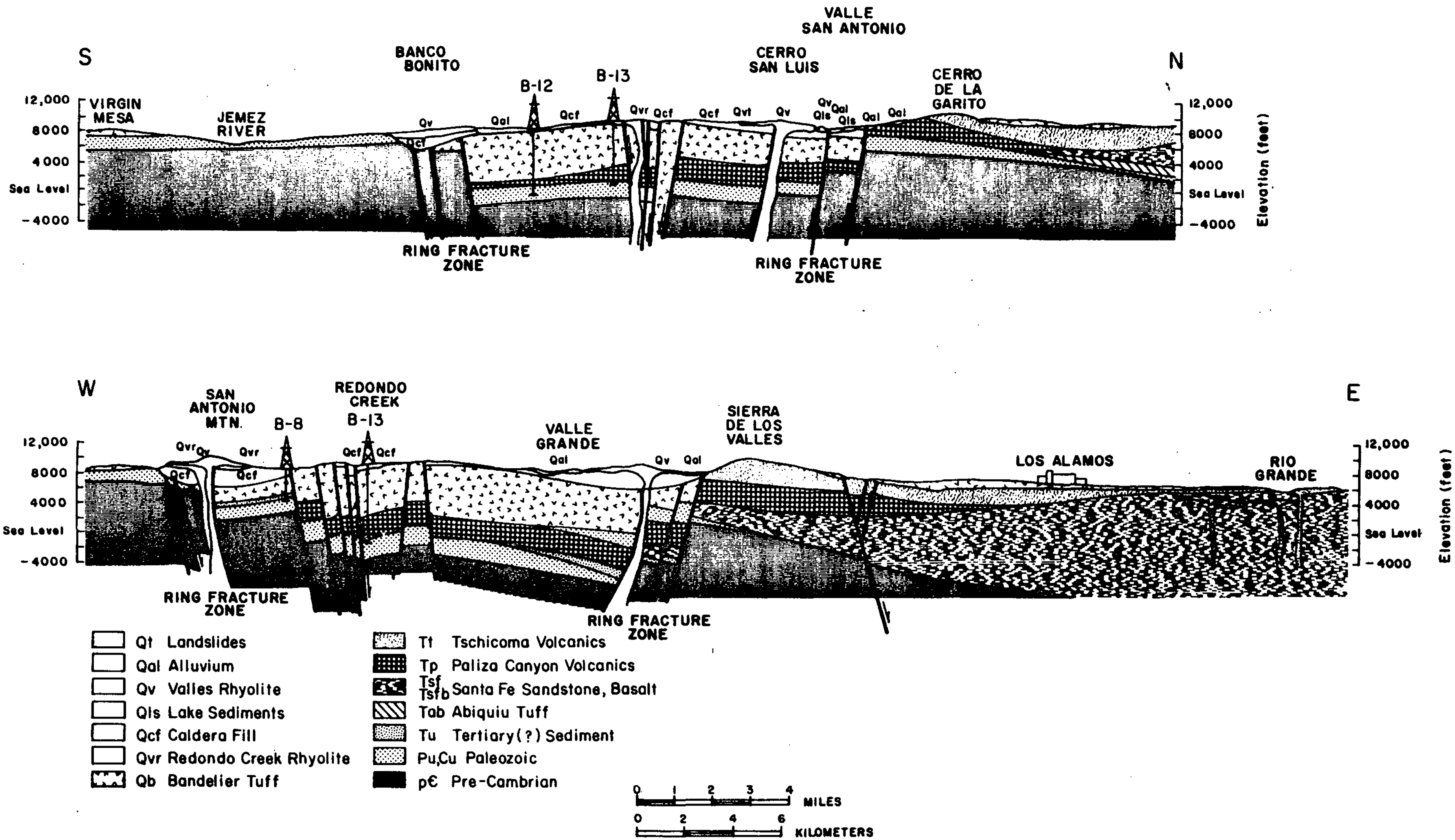
9. Cross-section of Baca wells along line AA' with temperature contours and the boundary of the two-phase region indicated.

