DEPOSITIONAL ENVIRONMENT OF THE CABALLOS FORMATION, SAN FRANCISCO FIELD, NEIVA SUB-BASIN, UPPER MAGDALENA VALLEY, COLOMBIA

A thesis

by

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ABSTRACT

Depositional Environment of the Caballos Formation,
San Francisco Field, Neiva Sub-basin,
Upper Magdalena Valley, Colombia
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Chair of Advisory Committee: Dr. Robert R. Berg

The Early Cretaceous Caballos sandstones in the San Francisco field, Upper Magdalena Valley, Colombia, contain approximately 500 million barrels of oil in place in the Upper and Lower members. Most of the oil is in the Upper Caballos sandstone. The Upper and Lower Caballos average 45 ft and 85 ft of sandstone, respectively. The Caballos lies at a depth between 2,080 and 3,680 ft. Both the sandstones are capped by marine shales.

The Caballos Formation was deposited during a world-wide transgression, and rests nonconformably on Jurassic volcanics. The Lower Caballos is composed of braided stream deposits with individual reservoir sandstones up to 20 ft thick. The sandstone in the Lower Caballos is variable in content and discontinuous. The Lower Caballos sediment was derived from quartz arenites of the Guayana shield and from local erosion of the basement. The Middle Caballos consists of shale and sandy shale deposited in restricted to open-marine and bay environments. The Upper Caballos was deposited in a fluvial-deltaic environment, and individual

sandstone units, which are separated by shale, have a lobate to elongate to ovate shape. The sediments in the Upper Caballos were derived from the Guayana shield and reworked Lower Caballos sandstones.

The Lower Caballos sandstones are fine-grained to granule, with a mean grain size of 0.63 mm (coarse grained); individual bed sets fine upward. The Lower Caballos composition averages 48.1% monocrystalline quartz and is classified as a litharenite. Quartz cement averages 4.6%; calcite cement averages 3.1%. Clean sandstones have porosities from 15% to 20% and permeabilities from 10 md to 1,000 md.

The Upper Caballos sandstone is fine to very coarse-grained with a mean grain size of 0.62 mm (coarse grained). Individual bed sets of the delta bars coarsen upward; individual bed sets in the distributary channels fine upward. Quartz cement averages 5.7%, and carbonate cement averages less than one percent. Clean sandstones have porosities from 12% to 26% and permeabilities from 70 md to 6,000 md.

The distribution of the reservoir quality sandstone and the reservoir barriers, siltstone and shale, are controlled primarily by depositional environment. Diagenesis also plays a major role in determining reservoir quality. Dissolution of volcanic rock fragments, feldspar and calcite cement contribute significantly to sandstone porosity and permeability.

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INTRODUCTION

In 1985, Tenneco discovered the San Francisco field in the Upper Magdalena Valley of Colombia, South America. The San Francisco field produces from the Cretaceous sandstones of the Caballos Formation, and is estimated to contain approximately 500 million barrels of oil in place. Although development of the field is not completed, plans are already underway to increase recovery by a waterflood.

To enhance the success of the waterflood in the Caballos reservoirs, a detailed stratigraphic study is needed to determine the geometry and environments of deposition of the reservoir units and to aid in accurately determining the location of future development and injection wells.

Understanding primary rock properties, which include sedimentary structures, texture, composition, and morphology, is essential to an effective stratigraphic study. The primary rock properties were determined from cores, thin sections, and well logs. Porosity and permeability were correlated with composition, texture and borehole log responses so that reservoir character can be determined from well logs in uncored intervals.

The citations on the following pages follow the format and style of the American Association of Petroleum Geologists Bulletin.

Regional Geology

Colombia can be divided into two major regions, the eastern Llanos platform and western Andean region (Bürgl, 1967) (Figure 1). The Precambrian Guayana Shield and the eastern Llanos platform furnished the bulk of sediment to the western part of Colombia, and comprise the eastern region. This eastern region has been stable since the Precambrian. The western region, or Andean zone, is further divided into the western and eastern Andes, which are separated by the Central Cordillera and, to the north, by the Sierra Nevada de Santa Marta and the Guajira Peninsula. The Andean zone has been tectonically active since the Cambrian.

Tectonics

The tectonics of western South America can be summarized as two compressional phases separated by a tensional phase in the Cretaceous.

During the Cambrian and Ordovician periods, most of Colombia, except the Guayana Shield, was covered by the sea (Bürgl, 1967). During the late Ordovician and Silurian, the east Andean region was uplifted to form the Paleo-Andes, which were exposed during the early or middle Devonian. The Andean region then underwent subsidence, which persisted to the end of the Paleozoic, while the eastern Llanos Platform remained emergent during the Devonian, Carboniferous, and Permian. Tectonic movements during the Paleozoic Era were

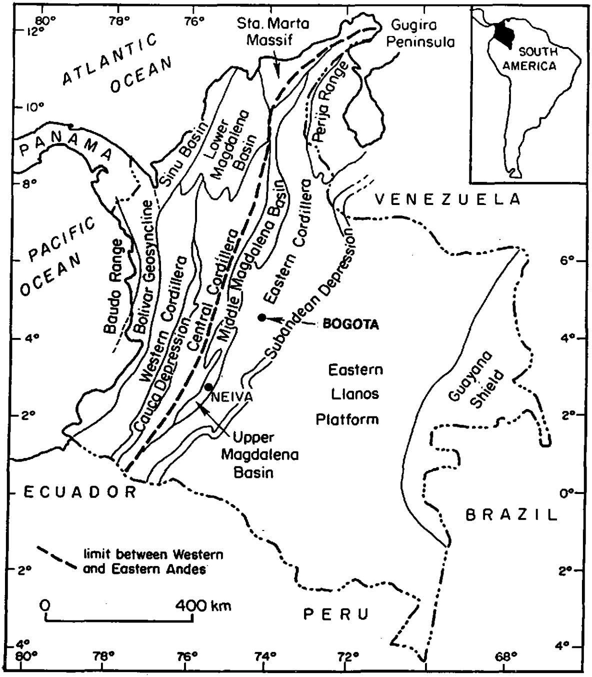

Figure 1 - Geological provinces of Colombia. Map after Bürgl (1967).

essentially compressional. This caused steady growth and temporal consolidation of the continent at the expense of the marine realm.

During the Mesozoic, tectonic forces were tensional rather than compressional. From the Tithonian to Albian, the region subsided and became a marine provence. The deepest part of the basin was in the Cundinamarca Basin near Bogata (Bürgl, 1961, 1967), which is filled with euxinic shales that grade into epicontinental shale, limestone, and sandstone towards the north, east, and southward. These Cretaceous deposits reach a total thickness of 12,000 m.

During a pre-Albian tectonic phase, the eastern part of the east Andean region was uplifted, the western part subsided, and intrusions of tonalitic and granodioritic plutons into the Central Cordillera (100-115 my., Botero, 1963) began and continued almost until the end of the Cretaceous. The east Andean Sea reached its maximum extension during the Albian.

During the Cenozoic and the latest Cretaceous, compressional tectonics again dominated the region. During the Pyrenen phase (middle Eocene), the Central and Eastern Cordillera and the Guayana Shield were raised while the Sub-Andean, Magdalena and Cauca depressions subsided (Stille, 1907). Debris from the rising cordilleras accumulated in these depressions as thick conglomerates and coarse sandstones. The strong compressional movement consolidated and restored the continent to its early Mesozoic extent, incorporated the west Andean province into the mainland, and uplifted the Andean chains. Much of the present-day structure was formed during the Cenozoic.

Local Structure

The San Francisco field is located on the eastern flank of the Central Cordillera, in the Neiva sub-basin of the Upper Magdalena Valley (Figure 2). The Upper Magdalena Valley is a narrow, northeast-to-southwest trending structural depression approximately 400 km long, and it lies between the Central Cordillera to the west and the Eastern Cordillera to the east. The two sub-basins in the Upper Magdalena Valley, the Neiva and the Girardot, are separated by the Natagaima Arch.

The San Francisco field is part of a series of folds in a folded thrust trend that formed as a result of compression during the Andean orogeny (Butler, 1983). The anticlines in this trend formed by roll-over of the hanging walls as they were thrust over the foot walls. The Middle Caballos shale acts as a decollement surface in much of the basin. Thrusts cut down through the Caballos and into the basement.

The structure of the San Francisco field expresses itself at the surface as a large hill with four-way closure. The trend continues to the east, but at a greater depth, and is not expressed at the surface.

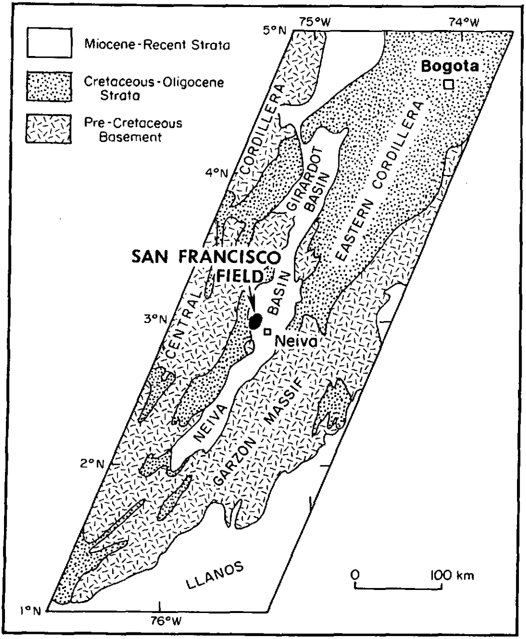

Figure 2 - General geological map of the Upper Magdalena Valley. Map from Butler (1983).

Regional Stratigraphy

During the Cretaceous, a mostly marine sequence was deposited. Thickness increases to the north from 1,030m in the Neiva sub-basin (Beltrán & Gállo, 1979) to 3,050m in the Girardot sub-basin (Corrigan, 1979) (Figure 3). The thickest accumulation of Cretaceous sediment (over 15,000m) is preserved in the Bogota trough, which is located north of the Neiva sub-basin.

A series of depositional cycles of Tithonian to Maastrichtian age are recognized in different locations in northwestern South America (Figure 4), and can be correlated with global sea level changes during the Cretaceous (Figure 5) (Van Hinte, 1976). The Aptian-Albian-age cycle is the first to effect the Neiva sub-basin, and marks the initiation of widespread sedimentation in Colombia and western Venezuela. The sedimentary cycles were deposited uniformly throughout the pericratonic basins. Each cycle consists of a basal sandstone overlain by limestone and shale. The Aptian-Albian sediments were deposited in an anoxic environment and thus preserved a high percentage of their original organic carbon. The high organic content of the Cretaceous shales supply a ready source rock for oil generation (Macellari, 1985).

Uplift during the early stages of the Andean orogeny resulted in a non-depositional episode which extended to the late Eocene. Continual uplift of the Central Cordillera,

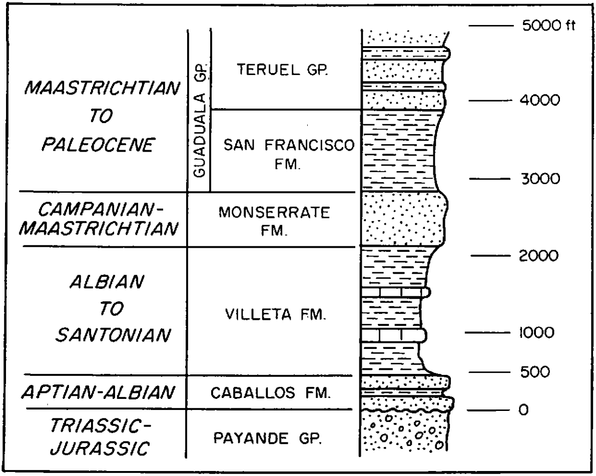

Figure 3 - Cretaceous section in the Neiva Sub-basin. From Macelleri, (1985). Modified from Beltrán and Gállo (1979).

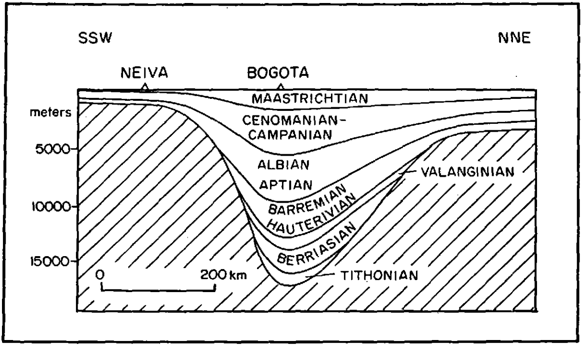

Figure 4 - Depositional cycles of the Cretaceous in northwestern South America. From Macellari (1985).

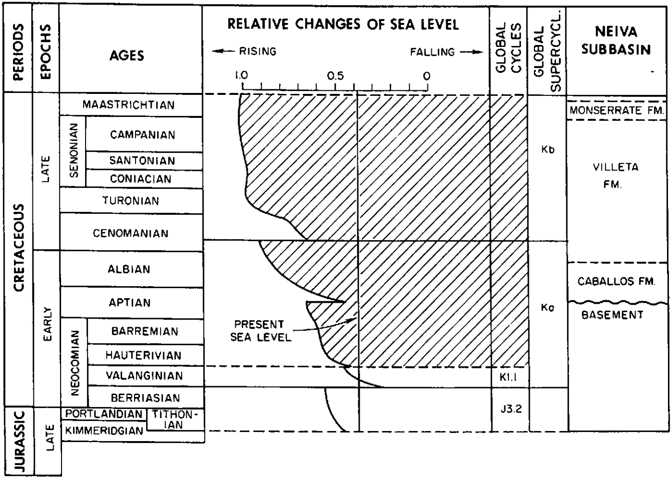

Figure 5 - Relative global sea level changes in the Cretaceous in relation to sedimentation of the Neiva sub-basin. Modified from Van Hinte (1976).

and later the Eastern Cordillera, resulted in the accumulation up to 12,000 m of volcanic deposits (Van Houten & Travis, 1968; Beltrán & Gállo, 1979; Butler, 1983).

Local Stratigraphy

Basement

Outcrops of basement along the eastern margin of the Central Cordillera and western flank of the Garzon Massif consist of Paleozoic crystalline rocks. They are composed of post-tectonic granitic and granodioritic intrusions and of regionally metamorphosed rocks up to the greenschist facies (Pedriera & Rosenmam, 1973). Triassic-Jurassic low-grade metasediments of the Payande Group unconformably overlie these Paleozoic igneous-metamorphic rocks (Cediel et al., 1981; Butler, 1983). The basement rocks were deeply eroded before the Cretaceous transition. Seas only covered the Upper Magdalena Valley during the Aptian-Albian Age.

Neiva Sub-Basin

The Neiva sub-basin is a narrow north-northeast to south-southwest basin bounded to the west by the Central Cordillera and to the east by the Garzon Massif (Figure 2). The Cretaceous strata from oldest to youngest are: Caballos Formation, Villeta Formation, Monserrate Formation and the lower portion of the non-marine Guaduala Group (Figure 3).

Caballos Formation (Kb)

The type locality of the Caballos Formation is at Cerro Caballos, south of Ortega, Tolima. The name was first published in Olssan (1956) for the basal sandstone of the Putumayo basin, and was proposed for the Neiva sub-basin by Conard et al (1964) to replace Kb (Dixon, 1952). The Caballos rests disconformably on the basement rocks, and its upper contact is placed where the clean quartz sandstone of the Caballos Formation is replaced by either the shale or dirty calcareous sandstone of the Villeta Formation (Conard et al., 1964). This unit is equivalent to part of the Hollín Formation of Ecuador (Beltrán & Gállo, 1979; Geyer, 1980), as well as the Une sandstone of the Cundinamarca and Aguardiente Formations of Tachira (Venezuela) (Trump & Salvador, 1964; Ramírez & Campos, 1972).

The Caballos Formation is subdivided into three members (Conard et al., 1964; Beltrán & Gállo, 1979). The lowest member of the Caballos Formation consists of argillaceous to clean cross-bedded sandstone with occasional conglomeratic sandstones that thin rapidly southward in the basin. A basal arkosic conglomerate is also found at many localities.

The Middle member is composed predominantly of medium to light gray shale with numerous limonitic concretions and thin beds of limonite or limonitic shale. Siltstone beds and sandstone lenses increase in frequency upward. The shales of the Middle member were deposited throughout the basin except in the southwest, where sandstones predominate. The top of the Middle member in the San Francisco field area is the first occurrence of significant siltstone and sandstone.

Conard et al (1964) believed that the Middle member represents a shallow to restricted marine environment. Macellari (1985) believes that the presence of plant debris and the absence of marine macrofauna indicate that deposition probably took place in a non-marine environment in the interdistributary areas of the delta-top facies.

The Upper member is composed of clean, white, quartzose sandstone. It is thick, massive to cross-bedded, and the quartz grains are generally subrounded. This member has a relatively constant thickness, and was probably deposited in a near-shore environment above the wave base (Macellari, 1985).

The Caballos section thickens in a northeastern direction, with the maximum thickness east of Neiva (Conard et al., 1964). The trend is also consistent with a southwest or westward thinning of the Caballos Formation away from the source, the Guayana Craton. The presence of ironstones at the top of the formation can be interpreted as a locally regressive episode in an overall transgressive sequence (Hallam, 1978). Conditions favoring deposition of iron-rich sediment are a warm climate, deep weathering, and transition from oxygenated to poorly oxygenated oceans (Van Houten & Arthur, 1984).

Villeta Formation

The Villeta Formation rests conformably above the

Caballos Formation. It is composed of medium gray to black shale with intercalations of organic-rich micrite that are very thinly bedded (Hays, 1962; Conard et al., 1964). Its thickness ranges from 630m north of the sub-basin to 415m to the south. The Villeta was deposited during the peak of the Cretaceous transgression in northwest South America (Macellari, 1985). Conard et al (1964) thinks the Villeta Formation is the source of the hydrocarbons in the Neiva sub-basin. Preservation of organic matter is believed to be caused by a high stand of sea level at the peak of the Cretaceous transgression, development of world-wide anoxic seas, basin shape, latitude, and geographic orientation (Macellari, 1985).

Montserrate Formation

The Montserrate Formation was deposited in the regressive hemicycle of the Cretaceous transgression of northwest South America. It contains a varied lithology dominated by sandstone with intercalations of siltstone, chert and minor amounts of shale and phosphorite (Beltrán & Gállo, 1979). Its thickness ranges from 267 m in the north to 86 m in the south.

The sands were derived mostly from the Guayna Shield to the east, but the emergence of the Central Cordillera in the west provided an additional, subordinate source (Waddell, 1982).

Guaduala Group

The Montserrate Formation is overlain by the paralic sediments of the Guaduala Group (Beltrán & Gállo, 1979). In the Neiva sub-basin, the Guaduala group is subdivided into the San Francisco Formation and the Teruel Formation (Figure 3). The San Francisco Formation, which was deposited first, is 480 m to 670 m thick, and consists of light to medium gray, very soft to medium hard claystone withh a reddish-brown to purple weathering and mottling (Conard et al., 1964). The Teruel Formation consists of 200 m to 560 m of non-marine sandstone and red beds (Conard et al., 1964; Beltrán & Gállo, 1979).

Methods

The vertical sequence of sedimentary structures and deformation features were described in four conventional, 4-inch diameter cores of the Caballos. Three of the cores, the San Francisco 2, 14 and 56, were quarter-slabbed; the San Francisco 35 was three-quarter-slabbed.

Composition and texture were determined from 60 thin sections taken at selected intervals. Samples were selected to demonstrate changes in composition and texture with variations of porosity, permeability and depositional environment. The thin sections were analyzed using standard petrographic techniques. Composition was determined by counting at least 200 detrital grains. Detrital grains were classified as quartz (monocrystalline only), feldspar, rock fragments (including polycrystalline quartz), "other" (mica, zircon, tourmaline, opaques, organics and chalcedony), and matrix. Detrital grain compositions were then normalized to 100%. Quartz, calcite and siderite cement, as well as kaolinite, were considered as a percent of the whole rock. Texture was determined by measuring the apparent long axes of 50 randomly-selected monocrystalline quartz grains, and maximum, minimum and mean grain sizes were calculated for each sample. The trends in composition, texture and sedimentary structures were used to interpret the depositional environment.

Porosity, permeability and water saturation values were obtained from commercial core laboratories, and were plotted so that they could be correlated with gamma ray and resistivity logs. Gamma ray logs were used for correlation of cross sections and to construct isopach maps. Net sandstone was calculated by first drawing a line through the clean shale line and at the minimum gamma ray value in the sandstone interval. The differences between the clean sandstone and the clean shale lines was found in API units; this value was multiplied by 70%. The net sandstone cutoff was then determined by subtracting the API value calculated above from the API value read from the clean shale line. The 70% cutoff line is used because it correlates with clean sanstone in the cored wells.

CHARACTERISTICS OF THE CABALLOS FORMATION

Introduction

The Caballos Formation in the San Francisco field consists of three members (Figures 6 & 7). The Lower Caballos member is 110 ft to 220 ft thick and consists of interbedded sandstone, siltstone, and shale. Individual sandstone beds are up to 15 ft thick.

The Middle Caballos member consists predominantly of shale, and is about 90 ft thick.

The Upper member has an overall thickness of 170 ft, and is further divided into two submembers. The upper submember is approximately 100 ft thick, and the lower submember is approximately 67 ft thick. The upper submember of the Upper Caballos varies from a thick, massive sandstone approximately 100 feet thick to interbedded sandstone and shale (Figures 6 & 7). It averages 45 ft of sandstone, or 42% of the total thickness. The lower submember of the Upper Caballos is composed of sandstone, siltstone, shale and coal, and has a variable sandstone content. In some wells, lenses of sandstone reach 20 ft thick, but other wells contain no sandstone at all. When present, sandstone in the lower submember averages 5 ft, or 12% of the total thickness.

In order to gain a better understanding of the Caballos sandstone as a reservoir, its primary properties were studied. The primary rock properties, including sedimentary

SAN FRANCISCO 35

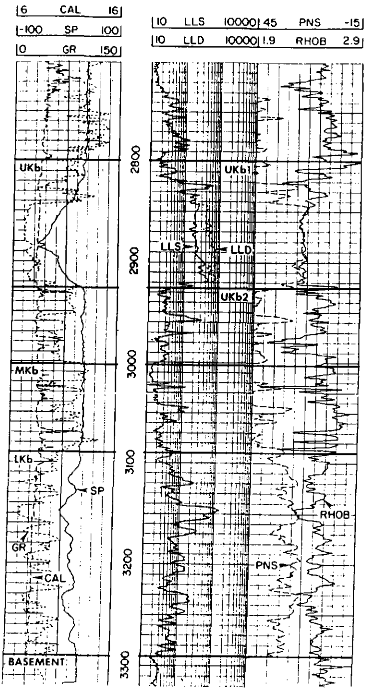

Figure 6 - Type log for the Caballos Formation in the San Francisco field. The log shows a massive upper submember of the Upper Caballos (UKb1), the lower submember of the Upper Caballos (UKb2), the Middle Caballos (MKb), and the Lower Caballos (LKb).

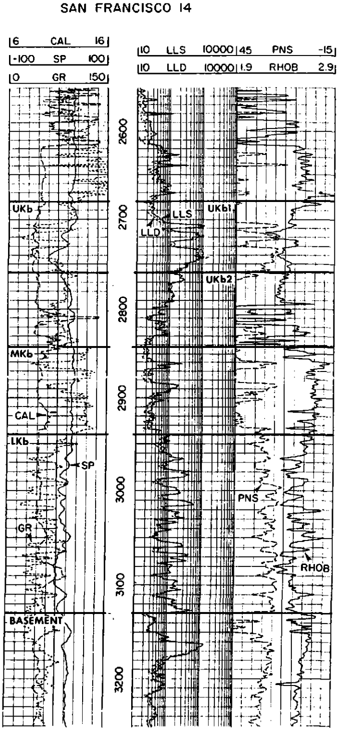

Figure 7 - Type log for the Caballos Formation in the San Francisco field. The log shows an interbedded sandstone and shale in the upper submember of the Upper Caballos (UKb1), the lower submember of the Upper Caballos (UKb2), the Middle Caballos (MKb), and the Lower Caballos (LKb).

structures, texture, composition, and morphology, control fluid production (Berg, 1986).

