Stratigraphy and Oil and Gas Production of Northwest New Mexico

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INTRODUCTION

This paper is a summary of the stratigraphy of the hydrocarbon-producing rocks of northwestern New Mexico and includes a discussion of the production from each of these rock units. (The reader is urged to refer to the time-stratigraphic nomenclature chart of the San Juan Basin by Molenaar, elsewhere in this volume, as a visual aid to the stratigraphic discussion in this report.) In addition, the most significant, recent stratigraphic references for each of the producing units are listed and discussed.

At the end of the report are two tables giving cumulative oil, dry-gas, casinghead-gas, and condensate production for all of the fields in northwestern New Mexico as of January 1, 1978. These tables also give the number of wells producing as of that date and the total cumulative production by stratigraphic unit. Two other tables list the total number of completions plus new, plugged, and abandoned wells and the temporarily doned wells in 1977, and the 1977 oil-well completions by pool and formation. A list of new pools established in 1978 is also included.

DEVELOPMENT AND PRODUCTION SUMMARY

Commercial oil-and-gas production in northwest New Mexico comes from Pennsylvanian, Jurassic, and, most importantly, Cretaceous rocks of the San Juan Basin. (The San Juan Basin extends into southwestern Colorado, but production from that part of the basin is not included in this report.) Hydrocarbons are produced in four counties in northwestern New Mexico: San Juan, Rio Arriba, Sandoval, and McKinley, with San Juan County being by far the largest producer.

As of January 1, 1978, the total cumulative production from northwest New Mexico (District 3 of the New Mexico Oil Conservation Commission) was: 168,296,257 barrels of oil; 10,168,822,932 MCF dry gas; 320,735,270 MCF casinghead gas; and 47,976,139 barrels of condensate (tables 1 and 2). In 1977, 58 oil-well completions and 587 gas-well completions were made; 62 wells were plugged and abandoned, and 5 others were temporarily abandoned (table 3). (Oil-well completions, by pool and formation, are listed in table 4; new pools established in 1978 are listed in table 5.)

NOTE—The statistical data included in tables 1 through 5 below were provided by the New Mexico Oil Conservation Commission. Producing zone designations do not always coincide with formal stratigraphic nomenclature.

Table 1—Cumulative oil and casinghead gas production by producing zone to January 1, 1978, in northwestern New Mexico.

Producing Zone	Pool	Wells 1/1/78	Bbls. Oil	MCF, Gas
Devonian	Ak-ah-nez	0	17,199	0
	Tom	1	1,239	0
Total		1	18,438	0
Mississippian	Beautiful Mtn.	1	9,229	0
Pennsylvanian	Buena Suerte	0	5,296	0
	Cone	1	15,354	347,003
	Four Corners	0	91,945	0
	Hogback	0	385,029	0
	Pajarito	1	154,449	0
	Rattlesnake	0	405,270	0
	Table Mesa	1	174,220	0
	Tocito Dome	55	11,460,688	22,974,873
	Undesignated	0	69,835	0
Total		58	12,762,086	23,321,876
Entrada	Eagle Mesa	4	320,223	0
	Media	7	964,479	0
	Media, Southwest	3	495,885	0
	Ojo Encino	2	22,397	0
	Papers Wash	6	244,442	0
	Snake Eyes	2	29,725	0
	Undesignated	1	13,013	0
Total		25	2,090,164	0

Producing Zone	Pool	Wells 1/1/78	Bbls. Oil	MCF, Gas
Dakota	Blackeye	3	1,258	0
	Chacon	28	245,282	2,077,434
	Duffers Point	9	147,210	16,642
	Five Lakes	1	40,847	0
	Hogback	23	5,211,391	0
	Hospah	8	169,310	742,849
	Lindrith	0	27,141	0
	Lone Pine	28	2,608,053	7,549,122
	Marcelina	4	9,354	2,452
	Ojito	0	203,290	312,626
	Rattlesnake	25	4,802,525	0
	Salt Creek	6	110,551	0
	Shiprock, North	1	1,069	0
	Slick Rock	36	619,091	0
	Table Mesa	9	1,363,550	0
	Wild Horse	2	91,688	980,716
	Undesignated	6	16,276	890,547
Total		189	15,667,886	12,572,388
Graneros	Undesignated	0	5,797	0
Greenhorn	Undesignated	0	1,126	165
Gallup and Dakota (commingled)	Lindrith, South	4	64,260	251,515
	Lindrith, West	39	1,312,683	9,222,281
	Undesignated	2	7,223	355
Total		45	1,384,166	9,474,151
Mancos	Boulder	18	1,716,186	1,435,819
	Puerto Chiquito, East	36	3,388,859	641,628
	Puerto Chiquito, West	22	6,080,600	4,375,344
	Undesignated	0	285	10,276
Total		76	11,185,930	6,463,067
Mancos-Dakota	Undesignated	0	39,892	3,065
Sanastee	Otero	0	29,882	0
Tocito	Blanco, South	13	3,888,826	7,832,963
Gallup	Amarillo	2	49,454	0
	Angel Peak	47	728,414	55,332,087
	Alamito	2	10,866	0
	Bisti Lower	220	33,704,857	67,298,429
	Cha Cha	76	8,699,177	17,139,767
	Cuervo	1	10,984	0
	Devils Fork	31	2,097,208	32,987,310
	Escrito	51	2,696,616	13,058,404
	Gallegos	49	1,797,719	26,966,387
	Horseshoe	369	35,496,489	7,688,714
	Hospah Lower Sand, South	70	3,629,174	37,179
	Hospah Upper Sand, South	65	3,487,431	4,500
	Hospah Upper Sand	59	6,567,518	0
	Jewett Valley	0	21,486	0
	Knickerbocker Buttes	1	2,832	14,863
	Kutz	15	547,607	1,679,295
	La Plata	6	528,082	402,697
	Lybrook	22	631,984	4,281,994
	Many Rocks	69	2,825,816	1,036,187
	Many Rocks, North	16	307,177	0
	Meadows	3	94,506	226,877
	Media	2	17,224	0
	Mesa	22	464,740	7,319
	Miguel Creek	5	10,781	0
	Nageezi	3	22,796	942
	Ojito	1	9,117	27,722
	Otero	60	2,300,468	2,355,356
	Pinon	3	314,378	119,219
	Rattlesnake	0	1,425	0
	Shiprock	41	227,024	0
	Simpson	6	864,022	3,446,079
	Tapacito	12	447,515	19,688,996
	Totah	48	3,323,447	0
	Verde	65	7,789,304	2,352,781
	Waterflow, South	3	213,162	248,786
	Undesignated	9	271,150	4,097,399
Total		1454	120,211,950	260,499,289
Mesaverde	Blackeye	3	21,447	0
	Chaco Wash	10	12,455	0
	Cuervo	1	43,038	0
	Devils Fork	7	79,229	126,121
	Franciscan Lakes	9	48,660	35,517
	Nenahnezad	0	1,025	0
	Otero Point	0	18,881	0
	Parlay	2	64,974	124,216
	Red Mountain	33	235,248	0
	Rusty Menefee	0	8,695	0
	San Luis	5	54,792	0
	San Luis, South	4	155	0
	Seven Lakes Menfee	4	1,206	0
	Venado	2	39,307	14,057
	Undesignated	5	19,174	19,601
Total		85	648,286	319,512
Pictured Cliffs	Sleeper	3	73,671	248,138
	Undesignated	1	15,951	0
Total		4	89,622	248,138
Farmington	Alamo	1	17,475	0
	Bloomfield	3	9,188	0
	Oswell	3	15,893	656
	Undesignated	2	26,980	0
Total		9	69,536	656
Subtotal		1960	168,102,816	320,735,270
Undesignated by County*		0	193,441	0
Grand Total		1960	168,296,257	**

*Oil not designated to a particular pool (e.g., wildcat wells).
**Casinghead gas incomplete.

