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Haar, S.P. Vonder

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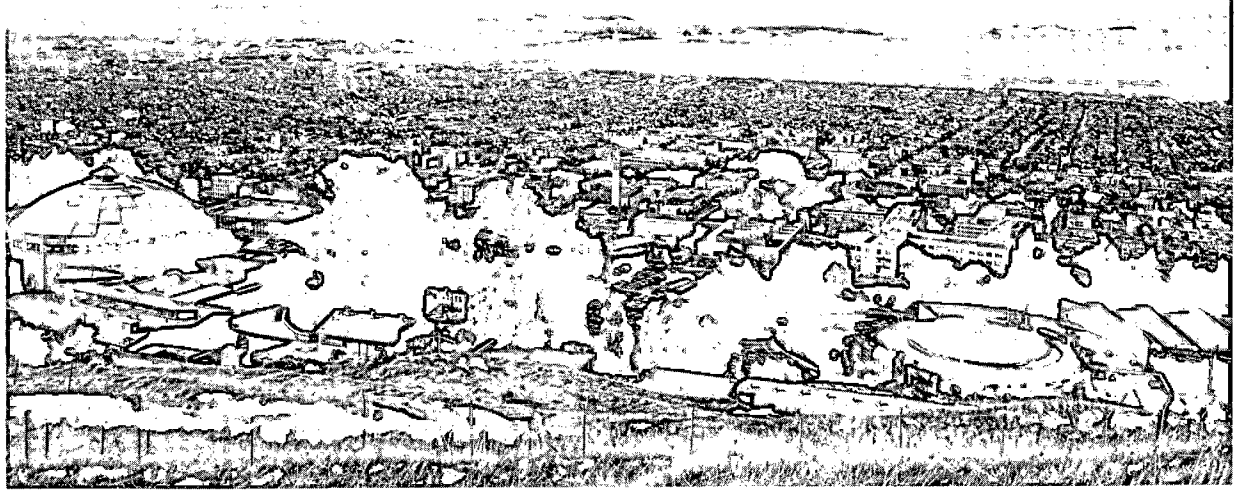
POROSITY OF COASTAL DELTAIC SANDSTONES, CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO

S.P. Vonder Haar

April 1984

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POROSITY OF COASTAL DELTAIC SANDSTONES, CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO

Stephen P. Vonder Haar

Earth Sciences Division*
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

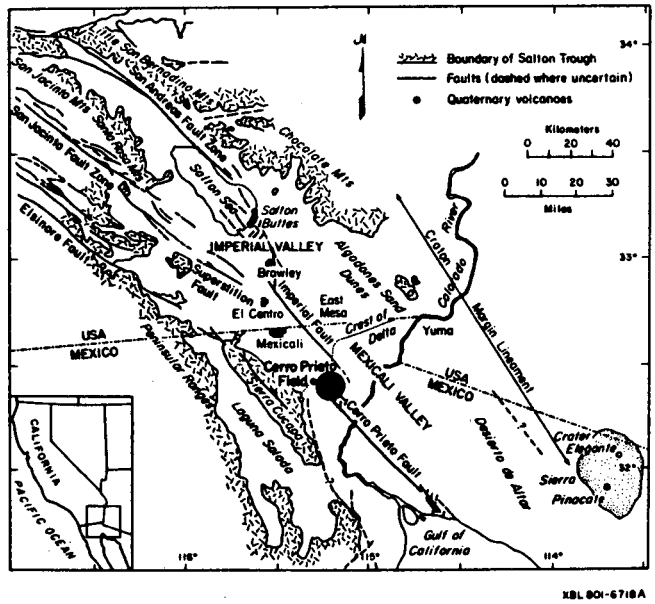
Core porosity values for sandstones and density log-derived porosities for sandstone-silstone-shale sequences indicate a range from less than 1% to 40% at the Cerro Prieto geothermal field, Baja California, Mexico. Mean porosity values indicate that a general trend of decreasing porosities with increasing depth from 35% at 600 m to 10% at 2300 m is complicated by the 15 to 30% porosities in the 350°C hot water zone at about 2700 m depth. Scanning electron microscopy documents secondary dissolution porosity, mineral overgrowths, and abundant clay minerals. Core permeability ranges from 0.1 to 1000 millidarcies for the more than 50 cores studied. The porosity variability indicates that geothermal systems provide an ideal setting for testing concepts of dissolution porosity and increased secondary dissolution permeability that could be useful for nuclear waste storage as well as petroleum reservoir engineering.

