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CLAY MINERAL FABRICS AMD CHEMISTRY IN SALTON TROUGH GEOTHERMAL FIELDS

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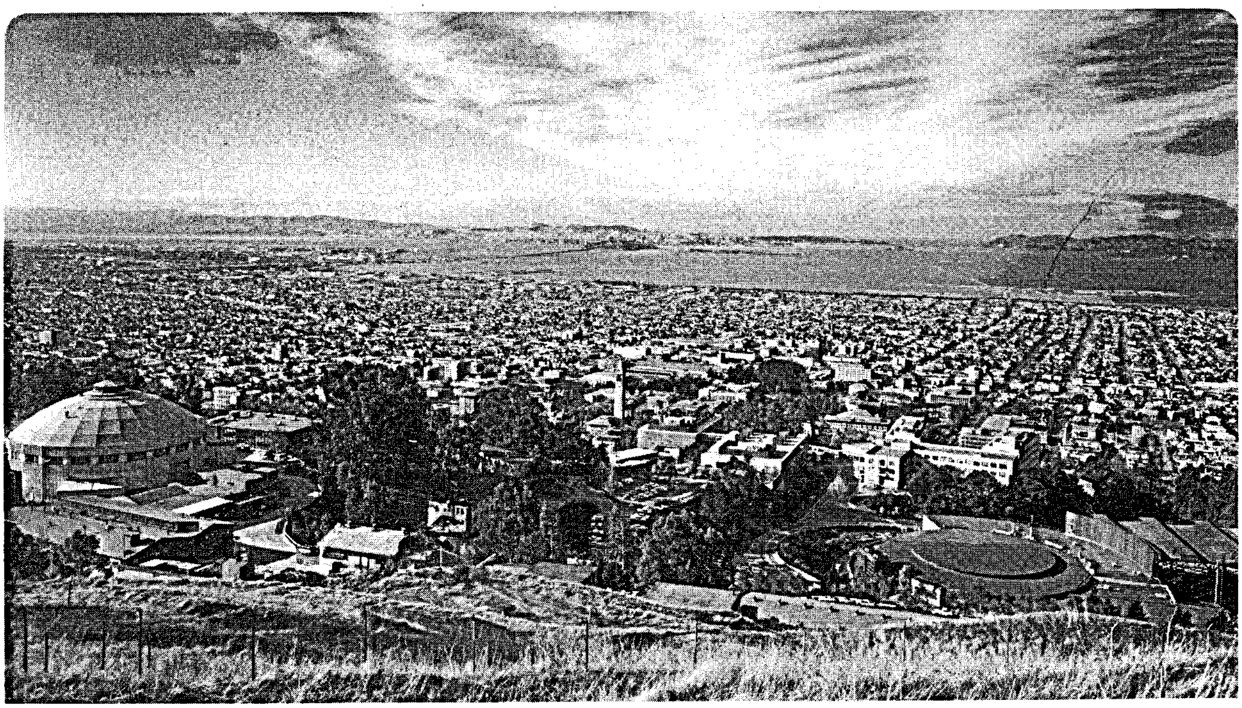

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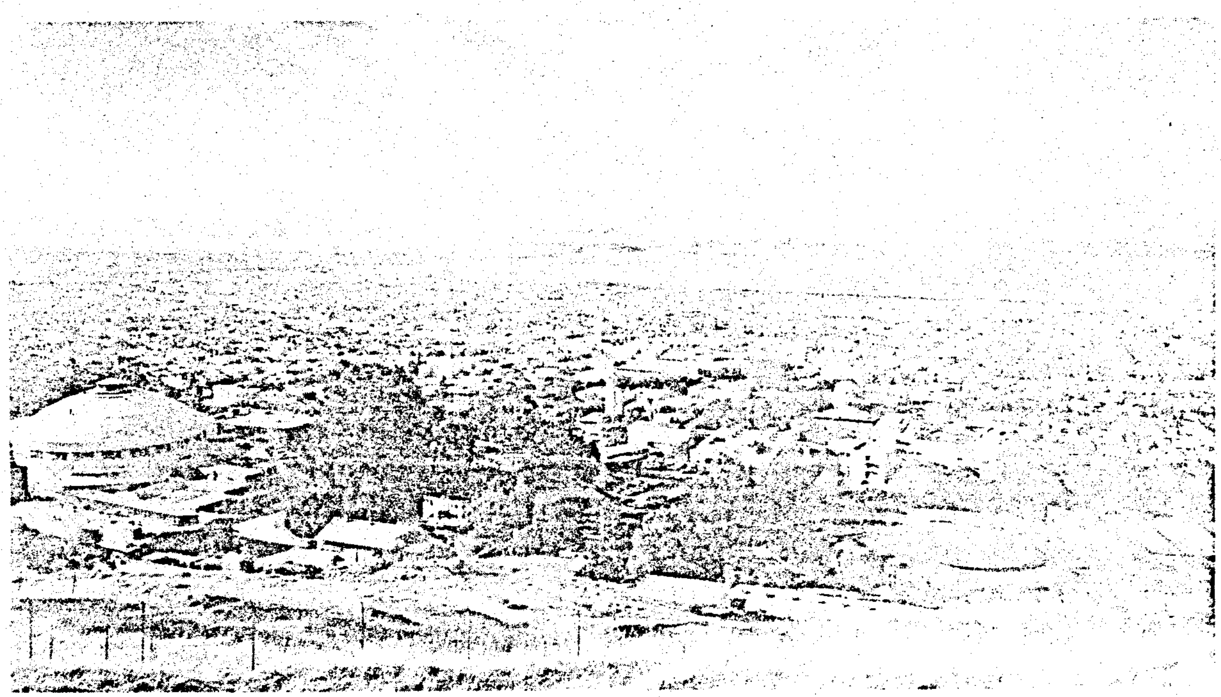

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ABSTRACT

Fluid production from, and hence the economic viability of, a geothermal field is related to the amount of clay minerals in the caprock and in the reservoir rocks. In both the East Mesa and Cerro Prieto fields in the Salton Trough of southern California, United States, and Baja California, Mexico, scanning electron micrography (SEM) has vividly documented the role of clay fabrics in deltaic quartz-sandstone reservoirs. For example, in East Mesa well 78-30 at 1630 m depth in a zone of quartz dissolution, the clay present in pores exhibits an irregular, crenulate, honeycomb fabric and has the following composition from energy dispersive x-ray analysis (EDAX): Si 61%, Al 25%, Fe 20%, Na 6%, K 2%, and Mg 1%. Platy clusters of clay (kaolinite?) in Cerro Prieto well T-366 at 2522 m in a 300°C geothermal aquifer were analyzed as: Si 62%, Al 25%, Mg 6%, and Fe 1%. In other samples, illite (?) takes the form of wispy fibers whose intertwined ends form bridges across pores. These clay fabrics appear to reduce permeability significantly by clogging the pore throats, even though dissolution porosity ranges from 25 to 35%. Nineteen wells have been studied to date.

INTRODUCTION

The importance of clays has been noted in the study of subsurface fluid movement for many years. In the moderate temperatures of petroleum reservoirs, an understanding of clays is critical for drilling and completion in pay zones (Wilson and Pittman, 1977; Almon and Davies, 1978). The role of clays in higher-temperature geothermal fields has also been studied. For example, at depths from 675 to 1350 m, hydrothermally precipitated montmorillonite in the basalts of well HGP-A at Puna, Hawaii, aids in forming a relatively impermeable caprock (Fan, 1978). At the Krafla field in Iceland, smectite in the lavas from 200 to 450 m depth forms a similar capping zone (Gíslason and others, 1978). Our ongoing study is an attempt to find out whether determination of the clay fabrics and clay chemistry in geothermal fields will allow us to predict zones of variable permeability within the reservoirs, as well as in the caprock. This report is an expanded version of a poster-session presentation made at the annual conference of the Clay Minerals Society, October 5-7, 1980, in Waco, Texas.

DATA AND COMMENTS

The geothermal province under consideration is the Salton Trough in southern California and northern Mexico (Figure 1). Much of our effort has focused on the Cerro Prieto field (Figure 2), which has an installed electric capacity of 150 MWe. Production may exceed 400 MWe in the late 1980s. More than sixty-five wells have been drilled in the deltaic sandstones and shales to depths ranging from 1.5 to 3.2 km. Fluid temperatures range up to 350°C, and total dissolved solids are approximately 20 parts per thousand. Details of research on Cerro Prieto can be found in the symposia volumes (Reed, 1975; Lawrence Berkeley Laboratory, 1978; Comisión Federal de Electricidad, 1979).

The East Mesa geothermal field has approximately nineteen wells. The maximum depth drilled is 2.7 km with temperatures up to 200°C and total dissolved solids ranging from 2 to 20 parts per thousand (see Howard and others, 1978, for details).

Previous research in the Cerro Prieto reservoir has indicated extensive dissolution porosity at depth (Lyons and van de Kamp, 1980; Noble and Vonder Haar, 1980). Figures 3, 4, 5, and 6 illustrate this work, which has been augmented by recent Terra Tek studies (Abou-Sayed and others, 1979; Schatz and others, 1980).

Research by Elders and others (1981) using computerized x-ray diffraction techniques have provided useful information on the clay mineralogy at Cerro Prieto. These data suggest a transition from kaolinite and montmorillonite at 175°C and approximately 1 km depth to illite and chlorite in a zone that extends to about 240°C. The chlorite/illite ratio increases with depth and temperature. The x-ray analyses of bulk well cuttings indicate that the reservoir sandstones consist of 5 to 25% clay. Our work centers on the clay fabrics and their suggested influence on porosity and permeability.

The SEM and EDAX data are presented in Table 1 and in Figures 7 through 18; interpretations are provided in the figure captions. Note the minor variation in Mg and K percentages from samples with similar fabrics in Table 1.

TABLE 1. Chemical data from EDAX analyses, fabrics from SEM.

Well	Depth	Si	Al	Mg	K	Ca	Fe	Na	Fabric*
Cerro Prieto									
NL-1	2720	46	16	15	13	—	10	—	stacked plates
	2720	33	9	6	15	—	37	—	stacked plates
	2720	58	10	9	6	9	9	—	stacked plates
	2720	54	10	10	5	11	10	—	tangled hairs
	2720	48	12	12	14	—	13	—	smeared plates
	2720	56	10	10	11	—	12	—	stacked plates
	2720	51	13	12	13	—	11	—	stacked plates
M-38	1215	45	24	18	3	—	10	—	thin plates
	1215	54	19	11	3	—	12	—	smeared plates
	1215	57	23	4	11	2	4	—	shale
	1215	56	24	7	8	—	6	—	shale
M-3	2203	54	27	10	—	—	9	—	honeycomb
	2203	58	23	7	9	—	3	—	mixed and smeared honeycomb
	2203	51	29	11	3	—	5	—	honeycomb
	2203	58	20	—	23	—	—	—	clay? lathe shaped
	2203	47	36	14	—	—	3	—	collapsed honey-comb
	2203	53	32	13	—	—	3	—	honeycomb
	2203	56	29	12	—	—	3	—	honeycomb
M-93	1566	58	22	1.6	2	0.4	12	4	smeared, no clear fabric
T-366	2522	62	25	6	6	—	1	—	layered platelets
	2522	48	17	13	12	—	9	—	interlaced hairs
East Mesa									
78-30	1680	61	10	1.1	1.8	0.3	20	5.8	honeycomb
	1680	50	29	7	3.7	0.7	8	1.6	wispy, plus honeycomb
	1680	33	18	1.6	6	16	22	4.4	honeycomb (in microfracture)
	1680	60	23	—	16.5	—	0.5	—	wispy, plus honeycomb

*In sandstone pores except where the rock is noted as shale.

