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OIL, NATURAL GAS, AND GROUNDWATER IN THE SAN JUAN BASIN A SUMMARY

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INTRODUCTION

The San Juan Basin produces natural gas and oil from four counties in northwestern New Mexico and two counties in southwestern Colorado (Figure 1). Through the end of 1994, oil and gas pools in the New Mexico part of the basin had produced a cumulative total of 18.8 trillion ft³ gas (TCFG) and 248 million bbls oil and lease condensate (MMBO). During 1994, production from the four New Mexico counties was 939 billion ft³ gas and 4.1 MMBO (Table 1). Approximately 94% of the oil and gas have been produced from the New Mexico part of the basin. Proved gas reserves in the New Mexico part of the basin were 17.1 TCF as of December 31, 1994, 8.5% of total U.S. gas reserves (Energy Information Administration 1995); 91% of the reserves are non-associated gas and 9% are associated gas. Proved reserves of oil and lease condensate were 69 MMBO, 0.3% of total U.S. reserves (Energy Information Administration 1995). The U.S. Geological Survey (Gautier et al. 1996) has estimated recoverable resources of 29.63 TCFG and 349 MMBO in the San

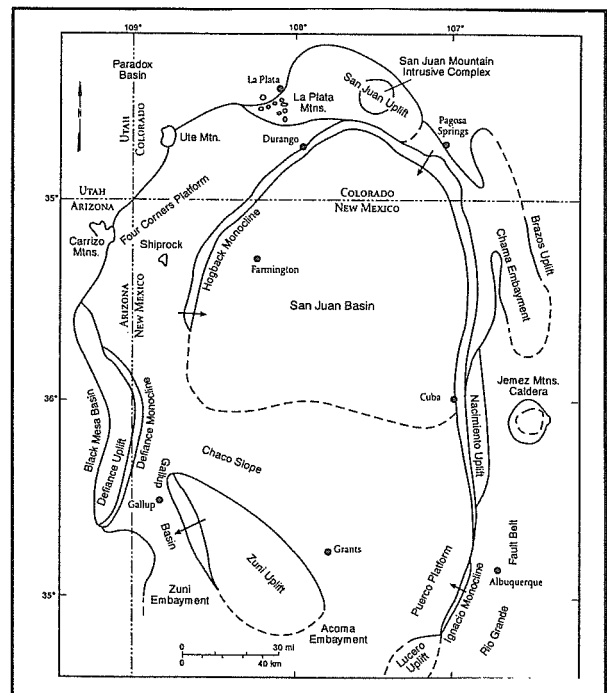


Figure 1. Location and regional tectonic setting of the San Juan Basin of northwestern New Mexico and southwestern Colorado (Laubach and Tremain 1994).

Juan Basin. This includes potential undiscovered resources as well as discovered resources.

Table 1. Production of oil and natural gas in the New Mexico part of the San Juan Basin in 1994; million bbls oil (MMBO); billion ft³ gas (BCF). Data from New Mexico Oil Conservation Division.

<u>County</u>	Oil Production	Gas Production
	<u>MMBO</u>	<u>BCF</u>
San Juan	1.92	579
Rio Arriba	1.86	358
Sandoval	0.19	2
McKinley	<u>0.15</u>	<u>0.15</u>
Totals	4.12	939

OIL AND GAS IN THE SAN JUAN BASIN

Oil and natural gas are produced primarily from Upper Cretaceous strata in the San Juan Basin (Table 2). Most gas production has been from nonassociated gas reservoirs in the Fruitland Formation, Pictured Cliffs Sandstone, Mesaverde Group, and Dakota Sandstone (Upper Cretaceous; Figure 2). Most oil has been produced from reservoirs in the basal Niobrara ("Tocito") sandstones and from fractured shales in the Upper Mancos Shale (Upper Cretaceous). Relatively modest amounts of oil have been produced from the Entrada Sandstone (Jurassic). Oil and gas have been produced from Paleozoic reservoirs on the west flank of the basin.

The stratigraphy of major gas and oil occurrences are discussed below in descending stratigraphic order.

Nacimiento Formation (Tertiary: Paleocene)

Three minor gas pools have been discovered in the Nacimiento Formation: Kiffen, Arch and Gavilan (Figure 3). These reservoirs produce nonassociated gas. Nacimiento reservoirs produced 2 million ft³ (MMCF) gas in 1994 (Table 2). The reservoirs in these pools are discontinuous channel sandstones. Because of the reservoir discontinuity, reserves in each well are generally limited (Emmendorfer 1983; Riggs 1983; Dugan 1983). Traps are stratigraphic. Discoveries are spurious and have been made when drilling wells for deeper objectives. It is quite probable that many small noncommercial to marginally commercial gas accumulations in the Nacimiento

Table 2. Production of oil and natural gas in the New Mexico part of the San Juan Basin in 1994 by stratigraphic unit; million bbls oil (MBO); billion ft³ gas (BCF). Does not include production from wells that have not been designated by the State of New Mexico as belonging to a named field.

