DIAGENETIC TRENDS, SECONDARY POROSITY, AND HYDROCARBON MIGRATION IN MIOCENE TEMBLOR FORMATION ARKOSIC SANDSTONES, COALINGA OIL FIELD, CALIFORNIA

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INTRODUCTION

The Coalinga oil field is located on the western margin of the central San Joaquin basin (Fig. 1). It was discovered in 1890 and is the sixth largest oil field in California. Cumulative oil and condensate production has reached almost 744 million barrels and estimated oil reserves at year-end 1987 were 162.4 million barrels (Mefferd, 1987). Oil is produced from immature marine and nonmarine sandstones of Miocene and Pliocene age. Sediment diagenesis, leading to the creation of secondary porosity, has been shown to be important in the formation of hydrocarbon reservoirs in this and other petroleum fields of the San Joaquin basin (Merino, 1975; Boles, 1984; Tieh and others; 1986; Horton and Menzie, 1987; Boles and Ramseyer, 1988). This study was undertaken to investigate the relationships between diagenesis and porosity creation in oil-bearing sandstones ("C", "E", and "G" sands) of the Temblor Formation (Fig. 2). Two outcrop samples and data from six cored wells were evaluated for the purpose of this investigation.

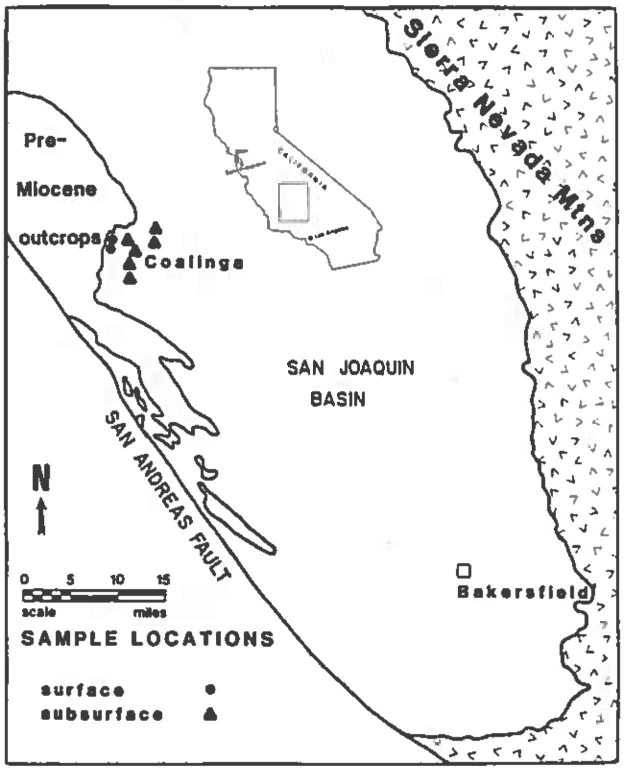

Figure 1. Map of the southern San Joaquin Valley showing the location of Coalinga oil field.