Further study is needed to determine if such variation is of diagnostic use for permeability studies. EDAX geochemical data are best considered semi-quantitative rather than exact. In general, we have found three types of clay fabrics in the Cerro Prieto and East Mesa samples:

1. A crenulate honeycomb as in Figure 13, with Si 52%, Al 31%, Mg 12%, Fe 5%, K trace?; or as in Figure 14, with Si 53%, Al 20%, Fe 12%, K 8%, Na 4%, Ca trace?
2. Plates as in Figures 10 and 16, with Si 48%, K 15%, Fe 15%, Al 12%, Mg 10%, Ca trace?
3. Hair-like clays, difficult to analyze by EDAX (one analysis showed Si 48%, Al 17%, Mg 13%, K 12%, Fe 9%).

Our working hypothesis, based on microphoto interpretation, is that these clays, collectively, clog pore throats between sand grains, thus reducing permeability even when dissolution porosity ranges from 25 to 35%, as shown in Figures 3 and 4. Additional work is needed to test this concept. We have been cautious about applying names to these clays without further comprehensive work, and refer interested parties to the nomenclature recommendations of Bailey and others (1980).

The East Mesa and Cerro Prieto geothermal fields appear to be natural laboratories for documenting accelerated clay mineral alteration and diagenesis in deltaic sandstones. Previous work has not taken into account the detailed role of clays on permeability and hence recoverable energy. Our data reveal enough variation in clay fabric and clay chemistry to warrant further investigation. Such a study could significantly augment the understanding of similar resources worldwide.

ACKNOWLEDGMENTS

Special thanks are due our colleagues at the Comisión Federal de Electricidad for their help. Marcelo Lippmann, Jack Howard, and Ruben Zelwer of Lawrence Berkeley Laboratory have given many useful suggestions, and Ellen Gailing has provided excellent coordination.

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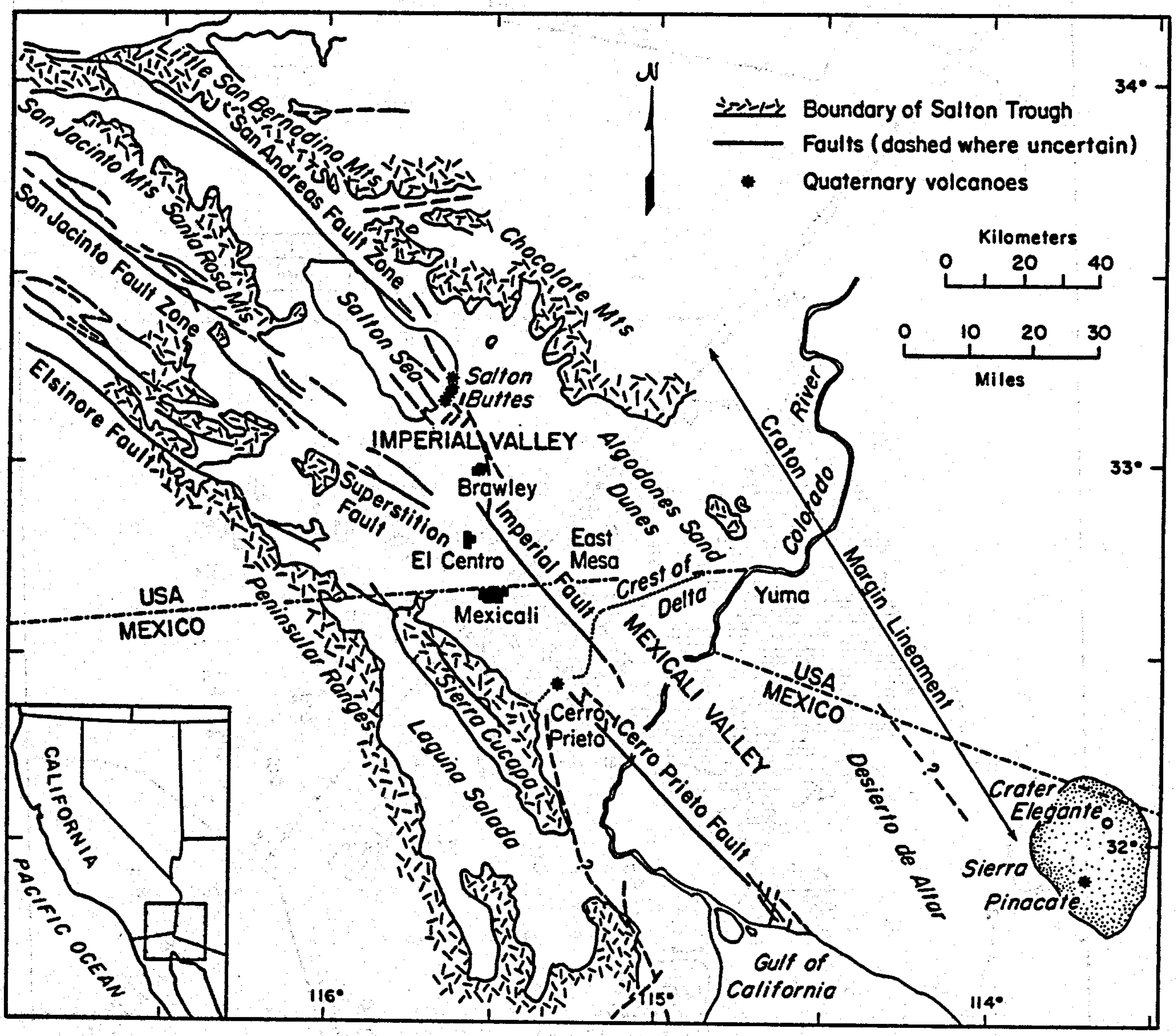

Figure 1. Location of the Cerro Prieto and East Mesa geothermal fields in the Salton Trough.

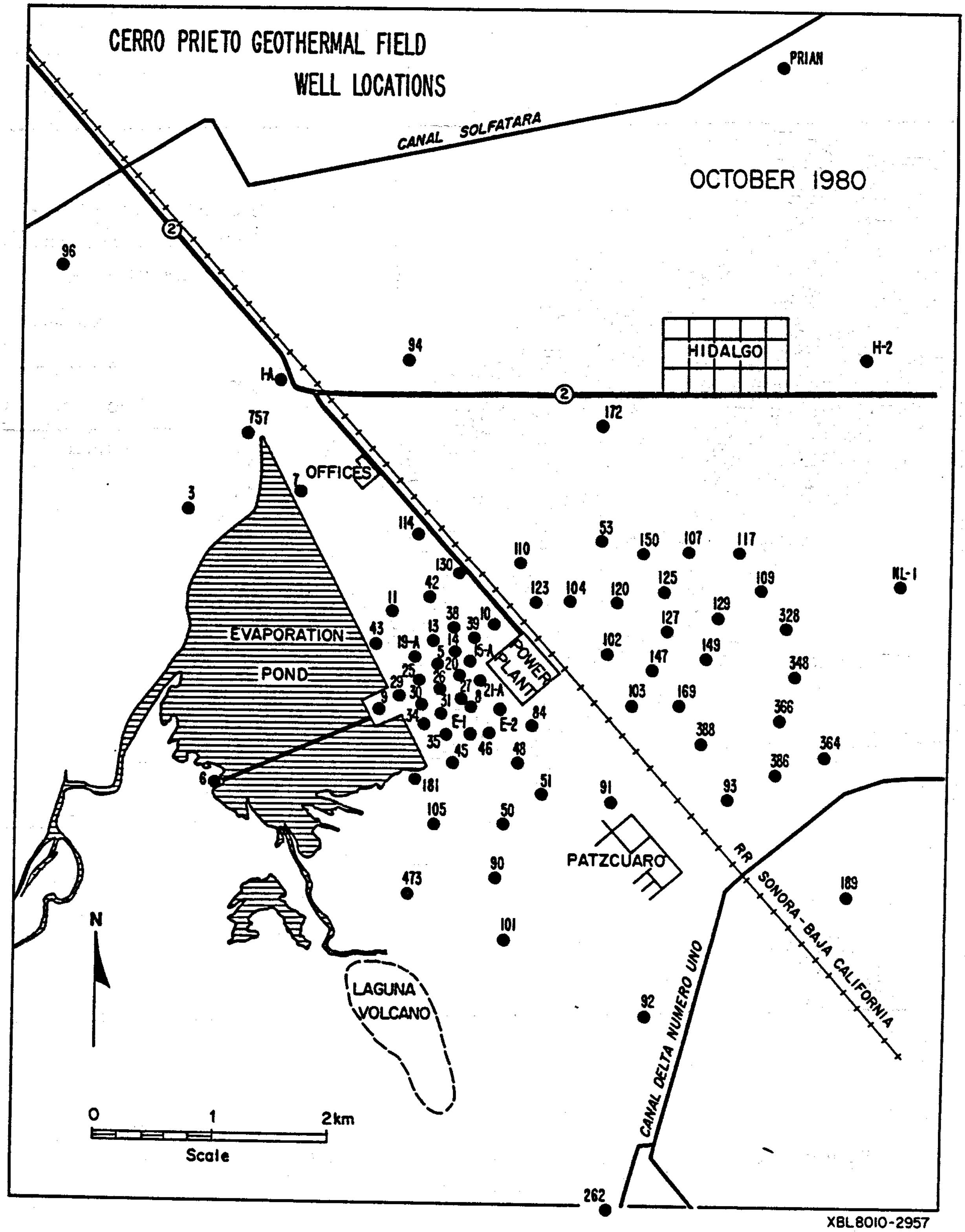

Figure 2. Cerro Prieto well locations (also refer to Table 1). To date, cores from nineteen wells have been analyzed using SEM.

