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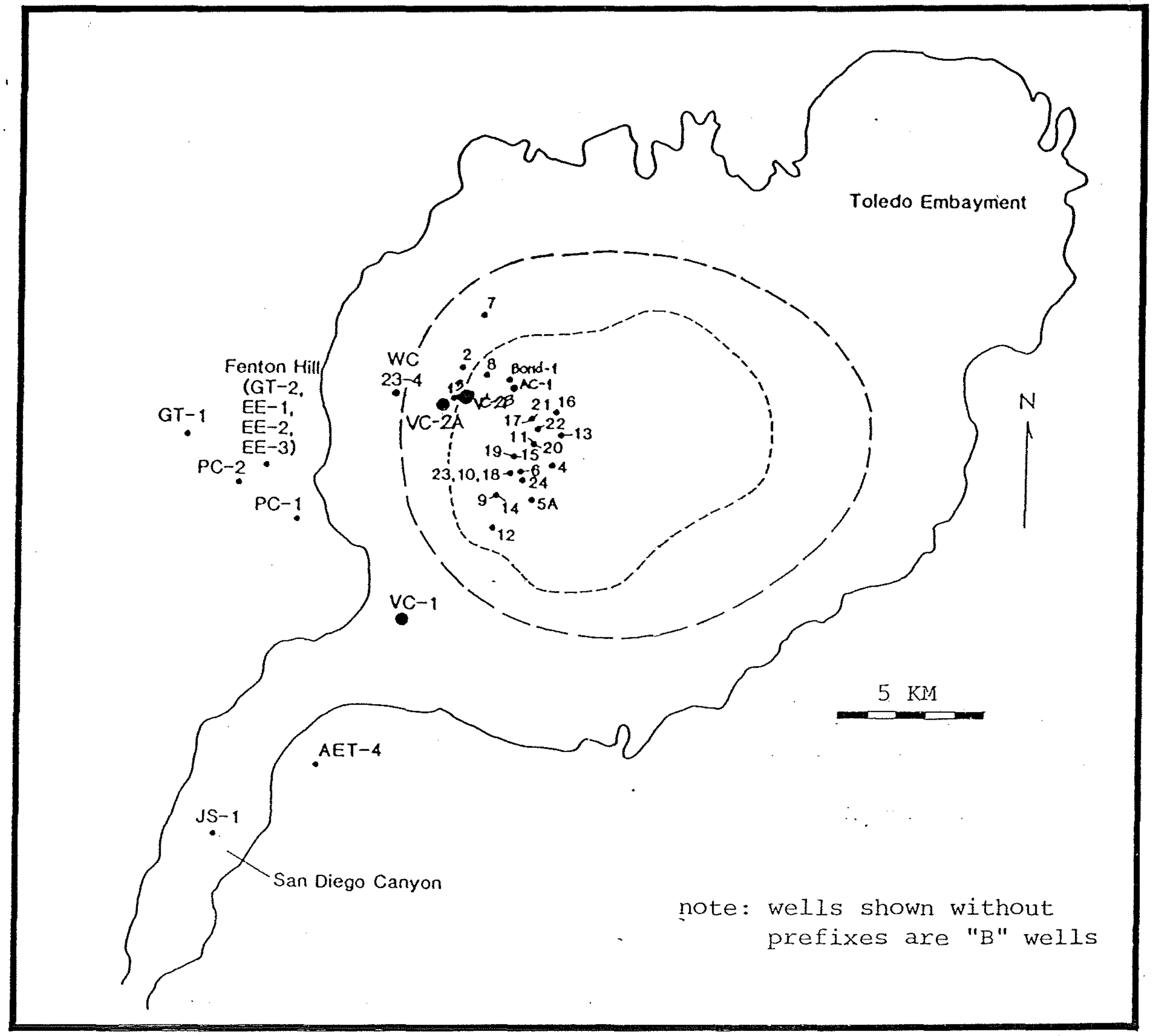


Figure 2. Map showing locations geothermal wells and scientific coreholes completed to date within and adjacent to the Valles caldera complex. Long dashes delineate the ring-fracture margin of the Valles caldera. Short dashes outline the Valles caldera's resurgent dome.

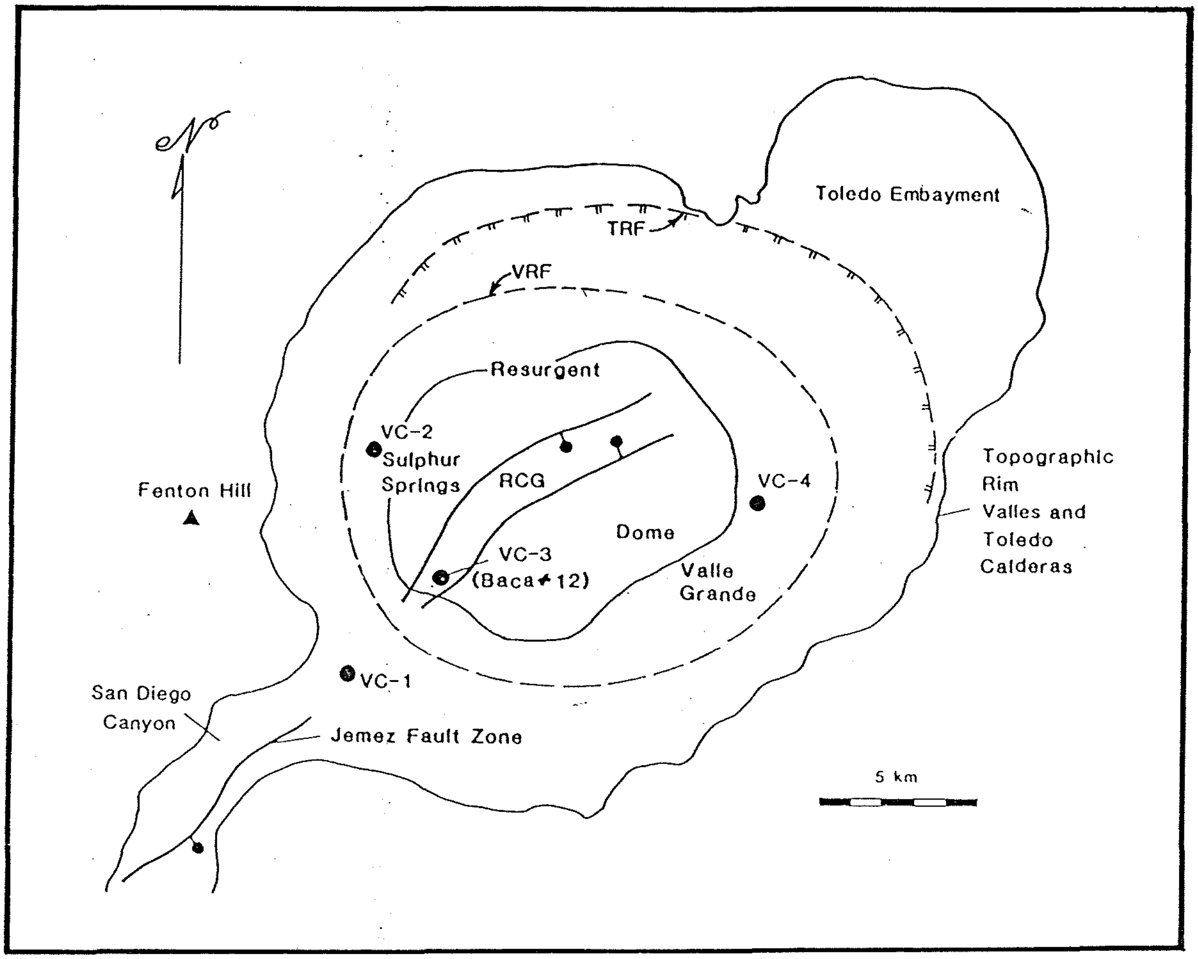


Figure 3. Map of the Valles caldera complex showing locations of completed and proposed CSDP coreholes. VC-1 and VC-2A are already completed. VC-5 will be located in the Toledo embayment. RCG - Redondo Creek graben. VRF - Valles caldera ring-fracture zone. TRF - Toledo caldera ring-fracture zone.

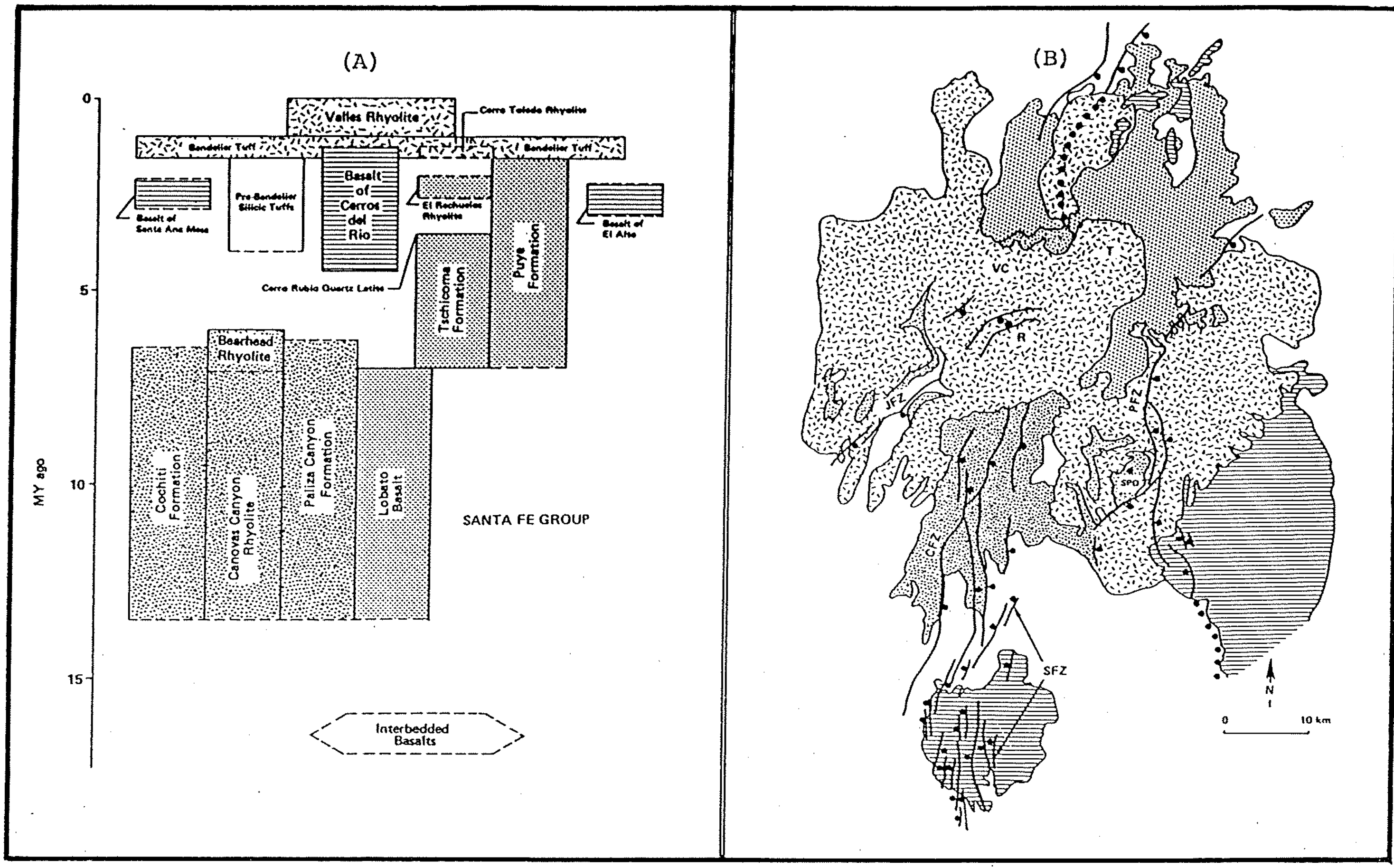
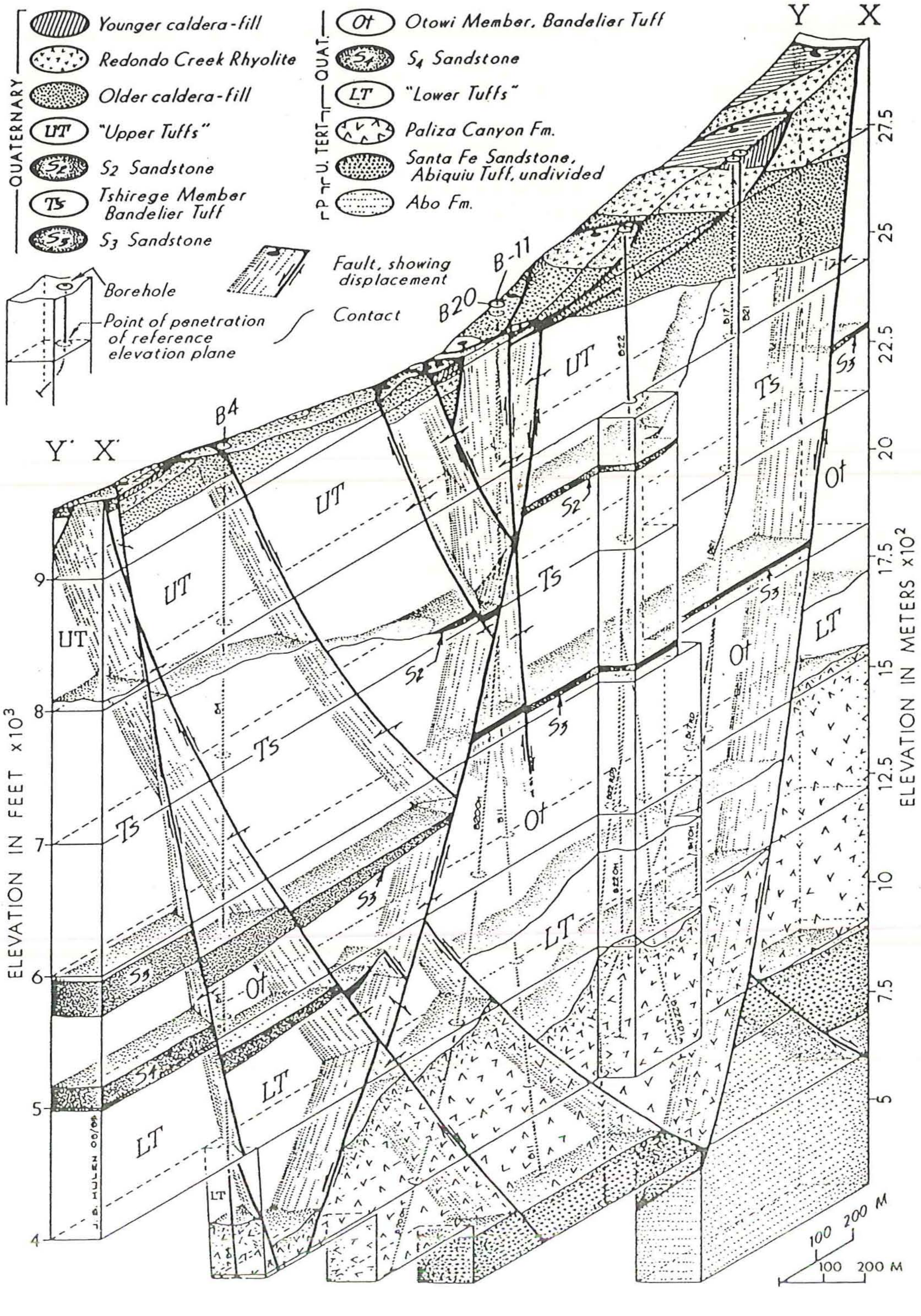