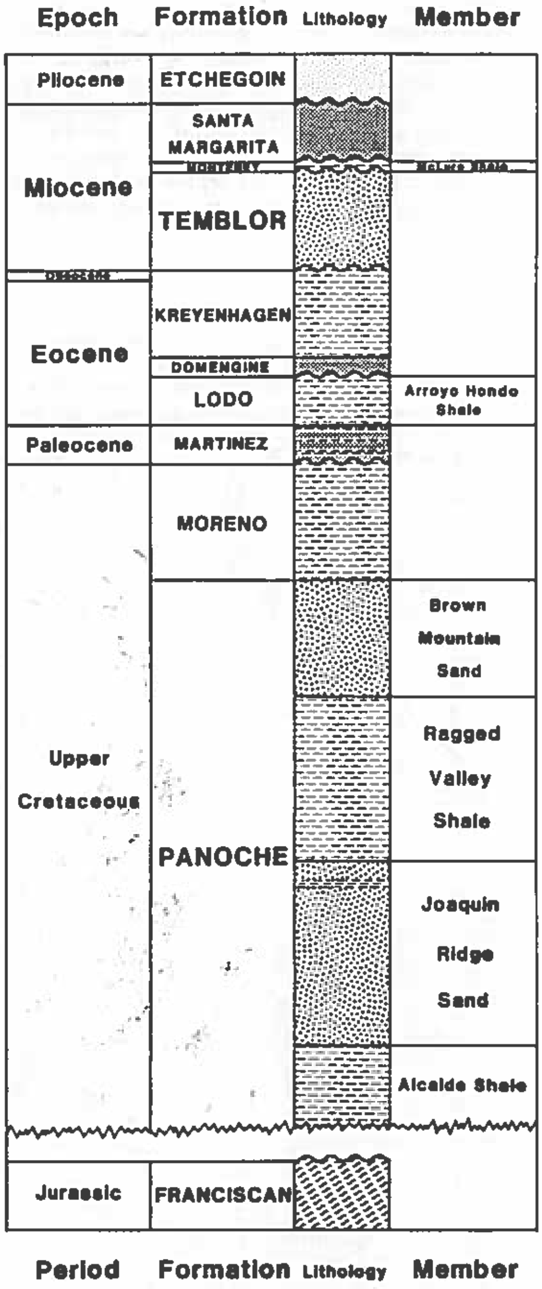

Figure 2. Generalized subsurface stratigraphy of the Coalinga oil field. The McLure Shale Member of the Monterey Formation and the Santa Margarita Formation become thinner towards the west in this area due to erosion that took place prior to deposition of the Etchegoin Formation.

GEOLOGIC SETTING

The San Joaquin basin is located between the Sierra Nevada Mountains on the east and the southern Coast Ranges on the west (Fig.1). The basin formed in latest Mesozoic time as the Sierra Nevada were uplifted and began shedding terrigenous sediments toward the west. Since then, the basin has had a complex history as the tectonic regime changed from convergence associated with subduction of the Falleron Plate beneath the North American Plate to wrenching associated with the San Andreas fault (Bandy and Arnal, 1969; Graham, 1978). Thus, very rapid initial subsidence was followed by gradual filling of the basin, first by marine and later by nonmarine sedimentation.

Wrenching associated with the San Andreas fault system has contributed to the development of numerous low amplitude folds along the western side of the basin. A northwest-trending antiformal structure known as the Coalinga anticline which the Coalinga oil field straddles, was formed by this process (Fig. 3). Formation of this structure began during the middle Tertiary concurrent with emplacement of the Idria serpentinite diapir. Folding is still occurring in this region and anticlines are expressed as topographic highs along the western side of the San Joaquin Valley.

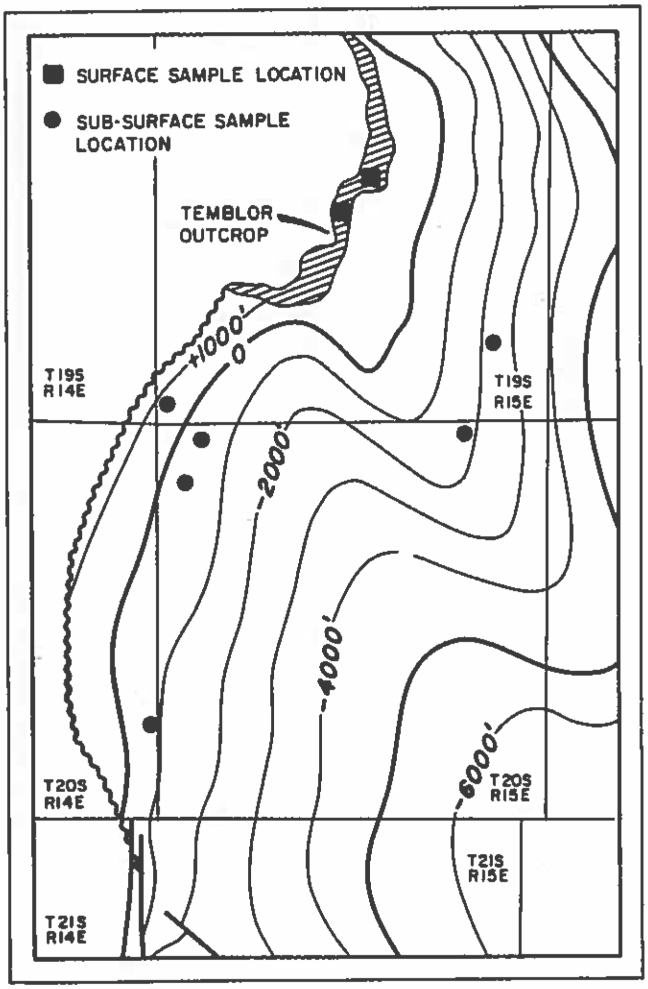

Figure 3. Structure contour map of the top of the Temblor Formation at Coalinga oil field. Outcrops of the Temblor Formation northwest of the field are also indicated, as are locations for samples used in this study.