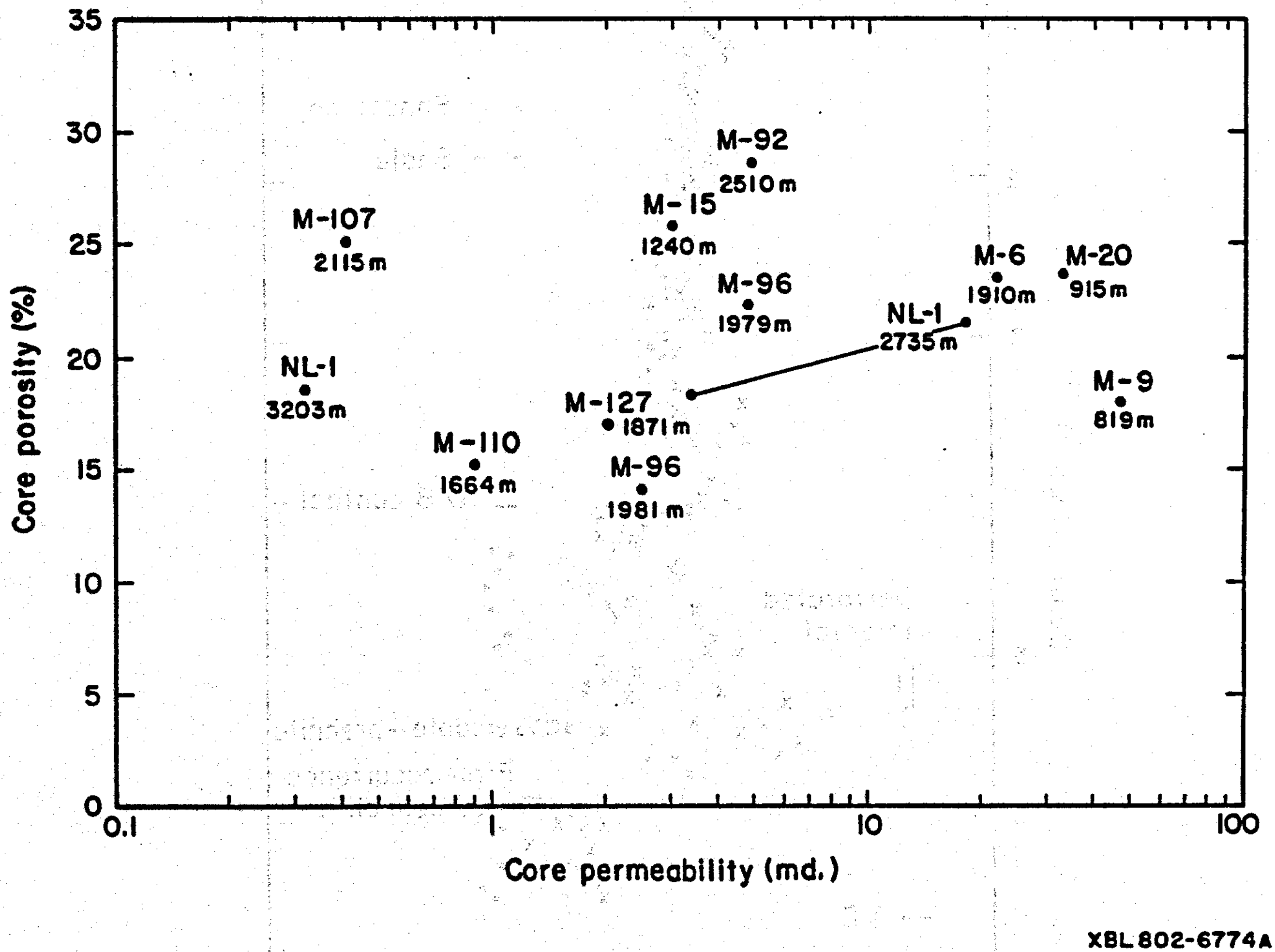

Figure 3. Permeability and porosity summary as determined by conventional Core Lab techniques for Cerro Prieto cores. Well names shown by M-107, M-96, etc. Depths are in meters from the surface. The core for well NL-1 at 2735 m shows a range in values as noted by the connecting line.

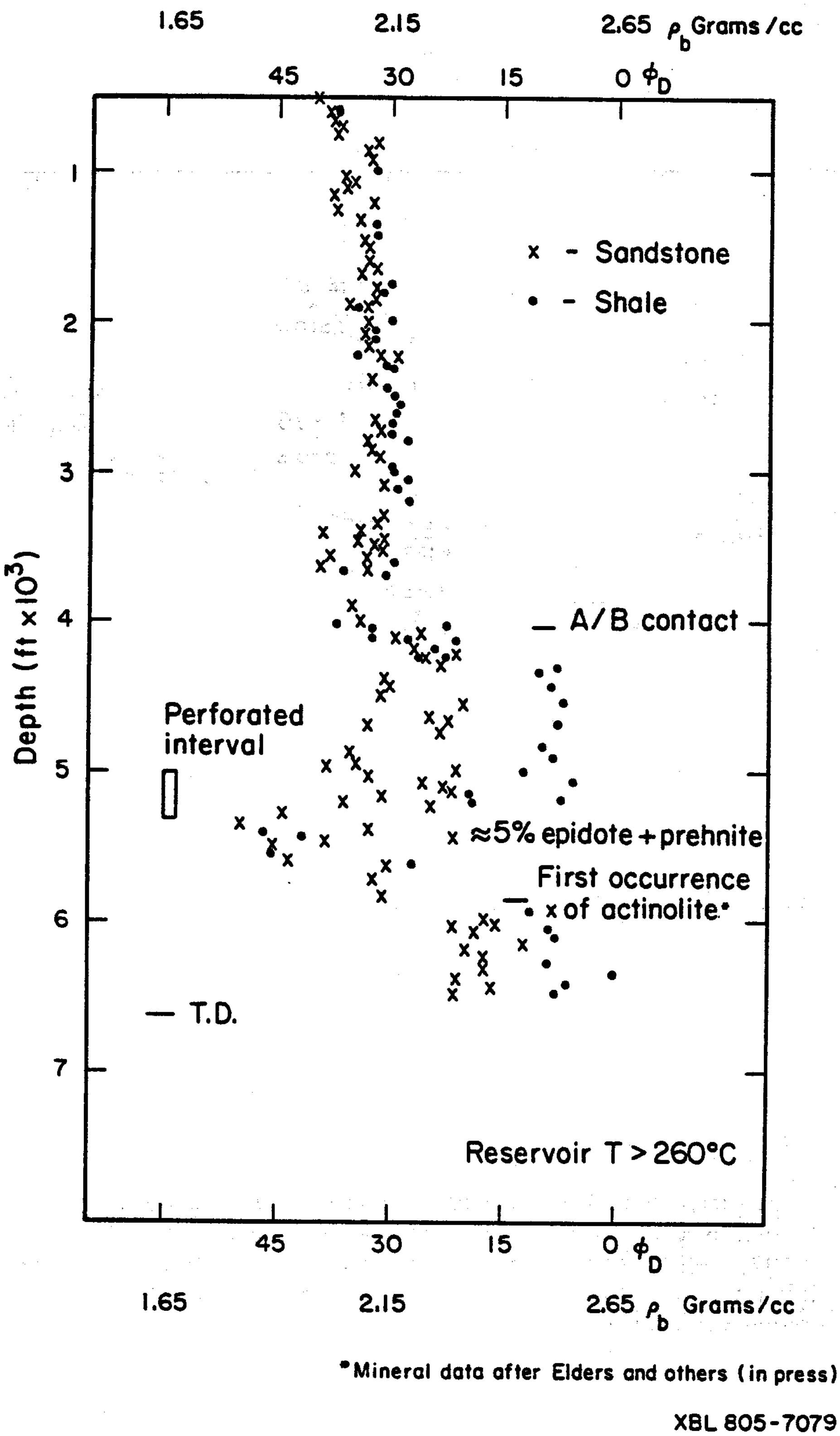

Figure 4. Porosity and density plot versus depth for Cerro Prieto well M-103 from downhole electrical logs. The variable porosity below 4000 ft suggests that the original shale and quartz deltaic sandstone have been extensively altered.

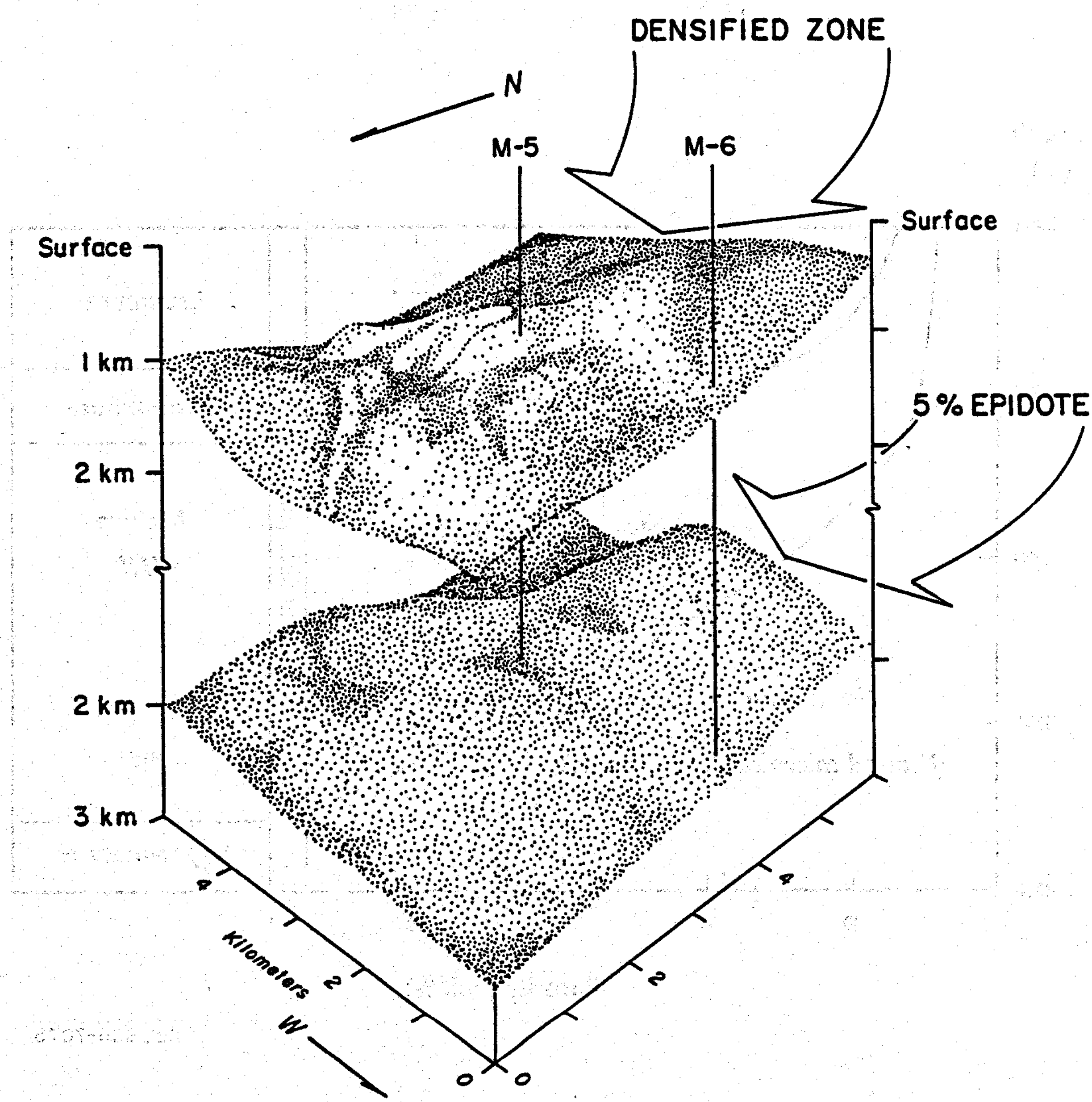

Figure 5. Computer modeled surfaces at Cerro Prieto based on thirty wells. The upper densified zone represents a change in carbonate percent combined with a shift in illite/chlorite/montmorillonite ratios (see Elders and others, 1981, for data) along with a change from clay and sand to shale and sandstone. This change from unconsolidated sand to sandstone is termed the A/B contact by geologists at the Comisión Federal de Electricidad. Between the densified surface and the 5% epidote surface is the main geothermal reservoir studied by SEM for clay fabrics.