<u>Stratigraphic Unit</u>	Oil Production	Gas Production
	<u>MBO</u>	<u>BCF</u>
Nacimiento Formation (Tertiary: Paleocene)	0	0.002
Farmington Sandstone (Upper Cretaceous)	1	0.086
Fruitland Formation (Upper Cretaceous)	22	531
Pictured Cliffs Formation (Upper Cretaceous)	28	67
Mesaverde Group (Upper Cretaceous)	903	202
basal Niobrara "Gallup" sandstones (Upper Cretaceous)	1788	22
"true" Gallup Sandstone (Upper Cretaceous)	141	0
fractured Mancos Shale (Upper Cretaceous)	446	4.8
Dakota Sandstone (Upper Cretaceous)	693	111
Entrada Sandstone (Jurassic)	6	0
Pennsylvania carbonates	37	4.7

have been drilled through, not tested, and even not recognized in efforts to drill to deeper, more prolific pay zones. Emmendorfer (1983) postulated that the gas originated in coals in the Nacimiento Formation and migrated into the sandstone reservoirs after generation. Depth to Nacimiento production is 700 ft at the Kiffen pool, 1,000 at the Arch pool, and 2,400 ft at the Gavilan pool.

Farmington Sandstone (Upper Cretaceous)

Relatively minor volumes of gas and condensate are produced from reservoirs in the Farmington Sandstone Member of the Kirtland Shale. Farmington reservoirs produced 86 MMCF gas and one thousand bbls oil (MBO) from eight pools in 1994 (Table 2). Accumulations of both oil with associated gas and nonassociated gas are present. Principal oil and gas pools in the Farmington Sandstone are the Bloomfield, Kutz, and Bisti pools (Figure 4). The reservoirs in these pools are discontinuous fluvial sandstones. Traps are stratigraphic. Although of minor importance as gas producers, the Farmington pools are