Sedimentary Structures

Sedimentary structures are the best indications of the original depositional environment. A better understanding of depositional environments enables prediction of reservoir trends and variability.

The Caballos Formation in the San Francisco field consists of five major composite sets of sedimentary structures, each of which is composed of several cosets (Mckee & Weir, 1953). Each composite set is indicative of a specific depositional process.

Lower Caballos

The Lower Caballos member consists of braided stream deposits (the first composite set). These deposits begin with an erosive base overlain by either a massive to planar-laminated conglomerate or a cross-laminated, medium to coarse-grained sandstone rich in quartz and volcanic chert (Figure 8 J, K). The amount of conglomerate increases with depth. The sandstone has cross laminations inclined to approximately 15°, though it may appear massive (Figure 8 D,B; Figure 9 M), and has a dark brown oil stain and visible porosity.

The cross-laminated to massive sandstone is overlain by sandstone with low-angle cross-laminations and ripple-laminations, and is finer grained and more matrix-rich

Figure 8 - Sedimentary structures in the Caballos Formation, San Francisco 35, 3238 ft - 3305 ft (986.9 m - 1007.0 m).

A, Cross-laminated sandstone that fines upward. Oil stain decreases upward in the finer-grained sandstone; 3238.0 ft (987.6 m).

B, Cross-laminated sandstone that fines upward. Oil stain decreases upward in the finer-grained sandstone; 3238.5 ft (987.7).

C, Fine-grained, low-angle, cross-laminated sandstone from the upper part of a braided stream channel. Sandstone is not oil stained; 3252.0 ft (991.9 m).

D, Coarse-grained channel sandstone with faint cross-laminae and an elongated clay clast; 3255.0 ft (992.8 m).

E, Ripped-up clay clasts; 3265.0 ft (995.8 m).

F, Sandstone with highly contorted, organic-rich laminae which indicate rooting; 3267.0 ft (996.4 m)

G, Matrix supported sand grains with vertical carbonaceous stringers (roots?); 3270.0 ft (997.4m).

H, Thin bed of ripple-laminated sandstone above a low-angle, cross-laminated sandstone. Oil stain in lower part of photograph reflects an increase in grain size. Photograph H is the top of a coset which continues in photographs J and K; 3286.0 ft (1002.2 m)

J, Planar cross-laminated conglomerate truncating a coarse-grained, cross-laminated sandstone; 3287.0 ft (1002.5 m).

K, Erosional contact between mottled, overbank claystone and channel lag in photograph J; 3288.0 ft (1002.8 m).

L, Dessication fracture in a mottled claystone filled with sand grains and associated with abundant crystal aggregates of siderite; 3302.0 ft (1007.0 m).

M, Dessication fracture in a mottled claystone filled with clay and lined with organic material; 3305 ft (1008.0 m)

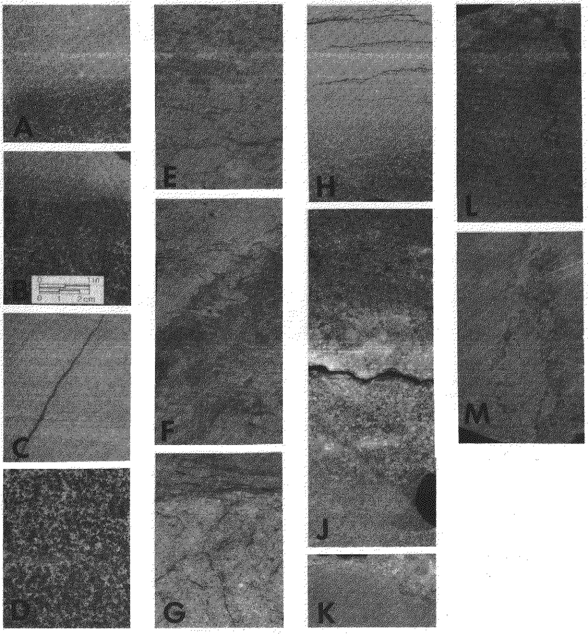
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Figure 9 - Sedimentary structures in the Caballos Formation, San Francisco 14, 2749 ft - 3138 ft (837.9 m - 956.5 m).

A, Fine-grained, ripple-laminated, slightly burrowed sandstone; 2749.0 ft (838.4).

B, Horizontally-laminated, gray shale (varved?); 2796 ft (851.9 m).

C, Limonite-rich claystone with vertical organic stringers (roots?); 2796.0 ft (852.8 m).

D, Sandy shale with ripple laminations. Oyster shells, some in living position; 2869.0 ft (875.0 m).

E, Soft sediment deformation forming tight folds in the shale; 2872.0 ft (876.0 m).

F, Normal open-marine shale and a graded bed of a storm deposit. Arrow indicates scour at base of storm deposit and resumption of normal-marine deposition at the top of the storm deposit. Note articulated shells above and below the storm deposit; 2892.0 to 2893.0 ft (882.1 to 882.4 m).

G, Highly burrowed, carbonate-rich shale; 2894.0 ft (882.7 m).

H, Elongated shale clast in a marine shale; 2902.0 ft (885.1 m).

J, Condrites burrows in a restricted shale; 2942.0 ft (897.3 m).

K, Ripple-laminated sandstone and shale which is slightly burrowed; 2952.0 ft (900.4 m).

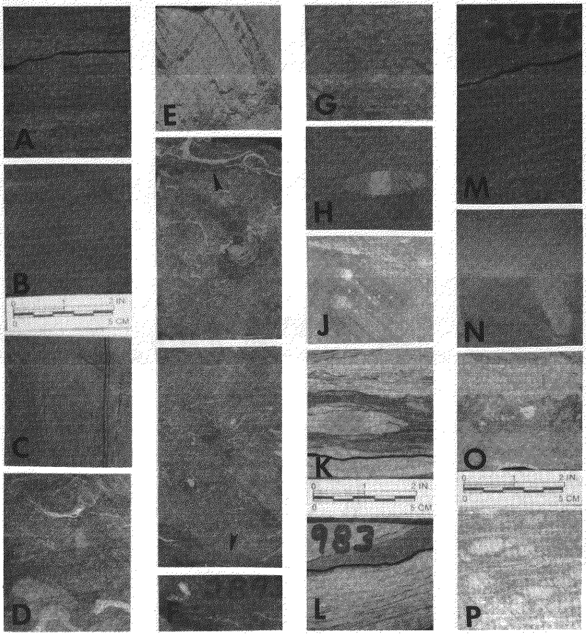
L, Ripple-laminated sandstone and siltstone; 2983.0 ft (909.8 m).

M, High-angle cross-laminated, coarse-grained channel sandstone; 2985.0 ft (910.4 m).

N, Large burrow in the fine-grained sandstone facies. Sandstone contains low-angle cross-laminae; 3010.0 ft (918.1 m).

O, Soil zone with concretions and red clay; 3023 ft (922.0 m).

P, Volcanic tuff with large nodules of devitrified glass; 3128 ft (954.0 m).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(Figure 8 A,C,H). The horizontally-laminated and the low-angle cross-laminated sanstone facies are more common than the ripple-laminated sandstone which is commonly only a few inches thick. This sandstone is not oil stained, and in the upper part of the Lower Caballos, it may be burrowed (Figure 9 N,K). Crystal aggregates of siderite and calcite are also present in some of thhe low-angle cross to ripple-laminated sandstones. The entire sequence is capped by a massive to mottled claystone (Figure 10 N). The claystone is black to dark gray and nonfissile. Vertical fractures up to 5 mm are present, and are filled with clay or sandstone (Figure 8 L,M). These fractures probably represent desiccation fractures due to subaerial drying of the overbank clay. Also present in the mottled claystones are zones with matrix-supported sand grains, concentric mud nodules, crystal aggregates of siderite and calcite, pyrite, and wavy, discontinuous organic lamina indicating zones of rooting and soil formation (Figure 8 E, F, G; Figure 9 O, Figure 10 M).

The Lower Caballos was deposited as a braided stream complex and is composed predominantly of fluvial-channel sandstones and conglomerates, overbank shales and siltstones, and paleosols. As described in cores, the sandstones in the Lower Caballos member decreases in grain size upward, increases in matrix upward, and decreases in flow-regime structures upward from cross to ripple

Figure 10 - Sedimentary structures in the Caballos Formation, San Francisco 35, 2827 ft - 3226 ft (871.8 m - 994.9 m).

A, Large piece of lignite in an organic-rich shale; 2827.0 ft (871.8 m).

B, Contact (arrow) between mottled claystone with scattered lignite stringers at the base of the photograph and the organic-rich shale at the top; 2829.0 ft (872.5 m).

C, Ripple-laminated, fine-grained sandstone with organic-rich laminae; 2845.0 ft (877.4 m).

D, Varved shale; 2851.0 ft (879.2 m).

E, Low-angle cross-laminated, medium-grained sandstone; 2860.0 ft (882.0 m).

F, High-angle cross-laminated, very coarse-grained sandstone with some organic-rich laminae; 2878.0 ft (887.6 m).

G, Horizontally-laminated, coarse-grained sandstone; 2897.0 ft (893.4 m).

H, Slightly-inclined cross-laminated to ripple-laminated, medium-grained sandstone; 2906.0 ft (896.2 m).

J, Ripple-laminated, fine-grained sandstone; 2909.0 ft (897.1 m).

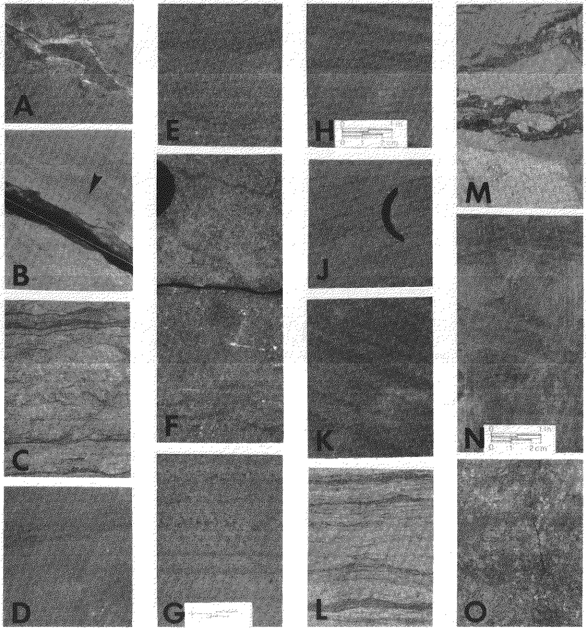
K, Cross-laminated, coarse-grained sandstone with lamina inclined to 15°; 2929.0 ft (903.3 m).

L, Ripple-laminated siltstone and shale; 2934.0 ft (904.8 m).

M, Rip-up clasts and chips of siltstone and claystone; 3221.0 ft (993.4 m).

N, Mottled claystone; 3223.0 ft (994.0 m).

O, Matrix supported sand grains; 3226.0 ft (994.9 m).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laminations. These trends indicate a decrease in water velocity upward, and are characteristic of fluvial deposition (Berg, 1986). Individual sets of cross-laminated sandstone reach several feet in thickness; cosets reach a thickness of 20 ft, which is typical of braided streams (Miall, 1977). Foraminifers studied by commercial companies indicate deposition in fresh to brackish water. The crystal aggregates of siderite found in the low-angle cross-laminated sandstones, and in the finer-grained facies indicate that the sediment was rapidly buried in an organic-rich, reducing environment (Gautier, 1982). The presents of rooting and soil formation suggest prolonged subaerial exposure of the overbank deposits.

The abundance of volcanic rock fragments in the Lower Caballos Formation with a composition similar to the basement suggest erosion of basement. Basement topography probably had a significant control on deposition of the Lower Caballos.

Comparison of core data and outcrop data also supports the interpretation of braided streams. In outcrop, the Lower Caballos Formation consists of truncating channel sandstones which fine upward. Conglomerates are more common in the lower section of the outcrop, similar to the the conglomerates San Francisco field.

Middle Caballos

The Middle Caballos rests conformably on the sandstone and shales of the Lower Caballos. The base of the Middle Caballos consists of restricted-marine or bay deposits which are followed stratigraphically by an open-marine shale. In the upper part of the Middle Caballos, the shale again becomes restricted, similar to the basal section of the Middle Caballos. The restricted sediments are described in the second composite set, and the open-marine sediments are described in the third composite set.

The second major composite set of the Caballos consists of interlaminated shale, limonite and siltstone. The shale is often highly fissile. The limonite is found as beds and nodules; the beds are common, and usually less than an inch thick, but can be up to four inches thick. Sparse horizontal burrows, Condrities burrows, and scattered organic material are also present (Figure 9 J), and the siltstone and shale laminae are occasionally highly contorted.

The restricted shale above the open-marine section may represent a bay possibly caused by deltaic deposition lateral to or behind the field area.

The third major composite set consists of shale which is light gray to greenish and silty to sandy, and has a sharp upper and lower contact with the dark shale described in the second composite set. The shale is well cemented and has a high carbonate content, and large-scale burrowing is present in zones that appear to be sheared by soft-sediment deformation (Figure 9 G). These composite sets also contain beds of shell-hash composed of small bivalves, oysters and some snails. The oyster shells are pale-blue calcite and the bivalve shells are white calcite, which probably recrystallized from aragonite.

These shell-rich zones occur in two modes. In the first mode, which is the normal depositional sequence, the bed contains articulated oyster shells in either a horizontal to slightly wavy-laminated sandy shale or a massive shale (Figure 9 D). The second mode is as slightly graded beds of bivalve shell-hash and broken oyster shells (Figure 9 F) with sharp and apparently erosive basal contacts. The graded beds of shell-hash are capped by the normal depositional sequence. Intervals of soft sediment deformation, clast of clay, and a few limonite layers are are also present (Figure 9 E, H).

The lighter color of the shale, the high carbonate content, the presents of sand grains and the abundance of large-sized burrows and fossil fragments in the third composite set indicate that the environment at this time was open to marine circulation. This resulted in higher orgainic productivity. The first mode of occurrence is interpreted to be the normal marine shelf deposition. Oyster shells are articulated and in growth position. The shale is very sandy in places and may contain low amplitude ripples which represent marine currents on the open shelf. The graded beds of shell hash, which are erosional at the base, probably represent storm deposits. The shells in the storm deposits, which are different than in the surrounding shales, contain clam shells and broken oyster shells. These zones of carbonate-rich shale, shells and burrows, are concentrated in two major sections approximately 10 ft thick that can be correlated in well logs across the field and in the basin (Figures 6 & 7). Below the two major concentrations of carbonate material is a third zone which has variable thickness across the field and basin. These zones are separated by a more restricted shale.

Upper Caballos

Sediments in the Upper Caballos are typlified by the fourth and the fifth composite sets. The fourth composite set is composed of alternating beds of sandstone and shale. The base of the sets contains burrowed shale with lenses of sandstone (Figure 11 L; Figure 10 L), and the shale is overlain by cross-laminated sandstone with an abrupt base (Figure 11 K). The basal sandstone is overlain by cosets of coarsening upward sandstones, the sedimentary structures of which show an increase in flow regime upward. At the base of these cosets, the sandstone contains wavy, organic-rich laminae that may be separated by thin horizontal laminae of shale (Figure 11 N, O; Figure 10 L). The sandstone may also

Figure 11 - Sedimentary structures in the Caballos Formation, San Francisco 56, 2470 ft - 2809 ft (752.9 m - 856.2 m).

A, Organic-rich shale with horizontal burrows. Burrows have been replaced by pyrite; 2470.0 ft (752.9 m).

B, Contact between organic-rich shale and fine-grained, burrowed sandstone; 2472.0 ft (753.5 m).

C, Thin bed of pyroclastic glass spheres in an orgainic-rich shale that fills a soft sediment fracture; 2473.0 ft (753.8 m).

D, Thin bed of organic-rich shale and siltstone seperating two beds of coarser grained sandstone; 2535.0 ft (772.7 m).

E, Interlaminated siltstone and organic-rich shale; 2538.0 ft (773.6 m).

F, Coarse-grained sandstone with cross lamina inclined to 20°; 2539.0 ft (773.9 m).

G, Contact between two cosets of coarsening upward cosets of sandstone. The lower coarse-grained coset is continued in photograph H. Oil stain increases upward in the coset; 2542.0 ft (774.8 m).

H, Coarsening upward coset of discontinuous wavy laminated sandstone. Coset continues in photograph G. Oil stain increases upward in the sandstone; 2542.5 ft (775.0 m).

J, Interlaminated shale, siltstone and very fine-grained sandstone. Siltstone and sandstone have very discontinuous, wavy laminae; 2545.0 ft (775.7 m).

K, High-angle, cross-laminated, coarse-grained sandstone; 2547.0 ft (776.3 m).

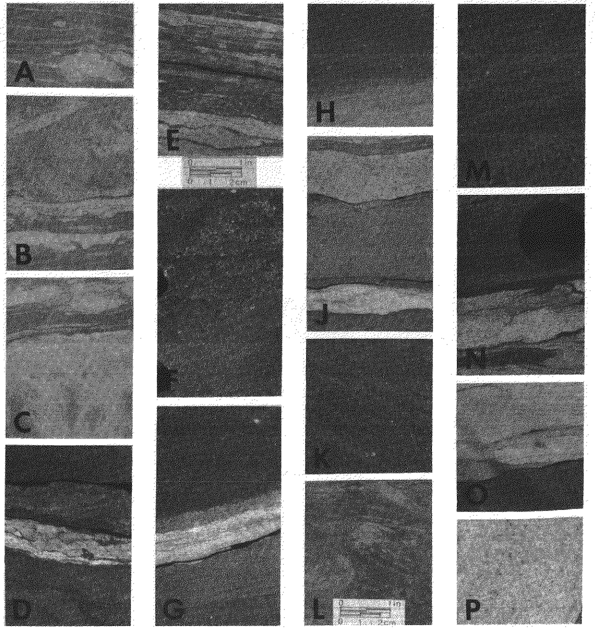
L, Highly burrowed shale. Burrows are filled with siltstone; 2561.0 ft (780.6 m).

M, High-angle, cross-laminated, coarse-grained sandstone; 2597.0 ft (791.6 m).

N, Contact between ripple-laminated, fine-grained sandstone with lignite laminae and cross-laminated, oil stained sandstone above; 2598.0 ft (791.9 m).

O, Contact between organic-rich shale and ripple-laminated, fine-grained sandstone; 2599.0 ft (792.2 m).

P, Tuff with phenocrysts of feldspar; 2809.0 ft 856.2 m).



be burrowed which may distort the laminae. This laminated sandstone is overlain by cross-laminated or massive sandstone which may also be burrowed; the laminae are horizontal or inclined up to 10° (*Figure 11 D, F, G; Figure* 10 G). The cosets of sandstone are seperated by either a black organic-rich shale, an interlaminated siltstone and shale, or a varved shale (Figure 11 E). The black shale is generally massive and organic-rich. Sparse burrowing is present in some shale intervals. The shale is also lignitic in places, and may also contain large pieces of woody material especially at the top of the composite set. Slumping of these sediments causes high-angle inclination of the shale/sandstone contact in parts of the sequence. The shoaling upward sequence described in the fourth composite set is consistent with sediments *described in* a deltaic bar (Coleman, 1981, Berg, 1986).

The fifth composite set consists of cosets of sedimentary structures that show a decrease in flow regime upward. In the lower part of the fifth composite set, the sandstone is very coarse-grained and its cross laminae are inclined to 20° (Figure 10 F, K). The laminations are often outlined by lignitic material which indicate a break in deposition. The sets or cosets may reach 10 to 15 ft in thickness. Above the thick cosets of cross-laminated sandstone are thinner cosets consisting of cross laminae at the base and ripple laminae at the top, and reach a thickness of 5 ft. The cosets continue to decrease in thickness upward in the section. The ripple-laminated sandstone appears to be highly weathered in the top part of the fifth composite set, and contains abundant organic-rich lamina (Figure 10 C, E). Burrowing is not noted. The smaller cosets at the top of the composite set are sometimes separated by a dark gray shale that has slightly wavy, continuous, horizontal, black laminations (Figure 10 D). A mottled claystone which has an abrupt and uneven contact with the overlying black, massive, organic-rich, shale caps the fifth composite set (Figure 10 A, B). The sediments of the fifth composite are consistent with those of a distributary channel (Coleman, 1981; Berg, 1986).

Above the fourth and fifth composite sets is a black, highly fissile shale. The shale contains horizontal burrows that are filled with sandstone and siltstone, and are often replaced by pyrite (Figure 11 A). Burrowed fine to very fine-grained sandstone is found within the shale in small beds less than 1 ft thick (Figure 11 B). Soft-sediment fractures present in the San Francisco 56 core are filled with pyroclastic debris. The pyroclasts are glass balls that fill the fracture and form laminae in the shale (Figure 11 C).

The sandstones in the lower submember, described in composite four, are not reworked, and appear to be deposited in a low energy environment. The small deltaic lobes are classified as a river dominated delta (Galloway, 1979; Coleman, 1981), and are probably bay-head deltas. The lower submember of the Upper Caballos contains at least three separate mappable sandstone bodies. Shale in the San Francisco 14 core appears to be varved at the top of the lower submember, indicating deposition in an interdistributary lake. The shales in the upper section in the other cores, the San Francisco 56 and 35, appear to be shallow marine or bay. Each of these bodies occurs in zones with a high concentration of coal. Organic-rich material probably concentrated in depositional lows between times of sand deposition. Maximum coal thickness seen on well logs is 20 ft.

Sandstones in the upper submember were deposited in a high-energy delta bars (composite set 4) which were cut by distributary channels (composite set 5).

The ripple-laminated to low-angle cross-laminated sandstones, which sometimes are burrowed, are interpreted to be distal deltaic bars. The sandstones above the burrowed sandstones, which are coarser grained and have either high-angle, inclined cross laminations or horizontal cross laminations, are interpreted to be proximal deltaic bars. The high-angle, cross-laminated sandstones are interpreted to be the original sedimentary structures of the delta bars while the horizonally-laminated sandstone is interpreted to have been reworked by waves.

The deltaic bars are separated by black, organic-rich shale, varved shale, or alternating siltstone and sandstone with organic-rich shale. The black shale is interpreted to be prodelta shale which probably was deposited more laterally to the major areas of deposition than offshore. The varved shale is interpreted to be interdistributary lake deposits located updip from deltaic deposition on the lower deltaic plain. The interlaminated deposits of siltstone and shale are interpreted to be bay-fill deposits.

Scattered in the sandstone of the delta bars is organic-rich lamina which are interpreted to indicated drainage of an organic-rich area, possibly a swamp located behind the delta.

The distributary channels truncate the other deltaic deposits. The distributary channel sequence is described in the fifth composite set, and it appears to have been abandoned slowly. The channel is filled with sandstone, most of which is cross laminated. Ripple-laminated sandstone caps the section. Breaks of organic-rich shale a few centimeters thick divide high flow-stages in the distributary channel and probably represent the remnants of shale plugs which fill the channel between flood episodes. At the top of the distributary channel is mottled claystone which probably represents the exposed portion of the distributary channel levee.

At least one and possibly two other channels are identified from well logs in the Caballos sandstone. In the San Francisco 39 and 61, the channel sandstones contain a higher shale content in the upper part of the section than does the San Francisco 35, which indicates a more rapid abandonment of the channel. Another channel is interpreted in the San Francisco 5 well.

