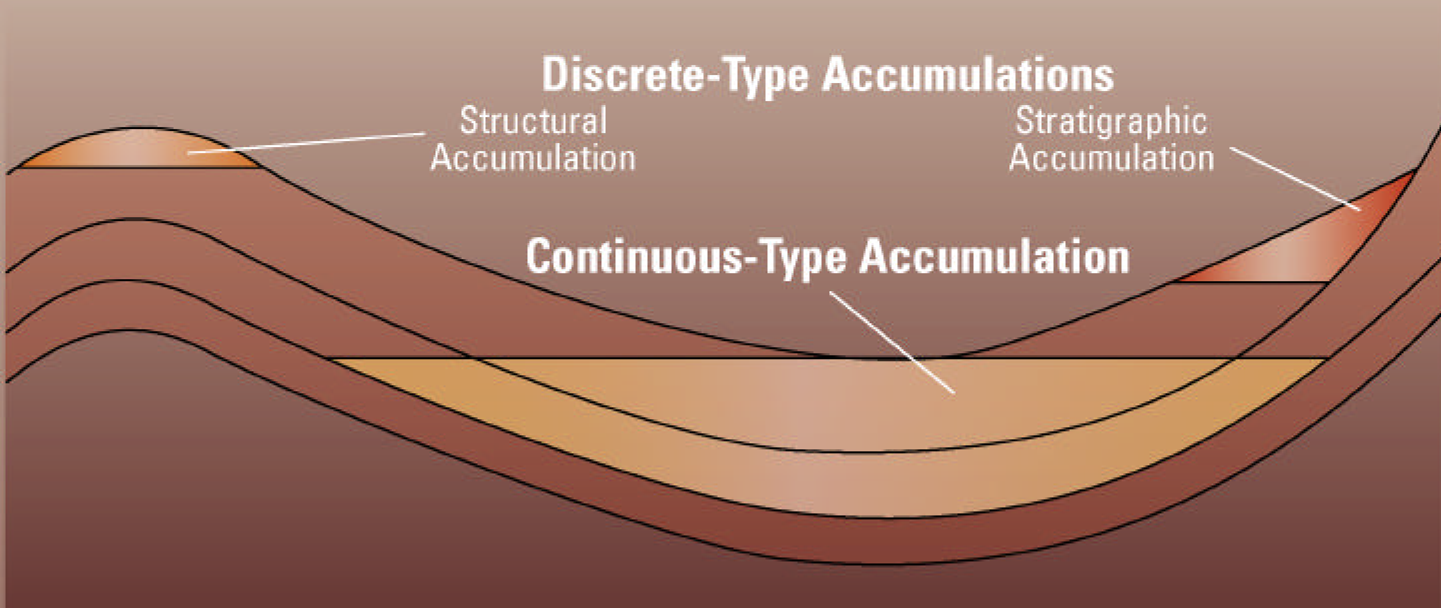
Potential for a Basin-Centered Gas Accumulation in the Albuquerque Basin, New Mexico

Geologic Studies of Basin-Centered Gas Systems

U.S. Geological Survey Bulletin 2184-C



U.S. Department of the Interior
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By Ronald C. Johnson, Thomas M. Finn, *and* Vito F. Nuccio

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Edited by Vito F. Nuccio *and* Thaddeus S. Dyman

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Abstract

The potential that a basin-centered or continuous-type gas accumulation is present in the Albuquerque Basin in central New Mexico was investigated. The Albuquerque Basin is one of the many rift basins that make up the Rio Grand rift system, an area of active extension from Oligocene to recent time. The basin is significantly different from other Rocky Mountain basins that contain basin-centered gas accumulations because it is actively subsiding and is at near maximum burial and heating conditions at the present time. Burial reconstructions suggest that Cretaceous-age source rocks began to generate gas in the deeper parts of the basin about 20 million years ago and are still generating large amounts of gas. The high mud weights typically used while drilling the Cretaceous interval in the deeper areas of the basin suggest some degree of overpressuring. Gas shows are commonly reported while drilling through the Cretaceous interval; however, attempts to complete gas wells in the Cretaceous have resulted in subeconomic quantities of gas, primarily because of low permeabilities. Little water has been reported. All of these characteristics suggest that a basin-centered gas accumulation of some sort is present in the Albuquerque Basin.

Introduction

The Albuquerque Basin occupies the central portion of the Rio Grande rift system, an area of presently active extensional tectonics that reaches from the Upper Arkansas Valley near Leadville, Colo., southward through New Mexico to the State of Chihuahua, Mexico (fig. 1). The Rio Grande rift is part of the greater Basin and Range Province, which has been undergoing extension since Oligocene time.