Table 2—Cumulative dry gas and condensate production by producing zone to January 1, 1978, northwestern New Mexico.

Producing Zone	Pool	Wells 1/1/78	Gas, MCF	Condensate Bbls.
Mississippian	Table Mesa	0	1,193,006	0
	Tocito Dome	2	1,054,190	828
	Undesignated	1	188,821	0
Total		3	2,436,017	828
Pennsylvanian	Barker Creek	8	101,649,748	0
	Blue Hill Paradox	0	1,221,724	0
	Tocito Dome, North	2	409,225	0
	Ute Dome	7	49,543,605	0
	Undesignated	1	0	0
Total		18	152,824,302	0
Dakota	Basin	2437	2,896,748,168	28,093,856
	Barker Creek	4	20,375,214	0
	Lone Pine	5	1,298,364	0
	Snake Eyes	0	671,555	0
	Ute Dome	16	7,446,055	110,698
	Undesignated	2	318,651	0
Total		2464	2,926,858,007	28,204,554
Greenhorn	Undesignated	2	276,868	0
Gallup	Albino	1	66,217	0
	B. S. Mesa	12	8,244,237	75,700
	Choza Mesa	1	8,799	0
	Flora Vista	3	5,999,465	72,599
	Largo	4	10,876,026	83,932
	Lindrith	1	435,131	0
	Ojo	1	779,681	9,341
	Rosa	1	69,028	0
	Rusty	1	34,450	0
	Shiprock, North	1	82,894	0
	Wild Horse	12	32,110,235	0
	Undesignated	6	247,919	0
Total		44	58,954,082	241,572
Mesaverde	Blanco	2559	4,653,187,724	18,985,268
	Crouch Mesa	3	3,236,956	0
	Flora Vista	9	18,610,231	94,135
	Gonzales	17	5,372,958	47,820
	Twin Mounds	0	652,995	0
	Undesignated	1	186,366	0
Total		2589	4,681,247,230	19,127,223
Chacra	Bloomfield	15	1,657,085	0
	Harris Mesa	15	1,567,973	0
	Largo	46	4,081,318	0
	Otero	183	76,888,044	12,988
	Undesignated	9	4,462,147	386
Total		268	88,656,567	13,374
Pictured Cliffs	Aztec	500	243,075,436	15,147
	Ballard	613	289,703,573	0
	Blanco	493	248,953,690	170,822
	Blanco, East	26	13,012,328	0
	Blanco, South	1526	807,530,767	51,786
	Choza Mesa	13	3,148,347	225
	Fulcher Kutz	335	237,548,183	0
	Gallegos, South	5	202,958	0
	Gavilan	93	42,731,571	115,608
	Gobernador	9	942,461	0
	Huerfano	2	1,350,378	0
	Kutz, West	206	125,529,772	0
	Nipp	35	1,458,316	0
	Tapacito	292	199,817,159	13,438
	Twin Mounds	3	1,344,972	0
	Undesignated	4	738,544	470
Total		4155	2,217,088,455	367,496
Fruitland	Aztec	51	14,508,659	2,117
	Aztec, North	0	15,138	0
	Blanco	9	1,601,209	18,975
	Conner	3	7,971	0
	Cottonwood	0	0	0
	Crouch Mesa	1	113,034	0
	Flora Vista	5	1,415,952	0
	Gallegos	3	836,539	0
	Gallegos, South	11	3,241,309	0
	Jasis Canyon	1	92,927	0
	Kutz	15	6,439,667	0
	Kutz, West	2	777,724	0
	La Jara	0	0	0
	Los Pinos, North	3	852,770	0
	Los Pinos, South	1	947,221	0
	Mt. Nebo	2	318,415	0
	Pinon	12	5,822,941	0
	Pinon, North	1	94,962	0
	Pump Mesa	1	301,891	0
	Sedro Canyon	1	129,665	0
	Undesignated	6	298,818	0
Total		128	37,816,812	21,092
Farmington	Gallegos, South	1	0	0
	Kutz	3	265,694	0
	Undesignated	6	727,688	0
Total		10	993,382	0
Fruitland and Pictured Cliffs (commingled)	Harper Hill	2	599,466	0
	Ojo	15	428,042	0
	Waw	16	626,412	0
Total		33	1,653,920	0
Nacimiento	Undesignated	2	17,290	0
Grand Total		9,699	10,168,822,932	47,976,139

Table 3—Oil, gas, and service wells drilled during 1977 in District 3, northwest New Mexico (P&A, plugged and abandoned; TA, temporarily abandoned)

	Total
Oil well completions;	
New oil wells	53
Oil wells drilled deeper	1
Oil wells plugged back	2
Oil well re-entry	1
Additional zone	1
Total oil well completions	58
Gas well completions:	
New gas wells	572
Gas wells drilled deeper	3
Gas wells plugged back	10
Gas well re-entry	1
Additional zone	1
Total gas well completions	587
Service well completions:	
New service wells	1
P&A wells:	
New P&A wells	61
Re-entry wells	1
Total new P&A wells	62
TA wells:	
New TA wells	5
Grand total	712

Table 4—Oil-well completions during 1977 in northwest New Mexico by pool and stratigraphic unit

Name of Pool	Total oil-well completions	Percent of total completions
Pennsylvanian System		
Tocito Dome	3	5
Entrada Sandstone		
Papers Wash	5	
Media, Southwest	1	
Wildcat	2	
Formation total	8	13.1
Dakota Sandstone		
Chacon	13	
Marcelina	2	
Slick Rock	5	
Snake Eyes	2	
Lindrith, West (Dakota-Gallup)	2	
Undesignated	1	
Wildcat	1	
Formation total	26	42.6
Gallup Sandstone		
Bisti	1	
Devils Fork	1	
Dufers Point	1	
Gallegos	1	
Many Rocks	1	
Media	1	
Verde	1	
Lindrith, West (Gallup-Dakota)	1	
Undesignated	1	
Wildcat	1	
Formation total	11	18
Mancos Shale		
Puerto Chiquito, West	1	1.6
Mesaverde Group		
Franciscan Lake	2	
San Luis, South	9	
Undesignated	1	
Formation total	12	19.7
Grand total	61	100

Table 5—Gas and oil pools established in 1978 in San Juan and Rio Arriba Counties, New Mexico

Name of pool	Location	Date established
San Juan County		
Leggs Entrada	T. 21 N., R. 10 W., sec. 11	1-1-78
White Wash Mancos-Dakota	T. 24 N., R. 9 W., sec. 2	7-1-78
Gallegos Pictured Cliffs, South	T. 27 N., R. 12 W., sec. 36	1-1-78
Navajo City Chacra	T. 30 N., R. 8 W., sec. 35	7-1-78
Conner Fruitland	T. 30 N., R. 14 W., sec. 12	1-1-78
Animas Chacra	T. 31 N., R. 10 W., sec. 6	7-1-78
Kiffen Nacimiento	T. 32 N., R. 11 W., sec. 24	7-1-78
Rio Arriba County		
Gallo Dakota	T. 24 N., R. 5 W., sec. 29	7-1-78

Oil and Gas Fields of the Four Corners Area]

PRODUCTION BY STRATIGRAPHIC UNIT

Pennsylvanian System

The San Juan Basin (fig. 1) contains two basic structural elements, as defined by Kelley (1951, p. 125): (1) a Central Basin, which is defined by the Hogback Monocline around the west, north, and east sides and which coincides, for the most part, with the outcropping Mesaverde Group; and (2) an outer basin, the limits of which are much less sharply defined, as figure 1 clearly shows. According to Jentgen (1977, p. 132), the majority of the Pennsylvanian production has come from the northwest part of the outer basin area with only 20 oil-and-gas tests in the Central San Juan Basin "within the Cretaceous Pictured Cliffs Sandstone outcrop." Cumulative production from the Pennsylvanian, as of January 1, 1978, was 12,762,086 barrels of oil. The production came from nine pools, with Tocito Dome contributing 11,460,688 barrels. (In 1977, only four pools were producing). According to Jentgen (1977, p. 132): "The most recent well to penetrate the Pennsylvanian in the basin is the Mountain Fuel Supply Co. No. 1 Fruitland, in sec. 28, T. 30 N., R. 14 W. There were noncommercial shows in Pennsylvanian rocks." This well, which was a basement test (Precambrian at 12,251 feet, total depth 12,448 feet), was plugged back to the Cretaceous Menefee Formation (initial potential of 4 BCD and 331 MCFGD, according to Crowley (1978, p. 1362), and is now shut-in.