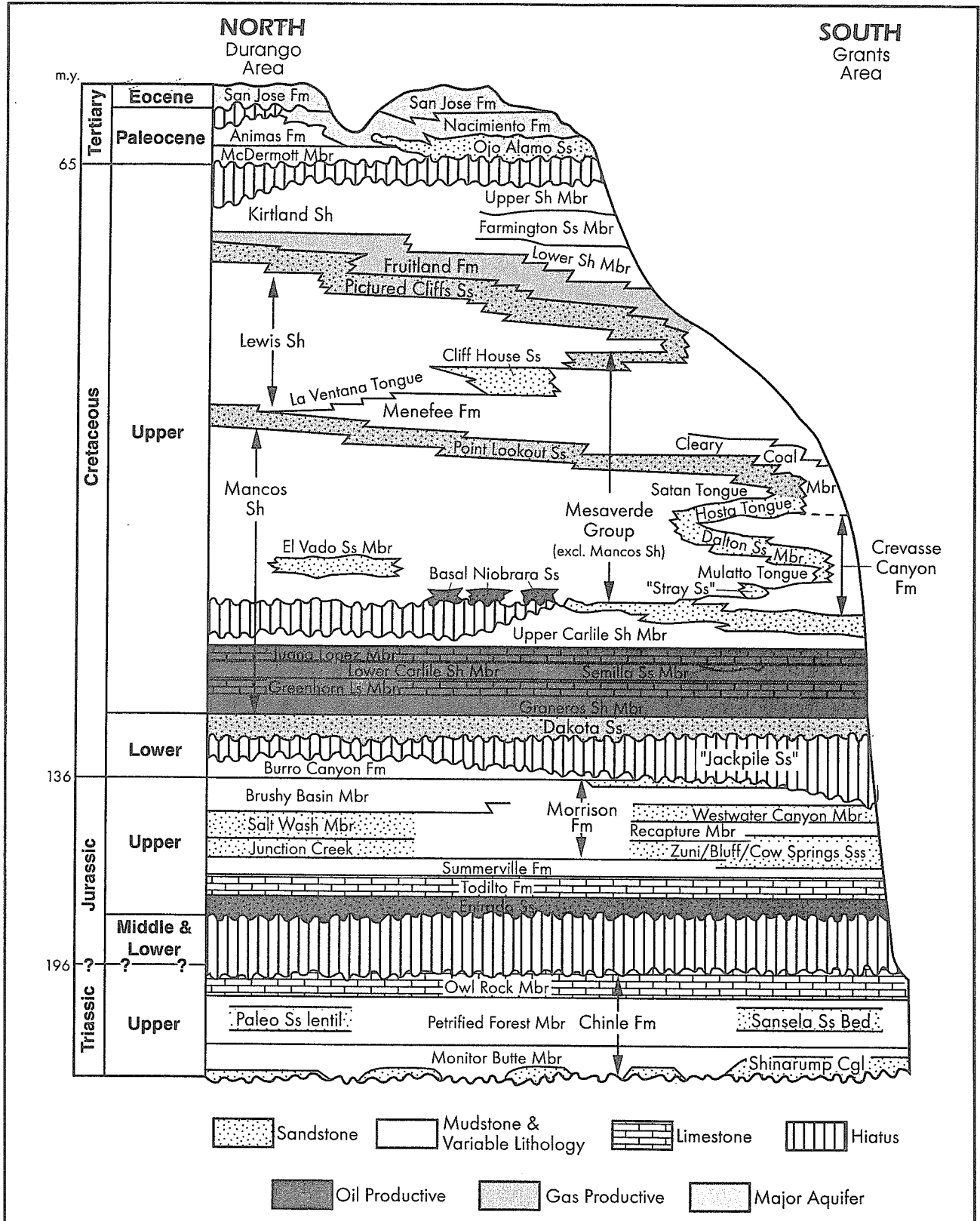


Figure 2. Time-stratigraphic framework and nomenclature, Mesozoic and Tertiary rocks, San Juan Basin. Modified from Stone et al. (1983), after Molenaar (1977).

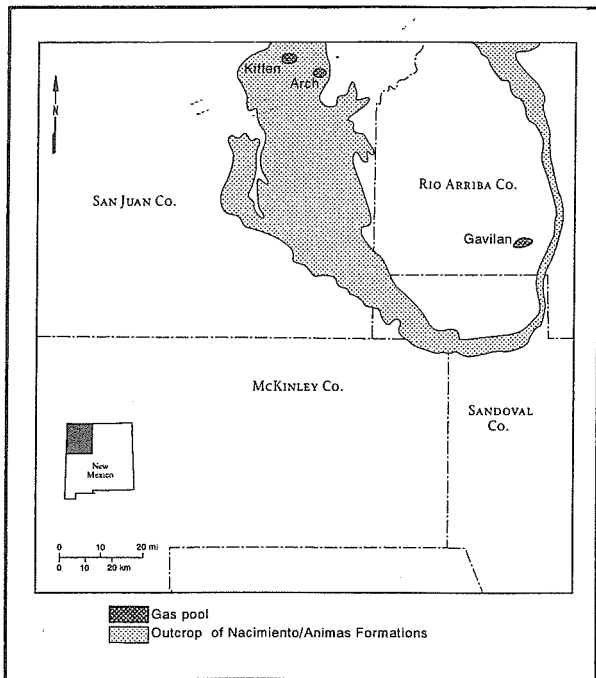


Figure 3. Gas pools productive from the Nacimiento Formation (Tertiary: Paleocene), New Mexico part of the San Juan Basin.

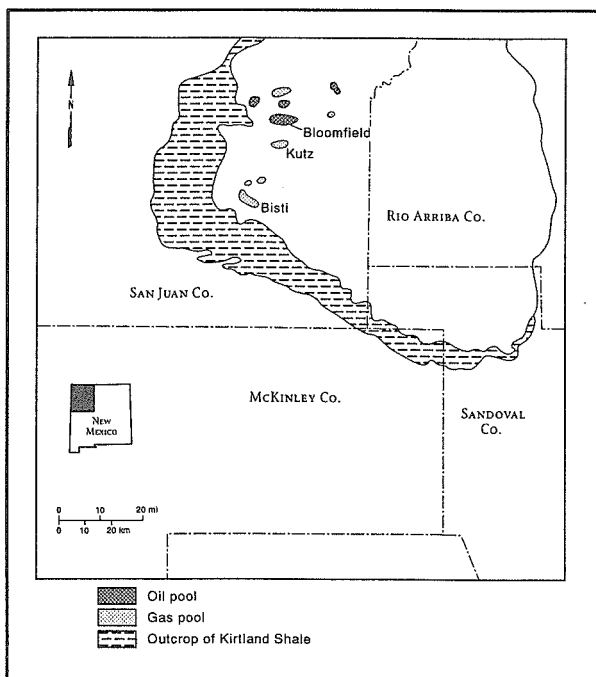


Figure 4. Oil and gas pools productive from the Farmington Sandstone Member of the Kirtland Shale (Upper Cretaceous), New Mexico part of the San Juan Basin.

mentioned here because they are the shallowest reservoirs in the Cretaceous section. Depth to production is 700 to 1,200 ft.