For the past 24 years, the U.S. Geological Survey has been studying basin-centered gas accumulations in Rocky Mountain basins under various projects funded by what is now the United States Department of Energy National Energy Technology Lab (NETL) in Morgantown, W. Va. These investigations have added greatly to our understanding of how these "unconventional" accumulations formed. Basin-centered continuous-type gas accumulations cover vast areas of the deeper parts of Rocky Mountain basins formed during the Laramide orogeny (Late Cretaceous through Eocene) and appear to contain huge resources of in-place gas. These "unconventional" gas accumulations are different from conventional gas accumulations in that they occur in predominantly tight (< 0.1 millidarcy) rocks, cut across stratigraphic units, occur downdip from water-bearing reservoirs, and have no obvious structural or stratigraphic trapping mechanism. Reservoirs within the accumulations are almost always either abnormally overpressured or abnormally underpressured, indicating that they are isolated from the regional ground-water table.

The Albuquerque Basin was chosen for study because its geologic history is significantly different from other Rocky Mountain basins that contain identified basin-centered gas accumulations. Like other Laramide basins, the Albuquerque Basin contains a thick interval of Cretaceous-age coals, carbonaceous shales, and marine shales. In Laramide basins, Cretaceous-age source rocks are thought to be the source for gas found in basin-centered gas accumulations. The Albuquerque Basin is currently actively subsiding, whereas subsidence largely ceased at the end of the Laramide orogeny near the end of the Eocene in most other basins in the Rocky Mountain region. Laramide basins have undergone significant erosion and cooling within the last 10 million years as a result of regional uplift of the entire Rocky Mountain region. Rates of gas generation in Laramide basins have markedly declined since regional uplift began. In fact, gas generation has probably ceased altogether in all but the deeper areas of these basins. Thus, gas is probably not being replenished to these accumulations as fast as it is leaking out, causing these accumulations to actively shrink.

In the Albuquerque Basin, source rocks for hydrocarbons are at near-maximum burial and heating conditions throughout the deeper areas of the basin. Gas is being generated by these source rocks today, and this gas is probably migrating and accumulating in Upper Cretaceous sandstones at the present time. Whether or not this gas may be creating a basin-centered-type gas accumulation is the subject of this report.

