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GEOLOGY AND PETROLEUM SOURCE ROCKS IN THE HUNT NO. 1-16 STATE WELL

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Abstract—The Hunt Oil Company No. 1-16 State well was drilled for petroleum exploration to a total depth of 6890 ft in north-central Catron County, New Mexico during late 1989. The well drilled through the top of the Spears Group (Tertiary) near the surface, the Baca Formation (Tertiary) at 1370 ft, the Upper Cretaceous at 3290 ft, the Triassic at 3630 ft, the San Andres Formation (Permian) at 3890 ft, the Glorieta Sandstone (Permian) at 4290 ft, the Yeso Formation (Permian) at 4560 ft and the Abo Formation (Permian) at 6253 ft. Precambrian metarhyolites were encountered from 6792 ft to total depth. An intrusive diorite of probable Tertiary age is present within the Yeso from 5180 to 5580 ft. Drill cuttings were analyzed for petroleum source-rock potential. Dark-gray Cretaceous shales contain sufficient total organic carbon (TOC) to be petroleum source rocks but are thermally immature. Yellowish to brown San Andres limestones also contain sufficient TOC to be source rocks and are moderately mature. Kerogens in the San Andres are dominantly amorphous and herbaceous; a mixture of oil and gas is likely to have been generated. Hydrocarbon shows were encountered in the San Andres. Yellowish to brown Yeso limestones also contain sufficient TOC to be source rocks. The Yeso is thermally mature and yielded several hydrocarbon shows. Maximum thermal maturation has been attained by carbonates proximal to the diorite intrusive, indicating that heat emitted from the intrusive enhanced thermal maturation.

INTRODUCTION

The Hunt Oil Company No. 1-16 State Well was drilled to a total depth of 6890 ft in sec. 16, T3S, R13W, Catron County, New Mexico (Figs. 1, 2; Table 1). It was completed as an unsuccessful wildcat well on November 7, 1989. It antedated the three wells that Shell drilled as part of the "Magic play" (Fig. 1). A full set of drill cuttings was donated to the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) at the conclusion of drilling operations. Selected drill cuttings were analyzed as part of the NMBMMR Petroleum Source-Rock Project. Those analyses are the basis for this paper.

GEOLOGY OF THE WELL

The Hunt No. 1-16 State well penetrated rocks from Cenozoic to Precambrian age (Fig. 3). The well was spudded in Quaternary alluvi-

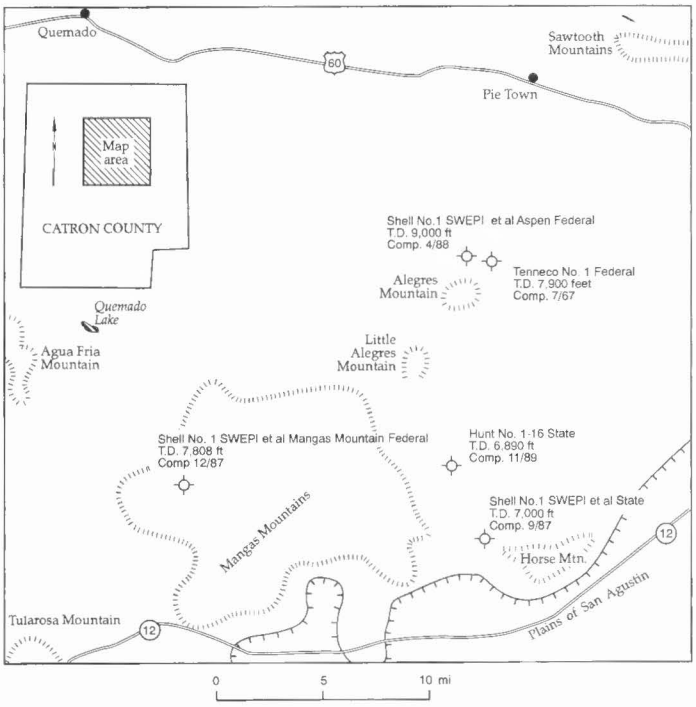

FIGURE 1. Hunt Oil Company No. 1-16 State well, the three exploratory wells drilled by Shell as part of the "Magic play", and the Tenneco No. 1 Federal well.