TEMBLOR FORMATION

Depositional Environment

In the western part of the Coalinga oil field the Temblor Formation unconformably overlies organic-rich, basinal mudstones and shales of the Eocene Kreyenhagen Formation. Overlying the unconformity at the top of the Temblor Formation is either the Miocene McLure Shale Member of the Monterey Formation or the upper Miocene Santa Margarita sand. The Temblor Formation consists primarily of arkosic sandstones and siltstones containing abundant lithic grains. These clastic rocks were deposited in lower delta plain, fluvial and coastal-marine environments along a fluctuating shoreline. The lower part of the Temblor Formation contains multiple oil-bearing sandstones including (from stratigraphic bottom to top) the "Jv", "J", "H", "G", "E", and "C" sands in the western part of the field that are stratigraphically below the "indicator bed" as defined by Adegoke (1969) and displayed by Bate (1985, Fig. 5). Deposition of this part of the Temblor Formation coincides with a period of marine transgression (Bate, 1985). Only the "G", "E", and "C" sands are considered in this study. The upper part of the Temblor Formation is absent in the western part of the Coalinga oil field due to post-depositional erosion (Fig. 4). The predominantly friable Temblor sandstones contain marine macrofossils in the cored intervals studied, but lateral equivalents of the "G" sand in outcrops to the north and west may be fluvial (Bate, 1985).

Diagenesis

Sandstones and siltstones examined during this study fall into two groups: well-winnowed sandstones cemented by calcite and poorly sorted sandstones and siltstones with a clay matrix. Diagenetic trends in these rocks are controlled by the presence or absence of clay matrix material (Figs. 5 and 6).

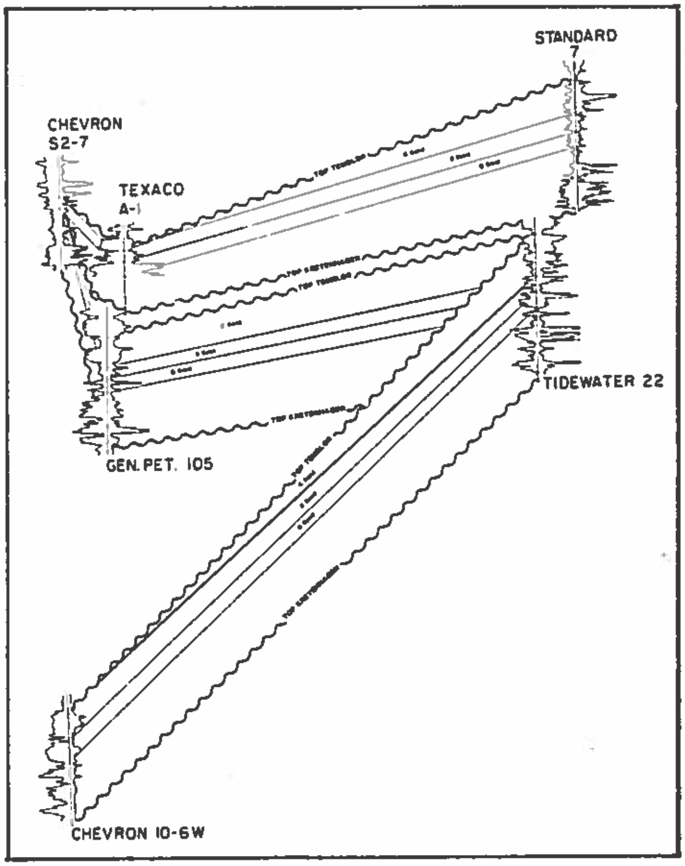

Figure 4. Fence diagram showing well logs for cores used in this study. The "C", "E", and "G" sands, included in this study, are indicated.