BACA DATA:

RESERVIOR CAPACITY/
GENERATING CAPACITY

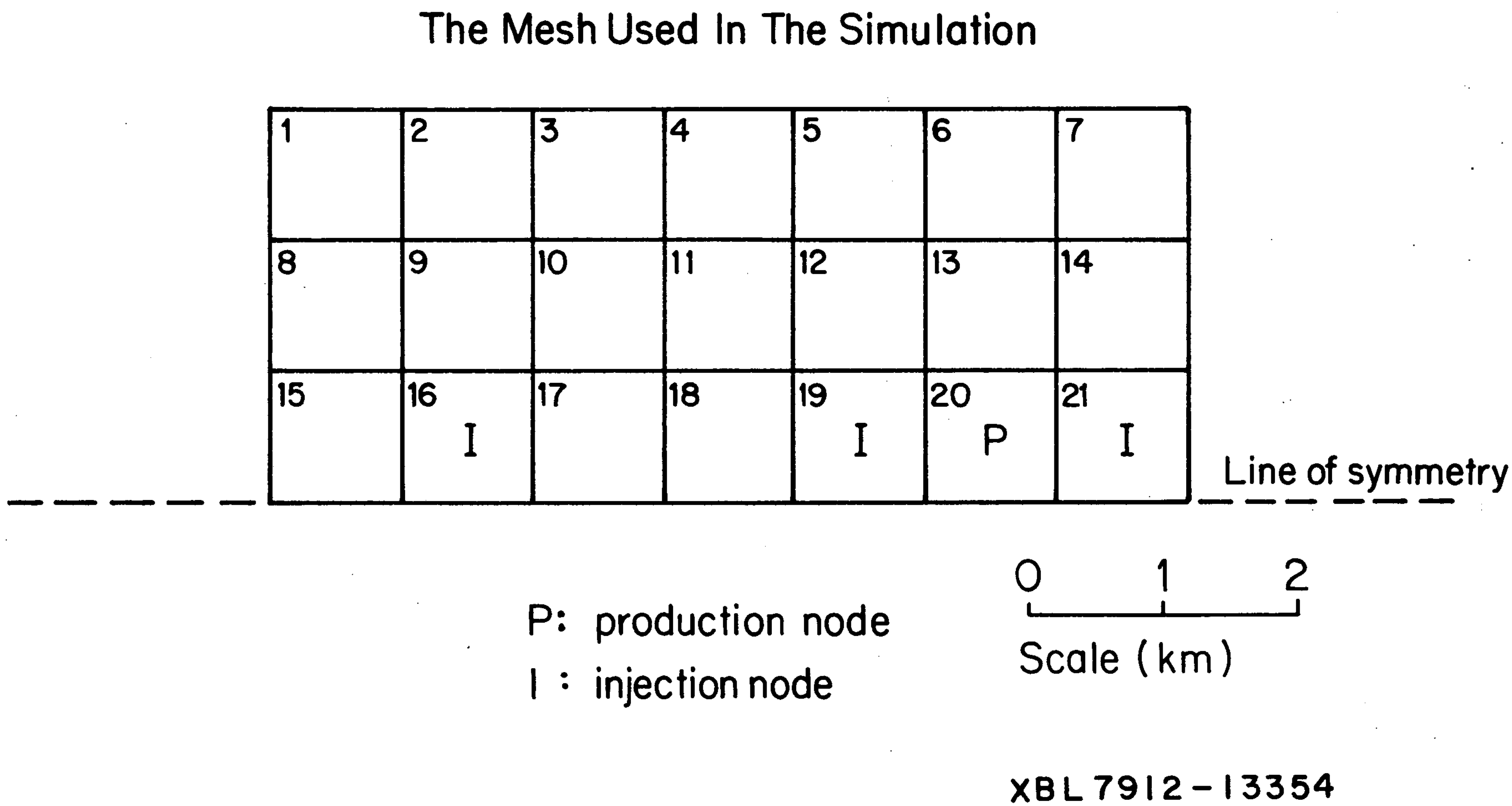
GUDMUNDUR S. BODVARSSON