Because of the small number of drill holes which have penetrated Pennsylvanian rocks in the San Juan Basin (only 20 holes in an area of 7,500 square miles within the Pictured Cliffs Sandstone outcrop, or one well per 375 square miles), the stratigraphy of the Pennsylvanian is still incompletely understood. As Jentgen showed (1977, fig. 1, p. 129), Paradox Basin nomenclature from southeast Utah is applied in the northwest part of the basin, whereas nomenclature from outcropping Pennsylvanian rocks in the Nacimiento, San Pedro, and Sandia Mountains is applied in the southeast part of the basin. How these nomenclatures correspond in the central part of the San Juan Basin is still largely unknown. Pennsylvanian production in the northwestern San Juan Basin is predominantly structurally controlled with thin zones of biostromal porosity or "carbonate buildups" often times being intersected by structurally-related fractures.

Some significant references on Pennsylvanian stratigraphy and oil-and-gas production in the San Juan Basin are Jentgen (1977), DuChene (1974), and Wengerd and Matheny (1958).

Jurassic System

Entrada Sandstone—The Entrada Sandstone, of Jurassic age, is mainly eolian in origin in the San Juan Basin, but in some places the upper part is lacustrine (Tanner, 1976, p. 219). The Entrada is overlain by the Todilto Limestone, which is composed of gypsum and fetid limestone. It is surmised that the Entrada dune field was invaded by either a lake or a sea resulting in the Todilto being deposited over the dune field topography, leaving individual dune crests as highs with the Todilto thinning over them. It is thought that much of the oil production from the Entrada is trapped in the fossil dune crests and that the oil originated in the organic-rich Todilto.

Interest in the Entrada Sandstone has increased recently and several new pools have been discovered within the last 3 years. As of August 1, 1977, there were six Entrada pools producing in the basin, two of which (Papers Wash and Snake Eyes) were brought into production in early 1977. These six pools are scattered along a 36-mile northwest-trending zone. All of the pools have similar reservoir characteristics with an average porosity of about 23 percent and permeability of about 300 millidarcies. The oil has a high pour point which necessitates the use of special production equipment. A large amount of formation water is usually produced with the oil. The total cumulative production for the Entrada in northwest New Mexico was 2,090,164 barrels of oil as of January 1978. A good reference on the Entrada is the discussion of the producing Entrada fields by Brown (1977, p. 22-24).

Cretaceous System

The Cretaceous rocks of northwest New Mexico (nearly all of Late Cretaceous age) represent a classic sequence of intertonguing marine and continental deposits. With few exceptions, Upper Cretaceous oil-and-gas production comes from the regressive and transgressive littoral sandstones laid down at the western edge of an interior seaway. The exceptions produce from either fractured marine shale or continental fluvial sandstone.

Much has been published on the Cretaceous rocks of the San Juan Basin and some of the more recent reports are: Molenaar (1977a), Peterson and Kirk (1977), Fassett and others (1977, p. 1-55), Fassett (1974), and Fassett and Hinds (1971). An excellent paper on the oil-and-gas developments of the eastern part of the San Juan Basin by Arnold (1974) is also recommended.

Dakota Sandstone—The Dakota Sandstone of the San Juan Basin has often been referred to as a "transgressive" deposit in geologic literature; for example, Molenaar (1977a, p. 160), and Peterson and Kirk (1977, p. 171). Although the Dakota was deposited at the time of the first incursion of the Late Cretaceous epeiric sea into the basin area, it should be remembered that in the northwest part of the basin the Dakota is composed of fluvial sandstones, whereas in the southeast part of the

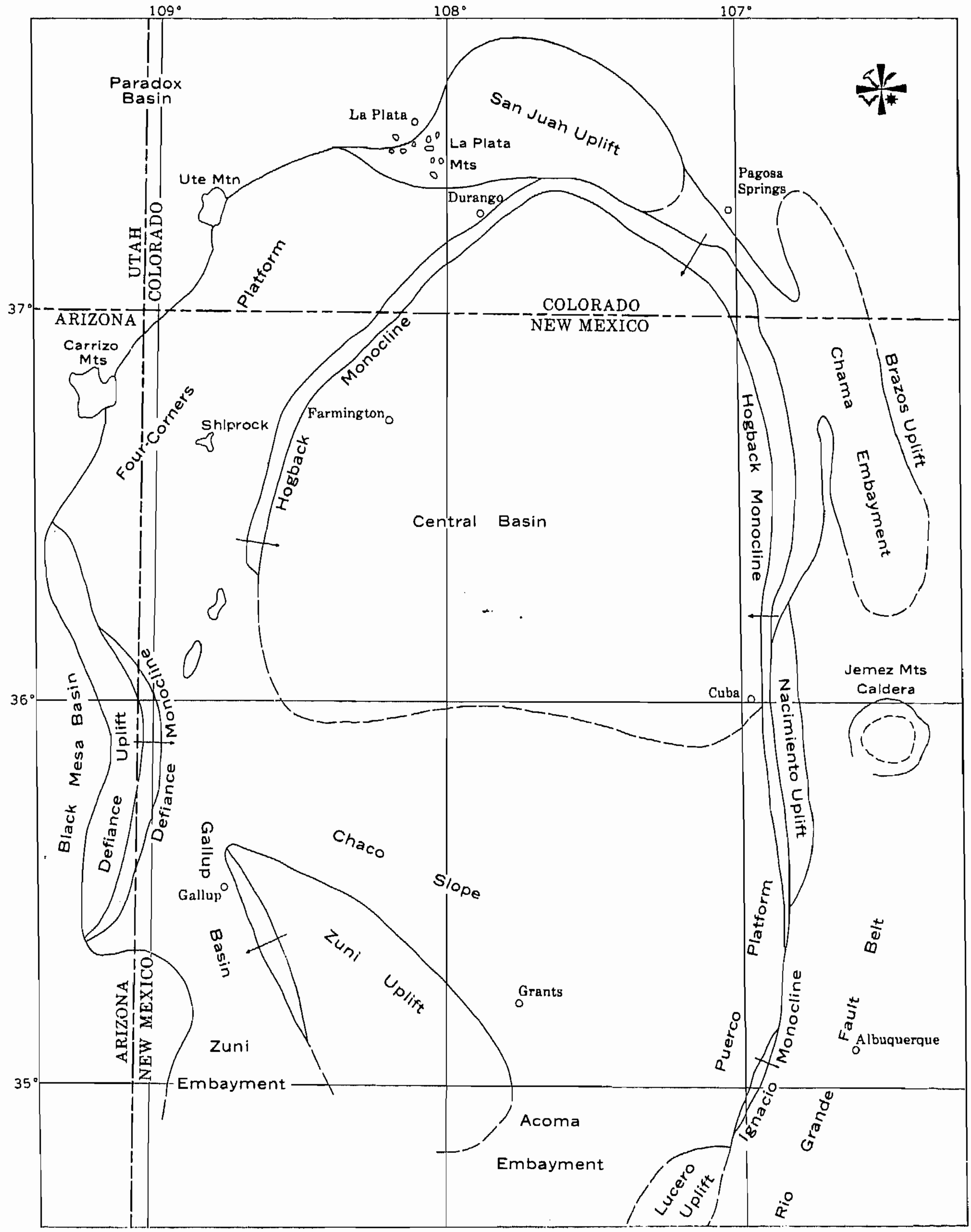


Figure 1—Structure map of the San Juan Basin. From Fassett and Hinds (1971, p. 35), after Kelley (1951, p. 125).

basin the Dakota is nearly all marine sandstones and shales (Grant and Owen, 1974, p. 239). In other words, the Dakota is not everywhere a "typical" littoral marine transgressive unit. Deischl (1973, p. 168) wrote: "Within the Central basin the basal Dakota sandstone is considered to be generally nonmarine and is often conglomeratic and rests unconformably on the underlying Jurassic Morrison Formation. Above the basal sandstone, the rocks become increasingly marine upward as a result of generally transgressive conditions. Undoubtedly, there were interruptions in the transgression of the Dakota sea over the area with subsequent relatively minor unconformities and local regressive depositional features. The Dakota Sandstone consists of fine-grained quartzose sandstones and carbonaceous shales with occasional conglomerates and coals generally in the basal section."