INTRODUCTION

The Cerro Prieto geothermal field in the Mexicali Valley of Baja California, Mexico (Figures 1 and 2), is presently producing 180 MWe from about 37 out of the more than 110 wells drilled. The greatest depth drilled to date is 3.5 km. Extensive analyses of this field in the southern Salton Trough have been published in numerous articles including a recent overview by Lippmann (1983). The Cerro Prieto wells are producing from Plio-Pliestocene sandstone-siltstone-shale sequences from a combined deltaic and longshore current protected embayment depositional environment (Lyons and van de Kamp, 1980; Halfman et al., 1984a). Since deposition of the sediment, the sandstones, siltstones and shales have undergone hydrothermal alteration that led to their unusual porosity and permeability characteristics. A reservoir model was presented by Halfman et al. (1984b), evidence of active metasomatism by Schiffman et al. (1984), a structural analysis by Vonder Haar and Howard (1981), and reservoir modeling by Lippmann and Bodvarsson (1983) and Comisión Federal de Electricidad (1983). This paper focuses on core porosity and density-log-derived porosity. Such porosity values and their impact on storage as-well-as production are a key element to successful long-term modeling of geothermal reservoirs.

POROSITY, PERMEABILITY AND SEM DATA

A summary of field-wide sandstone core porosities versus depth for Cerro Prieto is presented in Figure 3. These data indicate porosity values from more than 50 cores ranging from approximately 1% to a high near 40%. Maximum core porosity (39%) occurs at 1600 m in well M-93, with a relative high 30% porosity at 2500 m in well M-92. Other core porosity values are scattered throughout the various depths with an approximate mean of 22%. These core porosities are primarily (85%) from commercial Core-Lab type tests, augmented by research testing such as presented by Contreras (1983). In Figure 3 an approximate temperature scale is correlated to depth for convenience, although at a given depth actual temperatures obtained from downhole



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Figure 1. Location of the Cerro Prieto geothermal field in the Salton Trough.

*Presently with Pacific Energy Consultants, 540 Kenyon, Berkeley, CA 94708

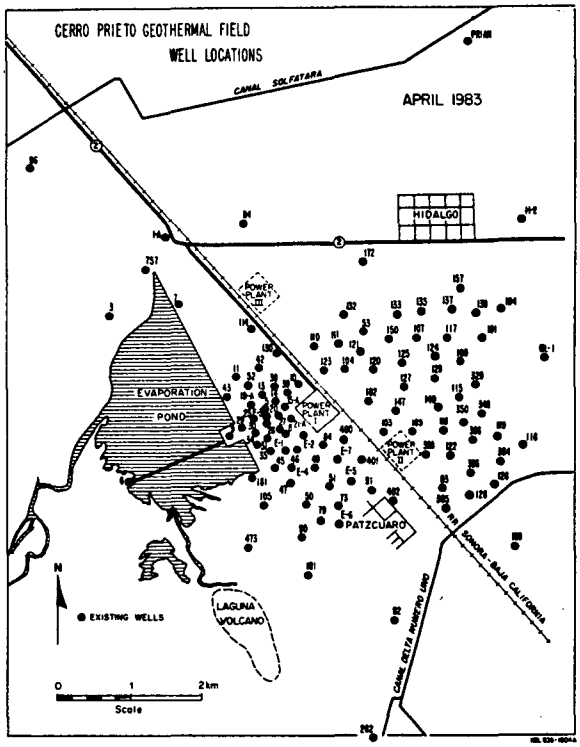


Figure 2. Cerro Prieto well locations.

logs and geochemical studies vary throughout the field (see, for example, Schiffman et al., 1984, Figures 2, 3 and 4; Lippmann and Bodvarsson, 1983, Figure 8).

Also presented in Figure 3 are the maximum, mean, and minimum values of density-derived-porosity from density logs of 32 wells. Porosities were averaged over about 150-m intervals for all sandstones, siltstones and shales. A general trend of decreasing mean porosities from 35% at 600 m depth to 10% at 2300 m is noted. Further studies of porosity below 2300 m are needed. For example, this trend is complicated by 15 to 30% porosities in the 350°C hot water zone at about 2700 m depth.

Permeability correlation to porosity, as shown in Figure 4, is not tightly constrained. Permeability ranges from less than 0.1 to 1000 md for 51 core samples. These values were primarily obtained from commercial laboratory tests. Note that core permeabilities greater than 10 md correspond to core porosities of 15 to 33%.