The deltaic bars are interpreted to have been deposited in a high-energy environment because they are sand-rich and show little or no clay or silt as either layers or dispersed within the sandstone in the upper part of the sandstone body. Significant amounts of clay and silt are only found in the lower quarter of the sandstone body.

The sandstones in the river-mouth bars in a high-energy delta are often merged together to form a more or less continuous sand sheet (Sneider, 1982). River-mouth bars in the Caballos sandstone, however, appear on logs to be discontinuous vertically and horizontally. The individual sandstone lobes are vertically continuous in some of the wells and isolated in others. The San Francisco field appears to contain at least two and probably three distributary channels. The deltaic bars in the San Francisco field are lobate, cuspate or elongate. Comparison of deltaic bars in the San Francisco field with the deltaic classification system of Galloway (1979) and Coleman (1981) indicates that the deltas were probably deposited under conditions intermediate between wave domination and river domination.

Depositional History

The Caballos Formation was deposited during a global rise in sea level (Figure 5). The base of the Caballos Formation in the San Francisco field is marked by a nonconformity between the Cretaceous Lower Caballos sandstones and shales and the Jurassic volcanic tuff of the basement. The sediments of the Upper and Lower Caballos is interpreted to have been deposited from the south or east toward the north and west. The Lower Caballos is interpreted from cores, well logs, and map data to be an incised valley-fill that was deposited during a lowstand systems tract and the later transgressive systems tract (Vail, 1987). As the sea level continued to rise, the braided stream deposits of the Lower Caballos were flooded, and both restricted and open-marine shales were deposited. Fluvial-deltaic deposits then prograded onto the shelf in the region of the San Francisco field. As the transgression continued, the region was flooded and covered by the highstand deposits of the Villeta Formation.

Texture

Samples of cores from the San Francisco 2, 14, 35 and 56 cores were selected to determine the textural characteristics of the Caballos Formation. The mean grain size of the monocrystalline quartz grains in the Upper Caballos is 0.62 mm (coarse-grained) with a standard deviation of 1.75 phi (0.3 mm). In the Lower Caballos, the mean grain size of monocrystalline quartz is 0.63 mm (coarse-grained) with a standard deviation of 1.59 phi (0.33 mm). According to Beard and Weyl's (1973) sorting criteria, the Upper and Lower Caballos sandstone are both moderately sorted.

The textural characteristics of the Caballos sandstone vary in the different composite sets. The first composite set contains granule-size particles in the channel lag and has a mean grain size of 0.7 mm in the cross-laminated channel sandstones (Figure 12). The mean grain size dramatically decreases upward to 0.2 mm in the nonstained overbank sandstone.

The fourth composite set shows an increase in grain size upward (Figures 13 & 14). The ripple-laminated sandstones at the base of the coset have a mean grain size of 0.2 mm with a standard deviation of 2.23 phi (0.19 mm). The mean grain size increases upward in these coset to 0.6 mm with a standard deviation of 1.0 phi (0.75 mm) in the cross-laminated to massive sandstones.

In the fifth composite set, the overall grain size decreases upward, as does the grain size of the individual cosets (Figure 14). The basal, massive to cross-laminated sandstones have a mean grain size of 0.8 mm with a standard deviation of 1.21 phi (0.43 mm). In the ripple laminated sandstones, the grain size decreases upward to 0.6 mm with a

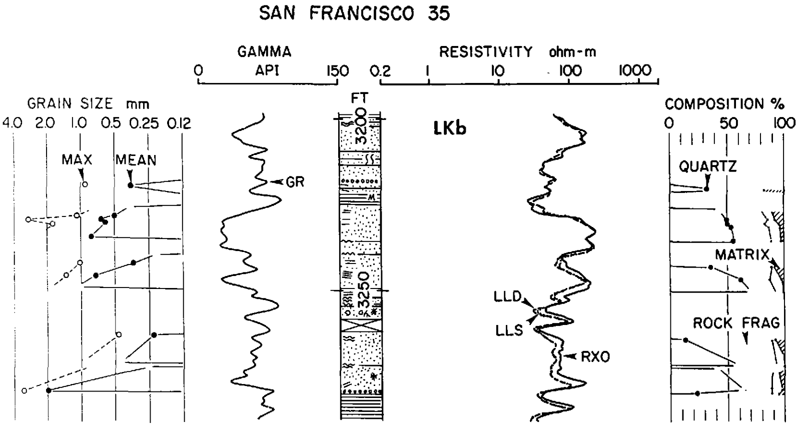


Figure 12 - Texture, sedimentary structures and composition of the Lower Caballos for selected beds from 3200 to 3290 ft (975.4 m to 1002.8 m) in the core from the San Francisco 35, Upper Magdalena Valley, Colombia.

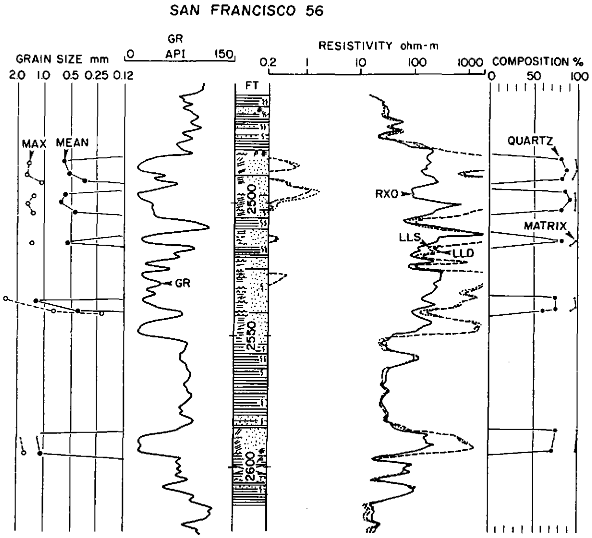


Figure 13 - Texture, sedimentary structures and composition of the Upper Caballos for selected beds from 2460 to 2620 ft (749.8 m to 798.6 m) in the core from the San Francisco 56, Upper Magdalena Valley, Colombia.

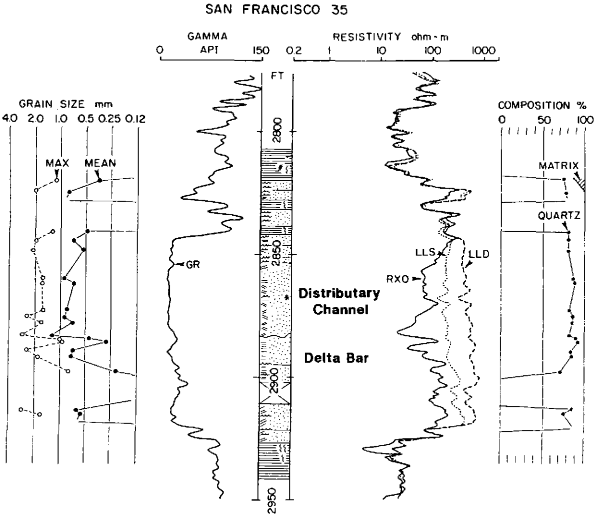


Figure 14 - Texture, sedimentary structures and composition of the upper submember of the Upper Caballos for selected beds from 2800 to 2950 ft (853.4 m to 899.2 m) in the core from the San Francisco 35, Upper Magdalena Valley, Colombia.

standard deviation of 2.25 phi (0.21 mm).

The fining-upward trend of the first and fifth composite sets is indicative of an upward decrease in the hydrodynamic flow regime. This is characteristic of channel deposition. The first composite set is interpreted to be deposited in a braided stream complex and the fifth composite set is thought to be deposited in a distributary channel. The upward increase in grain size in the fourth composite set indicates a shoaling upward sequence which is interpreted to be caused by delta-front progradation.

Composition

In hand-sample examination, the Caballos sandstone is light tan where not oil stained, but most of the reservoir quality sandstone is heavily stained by oil. The sandstone is cross-laminated to ripple-laminated, very fine to very coarse-grained, quartz-rich and moderately to weakly cemented. The sandstones in the Upper Caballos are seperated by black, organic-rich shales, whereas the sandstone beds in the Lower Caballos are seperated by mottled, dark-gray claystones.

The mean values of detrital grains and cements are displayed in the Appendices. Quartz consists only of monocyrstalline quartz. Rock fragments consist of polycrystalline quartz, volcanic chert, volcanic rock fragments, metamorphic rock fragments, siltstone and mudstone. Heavy minerals consist of zircon and minor amounts of tourmaline. Opaques (probably pyrite), mica, chalcedony and altered rock fragments also are present.

Monocrystalline quartz is the most common detrital grain type in both the Upper and the Lower Caballos sandstone. Much of the quartz in the Lower Caballos has simple extinction, euhedral shape, and is water-clear with few inclusions. These characteristics are common to volcanic quartz (Pettijohn et al., 1972). Much of the quartz in the Upper Caballos has undulatory extinction, Boehm lamellae and inclusions, indicating a plutonic origin. Both the Upper and Lower Caballos contain embayed quartz, and the ratio of embayed versus nonembayed increases with increasing grain size. In both sandstones, quartz grains are generally subrounded with curved to straight contacts. Under cathodeluminescence, the detrital quartz grains are well rounded.

Rock fragments are the second most abundant detrital grain type. Rock fragments consist predominantly of volcanic rock fragments and polycrystalline quartz with minor amounts of sedimentary rock fragments. Volcanic rock fragments are composed mainly of devitrified volcanic glass with some quartz, kaolinite (altered feldspar?), titanium oxide and clay. The devitrified volcanic glass, referred to as volcanic chert, is present in a fine and coarse crystalline variety. The volcanic cherts have a dusty appearance, and are similar in appearance to the matrix of the volcanic tuffs that were sampled from the basement. They are commonly corroded. The polycrystalline quartz grains contained a wide range of subgrain boundaries, crystal sizes and number of crystals per fragment. The sedimentary rock fragments consist of shale and siltstone fragments.

Matrix content is low, but reaches a maximum of 17% in some ripple-laminated sandstones. Matrix consists of brown clay and green clay. X-ray analysis by commercial labs identified the matrix clays as interlayered smectite and illite. The greenish clay is associated with kaolinite and may be authigenic.

Basement samples are composed of volcanic tuff. The matrix of the tuff is composed of devitrified volcanic glass with phenocrysts of plagioclase feldspar and quartz (Figure 9 P; Figure 11 P). The samples examined contain between 70% and 100% matrix. Most of the devitrified volcanic glass had a dusty appearance caused by an oxide. The matrix is composed of the same material as the volcanic chert grains seen in the Lower Caballos. The phenocrysts of plagioclase feldspar comprise 0 to 30% of the rock's composition, and the crystals are highly altered and partly replaced by carbonate cement. Secondary carbonate cement and replacement is common in the basement rock and appears to be of hydrothermal origin. Volcanic quartz comprises less than 1% of the basement's composition.

Acording to Folk's classification (1968), the sandstone in the Upper Caballos is a quartz arenite, and the sandstone of the Lower Caballos is a litharenite (Figure 15). The Upper Caballos sandstone averages 82.3% monocrystalline quartz, 11.1% total rock fragments, and 1.9% matrix, with minor amounts of carbonaceous material, zircon, tourmaline, opaque, kaolinite and mica. The Lower Caballos sandstone averages 48.1% monocrystalline quartz, 39.8% total rock fragments, and 7.4% matrix with, minor amounts of carbonaceous material, feldspar, zircon, tourmaline, chalcedony, opaque, kaolinite and mica.

To insure that the difference in composition is not a function of grain size, a graph of grain size versus quartz content was constructed (Figure 16). The graph of grain size versus quartz clearly shows that the variation in composition between the Upper and Lower Caballos members is not due to variations in grain size, but to a change in source.

Provenance

The composition of the Caballos Formation shows a striking difference between the Lower and Upper members. The Lower Caballos contains quartz and volcanic rock fragments, whereas the Upper Caballos contains predominately quartz and rare volcanic rock fragments. Figure 17 shows the fraction of all rock fragments (except for polycrystalline quartz) for 60 thin sections. This diagram

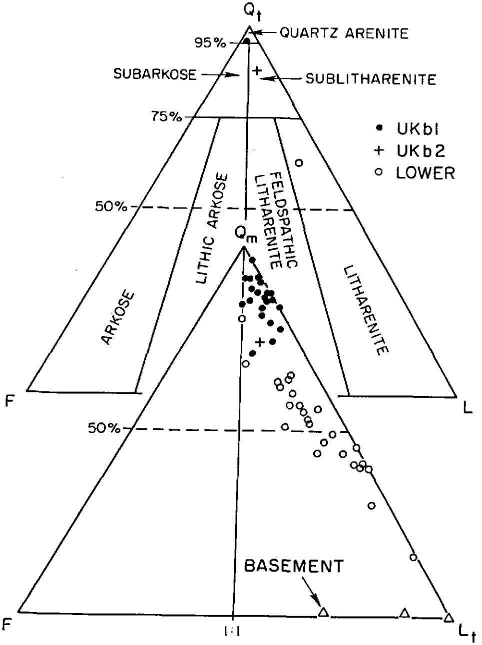


Figure 15 - Ternary diagrams displaying composition of the samples taken from the San Francisco 14, 35 and 56, Upper Magdalena Valley, Colombia. In the upper diagram, symbols represent average compositions with Qt = monocrystalline and polycrystalline quartz, L = all rock fragments excluding polycrystalline quartz, and F = feldspar and kaolinite. In the lower diagram, Qm = monocrystalline quartz and Lt = all rock fragments including polycrystalline quartz.

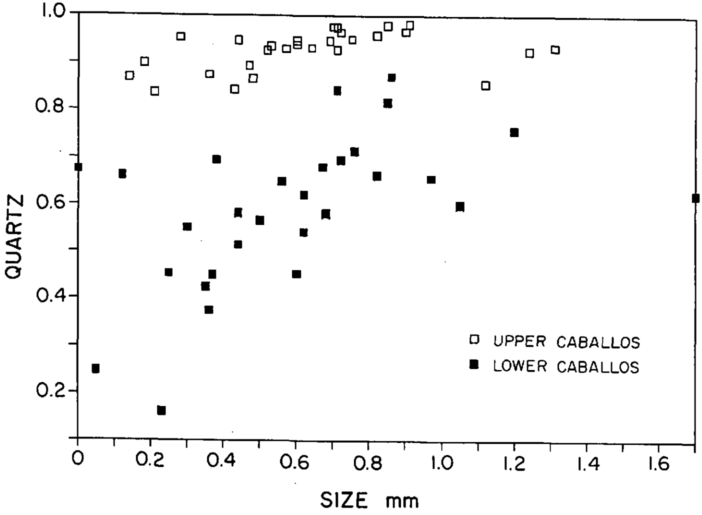


Figure 16 - Plot of monocrystalline quartz versus grain size for the Caballos sandstone in the San Francisco field, Upper Magdalena Valley, Colombia.

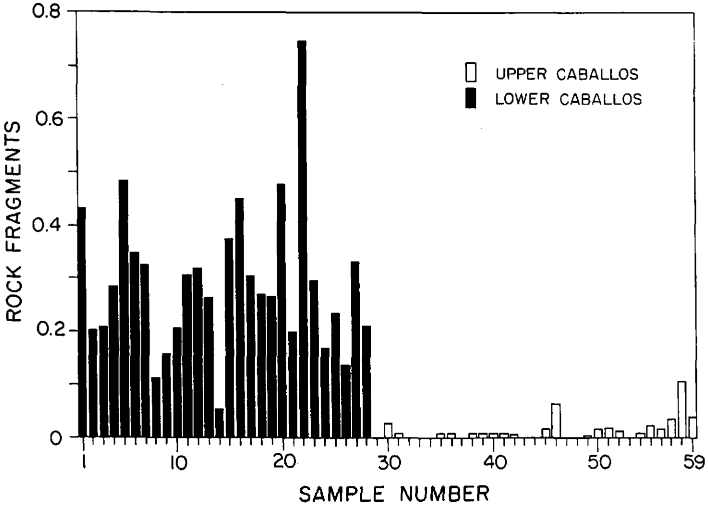


Figure 17 - Histogram of the fraction of rock fragments from samples in the San Francisco 14, 35, and 56 cores for the Caballos sandstone, Upper Magdalena Valley, Colombia.

clearly shows the difference in composition between the Lower and the Upper Caballos, and indicates a difference in their sediment source.

The two major sources of sediment for the Caballos sandstones are: (1) Paleozoic quartz arenites from the Guayana shield, and (2) volcanic tuff that was eroded locally from the Triassic and Jurassic basement, and is composed predominantly of devitrified volcanic matrix (which looks similar to chert) and a small percent of altered feldspar. These two sources can be thought of as endmembers; the resulting composition of the sandstones is a combination of varying proportions of them, and the real percentages of quartz and rock fragments can be used to represent the relative concentribution of endmember 1 and endmember 2 respectively.

Figure 18 is a graph of rock fragments (endmember 2) versus quartz (endmember 1). For reference, the composition of the basement is noted on the graph. The composition of the Lower Caballos sandstone is intermediate between endmember 2 and endmember 1, indicating a varying sediment contribution from both the basement tuffs and the Paleozoic quartz arenites. The primary source of sediments for the Lower Caballos was probably the Guayana shield with a lesser sediment contribution from the basement. The incised braided streams presumably incorporated a large amount of detrital material from erosion of the basement, so that the

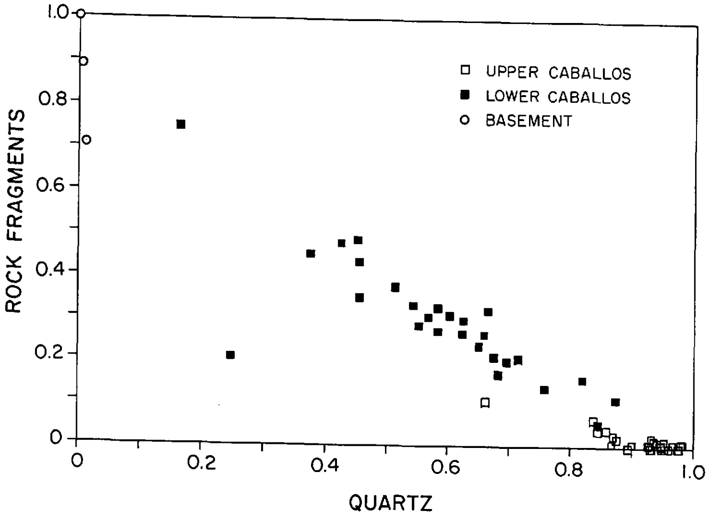


Figure 18 - Plot of fraction of rock fragments (endmember 2) versus monocrystalline quartz (endmember 1) from the San Francisco 14, 35, and 56 cores for the Caballos sandstone, Upper Magdalena Valley, Colombia.

resulting composition is a quartz-rich sandstone with a large percentage of relatively unstable volcanic rock fragments.

The Upper Caballos sandstone has an upper and a lower submember. Both submembers of the Upper Caballos plots very close to endmember 1, indicating that its main source is from the quartz arenite of the Guayana shield. Dissolution in the Upper Caballos has slightly changed the compositon, and enriched it in quartz. From Figure 18, it appears that the major source of sediment in upper submember of the Upper Caballos is endmember 1 or the Paleozoic quartzarenite. The upper submember contains only one volcanic chert grain in thin section analyses. The presence of the volcanic chert grain indicates some reworking of the Lower Caballos member and possibly the lower submember of the Upper Caballos. Another indication that the Lower Caballos was reworked is that some embayed quartz has thin rims of volcanic glass in the Lower Caballos, but similar grains without volcanic glass are found in the Upper Caballos.

Only one lower submember sample was examined, and it plots at an intermediate position between the average composition of the Lower Caballos and the average composition of the upper submember of the Upper Caballos. The composition of the lower submember falls within the range of compositions found in the upper submember, and thus it is indeterminate whether the lower submember has a different composition than the upper submember. The lower submember also contains significant amounts of volcanic chert, which is extremly rare in the upper submember, and this may indicate a difference in provenance between the two submembers.

A difference in quartz type between the Upper and Lower Caballos also indicates a different sediment source for the two sandstones. The majority of quartz in the Lower Caballos has simple extinctions, which indicates a volcanic origin, whereas the majority of quartz in the Upper Caballos has undulatory extinction, which indicates a plutonic origin.

Diagenesis

The sandstones of the Caballos Formation display a variety of diagenetic features. Early diagenesis of the Upper and Lower Caballos sandstone took place at separate times, while later diagenesis may have been concurrent. Three stages of diagenesis are observed: early carbonate and quartz cementation, dissolution and alteration of volcanic rock fragments and feldspar, and dissolution of calcite cement.

Quartz Cement

Quartz cement averages 4.6% in the Lower Caballos and ranges between 0 and 13%; it averages 5.7% in the Upper Caballos and ranges between 0 and 18%. Quartz cement forms pore-lining overgrowths that reduces pore space but does not occlude pore throats. The merging of quartz overgrowths from different grains forms angular and triangular pore spaces and straight grain contacts (Figure 19 A). In the Lower Caballos, detrital quartz grains are usually defined by well developed dust rims, but they are not as well marked in the Upper Caballos therefore, it is difficult to distinguish from the overgrowths. When present, calcite cement precluded formation of quartz overgrowths.

Calcite Cement

Calcite cement in the Lower Caballos averages 3.1%, and ranges between 0 and 13%. It is less common in the Upper Caballos averaging less than 1 percent, but reaches a maximum of 5%. Most of the calcite cement forms large, interlocking crystals which completely block the pore spaces. It is also present in minor amounts with crystal aggregates of siderite cement in the finer-grained sediments of the Lower Caballos.

Calcite cement probably was more prevalent in the sandstone, but it has subsequently been leached. Evidence for this leaching is the ragged edges of carbonate cement, which indicate dissolution, and a fabric of loosely packed grains which presumably resulted from the dissolution of early calcite cement that had prevented compaction (Figure 19 B).

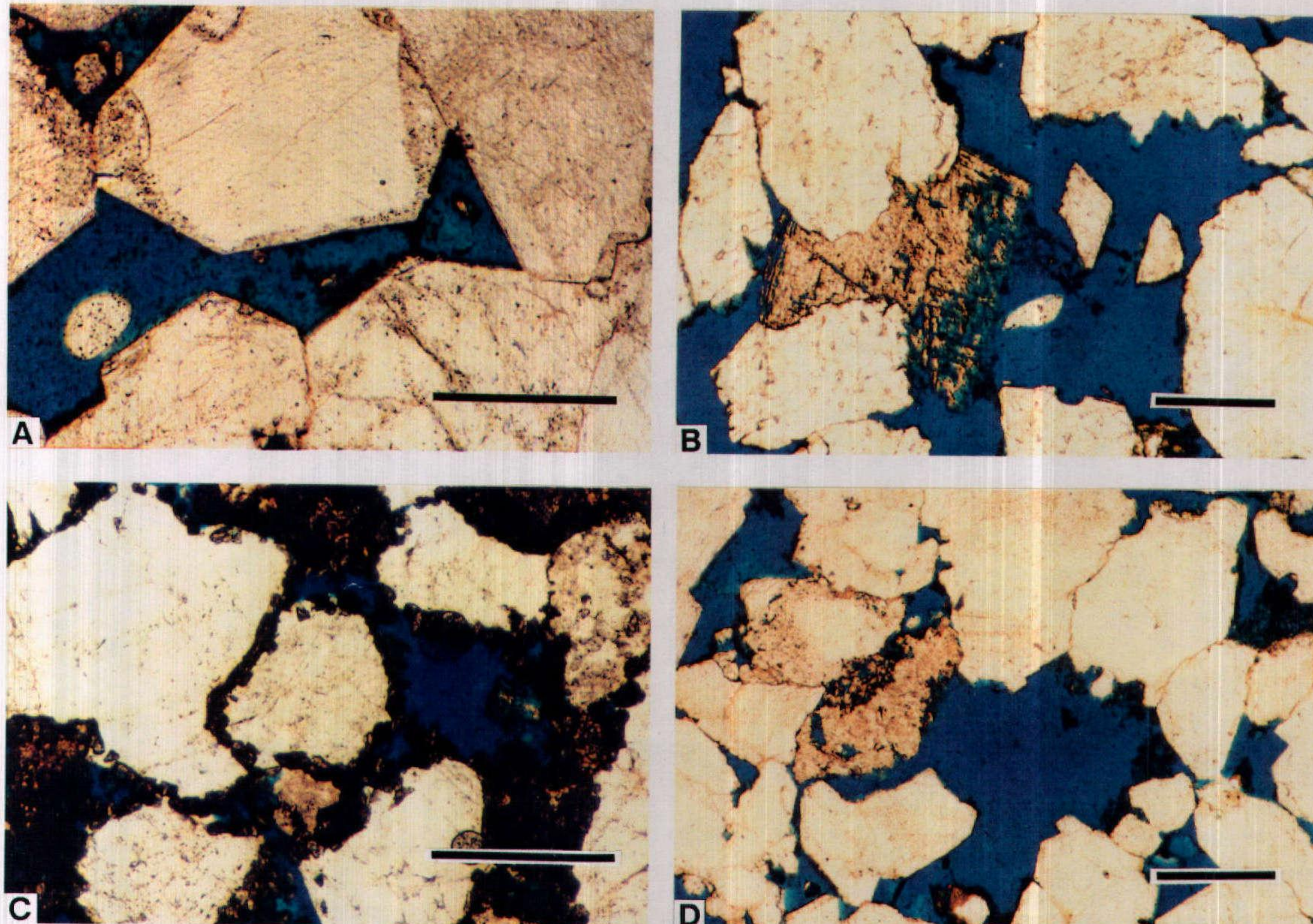
Figure 19 - Photomicrographs from the Caballos sandstones. Bar in photomicrographs represents 0.5 mm.