Disagreement exists as to the location of the top of the Dakota Sandstone in the basin. Figure 2 shows two of the interpretations. The New Mexico Oil Conservation Commission has defined the Dakota producing interval as extending 400 feet below the base of the overlying Greenhorn Limestone Member of the Mancos Shale (Deischl, 1973). (This definition includes the Graneros Shale Member of the Mancos Shale in the Dakota producing interval.)

The Dakota Sandstone produces both gas and oil in the San Juan Basin. The gas accumulation has little relationship to structure, being concentrated in a northwest-trending lobe which extends across the central part of the basin (see Deischl, 1973, fig. 4; and Hoppe, 1978, this volume). The trapping mechanism for Dakota gas is not fully understood; particularly the fact that the sandstone, which crops out all around the rim of the basin and which contains huge reserves of natural gas in the deeper central part of the basin, has no apparent seal to prevent the gas from migrating updip and escaping.

Deischl (1973, p. 168-169) suggested the possibility of "decreased permeability and strong hydrodynamic pressure on the steep flanks" as forming the trap. He further stated: "The transmissability of the Dakota sandstones is generally consistent from the Central basin to the outcrop and therefore hydrodynamic forces, acting in a basinward direction, are essential to prevent the gas from escaping. Although the hydrodynamics of the basin are not fully understood, it is believed that the hydrodynamic pressure of the water which enters the Dakota sandstones on the basin margins is sufficient to contain the gas within the basin." This explanation has problems, however, and the complete picture has not yet been drawn.

The Dakota gas field, labeled the Basin Dakota Gas Pool by the New Mexico Oil Conservation Commission, covers an area of approximately 1,500 square miles. Porosities in Dakota pay sandstones range from 7 to 11 percent and permeabilities average 0.15 millidarcy. Fracturing, both induced and natural, is necessary to attain commercial flow rates. Dakota production is not continuous across the productive trend because of lack of continuity of the reservoir sandstones. Gas production has been excellent in some areas, such as the Angel Peak, Huerfano, Gallegos Canyon, South Blanco, and Otero areas.

As of January 1, 1978, 2,437 gas wells were producing from the Basin Dakota Gas Pool. Of these, 1,637 are located in San Juan County and 800 in Rio Arriba County. Production from the pool totaled 2,897,000,000 MCF of gas, of which 2,153,000,000 MCF was from San Juan County and 744,000,000 MCF was from Rio Arriba County. In addition to the Basin Dakota Gas Pool, the Oil Conservation Commission has designated five other Dakota pools: Barker Creek, 4 wells; Lone Pine, 5 wells; Snake Eyes, 0 wells; Ute Dome, 16 wells; and Straight Canyon, 2 wells (table 2). There are two undesignated wells. Total cumulative production from all Dakota gas fields in New Mexico, as of January 1, 1978, was 2,926,858,007 MCF of gas. Oil and condensate production separated from the gas stream at the well has totaled 28,204,554 barrels—21,492,984 barrels from San Juan County and 6,711,570 barrels from Rio Arriba County.

In contrast to the gas production from the Dakota Sandstone, the oil production from this unit is mostly structurally controlled with some stratigraphic production. A quick examination of the map showing the location of the oil fields of northwest New Mexico (Matheny, this volume) reveals a curious fact; with but one exception, all of the Dakota oil fields are located near the edge of the basin either outside of or close to the rim of the Central Basin of Kelley (see fig. 1). Thus, Dakota gas is present in the interior deeper parts of the basin, whereas most Dakota oil is located on the rim, in the shallower parts of the basin. No satisfactory explanation of this remarkable juxtaposition of oil and gas has as yet been given. Sixteen Dakota oil pools have been designated (table 1; and Matheny, this volume), there is one Gallup-Dakota commingled pool, and there are six undesignated wells. The total cumulative production from the 16 pools and undesignated wells, as of January 1, 1978, was 15,667,886 barrels of oil and 12,572,388 MCF of casinghead gas.

There are numerous publications on the Dakota of the San Juan Basin, the majority based on surface geologic studies. As of this writing, no detailed, comprehensive, basin-wide studies of the Dakota in the subsurface of the basin have been published. Some recommended papers on the surface Dakota of the basin, in addition to those cited above, are: Owen and Siemers