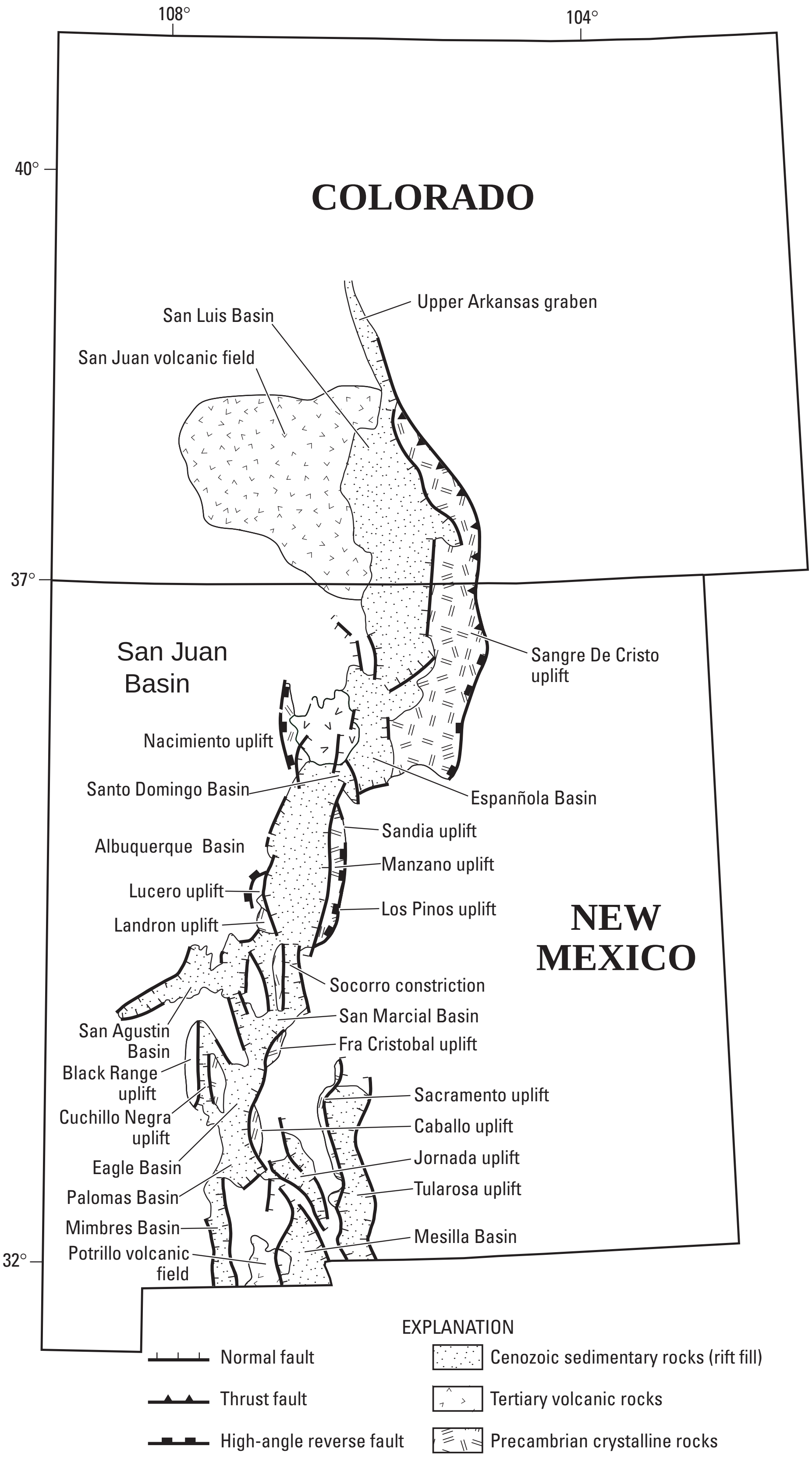


Figure 1. General location map of selected basins and uplifts along the Rio Grand rift, Colorado and New Mexico. Approximate location of San Juan Basin also shown (modified from Russell and Snelson, 1994).

Structure and Stratigraphy

The Rio Grande rift is a series of generally north-south-trending en echelon extensional basins that reach from central Colorado to at least southern New Mexico (Chapin, 1971, 1979). The basin contains a thick section of sedimentary rocks ranging in age from Mississippian to Holocene (fig. 2). Rifting began about 32 to 27 million years ago in middle Oligocene time and is probably still occurring at the present time. The

Table 1. List of oil and gas tests in the Albuquerque Basin (modified from Black, 1982).