A - Pore linning quartz overgrowths merging to form triangular pore spaces.

B - Pore plugging calcite cement with ragged edges.

C - Rhombohedral siderite cement encrusting quartz grains.

D - Oversized pore rimmed with kaolinite. Note partially dissolved volcanic rock fragment.


A
B
C
D

Siderite Cement

Siderite cement is present in a few samples of the sandstones of the Lower Caballos and in a thin bed of pyroclastics found above the sandstones of the Upper Caballos. When present, siderite cement is usually abundant and reaches a maximum of 35%. Siderite cement forms crystal aggregates in the finer-grained sandstones and organic-rich clays of the Lower Caballos. The crystal aggregates of siderite cement are semi-spherical, reaching several millimeters in diameter. It also occurs as flattened rhombs in one sample of coarse-grained sandstone in the Lower Caballos, and rims spherical pyroclastic glass balls above the sandstone of the Upper Caballos. The rhombs of siderite rim the detrital grains and occlude much of the pore space (Figure 19 C).

Pyrite

Pyrite is found in minor amounts as a replacement of volcanic rock fragments and heavy minerals. It does not appear to significantly affect porosity or permeability.

Authigenic Clay

Authigenic kaolinite is common in both the Upper and the Lower Caballos. The Lower Caballos averages 6.1% kaolinite, and ranges between 0 and 17%; the Upper Caballos averages 3.2% kaolinite, and ranges between 0 to 10%. The kaolinite forms well developed vermicular books, and pseudomorphs of detrital grains. The later indicats that they formed as alteration products of feldspar and/or rock fragments. Feldspar is rare in the sandstones, but is common in samples of basement.

Dissolution

Most of the Caballos sandstone contains significant amounts of intergranular porosity, moldic porosity, and intragranular microporosity. More grain dissolution has taken place in the coarer-grained sediments. Only minor dissolution has taken place in the fine and very fine-grained sandstones. The moldic porosity presumably formed as a result of dissolution of feldspar and rock fragments, whereas the microporosity forms within volcanic rock fragments. The result of the grain dissolution is abundant oversize pores and 'floating' grains (Figure 19 D). Intergranular pores are often rimmed with remnants of kaolinite (Figure 19 D).

Compaction

Effects of compaction are not very extensive in most of the sandstones in the Upper Caballos or the coarser-grained sandstones of the Lower Caballos, and was apparently inhibited by early calcite cementation, which also preserved much of the intergranular pore space. However, the finer-grained sandstones in the Lower Caballos lack abundant calcite cement, and therefore their porosity has been reduced to only a few percent by the compaction of volcanic rock fragments and authigenic kaolinite.

Diagenetic Sequence

Siderite and calcite crystal aggregates in the Lower Caballos member probably formed soon after deposition in an organic-rich, reducing environment (Gautier, 1982). The pore-occluding calcite cement formed before compaction. Because quartz overgrowths are precluded by calcite cement, the quartz cement in the Lower Caballos formed after calcite cement.

Diagenesis of the Upper Caballos follows a pattern similar to that of the Lower Caballos.

RESERVOIR CHARACTERISTICS

Reservoir Properties

The productivity of any hydrocarbon reservoir depends on the secondary rock properties of porosity and permeability. These properties are controlled by the primary rock properties of sedimentary structure, composition and texture. In order to determine how secondary properties varied with the primary properties at various depths, core analyses data including porosity, permeability and water saturation, were plotted versus depth for the San Francisco 14, 35 and 56 cores.

Porosity, permeability and water saturation vary with grain size, matrix, cement, and kaolinite content. An increase in grain size and a decrease in matrix, cement or kaolinite results in an increase in porosity and permeability. On the other hand, water saturation increases with a decrease in grain size, as does the abundance of kaolinite. Thus, diagenesis and the depositional environment greatly control the reservoir rock properties.

The best porosity and permeability are found in the fifth coset or main distributary channel sandstones in the Upper Caballos. In this zone, the average porosity is about 20% and the average permeability is 3,000 md (Figure 20). Porosity and permeability decrease vertically upward in the section as the zones become ripple laminated, finer grained, and more enriched in matrix. These ripple-laminated

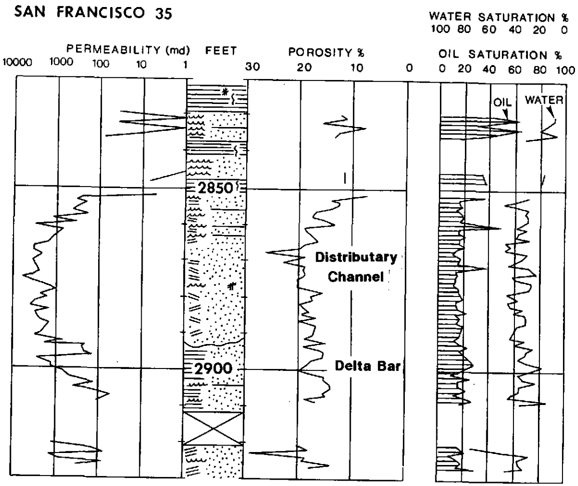


Figure 20 - Permeability, porosity, and fluid saturations from 2821.0 to 2930.0 ft (846.3 to 879.0 m) in the core of the Upper Caballos sandstone, San Francisco 35, Upper Magdalena Valley, Colombia.

intervals have permeabilities averaging between 6 md and 300 md and porosities averaging between 8% and 14%. The distributary channel in the San Francisco 35 has a water saturation of approximately 35% and an oil saturation of approximately 18%.

Porosity and permeability in the fourth composite set or delta bar sandstones in the San Francisco 35 average 15% and 70 md respectively in the distal part of the bar and 20% and 3,000 md in the proximal part of the delta bar (Figure 20). They also have water saturations of approximately 35% and an oil saturation of approximately 18%. Delta bars in the San Francisco 56 have permeabilities of 1 md to 150 md and porosities of 12% to 16% in the distal part of the bars, and respective values of 800 md to 1,500 md and 18% to 20% in the more proximal part of the bars. Their water saturations range from 15% to 40%, and their oil saturations range from 15% to 50%.

The Lower Caballos sandstones, the fourth composite set, have highly variable reservoir properties (Figure 21). The best porosity and permeability are in the coarse-grained, quartz-rich, cross-laminated sandstones of the braided channels. These sandstones have porosity and permeability values that can approach 20% and 1000 md respectively, but most channels have lower porosity and permeability values. Most cross-laminated channel sandstones have porosities averaging 10% to 16% and

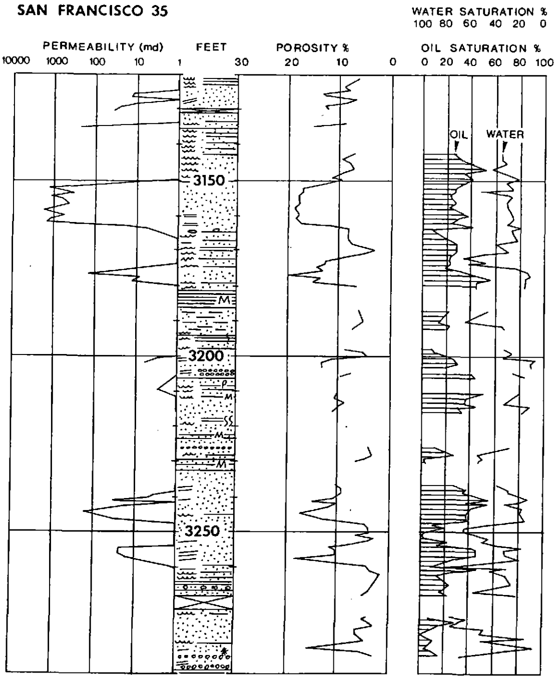


Figure 21 - Permeability, porosity, and fluid saturations from 3120.0 to 3285.0 ft (936.0 to 985.5 m) in the core of the Upper Caballos sandstone, San Francisco 35, Upper Magdalena Valley, Colombia.

permeabilities from a few hundred to tens of millidarcies. The ripple-laminated sandstones have significantly lower porosity and permeability values of less than 10% and commonly less than 1 millidarcy respectively.

Resistivity versus porosity cross plots (Pickett, 1972) identify productive and nonproductive zones, and indicated water saturations in some of the productive zones are less than 15%. From the Pickett plots, the water salinity is found to be approximately 2,000 ppm NaCl.

Capillary pressure curves were measured by a commercial laboratory using both an air-brine and a mercury-air system. These tests found that the calculated average irreducible "water" saturation is less than 20%, and in the best rock types, less than 10%.

Reservoir Morphology

The sequence of sedimentary structures, composition and texture strongly suggests that the Lower Caballos was deposited in a braided stream complex and the Upper Caballos was deposited in deltaic bars and distributary channels. Thus, the Lower Caballos sandstones can be expected to have low sinuosities and to be discontinuous and locally isolated, whereas the Upper Caballos sandstones can be expected to have lobate to ovate geometery that may or may not be continuous with other sandstone bodies in the Upper Caballos Formation.

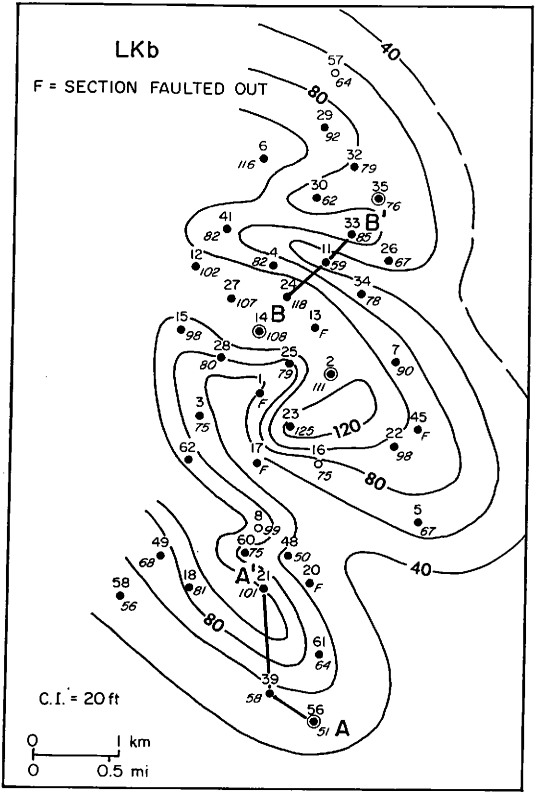
Lower Caballos

Because the Lower Caballos rests unconformably on basement, original topography probably controlled early deposition. Figure 22 is a Lower Caballos net sand isopach map, which reflects the basement topography. The alternating net sand thin and thicks indicate a series of ridges and valleys that deepen to the northwest, and a probable southeast to northwest orientation of the channels.

Cross sections A-A' and B-B' illustrate the incised nature of the channels (Figures 23 & 24). Erosion of the basement provided rock fragments that were incorporated into the Lower Caballos sandstone. The cross sections display the high thickness variability of the sandstone bodies within the correlated units, and shows that the individual sandstone beds are thicker in the valleys than on the ridges. Because of the relatively wide spacing of the wells, correlation of individual sandstones is difficult.

Comparisons can be made between the channels in the San Francisco field and other channels known in more detail from other areas. Individual braided channels of the Lower Caballos member that were observed in outcrops 15 km to 20 km to the south of the San Francisco field, have a width of 25 to 30 ft and a thickness averaging 6 ft. The thickness of these channels is comparable to the channels in the San Francisco field. Therefore, the sandstones in the Lower Caballos can be expected to have similar widths. Sandstones

Figure 22 - Net sandstone isopach map of the Lower Caballos (LKb) member. The cored wells are circled. Lines A-A' and B-B' indicate the locations of the cross-sections shown in Figures 23 and 24, respectively.


LKb
F = SECTION FAULTED OUT
C.I. = 20 ft
0 1 km
0 0.5 mi
40
80
120
B
B'
A
A'

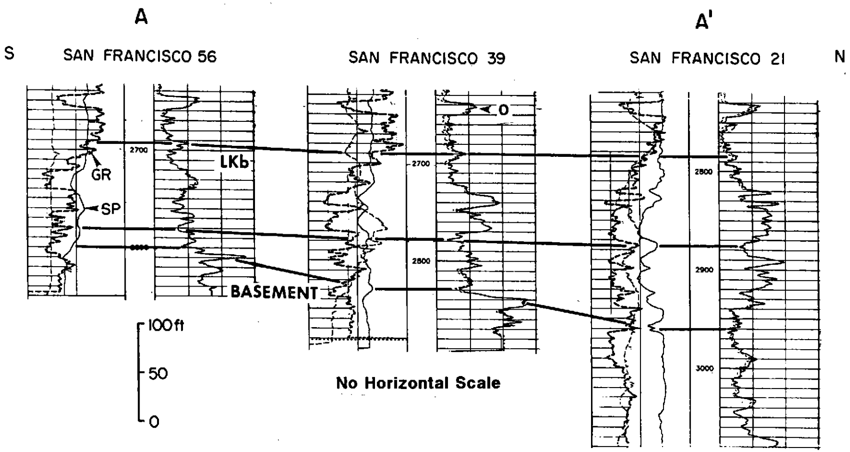


Figure 23 - Dip cross-section A-A' down an incised valley. Datum is the Middle Caballos oyster beds (o) and the cross-section location is shown in Figure 22.

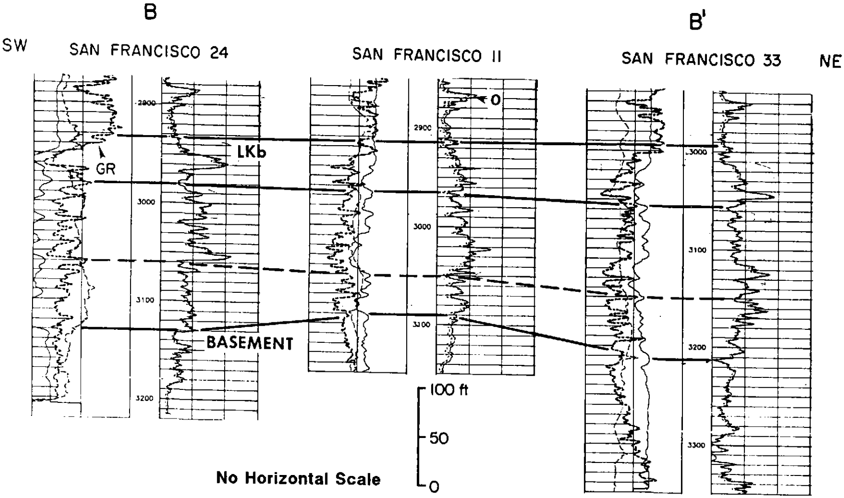


Figure 24 - Strike cross-section B-B' across an incised valley and ridge. Datum is the Middle Caballos oyster beds (o), and the cross-section location is shown in Figure 22.

in a braided stream are discontinuous and locally isolated, but may be more continuous because of erosion and migration of the channels (Berg, 1986). Braided stream channels have a low sinuosity.

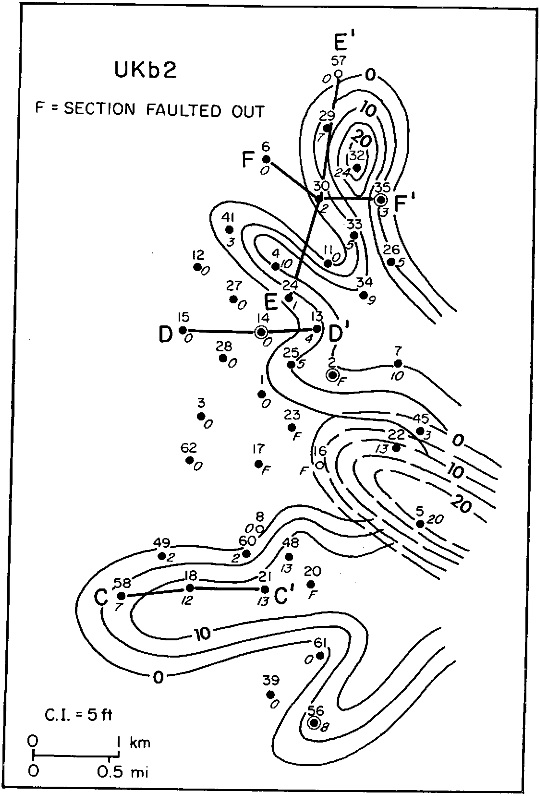
Lower Submember of the Upper Caballos Member

The lower submember of the Upper Caballos member has a variable sandstone content, and is confined to three separate, lobate sandstone units (Figure 25). The sandstones tend to be confined to a relatively narrow belt, and are at different stratigraphic levels. The lowermost sandstone, which probably is a channel deposit, is isolated in the east-central part of the San Francisco field. The other two sandstone bodies lie at a higher stratigraphic level on either side of the lower sandstone body, one to the north and one to the south.

The northern sandstone body has the most control and therefore is probably a more accurate representation of the morphology of the sandstones in the lower submember. Sandstones appear to have originated from the east and deposited in an westward direction.

The lower portion of cross sections C-C′, D-D′, E-E′ and F-F′ illustrate the variability of the sandstone in lower submember of the Upper Caballos member. The southern sandstone unit is continuous across cross section C-C′ which runs lengthwise in the bar (Figure 26). Cross sections D-D′, E-E′ and F-F′ show the northern unit. Cross sections D-

Figure 25 - The net sandstone isopach map of the lower submember of the Upper Caballos member (UKb2) illustrates the three seperate lobes. The cored wells are circled. Lines C-C', D-D' and E-E', and F-F' indicate the location of figures shown in Figure 26, 27, 28, and 29, respectively.


UKb2
F = SECTION FAULTED OUT
E'
F
F'
E
D
D'
C
C'
C.I. = 5 ft
0
1 km
0
0.5 mi

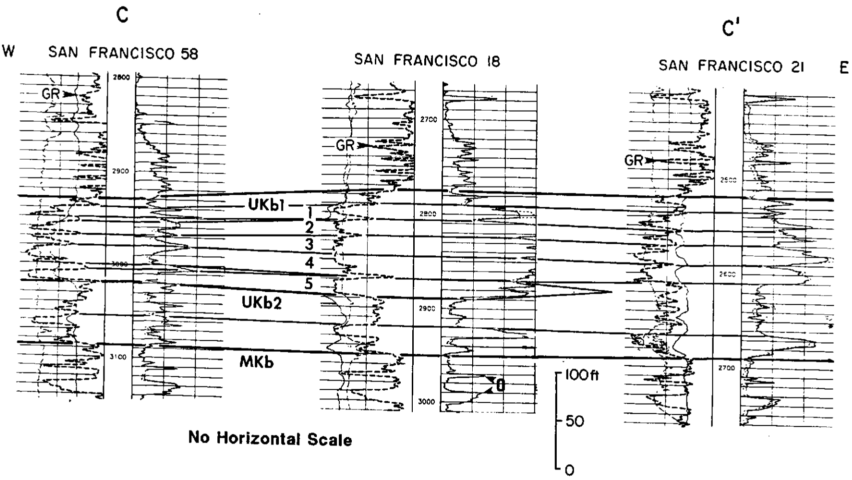


Figure 26 - Cross-section C-C′ through the upper and lower submember of the Upper Caballos (UKb1 and UKb2 respectively). Datum is the Middle Caballos oyster beds (o), and the cross-section location is shown in Figure 25.

D' and F-F' show the sandstones in the lower submember pinch out to the west (Figures 27 & 29). Cross section E-E' shows poorly developed sandstone in the lower submember (Figure 28).

Coals are present in elongated trends roughly parallel to the trends of the sandstone units.

Upper Submember of the Upper Caballos

The upper submember of the Upper Caballos is interpreted to consist of deltaic bars and distributary channels. The deltaic bars have a lobate to ovate morphology that pinch out laterally. The distributary channels can be expected to have an elongate and narrow morphology. The sinuosity of distributary channels can be variable from straight to highly sinuous, but cannot be determined with a high degree of accuracy with the data available. Sandstone in the distributary channels is interpreted to cut through and terminate abruptly against the deltaic bars in the San Francisco field. These sands were transported from the south to southeast and were deposited in a north to northwest direction

Thicker accumulations of sandstones are located in the northern and southern part of the field. These thicker sandstone zones are located where the deltaic bars are best developed. To illustrate the morphology of the upper submember in the field, six separate sandstone units were mapped, three from the north and three from the south.