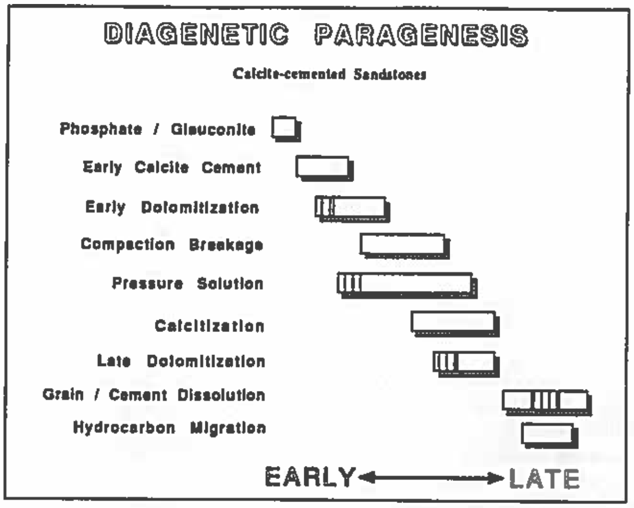

Figure 5. Paragenetic sequence of diagenetic events in well sorted sandstones containing calcite cement.

Sandstone with Calcite Cement

Rocks which were originally deposited as well-winnowed sands underwent a general sequence of diagenesis which is depicted in Figure 5. These rocks contain abundant glauconite and phosphate grains. Both phosphate and glauconite commonly occur as structureless grains of unknown origin, but phosphate also replaces fossil fragments. Less commonly, phosphate or glauconite replace volcanic fragments.

Framework grains are loosely packed and often contain poikilotopic calcite cement (Fig. 7) indicating early cementation at very shallow burial depths (McBride, 1977). In a few instances dolomite rhombs formed in the cement. The mode of occurrence of this dolomite as isolated rhombs which cut across the fabric of the calcite cement indicates that they formed as a result of dolomitization of calcite rather than precipitating as pore-filling cement.

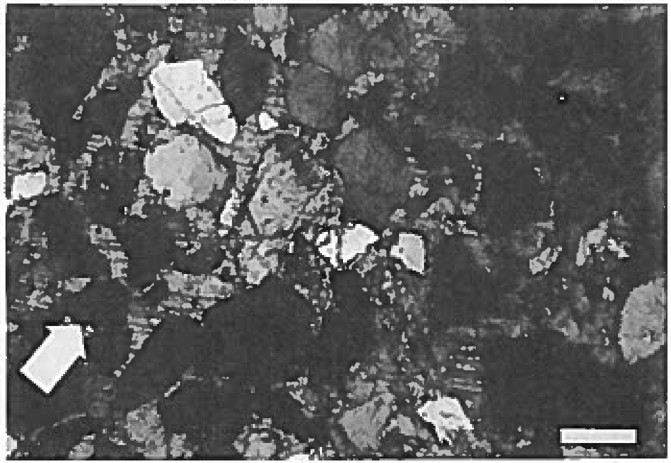

Figure 7. Well sorted, loosely packed sandstone with early, poikilotopic calcite cement indicating cementation within a few tens of meters of the sea floor (McBride, 1977). Some grains show evidence of grain-margin pressure-solution and replacement of silicates by calcite (arrows), and the cement contains lattice distortions due to differential compaction. There are also several framework-grain-dissolution pores. Scale bar equals 0.1 mm.

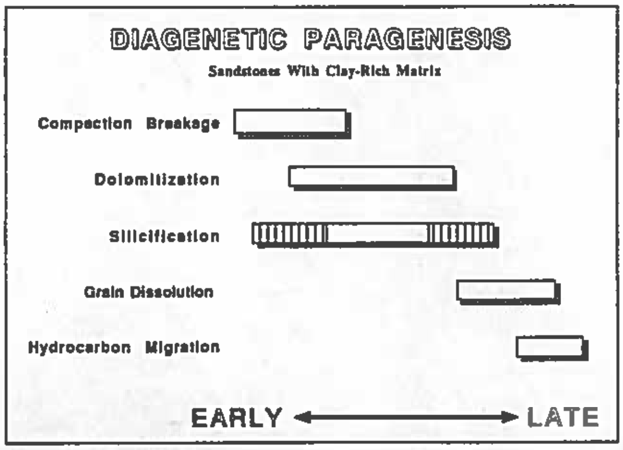

Figure 6. Paragenetic sequence of diagenetic events in sandstones containing a clay matrix.