To better understand these porosity ranges, scanning electron microscopy (SEM) was performed on more than 40 core samples. Figures 5 through 8 illustrate such features as secondary dissolution porosity, clays and mineral overgrowths. Within the approximate 300°C hot water zone decarbonation reactions have a tendency to produce secondary dissolution porosity with carbonate cement replaced by some epidote and wairakite. Sandstones in the > 330°C temperature range, on the other

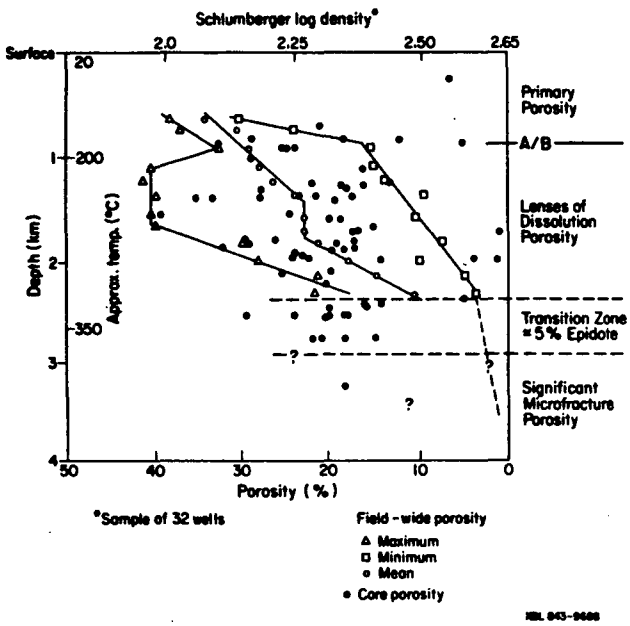


Figure 3. Field-wide porosity values for Cerro Prieto.

hand, can exhibit intensive recrystalization. W. A. Elders and his colleagues (e.g. Schiffman et al., 1984) have worked these correlations out in detail for Cerro Prieto wells. Chemical compositions from EDAX (Energy Dispersive Analysis by X-ray) scans and fabric type for the clays are listed in the figure captions. No clear correlation of clays to porosity or permeability ranges has been established from this study.

INTERPRETATION

The data presented in Figures 3 and 4 indicate the range of values in porosity, with a summary interpretation of zonation presented in the right-side column of Figure 3. At this time, the entire field-wide system can best be viewed as having lenses of dissolution porosity in sandstones below the A/B density pick of

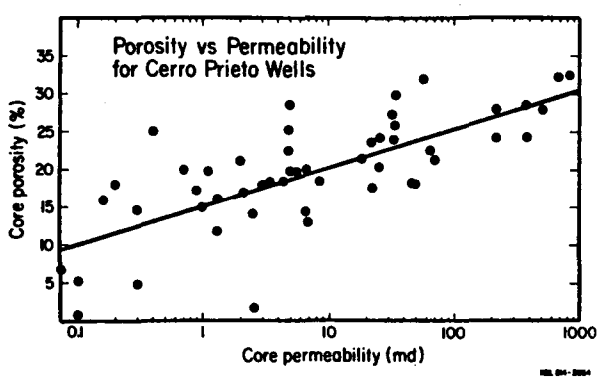


Figure 4. Permeability and porosity values for 55 Cerro Prieto cores.

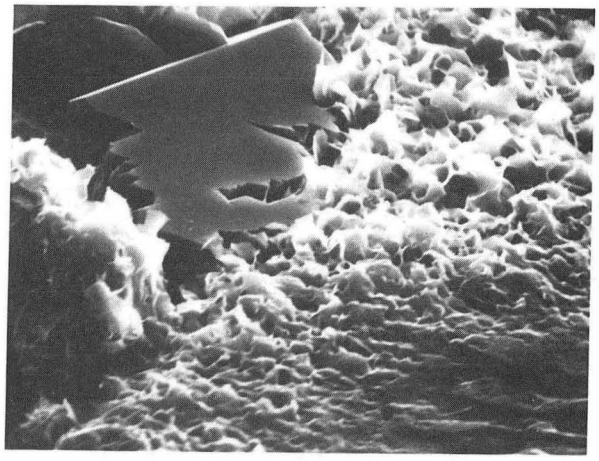


Figure 5. Cerro Prieto well M-3, 2203 m depth. Well developed quartz crystals and crenulate clay fabric. EDAX scan on the clay shows Si 56%, Al 29% Mg 12%, and Fe 3%. A sand grain in the lower right corner, which was plucked away during sampling, limited the clay fabric development.

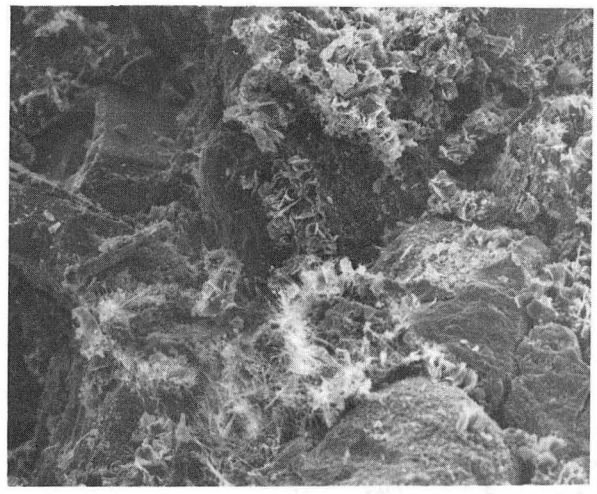


Figure 6. Cerro Prieto well NL-1, 2720 m depth. Sample showing clay platelets in both angular orientation and in the "book leaves" fabric. This sandstone illustrates the accicular clay fabric intermingled with the platelets, which show EDAX values of Fe 37%, Si 33%, K 15%, Al 9%, and Mg 6%.