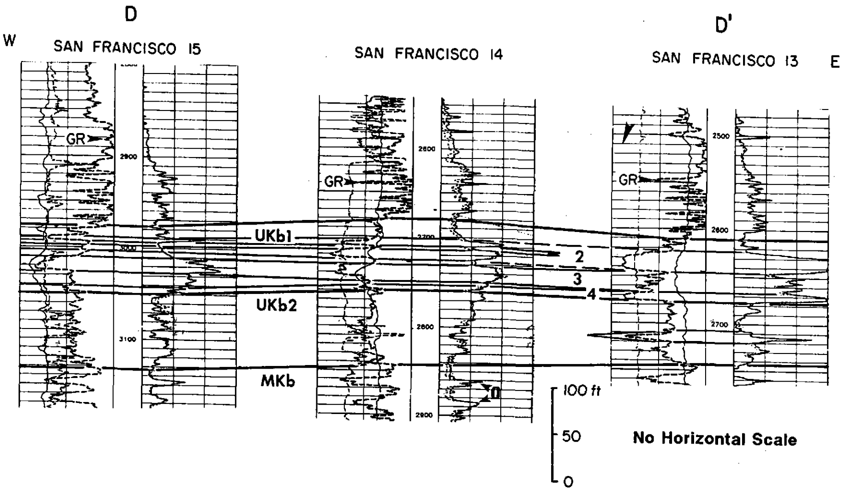
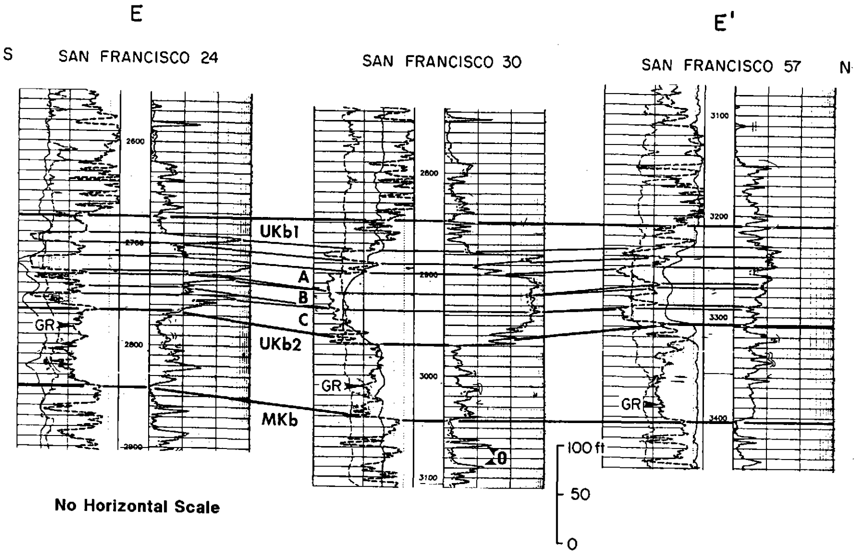


Figure 27 - Cross-section D-D′ through the upper and lower submember of the Upper Caballos (UKb1 and UKb2 respectively). Datum is the Middle Caballos oyster beds (o), and the cross-section location is shown in Figure 25.

Figure 28 - Cross-section E-E' through the upper and lower submember of the Upper Caballos (UKb1 and UKb2 respectively). Datum is the Middle Caballos oyster beds (o), and the cross-section location is shown in Figure 25.


E
E'
S
SAN FRANCISCO 24
SAN FRANCISCO 30
SAN FRANCISCO 57
N
2600
2700
2800
2900
2800
2900
3000
3100
3100
3200
3300
3400
UKb1
A
B
C
UKb2
MKb
GR
GR
GR
0
100 ft
50
0
No Horizontal Scale

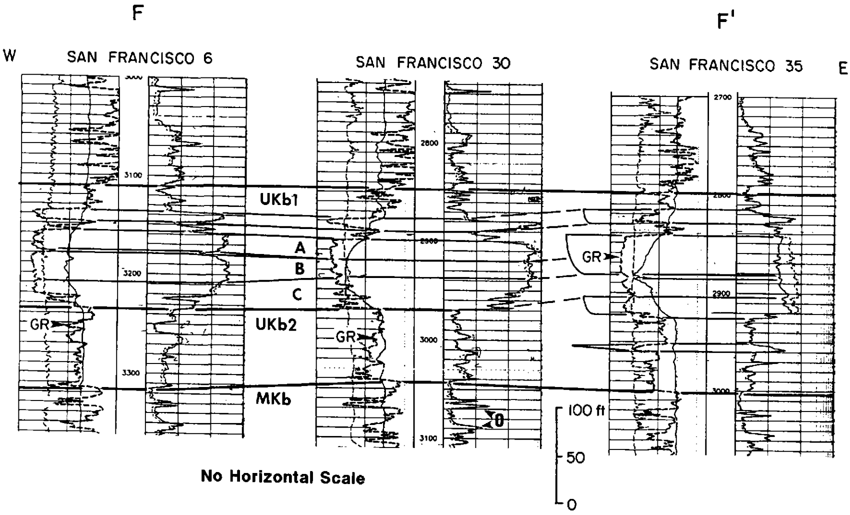


Figure 29 - Cross-section F-F' through the upper and lower submember of the Upper Caballos (UKb1 and UKb2 respectively). Datum is the Middle Caballos oyster beds (o), and the cross-section location is shown in Figure 25.

In the southern part of the field, five units were correlated (Figure 26). The sandstone units are designated 1 through 5, and net sand isopach maps of the 3, 4 and 5 units were constructed. Cross section C-C′ displays well developed sandstones in the San Francisco 18, but they thin and pinch out laterally (Figure 26). In cross section D-D′, located to the north of cross section C-C′, the sandstones significantly thin from 83 ft in the San Francisco 18 in cross section C-C′ to 26 ft in the San Francisco 14 in cross section D-D′ (Figures 26 & 27). The 1 and 5 units are no longer present to the north in cross section D-D′, and the sandstone of unit 4 is poorly developed.

Isopach maps of the 3, 4 and 5 sandstone units show a shifting of the deltaic units in a northerly direction, which suggest progradation of the southern deltas to the north. The fifth sandstone unit is ovate in shape and restricted to the southwestern corner of the field (Figure 30). This sandstone body may be a shallow-marine bar, not a deltaic bar. The isopach map of the fourth unit is elongate in shape and appears to be dissected by a distributary channel in the southern part of the field (Figure 31). The third sandstone unit, which is extends further to the north, has a similar morphology to the fourth unit, and is also cut by a distributary channel (Figure 32). Both the third and fourth units are thickest in the western part of the field and are elongated in a north-south direction. The third

Figure 30 - Net sandstone isopach map of the UKb1 "5" zone. The cored wells are circled.

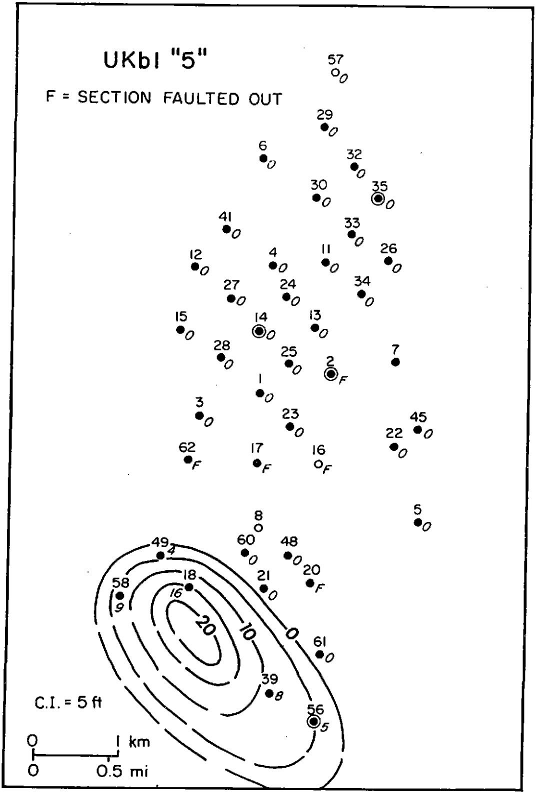
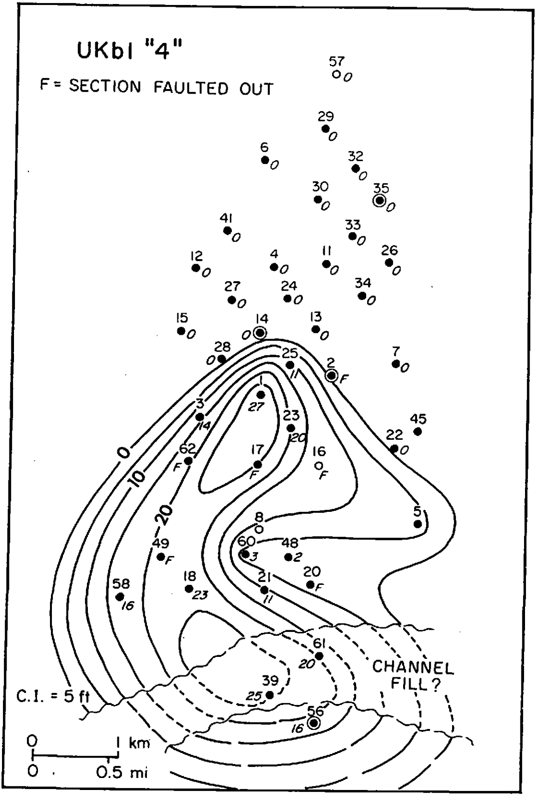
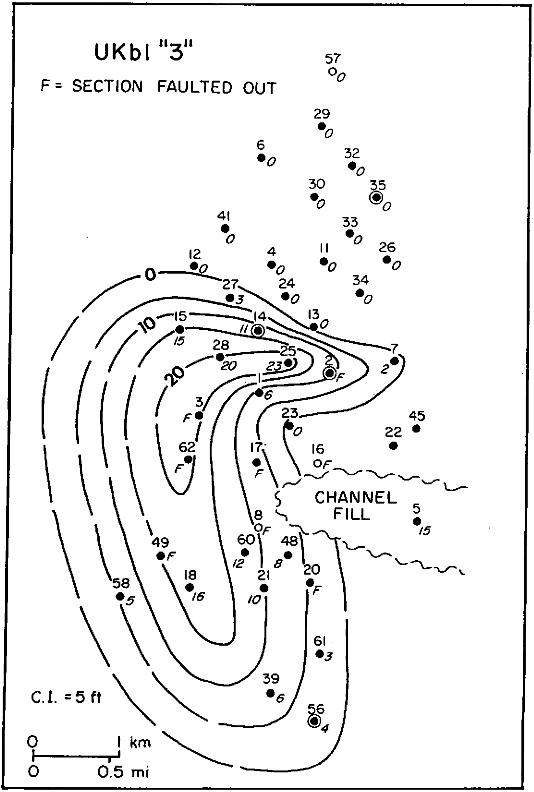

UKbl "5"
F = SECTION FAULTED OUT
57 0
29 0
6 0
32 0
30 0
35 0
41 0
33 0
12 0
4 0
11 0
26 0
27 0
24 0
34 0
15 0
14 0
13 0
28 0
25 0
2 F
7
1 0
3 0
23 0
45 0
22 0
62 F
17 F
16 F
8
5 0
49 4
60 0
48 0
20 F
58 9
18 16
21 0
20
10
0
61 0
39 8
56 5
C.I. = 5 ft
0 1 km
0 0.5 mi

Figure 31 - Net sandstone isopach map of the UKb1 "4" zone. The cored wells are circled.



UKbl "4"
F = SECTION FAULTED OUT
CHANNEL FILL?
C.I. = 5 ft
0 1 km
0 0.5 mi

Figure 32 - Net sandstone isopach map of the UKb1 "3" zone. The cored wells are circled.

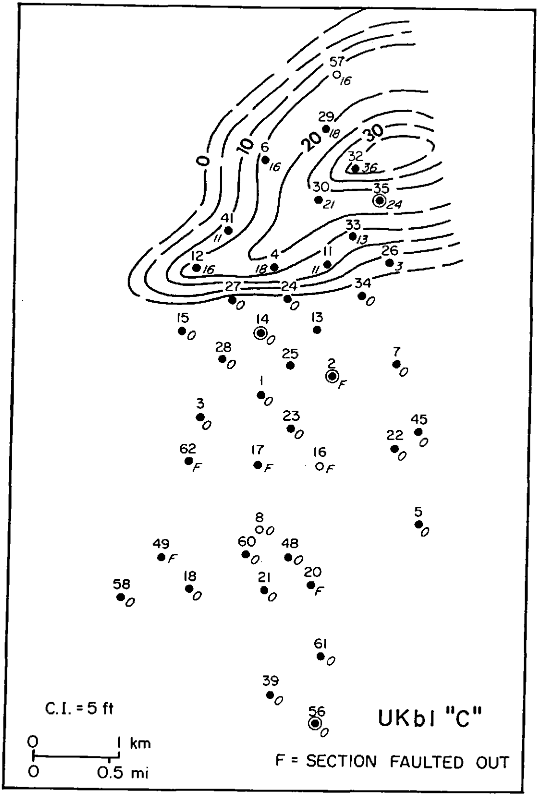

UKbl "3"
F = SECTION FAULTED OUT
CHANNEL FILL
C.I. = 5 ft
0 1 km
0 0.5 mi

unit pinches out farther to the north than the fourth unit.

In the northern part of the field, the sandstone has been divided into A, B and C units (Figuress 29 & 30). Cross section E-E' and F-F', orientated to the north-south and the east-west respectfully, are tied together at the San Francisco 30 to give a three dimenstional representation of the sandstone units in the northern part of the field (Figure 26 & 27). In cross section E-E', the sandstones of the A, B, and C units are stacked continuously on top of one another in the San Francisco 30, but to the north and south, the units thin and are separated vertically by shale. In cross section F-F', the sandstone units are continously stacked in the western part, but to the east in the San Francisco 35, they have been truncated by a distributary channel. The A and B units are missing, and the lower part of the C unit is replaced by a channel. The A and B sandstone units are interpreted to have been eroded by the distributary channel. The main distributary channel appears to have been abandoned slowly because it is filled with sandstone. Above the main distributary channel, and separated by varved shale, which is interpreted to be interdistributary lake deposit, is a poorly developed distributary channel.

Net sand isopach maps of the A, B and C sandstone units show the distribution of the sandstones (Figures 33, 34 & 35). The units are more ovate than the sandstone units in

Figure 33 - Net sandstone isopach map of the UKb1 "C" zone. The cored wells are circled.



0
10
20
30
57 16
29 18
6 16
32 36
30 21
35 24
41 11
33 13
12 16
4 18
11 11
26 3
27 0
24 0
34 0
15 0
14 0
13
28 0
25
2 F
7 0
1 0
3 0
23 0
45 0
22 0
62 F
17 F
16 F
5 0
8 0
49 F
60 0
48 0
58 0
18 0
21 0
20 F
61 0
39 0
56 0
C.I. = 5 ft
UKbl "C"
0 1 km
0 0.5 mi
F = SECTION FAULTED OUT

Figure 34 - Net sandstone isopach map of the UKb1 "B" zone. The cored wells are circled.

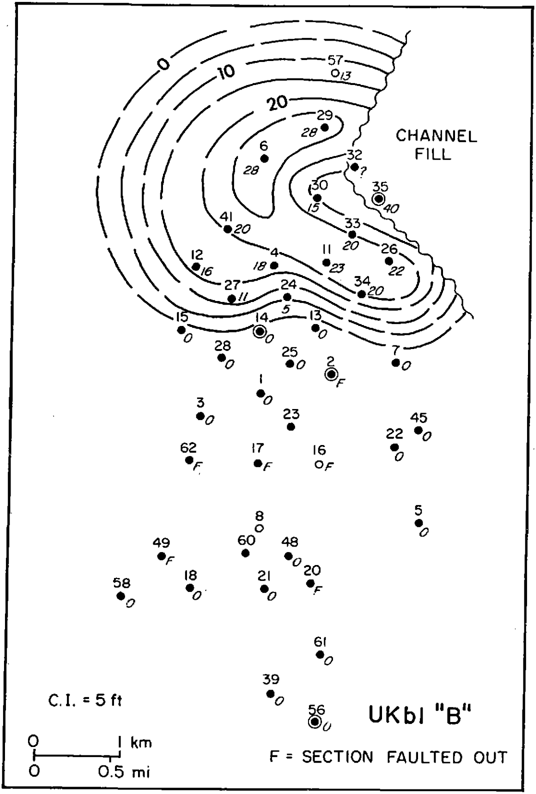
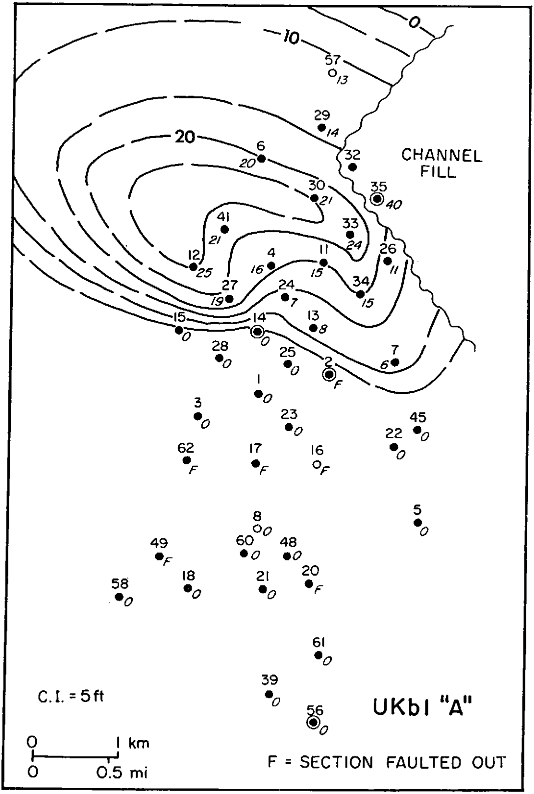

CHANNEL FILL
C.I. = 5 ft
0 1 km
0 0.5 mi
UKbl "B"
F = SECTION FAULTED OUT

Figure 35 - Net sandstone isopach map of the UKb1 "A" zone. The cored wells are circled.



0
10
20
57 13
29 14
32
CHANNEL FILL
6 20
30 21
35 40
41 21
33 24
12 25
4 16
11 15
26 11
27 19
24 7
34 15
15 0
14 0
13 8
28 0
25 0
2 F
7 6
1 0
3 0
23 0
45 0
22 0
62 F
17 F
16 F
5 0
8 0
60 0
48 0
49 F
18 0
21 0
20 F
58 0
61 0
39 0
56 0
C.I. = 5 ft
UKbl "A"
0 1 km
0 0.5 mi
F = SECTION FAULTED OUT

the southern part of the field. As seen in cross section F-F', the A and B sandstone units are truncated by a distributary channel in the eastern part of the field.

The cross sections and isopach maps of the upper submember of the Upper Caballos show that the sandstones are isolated at least partially from vertically adjacent sandstone units, and that each sandstone unit is not continuous across the field.

The implication of this interpretation is that each sandstone unit probably is not in communication with other sandstone units. Partial pressure communication between sandstone units may be assisted by the small normal faults that are present in the field, by down cutting of sandstone units in areas near the distributary channel, and by cross-cutting of the distributary channels.

As further development wells are drilled, each unit must be mapped more accurately, and pressure testing on isolated sandstone units must be conducted to determine the actual pressure communications of the sandstone units across the field. Understanding the pressure conductivity of the field is even more important for the planned waterflood. Misinterpretations of the sandstone distribution and communication could result in incomplete flooding of the reservoir.

CONCLUSIONS

The Caballos Formation of Early Cretaceous Aptian-Albian Age was deposited during a world-wide transgression. The base of the Caballos is marked by the nonconformity between Jurassic volcanics and the Lower Caballos sandstones and shales. The Lower Caballos was deposited as a braided stream complex with a variable distribution of sandstone. The Lower Caballos sandstone had two sediment sources: (1) quartz arenites derived from the Guayana shield and (2) volcanic rock fragments derived from local basement. As the sea level rose, the Lower Caballos was transgressed, resulting in deposition of Middle Caballos shale in a restricted to open-marine or bay environment. The Upper Caballos deltas then prograded over these restricted-bay shales. The deltaic bars were formed in a high-energy environment that produced clean sandstones, and were later cut by distributary channels. The Upper Caballos sediments were derived mainly from quartz arenites from the Guayana shield and from reworking of the Lower Caballos sandstone. The Caballos Formation was capped by the marine shales of the overlying Villeta Formation.

The present-day anticlinal structure of the San Francisco field is a result of compressional forces caused by the Andean orogeny. Minor normal faulting occurs within the Caballos reservoir.

The depositional environments of the Caballos Formation in the San Francisco field have important implications for future development and exploration in the Neiva and Giradot sub-basins. Shale breaks located between units in the Upper Caballos sandstone form fluid-flow barriers, and the depositional environment and diagensis control reservoir properties. An increase in grain size increases porosity and permeability, and decreases irreducible water saturation. A decrease in grain size also corresponds with a decrease in matrix and authigenic kaolinite. Cements decreases the porosity and permeability of the reservoir. Siderite and calcite cement greatly reduce the permeability of the sandstone because they occlude the pore space.

The small normal faults may isolate blocks of sandstone or provide conduits for water flow during a waterflood.

The interpretation that the sands were derived from the south or west has important implications for exploration in the Neiva and Giradot sub-basins. It appears that the Central Cordillera was not well exposed in the Neiva sub-basin. If the high-energy deltas of the Upper Caballos were derived from the east, widespread coastal sandstone bodies may have been developed as littoral and deltaic sands along the entire eastern margin of the Neiva sub-basin. The presence of pyroclastics in the shale above the Caballos indicate that the Central Cordillera was active, possibly to the north in the Giradot sub-basin. The Caballos sandstones in the Giradot sub-basin may contain sediments derived from the east and the west.

Future work in the field should be directed toward more accurate mapping of the individual sandstone units in the reservoir, and toward detailed pressure testing in order to understand the pressure communication of the units across the field.

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APPENDICES

APPENDIX I - core descriptions for the cored interval of the San Francisco 14.

APPENIDIX II - core descriptions for the cored interval of the San Francisco 35.

APPENDIX III - core descriptions for the cored interval of the San Francisco 56.

APPENDIX IV - summary of petrographic analysis for the San Francisco 14, 35, and 56.

APPENDIX V - plot of reservoir properties for the San Francisco 14, 35, and 56.

APPENDIX I

Tenneco San Francisco 14

Department of Huila, Colombia, South America

San Francisco Field

Caballos Formation, Albian to Aptian, Cretaceous

Completed: December 1986

CORE DESCRIPTION
San Francisco No. 14
Huila Dept., Colombia
San Francisco Field
Caballos Sandstone
Core: 2747.0 to 3140.0

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2747.0	8.5	Sandstone; brown oil stain not constant throughout, nonstained sandstone is tan and bounded by lamina of organic-rich shale to 2 cm thick; very fine to medium-grained. Lamina are defined by organic-rich shale. Most lamina are wavy, discontinuous, and nonparallel (ripples). Some lamina are even, parallel and continuous with a low angle of inclination, and may also be slightly curved; these sandstones are medium grained. Some organic-rich lamina are as thick as 2 cm and some are be continuous across core and have sharp boundries which seperate zones of oil stain from unstained zones. Nonstained sections generally contain discontinuous, wavy, and nonparallel lamina. Visible secondary porosity is seen in zones with a high oil stain and are greater than 1 mm in diameter. Zones with no oil stain have no visible porosity.
2755.5	7.5	Interlaminated shale and siltstone with alternating beds of sandstone: Sandstone and siltstone; tan to brown where oil stained; coarse silt to fine-grained sandstone in bedsets up to 1 ft. Shale; black, nonfissile. Sandstone has wavy, discontinuous, and nonparallel lamina. Sandstone with less oil stain has more continuous lamina that reach 1 mm thick and hve a sharp boundry; A few lenses of very fine-grained sandstone occur up to 5 cm thick that is surrounded by shale. Secondary porosity visible in oil stained sandstones, and are up to 1/2 mm in diameter. Shale is interlamina-

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		ted with siltstone and is continuous, wavy and nonparallel. Shale lamina reach 2 cm. Shale clast 1 cm in diameter at 2760.0. Soft sediment defermation at 2757.0 with irregular contact with claystone and sandstone and has inclined ripples at base. Zone is 1 ft to 6 inches thick. Amber color, non-crystalline substance between shale layers (oil?). Sharp contact at base with chlaystone, bottom is irregular with load and flame structure.
2763.0	3.0	Interlaminated shale (mudstone) and siltstone; shale is black and siltstone is tan with a light brown oil stain. Contains mainly horizontal lamina of shale with a few lenses of siltstone with slightly wavy and nonparallel lamina. (Varves?).
2766.0	3.5	Sandstone to siltstone; light brown oil stain; very fine-grained sandstone to coarse siltstone. Lamina are wavy and nonparallel which are closely spaced (ripples).