Figure 4. Generalized stratigraphic relations (A) and aereal distribution (B) of major rock units in the Jemez volcanic field. Irregular stipple - Keres Group formations. Regular stipple - Polvadera Group formations. Random dashes - Tewa Group formations. A - Dashed lines indicate uncertainty. B - Major fault zones and geomorphic features labeled as follows: JFZ - Jemez fault zone; SFZ - Santa Ana Mesa fault zone; CFZ - Canada de Cochiti fault zone; PFZ - Pajarito fault zone; VC - Valles caldera complex; R - resurgent dome of VC; T - Toledo embayment; SPD - St. Peter's dome. From Gardner et al. (1986), as modified from Gardner and Goff (1984) and Smith et al. (1970).



(Looking Southwest)

Figure 5. Southeast (left) to northwest (right) geologic section through the medial graben of the Valles caldera's resurgent dome, with control provided by UOC geothermal wells. Section shows most of the major stratigraphic units intersected in the explored portion of the caldera as well as major structures.

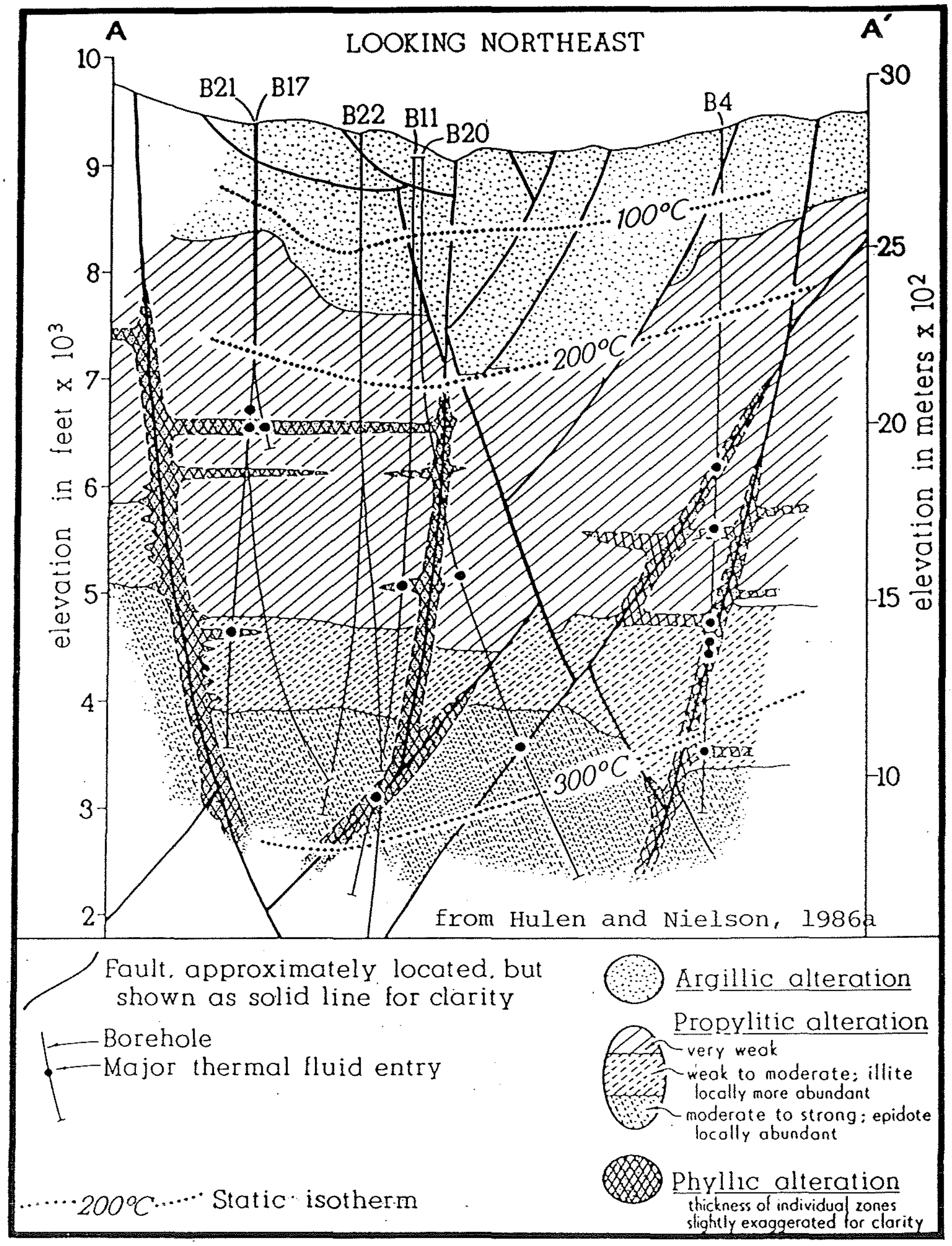


Figure 7. Generalized northwest-southeast hydrothermal alteration cross-section through the medial graben of the Valles caldera's resurgent dome (Redondo Creek area) with control provided by UOC geothermal wells. Corresponds to geologic cross-section of Figure 5, except viewed from the southwest.

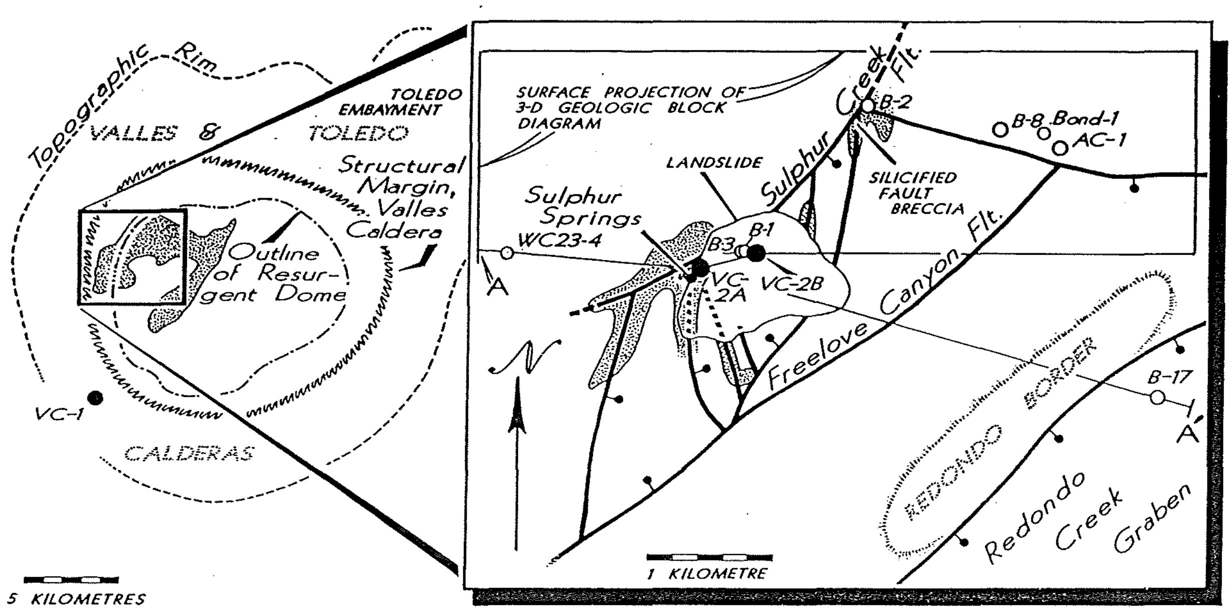


Figure 8. Location map, showing position of CSDP coreholes VC-2B and VC-2A relative to the Sulphur Springs area of the Valles caldera complex. Stippling at left shows extent of active or recent surficial alteration. Stippling on right shows areas of phyllic, argillic, and advanced argillic acid-sulfate alteration. A-A' is cross-section of Figure 14. Note also location of 3-D geologic block diagram of Figure 10. Modified from Goff and Gardner (1980) and Charles et al. (1986).

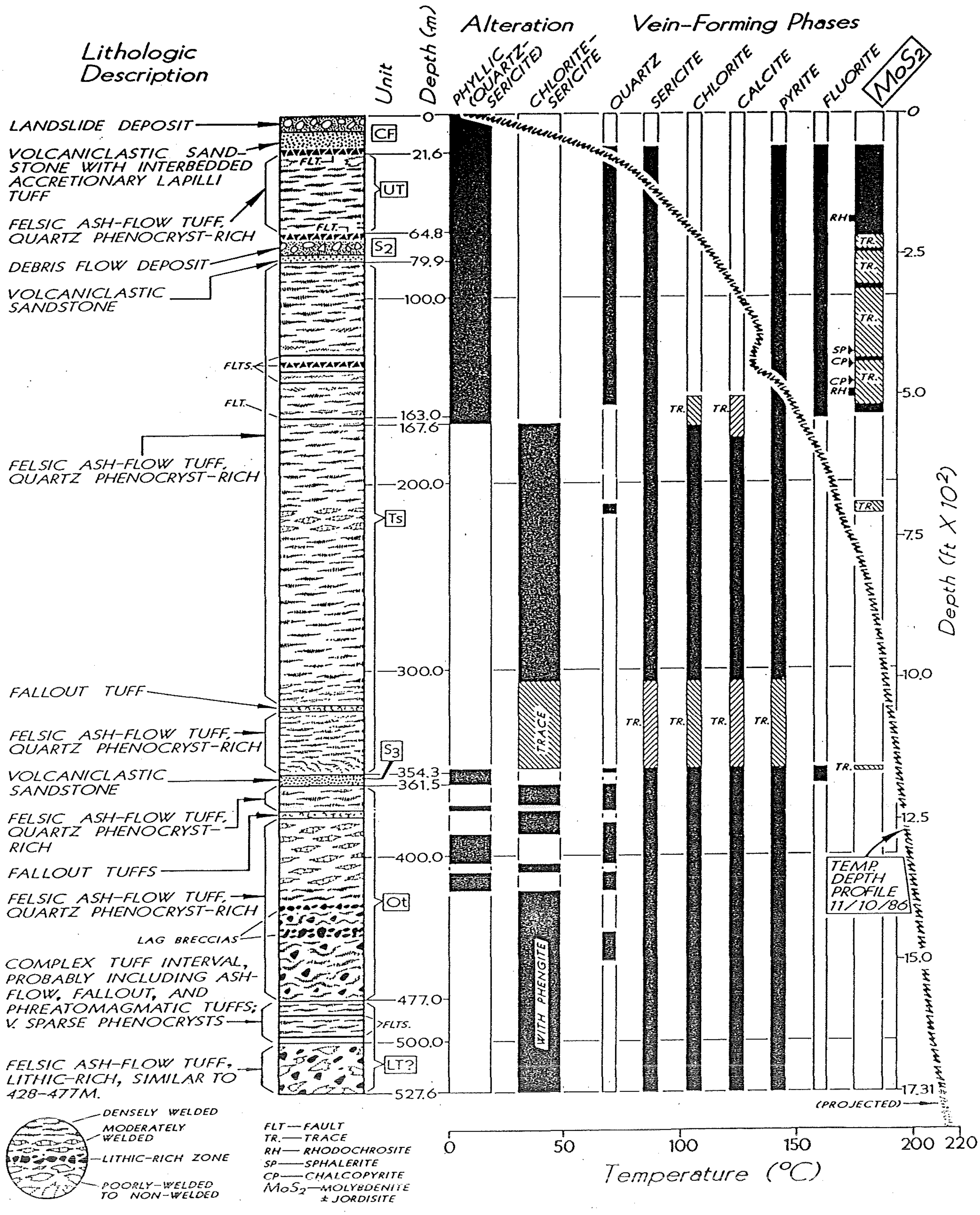
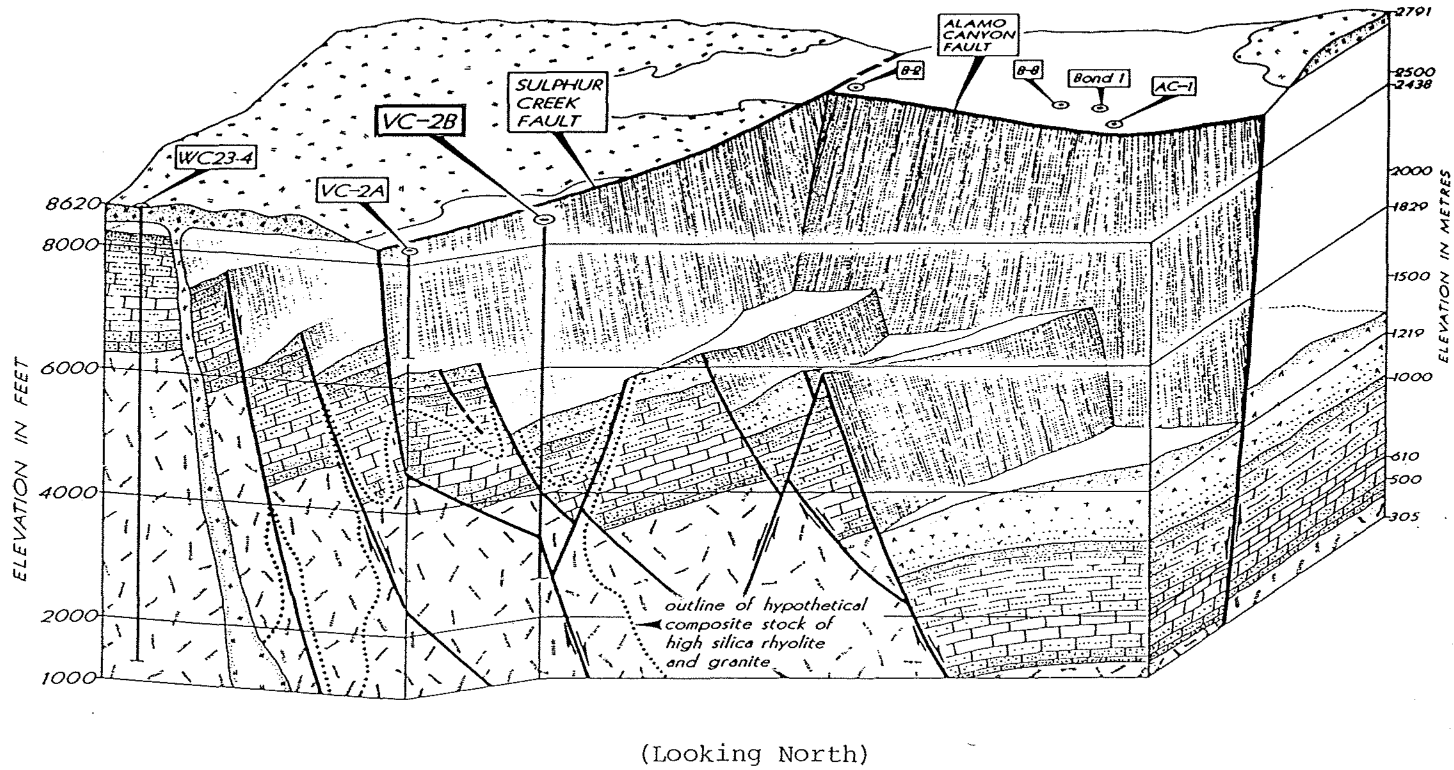