With increased burial, compaction fracturing and pressure solution along grain-grain and grain-cement boundaries occurred (Fig. 7). This was accompanied by replacement of silicates by calcite and occasionally by dolomitization. Dolomite formed at this time is zoned with cloudy cores and clear rims and may have nucleated around earlier formed crystals (Fig. 8). The cloudy cores sometimes have non-rhombic forms suggesting partial dissolution prior to formation of the clear outer zones (Fig. 8).

This was followed by a period of dissolution and creation of secondary porosity. Framework grains of all types (Figs. 9 and 10), calcite cement (Fig. 11), and early dolomite were all affected. Late dolomite was relatively unaffected by this event, resulting in dolomite rhombs with leached cores.(Fig. 12). Hydrocarbons migrated into secondary porosity created by this dissolution event. Dissolution continued on at least a limited scale indicating the presence of water as well as oil (Fig. 13).

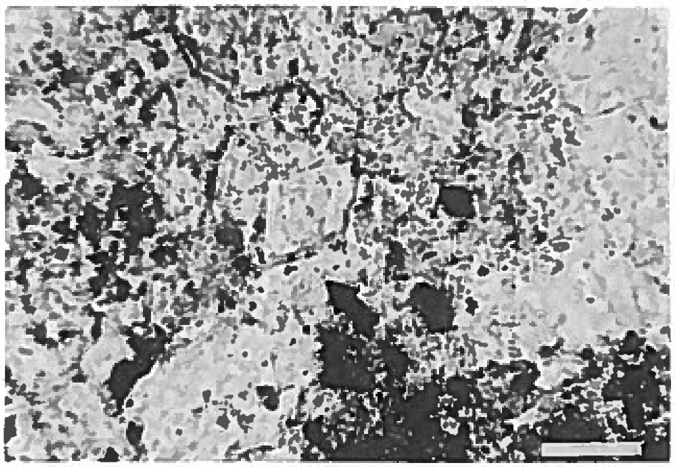

Figure 8. Late, zoned dolomite crystals replacing early calcite cement. Some of the rhombs have non-rhombic cores, including some with sutured boundaries (arrow), suggesting nucleation on an earlier dolomite crystal which had undergone partial dissolution. Scale bar equals 0.05 mm.

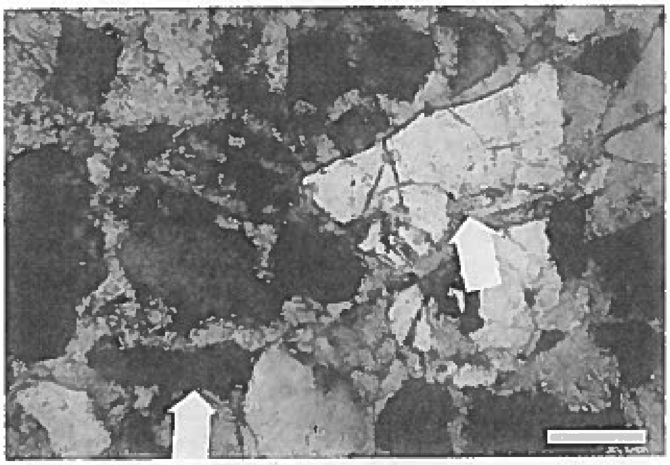

Figure 9. Loosely packed sandstone cemented by non-poikilotopic, early calcite cement containing abundant framework-grain-dissolution pores. Many of the quartz grains have been partially replaced by calcite (arrows). Scale bar is 0.05 mm.

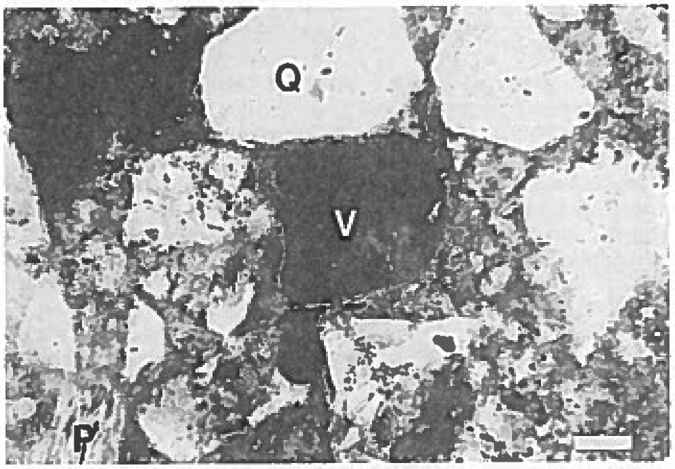

Figure 10. Sandstone with oil in secondary pores. Different materials exhibit varying degrees of resistance to dissolution. Quartz (Q) is essentially undissolved, plagioclase (P) and potassium feldspar (K) are only slightly affected, but volcanic grains (V) have been preferentially removed. Calcite cement has also been dissolved. Scale bar equals 0.01 mm.