LAWRENCE BERKELEY LABORATORY

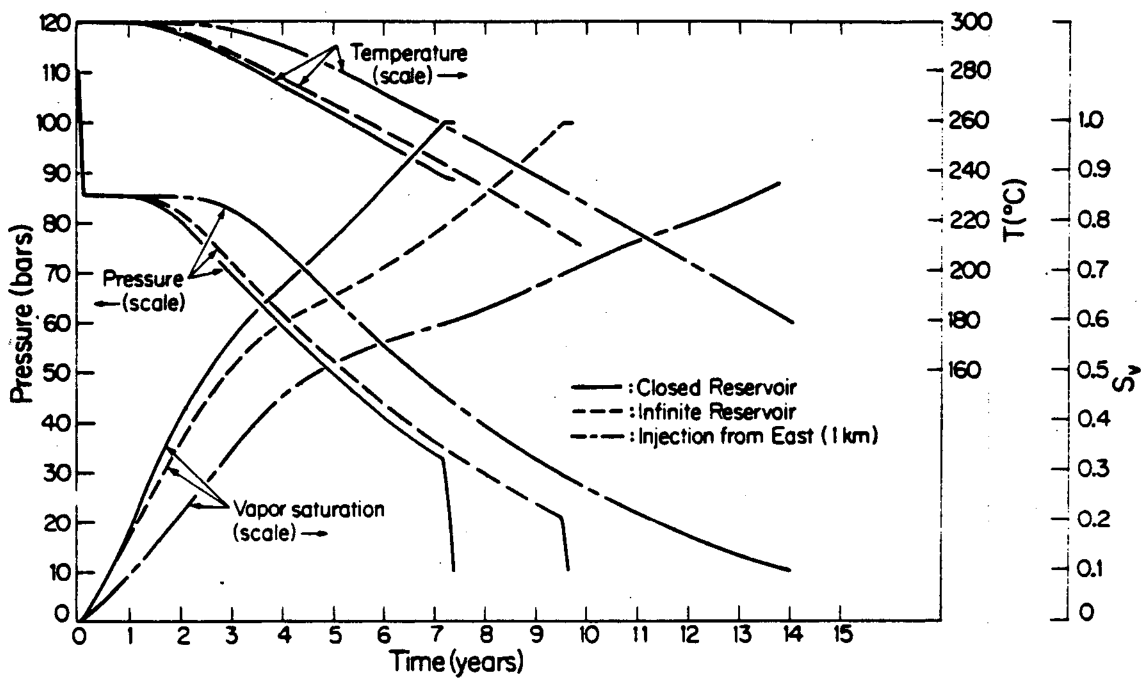


XBL 799-11548B