Fruitland Formation (Upper Cretaceous)

The Fruitland Formation produces major volumes of nonassociated gas in the San Juan Basin (Table 2). Production has been obtained from sandstone channels in the lower part of the Fruitland and from coals within the lower Fruitland. Prior to the late 1980s, most Fruitland wells were completed in the sandstones. Most wells drilled from the late 1980s to the present have been completed in Fruitland coals. Production from the New Mexico part of the basin during 1994 was 531 billion ft³ (BCF) gas and 22 thousand bbls condensate (MBC) from 26 pools, with production from coals dominating.

Depth to production in the Fruitland is 1,000 to 3,500 ft. Reservoirs in the Fruitland sandstones are discontinuous channel deposits. Trapping is stratigraphic. In the coals, however, reservoirs are formed by widespread coal beds. The methane is adsorbed onto the coal in the reservoir. When water is produced from fractures (cleats) in the coalbed, reservoir pressure is lowered and the methane is subsequently desorbed from the coals and is produced (Murray 1993).

Shows and other occurrences of gas in the Fruitland coals were ignored for decades. Drillers, targeting deeper and more conventional reservoirs, often drilled through productive coalbeds and sealed them off behind casing (Fassett and Hinds 1971). Production was not attempted because of the large flows of water that accompanied the gas. In 1977, Amoco drilled the first well intended to be completed in the Fruitland in 1977; this well was located in what was to become the Cedar Hill field (Whitehead 1993a). In 1986 Meridian Oil drilled several wells in northwestern Rio Arriba County in order to evaluate the commercial potential of coalbed methane reservoirs and concluded that drilling wells for coalbed methane was economically feasible (Whitehead 1993a). Drilling for this gas increased markedly in 1988 when regulations were promulgated for the Fruitland Formation that allowed producers to utilize federal tax credits for gas produced from Fruitland coals. As a result, a large part of the area with potential for Fruitland production was quickly developed

(Figure 5) and the Fruitland became the major gas-producing unit within the San Juan Basin.

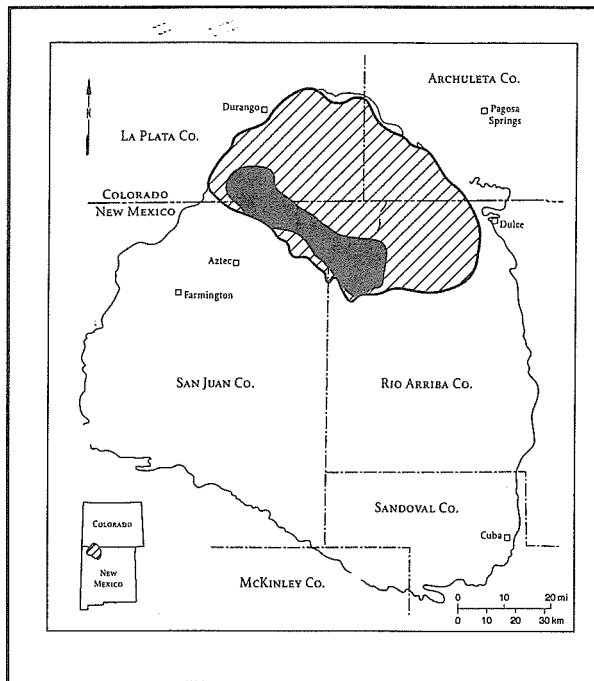


Figure 5. Area of gas production from Fruitland Formation (Upper Cretaceous), San Juan Basin. Main productive fairway shown as darker area. Modified from Logan (1994).

Pictured Cliffs Formation (Upper Cretaceous)

The Pictured Cliffs Sandstone produces major volumes of nonassociated gas and gas condensate in the San Juan Basin. Pictured Cliffs gas pools (Figure 6) produced 67 BCF gas and 28 MBO from 16 pools in 1994 (Table 2). The reservoirs in the Pictured Cliffs pools are formed by northwest-southeast trending coastal barrier sandstones (Molenaar 1988), which are reflected by the shape of the gas pools (Figure 6). The trap is a large basin-centered gas accumulation (Law and Dickinson 1985; Whitehead 1993b) characterized by gas downdip and free water updip with no intervening lithologic barriers or seals. The gas is produced with little water. The updip seal is thought to be caused by a relative permeability barrier where water-saturated fine-grained sandstones have no permeability to gas (Masters 1979). This trapping mechanism has led the gas to be confined to the deeper, more central parts of the basin. Depth to production varies from 1,200 to 4,000 ft.