Figure 9. Generalized lithologic, structural, alteration, and vein mineralization log for CSDP corehole VC-2A (modified from Hulen et al., 1987). Please refer to Table 1 for abbreviations of stratigraphic units.



Postcaldera rhyolite 0.43-1.09 Ma

Caldera-fill rocks (<3.6 Ma) principally the Bandelier Tuff (1.45-1.12 Ma) and associated ignimbrites

Miocene volcanic and sedimentary rocks

Paleozoic sedimentary rocks

Precambrian granite and gneiss

Fault; arrows indicate displacement

Figure 10. Geologic block diagram showing interpreted subsurface structure and stratigraphy in the Sulphur Springs area of the west-central Valles caldera complex. For location, please refer to Figure 8. Caldera-fill units south of the Alamo Canyon fault and east of the Sulphur Creek fault are stripped away in the drawing to show conceptually complex configuration of basement rocks in the floor of the caldera. Wells B-1 and B-3 not shown for clarity. Surface geology from Goff and Gardner (1980).

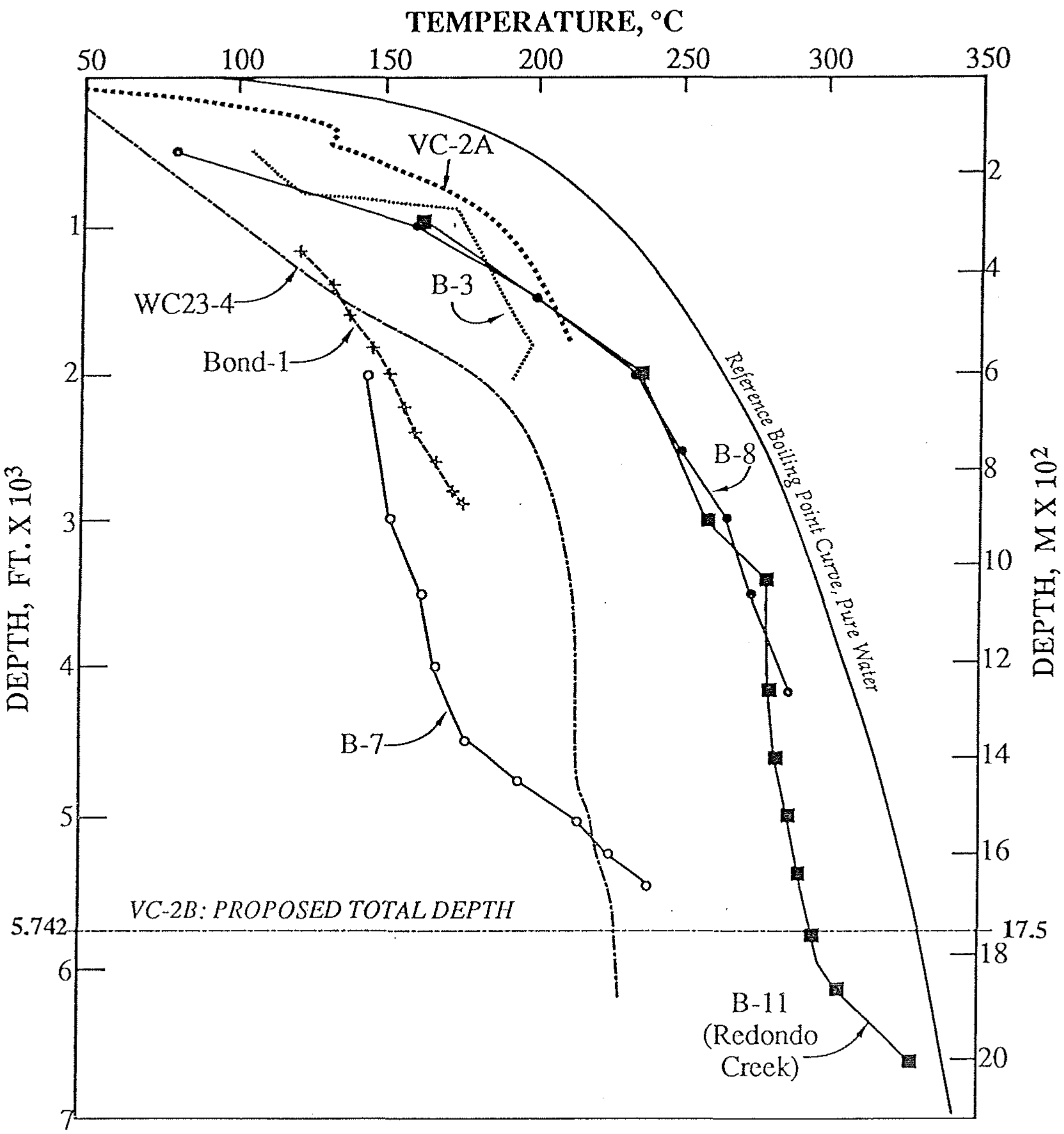


Figure 11. Temperature surveys for geothermal wells and CSDP corehole VC-2A, Sulphur Springs area. Shown for comparison is a temperature survey for well B-11, in the Redondo Creek area. Data from UOC (1982) and Dondanville (1971)(B-1 to B-11, Bond-1); Goff et al. (1987)(VC-2A); Shevenell et al. (1987)(WC-23-4).

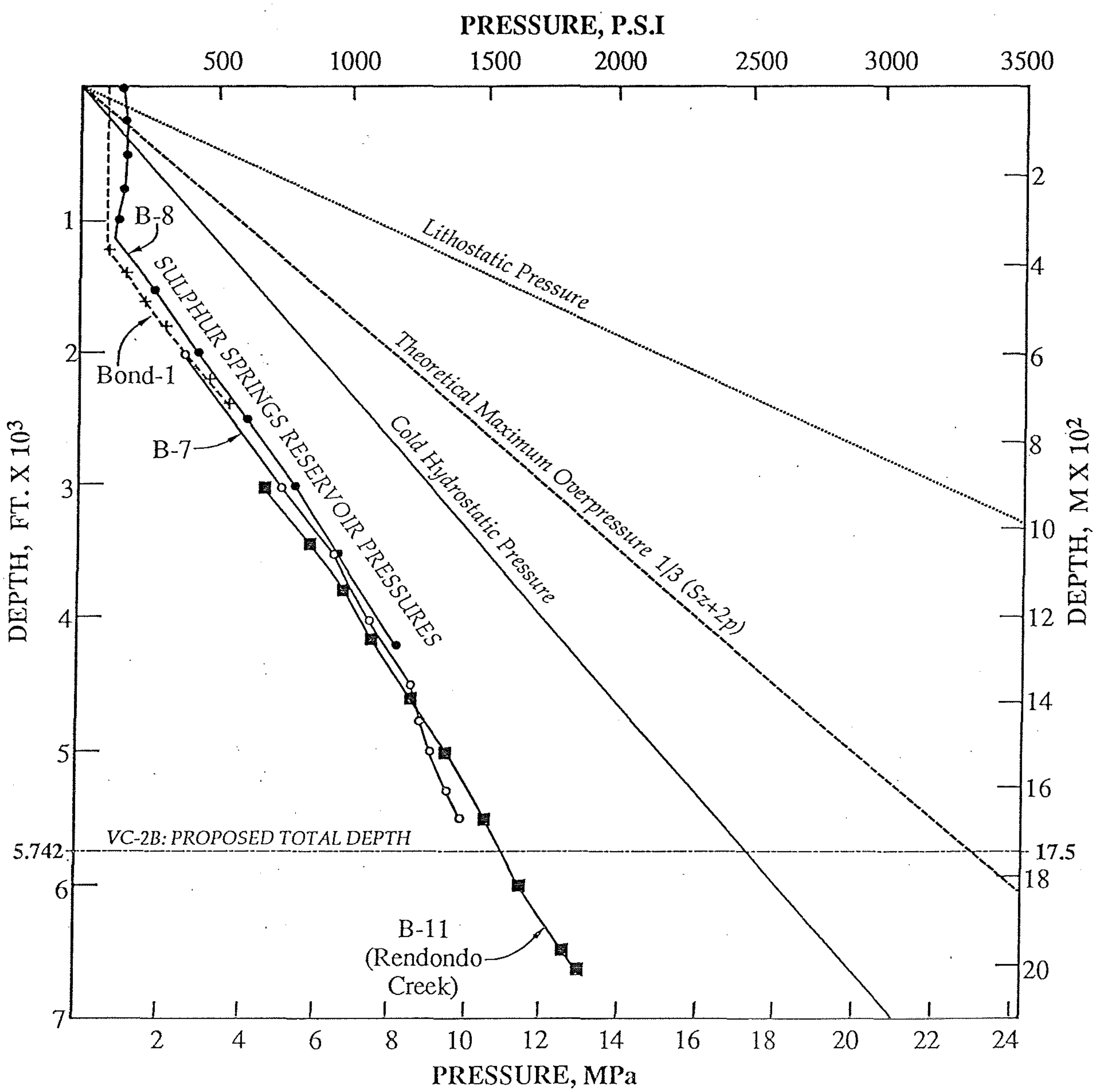


Figure 12. Pressure surveys for various geothermal wells in the Sulphur Springs area and, for comparison, for well B-11 in the Redondo Creek area. Also shown are cold hydrostatic and lithostatic (2.5g/cm) pressure profiles and a profile corresponding to theoretical pressurs required for hydraulic rock rupture (from Hubbert and Willis, 1957). Well data from UOC (1982) and Dondanville (1971).