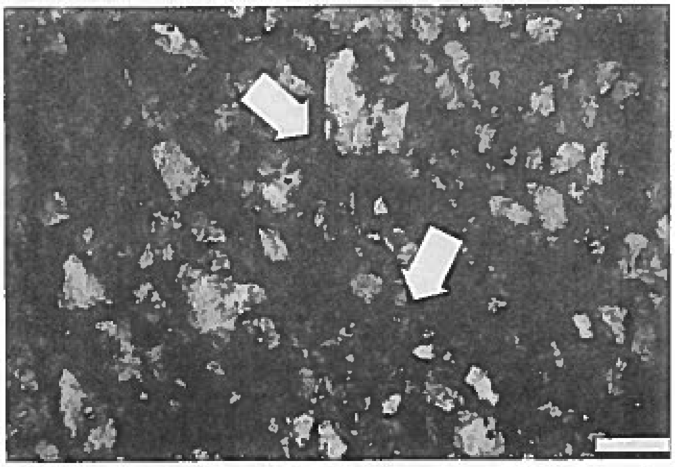

Figure 11. Loosely packed siltstone with poikilotopic, early calcite cement. Oil is present in secondary pores formed by dissolution of cement as indicated by remnants of cement, in optical continuity with pore filling matrix cement, isolated within oil (arrow). Scale bar equals 0.1 mm.

Sandstones with Clay Matrix

The general sequence of diagenetic events which occurred in rocks containing a clay matrix is shown in Figure 6. These sediments did not undergo a period of early cementation; consequently, they were tightly compacted during burial. Pressure solution was not observed in these rocks but compaction-induced fracturing of grains was common. This was followed by silicification of carbonate grains (Fig. 14) and dolomitization. Dolomite rhombs occur interstitially to framework grains, but constraints on their distribution are unclear. Pyrite formed within silicified areas of molluscs, but the timing of this event is also unclear.

A period of framework grain dissolution followed during which both silicate and carbonate grains dissolved (Figs. 15 and 16). All types of silicate grains were affected, but quartz and K-feldspar appear to have been more resistant to dissolution than either plagioclase or lithic (mainly volcanic) grains. Hydrocarbon migration followed after which no identifiable diagenetic changes occurred.

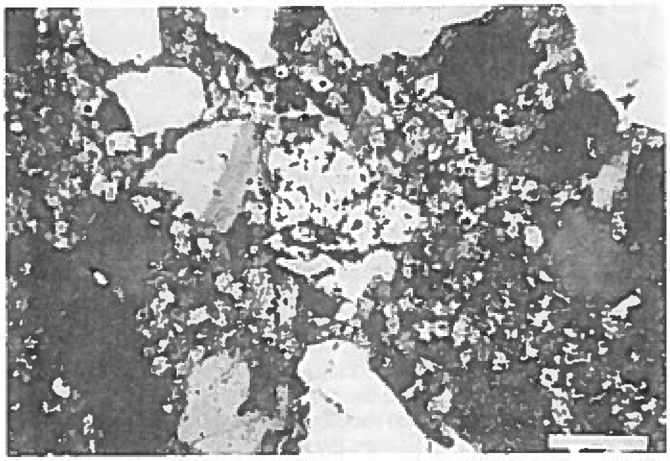

Figure 12. Sandstone cemented by late dolomite. Secondary porosity in this photomicrograph formed by dissolution of framework grains, including partially dissolved microcline grain in center, and cement. Many dolomite crystals have corroded centers suggesting two episodes of dolomitization in somewhat differing physiochemical environments. Scale bar equals 0.05 mm.

CONCLUSIONS

Sandstones containing abundant hydrocarbons in the Coalinga oil field are invariably lacking in clay matrix. Additionally, evidence indicates that the porosity present in oil-bearing sandstones is almost entirely of secondary origin. Analysis of both surface and subsurface data from the Coalinga oil field indicates that this secondary porosity resulted from dissolution of framework grains, early calcite, and dolomitized early calcite cement.