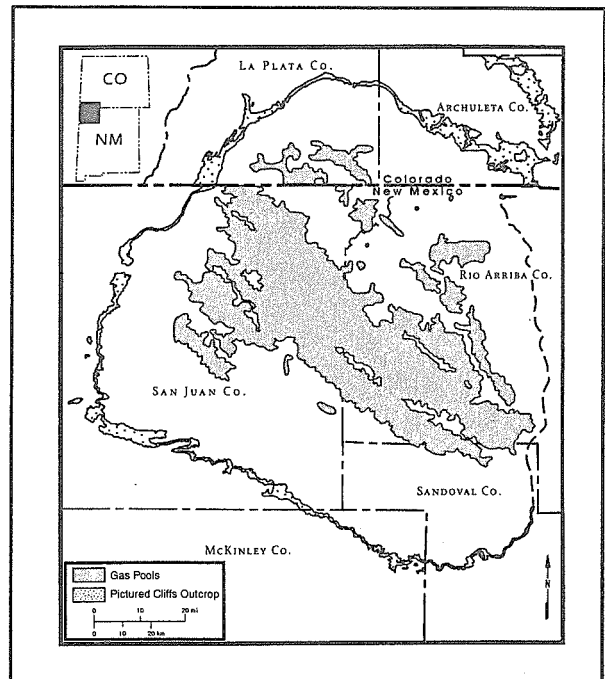


Figure 6. Gas pools productive from the Pictured Cliffs Formation (Upper Cretaceous), New Mexico part of the San Juan Basin.

Mesaverde Group (Upper Cretaceous)

The Mesaverde Group is another major gas-producing unit within the San Juan Basin. Production from the Mesaverde was 202 BCF gas and 903 MBO + MBC from 26 pools in 1994 (Table 2). Most gas is produced from the Point Lookout Sandstone at the top of the Mesaverde, but significant volumes of gas also are produced from the Cliff House Sandstone and sandstones of the Chacra producing interval (Figure 2). Similar to the Pictured Cliffs, the Mesaverde reservoirs are mostly coastal barrier sandstones and the Mesaverde gas occurs as a basin-centered gas accumulation (Figure 7). Similar to the Pictured Cliffs, the trap appears to be formed by an updip relative-permeability barrier created by water-saturated, fine-grained sandstones; downdip gas can not displace the updip water (Masters 1979; Spencer 1989). Depth to production in the Mesaverde varies from 3,400 to 4,500 ft.

Basal Niobrara and Gallup Sandstones (Upper Cretaceous)

A system of northwest-southeast trending sandstones is present just above the major unconformity that separates the lower part of the Mancos Shale

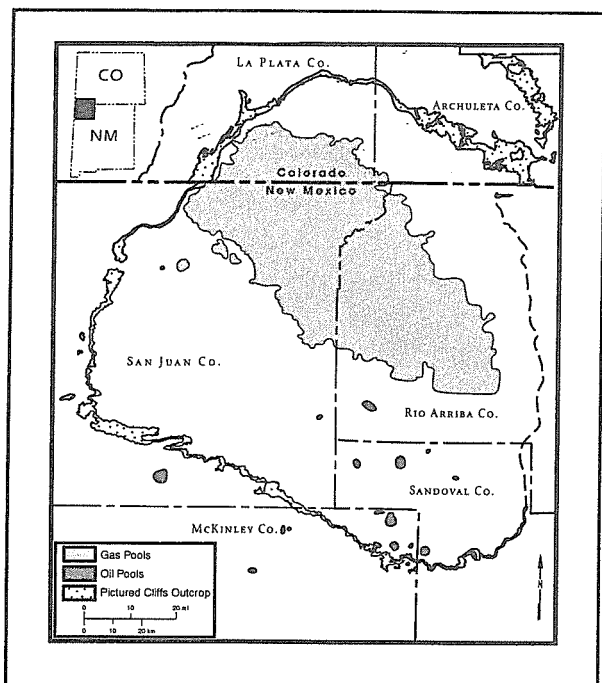


Figure 7. Oil and gas pools productive from the Mesa-verde Group (Upper Cretaceous), New Mexico part of the San Juan Basin.

from the upper part of the Mancos Shale. These sandstones are the basal Niobrara or “Tocito” sandstones. They were deposited as transgressive offshore bars above the unconformity and are time equivalents of the basal parts of the upper Mancos Shale (figures 2 and 8). They are commonly referred to as the Gallup sandstones because of miscorrelations by early workers in the subsurface of the basin. In fact, their deposition postdates the deposition of the “true” Gallup, which is a regressive strandplain deposit (Molenaar 1974). Oilfield and regulatory terminology still refers to these reservoirs as “Gallup,” however. The basal Niobrara and the true Gallup sandstones are separate stratigraphic entities (Figure 2). Production from the true Gallup sandstone comes from an area around the Hospah and Miguel Creek pools in McKinley County (Figure 8), and this is minor production. Production from the basal Niobrara sandstones was 1.8 MMBO and 22 BCF gas from 61 pools in 1994 (Table 2). Depth to production varies from 5,000 to 7,000 ft. Production from the true Gallup sandstones was 141 MBO from four pools.