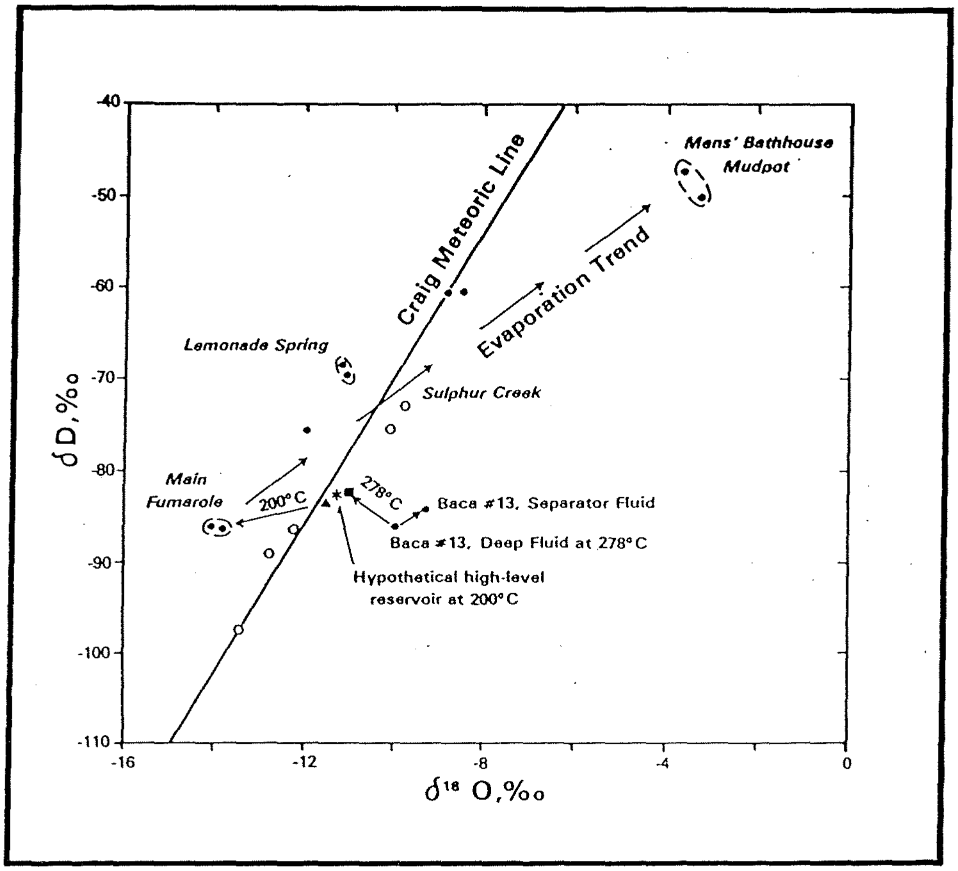
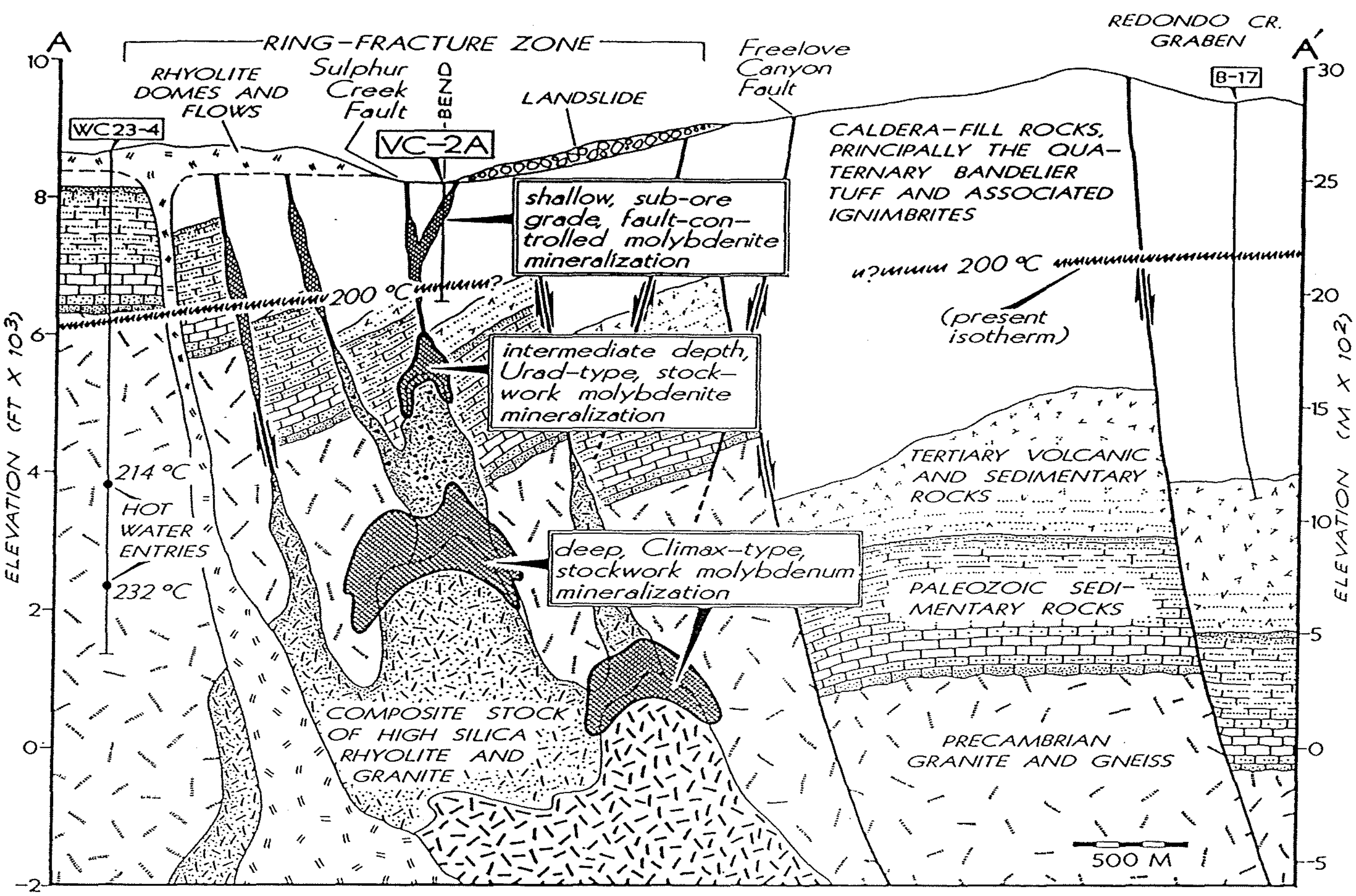


Figure 13. Plot of deuterium vs. oxygen-18 from geothermal and surface meteoric waters, Sulphur Springs area. Open circles denote meteoric fluids; dots denote thermal fluids; square represents composition of steam produced by single-stage boiling of reservoir fluid from well B-13 (Fig. 2) at 278°C; triangle represents composition of parent water that produces fumarole steam by single-stage boiling at 200°C; star represents a hypothetical, high-level reservoir at 200°C beneath Sulphur Springs. (From Goff et al., 1985)



(Looking North)

Figure 14. West-east conceptual geologic cross-section through the Sulphur Springs area and the west-central Valles caldera complex (see Fig. 8 for location). Control provided by geothermal wells along and north of the section, by CSDP corehole VC-2A, and by the geologic mapping of Goff and Gardner (1980). Section shows position of hypothetical Urad- and Climax-type stockwork molybdenum mineralization relative to the low-temperature, high-level molybdenite occurrence of VC-2A. Also shown is a hypothetical composite stock of high-silica rhyolite and granite genetically related to the molybdenum mineralization. From Hulen et al., 1987.

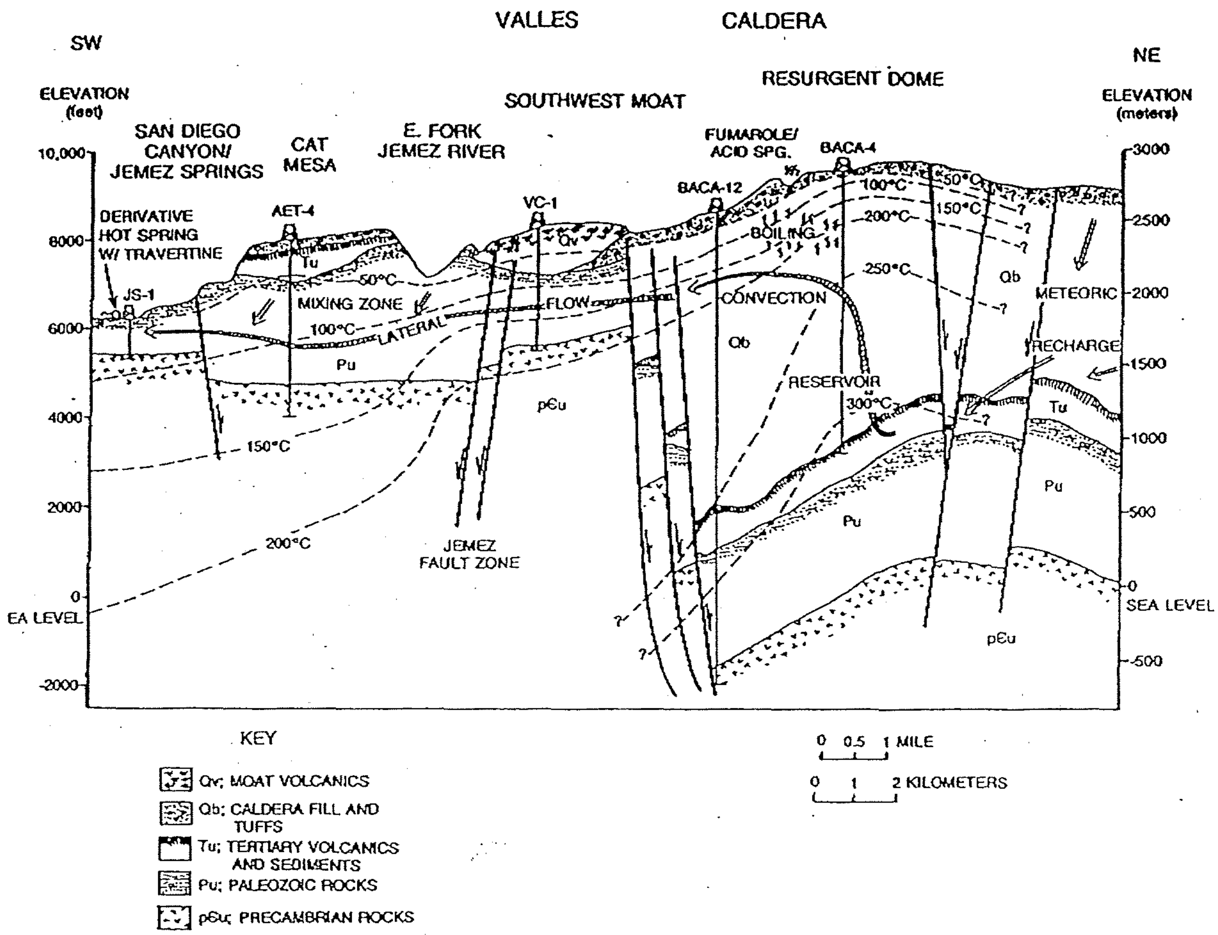


Figure 6. Southwest-northeast cross-section showing stratigraphy, structure, isotherms, and conceptual fluid pathline in the Valles hydrothermal system.

Table Aspects of the active Sulphur Springs hydrothermal system addressed by collaborating investigators.

TOPIC OF INVESTIGATION	INVESTIGATOR(S)	METHOD OF INVESTIGATION
Thermal conductivity of reservoir rocks; heat flux at Sulphur Springs and throughout the Valles caldera complex	Sass (USGS), Morgan (NAU), Lachenbruch (USGS), Christensen (PU)	Thermal conductivity measurements of water-saturated VC-2B core at simulated reservoir pressures and temperatures; computer modeling
Variation in fluid composition with depth	Goff (LANL)	Geochemical and isotopic analysis of fluids collected both at the wellhead and at specific sites down the borehole
Current state-of-stress	Sattler (SNL)	Differential strain-curve analysis and/or waveform analysis; petrographic characterization of microcracking in oriented core; sonic wave amplitude and relative to core diameter and orientation
Nature of permeability and porosity	Owen and Little (TTR)	Measurement of permeability at simulated overburden pressure; 3-D reconstruction of porosity network from computerized X-ray tomography (CT) scans; measurement of visible fracture orientation using computerized goniometer
	Heiken, Broxton, Krier, Wohletz (LANL)	Characterization of primary permeability (nature and distribution) intracaldera volcanic and volcaniclastic units)
Electrical properties of reservoir rocks	Owen (TTR)	Measurement of dielectric permittivity and electrical resistivity of core at various simulated reservoir pressures and temperatures
Thermal conductivity of reservoir rock during drilling	Lee (NMIMT)	Mathematical modeling of effective thermal conductivity, theoretically removing effects of drilling fluid and its circulation

*numbers refer to research objectives listed on pages

Table Aspects of evolution of the Sulphur Springs hydrothermal system addressed by collaborating investigators.