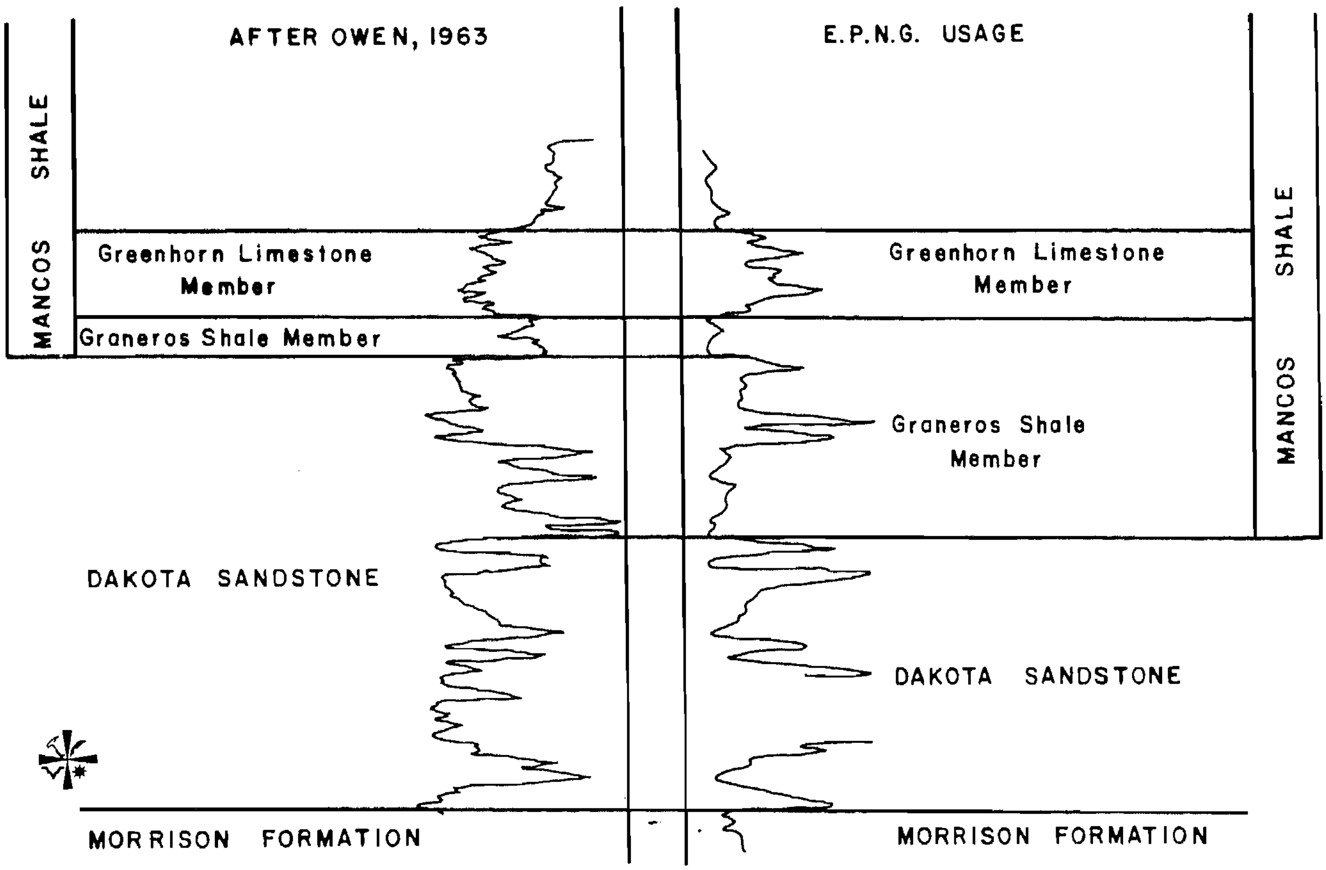


Figure 2—Typical well log showing different nomenclature used in the San Juan Basin. From Deischl (1973).

(1977); Owen (1963, 1966, and 1973); Landis, Dane and Cobban (1973); and Young (1973). Papers on subsurface geology are limited to Deischl (1973) and Marvin (1967).

Mancos Shale—The stratigraphy of the Mancos Shale is well summarized by Molenaar (1977a, p. 161): "The Mancos Shale comprises the bulk of marine deposits in the San Juan Basin. It represents deposition in deeper, quieter water in offshore areas where energy levels were lower and finer clastics could settle out. How deep the sea was in the more distal areas is speculative. It probably wasn't too deep, possibly 300-400 feet at the most, as suggested by foraminiferal data and very low-angle foresets (less than ½ degree) of time-marker beds.

"In addition to shale and siltstone, the Mancos contains zones of calcareous concretions, a few thin limestone beds, many thin bentonite beds and a few offshore sandstone buildups. Some of these can be correlated for many miles on well logs in the subsurface. Some are prominent enough both in outcrops and subsurface to warrant member status. In addition, the southwesterly extending tongues of Mancos Shale have been given names."

Commercial oil production from the Mancos Shale comes from areas where flexure of the strata has caused fractures which provide the porosity and permeability that create the reservoir. Three fractured-shale Mancos fields have been discovered in the basin: the Boulder, Puerto Chiquito East, and Puerto Chiquito West (table 1). (A fourth field, the Verde Gallup is discussed below under "Gallup Producing Interval.") As of January 1, 1978, the Mancos had produced a cumulative total of 11,185,930 barrels of oil and 6,463,067 MCF of casinghead gas. (A paper by Gorham and others (1977) gives a good description of the mechanism of fractured-shale reservoirs in the San Juan Basin.)

Two undesignated fields have produced from the Greenhorn Limestone Member of the Mancos Shale (probably produced from fractures). The total cumulative production was 1,126 barrels of oil and 276,868 MCF of gas (table 1).

Gallup Producing Interval—The Gallup producing interval is defined by the New Mexico Oil Conservation Commission as that stratigraphic interval between the top of the Greenhorn Limestone Member of the Mancos Shale and the base of the overlying Mesaverde Group.

(This definition, applied for reasons of convenience in describing an oil and gas productive interval, clearly includes other named stratigraphic units.) Five fields which produce from this interval have been given different designations by the state Oil Conservation Commission; these are: Boulder, Puerto Chiquito East, and Puerto Chiquito West fields which are defined as fractured Mancos Shale reservoirs (described above); and the Sanastee Otero and Tocito Blanco South fields, which were named prior to the above mentioned Gallup-producing-interval definition.

The Gallup producing interval can be divided into two stratigraphic parts in the San Juan Basin. The first (lower part) contains a series of marine and fluvial sandstones and shales with thin coal beds near the top. This unit, representing a major regression of the sea across the basin toward the northeast (see San Juan Basin nomenclature chart, this volume) has been called the "regressive Gallup." The uppermost part of this unit, a high-energy fluvial sandstone, has been named the Torrivio Sandstone Member of the Gallup Sandstone by Molenaar (1973, p. 98). The "regressive Gallup" is present up to a line which runs diagonally across the basin approximately from the Four Corners area to Albuquerque, according to Molenaar (see fig. 3).

The second (upper) stratigraphic interval contains a series of sandstone lenses at its base which have been assigned to several different formations. These lenses occur in a band of discontinuous, northwest-trending sandstone bodies in the northwest part of the basin; this band lies northeast of the edge of the regressive Gallup unit, as shown on figure 3. Some of the names which have been used to refer to this unit (or parts of it) are: transgressive "Gallup offshore bar sandstones" (Campbell, 1973, p. 80); "Bisti bar complex" of the Gallup Sandstone, which includes the Marye, Huerfano, and Carson Sand Members of the Gallup Sandstone (Sabins, 1963, p. 198 and fig. 5); "basal Niobrara transgressive sandstones" (Molenaar, 1973, p. 86 and fig. 2), and Tocito Sandstone, proposed as a lentil in the Mancos by Lamb (1968, p. 832 and 1973, p. 73). (A paper in this volume by Fassett and Jentgen (1978) also recommends that the name "Tocito Sandstone Lentil of the Mancos Shale" be adopted for this unit.) In the Boulder Lake area, on the east side of the basin, a thin basal sandstone of Niobrara age has been named the Cooper Arroyo Sandstone Member of the Mancos Shale by Landis and Dane (1967). In the southwest part of the basin, a discontinuous transgressive basal sandstone of Niobrara age, the Borrego Pass Lentil of the Crevasse Cañyon Formation (Correa, 1970), occurs. This sandstone is also referred to as the "stray" sandstone. As shown on Molenaar's San Juan Basin nomenclature chart (this volume), an unconformity separates the "regressive Gallup" unit from the "transgressive Gallup" unit in the northern part of the basin.

The "transgressive Gallup sandstones" are the major oil-producing rocks of the San Juan Basin. Most of them are stratigraphic traps consisting of sandstone bars enclosed by the marine Mancos Shale. A few of these fields are, at least in part, also structurally controlled. The largest of the "transgressive Gallup" oil fields are the Horseshoe and the Lower Bisti fields which had a cumulative production, as of January 1, 1978, of 35,496,489 and 33,704,857 barrels of oil, respectively (table 1). Some so-called "Gallup" production actually comes from fractured basal Niobrara silty shale (see paper on the Verde Gallup field, this volume).

The only known field producing from the "regressive" or true Gallup Sandstone is the Hospah field (fig. 3). This field, which is structurally controlled, produces, according to Molenaar (1973, p. 98), from the "Hospah sandstone," an economic name used in the Hospah field which is equivalent to the Torrivio Sandstone Member of the Gallup. The Pinedale oil seep (Molenaar, 1977b) also contains oil in the Torrivio Sandstone Member of the Gallup in the southern part of the basin. As of January 1, 1978, the cumulative production from the Hospah field was 13,684,123 barrels of oil.

The Gallup producing interval in northwest New Mexico has a total cumulative production of 120,211,950 barrels of oil, 241,572 barrels of condensate, 58,954,082 MCF of dry gas, and 260,499,289 MCF of casinghead gas.

In addition to the papers cited above, other recent publications on the Gallup Sandstone of the San Juan Basin are: Molenaar (1974), Lamb (1973), McCubbin (1969), Fassett, Molenaar, and others (1977), and Fassett and Jentgen (1978), this volume.

Upper part of Mesaverde Group—The upper part of the Mesaverde Group of the San Juan Basin consists of three basic units: the basal marine regressive Point Lookout Sandstone, the continental Menefee Formation, and the transgressive marine Cliff House Sandstone. These units are illustrated on the electric log cross section, figure 4. The stratigraphy of the Point Lookout is relatively simple, whereas the Cliff House is more complex. For a more complete discussion of the stratigraphy of these units, see Fassett (1977).