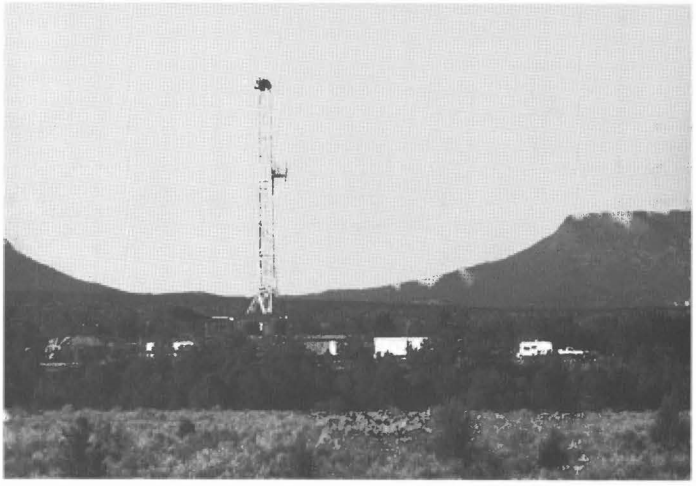

FIGURE 2. Hunt Oil Company No. 1-16 State drilling near Mangas Mountains, November 1989.

TABLE 1. Engineering and geologic data for the Hunt Oil Co. No. 1-16 State well.

Operator:	Hunt Oil Company
Well name & number:	State No. 1-16
Location:	1090 ft FSL, 660 ft FEL Sec. 16, T3S, R13W Catron County, New Mexico
Surface Elevation:	7573 ft, ground level
Total Depth:	6,890 ft (plugged back to 1,825 ft)
Spud Date:	October 6, 1989
Completion Date:	November 9, 1989, Plugged & Abandoned
Casing:	20 inch at 40 ft 13⅜ inch at 454 ft 9⅝ inch at 4,563 ft

um and drilled through 1370 ft of gray andesitic sandstones of the lower Spears group (Tertiary) and 1920 ft of siliceous sandstones, conglomerates and mudstones of the Tertiary Baca Formation. The probable top of Cretaceous strata was encountered at 3290 ft. The Mancos Shale was drilled from 3290 to 3590 ft and consists of dark-gray shales interbedded with minor light-gray, fine-grained sandstones. The Twowells Sandstone Tongue of the Dakota Sandstone (Cretaceous) is present from 3526 to 3550 ft. The main body of the Dakota Sandstone (Cretaceous) (3590 to 3630 ft) consists of white, fine- to medium-grained sandstone. No Jurassic section was identified in the well; the Cretaceous rests unconformably on the Triassic.

Triassic strata, encountered from 3630 to 3890 ft, consist of red to brown shales and minor interbedded siltstones. Prominent fine- to coarse-grained sandstones are present from 3630 to 3660 ft and 3880 to 3890 ft.

The unconformity at the top of Paleozoic strata was drilled at 3890 ft where the Triassic red beds rest on the San Andres Formation (Permian). The San Andres, present from 3890 to 4290 ft, consists of dark-gray to brown, finely crystalline dolostones and limestones. Circulation was lost from 3970 to 4150 ft and was only regained after cement was pumped into the wellbore. The dipmeter log indicates chaotic dip orientations in the San Andres from 3890 to 4100 ft. Lost circulation was probably caused by penetration of an extremely permeable zone of cavernous porosity. Cavernous porosity is widespread in the San Andres of west-central New Mexico and developed during two stages of karstification (White and Kelly, 1989). The first stage occurred during formation of the Permo-Triassic unconformity. The second stage occurred after the San Andres was exposed on the flanks of the Zuni uplift; this exposure may have occurred as early as Laramide time. The chaotic patterns recorded on the dipmeter log may result from poor resolution of caverns within the carbonate sequence or these patterns may reflect collapse of overlying strata into caverns within the San Andres. Chaotic dips in the lower 30 ft of the Triassic tend to confirm the latter possibility.