TOPIC OF INVESTIGATION	INVESTIGATOR(S)	METHOD OF INVESTIGATION
Variation in fluid composition with depth and time	Musgrave (NMIMT)	Geochemical and light stable isotopic analysis of secondary phases and inclusion fluids; fluid-inclusion microthermometry; gas analysis of fluid inclusions.
	Bohlke (ANL)	Halogens and noble gas isotopes in fluid inclusions
	W-Gabriel (LANL)	Oxygen isotopes in sericite
	McKibben and Williams (UCR)	Gas analysis of fluid inclusions
	Sasada (GSJ)	Fluid inclusion microthermometry
Variation in temperature/ pressure with depth and time	Sasada (GSJ)	Fluid-inclusion microthermometry
	Musgrave (NMIMT)	Fluid-inclusion microthermometry
	Geissman (UNM)	Determination of past maximum temperatures by progressive demagnetization of rock
Sources of fluids at different stages of the system's evolution	Bohlke (ANL) and Irwin (UCB)	Halogens and noble gas isotopes in fluid inclusions
	Musgrave (NMIMT)	Light stable isotopic, helium isotopic, and Pb/Sr isotopic analysis of inclusion fluids
Relative ages of alteration/ mineralization events	Musgrave (NMIMT)	Surface geologic and alteration mapping, core logging, petrography
	Geissmann (UNM)	Measurement of intensity and polarity of secondary magnetism acquired during hydrothermal events
Absolute ages of alteration/ mineralization events; distinguishing present (active) from past alteration and mineralization	W-Gabriel (LANL)	K-Ar dating of hydrothermal sericites
	Sturchio and Bohlke (ANL)	U-series isotopic geochronology
Metamorphic and contact-metasomatic mineralogy, zoning, paragenesis; active metamorphic and metasomatic reactions (conductive/convective heat transfer zone)	Elston and Grambling (UNM)	Geochemical and light stable isotopic analysis of secondary phases and inclusion fluids; petrography, XRD

*numbers refer to research objectives listed on pages

Table continued. Aspects of evolution of the Sulphur Springs hydrothermal system addressed by collaborating investigators.

TOPIC OF INVESTIGATION	INVESTIGATOR(S)	METHOD OF INVESTIGATION
Sources and migration of sulphur in the Sulphur Springs hydrothermal system	McKibben (UCR) and Eldridge (ANU)	Sulphur isotopic analysis of sulfides, sulfates, and fluids
Sources of metals in the Sulphur Springs hydrothermal system	Musgrave (UNM)	Pb and Sr isotopic analysis of inclusion fluids and metallic minerals of hydrothermal origin
Mechanisms of alteration and metallic mineralization	Bohlke (ANL) and Irwin (UCB)	Halogens and noble gas isotopes in fluid inclusions
	Sasada (GSJ) Musgrave (NMIMT)	Phase relations in fluid inclusions
Clay mineral geothermometry	Ballantyne and Moore (UURI)	Sericite geochemistry and expandability as correlated with past and present temperatures
Compositions of unaltered lithologies (protoliths) as references for studies of alteration and fluid-rock interaction	Wolff (UTA), Gardner (LANL), Sykes (UTA), Self (UTA)	Major/minor/trace element and isotopic analysis of unaltered caldera-fill lithologies or their proximal-facies, outflow-sheet equivalents
	Elston and Grambling (UNM)	Major/minor/trace element and isotopic analysis of unaltered, pre-caldera lithologies.

*numbers refer to research objectives listed on pages

Table continued. Aspects of the active Sulphur Springs hydrothermal system addressed by collaborating investigators.

TOPIC OF INVESTIGATION	INVESTIGATOR(S)	METHOD OF INVESTIGATION
Subsurface configuration of fluid regimes	Wannamaker (UURI)	Controlled-source audiomagnetotelluric survey
Physical/chemical controls on contemporary hydrothermal alteration and metallic mineralization	Musgrave (NMIMT)	Combining geochemical and isotopic analyses of fluids and secondary phases with which they are in contact; computer modeling
	Sturchio and Bohlke (ANL)	U-series disequilibrium studies
	Laul and Gosselin (BPNWL)	Measurement of radionuclide abundance patterns, correlations, and activity ratios; REE geochemistry, relative abundances
Rates of mass transport	Laul and Gosselin (BPNWL)	U-series disequilibrium studies
	Sturchio and Bohlke (ANL)	U-series disequilibrium studies
Contemporary fluid sources	Kennedy (UCB)	Measurement of elemental and isotopic compositions of noble gases in fluids
	McKibben (UCR) and Eldridge (ANU)	Sulphur isotopic analysis of reservoir fluid
	Goff (LANL)	Geochemical and isotopic analysis of reservoir fluids
	Laul and Gosselin (BPNWL)	REE geochemistry of reservoir fluids
Physical/chemical controls on contemporary isochemical thermal metamorphism and contact metasomatism	Elston and Grambling	Geochemical and isotopic analysis of fluids, solutes, and the secondary minerals with which they are in contact

*numbers refer to research objectives listed on pages

Table Aspects of tectonic, volcanic and magmatic evolution of the Valles caldera complex addressed by collaborating investigators.

TOPIC OF INVESTIGATION	INVESTIGATOR(S)	METHOD OF INVESTIGATION
Facies within caldera-fill units and their relationship to hydrothermal systems	Heiken, Broxton, Krier, Wohletz (LANL)	Geologic mapping, core logging, stratigraphic correlation, various petrographic techniques
Vertical variation in rock composition, VC-2B (as a guide to magmatic evolution	Goff (LANL)	Major/minor/trace element geochemistry and isotopic analysis of whole-core samples
	Wolff (UTA), Gardner, (LANL), Sykes (UTA), Self (UTA)	(Bandelier Tuff) petrographic study; geochemical analysis of whole-pumice and matrix in rhyolitic ignimbrite cores; correlation with outflow-sheet characteristics; integration of these data to model magmatic evolution
Pre- and post-eruptive volatile distributions in intracaldera rhyolites (as a guide to magmatic evolution)	Stix (UT), Gorton (UT), Williams (LSU)	Analysis of H_2O, CO_2, F, S, and Cl in melt inclusions in phenocrysts and in coexisting matrix glass
Paleomagnetic stratigraphy	Geissman (UNM)	Measurement of intensity, orientation, and polarity of paleomagnetism in core samples
Comparison of intracaldera ignimbrites with corresponding outflow sheets	Wolff (UTA), Gardner (LANL), Sykes (UTA), Self (UTA)	(Bandelier Tuff) integration of results of past field studies with petrographic, geochemical, and isotopic characterization of the Bandelier Tuff in cores from VC-2A and VC-2B
Geometry, caldera-fill characteristics, and evolution of the pre-Bandelier-age Lower Tuffs caldera	Hulen and Nielson (UURI)	(Lower Tuffs) detailed logging, petrographic examination, geochemical and isotopic analysis of cuttings from UOC geothermal wells and core from VC-2A and 2B; 3-D reconstruction of caldera
Petrography and composition of a hypothetical, subvolcanic, rhyolitic pluton beneath the VC-2B site	Musgrave (NMIMT)	Petrography, XRD
	Goff (LANL)	Major/minor/trace element geochemical and isotopic analysis of core

*numbers refer to research objectives listed on pages

Table 2. Proposed research to augment the VC-2B drilling project.

THE ACTIVE HYDROTHERMAL SYSTEM

RESEARCH TOPIC	PRINCIPAL INVESTIGATOR #	INSTITUTION
In situ sampling of fluids in geothermal wells using synthetic fluid inclusions	P.M. Bethke	U.S. Geological Survey Reston, Virginia
Studies of the natural thermodynamic conditions at the Sulphur Springs area (A1-A7, B1)*	G.S. Bodvarsson	Lawrence Berkeley Laboratory, Berkeley, California
Chemical and isotopic studies of fluids and core samples, VC-2B (A1-A7, B1)*	F. Goff	Los Alamos National Laboratory Los Alamos, New Mexico
Determination of formation thermal conductivities during drilling (A1, A7)*	R.L. Lee	New Mexico Institute of Mining and Technology, Socorro, New Mexico
Isotopic compositions of noble gases in fluids (A1-A6, B1)*	B.M. Kennedy	University of California at Berkeley, Berkeley, California
Low-frequency, saturation-dependent electrical properties of VC-2B lithologies at elevated temperatures and pressures. (A1, A7)*	L.B. Owen	Terra Tek Research, Salt Lake City, Utah
Laboratory measurement of dielectric permittivity and associated electrical properties of VC-2B lithologies (A1)*	L.B. Owen	Terra Tek Research, Salt Lake City, Utah
Quantitative fracture mapping of VC-2B core (A1, A7)*	L.B. Owen	Terra Tek Research, Salt Lake City, Utah

*refers to specific research objectives listed on pages 52-54, 59-61, 64-66

#for a full listing of all collaborating investigators and istitutions, please refer to Appendix 1.

Table 2, continued. Proposed research to augment the VC-2B drilling project

THE ACTIVE HYDROTHERMAL SYSTEM

RESEARCH TOPIC	PRINCIPAL INVESTIGATOR #	INSTITUTION
Thermal conductivity, heat flow, and hydrothermal regime of VC-2B, Valles caldera, New Mexico (A1, A3-A7, B1)*	J.H. Sass	U.S. Geological Survey, Flagstaff, Arizona
In-situ stress azimuth information from VC-2B core (A1, A7)*	A. Sattler	Sandia National Laboratory, Albuquerque, New Mexico
In-situ stress and fracture analysis using borehole televiewer log and core (A1, A7)*	J. Vernon	Los Alamos National Laboratory, Los Alamos, New Mexico

EVOLUTION OF THE HYDROTHERMAL SYSTEM
FLUID-ROCK INTERACTION, ALTERATION, AND MINERALIZATION

RESEARCH TOPIC	PRINCIPAL INVESTIGATOR	INSTITUTION
Illite and illite-smectite geothermometry (A1, B1, B3)*	J.M. Ballantyne	University of Utah Research Institute, Salt Lake City, Utah
Halogens and noble gas isotopes in fluid inclusions (B1, B5, B6)*	J.K. Bohlke	Argonne National Laboratory, Argonne, Illinois
Characterization of the conductive-convective zone (A5, A7, B1, B2, B4-B6)*	W.E. Elston	University of New Mexico, Albuquerque, New Mexico
Mineralogy and composition of hydrothermal alteration (A1, A4-A6, B-1, B3, B4-B6)*	D.R. Janecky	Los Alamos National Laboratory, Los Alamos, New Mexico

* refers to specific research objectives listed on pages 52-54, 59-61, 64-66

for a full listing of all collaborating investigators and institutions, please refer to Appendix 1.

Table 2, continued. Proposed research to augment the VC-2B drilling project

EVOLUTION OF THE HYDROTHERMAL SYSTEM
FLUID ROCK INTERACTION, ALTERATION, AND MINERALIZATION

RESEARCH TOPIC	PRINCIPAL # INVESTIGATOR	INSTITUTION
Evolution of the Valles caldera hydrothermal system -- Evidence from natural radionuclides of the uranium-thorium series and rare earth elements (A1, B1, B2)*	J.C. Laul	Batelle Pacific Northwest Laboratory, Richland, Washington
Chemical evolution and mineralization of the Sulphur Springs area (A1-A7, B1-B6)*	J.A. Musgrave	New Mexico Institute of Mining and Technology, Socorro, New Mexico
Gas contents of fluid inclusions in authigenic vein minerals from VC-2B (A1, A2, A6, B1, B5, B6)*	M.A. McKibben	University of California at Riverside, Riverside, California
Origin and migration of sulphur in the Valles caldera hydrothermal system -- A SHRIMP ion microprobe and conventional isotopic study (A1, A2, A4, A6, B1, B5, B6)*	M.A. McKibben	University of California at Riverside, Riverside, California
Microthermometry of fluid inclusions in minerals from VC-2B (A1, B1, B6)*	M. Sasada	Geological Survey of Japan
Uranium-series studies -- Ages of hydrothermal veins, radioisotope hydrology, and rates of mass transport (A1, B1, B2)*	N.C. Sturchio	Argonne National Laboratory, Argonne, Illinois
Fossil hydrothermal systems in the Jemez volcanic field (A1, B1, B2)*	G. W-Gabriel	Los Alamos National Laboratory. Los Alamos, New Mexico
Natural radioelements in caldera-fill and subcaldera rocks (A1, B1, B5)*	H. Wollenberg	Lawrence Berkeley Laboratory, Berkeley, California

* refers to specific research objectives listed on pages 52-54, 59-61, 64-66
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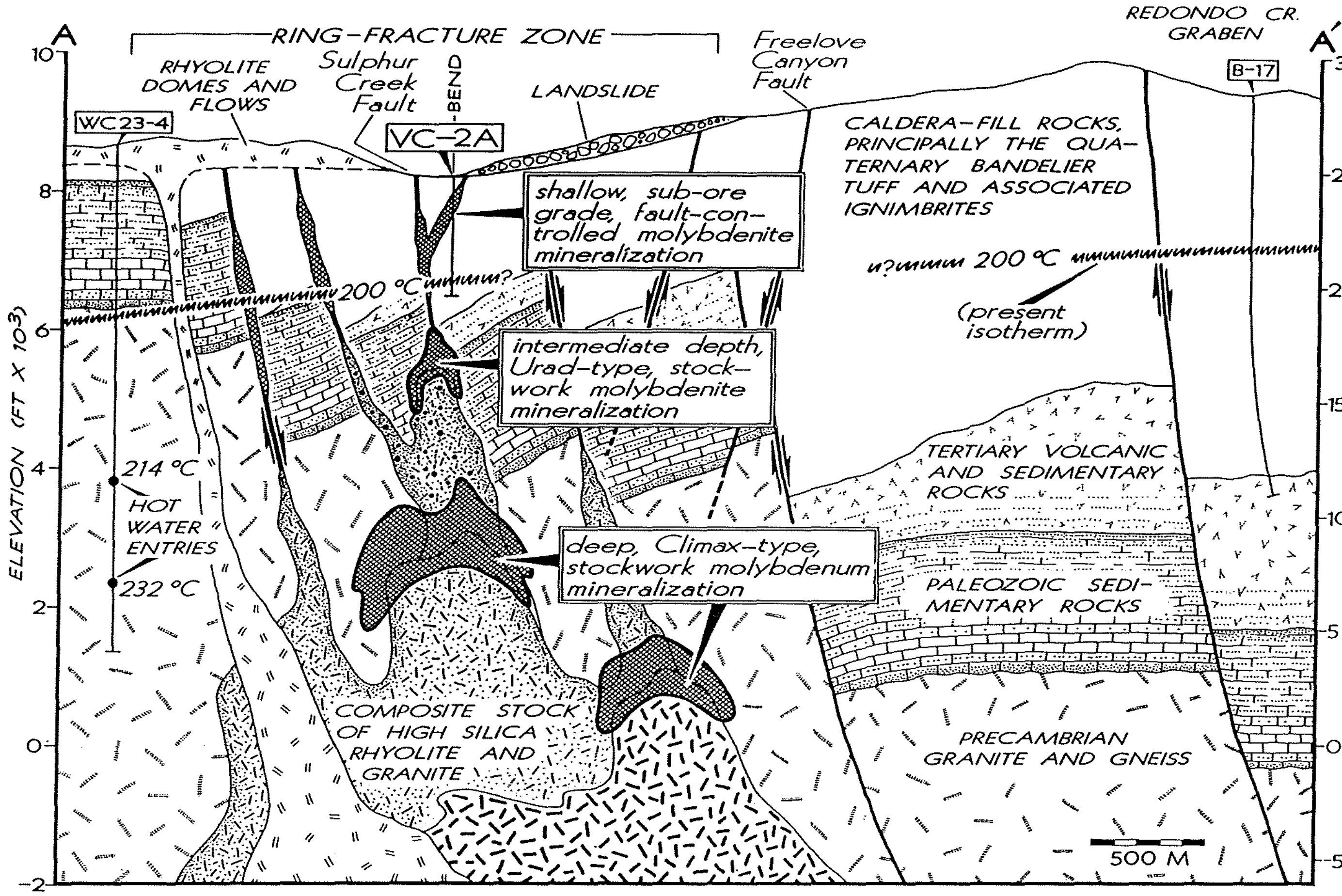