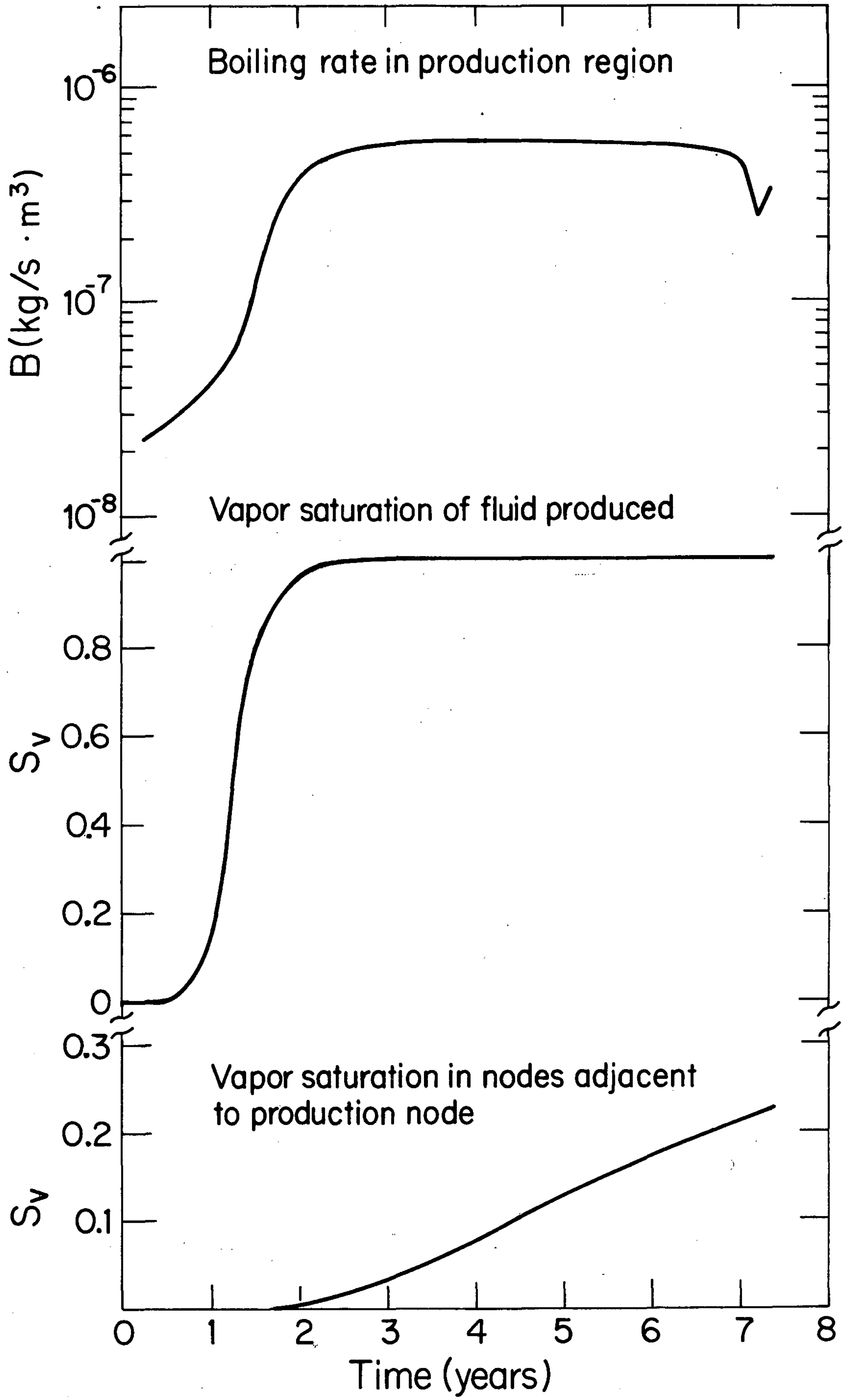
1. Geologic cross-sections of the Valles Caldera region (after Bailey and Smith, 1978).