Well name	Location	Year	Total depth (ft)	Total depth (m)	Remarks
1. Tejon Oil & Dev. 1	7-14N-6E	1914	1850	564	Show of oil at 1,000 ft
2. Cal-New Mexico Dechares 1	8-6N-1E	1925	2900	884	Shows of oil and gas
3. Stone 1	25-7N-2E	1926	1405	428	
4. Belen Oil 1 Seipple	23-4N-1E	1926	3545	1081	Show of oil
5. Gilmore & Sheldon 1 Tome Grant	30-6N-2E	1926	1180	360	
6. Hub Oil-HNTH 1	13-6N-1W	1926	3425	1044	
7. Stone Horeland 1	32-7N-2E	1927	2144	653	Show of oil
8. Gilmore and Sheldon Tome 1	30-6N-3E	1928	1100	335	
9. Stone 2	25-7N-2E	1928	1976	602	Show of oil
10. Norris 2	22-9N-1E	1928	2780	847	
11. Harlan 1 Harlan	5-6N-2E	1930	4223	1287	Show of oil
12. Harlan 2	5-6N-2E	1930	4021	1225	
13. Harlan 3	5-6N-2E	1931	6474	1973	Several gas shows
14. Harlan 4	5-6N-2E	1931	3820	1164	Shows of oil and gas
15. Harlan 5	5-6N-2E	1931	4007	1221	Several gas shows
16. Norins Pajarito 1 Grant	22-9N-1E	1931	5104	1556	Numerous oil and gas shows
17. West 1 Natural Resources	8-6N-1E	1932	1725	526	
18. Mills 2 Tome	9-6N-3E	1932	446	136	
19. Mills 1 Tome	29-6N-3E	1933	507	155	
20. Ringle Dev. 1 Fee	36-6N-3E	1935	1115	340	
21. Ringle Dev. 1 Fuqua	13-5N-3E	1935	100	30	
22. Norins 1 N. Alb. Acres	19-11N-4E	1935	573	175	
23. Norins 2 N. Alb. Acres	19-11N-4E	1935	5024	1531	Show of CO_2
24. Ringle Dev. Co. 1 Ringle	6-5N-2E	1935	750	261	
25. Big Three Dalies Townsite 1	5-6N-1E	1937	6113	1863	Numerous oil shows
26. Central New Mexico 1 Brown	17-3N-1E.	1937	2840	866	Numerous oil and gas shows
27. Norins 3 Pajarito	22-9N-1E	1938	2780	847	
28. Joiner Sanclemente 1	23-7N-1E	1939	5606	1709	Shows of gas
29. Grober 1 Fuqua	19-5N-3E	1940	3978	1212	Lots of gas at TD
30. Ringle 1 Tome	34-6N-4E	1947	823	286	25–50 MCFPD from Penn.
31. Ringle 2 Tome	35-6N-4E	1947	890	271	Oil show
32. Ringle 3 Tome	34-6N-4E	1947	597	181	
33. Castleberry 1 Tome	20-6N-4E	1947	500	152	
34. Carpenter Alrosco 1	28-10N-1E	1948	6652	2027	
35. Von G 1	5-6N-1E	1949	6096	1858	Numerous oil and gas shows
36. Long Dalies 1	32-7N-1E	1952	6091	1857	Slight show of oil and gas with DST
37. Humble 1 Santa Fe	18-6N-1W	1953	12691	3868	Gas-cut mud with DST, TD in Cret.
38. Shell 1 Santa Fe	18-13N-3E	1972	11045	3387	Oil & gas shows in Cret., TD in Precamb.
39. Shell 1 Laguna Wilson Trust	8-9N-1W	1972	11115	3410	Gas shows, TD in Precambrian
40. Shell 2 Santa Fe	29-6N-1W	1974	14305	4360	Gas shows, TD in Triassic
41. Shell 1 Isleta	7-7N-2E	1974	16346	4982	Gas & oil with DST in Cret., TD in Perm.
42. Shell 3 Santa Fe	28-13N-1E	1976	10276	3132	Minor gas shows, TD in Triassic
43. Trans Ocean 1 Isleta	8-8N-3E	1978	10378	3163	Gas shows, TD in Precambrian
44. Shell 2 Isleta	16-8N-2E	1979	21268	6482	Did not reach Cret. rocks
45. Shell 1 West Mesa Fed.	24-11N-1E	1981	19375	5906	Several hundred MCF in Point Lookout Ss
46. Utex 1-1J1E	1-10N-1E	1984	16665	5079	TD in Point Lookout Ss.
47. Davis 1 Tamara	3-13N-3E	1996	8732	2662	Minor oil and gas shows, TD in Chinle Fm
48. Davis 1 Angel Eyes	19-4N-1E	1996	8074	2461	TD in Tertiary
49. Twinning 1 NFT	33-5N.-1E	1997	7441	2268	
50. Burlington-Westland 1Y	21-10N-1E	1997	7800	2377	Minor oil and gas shows, TD in Chinle Fm