(Looking North)

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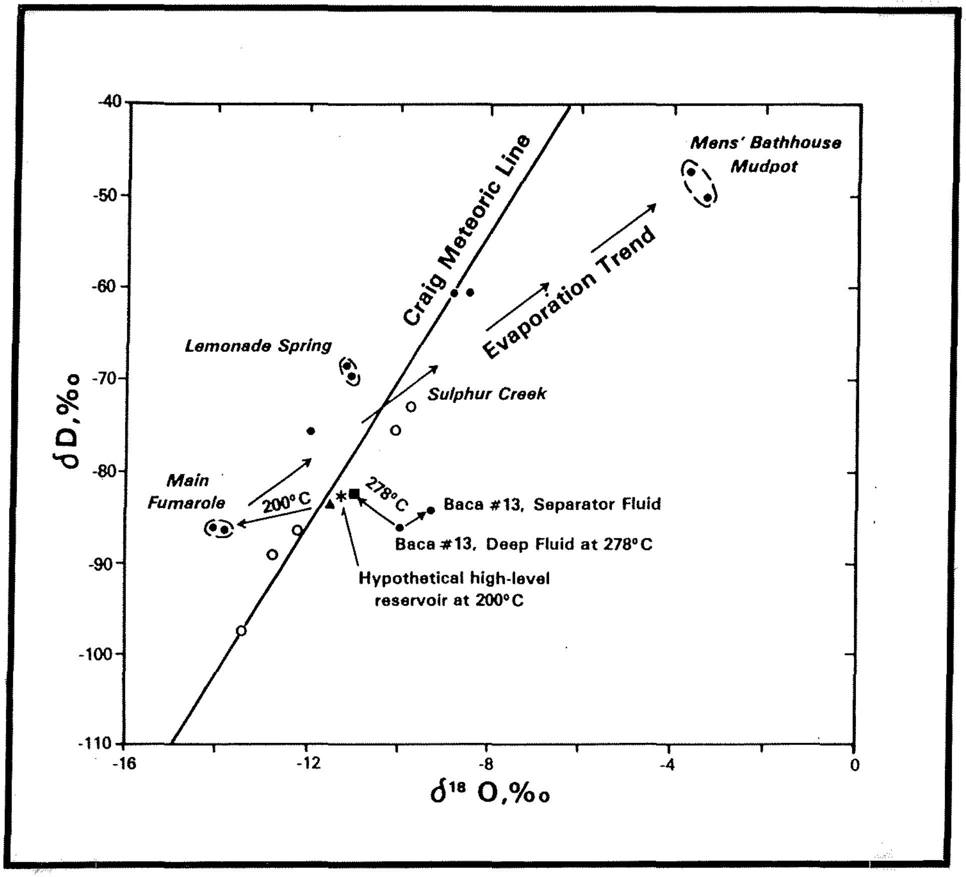
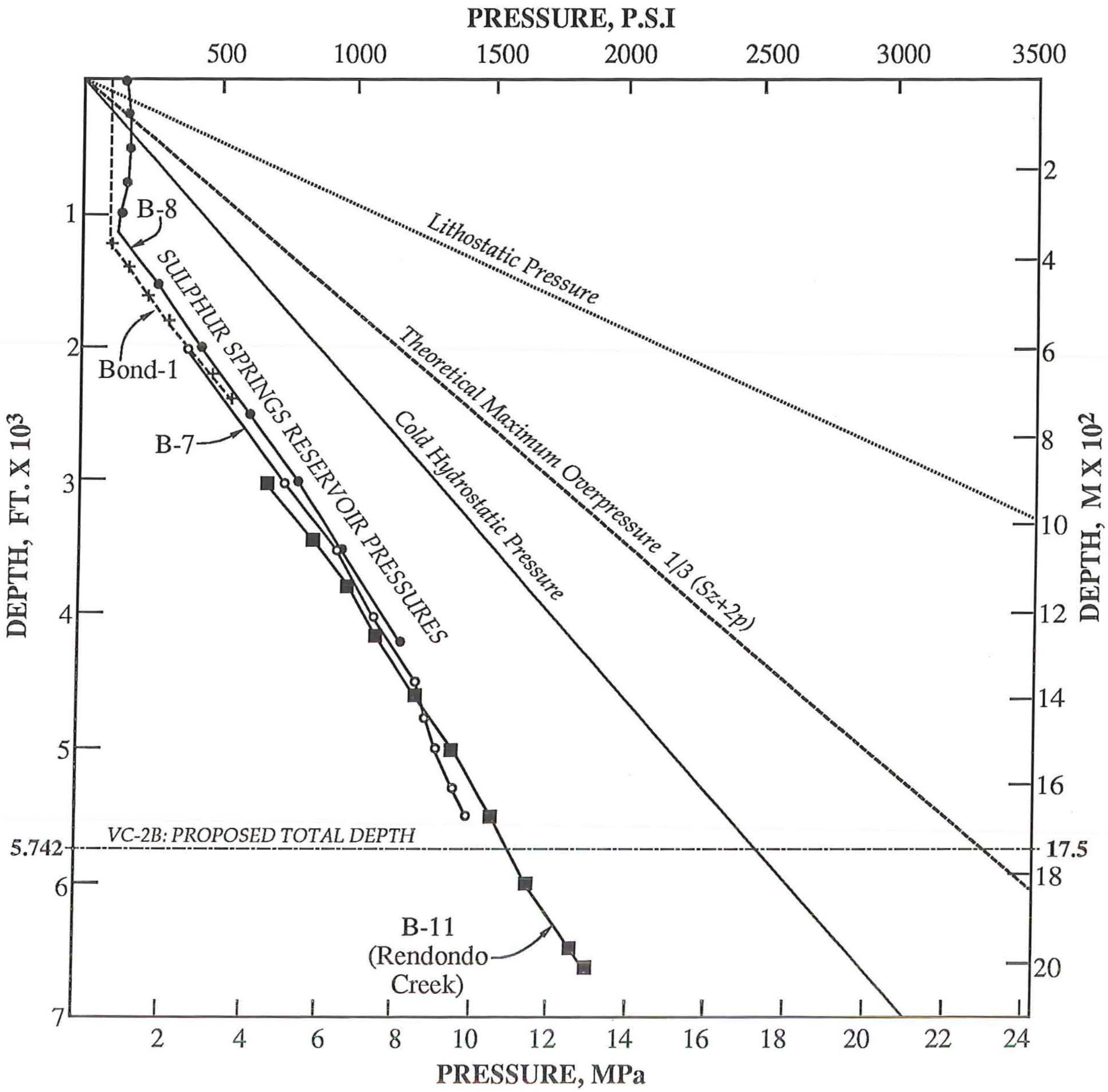


Figure 13. Plot of deuterium vs. oxygen-18 from geothermal and surface meteoric waters, Sulphur Springs area. Open circles denote meteoric fluids; dots denote thermal fluids; square represents composition of steam produced by single-stage boiling of reservoir fluid from well B-13 (Fig. 2) at 278°C; triangle represents composition of parent water that produces fumarole steam by single-stage boiling at 200°C; star represents a hypothetical, high-level reservoir at 200°C beneath Sulphur Springs. (From Goff et al., 1985)



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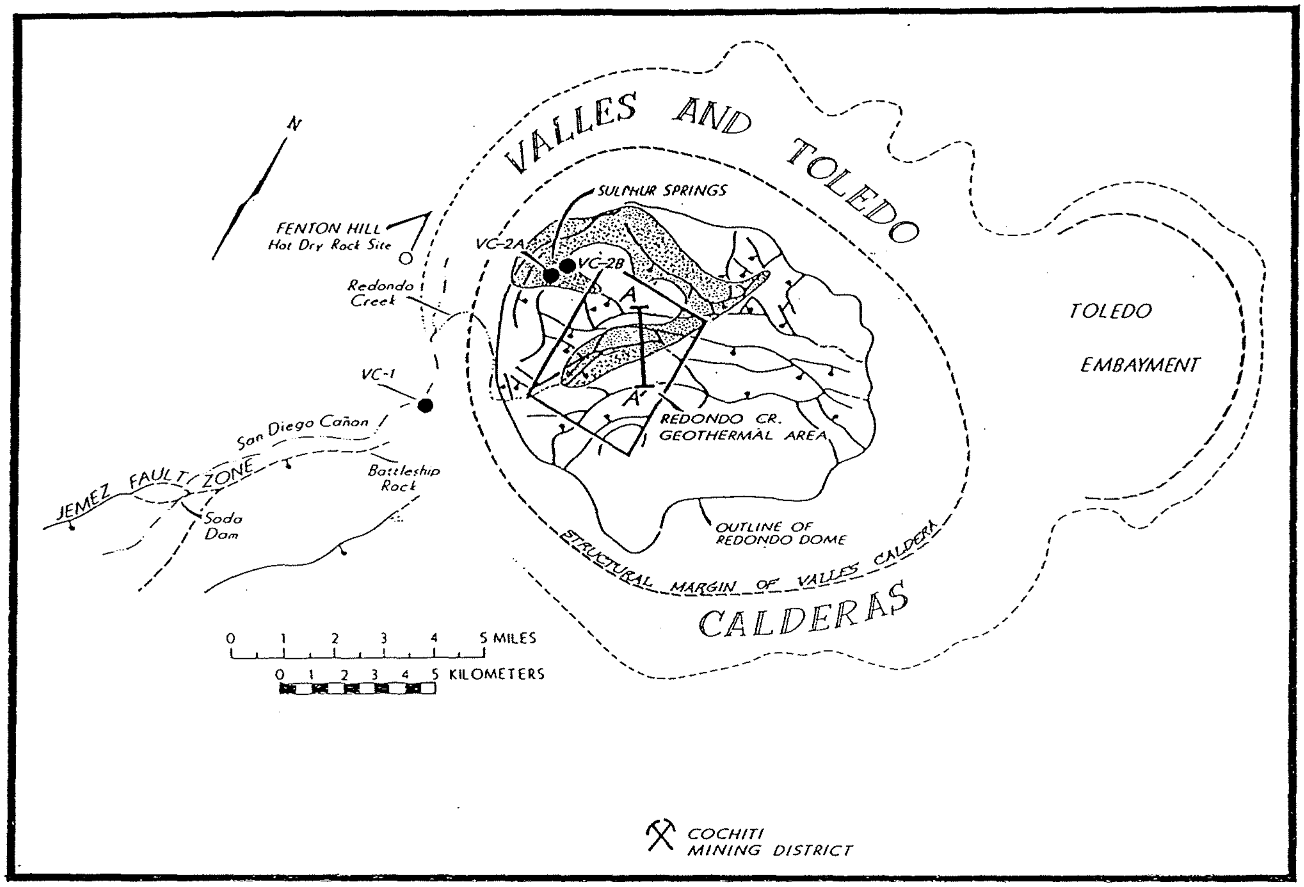
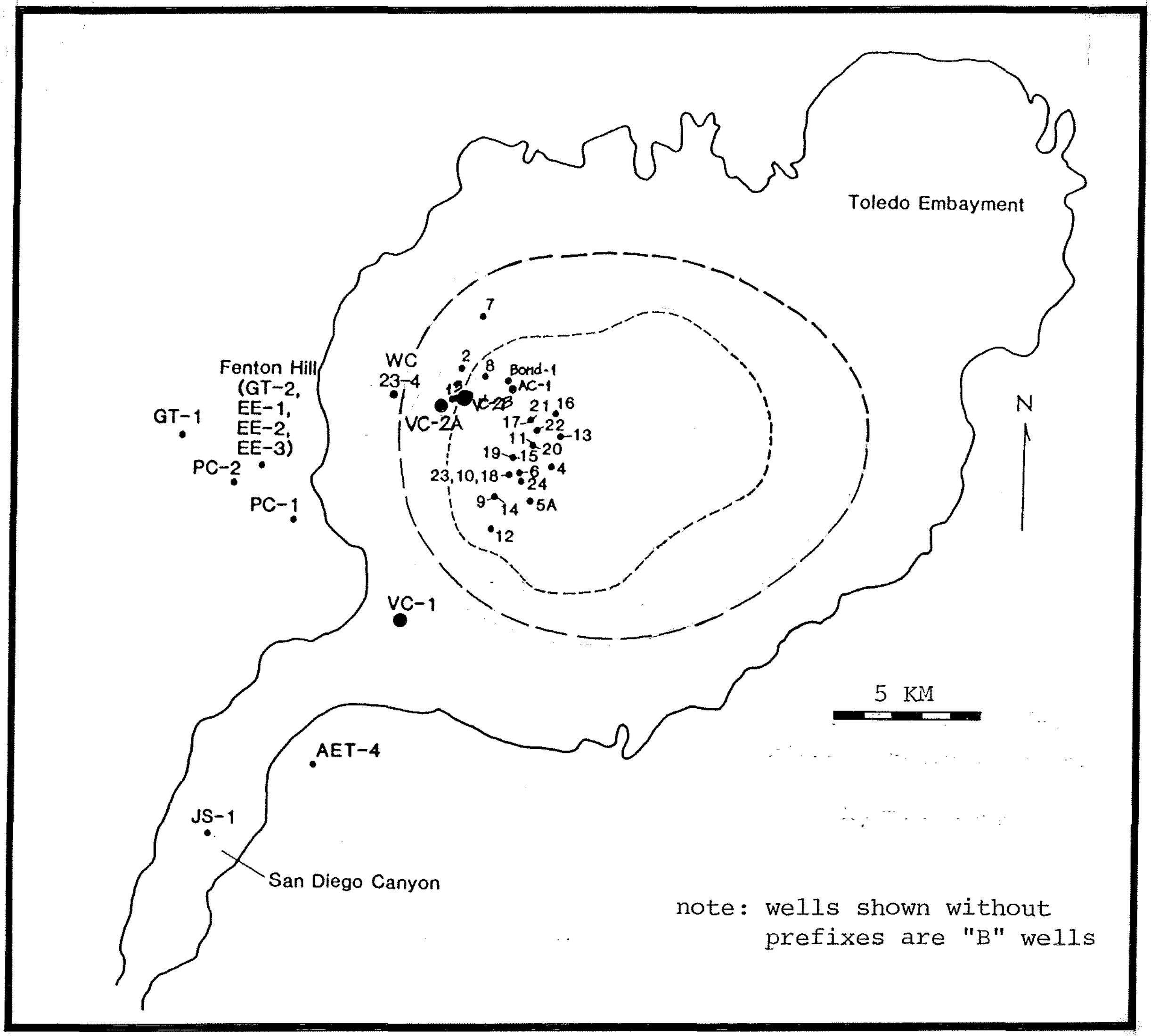