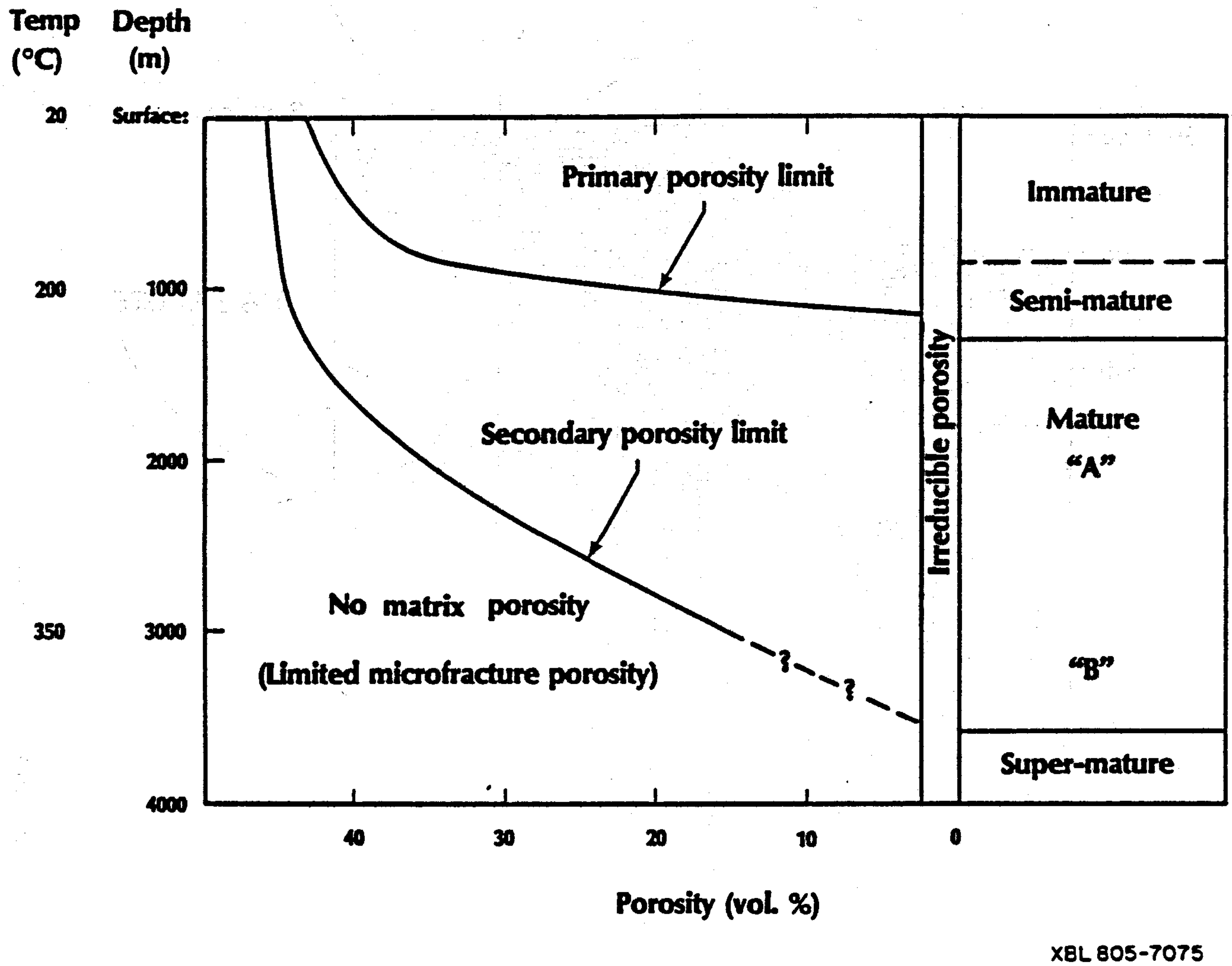

Figure 6. Conceptualized porosity zones at Cerro Prieto. Curve limits set by available porosity data from cores and downhole electrical logs (see Vonder Haar, 1981). The immature stage represents mainly mechanical reduction of primary porosity and early clay diagenesis. The semi-mature stage is mainly chemical reduction of primary porosity, and corresponds to the A/B density contact in Figures 4 and 5. Mature "A" and "B" are zones of extensive carbonate and silicate mineral dissolution, respectively. Most of the SEM and EDAX data of this study falls within these mature zones. The super-mature zone is a metamorphic zone from which little information is available. Terminology follows Schmidt and McDonald, (1979).

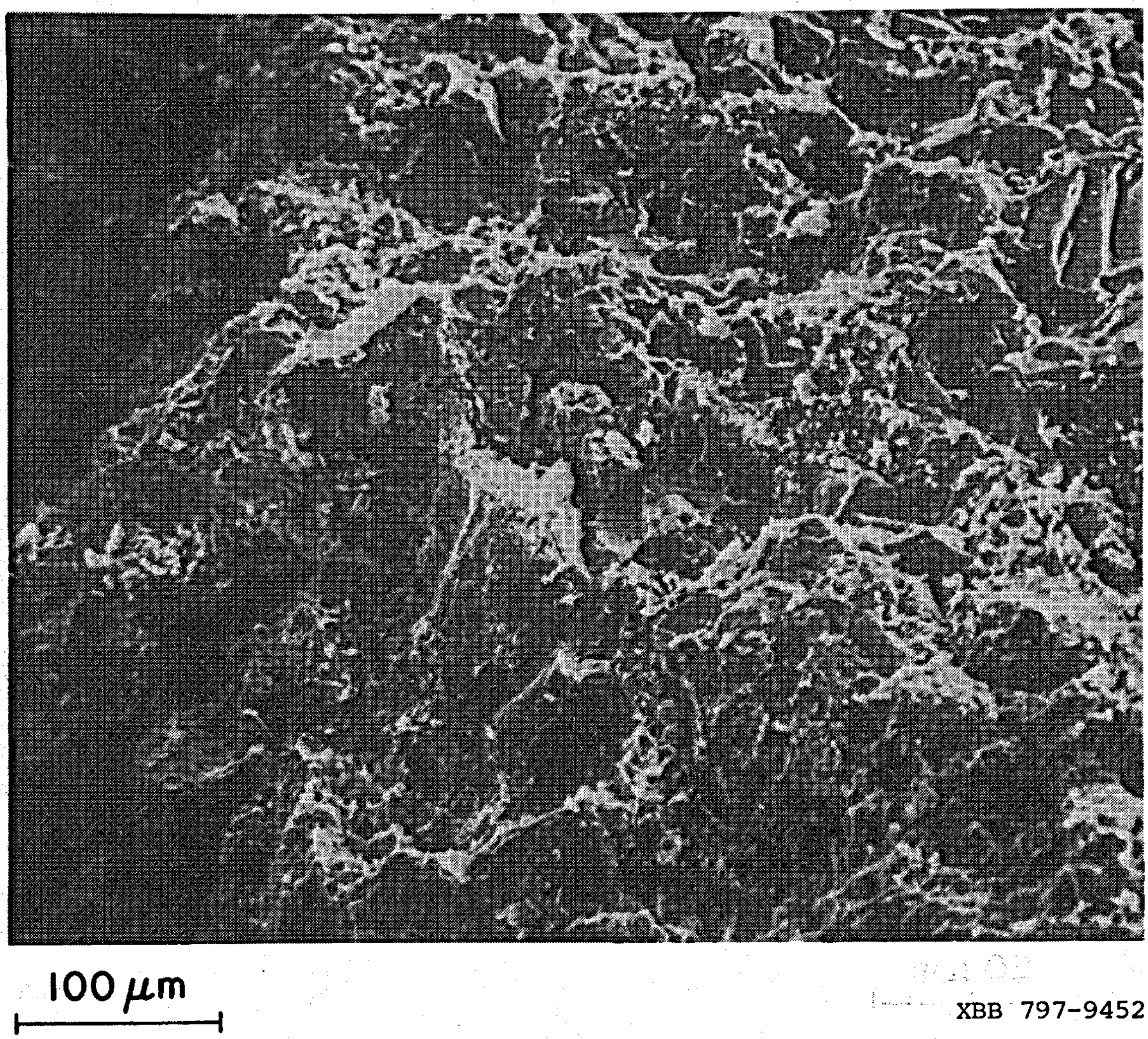

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Figure 7. Well M-38 at Cerro Prieto, 1215 m. A typical low-magnification view of the deltaic quartz sandstones in the geothermal reservoir (see Figure 8 for details).