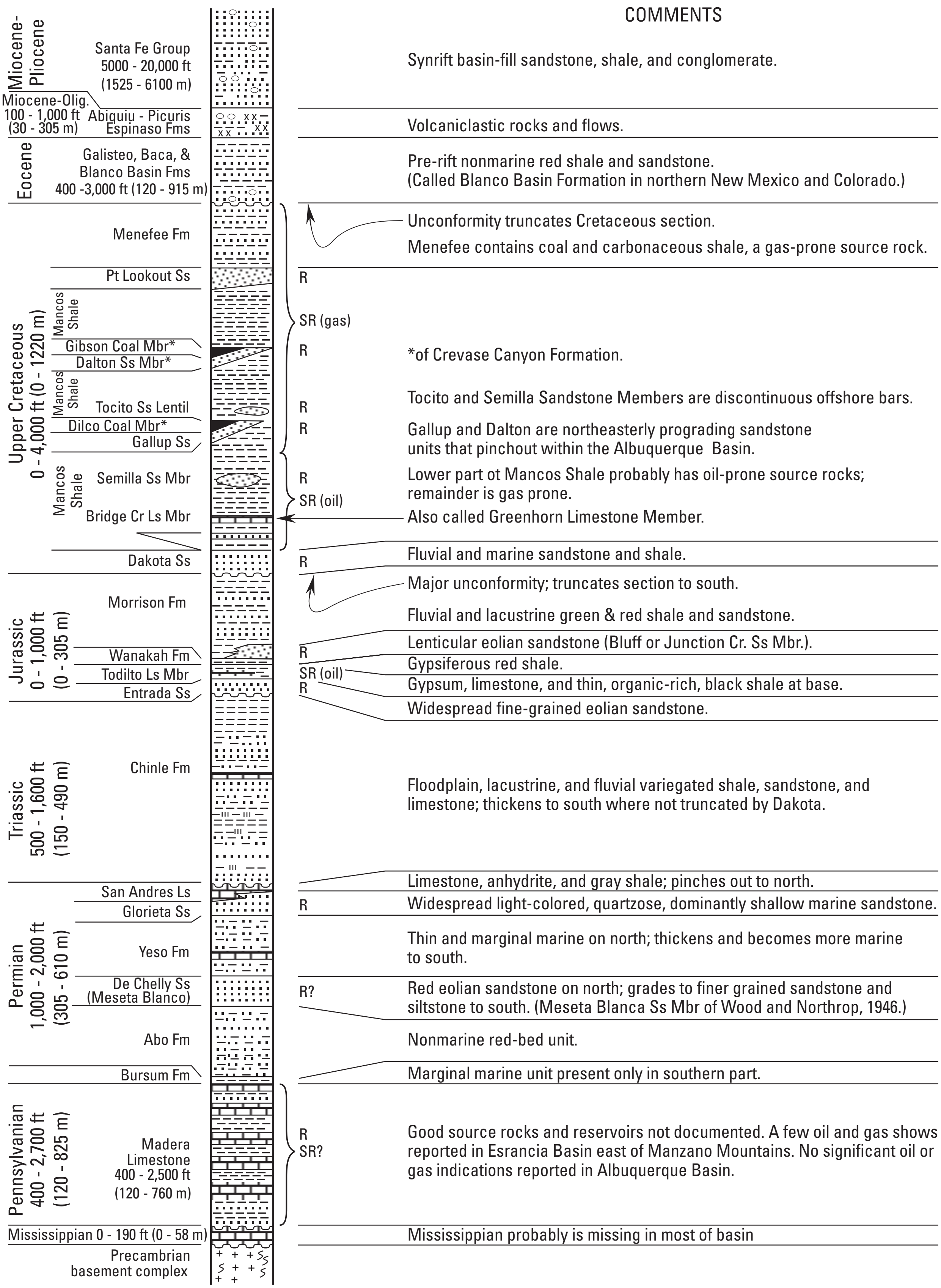


Figure 2. Generalized stratigraphic chart for the Albuquerque Basin (from Molenaar, 1988b). R, potential reservoir rock; SR, potential source rock.

Albuquerque Basin covers an area of about 2,160 mi^2 (5,600 km^2) and is one of the deepest basins along the Rio Grande rift (Lozinsky, 1994). In 1979, Shell drilled a well to a depth of 21,266 ft (no. 44 on table 1) in one of the deepest parts of the basin and did not reach the base of Oligocene or younger rift fill. Seismic data published by Russell and Snelson (1994) demonstrates that the basin generally consists of a deep inner graben flanked by shallower benches (figs. 3–6). The inner graben in the northern part of the basin is tilted eastward (fig. 5), whereas, in the southern part, the graben is tilted westward (fig. 6). An east-west zone of accommodation occurs between these two oppositely tilted blocks.

Of importance to this investigation is a pre-Eocene unconformity that has removed varying amounts of the Cretaceous section in northern New Mexico, including the Albuquerque Basin area. The Cretaceous section contains both source and principal reservoir rocks for basin-centered gas accumulations in other Rocky Mountain basins, and, had the Cretaceous section been largely removed by this unconformity, there would be little chance that a basin-centered accumulation would be present in the basin. Both surface control on the flanks of the Albuquerque Basin and subsurface control within the basin indicate that much of the Cretaceous section is intact, although the Cretaceous section is completely removed in the Espanola Basin to the north (Molenaar, 1988b). Cretaceous strata in the Albuquerque Basin are similar to the highly gas productive Cretaceous interval in the San Juan Basin to the north (fig. 1), and many of the same stratigraphic names are used in both basins (fig. 2).

Drilling Activity in the Albuquerque Basin

The Albuquerque Basin has been sparsely explored for hydrocarbons. At the present time there is no established hydrocarbon production in the basin (table 1). At least 50 wells have been drilled for hydrocarbons in the basin, with the oldest known test drilled in 1914. Drilling prior to 1953 was mainly shallow, penetrating only the Tertiary fill (table 2) (Black, 1982). Numerous oil and gas shows were reported with these shallow tests. After 1953, the Cretaceous section beneath the Tertiary fill became the primary target for exploration (Black 1982).