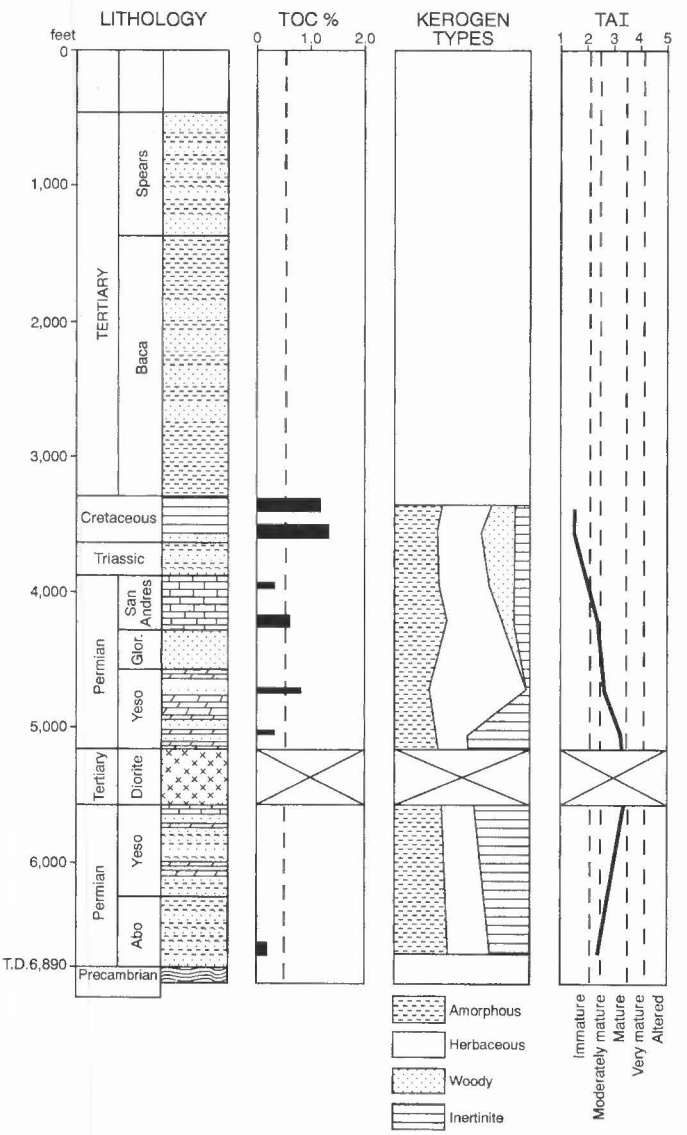

FIGURE 3. Stratigraphic section and profiles of source-rock data for Hunt Oil Company No. 1-16 State well. See Table 2 and Bayliss (1990) for source-rock data.

Numerous hydrocarbon shows were encountered in the San Andres. The mud log indicates numerous occurrences of hydrocarbon fluorescence and hydrocarbon cut in chloroethane throughout the San Andres; stains of oil and asphalt were also common.

The Glorieta Sandstone was drilled from 4290 to 4560 ft. It consists mostly of white, very fine- to medium-grained sandstone. Interbedded brown, finely crystalline dolostones are present in the upper 80 ft. The sandstones and dolostones are visibly porous. Circulation was lost from 4470 to 4550 ft and was reestablished only after an intermediate string of 9 ⅝ inch diameter casing was set at 4563 ft.