Location map, showing extent of active or recent surficial alteration (stippled pattern) in the Valles caldera complex. Also shown are locations of scientific coreholes VC-1, VC-2A and VC-2B as well as the Miocene mineralization of the Cochiti mining district. Note location of alteration cross-section A-A' (Figure B) through the apical graben of the Valles caldera's resurgent dome.



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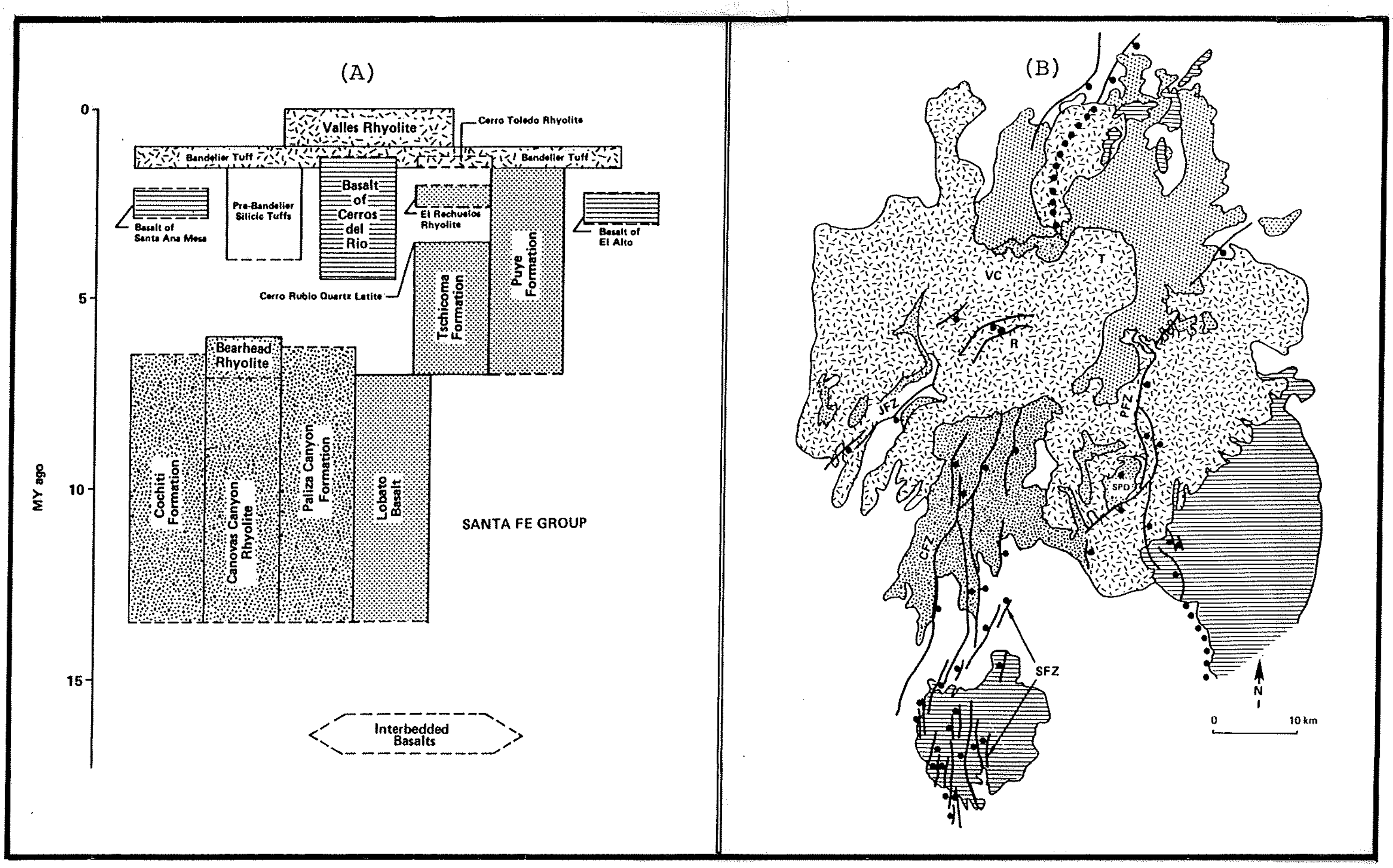

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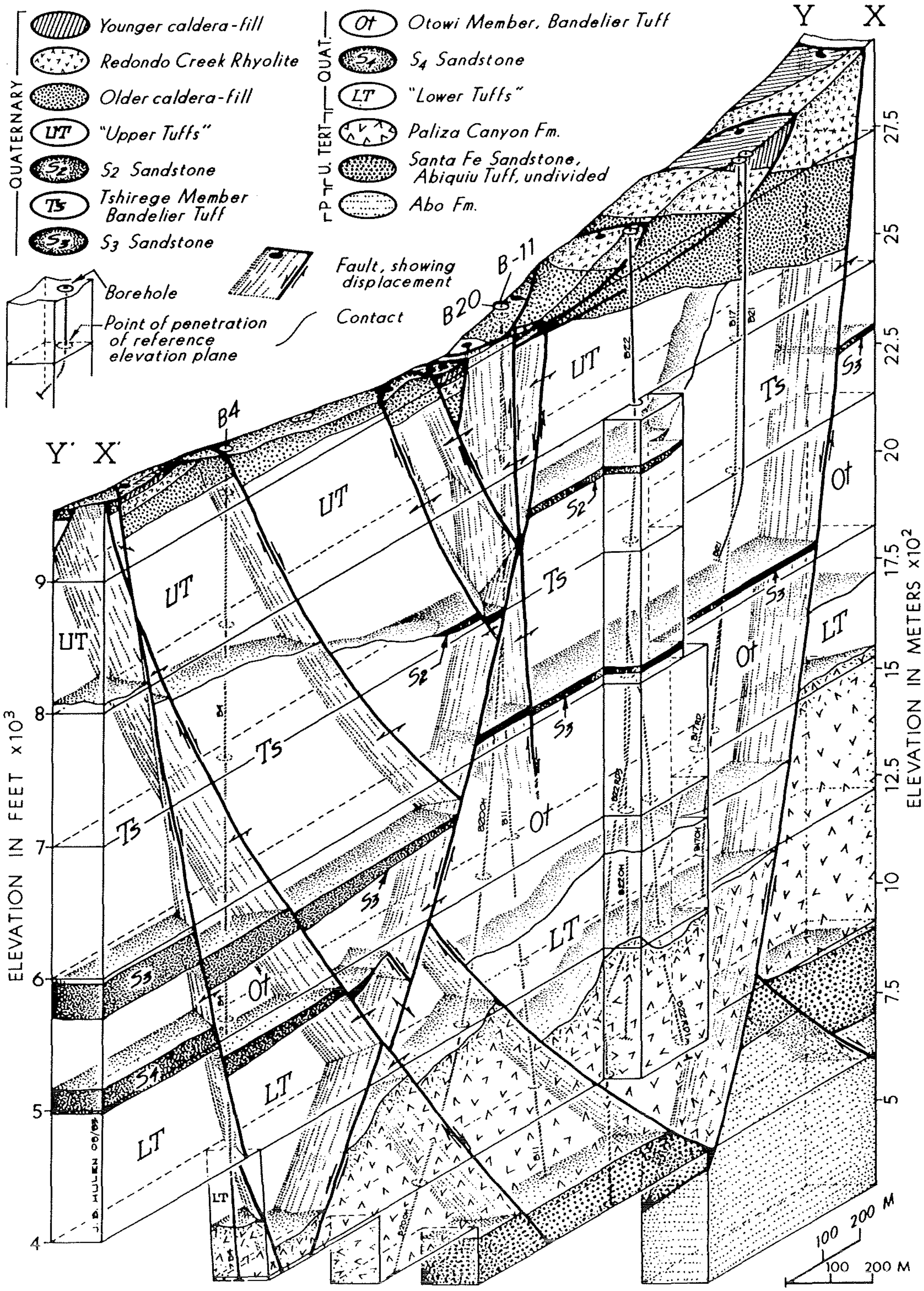

(Looking Southwest)

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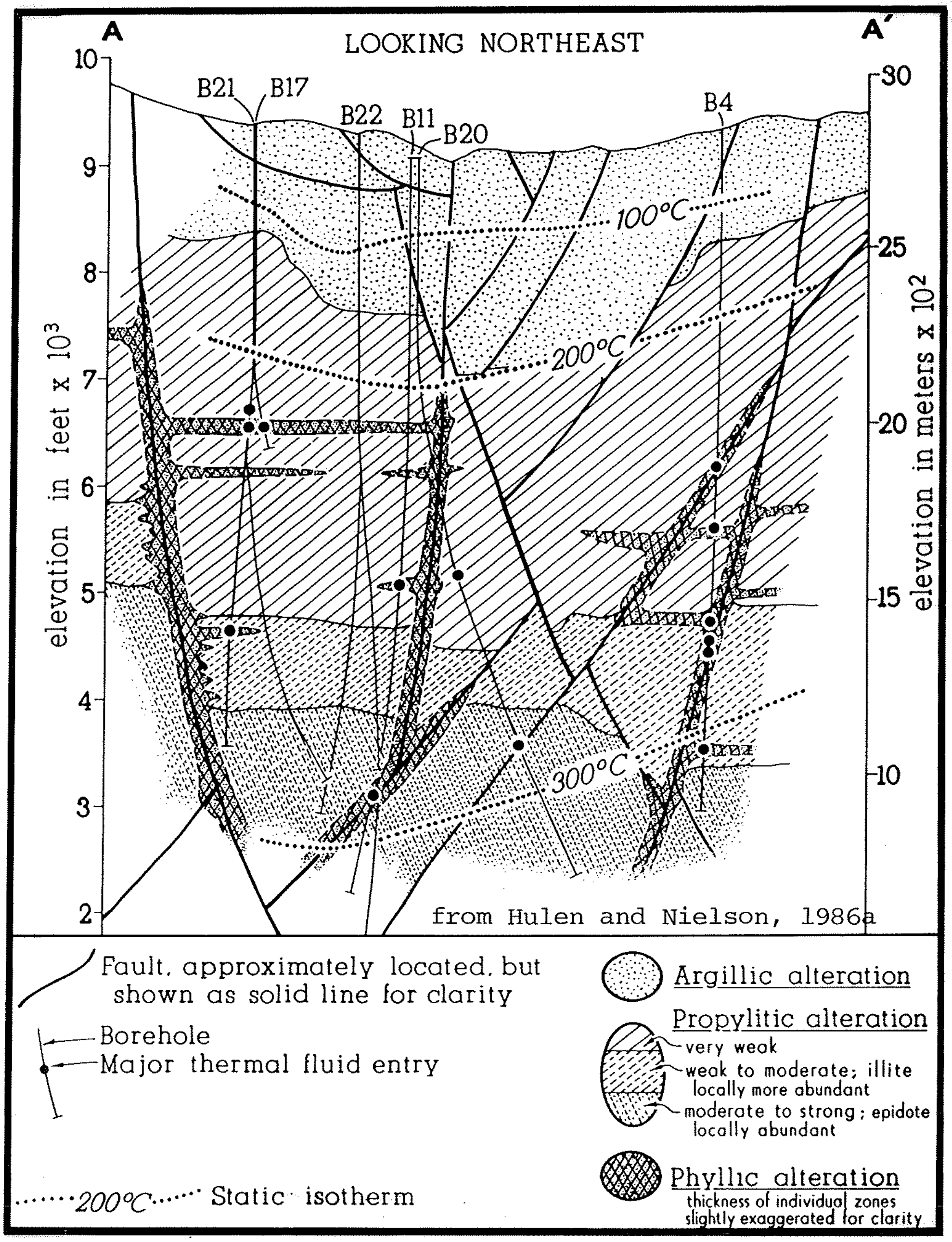

Figure 7. Generalized northwest-southeast hydrothermal alteration cross-section through the medial graben of the Valles caldera's resurgent dome (Redondo Creek area) with control provided by UOC geothermal wells. Corresponds to geologic cross-section of Figure 5, except viewed from the southwest.