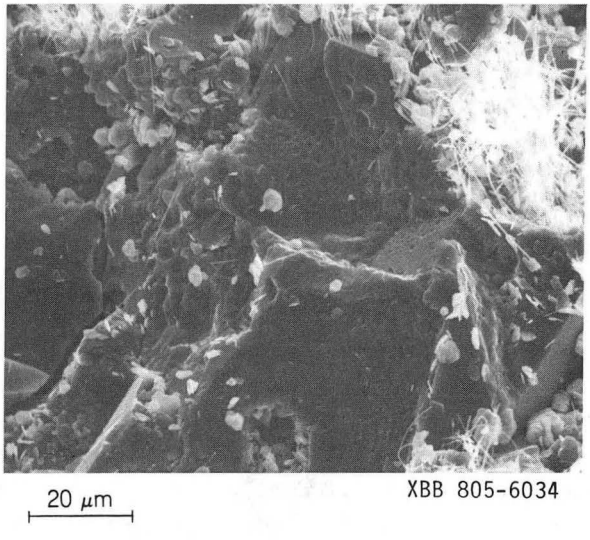


Figure 7. Cerro Prieto well T-336, 2522 m depth. A dissolution zone, as shown by the pitted quartz. The wispy clay clusters cover 20% of the surface area of the sample; their composition is Si 49%, Al 17%, Mg 13%, K 12%, and Fe 9%. The clay platelets in the upper left are composed of Si 62%, Al 25%, Mg 6%, K 6%, and Fe 1%.

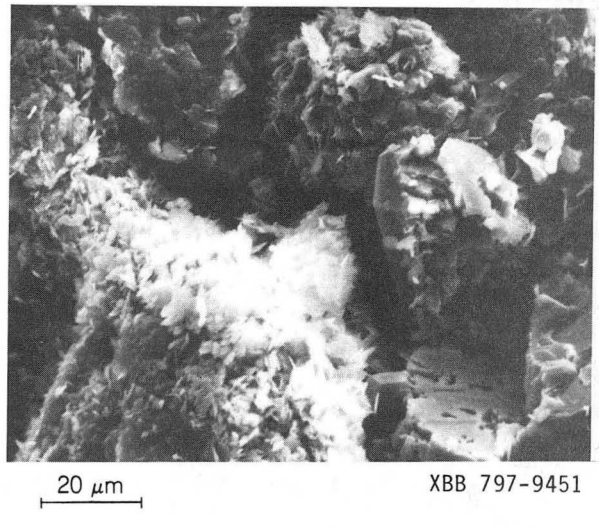


Figure 8. Cerro Prieto well M-38, 1215 m depth. Sample showing partial removal of quartz and feldspar in the sandstone by fluids hotter than 270°C, with addition of clay minerals. EDAX scan on the clays shows Si 45%, Al 24%, Mg 13%, Fe 10%, and K 3%.

drillers (as described in Vonder Haar and Howard, 1981). There is clear evidence from the SEM photographs and geochemical studies of a 500 m-thick transition zone characterized by approximately 5% epidote near 2500 m depth. This transition zone is shown in cores to have up to 30% porosity. The minimal quantity of data below 3000 m makes interpretations difficult, but potential production is assumed to come primarily from microfractures (Vonder Haar and Howard, 1981). High permeability values (>10 md) appear to correlate to high porosities as can be expected in dissolution porosity zones.

A geothermal developer at a new site in the Salton Trough could, for a given depth, anticipate the average porosity of a 150-m-perforated interval of interbedded sandstones, siltstones and shales by referring to Figure 3. By no means is the data in Figures 3 and 4 to be considered the last word. As proprietary information from other Salton Trough fields becomes available, the minimum, mean, and maximum permeabilities and porosities in this geologic province will be revised. Certainly enough data is presented herein to provide reservoir modelers with a range of values suitable for constraining computations, or for helping to determine "worst case" and "best case" scenarios as to 30 years economic productivity.

A particularly intriguing aspect of dissolution porosity is its role in enhancing permeability. The hypothesis being that hot geothermal fluids tend to preferentially form interconnected paths thus augmenting primary permeability. This geothermally enhanced permeability can be termed secondary dissolution permeability. As with secondary dissolution porosity, secondary dissolution permeability is of keen interest for modeling not only geothermal fields, but also deep petroleum reservoirs and nuclear waste storage sites. Care must be taken in modeling such systems because of the possible presence of deep zones of increased porosity as documented at Cerro Prieto.

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