Most of the gas production from the upper part of the Mesaverde Group is from the marine sandstone units: the Point Lookout Sandstone and the Cliff House Sandstone and its associated units. Some dry gas is also produced from the fluvial sandstone beds and coal beds of the Menefee Formation. According to Pritchard (1973, p. 174): "The Point Lookout Sandstone is described as a light to medium gray, angular to subangular, fine to

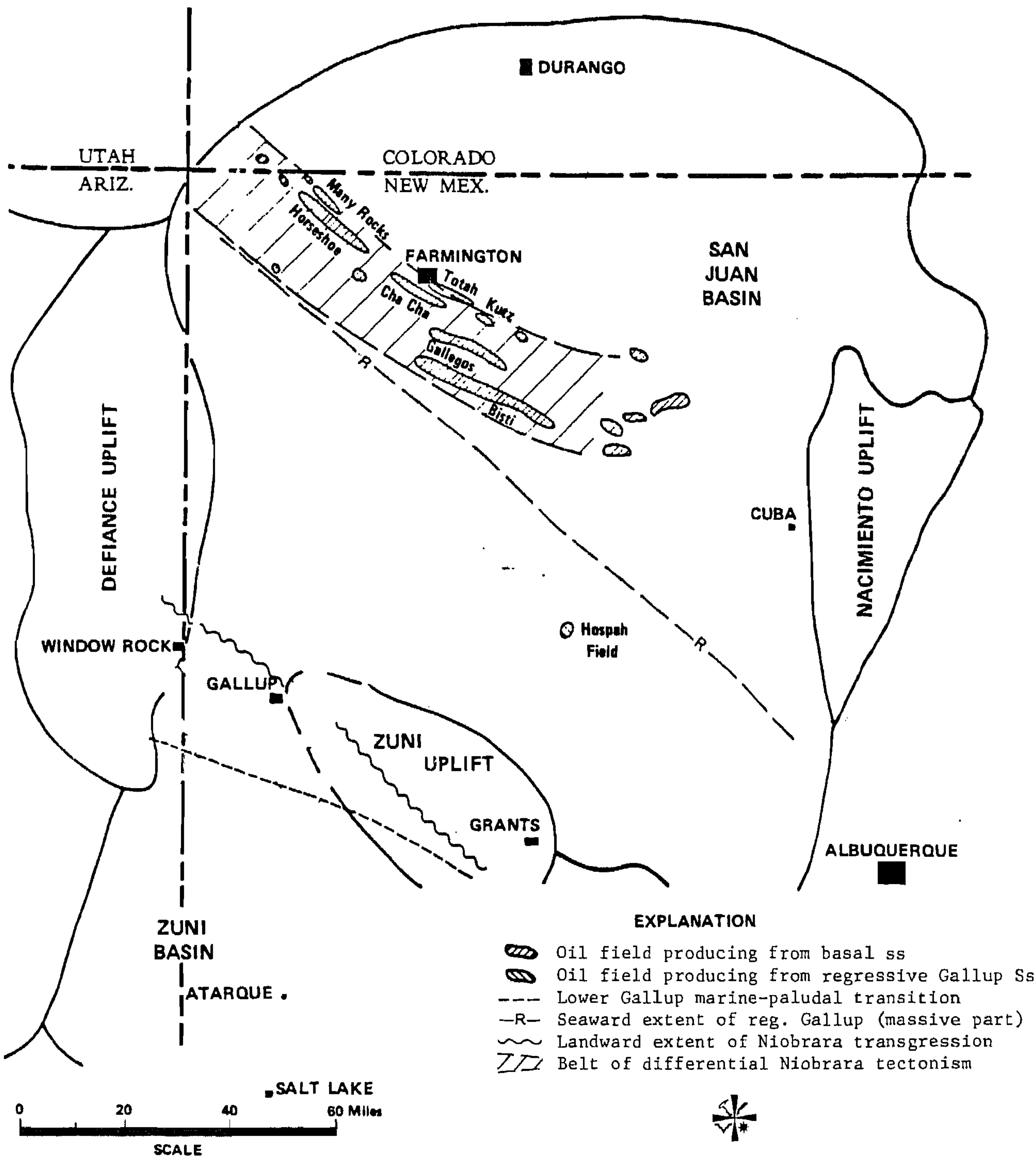


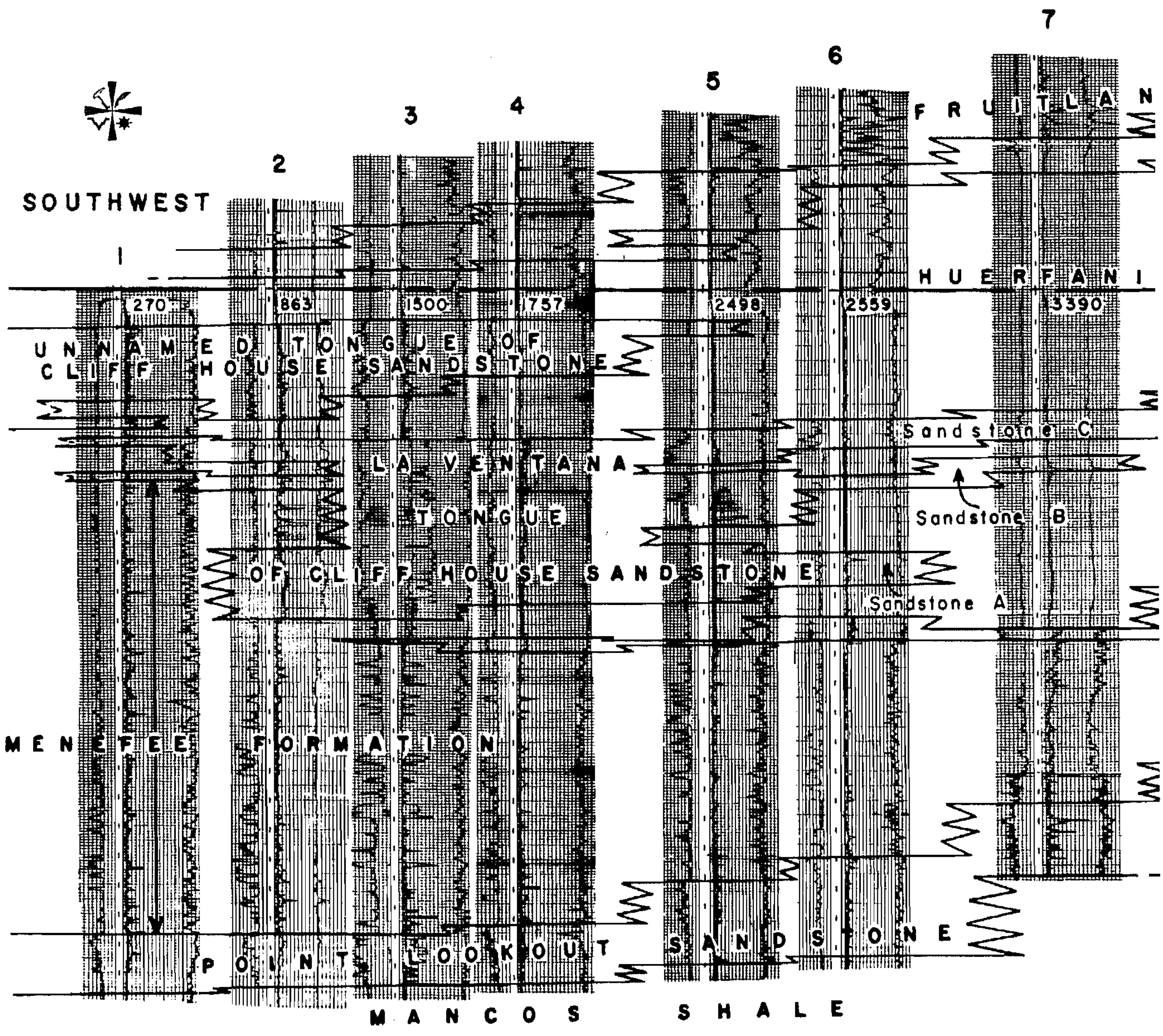
Figure 3—Producing Gallup oil fields of the San Juan Basin, New Mexico. (Modified from Molenaar, 1973.)

very fine grained, well-cemented sandstone with laminations of light to dark gray carbonaceous shale. The Cliff House Sandstone is light to medium gray, angular to subangular, very fine grained, well cemented and laminated with light- to dark-gray carbonaceous shales." "Porosities of the Mesaverde sandstones range from four to fourteen percent and average about nine percent. The average permeability of the Cliff House is five tenths millidarcy and the Point Lookout about two millidarcies. The difference in productivity from well to well can only be satisfactorily explained by the knowledge that the sandstones were naturally fractured. The fracture frequency in the sandstone around the well determines the productivity."