The Yeso Formation (Permian) is present from 4560 to 6253 ft. A diorite sill has intruded the Yeso from 5180 to 5580 ft. The Yeso consists of interbedded anhydrites, dolostones, sandstones and shales. The dolostones are light gray and light to dark brown and are microcrystalline to finely macrocrystalline; visible porosity is common in the dolostone cuttings. The sandstones are white and very fine to fine grained; some sandstones have visible intergranular porosity and other sandstones have no visible porosity and are well cemented with anhydrite, calcite and dolomite. Yeso shales are orange to brown in color.

Several hydrocarbon shows were reported in the Yeso. Most shows occurred above the diorite sill. The mudlog indicates that dolostones at 4600 ft and at 4720 ft exhibited hydrocarbon fluorescence and yielded a yellowish-blue cut in chloroethane. Black asphaltic and oily stains were described in dolostones above the sill. Numerous shows of hydrocarbon gases were recorded by the gas detector on the mudlogging unit. Gas concentrations of 5000 ppm in the drilling mud occurred in 10-200 ft thick zones; although composed mostly of methane, these gases also contained ethane and propane and appear to have emanated from dolostones.

Intrusive diorite of probable Tertiary age was drilled from 5180 to 5580 ft. Thin-section and x-ray diffraction analyses indicate it is composed dominantly of plagioclase (albite-oligoclase) with minor quartz and potassium feldspar. Crystal size averages 0.08 mm.

The Abo Formation (Permian), drilled from 6253 to 6792 ft, consists of orange, very fine- to coarse-grained, arkosic sandstone interbedded with red shale, orange siltstone, and minor brown microcrystalline to cryptocrystalline dolostone. No hydrocarbon shows were encountered in the Abo.

Precambrian basement was drilled from 6792 ft to total depth of 6890 ft. The Precambrian is a foliated igneous rock composed of phenocrysts of strained quartz and potassium feldspar in a microcrystalline matrix of silica and mica. It appears to be of the same composition and texture as the Precambrian basement in the Shell No. 1 Mangus Mountains Federal well (Fig. 1) where samples were recovered in sidewall cores and the foliation was observed to be horizontal. Although lack of a large fragment of the Precambrian makes identification problematic, the composition and foliated porphyritic-aphanitic texture indicate it may be a metarhyolite.

PETROLEUM SOURCE ROCKS

Drill cuttings from the Hunt No. 1-16 State well were analyzed for source-rock potential as part of the NMBMMR Petroleum Source-Rock Evaluation Project (Bayliss, 1990). Seven samples of drill cuttings were collected for analysis (Fig. 3; Table 2). Each sample consists of cuttings picked from several 10 ft depth intervals. Individual cuttings were selected carefully under the microscope by the author so

that only lithologies likely to be indigenous source rocks were included in the samples (i.e. cavings and non-source materials were removed from the sample). Samples were analyzed by Geoff Bayliss of Geochem Laboratories, Inc. for (1) Total organic carbon (TOC); (2) Kerogen type by visual kerogen analysis; (3) Thermal Alteration Index (TAI) by visual kerogen analysis and (4) Rock-eval pyrolysis to determine maturity and other source-rock parameters. The TOC and visual kerogen analysis of kerogen type and thermal maturity are stressed in this report. These analyses are generally considered more accurate than pyrolysis techniques, which are best used to screen samples for more rigorous analytical procedures (Philp and Galvez-Sinibaldi, 1991).

Total organic carbon (TOC) was measured to determine which stratigraphic units contain sufficient organic carbon to be source rocks. Jarvie (1991) summarized the minimum amount of TOC required to form a petroleum source rock (Table 3). Shales in the Mancos and Dakota (Cretaceous) and limestones in the San Andres and Yeso (Permian) contain sufficient TOC to be petroleum source rocks. The red Abo shales contain insufficient TOC to be source rocks. Because the analyzed samples are composites of cuttings from several 10-ft drill intervals, the TOC values are inexact estimates of the average TOC content in the sampled interval; some parts of the analyzed interval are likely to exceed this average value and other parts of the same interval are likely to be less than this average value.