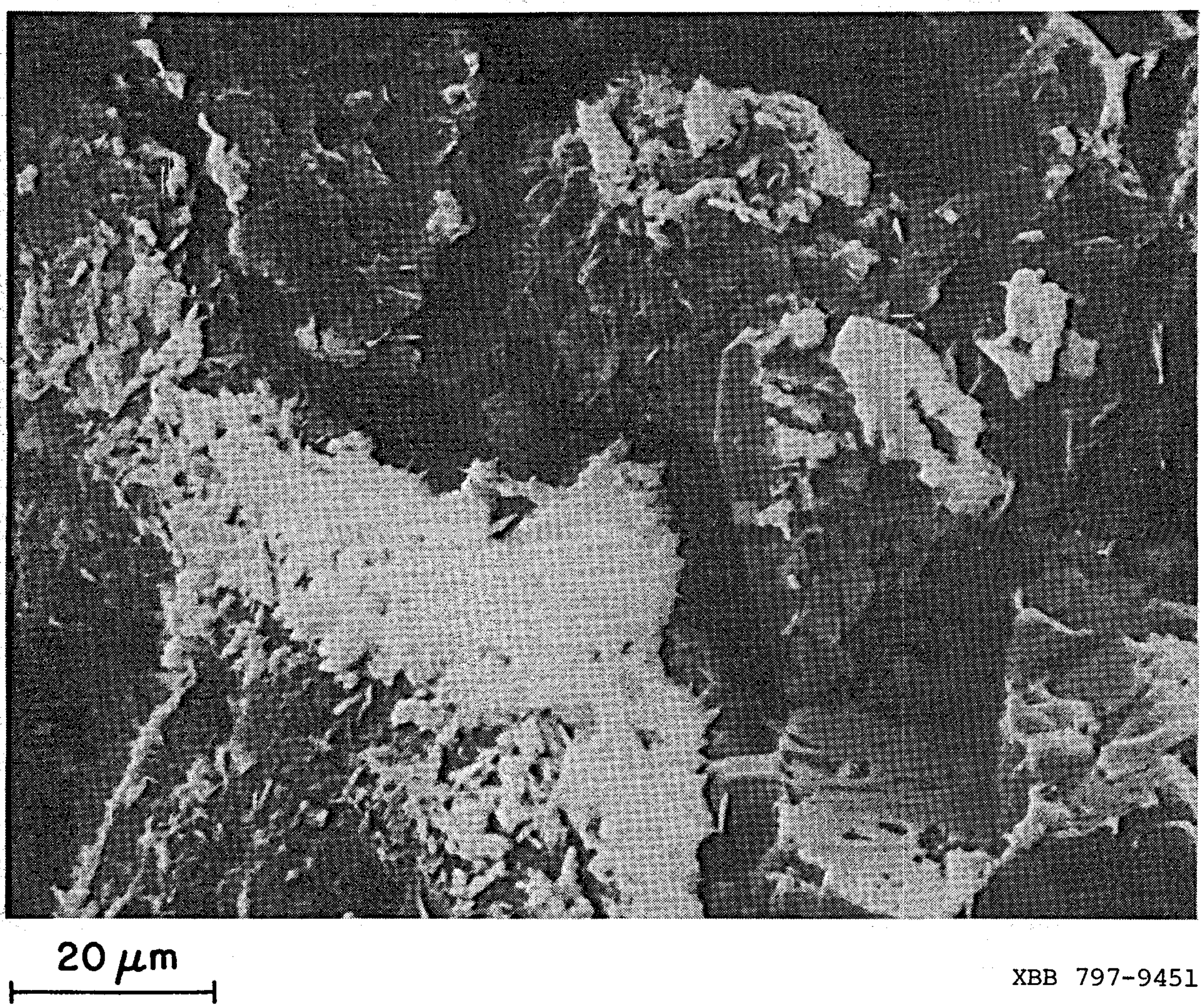

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Figure 8. Close-up of the center of Figure 7, showing partial removal of quartz and feldspar by fluids hotter than 270°C, with addition of clay minerals. Composition from EDAX: Si 45%, Al 24%, Mg 13%, Fe 10%, K 3%.

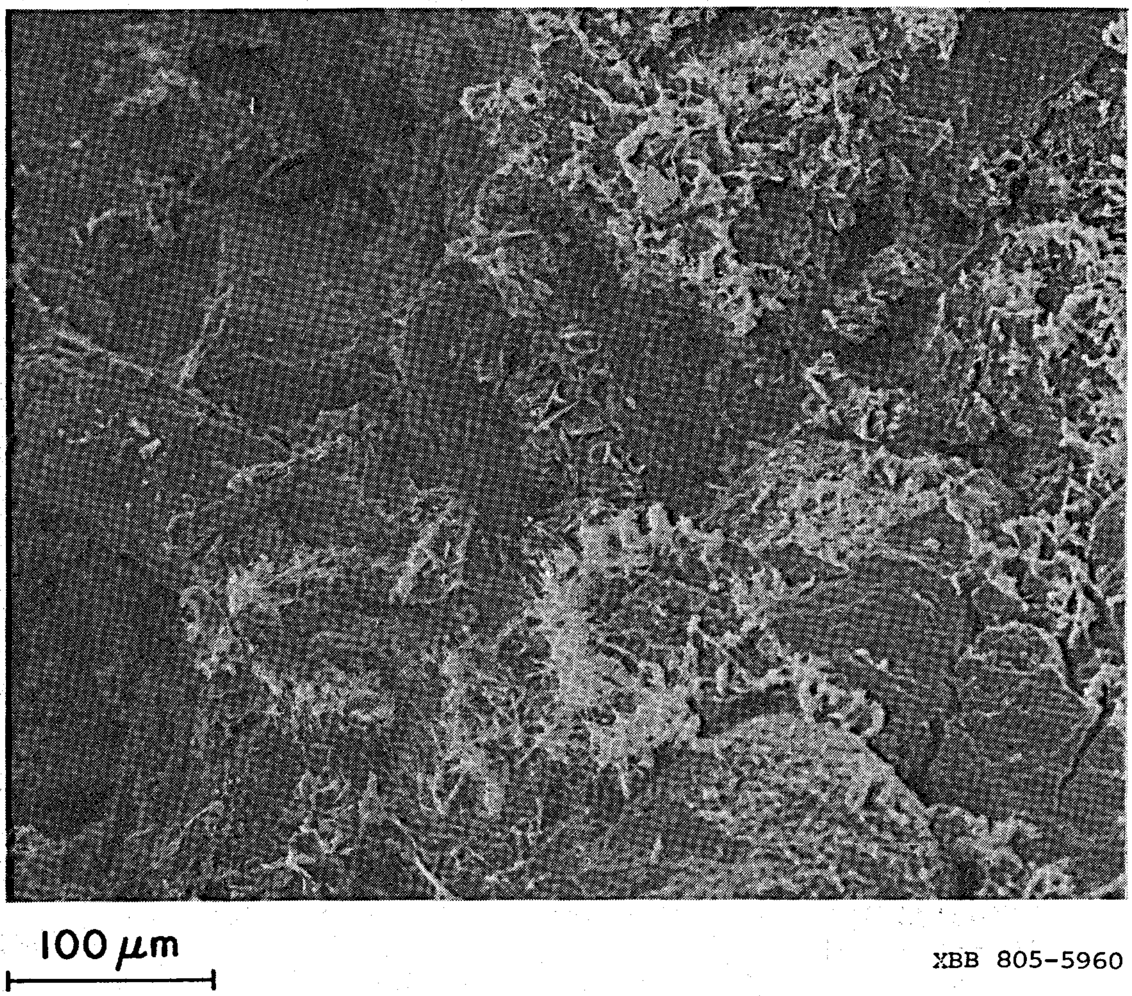

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Figure 9. Well NL-1, Cerro Prieto, 2720 m. Note the extensive clay development of intermixed stacked plates (best developed near the center of the photograph) and the tangled hairs in the lower center.

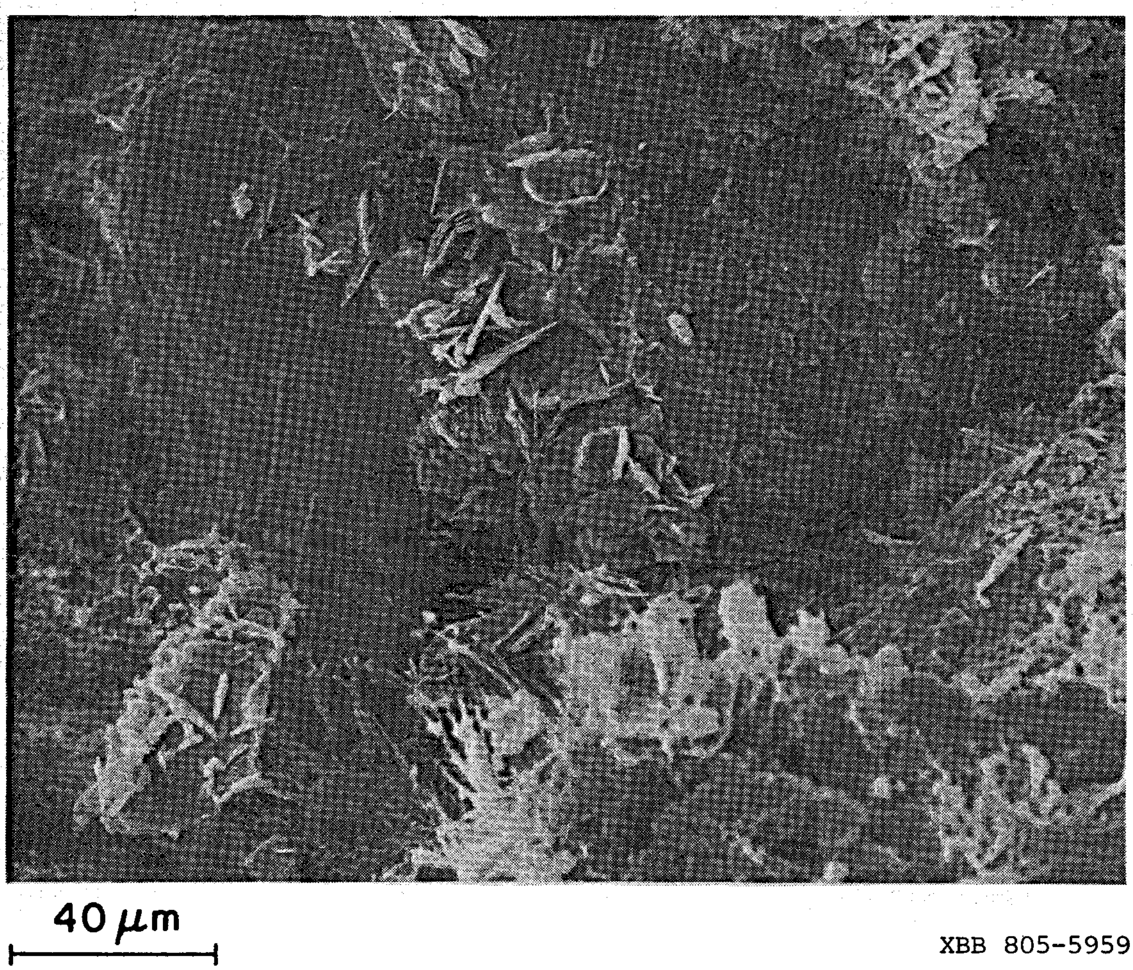

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Figure 10. Close-up of the center of Figure 9, showing the platelets in both angular orientation and in the "book leaves" fabric. This sandstone illustrates the hair-like growths intermingled with the platelets, which show EDAX values of Fe 37%, Si 33%, K 15%, Al 9%, Mg 6%.