The trapping mechanism for Mesaverde gas is as much an enigma as for the Dakota Sandstone gas. The producing area is a northwest-trending lobe extending through the deepest part of the San Juan Basin. There is no apparent seal which has contained the gas. One theory is that swelling clays or hydrodynamic forces have held the gas in the trap, but more studies need to be made to prove this.

As most of the wells have been completed through the entire Mesaverde section with the gas comingled, it is impossible to know how much gas was produced from the Point Lookout, Menefee, or Cliff House. However, the Point Lookout Sandstone is probably the largest producer as it is thicker and has greater continuity than the Cliff House Sandstone (see fig. 4).

The Mesaverde producing zone contains five pools and one undesignated area. As of January 1, 1978, there were 2,589 wells and the largest pool, Blanco Mesa-



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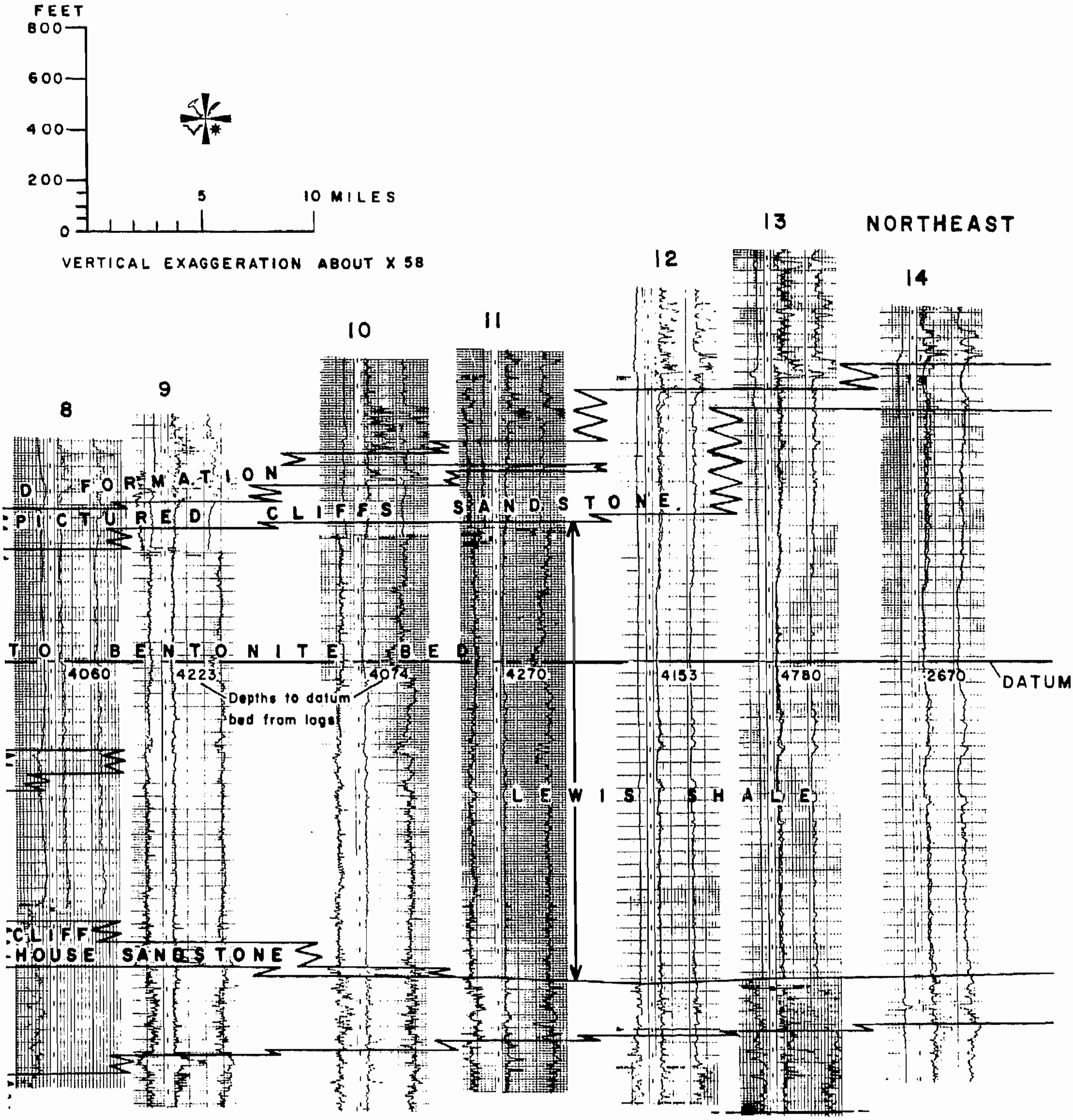

Figure 4—Stratigraphic, subsurface cross section across the San Juan Basin. (From Fassett, 1977, p. 194-195.)

verde, had 2,559 wells. The Blanco pool covers an area of about 2,800 square miles and is about 70 miles long and 40 miles wide and has produced a cumulative total of 4,653,187,724 MCF of gas and 18,985,268 barrels of condensate. The total production from all Mesaverde Group pools, as of January 1, 1978, was 4,681,247,230 MCF of gas and 19,127,223 barrels of condensate. Obviously, the Mesaverde is the most productive zone of the San Juan Basin.

Recent publications on the Mesaverde Group include Fassett (1977), Fassett and others (1977; road logs, all 3 days, see refs. list), Pritchard (1973), and Hollenshead and Pritchard (1961). The Hollenshead and Pritchard report has become a classic of subsurface stratigraphic methodology.

Chacra producing interval—The "Chacra producing interval," as defined by the New Mexico Oil Conservation Commission (Order No. R-5459), is the interval in the Lewis Shale extending from the Huerfanito Bentonite bed (see fig. 4) to 750 feet below this bed. As shown on figure 4, this interval includes sandstone B and sandstone C which are extensions of the La Ventana Tongue of the Cliff House Sandstone into the marine Lewis Shale. These two beds represent relatively clean sandstone developments separated by an interval of gray shale and siltstone. The upper sandstone (C) generally has better development with the net effective pay zone ranging in thickness from 10 to 40 feet. Net effective pay in the lower sandstone (B), when present, seldom exceeds 20 feet in thickness. Sandstone characteristics, including permeabilities, are similar to those of the Cliff House Sandstone. Well potentials range from 500 to 2,000 MCF of gas per day and average about 1,000 MCF of gas per day.

Production from the "Chacra interval" has been confined to a narrow belt not exceeding 4 miles in width and trending northwest across the central part of the basin. Extensive exploration and development of the "Chacra producing interval" is now being done. The "Chacra" will not be a major gas-producing zone in the basin, but it may provide several hundred additional producing gas wells. Total cumulative production from four pools and nine undesignated areas, as of January 1, 1978, was 88,656,567 MCF of gas and 13,374 barrels of condensate. As with most of the other gas-producing units in the basin, trapping mechanisms are still not fully understood.