Conversely, sandstones in the Coalinga oil field with abundant clay matrix exhibit less secondary porosity development and smaller amounts of hydrocarbons than clay-free sandstones. The presence of clay matrix inhibited early cementation and the development of the secondary porosity in these sandstones.Thus, these rocks did not develop into reservoir-quality sandstones in the Coalinga oil field.

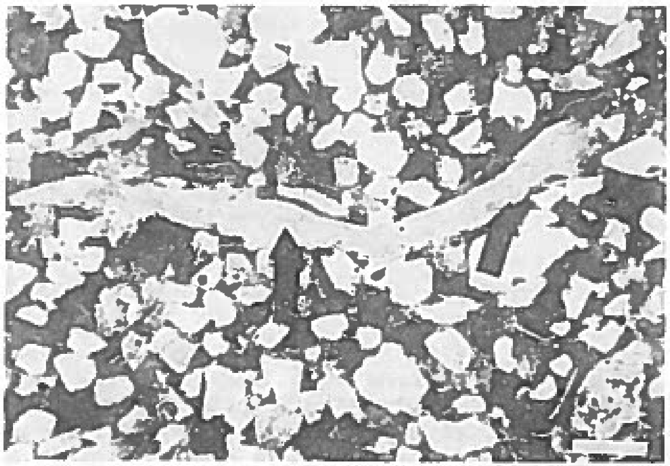

Figure 13. Mollusc fragment in siltstone. Most pores are saturated with oil. However, several pores formed by dissolution of silicate grains, and all pores formed by partial dissolution of the mollusc fragment (arrows), are open. This suggests that these pores formed subsequent to migration of oil into this rock. Traces of formerly extensive early calcite cement are also present. Scale bar equals 0.1 mm.

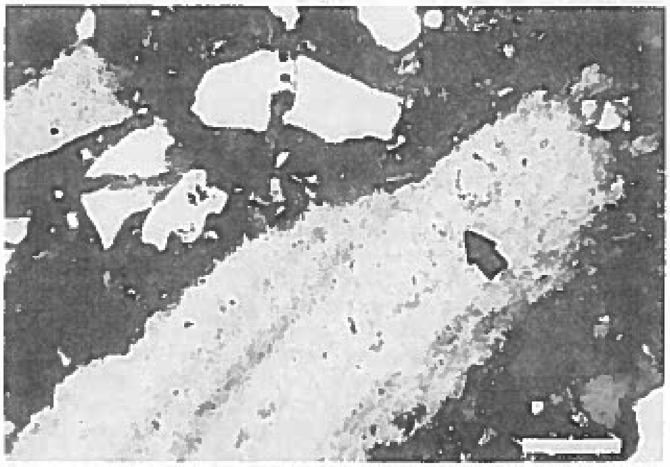

Figure 14. Partially silicified mollusc fragment in sandstone containing a clay matrix. Arrow indicates silicified area. Scale bar equals 0.05 mm.

Figure 15. Plagioclase grain in poorly sorted sandstone with clay matrix. The center of the plagioclase grain has dissolved and the resulting pore is filled with oil. Scale bar equals 0.01 mm.

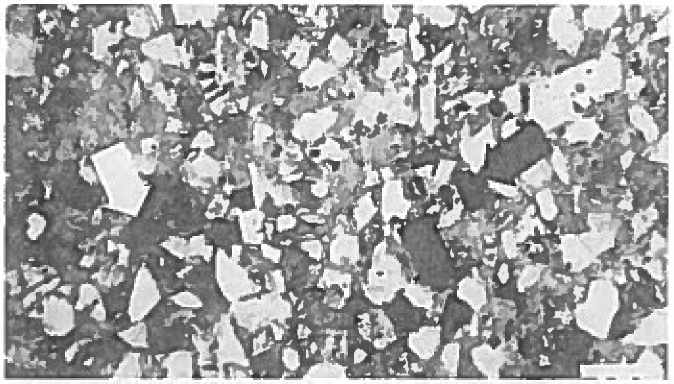

Figure 16. Quartz with minor feldspar and volcanic silt in a clay matrix. Framework-grain-dissolution pores are filled with oil. Scale bar equals 0.01 mm.

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