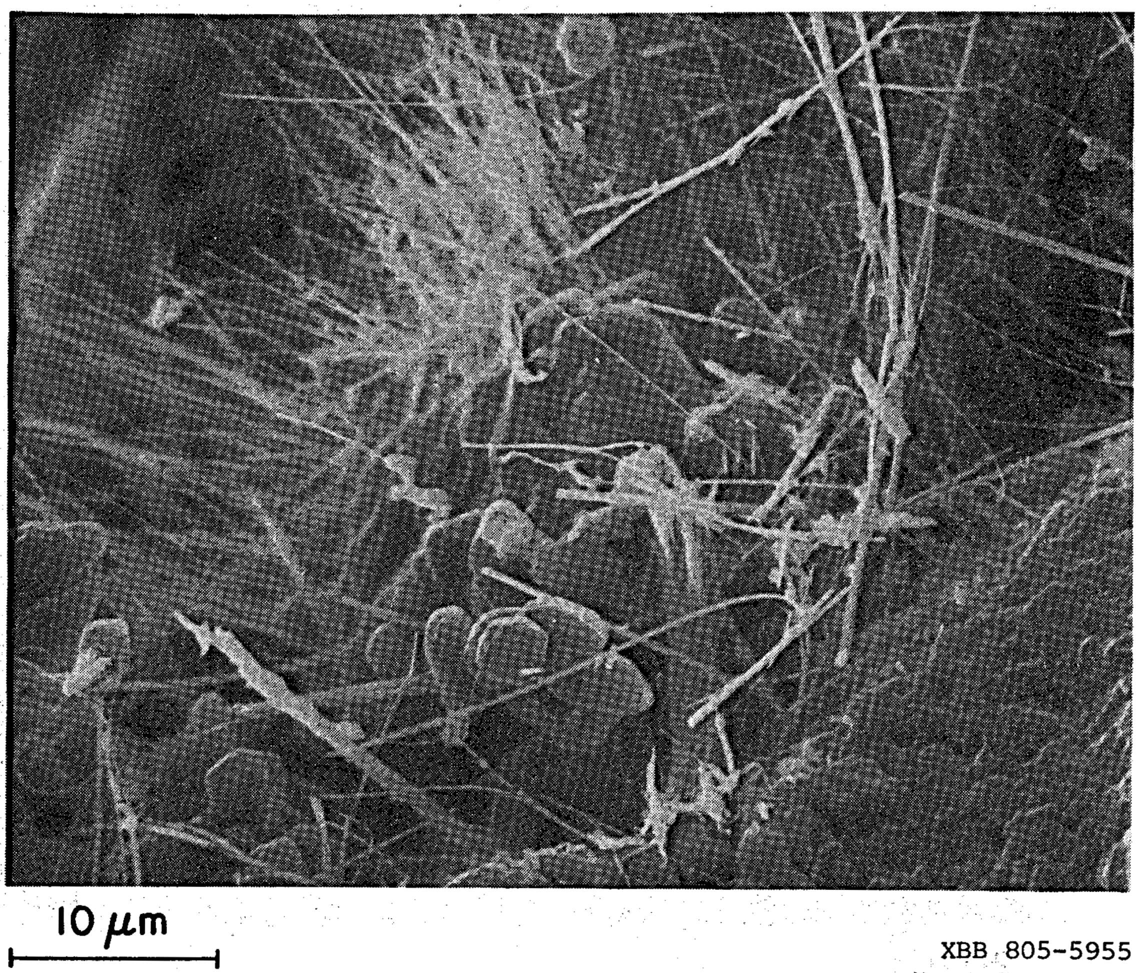

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Figure 11. High-resolution close-up of part of Figure 9. These platelets, with a composition of Si 58%, Al 16%, Mg 9%, Fe 9%, Ca 9%, and K 6%, are similar to the wispy fabrics of Si 54%, Ca 11%, Mg 10%, Al 10%, Fe 10%, K 5%. Perhaps they were precipitated from a mother fluid at the same time. Also note the bundle of wispy fibers to the lower right of center.

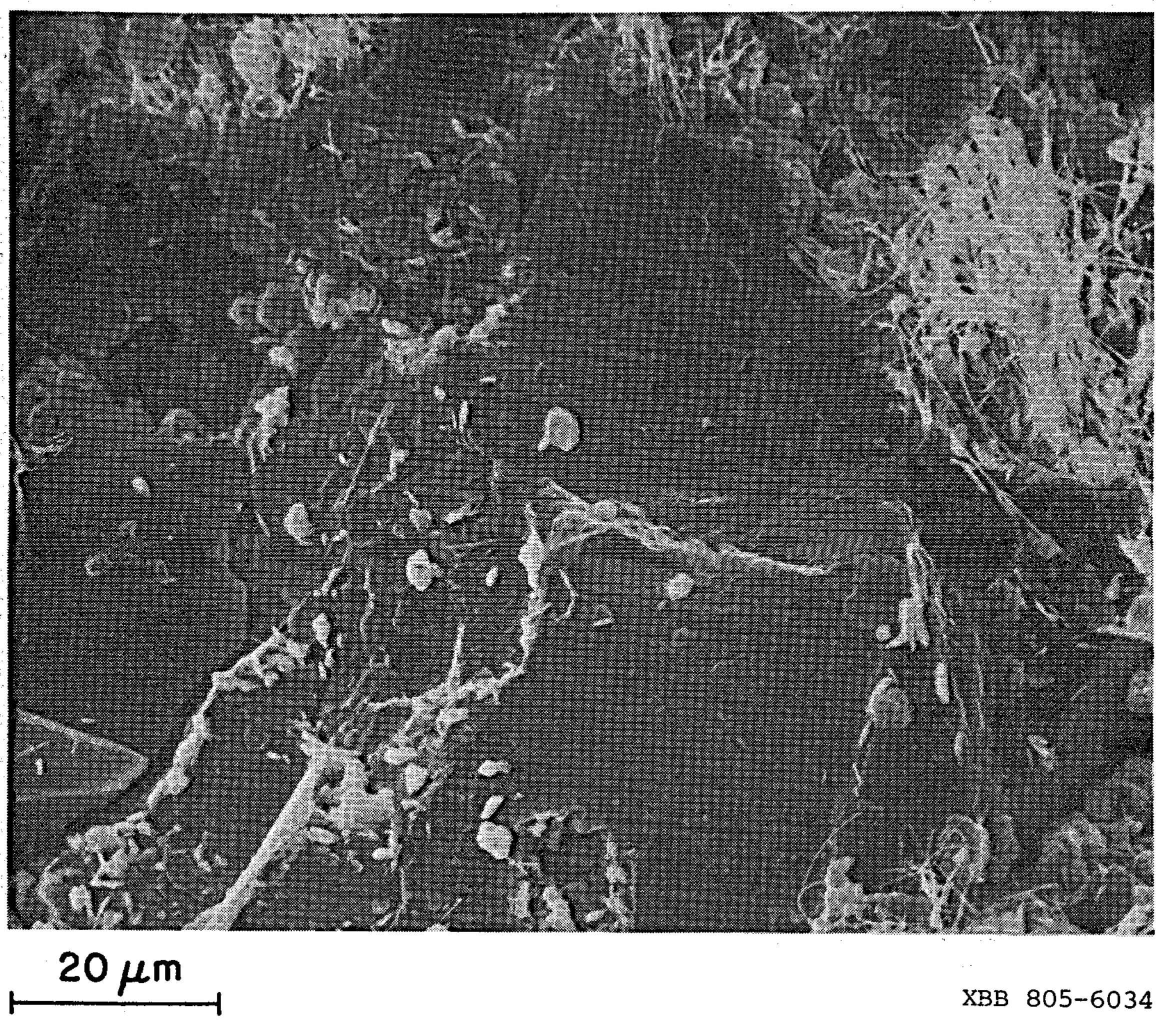

Figure 12. Well T-366 at Cerro Prieto, 2522 m. A dissolution zone, as shown by the pitted quartz. The wispy clusters cover 20% of the surface area of the sample; their composition is Si 49%, Al 17%, Mg 13%, K 12%, Fe 9%. The platelets in the upper left are composed of Si 62%, Al 25%, Mg 6%, K 6%, and Fe 1%.

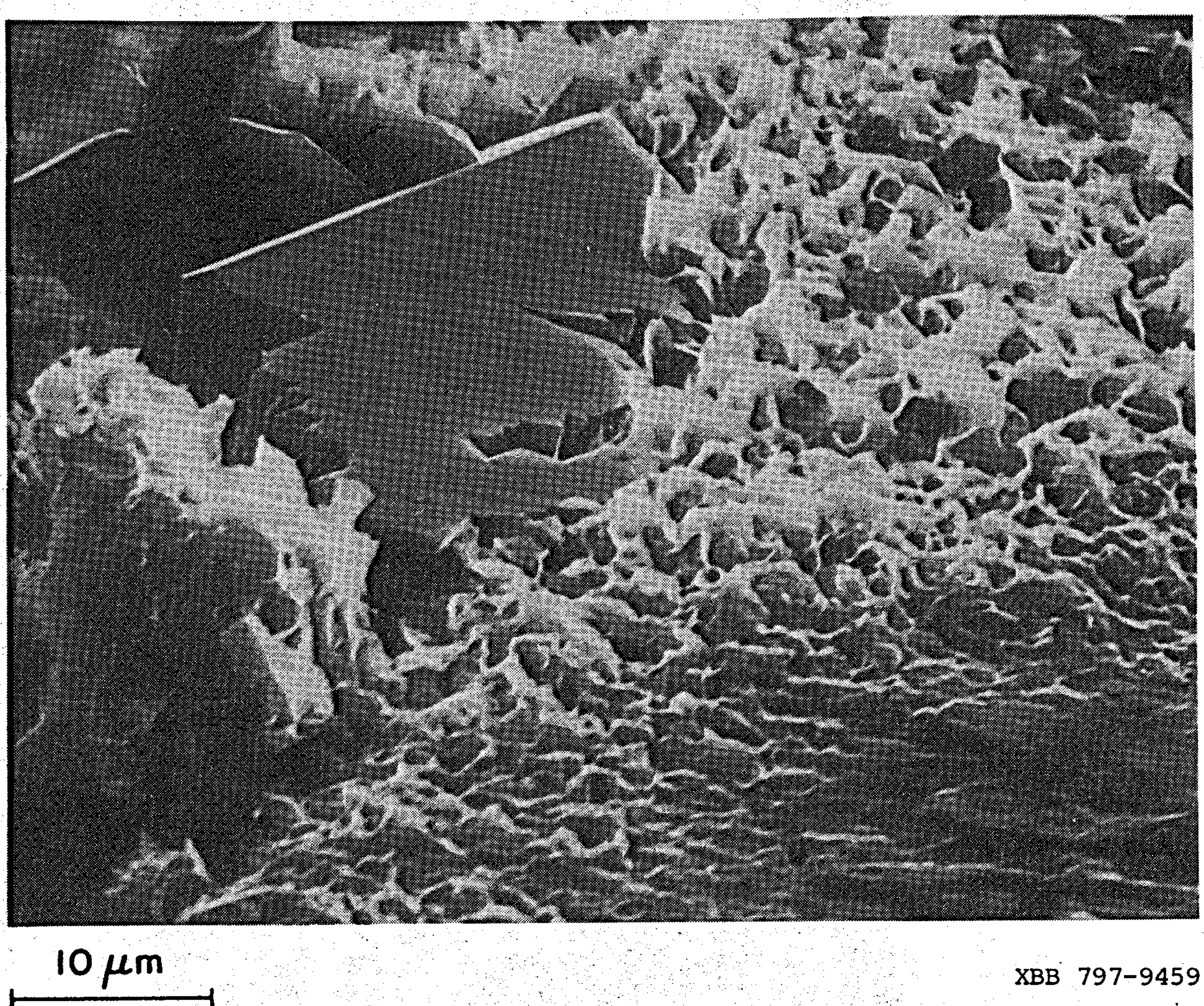

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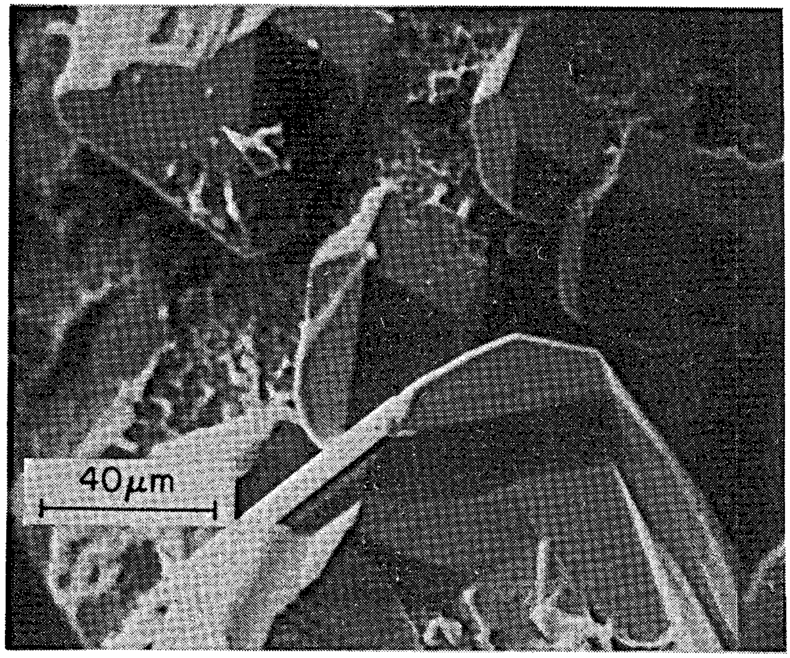
Figure 13. Well M-3, Cerro Prieto, 2203 m. Quartz crystals and crenulate clay fabric. EDAX: Si 56%, Al 29%, Mg 12%, Fe 3%. A sand grain in the lower right corner, which was plucked away during sampling, limited the clay fabric development.