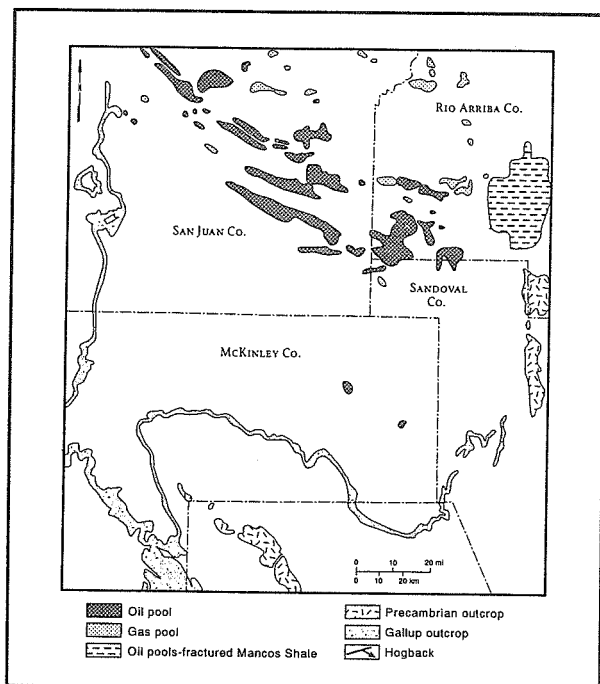


Figure 8. Oil and gas pools productive from the basal Niobrara (“Tocito”) and Gallup sandstones and fractured Mancos Shale (Upper Cretaceous), New Mexico part of the San Juan Basin.

Fractured Mancos Shale (Upper Cretaceous)

Oil and associated gas are produced from fractured Mancos Shale in six fields along the southeastern margin of the San Juan Basin (Mallory 1977; Greer and Ellis 1991; Figure 8). Most production is obtained from the upper part of the Mancos Shale (that part of the Mancos above the basal Niobrara unconformity), but some production also has been obtained from the lower part of the Mancos Shale (between the basal Niobrara unconformity and the top of the Dakota Sandstone). Production is generally confined to zones of brittle shale within the Mancos that lay astride tectonic fracture systems. Production from fractured Mancos shales was 446 MBO and 4.8 BCF during 1994 (Table 2).

Dakota Sandstone (Upper Cretaceous)

The Dakota Sandstone forms the base of the Upper Cretaceous section and is a major reservoir of nonassociated gas in the San Juan Basin. Most production is obtained from the giant Basin Dakota pool in the central part of the basin (Figure 9). Production from the Dakota was 111 BCF gas and 693 MBO + MBC from 22 pools during 1994 (Table 2). Depth to

production in the Dakota is 2,700 to 8,200 ft. In some fields, production from the Dakota is typically commingled with production from basal Niobrara sandstones (Figure 10) or sandstones and limestones in the lower part of the Mancos Shale and it is difficult or impossible to differentiate between produced Dakota gas and oil and basal Niobrara gas and oil in these fields.

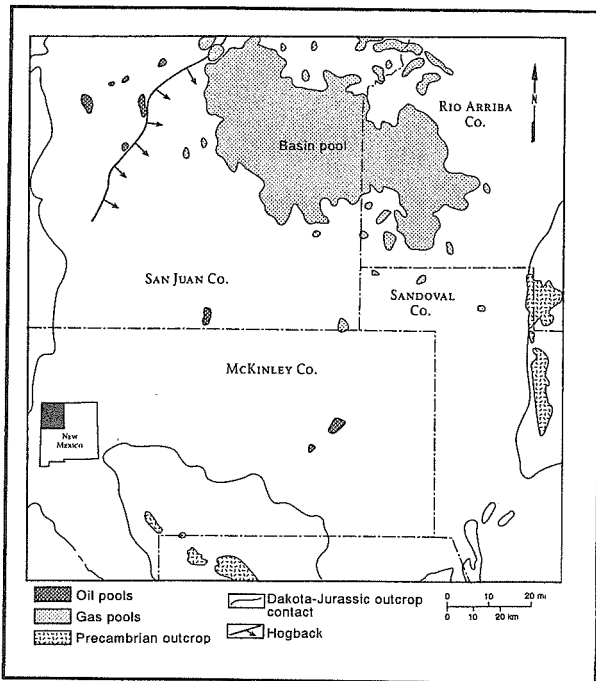


Figure 9. Oil and gas pools productive from the Dakota Sandstone (Upper Cretaceous), New Mexico part of the San Juan Basin.