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2769.5	26.5	Interlaminated shale and siltstone; black to dark gray shale, orange-red claystone lamina, and light gray siltstone. Shale is very well laminated. Most lamina are thin, slightly wavy, continuous, and nonparallel. Other lamina are even or slightly wavy, horizontal, continuous and nearly parallel. Lamina of siltstone and shale reach 1.5 cm but most are less than 1 cm thick. Some zones have horizontally laminated shale with no siltstone. With increasing depth, siltstone decreases and shale contains more orange-red claystone. Lamina also become more even, parallel, continuous and may be slightly inclined to 10°. At 2794.5 to 2795.5, coarse siltstone and very fine sandstone layers 2 cm thick which are wavy, continuous and nonparallel. At 2775.5, lignite partical 3 cm X 5 mm aliened parallel to laminations. At 2792.0, shale becomes greenish. At base, 1 cm lignite streak. Section appears varved?
2796.0	7.0	Shale; medium gray. Top foot covered with orange-red (ironstone) material, which contains vertical organic stringers (roots). Small fragments of organic materal are scattered throughout. At 2797.0, 2.5 inches of coal which contains no laminations. Vertical fractures below coal (roots?) but contain no organic material.
2803.0	1.5	Shale; black with lamina of light gray shale. Siltston laminations in shale less than 1 mm thick. Lamina are slightly wavy, and nonparallel.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2804.5	6.75	Shale; dark gray with greenish tint on faces of some core. Bioturbated by rooting? with carbonaceous root traces. Coal 4 inch thick. Below coal is 3 inches of shale with wavy, discontinuous, and nonparallel lamina (ripples). Below ripples is carbonaceous-rich shale 4 inches thick. Below 2804.0, shale has scatted lignitic material may represent roots. Remnant laminations can be see, is wavy and discontinuous.
2811.2	37.3	Missing section. Only 1 ft represent-ed. Contains small peices of sandstone (2.5 cm X 4.0 cm) which is goarse grai-ned and oil stained. It also contains visible secondary porosity. Rest of rubble is fissil shale.
2849.5	12.5	Shale with layers of ironstone (limonite?); black shale with orange-brown ironstone. Shale is fissil and organic-rich. Layers of ironstone up to 3 inches thick and are relatively undeformed. At 2854, carbonate-rich zone that looks sheared.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2875.0	18.5	*Shale*; gray to dark gray with variable greenish tint. Carbonate-rich in parts. Some shale is fissile and in some parts has horizontal white fractures 2 to 3 mm apart which do not react with HCl. Shale is less fissile in carbonate-rich zones. Scattered shell fragments from 3 to 0.5 cm near base. Most shell fragments are articulated oyster shells which may appear to in life position. Oyster shells are transparent and pale blue. Top 13 ft and bottom three feet of section less fissil (higher carbonate content) with abundant fossil fragments. At 2869.0, zone of tightly folded shale (cone in cone?) which represents a zone of soft sediment deformation. At 2885.0, ironstone (limonite?, orange-rust color) 6 inches thick. From 2869.0 to 2872.0, zone has high amount of oyster shells many appear to be in place. At 2869.0 to 71.0, zone is very sandy and contains wavy, continuous to noncontinuous and nonparallel lamina. At 2874.3 to 75.0, shell-rich zone. At 2892.5, abrupt contact with zone containing smaller, white bivalve shells which are scattered. It also contains oyster shells which are not articulated and are broken. Bivalve shells are white (possible recrystallized aragonite?). Shells in this zone appear to be graded, may represent a stoarm deposite. At 2893, abrupt base (scour) where graded bed ends and shale returns to previous character.
2893.5	6.5	Shale; light gray to greenish gray. Shale rich in carbonate material. Carbonate-rich shale is interbedded with fissil shale similar to that described above. Shale very churned with horizontal burrows up to 1 cm in diameter which overall decrease in abundance with depth. Burrows are filled with carbonate-rich shale and are ovate in shape. In lower part of clay, blotchs of carbonate-rich shale

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		up to several cm across. Clay clasts which are symetrical and elongate scattered in core with scattered shell fragments (mostly oysters?).
2900.0	13.0	Shale; greenish gray. Fissile shale espceially inbetween layers of shell material. Zones of shell fragments (oysters) are less fissil and have a high carbonate content. Ovate clay clasts to 1 cm are present. Around clasts, material appears deformed. Small flects of lignite material scattered in zone.
2913.0	25.0	Shale; greenish gray. Similar to above but more fissil and contains interbedded rust-orange layers (limonite? or ironstone) up to 8 cm thick or forming clasts. Most forms layers. Ironstone is irregular in shape and appears to be deformed by soft sediment deformation. Ironstone is concentrated at the top and bottom of the zone. Above 2930.0, some small shell fragments. At 2930.0, small shale and clay clasts a few mm to 1 cm in diameter. At 2933, lenses of very fine-grained sandstone that is highly folded indicating soft sediment deformation.
2938.0	5.0	Shale with lamina of sandstone; light gray. Condrites burrows abundant at top and especially at bottom of section.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2943.0	23.0	Interbedded shale, sandstone and ironstone (limonite?); dark gray shale, tan sandstone, and orange-rust ironstone. Sandstone is fine grained and occurs in lamina 1 to 3 mm thick at the top of the section and reaches 6 to 7 inches near the base (15cm). Sandstone lamina are wavy, discontinuous and nonparallel (ripples). Some of lamina in sandstone is organic-rich. Sandstone content varies from abundant to rare. At 2952 to 54, the zone is sand-rich and has abundant load structures. Shale is nonfissil and contains Condrities burrows, especially at 2949.0 and below 2951.0. Some larger horizontal burrows are also present. Ironstone forms layers and is scattered throughout the interval reaching a thickness of 4 cm. At 2958 to 59, nodules of ironstone are present with diameters reaching 2 cm. Gradational contact at base.
2966.0	5.0	Sandstone with layers of shale and siltstone; sandstone is tan with light brown oil stain near base, shale and siltstone is light gray; very fine to fine-grained. Layers of interlaminated siltstone and shale reach 6 cm. Carbonaceous stringers scattered in sandstones (rooting?) and aliened with lamina. Lamina are continuous to discontinuous, nonparallel and wavy. Slumping of lamina (inclined) from 2966.0 to 67. Root traces at 2967.5. Some carbonaceous material has greenish material on edges. Abrupt contact at the base.
2971.0	2.5	Sandstone; dark brown oil stain; medium to coarse-grained which slightly fines upward. Lamina even, continuous and horizontal or slightly inclined in the upper part becoming inclined to 20° in the lower part. Some lamina are organic-rich. Sharp basal contact.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2973.5	11.0	Interlaminated shale, sandstone, siltstone and ironstone layers; shale is gray, sandstone and siltstone are light gray, ironstone is a orange-red-brown; sandstone is very fine grained. Lamina are wavy, discontinuous and nonparallel. alternating layers of sandstone and shale are inclined to 15° (soft sediment deformation, slumping). Some lamina are wavy and straight. At 2979.5, load and flame structures present. Some small-scale burrows are scattered throughout section. Carbonacous stringers present and associated with greenish growth (rooting?).
2984.5	1.0	Sandstone; dark brown oil stain; medium-grained finning upward. Lamina are even, parallel, continuous and inclined to 20°. At top, lamina are wavy, nonparallel, and discontinuous (ripples).
2985.5	1	Missing Core
2986.5	0.5	Sandstone; Brown oil stain; medium-grained. No sedimentary structures present. Clay clasts and organic clasts abundant to 1.5 cm in diameter and are well rounded (channel lag).
2987.0	0.4	Sandstone and siltstone; light gray; very fine-grained sand to silt. Lamina are wavy, nonparallel and discontinuous with carbonaceous material linning some lamina. Few shale clasts at base. Sharp contacct at base.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2987.4	5.6	Sandstone; dark brown oil stain; fine to coarse grained. Lamina in upper part are continuous, even, parallel and inclined 20 to 25°. Some lamina are slightlty curved at the base. Lamina are outlined by organic-rich material. With depth, lamina become less inclined. The lamina become wavy, discontinuous and nonparallel at 2990.0. At 2990.5, reddish-brown clay layer 4 mm thick. Shale clasts present to 4 mm in diameter 3 inches below clay. Right below this, sandstone has less oil stain. From 2991.3 to 2991.9, core is missing. Carbonaceous shale layers are present in lower part to 2mm thick. Near base, lamina become even, straight and horizontal. Sharp basal contact.
2993.0	6.0	Shale to siltstone; light gray to very faint green at base. Mottled appearance with faint, very discontinuous, rare dark lamina (wisps). Thin mostly horizontal fractures present. At 2994 and 2996, reddish grains (probably crystal aggregates of siderite and maybe pyrite).
2999.0	3.0	Sandstone; vary light gray; fine-grained, slightly finning upward. Zone has a faint mottled appearance. Lamina are very discontinuous, wavy, nonparallel, and scattered. Faint horizontal lamina present? Few carbonaceous stringers possibly rooting. Red grains present to 2 mm (probably crystal aggregates of siderite). Below 3000.0 ft, massive except banding of oil stain.
3002.0	2.0	Sandstone; stained brown by oil; coarse to very coarse-grained. Lamina are continuous, even, parallel and inclined to 25 to 30°. Lower part of sandstone missing.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3004.0	6.5	Sandstone; tan with a brown oil stain in the coarser sandstone; coarse to very fine-grained, finning upward in cosets approximately 1 ft thick. Lamina in the coarser sanstone has even, parallel, continuous lamina inclined to 15°. In the finner sandstones, te lamina are wavy, discontinuous and nonparallel. Carbonaceous material lines many ripples and lamina in the coarser sandstones. Most organic-rich lamina occur with bedding with some cutting across bedding (roots?). Gradational contact on top and bottom.
3010.5	5.0	Shale and siltstone; light gray to tan. At top of section, 2 large, 4 X 1.5 cm, vertical burrows are filled with sandstone. To 3011, lamina are very discontinuous, wavy, and nonparallel. Zone appears churned. A silty zone 6 cm thick is also present. At 3014, lamina become more continuous, wavy, and nonparallel. Several silt-rich zones up to 7 cm are present and have a few discontinuous, wavy, and nonparallel lamina. In some zones with poor laminations, small flakes of carbonaceous material are present and reach 3mm. Small vertical fractures which may represent rooting are scattered in the section. A mineral with a goldish color and a metalic luster can be seen under the binocular microscope (pyrite ?).

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3015.5	7.0	Sandstone; tan but most with dark brown oil stain; Very fine to coarse grained, generally finning upward. Near the top, lamina are wavy, nonparallel, and discontinuous. Internal structure of t he sandstone is difficult to see but appears mostly massive with even, parallel, continuous and inclined from 5 to 20°. Carbonaceous material lines some lamina and is approximately 1 cm apart. Thhe carbonaceous lamina rich 2 mm thick. The top contains no visible porosity while the base has abundant visible porosity which is probably secondary in source. Sharp basal contact.
3022.5	6.5	Interlaminated sandstone and siltstone with some mudstone; tan to light gray with some sections greenish gray and with red clay. Lamina are wavy, discontinuous and nonparallel. At 3022.5 and 3028.0, reddish clay with concretions to 2.5 cm. At 3024.0 to 3025.0 concretions in gray shale. Burrows at 3026.0 filled with sand. At 3027.0, large root filled with carbonaceous material in a greenish shale. As approach base of section, zone increases in carbonaceous material.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3029.0	11.5	Cosests of sandstone with layers of and shale which fine upward. -3029.0 to 3030.8: Sandstone; increase in brown oil stain with depth; grain sire fines upward from pebbles at the base up to 0.5 cm to very coarse to very fine. Carbonaceous material increases with depth. Near base is a 0.6 cm layer of lignite. At top of section, no sedimentary structures apparent. With increasing depth lamina are discontinuous, nonparallel and wavy. -3030.8 to 3031.3: Siltstone with shale lamina and red clay. Lamina are wavy, discontinuous and nonparallel. Clay to 3 cm thick and irregular. Carbonaceous lamina to 4 mm thick. -3031.3 to 3032.2: Sandstone; brown oil stain; medium grained with clay clasts to 1.3 cm. Lamina are wavy, discontinuous, nonparallel and not very common at top. Near base lamina are outlined with thicker carbonaceous material. Sharp basal contact. -3032.2 to 3033.0: Sandstone; tan at top, light brown oil stain with depth; very fine to fine grained, fines upward. Lamina are wavy, nonparallel and discontinuous at the top. Lamina decrease downward, and the sandstone appears massive. Carbonaceous lamina outlines ripples. -3033.0 to 3036.0: Sandstone to siltstone; light gray in siltstone at top to dark brown oil stain with depth; grain size increases with depth from siltstone to coarse grained. Lamina at top are wavy, discontinuous to continuous and nonparallel. Siltstone has a sharp contact with the sandstone below. Sandstone appears massive and contains less carbonaceous material

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		with depth. At top of sandstone is a 1 cm red clay clast. -3036.0 to 3041.5: Siltstone to sandstone at the base; light gray siltstone to tan sandstone some with a light brown oil stain; at bottom is very fine-grained sandstone. Siltstone at tope is massive with flecks of organic shale. At 3038.0, more lamina outlined by carbonaceous material. Lamina are wavy, nonprallel and discontinuous. Sandstone from 3039 to base is interlaminated with zones of oil stain and no oilstain. Lamina in the sandstone is very discontinuos and appears to be disturbed. At 3038.5, lamina are inclined with vertical fractures that may be rooting. At 3040.0, 2 inches of slightly red clay rich in siltstone and organic-rich shale. Top of sandy part contains load and flame structures with shale. Some shale lamina are inclined (slumping).
3040.5	8.0	Siltstone, shale and sandstone; light gray with some light brown oil stain; sandstone is very fine grained to medium grained at base. Upper part is massive to mottled siltstone and sandstone with red grains in top 1 ft (crystal aggregates of siderite?). To 3047.5, zone is massive or has very discontinuous and nonparallel lamina with orgainic-rich shale. At 3046.0, some wavy, discontinuous, nonparallel lamina that are inclined and deformed possible from soft sediment deformation. Below 3047.5, all is stained light brown and zone appease massive with some wavy, discontinuous lamina outlined by orgainc-rich shale near the base. Possible some faint even, straight and parallel lamina which forms a 2 ft bed set at the base. Sharp basal contact.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3048.5	11.0	Shaly siltstone with sandstone; medium gray; coarse siltstone to very fine sandstone. Reddish grains common throughout (crystal aggregates of siderite) up to 1 mm diameter. Some zones contain 20 to 30 % reddish grains. Most of siltstone looks mottled with scattered red grains. Few zones of wavy, discontiuous, and nonparallel lamina. At 3049.0, mottled gray shale with fine sandstone interlaminated in zone less than 4 mm. At 3051.0, 2 vertical fractures with calcite lining them. At 3053.0, 1.2 X 2 cm vertical burrow filled with sandstone. Few scattered vertical fractures near bottom few feet (rooted?). Near base 4 cm of coarse-grained sandtone with brown oil stain.
3059.5	9.5	Sandstone; tan with dark brown oil stain; siltstone at top to very coarse grained in cosets a few feet thick which fine upward. At top 1 ft, wavy, nonparallel and discontinuous lamina scattered in a shaly siltstone. Sandstone contains even, straight, parallel and inclined lamina. Lamina are inclined to 30°. An increase in oil stain corresponds with an increase in visible prosity (secondary).
3065.0	3.0	Shaly siltstone; light gray. Similar to shaly siltstone described above. Red grains (crystal aggregates of siderite ?) are scattered in zone. At 3066.0, 1 ft with darker organic material scattered with a mottled appearance. Some root traces present?
3068.0	5.5	Missing core.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3073.5	42.0	Sandstone in cosests up to 4 ft thick; tan with brown oil stain. Oil stain increases with depth in each coset except in the conglomerate which has little oil stain; individual cosets fine upward from very coarse sandstone and some gravel to very fine sandstone and siltstone. In the bottom part of coset, lamina maybe even, continuous, parallel and inclined or the sandstone maybe massive. Top of cosets may have wavy, discontinuous and nonparallel lamina. At 3081.0 and 3107.0 to 3108.0, numerous lignite stringers (rooting?). At 3108.5, 3 cm ripp up clast of clay. At 3111.0 to 3113.0, root traces. In lower part of cosets, abundant visible porosity (secondary).
3115.5	6.0	Interbedded shale and sandstone with layers and nodules ironstone (reddish-orange clay); tan to light gray, no oil stain; finning upward from medium grained at the base to very fine to fine at the top of the section. To 3117.0, section has mottled appearance with very discontinuous, nonparallel and wavy lamina. Some horizontal burrows?

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3121.5	15.2	Sandstone in cosets of 3 ft or less; tan with brown oil stain, oil stain generally increases with depth in each coset except in the conglomerate which has little oil stain; cosets fine upward from gravel to siltstone. Cosets are often stacked on top of each other and are erosional at the base. At the base is either gravel (channel lag?) or coarse to very coarse sandstone. The coset fines upward and may be capped by interlaminated siltstone or shale or is truncated by another coset. Capping some of the cosets is shaly siltstone with wavy, discontinuous and nonparallel lamina, or large shale rip up clasts to 4 cm. The base of the section is abrupt on basement.
3136.7	4.3	Basement composed of tuff with nodules of chert up to several cm long.

Core described in November 1986 by John S. Sneider. Slabbed 4" core in good condition, bagged, and boxed.

APPENDIX II

Tenneco San Francisco 35

Department of Huila, Colombia, South America

San Francisco Field

Caballos Formation, Albian to Aptian, Cretaceous

Completed: June 1987

CORE DESCRIPTION
San Francisco No. 35
Hulia Dept., Colombia
San Francisco Field
Caballos Sandstone
Core: 2817.0 - 2951.0; 3101.0 - 3318.4

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2817.0	13.5	Shale; gray-dark gray; thin lamina of siltstone to 2824.0, below this is more churned. Scattered lignite stringers increase at 2824.0. At 2827.3, lignite piece 5 x 2 cm. At 2823.0, 7 mm dia lignite rod extended through core (twig or root)., pyrite filled horizontal burrows beolw this. Slikenside surfaces present through out zone; at 2829.0, sharp uneven contact with lighter brown to gray mottled shale.
2830.5	6.1	Sandstone; Stain dark; very fine-grained to medium-grained, increasing downward. Sandstone is rich in organic-rich shale. Two cosets, 1st coset 3ft thick, Cross laminated to 10^{0} at base, siltstone present at top, sharp upper contact, 2nd coset 3ft thick, wavy, nonparallel, continuous to discontinuous lamina at top of coset. At base, lamina horizontal to inclined to 10^{0}.
2836.6	4.4	Shale; gray; Faint horizontal lamina of siltstone slightly burrowed, which are filled with pyrite. Small (2-3mm) horizontal burrows filled with siltstone.
2841.0	6	Sandstone to siltstone; tan to light tan; coarse silt to very fine-grained sandstone, finning upward. Lamina are wavy, discontinuous to continuous and nonparallel (ripples). Thick lamina of shale present. Concentric growths and appears highly weathered.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2847	4.8	Shale; gray; Faint horizontal lamina of alternating shades of gray. Small burrows? (1mm in dia) filled with pyrite and lighter color shale.
2851.8	59.7	Sandstone; stain dark brown; very fine -very coarse grained. Several finning upward cosets. Base of cosets are cross laminated becoming wavy, nonparallel, and discontinuous at the top of the cosets, especially near the top of the section. Lamina are outlined by organic rich shale. -Coset from 2852.8 to 2855.5. Coarse grained at base to very fine grained at top. Lamina are even, straight, continuous and inclined to 10^0 at base and become vavy, discontinuous, nonparallel toward the top. Coset rest on 1 cm of shale and silt. Sharp basal contact. -From 2855.5 to 2861.1ft. Composed of several cosets. Grain size variable from silt to medium grained sandstone. Lamina are even, straight, inclined to 15^0 to ripple laminated (wavy, discontinuous). At 2857.5 carbonaceous material 3 cm by 1cm. Capped by shale and rest on shale 1 cm thick. Composed of several cosets. -Coset from 2861.1 to 2963.1. Coarse grained, slightly finner at the base. Even, straight, continuous lamina inclined to 15^0 at base to horizontal at top. Part of section is massive. Sharp basal contact on 1 cm of shale. -Coset from 2863.1 to 2872. Overall grain size increasing downward from medium to coarse to very coarse grained with local variation. Lamina inclined from 15^0 to 20^0. Lamina very distinct at base becoming faint upward in seciton. Shale break at top few cm thick. High amount of visible porosity which is probably secondary porosity decreasing upward in the section. Scattered lignitic material in sand. Probably several samller cosets.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		-Coset from 2872 to 2878. Sam as above. Coarsens downward to granuals. Coarser than material directly below base. Lignitic shale lamina 3 to 4 mm thick at base. High amount of visible porosity. -Coset from 2878 to 2894.4. Same as above. Coarse grained to very coarse grained with some granules. Lamina generally increasing in inclination from horzontal to inclined from 15^0 to 20^0.
2894.4	11.1	Sandstone; stain dark brown; fine grained at top on top of coarse to very coarse grained sandstone which fines slightly downward. Even, straight lamina with low angle inclination to 10^0. Abrupt contact at base.
2905.5	6.0	Sandstone; stain dark brown; siltstone layer 1 cm thick at top, very fine grained to coarse grained in small cosets coarsening upward. Even, straight lamina inclined to 20^0 at top grading to wavy, discontinuous, nonparallel lamina at base. Two cosets seperated at 2909.
2911.5	9.5	Missing core
2921.0	8.0	Sandstone; stain dark brown; coarse grained, slightly finner at 2925.5. Lamina horzontal to inclined to 15^0. At 2525.5-26 horzontal to rippled (coset).
2929.0	1.5	Sandstone; stain dark brown; fine grained to coarse grained at base; top of unit composed of wavy, nonparallel, discontinuous to continuous (ripples), sandstone massive to cross lamina inclined to 15^0.
2930.5	1.5	Shale; gray; ripple of siltsiltstone.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2932.0	3.0	Sandstone with interlaminations of shale at the top; tan with slight brown oil stain in spots; very fine sandstone to shale; wavy, continuous, nonparallel lamina, increase in shale thickness and concentration upward to 5 mm thick; vertical fractures in sandstone (2933), sharp basal contact. 2935.016.0Shale; gray; well with horizontal lamina of siltstone generally decreasing with depth; moderate amount of burrowing at top generally decreasing with depth, horizontal and vertical burrows filled with silt; also <u>chondrites</u> burrows. At 2950, increase in siltstone.
2951	150.	Not cored.
3101.0	19.2	Shale; gray to light gray. Massive to mottled appearance with scattered wavy, discontinuous lamina of organic material. Vertical fractures present. At 3105.0, 1 cm diameter rod shaped lignite piece cutting through core with scattered lignite stringers. At 3115.0, mottled appearance with wavy, very discontinuous organic-rich material and thin vertical fractures. Possibly rooting. From 3117.0 to 3120.2, rubble and poorly slabbed core. At 3119.0, silt lamina with continuous, wavy nonparallel lamina with thin vertical fractures. Possibly rooting.
3120.2	0.8	Missing section.
3121.0	8.7	Siltstone and Sandstone; tan to dark brown oil stain. Top 3 ft continuous, nonparallel, wavy lamina in zones with massive appearance inbetween. Rest of section to bottom 2 ft is rubble. Bottom 2 ft, fine grained to coarse grained with even, straight lamina inclined to approaximately 15^{0}.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3129.7	2.5	Sandstone; stain dark brown; medium to coarse grained. Structures difficult to see because core is broken in pieces with uneven slab face. Some lignite stringers can be seen. Visible porosity very common (possibly secondary porosity).
3132.2	2.5	Shale to sandstone; light gray shale and light brown oil stain; fines upward from very fine sandstone to shale at top. Poorly slabbed core makes difficult to see structures. Few stringers of lignite present in shale. Few scattered, wavy, discontinuous lamina present (ripples?).
3134.7	0.9	Shale to siltstone; light gray. Massive with vertical fractures, may be rooting. Elongate clay clast 3 cm long.
3136.5	6.1	Interlaminated siltstone and shale; light brown stain in siltstone and very light gray to gray shale with some nodules and lamina of rust orange limonite. Siltstone-rich layers to 10 cm with wavy, discontinuous, nonparallel lamina with no burrows. Rest of core is interlaminated shale and siltstone with wavy, discontinuous, nonparallel lamina. Shale lamina up to 1 cm thick. Nodules and layers of limonite-rich claystone to 2 cm thick. Variable amount of horizontal burrows filled with siltstone sometimes abundant.
3142.6	7.4	Sandstone; light brown oil stain with very light gray siltstone; fines upward from very fine sandstone to siltstone and shale. Series of small cosets from 1 ft to 9 cm (3 inches). Sandstone contains slightly wavy, continuous, nonparallel lamina of dark shale (ripples).