A



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B

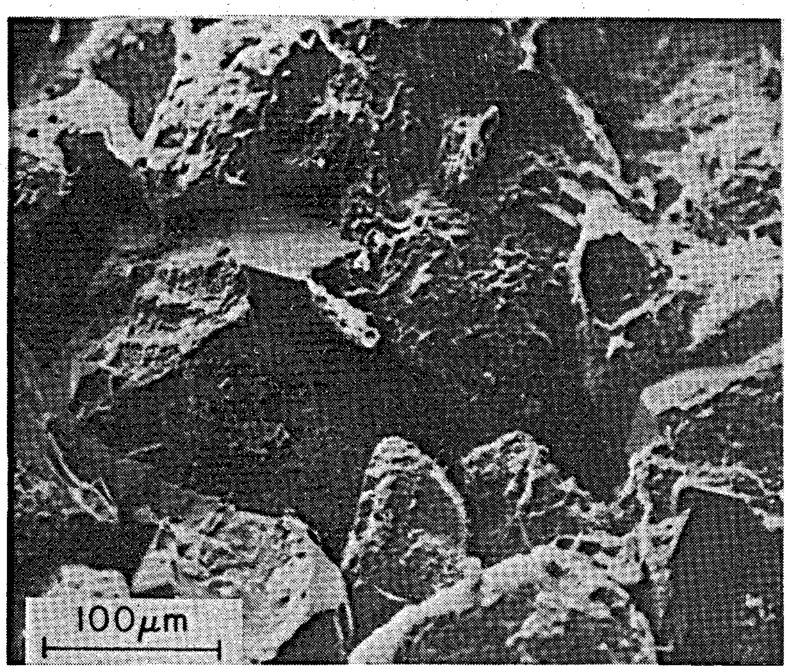

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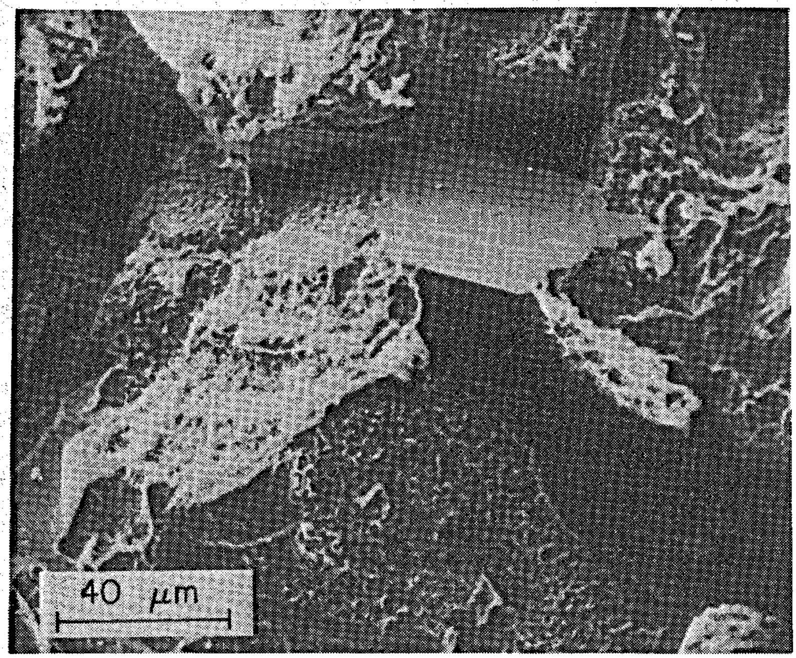
Figure 14. Well 78-30, East Mesa, 1680 m. Sandstone core after five days at simulated in-situ temperature (165°C) and pressure. (A) Quartz crystals with crenulate clays at their base. (B and C) Partially dissolved quartz, illustrating precipitation of the clays. (D) Close-up of crenulate clays shown in C. EDAX: Si 61%, Fe 20%, Al 10%, Na 6%, K 1.7%, Mg 1%, and Ca 0.3%.

C



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D

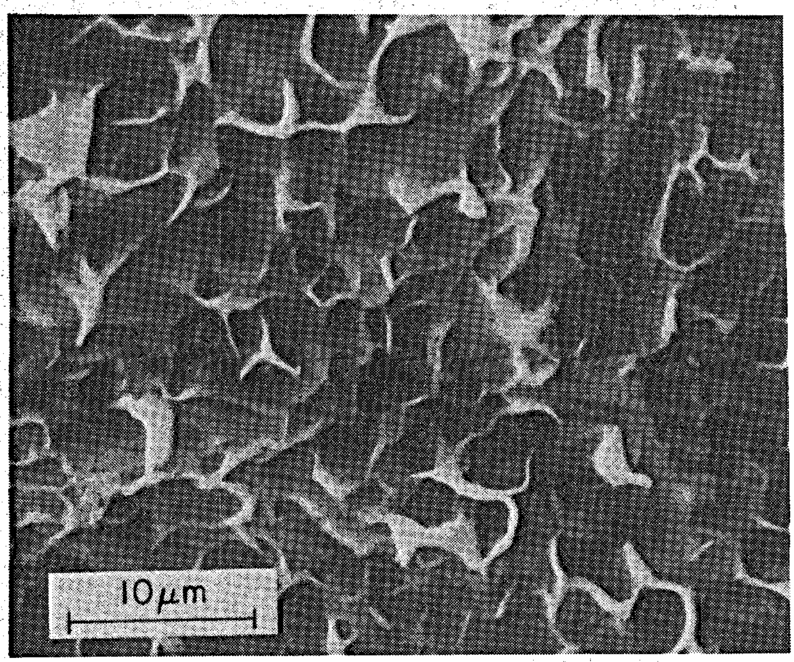

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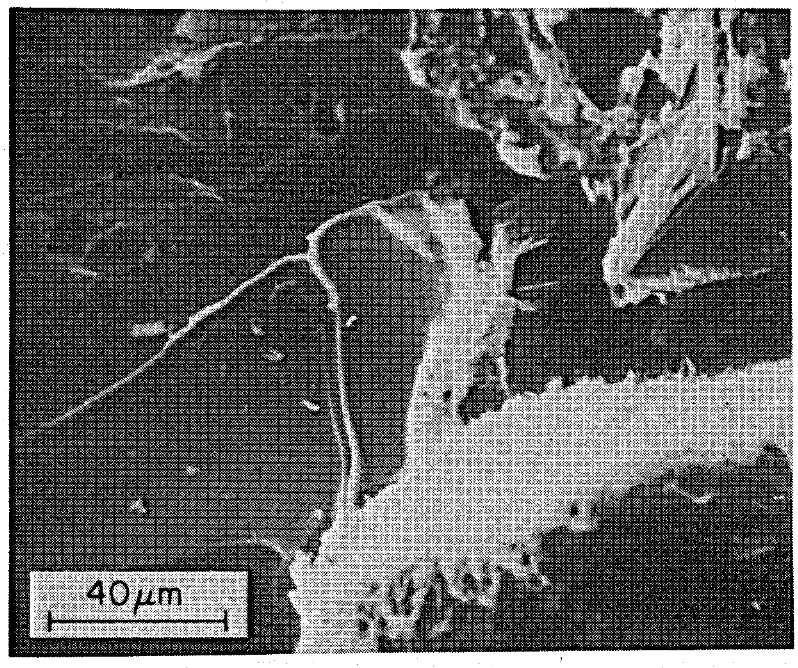
Figure 14. Continued.

A



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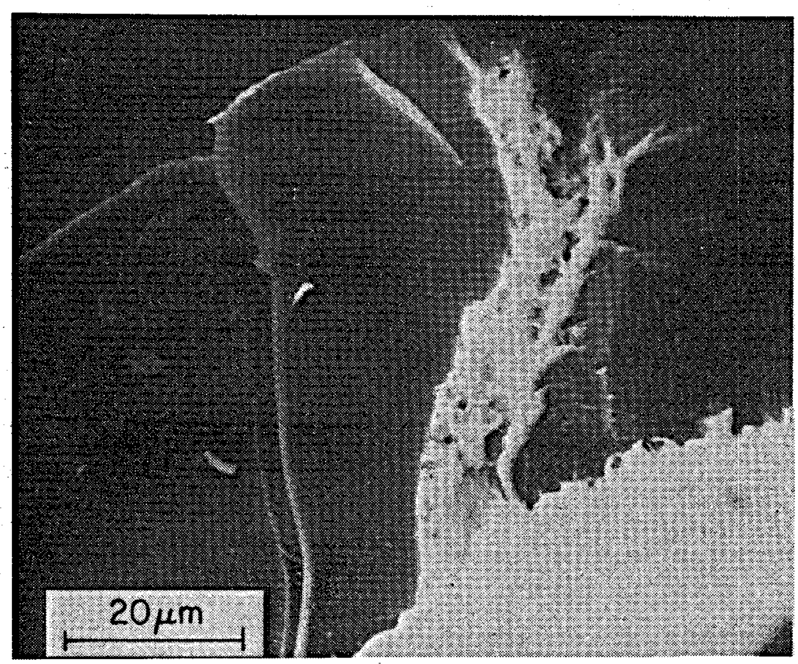

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Figure 15. Well 78-30, East Mesa, 1680 m. These high-resolution photographs indicate that substantial reduction of microfractures can occur by precipitation of clays. This core sample was studied before being subjected to high-temperature/pressure simulations. (A) The clays in the microfracture are composed of Si 32%, Fe 21%, Al 18%, Ca 16%, K 6%, Na 4%, and Mg 1%. (B) The clays in the lower right are composed of Si 60%, Al 22%, K 16%, Fe 1%.