The types of kerogens that constitute the organic fraction of a source rock determine if it will generate oil, gas, or both oil and gas (Hunt, 1979; Jarvie, 1991). Generally, algal and amorphous kerogens produce paraffinic oils and gas upon maturation; they have the highest percentage of convertible carbon (>70% by weight) and will produce more hydrocarbons per unit weight than other kerogen types. Herbaceous kerogens produce a mixture of liquid hydrocarbons and gases; they have an intermediate percentage of convertible carbon (30-70%) by weight. Woody kerogens produce mostly gas; they have only a small percentage of convertible carbon (<30% by weight) and will produce fewer hydrocarbons than amorphous, algal, or herbaceous kerogens per unit weight. Inertinite is carbonized kerogen that is capable of producing only small amounts of gas.

In the Hunt No. 1-16 State well, both oil-prone and gas-prone kerogens are present in possible source rocks (Fig. 3; Table 2). The gray shales of the Mancos and Dakota contain predominantly mixed amorphous and herbaceous kerogens, but significant amounts of woody kerogen and inertinite are also present. San Andres and Yeso limestones with more than 0.5% TOC contain predominantly herbaceous and amorphous kerogens and contain only minor woody kerogen and inertinite; these rocks should have generated oil upon maturation.

Visual analysis of kerogen was also used to assess thermal maturation of source rocks. The color of kerogen in transmitted light varies from yellow to orange to brown to black as thermal maturation increases (Staplin, 1969). The kerogen is assigned a numerical value of thermal maturity (TAI or Thermal Alteration Index) based upon its color; TAI values range from 1.0 for yellow-colored immature kerogen to 5.0 for black metamorphosed kerogen. TAI has been correlated with vitrinite reflectance and other maturation indices by several workers, including Dow (1977), Geochem Laboratories (1980), and Sentfle and Landis (1991).

TAI values in the Hunt No. 1-16 State well vary from 1.5 (immature) in the Cretaceous section to 3.2 (mature) in the Yeso Formation (Fig. 3; Table 2). Thermal maturity increases with depth from immature in the Cretaceous to moderately mature in the San Andres Formation (Permian) to mature in the Yeso Formation (Permian). This is expected because of increasing temperatures associated with increasing burial depths. However, maturity then decreases to moderately mature with deeper burial in the Abo Formation (Permian).

The maturation maximum at 5010 to 5030 ft within the Yeso may have been caused by heat emitted from the diorite sill that intruded the Yeso from 5180 to 5580 ft. Heat exuded by this sill during its intrusion and subsequent cooling elevated temperatures so that the Yeso entered the mature stage of oil generation but was not matured past the stage of oil preservation (TAI ≈ 3.4). The sill, rather than destroying any previously generated

TABLE 2. Hydrocarbon source-rock analyses, Hunt Oil Company No. 1-16 well. Data from Bayliss (1990)

Sample depth (ft)	Stratigraphic Unit	Lithology	Total Organic carbon*		Source type		Maturation	
			%	source potential	kerogen types	character	TAI	Maturity
3,300 - 3,400	Mancos (Cretaceous)	shale, dark grey	1.17	adequate	36% amorphous 36% herbaceous 19% woody 9% inertinite	oil + gas	1.5	immature
3,500 - 3,590	Dakota (Cretaceous)	shale, dark grey	1.28	adequate	33% amorphous 33% herbaceous 25% woody 12% inertinite	oil + gas	1.5	immature
3,940 - 3,970	San Andres (Permian)	limestone, brownish grey	0.27	inadequate	36% amorphous 36% herbaceous 19% woody 9% inertinite	nonsource	2.0	moderately immature
4,180 - 4,250	San Andres (Permian)	limestone, yellowish brown	0.57	marginal	40% amorphous 40% herbaceous 10% woody 10% inertinite	oil + gas	2.3	moderately mature
4,700 - 4,730	Yeso (Permian)	limestone, yellowish brown	0.80	marginal	28% amorphous 72% herbaceous 0% woody 10% inertinite	oil + gas	2.6	mature
5,010 - 5,030	Yeso (Permian)	dolostone, brownish grey	0.30	inadequate	33% amorphous 22% herbaceous 0% woody 45% inertinite	nonsource	3.2	mature
6,600 - 6,700	Abo (Permian)	shale, dark reddish brown	0.14	inadequate	42% amorphous 29% herbaceous 0% woody 29% inertinite	nonsource	2.4	moderately mature