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3150.0	1.4	Interbedded shale and siltstone; siltstone light gray to tan, shale is gray. Siltstone contains wavy, discontinuous, nonparallel lamina of shale and clay. Shale and siltstone contains mottled appearance with wavy, discontinuous lamina occuring locally. Layers occur up to 8 cm thick. Clay clast common especially at base. Clast up to 3 cm long and are reddish brown to cream in color (possible soil formation at base).
3151.4	12.6	Sandstone; dark brown oil stain; medium to very coarse grained, generally finning upward. Mostly massive with scattered pieces of lignitic material. Even, straight, continuous lamina in the lower section. Large amount of visible porosity up to several mm (secondary porosity?).
3164.0	2.0	Alternating Conglomeritic sandstone and shale; gray shale and tan to light brown oil stained sandstone; clast of clay to several cm, quartz grains to several mm. Top 1 ft consists of sandstone and clay clast to 2 cm with rod shaped lignite to 1mm thick. Lignite stringers cut at 45^0 angle and scattered lignite. Below this lies 0.5 ft of conglomerite resting on 2 inches of coarse sandstone which has a sharp basal contact on siltstone.
3166	3.3	Siltstone to sandstone; light gray with slightly brown oil stain increasing with depth; siltstone to very fine sandstone, slight coarsening downward. Horizontal lamina at top. Rest of section no visible structure.
3169.3	12.1	Missing Description.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3181.4	6.3	Shale; gray. Massive at top. Below 3185.0, mottled with black material which decreases at base. From 3183.0 to 3184.0, reddish grains (crystal aggregetes of siderite?) less than 1mm thick. Randomly oriented. Appear to be formed in place.
3187.7	5.0	Shaly and silty sandstone; light brown oil stain; medium to coarse grained with abundant fines and matrix. Low visible porosity. No sedimentary structures. Some of core is rubble.
3192.7	1.3	Shale; gray with orange brown nodules to 8 cm. Lamina very wavy, scattered and discontinuous. Burrowed.
3194.0	1.3	Sandstone; light brown oil stain; fine to very fine grained. Lamina are continuous, nonparallel and wavy (ripples).
3195.3	2.1	Shale; gray with orange brown clast to 8 cm. Lamina are very wavy, scattered and discontinuous. Burrowed.
3197.4	9.6	Sandstone; tan to brown oil stain increasing with depth; medium grained to granules at base, overall coarsening with depth. Top 1 ft rich in matrix. Below top 1 ft, interlaminated sandstone, siltstone and shale with wavy, discontinuous, nonparallel lamina. Lignite partical 3 cm across appears to be piece of wood. Below wavy laminated zone is horizontal laminated with vertical fractures. Spots of oil stain occur in coarse-grained sediment. At 3201.0, oil stain becomes very dark brown, and core is rubble so difficult to see sedimentary structures but appear to be low angle, even, parallel lamina. Bottom 2 ft is granular conglomerate with variable oil stain.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3207.0	10.3	Sandstone cosets capped by shale; gray shale and light brown stained sandstone; very fine to coarse-grained sandstone in cosets coarsening downward. Top two feet shale massive grading into very fine sandstone with crystal aggregates of siderite? to 1 mm thick. No sedimentary structures seen in section because poorly slabbed core. Below this is 2.5 ft of siltstone and sandstone with wavy, very discontinuous, nonparallel lamina that seem disturbed. Vertical fractures (roots?) and lignite stringers present. Sharp contact at base with sandstone few inches thick with 1 ft zone of alternatting sandstone and siltstone wavy, discontinuous, nonparallel lamina that caps sandstone that has a variable oil stain and is medium to coarse grained. The sandstone has low visible secondary porosity and a high matrix content. Few organic stringers near the base. Rubble at base of section.
3217.3	10.9	Alternating siltstone and sandstone with clay; gray; silt size to very coarse grained. Mostly siltstone with high clay matrix, lenses of sandstone and zones of sandstone in pods of nodules up to medium grained or in small bed sets. To 3219.5, siltstone with abundant pods of sandstone to 4 cm long and abundant small particals of lignite. Lamina are very discontinuous and nonparallel. At 3219.5, mottled, very fine-grained, matrix-rich sandstone with reddish clay and lignite clast 1.5 cm long above sandstone. Sharp contact with 1 ft of matrix rich sandtone, tan with slight oil stain and very fine to medium grained. At 3221.0 to 3225.6, very fine sandstone and siltstone; dark gray to black. Massive at top and mottled in lower section. Red grains found scattered throughout. From 3222 to 3223.5 abundant red grains, non depostional. From 3225.6 to 3226.3, sandstone rich in matrix and slightly stained brown by oil. From

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		3226.3 to 3227.0, conglomerate decreasing in grain size upward to medium grained. Dark gray and rich in matrix. From 3227.0 to 3228.1, mottled siltstone as from 3221.0 to 3225.6. Gray to black, lighter near base with very discontinuous lamina. Coarse sandstone grains present.
3228.1	3.9	Sandstone; light gray to gray; top very coarse to coarse grained. Rich in matrix till 3230.5. Top 1 ft alternating fine to coarse grained. Clay clast elongated to 0.5 cm. Below 3230.5, faint low-angle, straight, even, parallel lamina. Visual porosity and vertical fractues. At 3231.0, organic rich zone.
3232.0	4.5	Shale and Siltstone; dark gray shale and light brown oil stained siltstone. Discontinuous, contorted, black lamina. Base of section is rubble.
3236.5	21.5	Sandstone: stained brown, less stain as go up in cosets; very coarse at base to siltstone at top of cosets, coarsens downward. Top 6 inches are silty. High amount of vertical fractures (roots?) and high lignite content. Faint, even, continuous, parallel, low-angle lamina. Structures are difficult to see but appear to consist of several cosets. Moderate amount of visible porosity (secondary?) in lower part. At 3245.1 to 3248.0, shale break and coarsens down to very coarse grained and has abudant secondary porosity. At 3245.1, sandstone, gray to buff; very fine grained at top and rich in matrix, no oil stain to 3251. Does contain even, parallel lamina inclined to 10°. At 3254.5, strong oil stain in clean sandstone to 3258.0 with very coarse grain size and secondary porosity visible.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3258.5	3.4	Sandstone; light gray, no oil stain; very fine to fine grained at top to medium to coarse at base. Top capped with matrix-rich siltstone and sandstone. Faint, low-angle, even, parallel lamina. Some secondary porosity present.
3261.9	2.1	Interlaminated sandstone and shale; shale is black, sandstone tan to very light brown oil stain; very fine to fine grained. Shale organic-rich with slightly wavy lamina to 5 mm thick, continuous to discontinuous. Sandstone laminae from 3 cm to few mm. Becomes richer in shale with depth.
3264.0	1.5	Shale; black. Massive with a very sharp basal contact.
3265.5	2.9	Clay, sandstone and siltstone; tan; fine grained to very coarse grained. Top 1 ft very coarse grained to granual size quartz with clay clast up to 2.5 mm long and slightly rounded. Some very discontinuous, nonparallel lamina. Clay clast mostly alliened horizontally. Grades to zone with less clay clasts to no clay clasts. Becomes medium to fine grained, light brown stained, with zones very coarse grained. Organic rich lamina scattered with wavy, discontiunous and nonparallel lamina. Some lamina scattered with no order. At 3267.0, highly contorted zone of organic-rich lamina inclined 75° (roots). Organic-rich lamina to several mm thick. Scattered crystal aggregates of siderite?
3268.4	4.0	Missing Description.
3272.4	1.6	Siltstone, shale and sandtone; gray to dark gray; coarse silt to very fine grained. Lamina continuous to mostly discontinuous, nonparallel, wavy. Increases in shale as approach base.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3274.0	12.3	Sandstone in several cosets; top 1 ft tan, below core is tan to light gray; very fine to medium-grained. Top 1 ft very fine to fine-grained with lamina even, straight and parallel, inclined to 5^0. Some organic material and orange-red grains present (crystal aggregates of siderite). Below this very fine to medium grained. Poorly slabbed core so difficult to see structures. Wavy, discontinuous, nonparallel lamina present. May be even, straight and parallel lamina but difficult to see. No visible porosity. Red-orange grains present. Organic lamina and pieces of organics scattered throughout. At 3282, wavy, shale rich zone. At 3286.0, 2 cm layer of lignite. Below lignite layer, 2 inch zone of conglomerate composed of clay, chert(?) and quartz set in fine sandstone with discontinuous, wavy organic lamina.
3286.3	2.8	Sandstone at top to conglomerate at base; tan at top increasing in oil stain as increase in depth; fine to medium grained at top to granules at base. Top of section contains wavy, discontinuous to continuous lamina outlined by organic rich shale. Downward in section, lamina become even, straight, parallel and slightly inclined. Coarsens to a granule size to 1 ft from base of section. Bottom 1 ft coset from medium to coarse grained at the top to granuale size conglomerate at base. Abrupt erosional contact at the base resting on claystone.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
3289.1	29.5	Claystone; silty claystone with some sandstone grains suspended in clay matrix; medium gray to buff. Some wavy, nonparallel, continuous lamina, but most lamina is discontinuous. In places, claystone appears highly mottled with scattered patches of very black clay (organic-rich). At 3302, 8 inch zone of mottled clay and orange-red grains (Crystal aggregates of siderite?) associated with a vertical fractured filled with sand grains and orange-red grains. At 3303, another zone that is highly mottled directly below vertical organic stringers (root-s?). Orange-red grains are present but not as frequent as 3202.0. At 3306, vertical fracture lined with organic material and filled with same clay as found in matrix. Organic material also scattered in zone. To base, dark gray/brown, massive claystone. At 3313, planner layer of slightly reddish, hard material. Possible a fracture surface?

Core described in June 1987 by John S. Sneider. Slabbed 4" core in good condition, bagged, and boxed.

APPENDIX III

Tenneco San Francisco 56

Department of Huila, Colombia, South America

San Francisco Field

Caballos Formation, Albian to Aptian, Cretaceous

Completed: June 1987

CORE DESCRIPTION
San Francisco No. 56
Huila Dept., Colombia
San Francisco Field
Caballos Sandstone
Core:

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2460.0	5.0	Shale to siltstone; black; Shale is in 2 approximately 2 ft cosets. Shale is organic-rich and is filled with horizontal burrows and <u>Condrities</u> burrows which are with pyrite and greenish-gray, silty shale. The shale has shell fragments of bivalves and gastropods; the lower coset contains more shell fragments. The upper contact is erosional. The lower of the two cosets contains two orange-brown (ironstone) shale layers. One of the layers has a star-shaped fracture(?) filled with sand.
2465.0	1.7	Sandstone; light gray; very fine grained. Sandstone is heavily burrowed with some burrows filled with pyrite. The orange-brown (ironstone) claystone, similar to that described above, is present in patches and and also appears to be burrowed. The sandstone has an overall mottled appearance. Near the base is a a 5 X 2 cm piece of lignite. The basal contact is sharp.
2466.7	5.3	Shale with thin lamina of siltstone; black shale and tan siltstone. Shale is organic-rich and heavily burrowed. Most burrows are horizontal and are filled with siltsone, sandstone and pyrite. Burrows reach up to 3.5 cm in diameter. <u>Condrites</u> burrows are present. Shale has conchoidal fractures and slickensides (?). The siltstone lamina are even, horizontal and parallel, but most are disturbed by burrowing. Gradational basal contact.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2472.0	0.6	Sandstone; light tan with a light brown oil stain; fine grained. Sandstone appears mottled with one inclined burrow 4.5 cm X 7 mm. Some visilbe prosity (secondary?) present. Gradational contact at base with shale as above.
2472.6	2.1	Shale; black. Shale as 2466.7 but with fewer burrows and pyrite. Organic pieces are abundant. At 2473.0, a 10 cm deep and 3 cm wide soft-sediment fracture is filled with spherical, volcanic, glass balls.
2474.7	7.0	Shale with a layer of sandstone; black to dark gray. Shale is organic-rich with small, scattered pieces of lignite. Some of lignite is vertical (roots). At 2475.8, soft sediment fracture 5 X 1.5 cm filled with round pellets (volcanic glass balls, which are partially replaced by pyrite). At 2476.0, is 10 inches of very fine-grained sandstone with a light brown oil stain. The sandstone has scattered, wavy, continuous to discontinuous, nonparallel lamina, and contains scattered pieces of lignite. The top and lower contact of the sandsotne is sharp. Below the sandstone is a 1/2 ft of the shale with lenses of very fine-grained sandtone which grades to shale with lamina of siltstone. Some of the siltstone lamina are brown to gold in color. The laminated shale grades to churned shale with a high organic content with large pieces of lignite. Near the base the core contains a few feet of rubble. The base is gradational.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2481.7	25.3	Sandstone; stained dark brown by oil, with some of the finner-grained sandstone containing less oil stain; at least 2 cosets which coarsen upward from medium to very coarse grained. Top of the section contains interlaminated siltstone and sandstone with a mottled appearrance. Organic content is also hervy high. Small vertical gractures are also present in the upper part. Lamina, which are outlined by organic-rich shale, are straight to curved to wavy. The lamina are in at least 2 cosets, and generally have wavy, discontinuous and nonparalle lamina at the base and even, straight, parallel lamina inclined to 20°. At 2491.0, 6 inches of silty shale with orange-brown shale and light gray to tan siltstone. At 2506.0, a 2 cm diameter piece of lignite cuts core and is branched like a root. In this zone, the sandstone appears mottled. Sharp basal contact.
2507.0	5.0	Shale; gray. Shale contains scattered <u>Condrites</u> burrows filled with siltstone and pyrite, and burrows that cut the shale at an angle. As approach the base, the shale has lamaina of very fine sandstone and siltstone and burrows. The basal contact is gradational.
2512.0	7.0	Sandstone; dark brown oil stain with less stain at the base; medium to coarse grained. At the base, the lamina are faint, wavy, discontinuous and nonparallel. Upward, the lamina are straight, even, continuous and inclined to 20°. Some sections contain discontinuous, nonparallel and wavy lamina. At 2517.0 is a high concentration of organic-rich shale lamina. Shale lamina reach 2 mm in diameter and may prevent staining of small sections of sandstone. The basal contact is sharp.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2519.0	1.75	Shale; gray. Similar 2507.0 to 2512.0. Shale contains a horizontal layer of lignite 1 mm thick. Scattered pieces of lignite are found throughout the section. Small burrows scattered in zone and are filled with pyrite(?). The basal contact is sharp.
2520.75	0.75	Sandstone; dark brown oil stain; medium grained. Lamina are slightly discontinuous, nonparallel and slightly inclined to horizontal. Lamina are outlined by organic-rich shale. A minor amount of burrowing is also present. The basal contact is sharp.
2521.5	2.0	Shale; gray. Similar to 2507.0 to 2512.0. Shale has a high organic content. Top foot has horizontal lamina of lignite to 5 mm thick. Lignite content gradually decreases and becomes scatted and less continuous downward. Near the top of the section are small burrows. Some of the burrows are filled with a rust color material (alteration?). At 2522.0 is pieces of lignite which are 3mm thick an inclined to 45°. The basal contact is sharp.
2523.5	3.0	Sandstone; tan with a dark brown oil stain; medium to fine grained. Top of section contains wavy, discontinuous to continuous lamina of organic-rich shale to 3 mm thick. Lamina become increasingly discontinuous with depth and contains scattered pieces of lignite. Some of the sandstone is isolated by the lamina and is not stained by oil. Minor burrowing is present. Visible prosity (secondary porosity) increases with depth. The basal contact is sharp.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2526.5	2.0	Shale; gray. Similar to 2507.0 to 2512.0 with a lower organic content. Shale increases in lamina of siltstone and very fine-grained sandstone at the base. At the base is small ambur colored pieces up to 2 mm diameter (oil?).
2527.5	8.9	Sandstone; tan with dark brown oil stain; medium grained to siltstone in cosets from 1 to 3 ft thick which coarsen upward. Sandstone cosets are seperated by shale lamina, nonstained siltstone and very fine-grained sandstone. Lamina are variable with some zones containing even, straight, parallel lamina with a low angle of inclination. Sandstone in the lower section have more discontinuous, wavy and nonprallel lamina. Burrowing is present and increases in frequency with increasing depth. Visible prosity (secondary) is variable from low to moderate. At 2529.0, section is slumped (soft sediment). Base might be rooted??
2536.4	1.0	Interlaminated shale and siltstone; gray shale and tan siltstone. Top few inches contains sandsonte and siltsotne, Below this is organic-rich shale with lamina of siltstone and very fine sandstone. The shale contains small ambur colored particles up to 1.5 mm in diameter.
2537.4	6.2	Sandstone; dark brown oil stain which generally decreases with depth to tan; medium to very coarse grained in upper part to very fine to fine in the lower part. At the top few inches, lamina are discontinuous, slightly wavy nonparallel and horizontal. Below this the lamina are even, straight, continuous, parallel and inclined up to 20°. Below this 3 inches of finner-grained sandstones with wavy,

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		nonparallel, and continuous lamina. The sandstone returns to medium grained, and has even and inclined lamina as above. The medium-grained sandstone becomes finner grained and alternates with thick shale lamina at the base. The lower contact is gradational.
2543.6	2.9	Interlaminated sandstone and siltstone with shale; tan with brown oil stain, shale is light gray; very fine-grained sandstone to coarse-grained siltstone. Shale lamina reach 1.5 cm of thickness and seperate zones of siltstone and sandstone. The zones of siltstone and sandstone contain wavy, discontinuous, nonparallel and scattered lamina.
2546.5	9.5	Sandstone; dark brown oil stain; finning upward from coarse to medium grained. The upper 4 inches contain wavy, continuous to discontinuous and nonparallel lamina. The lamina below this are even, straight, continuous parallel, and inclined to 15°. The inclination of the lamina generally increases with depth. The lamina are outlined by organic-rich shale. Visible (secondary) porosity is common especially in the coarser-grained sandstones. The sandstone is burrowed at the base.
2556.0	32.75	Shale with siltstone lamina, and layers and nodules of rust-orange clay; gray. Rust-orange layers of claystone are generally less than a few cm thick with some layer up to 5 cm thick. Burrowing is variable from rare to high. Most burrows are horizontal and filled with very fine sandstone and siltstone. Very fine sandstone and siltstone also occurs in thin lamina of shale. The upper 5.5 ft contain little sandstone and few burrows, and contains

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		a lignite streak to 1 cm thick which cuts across the core. The top of the section has 1 mm layer of pyrite ? (altered organic lamina). From 2561.4 to 2563.0, the shale has a high sandstone content and is highly burrowed. From 2563.0 to 2577.0, the zone has a moderate to high amount of burrowing and a moderate to low sandstone content. Form 2577.0 to 2585.4 the concentration of burrowing and sandstone is low, but higher than the top of the section. From 2584.5 to 2566.6, the concentration of burrows sandstone increases. At the base, very fine-grained sandstone alternates with shale gradually becoming sandstone. The bottom contact is sharp.
2588.75	1.25	Siltstone and shale; light gray. No apparent sedimentary structures. Possible root traces at 2588.0. Circular burrow (4 cm long) filled with very fine-grained sandstone near the base. The basal contact with the sandstone below is gradational.
2590.0	8.25	Sandstone; very dark brown oil stain; medium to very coarse-grained, coarser at the base. Lamina are even, straight, continuous and inclined to 20°. The zone is divided into several cosets fro 2 to 3 ft thick. The cosets are seperated by large ripple laminations of orgainc-rich shale that prevent staining of some small zones. More visible (secondary) porosity at the base decreasing upward. At 2595.6, yellow-orange material (oil?). At base is a large layer of lignite. The basal contact is gradational.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2598.25	0.9	Interlaminated siltstone and sandstone; tan with some light brown oil stain; very fine-grained sandstone to siltstone. Lamina are thick, discontinuous to continuous, nonparallel and wavy. The top of the section is a 5 mm organic-rich lamina.
2529.2	0.8	Shale; black to dark gray. Shale is highly organic with conchoidal type fracture.
2600.0	0.5	Sandstone; medium brown oil stain; very fine grained. Lamina are wavy, dis-continuous, and nonparallel.
2600.5	1.5	Missing core.
2602.0	1.0	Shale; medium gray. Shale is highly contorted with moderate amount of burrows which are filled with siltstone. Organic-rich stringers scattered in zone may represent rooting. Near base are wavy, discontinuous and nonparallel almaina with siltstone. Gradational contact at the base.
2603.0	1.9	Siltstone and shale; tan to light gray. Zone is massive and rooted. At base, very fine-grained sandstone and siltstone have a light brown oil stain and wavy, discontinuos and nonparallel lamina. Rooting is also present in this lower zone.
2604.9	2.35	Rubble with pieces: of gray shale with horizontal lamina of siltstone, 2.5 cm layer of orange-rust claystone, and very fine sandstone and siltstone with light brown oil staine, vertical rooting? and wavy, discontinuous and nonparallel lamina.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2607.25	7.25	Siltstone and sandstone to siltstone to shale; siltstone and sandstone are tan, the shale is gray. Top of section is siltstone with scattered rust-orange claystone. The zone appears to be highlty rooted with a 6 inch root. Scattered lignite is present. Lamina are discontinuous, wavy and nonparallel. The amount of shale generally increases with depth, and the amount of rooting decreases with depth. Burrows are present with depth and are filled with sandstone. At the base is 4 inch organic stringer which cuts through the core at 45°.
2614.5	10.0	Shale; dark gray with rust-orange claystone. Claystone (ironstone) layers are up to 4.5 cm thick. No burrows observed.
2624.5	0.8	Shale; light gray to white. Shale is rich in carbonate. Shale is highly folded with cheveron style folds (cone-in-cone structure) presumable from soft sediment deformation. Pieces of darker shale and nodules of rust-orange claystone up to 3 cm present.
2625.3	5.3	Shale; dark gray with rust-orange layer (ironstone) as above. Shell-hash in zones and Condrites burrows at 2626.0 in ironstone and surrounding. At 2628.5 a large oyster shell 5 cm long. Less ironstone as you increase in depth. At 2628.6, horizontal burrows are filled with siltstone and ironstone. Near base, a large nodule of ironstone has a star-shaped fracture filled with sandstone. Sharp basal contact.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2630.6	3.7	Shale; very light gray. Rich in carbonate. Top 9 inches is burrowed with small shell fragments. Most shell fragments are small, white and many are broken. Some of the shells are ribbed. Larger shells (oysters) up to 4 cm across are also present. The shale is burrowed. Near the base is large ironstone nodule with small burrow in it. Basal contact is sharp.
2634.25	10.4	Shale; dark gray with rust-orange claystone (ironstone). Top 8 cm is ironstone with a snail shell. Zone contains burrows and scattered fossils concentrated in zones. At 2634.5, is a concentrated zone of shell hash. At 2637 and 38 are concentrated zones shell hash and vertical and horizontal burrows. Shells are mostly bivalves.
2647.4	15.3	Shale; light gray to white. Shale has a high carbonate content. Zone contains abundant shell fragments, both large oyster shells and small bivalves. Large scale and abundant burrowing is also present. Interval contains irregular zones of carbonate. White, eliptical shale clasts up several cm are present. Gradual contact at base with decreasing fossil and carbonate content at the base.
2660.0	8.4	Shale; dark gray with rust-orange layers. Scattered horizontal and vertical burrows filled with pyrite. At 2663.0 is a 4 cm burrow filled with sandstone in ironstone. Gradual contact at the base.
2668.4	1.4	Shale; light gray. Shale has a carbonate-rich matrix with abundant bivalve shells. Some of the shells are broken. Basal contact is sharp.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2669.8	13.2	Shale; gray with some rust-orange (ironstone layers and nodules. Scattered large burrows filled with siltstone or rust-orange claystone.
2683.0	9.8	Shale; similar to shale above with sandstone in lenses and infilling burrows, and with more abundant nodules and layers of ironstone. Bivalve shells are present in top of zone. Some large burrows are present up to several cm long. Sandstone-rich zones have wavy, discontinuous and nonparallel lamina. Flakes of lignite up to a few mm long are scattered along bedding planes. Basal contact is sharp.
2692.8	2.6	Siltstone; very light gray. Lamina are wavy, discontinuous and nonparallel. Zone has a mottled appearance possible from rooting. Vertical stringers of organic material (probably rooting). A few large burrows are also present, smaller near base and top. Basal contact is gradational.
2694.5	10.6	Shale with lamina of siltstone and very fine-grained sandstone; Shale is gray with rust-orange clay (ironstone), and sandstone and siltstone are tan. Tp ft has horizontal burrows with some Condrites. The next two ft have horizontal burrows and is rooted (vertical fractures filled with organic material). Sharper contrast of the sandstone and siltstone lamina downward. The lamaina are wavy, discontinuous and nonparallel. Abundant horizontal burrows to 2700.0 then burrows are scattered. The bottom 2 ft have more continuous lamina of siltstone and sandstone with minor amounts of burrowing.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2706.0	3.75	Shale; medium gray. Shale is mottled with scattered, discontinuous, wavy and nonparallel lamina. Lignite stringers are present in the bottom half of the section. One stringer cuts the core at 30° and may have been a root. Basal contact is sharp.
2709.75	4.25	Shale; light to medium gray. Shale is massive with a few scattered, discontinuous lamina of carbonaceous material. From 2711.0 to 2712.0 are red grains to 1 mm which are crystal aggregates of siderite or possibly some pyrite.
2713.0	7.0	Shale; medium gray, lighter at the base. Shale is mottled with scattered, discontinuous, faint, wavy and nonparallel lamina. Zone increases in siltstone content downward. A few scattered, discontinuous lamina of lignite are also present. From 2715.0 to 2716.0, red grains (crystal aggregates of siderite) up to 2 mm are present.
2720.0	3.0	Interlaminted siltstone and shale; siltsone is very light gray, shale is light gray. Lamina in siltstone-rich zones are wavy, discontinuous and nonparallel. Rooting is common with a 10 cm root filled with organic material at 2721.0.
2723.0	22.4	Sandstone; tan with a dark brown oil stain in the coarser sandstones; very fine to coarse grained in small, finning upward cosets with conglomerate at the base. Zone is composes of a series of cosets from 6 inches to several feet. Cosets have an abrupt base on siltstone or shale or on other sandstones. The base of the coset has even, straight and parallel lamina inclined to 10°. Avove these lamina, the lamina become wavy, discontinuous and nonparallel (ripples). The thick