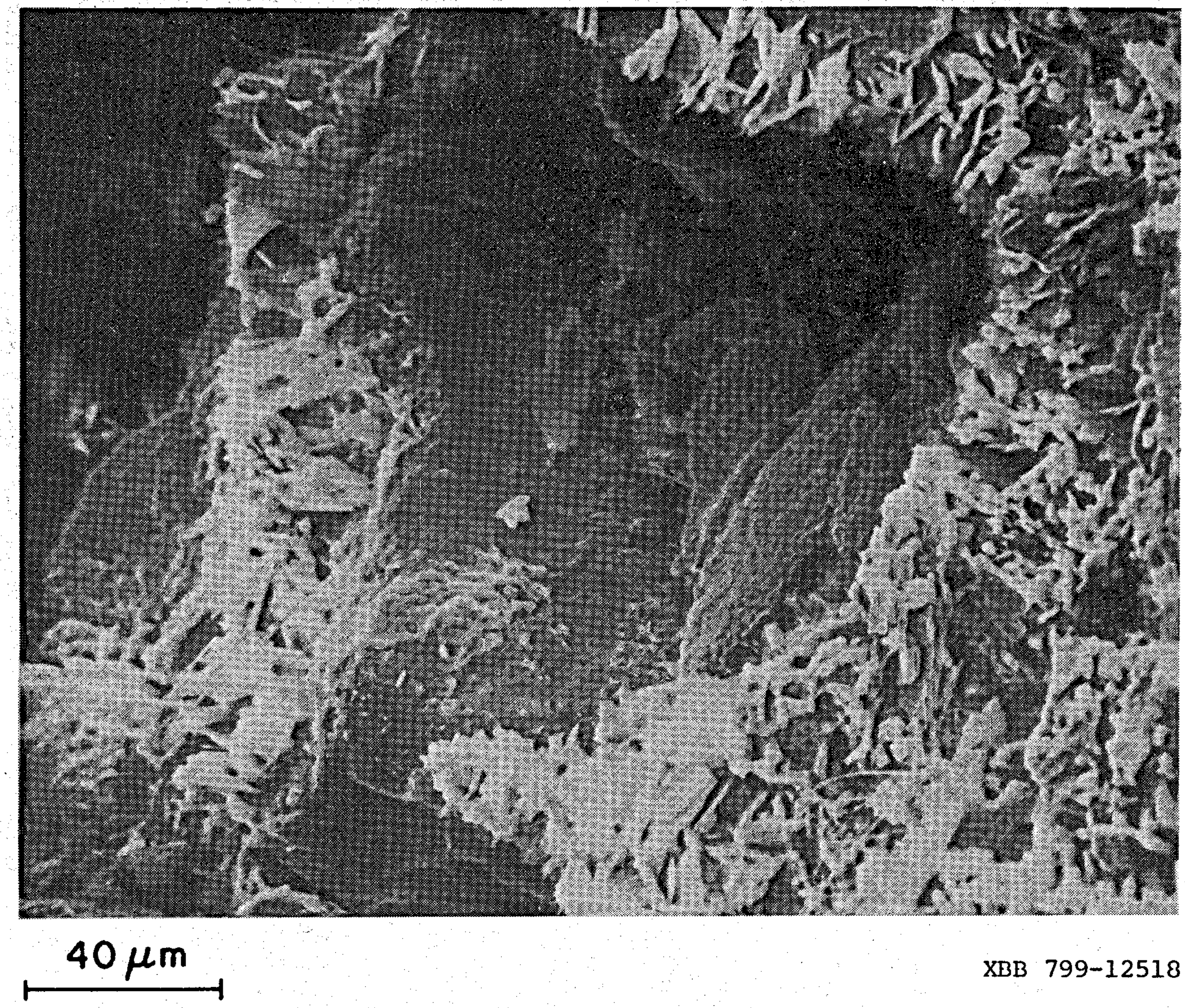

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Figure 16. Well NL-1, Cerro Prieto, 2720 m. A dramatic example of clay formation in the pores adjacent to a grain that was plucked away during sample preparation. The clays in the area outlined at the lower center yield EDAX data of Si 46%, Al 16%, Mg 15%, K 13%, and Fe 10%.

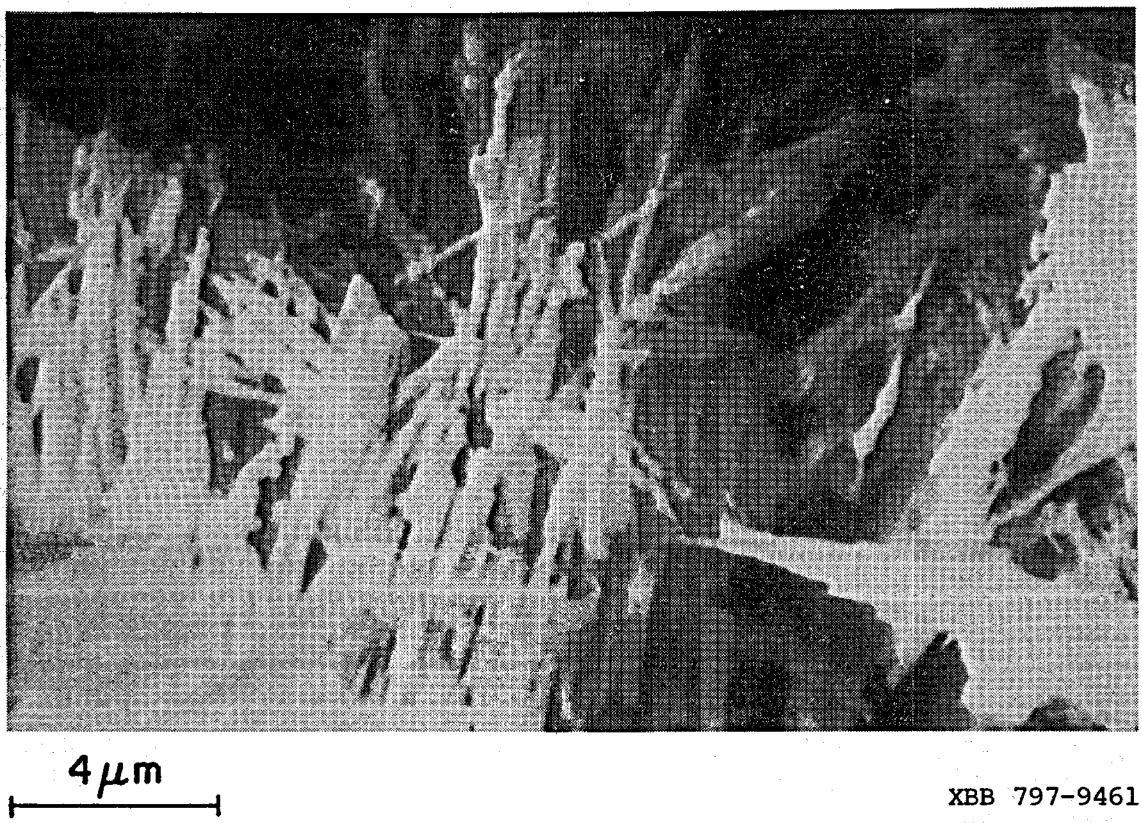

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Figure 17. Well M-3, Cerro Prieto, 2203 m. This high-magnification micrograph shows lathe-like crystals that may be clays. Composition is approximately Si 57%, K 23%, Al 20%. These crystals are in the pore throat between sand grains. Many other fabrics were observed while using the SEM in our field-wide studies, which may provide clues to pulses of fluid flow, permeability barriers, and thermal diagenesis when investigated further.

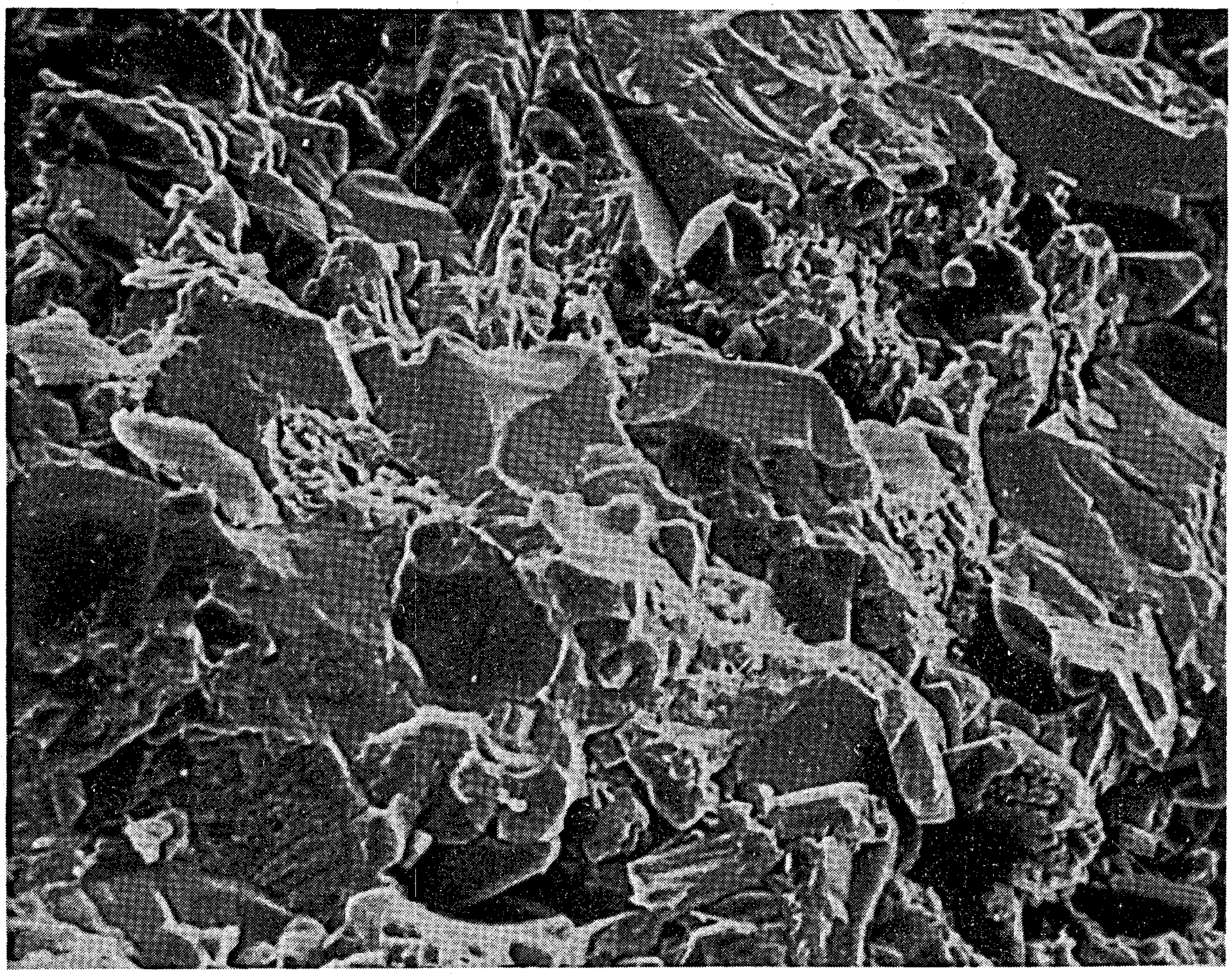

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Figure 18. Well NL-1, Cerro Prieto, 3209 m. This sample, taken from beneath the 5% epidote zone shown in Figure 5, represents the lower portion of the reservoir at Cerro Prieto, where clay minerals appear to be relatively rare and have little influence compared to framework crystal overgrowths and metamorphism from fluids in excess of 350°C.