2. The mesh used in the longevity study for "closed reservoir" cases.

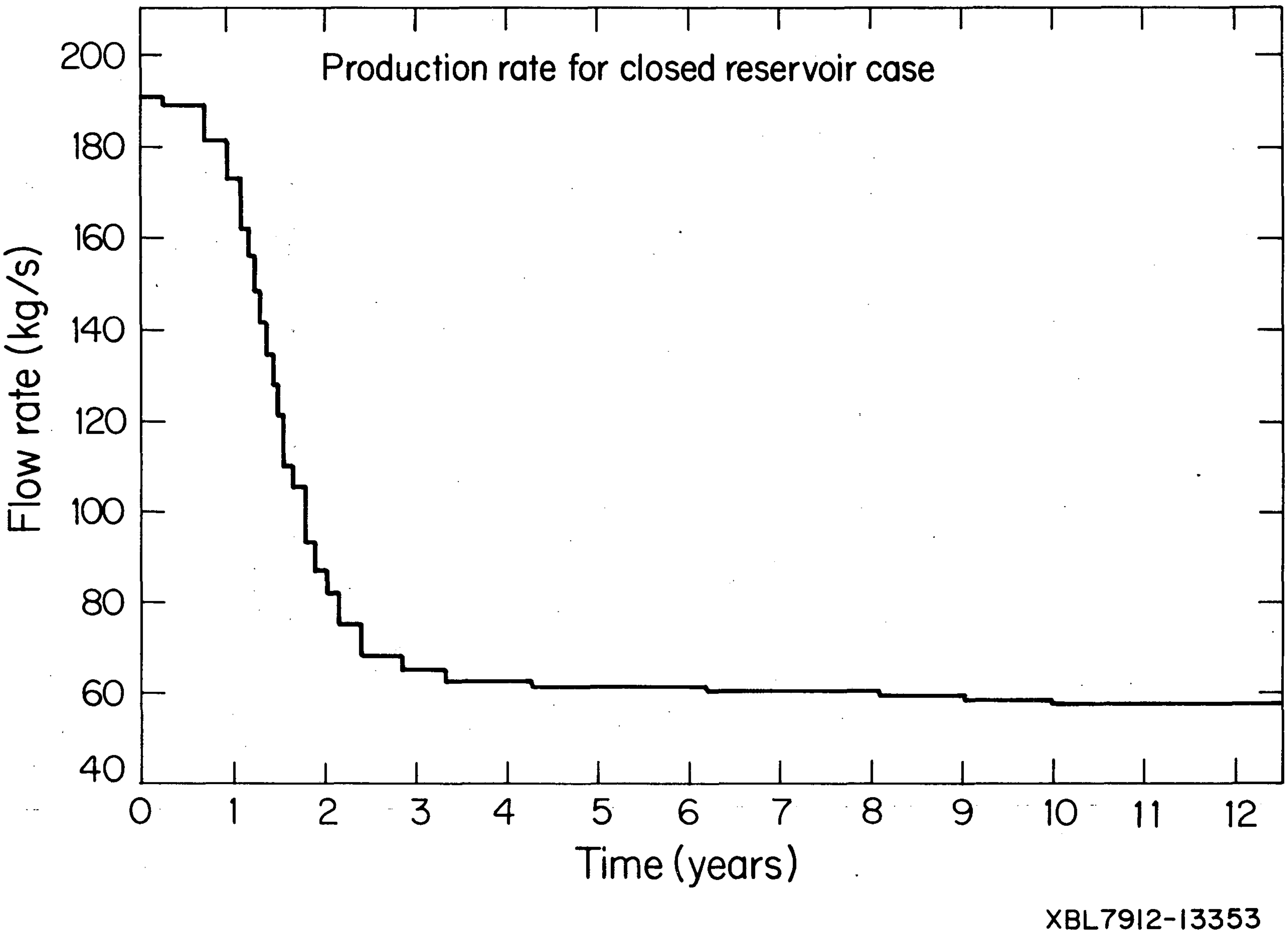


3. The temperature, pressure, and saturation behavior in the production node for three of the constant flow rate cases.

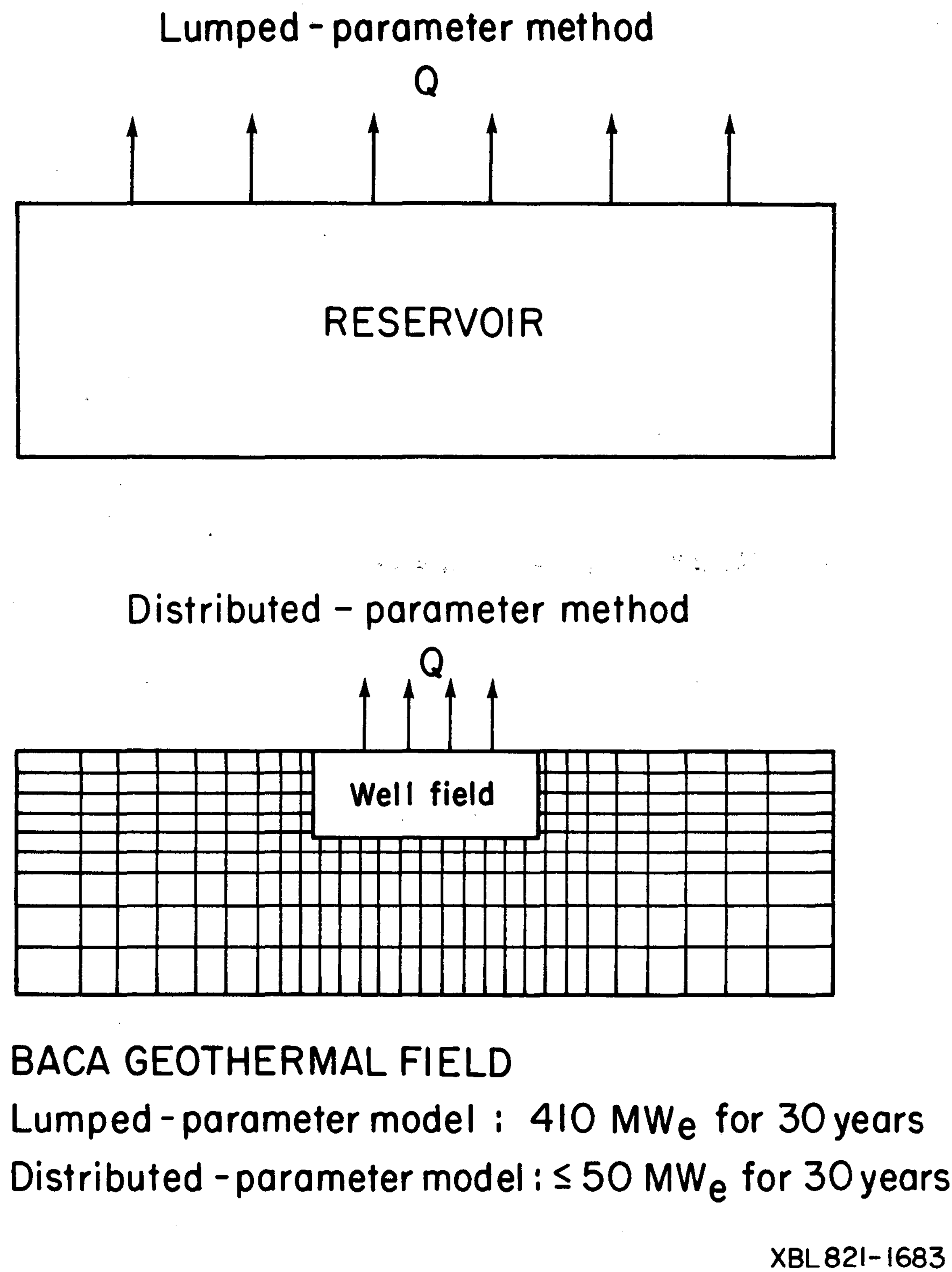


4. Variation with time of boiling rates and vapor saturation for the constant production, closed-boundary case.

XBL7912-13351



5. Production rate versus time for the closed-boundary case.



6. Comparison of lumped-parameter and distributed-parameter models.

Table 1. Summary of cases and primary results.

Case	Flow rate	Boundary conditions	Injection	Conditions at the end of the run: Time (yrs)	Pressure (bars)	Temp °C	Vapor saturation
1	Constant	Closed	None	7.4	10	237	1.0
2	Constant	"Infinite"	None	9.6	10	214	1.0
3	Constant	Closed	4 km to NW	12.9	10	180	0.99
4	Constant	Closed	1 km to NW	13.7	10	180	0.91
5	Constant	Closed	1 km to NE	14.0	10	180	0.87
6	Variable	Closed	None	25	10	214	1.0
7	Variable	"Semi-infinite"	None	26	10	213	1.0
8	Variable	"Infinite"	None	35	10	185	1.0
9	Variable	Bounded with a fault	None	50	10	180	0.48

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