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		ess and abundance of the organic-rich lamina in the ripple laminated sandstones increases with depth up to 3 cm thick 3 ft above the base. The oil stain decreases upward in the cosets. he bottom 2 ft of the zone is conglomerate which planar stratified to massive and has a low oil stain.
2745.4	22.0	Siltstone with interlaminated shale; gray to very light gray. Shale is mottled with scattered discontinuous, wavy and nonparallel lamina. Rooting present in zone. From 2750.0 to 2753.0, layers of very fine-grained sandstone which is tan with a light brown oil stain. Sandstone zone has small cosets from 6 inches to 1 ft. Lamina in the sandstone zone are continuous to discontinuous, slightly wanvy and nonparallel with organic rhch shale in the top of the cosets. At 2752.0, a 3 cm thick layer of lignite. The sandstone also appears rooted. Below the sandstone, the shale and siltstone appear weathered. From 2758.0 to 59.0, red grains present (crystal aggregates of siderite). From 2759.0 to 61.0, tan siltstone which is poorly preserved and has no apparent structures. At 2761.0, return to interlaminated siltstone and shale which has faint lamina. Appears rooted. From 2762.0 to 63.0, lamina of organic-rich shale are more continuous. From 2763.0 to 2765.0, red grains (crystal aggregates of siderite) are present. From 2765.0 to base of zone, siltstone and shale is mottled.
2767.4	15.6	Sandstone; tan with a dark brown oil stain; very fine grained to pebbles in finning upward cosets. To 2773.0, sandstone is coarse grained, and has even, straight, continuous and parallel lamina inclined to 10°. At base is gravel lag. From 2773.0 75.4, several cosets less than 1 ft thick which fine

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
		upward from fine-grained sandstone to shale. Sandstone has light oil stain, and shale is organic rich. From 2777.4 to 80.0, sandstone is very fine grained, tan with red grains (crystal aggregates of siderite) and root traces. From 2780.0 to 83.0, sandstone in a complete bedset. The bed set is very coarse grained at the base and hasa dark oil stain. Upward, the sandstone is very fine grained, is not oil stained and contains red grains (crystal aggregates of siderite). The base of the coset contains even, continuous, straight and parallel lamina. Above this zone, the sandstone is massive with root traces. The top of the coset has wavy, discontinuous and nonparallel lamaina.
2783.1	1.7	Rubble.
2784.75	5.25	Sandstone and siltstone; siltstone is tan, sandstone has a light brown to dark brown oil stain in the coarser sandstones; cosets fine upward from coarse grained to siltstone. The cosets are approximately 1 ft thick. The siltstone has discontinuous to continuous, wavy and nonparallel lamina with common rooting. The coarser grained sandstone hase even, straight, nonparallel lamina inclined to 15°.
2790.0	4.3	Siltstone and sandstone with interlaminations of shale; light gray to light tan oil stain; very fine-grained sandstone to siltstone. Lamina are wavy, discontinuouu and nonparallel. Some of the lamina is highly contorted by rooting. Much of the section has a mottled texture and contains scattered organic material. At top of section is rust-orange (ironstone) with 2 cm burrow or root filled silt sandstone. Basal contact is sharp with the sandstone below.

DEPTH (FT)	THICKNESS (FT)	DESCRIPTION
2794.3	9.7	Sandstone with siltstone; tan with a dark brown oil stain; finning upward cosets from very coarse-grained sandstone to very fine-grained sandstone and siltstone. Bed sets are small, approximately 1 ft. At the base of the set is even, continuous, straight parallel and inclined lamina. Upward in the coset, the lamina become, wavy, discontinuous and nonparallel in sandstone or siltstone. At the base of the zone is several feet of conglomerate composed of pieces of basement up to 2 cm. The conglomerate zone contains less stain. Conglomerate rests unconformably on basement.
2804.0	18.0	Tuff; buff to greenish. Basement is composed of tuff with a variable composition. The tuff is composed predominately of devitrified volcanic glass with phenocrysts up to several mm. The phenocrysts are plagioclase feldspar which has been largly replaced by hydrothermal carbonate. Zoned carbonate cement also fills fractures up to 1 cm wide which cut through the core.

Core described in June 1987 by John S. Sneider. Slabbed 4" core in good condition, bagged, and boxed.

APPENDIX IV

Summary of petrographic analysis for the cored interval of the San Francisco 14, 35, and 56.

PETROGRAPHIC ANALYSIS
San Francisco 14
Dept. of Huila, Colombia
San Francisco Field
Caballos Sandstone, Albian-Aptian
Core: 2747.0' - 3140.0'

Depth	Quartz Size [a]			Detrital Composition [b]					Cement [c]				Permea-	Poros-
ft	Mean mm	Max mm	S.D. mm	Qz %	F %	Rx %	Oth %	Mx %	Qz	Cal	Sid	Kaol	bility md	ity %
									% of total					
2749.0	0.14	0.30	0.05	84.82	0.00	4.83	8.28	2.07	7.06	0.00	0.00	2.72	1.50	11.40
2756.0	0.18	0.33	0.06	83.31	0.00	7.51	5.01	4.17	18.29	1.71	0.00	5.72	2.50	15.70
2971.0	0.25	0.61	0.14	36.36	0.45	52.27	4.55	6.36	4.06	13.28	0.00	0.74	114.00	16.60
2975.0	0.38	1.48	0.23	62.19	0.00	27.44	4.27	6.10	16.37	3.10	0.00	3.98	0.01	5.30
2985.0	0.76	1.44	0.30	63.64	0.00	28.57	2.16	5.63	7.56	2.06	0.00	5.50	63.90	15.30
2993.0	0.30	0.64	0.12	47.39	0.00	36.19	8.21	8.21	9.58	0.30	0.00	5.99	1.70	14.60
3003.0	0.37	1.04	0.21	40.46	0.00	48.37	3.73	7.44	1.28	0.00	0.43	2.13	14.80	14.30
3006.0	0.60	1.36	0.32	39.39	0.00	40.91	1.01	18.69	0.48	0.00	0.00	1.45	0.37	13.80
3016.0	0.44	0.84	0.19	53.40	0.00	37.38	0.98	6.80	8.08	0.00	0.00	12.69	1.15	16.10
3021.0	0.86	1.68	0.26	78.57	0.00	19.84	0.00	1.59	6.43	0.00	0.00	12.28	979.00	16.00
3035.0	0.85	2.28	0.36	63.77	0.00	33.86	0.01	2.36	9.57	10.11	0.53	5.32	80.50	13.50
3057.0	0.05			20.62	0.00	24.74	0.00	54.64	0.00	0.00	35.29	0.00		
3060.0	1.05	2.08	0.53	38.46	0.00	52.45	3.50	5.59	2.53	3.16	0.00	2.53		
3065.0	0.82	1.52	0.32	45.08	0.00	53.27	0.83	0.82	10.69	5.66	0.00	3.77	1.42	10.80
3111.0	0.97	1.80	0.40	47.37	0.00	44.74	1.32	6.58	9.28	6.19	0.00	6.19	1.96	9.90

[a] Long-axis measurements; Max = maximum, S.D. = standard deviation
[b] Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz and chert, Oth = carbonaceous material, zircon, tourmaline, opaques and mica, Mx = matrix
[c] Qz = quartz overgrowths, Cal = carbonate cement, Sid = siderite, Kaol = kaolinite
md = millidarcies

PETROGRAPHIC ANALYSIS
San Francisco No. 35
Dept. of Huila, Colombia
San Francisco Field
Caballos Sandstone, Albian-Aptian
Core: 2820.0' - 3315.0'

Depth ft	Quartz Size [a]			Detrital Composition [b]					Cement [c]				Permea-bility md	Poros-ity %
	Mean mm	Max mm	S.D. mm	Qz %	F %	Rx %	Oth %	Mx %	Qz	Cal	Sid	Kaol		
									% of total					
2836.00	0.82	2.04	0.46	79.36	0.00	16.67	0.01	0.00	6.79	2.47	0.00	3.09	79.00	14.10
2852.46	0.47	1.28	0.31	81.30	0.00	8.13	2.44	1.63	7.59	0.01	0.00	4.43	5.00	7.70
2856.30	0.71	2.04	0.44	80.98	0.70	11.97	3.53	1.41	2.96	0.59	0.00	1.18	321.00	14.20
2860.00	0.52	2.08	0.40	81.28	0.00	12.19	0.02	1.63	3.38	0.00	0.00	3.38	314.00	13.80
2871.00	0.91	1.64	0.30	86.20	0.00	12.93	0.01	0.00	2.68	0.01	0.00	0.67	3927.00	23.40
2873.40	0.70	1.64	0.36	89.92	0.00	7.75	1.55	0.00	5.85	0.00	0.00	0.58	3368.00	19.50
2883.50	0.85	1.64	0.41	81.73	0.00	17.31	0.00	0.96	3.33	0.67	0.00	0.00	4286.00	19.00
2887.00	0.90	2.64	0.53	84.42	0.00	13.11	0.01	1.64	0.00	0.00	0.00	0.70	2541.00	20.50
2889.00	0.72	1.68	0.34	85.46	0.00	11.96	0.02	1.71	3.27	0.00	0.00	0.65		
2894.00	1.24	2.80	0.72	80.64	0.00	12.90	4.04	1.61	3.29	0.00	0.00	0.66	2071.00	19.20
2895.70	0.44	1.00	0.25	89.47	0.00	6.02	1.50	0.00	7.87	0.00	0.00	2.25	220.00	15.90
2897.00	0.28	0.95	0.19	92.58	0.00	2.78	0.94	0.93	6.16	0.00	0.00	2.05	150.00	17.70
2901.00	0.71	2.56	0.45	83.33	0.00	14.17	0.00	1.67	0.73	0.00	0.00	0.73	708.00	18.00
2903.00	0.75	1.80	0.50	84.68	0.00	12.10	0.81	0.81	0.71	0.71	0.00	1.43	406.00	15.60
2909.40	0.21	0.80	0.12	70.92	0.71	19.15	3.55	0.71	1.86	0.00	0.00	4.35	114.00	16.90
2925.00	0.64	2.72	0.55	84.03	0.00	9.24	3.36	0.00	4.00	0.00	0.00	2.67	851.00	19.10
3154.00	0.71	1.44	0.25	79.69	0.00	10.16	0.39	0.39	5.81	0.00	0.00	7.74	1219.00	17.50
3177.00	0.44	0.74	0.15	45.01	0.00	43.82	0.01		0.57	2.01	16.33	5.16	158.00	20.00
3229.00	0.36	0.93	0.18	32.98	0.00	49.65	0.00	17.38	0.00	0.00	0.00	0.00	1.00	4.60
3238.00	0.50	1.08	0.21	50.78	0.00	36.36	0.94	8.15	0.58	5.52	0.00	3.49	1.00	8.90
3239.00	0.68	2.84	0.41	50.81	0.00	34.53	4.24	3.58	2.33	5.81	0.00	6.10	1.00	8.60
3240.00	0.62	1.80	0.30	54.76	0.00	34.01	0.00	3.74	1.23	6.17	0.00	6.79	4.00	10.70
3251.70	0.35	1.04	0.20	37.34	0.43	52.79	0.43	8.58	0.40	1.61	0.81	0.40		
3255.00	0.72	1.36	0.29	62.40	0.00	27.20	0.40	0.40	5.75	8.63	0.00	7.67	25.00	10.20
3273.00	0.23	0.47	0.10	14.93	0.00	76.01	0.91	7.24	0.00	3.72	19.93	0.68		
3289.00	1.70	3.32	0.86	28.80	0.00	63.20	0.00	4.00	0.00	3.08	0.00	3.85		

[a] Long-axis measurements; Max = maximum, S.D. = standard deviation
[b] Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz and chert, Oth = carbonaceous material, zircon, tourmaline, opaques and mica, Mx = matrix
[c] Qz = quartz overgrowths, Cal = carbonate cement, Sid = siderite, Kaol = kaolinite
md = millidarcies

PETROGRAPHIC ANALYSIS
San Francisco No. 56
Dept. of Huila, Colombia
San Francisco Field
Caballos Sandstone, Albian-Aptian
Core: 2460.0' - 2821.0'

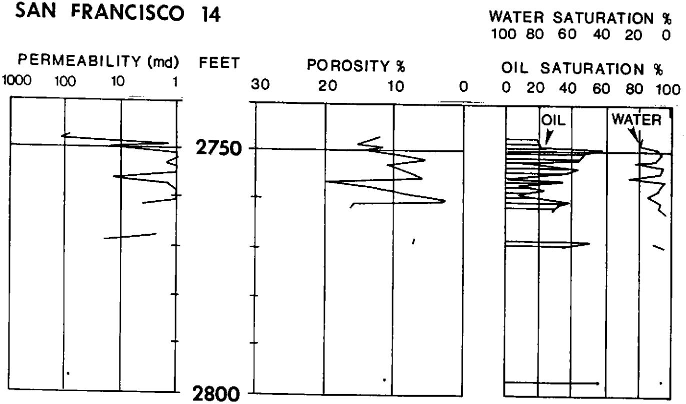
Depth	Quartz Size [a]			Detrital Composition [b]					Cement [c]				Permea-bility	Poros-ity
ft	Mean mm	Max mm	S.D. mm	Qz %	F %	Rx %	Oth %	Mx %	Qz	Cal (% of total)	Sid	Kaol	md	%
2485.40	0.60	1.48	0.36	82.46	0.00	12.72	0.44	2.19	5.07	0.00	0.00	2.19	641.00	18.60
2490.00	0.53	1.60	0.29	87.17	0.00	8.02	0.00	1.07	2.68	0.00	0.00	3.74	797.00	19.90
2493.00	0.36	1.08	0.20	82.44	0.00	7.12	3.05	6.62	6.97	0.00	0.00	0.76	321.00	19.10
2498.00	0.60	1.36	0.24	86.64	0.00	8.76	0.92	2.76	5.49	0.00	0.00	0.92	1770.00	21.00
2501.00	0.69	1.60	0.36	91.12	0.00	3.74	2.34	2.34	5.78	0.00	0.00	0.47	2019.00	21.30
2505.00	0.48	1.40	0.30	82.57	0.00	5.05	5.50	2.29	1.58	0.00	0.00	4.59	257.00	17.40
2516.60	0.57	1.44	0.33	83.41	0.00	11.98	2.76	1.84	3.77	0.00	0.00	0.00	764.00	20.60
2539.00	1.31	3.24	0.73	75.60	0.00	19.64	0.00	2.38	0.54	0.00	0.00	2.38	1992.00	18.90
2542.50	0.43	0.82	0.17	75.27	0.00	12.73	3.64	2.91	10.66	0.00	0.00	5.45	196.00	16.00
2543.50	0.12	0.24	0.05	61.51	0.00	15.06	5.86	7.53	16.39	0.00	0.00	10.04	0.17	8.60
2597.00	1.12	1.72	0.33	72.76	0.00	17.07	0.00	2.03	8.61	5.04	0.00	8.13		
2669.90	0.62	1.08	0.24	44.53	0.00	42.91	0.40	8.10	0.80	0.00	0.00	4.05		
2671.90				51.16	0.00	37.21	0.00	3.72	3.08	0.00	0.00	7.91		
2724.50	0.67	1.48	0.25	58.75	0.00	26.25	3.75	1.25	4.05	0.00	0.00	10.00		
2741.00	0.56	1.08	0.19	56.05	0.00	32.48	0.00	1.91	5.49	0.00	0.00	9.55	124.00	15.50
2773.50	1.20	2.08	0.51	43.15	0.00	46.31	0.02	1.05	2.00	0.00	0.00	9.47	28.00	13.70

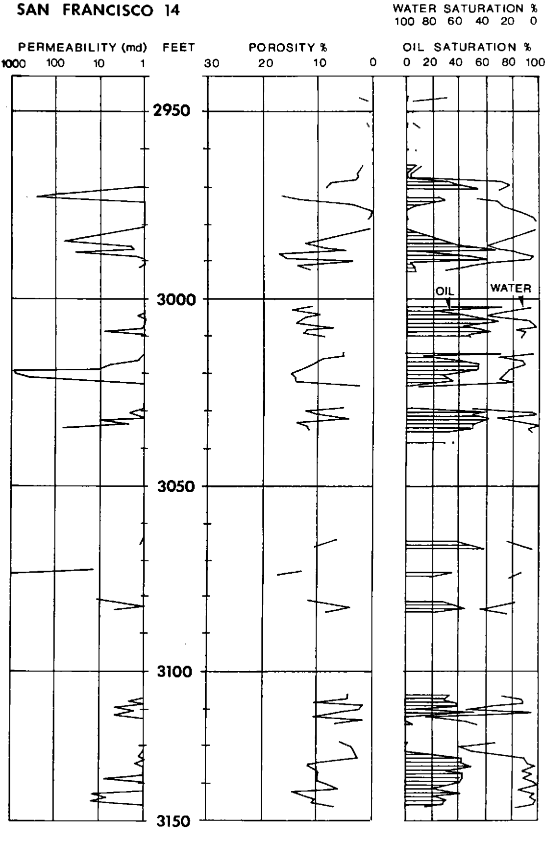
[a] Long-axis measurements; Max = maximum, S.D. = standard deviation
[b] Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz and chert, Oth = carbonaceous material, zircon, tourmaline, opaques and mica, Mx = matrix
[c] Qz = quartz overgrowths, Cal = carbonate cement, Sid = siderite, Kaol = kaolinite
md = millidarcies

APPENDIX V

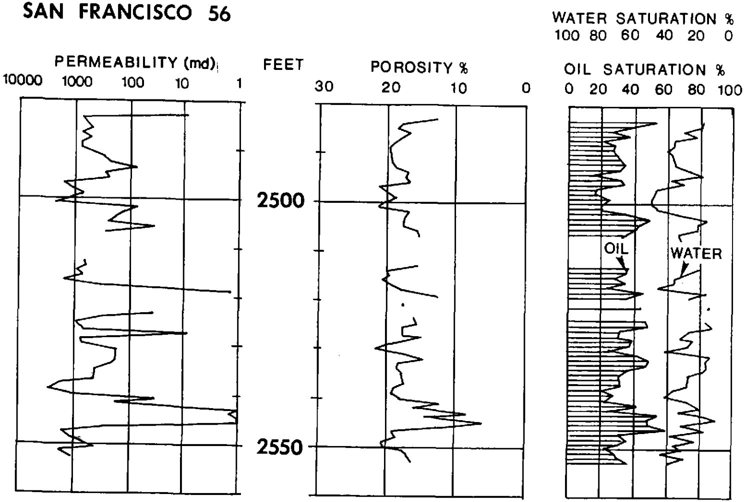
Plot of reservoir properties for the cored intervals of the San Francisco 14, 35, and 56.

SAN FRANCISCO 14

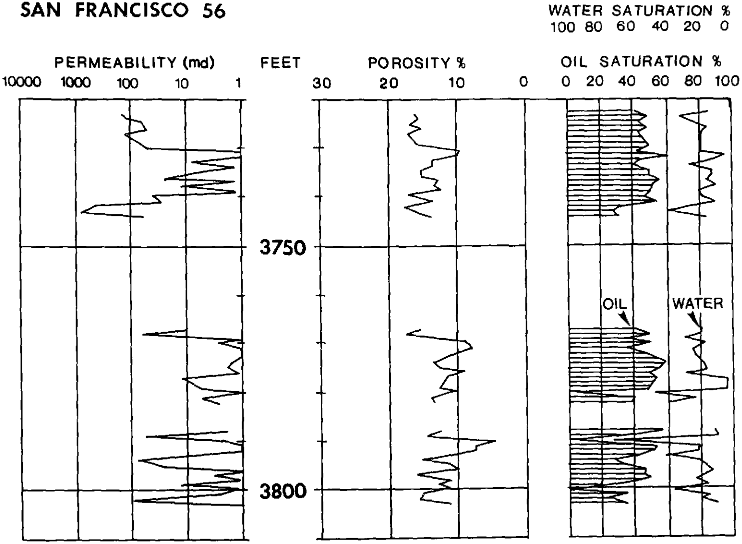



SAN FRANCISCO 14
WATER SATURATION %
100 80 60 40 20 0
PERMEABILITY (md)
1000 100 10 1
FEET
POROSITY %
30 20 10 0
OIL SATURATION %
0 20 40 60 80 100
2950
3000
3050
3100
3150
OIL
WATER

SAN FRANCISCO 56



SAN FRANCISCO 56



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