The Basin Dakota pool is a basin-centered gas accumulation thought to be trapped by updip permeability barriers caused by water-saturated fine-grained sandstones. It is similar to the shallower Pictured Cliffs and Mesaverde accumulations. The reservoir sandstones in the Dakota were deposited in a variety of environments with shallow marine offshore bars to the northeast, paralic sands in the center, and fluvial sands to the southwest (Nummedal et al. 1989; Molenaar and Baird 1991). Relatively minor production of oil and associated gas has been obtained from localized stratigraphic traps and combination stratigraphic/structural traps in fluvial Dakota sandstones in the southern part of the basin at the Hospah, Lone Pine, and Stoney Butte pools (Figure 9).

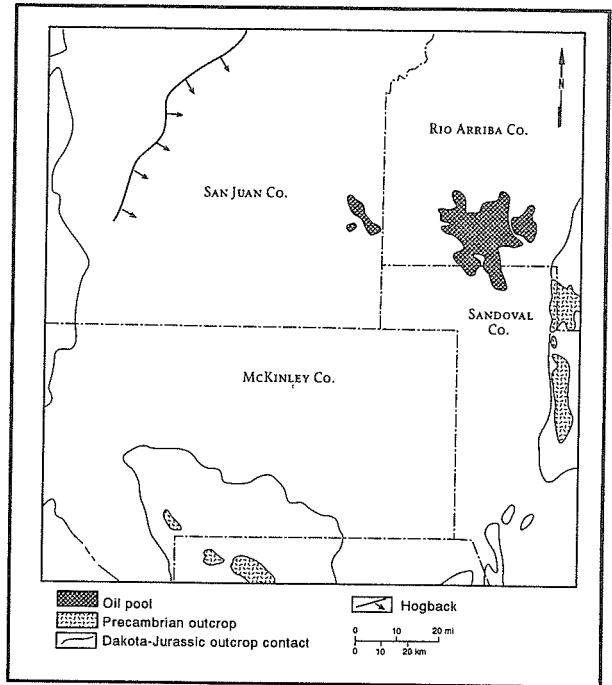


Figure 10. Oil and gas pools with extensively commingled production from basal Niobrara ("Tocito") and Dakota sandstones (Upper Cretaceous), New Mexico part of the San Juan Basin.

Entrada Sandstone (Jurassic)

Oil without gas is produced from eight small pools in the Entrada Sandstone in the south-central San Juan Basin (Figure 11). Production from Entrada reservoirs was 6 MBO during 1994 (Table 2). The Entrada is a blanket sand that covers most of the basin. Oil is trapped stratigraphically by eolian dunes that form local, closed paleotopographic highs on top of the sheet-like Entrada sand body (Vincelette and Chittum 1981). The Entrada has a high vertical permeability as well as a high horizontal permeability. Because of this, large volumes of water are produced along with the oil and the ratio of produced water to oil may be more than 50:1 in some wells. The water is brackish and dissolved solids range generally from 2,500 to 11,000 ppm. Depth to production ranges from 5,100 to 5,900 ft.

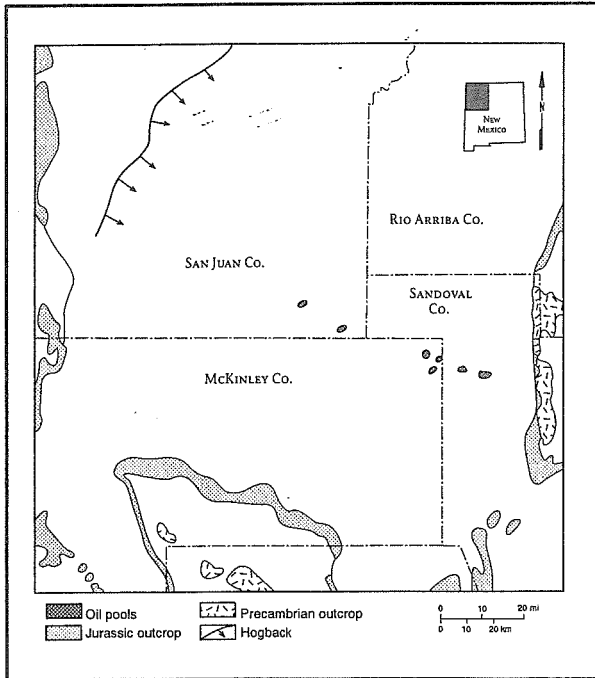


Figure 11. Oil pools productive from the Entrada Sandstone (Jurassic), New Mexico part of the San Juan Basin.