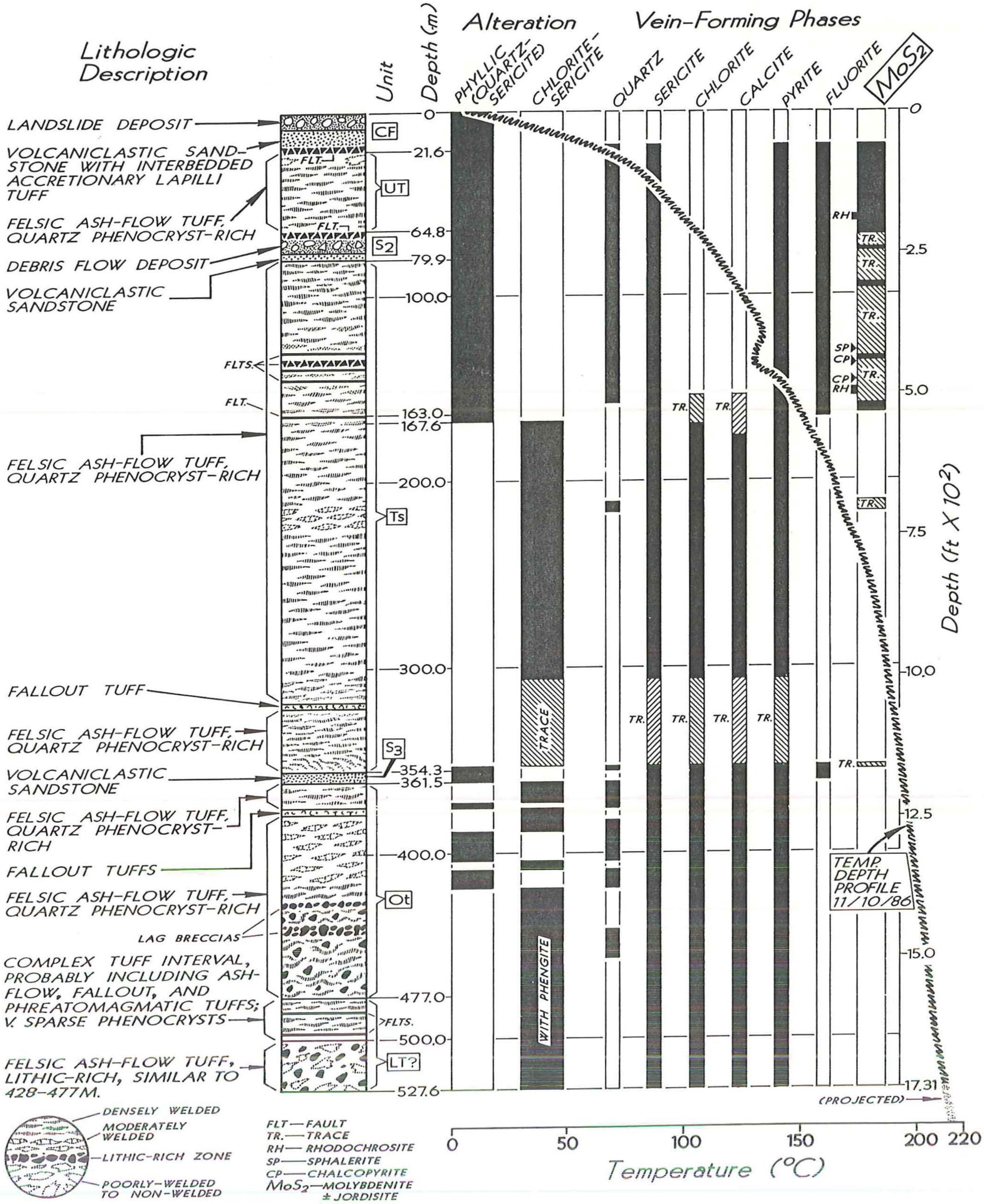

Figure 9. Generalized lithologic, structural, alteration, and vein mineralization log for CSDP corehole VC-2A (modified from Hulen et al., 1987). Please refer to Table 1 for abbreviations of stratigraphic units.

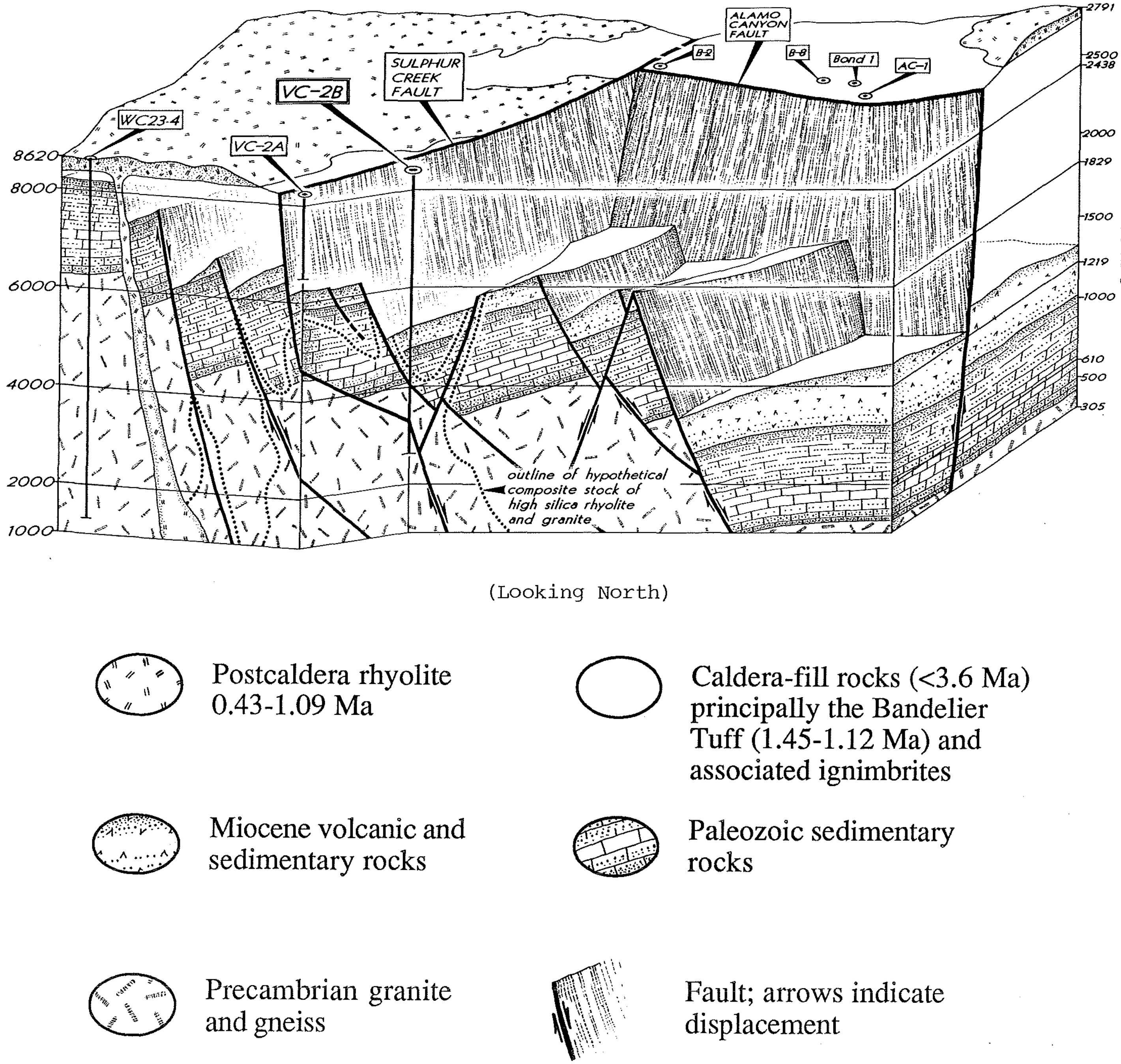

Figure 10. Geologic block diagram showing interpreted subsurface structure and stratigraphy in the Sulphur Springs area of the west-central Valles caldera complex. For location, please refer to Figure 8. Caldera-fill units south of the Alamo Canyon fault and east of the Sulphur Creek fault are stripped away in the drawing to show conceptually complex configuration of basement rocks in the floor of the caldera. Wells B-1 and B-3 not shown for clarity. Surface geology from Goff and Gardner (1980).

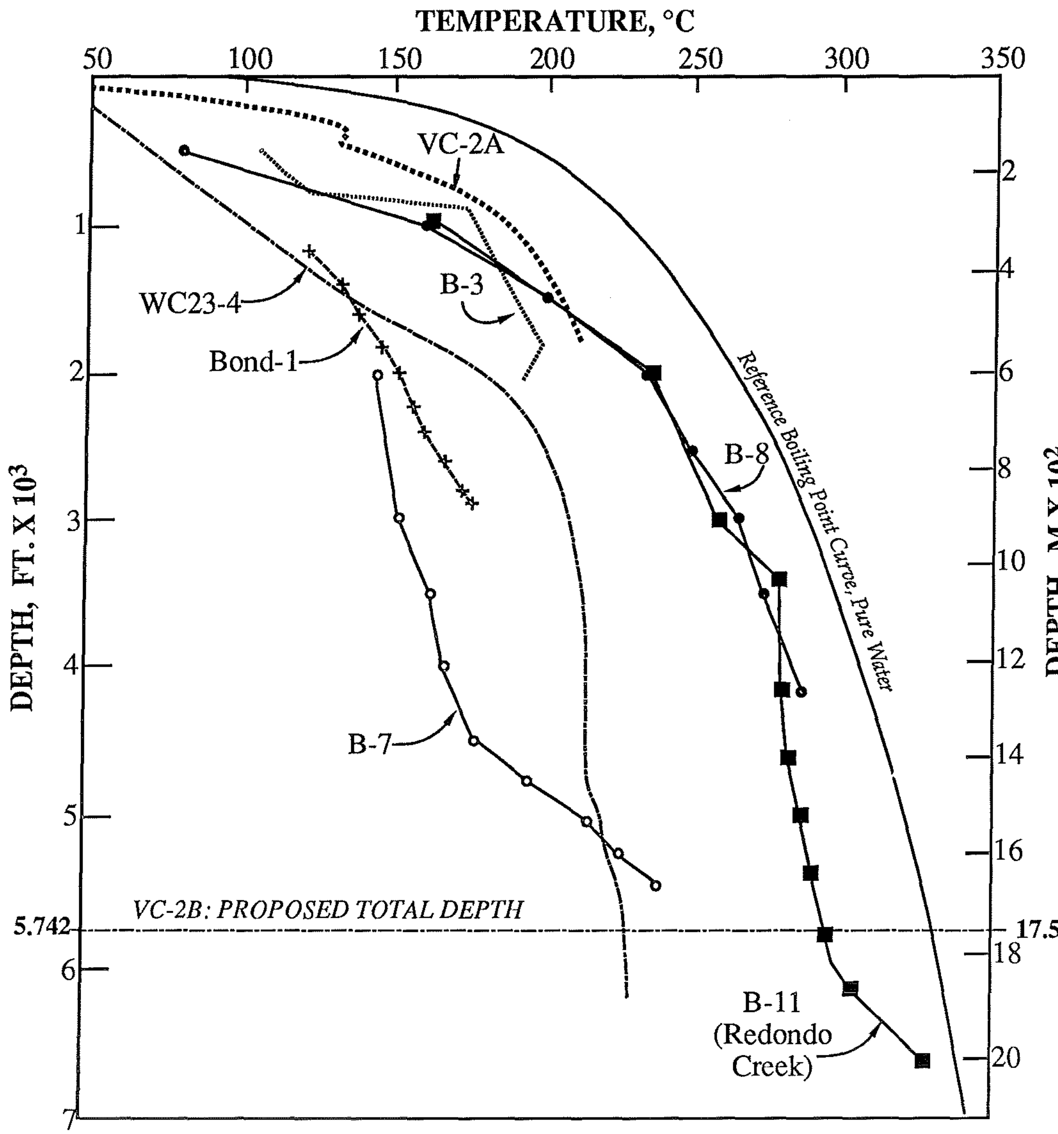

Figure 11. Temperature surveys for geothermal wells and CSDP corehole VC-2A, Sulphur Springs area. Shown for comparison is a temperature survey for well B-11, in the Redondo Creek area. Data from UOC (1982) and Dondanville (1971) (B-1 to B-11, Bond-1); Goff et al. (1987) (VC-2A); Shevenell et al. (1987) (WC-23-4).