In an effort to lessen confusion about the existence of two "Chacras" in the San Juan Basin, the following is a brief history of the nomenclature of the "Chacra" and related rocks in the basin. In 1936, the Chacra Sandstone Member of the Mesaverde Formation was defined by Carle Dane, who mapped this unit along part of the southwest flank of the basin. Later, Beaumont and others (1956) abandoned the name Chacra for this outcropping unit in favor of the name Cliff House Sandstone, Still later, in 1977, the New Mexico Oil Conservation Commission adopted the name "Chacra producing interval," as defined above. The name Chacra, even though abandoned as a formal rock-stratigraphic term by Beaumont and others in 1956, is still used by some workers in the basin for the same unit originally defined by Dane (1936) as the Chacra. (The Chacra of Dane is the unnamed tongue of Cliff House Sandstone shown at the left in figure 4.) As stated by Fassett (1977), ". . . this upper, unnamed tongue of the Cliff House Sandstone . . . is particularly well exposed in Tsaya Canyon in the southwest part of the basin."

Very little has been published on the "Chacra producing interval" except the publications cited above and Fassett and others (1977).

Pictured Cliffs Sandstone—The Pictured Cliffs Sandstone is the stratigraphically highest marine rock unit in the San Juan Basin and represents the final regression of the Late Cretaceous epeiric sea from the San Juan Basin area. The configuration of the Pictured Cliffs, in cross section, is shown in figure 4. As this cross section shows, the Pictured Cliffs rises stratigraphically from the southwest to the northeast across the basin; the amount of rise depicted in figure 4 is 1,026 feet.

Lithologically, the Pictured Cliffs is (Fassett, 1968) ". . . very fine grained to fine-grained sandstone composed of fairly well sorted quartz grains and a small amount of dark grains which include glauconite, mica, and carbonaceous shale. The dark grains give the sandstone a salt-and-pepper appearance. The average grain size of the sandstone decreases downward from fine to very fine at the top to very fine at the base. Many black shale interbeds as much as 0.65 foot thick are present in the lower part of the unit but the interbeds become fewer and thinner upward." Pictured Cliffs Sandstone coregraphs (Core Lab) show the following average values for all wells in the San Juan Basin: permeability average 2.96 millidarcies (range 0 to 159 millidarcies); porosity average 18.1 percent (range 2.8 to 32.2 percent); average oil saturation of 1.4 percent; average water saturation of 44 percent.

Production capacity of many wells is low because of the low permeability of the sandstone in the Pictured Cliffs. In all of the pools, the gas has accumulated in elongate northwest-trending beach or near-shore sandstone bodies which are separated, somewhat irregularly, by shale and siltstone beds trending in the same direction. The sandstone units tend to terminate abruptly to the southwest but wedge out gradually to the northeast in several of the pools. Net pay thickness varies from 10 feet to 50 feet and averages about 30 feet. Permeability generally decreases as sandstone units thin.

The Pictured Cliffs producing area trends northwest across the central part of the basin. It is about 80 miles long by 20 miles wide and covers about 1,600 square miles (see Brown, 1973, fig. 6). As of January 1, 1978, 4,155 wells were producing from 15 pools and 4 undesignated areas in the Pictured Cliffs. The total cumulative production was 2,217,088,455 MCF of gas and 367,496 barrels of condensate. The Blanco South is the largest single Pictured Cliffs pool with 1,526 wells. As of January 1, 1978, the Blanco South field had produced a cumulative total of 870,530,767 MCF of gas and 51,786 barrels of condensate.

The two principal publications on the Pictured Cliffs Sandstone are Brown (1973), which discusses the history of the gas production, and Fassett and Hinds (1971), which gives a detailed description of the stratigraphy of this unit throughout the San Juan Basin.

Fruitland Formation—The strata of the continental Fruitland Formation are back-shore swamp and flood-plain deposits associated with beds of the underlying regressive Pictured Cliffs Sandstone (Fassett and Hinds, 1971). The Fruitland produces only gas in the San Juan Basin of New Mexico, from stratigraphic traps occurring in lenticular channel sandstones or in coal beds. Fruitland pools are quite small. Open-hole completions result in wells which produce large amounts of water with the gas, and production problems sometimes develop because the water logs off the gas production. Gas with a minimum amount of water is difficult to produce if the casing is installed through the formation. Improved logging techniques may provide a clue to successful exploitation of gas reserves in the Fruitland.

According to Fassett and Hinds (1971, p. 40): "The sandstone beds in places contain gas under relatively high initial pressure, but completions in these beds have shown that the pressure usually declines rapidly. Reserves are generally small, and only a few of the wells have proved economical to complete and operate. Gas shows in the Kirtland and the Fruitland are ignored during most drilling in the San Juan Basin. In parts of the basin, however, it has become customary for drilling companies to take precautions against gas blowouts before penetrating the Kirtland and Fruitland, as at least five drilling rigs have been lost by fires owing to gas blowouts from these stratigraphic units." A map showing the locations of the oil and gas fields in the Fruitland and Kirtland, all in the northwest part of the basin, is included in Fassett and Hinds (1971, fig. 19).

Cumulative gas production from 21 pools and 6 undesignated areas, as of January 1, 1978, totaled 38,416,278 MCF of gas and 21,092 barrels of condensate. The largest New Mexico pool is the Aztec, which had a cumulative production of 14,508,659 MCF of gas. Of the 130 wells in the Fruitland, 51 are in the Aztec pool.

The reference for the Fruitland Formation of the San Juan Basin is Fassett and Hinds (1971).

Farmington Sandstone Member of the Kirtland Shale—The Farmington Sandstone Member of the Kirtland consists of a series of interbedded sandstones and shales. The sandstone lenses are usually small; in most instances, the maximum width is a few tens of feet and the thickness is from about 2 to 10 feet. A typical channel sandstone lense in the Farmington would be about 3 feet thick by 30 feet wide.

Although the Farmington Sandstone Member produces a very limited amount of oil or gas, this unit is important in the history of gas production in the San Juan Basin because it produced the first commercial gas in New Mexico in 1921 (Fassett and Hinds, 1971, p. 39). A detailed account of this discovery is included in the Aztec Farmington field paper by Kendrick and Dugan elsewhere in this volume.

The Farmington produces both oil and gas in the basin. There are three oil fields and one undesignated area which have produced a cumulative total of 69,536 barrels of oil and 656 MCF of gas from nine wells. There are two gas fields and one undesignated area, with a total of 10 wells, which has produced 993,382 MCF of gas as of January 1, 1978

Tertiary System

Nacimiento Formation—The Nacimiento Formation is a continental unit of Tertiary age which represents lake-bed deposition in the central part of the basin with an increase in fluvial sandstones around the north, east, and southeast parts of the basin. Only two wells in one undesignated pool produce from the Nacimiento; these wells are located about 8-10 miles northeast of Aztec, New Mexico. Because the Nacimiento Formation is a continental deposit which produces no hydrocarbons anywhere else in the basin, it is assumed that the gas being produced is not indigenous but that the gas-bearing sandstones have been charged by the migration of gas from deeper gas-bearing formations. The Nacimiento had a total cumulative production, as of January 1, 1978, of 17,290 MCF of gas.

The reference for the Nacimiento Formation of the San Juan Basin is Fassett and Hinds (1971).

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Could this be a San Juan Basin oil-and-gas engineer on his way out to the rig; or is it a petroleum geologist doing field work in the Four Corners area? Neither one, it is: "The dawn man on the 'dawn horse', drawn in jest by Thomas Huxley 102 years ago as his way of predicting the find by man of an early Eocene fossil horse with five toes." (Photograph is from the cover of Geology magazine, October 1978 and from a paper in that issue entitled "Horse Genealogy: The Oregon connection" by Ellen Drake.)