Paleozoic Reservoirs

Significant production has been obtained from 14 fairly small oil and gas pools in the Paleozoic on the Four Corners platform on the western flank of the San Juan Basin (Figure 12). These pools produced 37 MBO and 4.7 BCF gas during 1994 (Table 2). Most production has been from algal mounds and bioherms in Pennsylvanian carbonates, but significant production also has been obtained from Mississippian carbonates. Mississippian reservoirs were not produced during 1994. Very minor production has been obtained from Devonian sandstones at the now-abandoned Tom and Akah Nez fields (Figure 12). Gases in the Pennsylvanian and Mississippian reservoirs contain as much as 7.5% helium and, in the past, have been produced for their helium as well as for their hydrocarbons. Depth to production in Paleozoic reservoirs ranges from 6,000 to 10,000 ft.

OVERVIEW OF GROUNDWATER RELATIONSHIP TO OIL AND GAS

Principal aquifers in the San Juan Basin are in valley-fill and terrace deposits (Quaternary) and in San Jose, Nacimiento, and Animas formations (Tertiary) and the Ojo Alamo Sandstone (Tertiary) in the

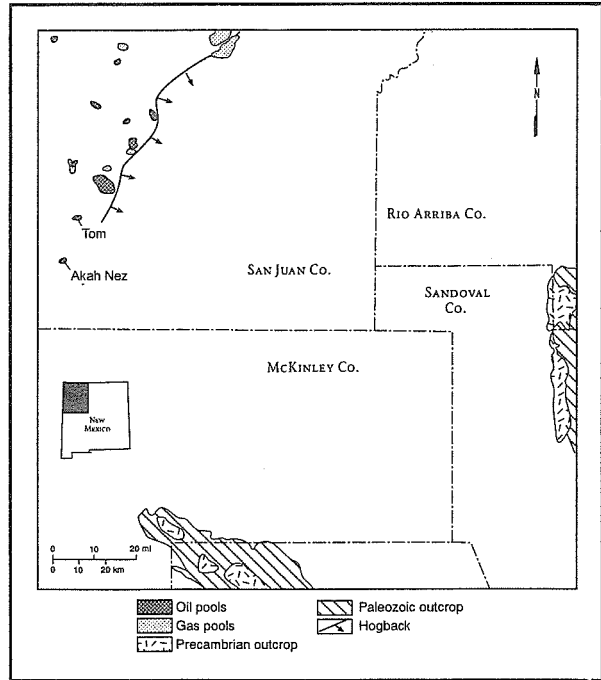


Figure 12. Oil and gas pools productive from Pennsylvanian, Mississippian, and Devonian reservoirs in the New Mexico part of the San Juan Basin. Only the Pennsylvanian reservoirs still produce.

center of the basin (Stone et al. 1983). Of these units, only the Nacimiento Formation has established production of oil and gas. The largest occurrences of natural gas in the basin are in the Upper Cretaceous stratigraphic units that underlie the Tertiary aquifers.

The Upper Cretaceous section contains aquifers that are locally important sources of water at the margins of the basin. In general, these units act as local sources of domestic and stock water in and near outcrop areas, but the salinity and specific conductance of water in these units increase toward the center of the basin (Stone et al. 1983). Specific conductance of waters in these units typically exceeds 10,000 micromhos near the central deeper parts of the basin (Stone et al. 1983); specific conductance of water in the Point Lookout Sandstone is at least 59,000 micromhos in the deeper parts of the basin.

The Gallup Sandstone (Upper Cretaceous) forms an important aquifer in the southern part of the basin (Stone et al. 1983), where it is a principal water source for the city of Gallup. As mentioned above, the Gallup Sandstone in this area is not stratigraphically continuous with the basal Niobrara sandstones that produce oil and gas along a northwest

trend in the center of the basin. A few small oil fields produce from the true Gallup in the south-central part of the basin (Figure 8), but this is in an area where specific conductance is 2,000-5,000 micromhos and where water quality is not as good as near the outcrop (Stone et al. 1983).

Jurassic stratigraphic units are important sources of potable water near the southern and western margins of the basin. The Morrison Formation is the water source for the village of Crownpoint, and also supplies significant volumes of water for the city of Gallup (Stone et al. 1983). The Entrada Sandstone has served as a local supply of water for domestic and stock wells in the southwestern part of the basin, but Entrada water is not usable throughout most of the basin (Stone et al. 1983). Fresh water was produced from the Entrada in a well near Sanostee (Figure 11), but could not be used because of naturally occurring oil and gas (Halpenny and Harshbarger 1950 cited in Stone et al. 1983).

Pre-Jurassic stratigraphic units are only minor sources of potable water. Generally, they produce usable water only in and very near outcrop areas.

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