TABLE 3. Source-rock potential based on total organic carbon (TOC) content. From Jarvie (1991).

TOC (Wt. %)	Source-rock potential
0.0 -0.5	inadequate
0.5 - 1.0	marginal
>1.0	adequate

liquid hydrocarbons, elevated temperatures in the Yeso so that the Yeso reached optimum oil generation. It is plausible that evaporite and shale seals within the Yeso prevented migration of heated formation waters to strata above and below (San Andres, Glorieta and Abo formations), resulting in thermal maturation stratigraphically confined to the Yeso.

Petroleum source-rock analyses are also available for the Tenneco Oil Co. No. 1 Federal well (Fig. 1; Bayliss and Schwarzer, 1987). Stratigraphic tops for this well are: Cretaceous – 3730 ft; Triassic – 4870 ft; San Andres – 5390 ft; Glorieta – 5710 ft; Yeso – 6050 ft; Abo- 7260 ft; Pennsylvanian – 7690 ft; and Precambrian basement – 7860 ft. Stratigraphic units below the Cretaceous are 1200-1400 ft deeper than in the Hunt well. Most of this difference is accounted for by the thicker Cretaceous section (1140 ft) present in the Tenneco well. Thickness of the Tertiary section is approximately the same in both wells (3290 ft in Hunt well and 3775 ft in Tenneco well). In the Cretaceous, San Andres and Yeso of the Tenneco well, TOC values and kerogen types are similar to those in the Hunt well. TAI values in the Tenneco well are 2.2 (moderately mature) in the Mancos Shale, 2.3 (moderately mature) in the San Andres and upper Yeso, and 2.4 (moderately mature) in the lower Yeso. Source-rock analyses were not performed on stratigraphic units below the Yeso. The Mancos is more mature in the Tenneco well than in the Hunt well. However, maturation levels in the San Andres and Yeso are similar to those in the Hunt well, except for the samples within 1000 ft of the intrusion in the Hunt well, where the highest levels of maturity are attained. This similarity supports the hypothesis that maximum kerogen maturation in the Hunt well is related to the diorite intrusion.

IMPLICATIONS FOR PETROLEUM EXPLORATION

The source-rock analyses of samples from the Hunt No. 1-16 State well have favorable implications for petroleum exploration in west-central New Mexico and east-central Arizona. Dark-gray Mancos shales (Cretaceous) and limestones in the San Andres and Yeso Formations (Permian) contain sufficient TOC to be petroleum source rocks. Significant hydrocarbon shows were encountered in both the San Andres and the Yeso. Generated hydrocarbons are likely to be both oil and gas, although oil may predominate in the San Andres and Yeso because of high percentages of oil-prone kerogens. The Cretaceous may not be sufficiently mature to have generated significant amounts of hydrocarbons. The San Andres and Yeso are likely to be moderately mature to mature throughout much of the region. Permian source rocks will have reached optimum maturity either where they have a history of deeper burial (in Paleozoic or Laramide basins) or where they are proximal to igneous heat sources.

Observations of a recently drilled geothermal test well core near Alpine, Arizona (see Witcher et al., this volume) confirm that significant hydrocarbons have been generated within the Yeso. Rauzi (1994 a, b) described oil shows in limestones of the Fort Apache Limestone Member of the Corduroy Formation (Yeso equivalent). Limestones may be widespread source rocks in the Yeso.

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