Between 1972 and 1976 Shell drilled five deep tests in the basin (fig. 3, table 1), targeting Cretaceous rocks in the deeper, hotter parts of the basin where Cretaceous source rocks are believed to have generated hydrocarbons (Black, 1999). The first well, the Shell No. 1 Santa Fe in sec. 18, T. 13 N., R. 3 E. was drilled in 1972 to a depth of 11,045 ft (3,387 m) and bottomed in Precambrian basement. The second well, the Shell No. 1 Laguna Wilson Trust in sec. 8, T. 9. N., R. 1 W. was drilled in 1972 to a depth of 11,115 ft (3,410 m) and also bottomed in Precambrian basement. The third well, the Shell No. 2 Santa Fe in sec. 26, T. 6 N., R. 1 W. was drilled in 1974 to a depth of 14,305 ft (4,360 m) and bottomed in Triassic rocks. All three wells encountered gas shows in the Cretaceous section, but no completions were attempted. In 1974, Shell drilled the No. 1 Isleta well in sec. 7, T. 7 N., R. 2 E. (fig. 3, tables 1, 3). The well penetrated the top of the Cretaceous section at 12,110 ft (3,691 m). It encountered a series of faults near the base of the nonmarine Cretaceous section, and the Dakota Sandstone—the primary objective of the test—was cut out by faulting. According to Black (1982, p. 315) the well encountered “tight” gas-saturated sandstones in the nonmarine Cretaceous interval. Several intervals were perforated in the nonmarine part of the Cretaceous between 12,209 ft and 13,246 ft (3,721–4,037 m), and noncommercial amounts of gas were produced. Maximum reported production was 29 thousand cubic feet of gas per day (MCFGPD) between 13,210 and 13,226 ft (4,026–4,031 m). In 1976, Shell drilled the No. 3 Santa Fe well in sec. 28, T. 13 N., R. 3 E. to a depth of 10,276 ft (3,132 m) that bottomed in the Triassic. Again, gas shows were encountered in the Cretaceous.

In 1978, Shell farmed out part of their acreage to Trans Ocean, who drilled the No. 1 Isleta well in sec. 8, T. 8 N., R. 3 E. to a depth of 10,378 ft (3,163 ft). The well bottomed in Precambrian basement and encountered gas shows in the Cretaceous. In 1979, Shell drilled the No. 2 Isleta well in sec. 16, T. 8 N., R. 2 E. The well was drilled to a depth of 21,268 ft (6,482 m) and did not reach Cretaceous rocks. In 1980 and 1981, Shell drilled the Shell 1 West Mesa well in sec. 24, T. 11 N, R. 1 E. to a 19,375 ft. and reportedly flared several hundred thousand cubic feet of gas per day from the Cretaceous section (Black, 1989). The well was eventually plugged and abandoned apparently because rates of production were insufficient at these drilling depths to be economic. In 1984, Utex drilled the No. 1-1J1E well in sec. 1, T. 10 N, R. 1 E. to a depth of 16,665 ft (5,079 m) (table 1). The well reportedly bottomed in the Point Lookout Sandstone at 16,665 ft (5,079 m); however, Black (1999) believes that the well bottomed in the Tertiary. No tests or completions were attempted, and only minor gas shows were reported in the well.

Low oil prices in the late 1980’s and early 1990’s brought a halt to oil and gas exploration in the Albuquerque Basin. Exploration resumed in 1996 with Davis Oil drilling two tests—the No. 1 Tamara well in sec. 3, T. 13 N., R. 3 E. and the No. 1 Angel Eyes well in sec. 19, T. 4 N., R. 1 E. (fig. 3). The No. 1 Tamara well bottomed in the Triassic Chinle Formation at a depth of 8,732 ft (2,662 m) and reported minor shows of oil and gas. The No. 1 Angel Eyes well bottomed in the Tertiary at a depth of 8074 ft (2,461 m) with no information on oil and gas shows (Black, 1999). Two additional tests were drilled in 1997—the Twining Drilling Corp No. 1 NFT, a 7,441-ft test of the Tertiary in sec. 33, T. 5 N., R. 1 E. and the Burlington Resources Westland Development Co. No. 1Y well in sec. 21, T. 10 N., R. 21 E., which bottomed in the Triassic Chinle at a depth of 7,800 ft (2,377 m). Minor oil and gas shows were reported in the No. 1Y well.

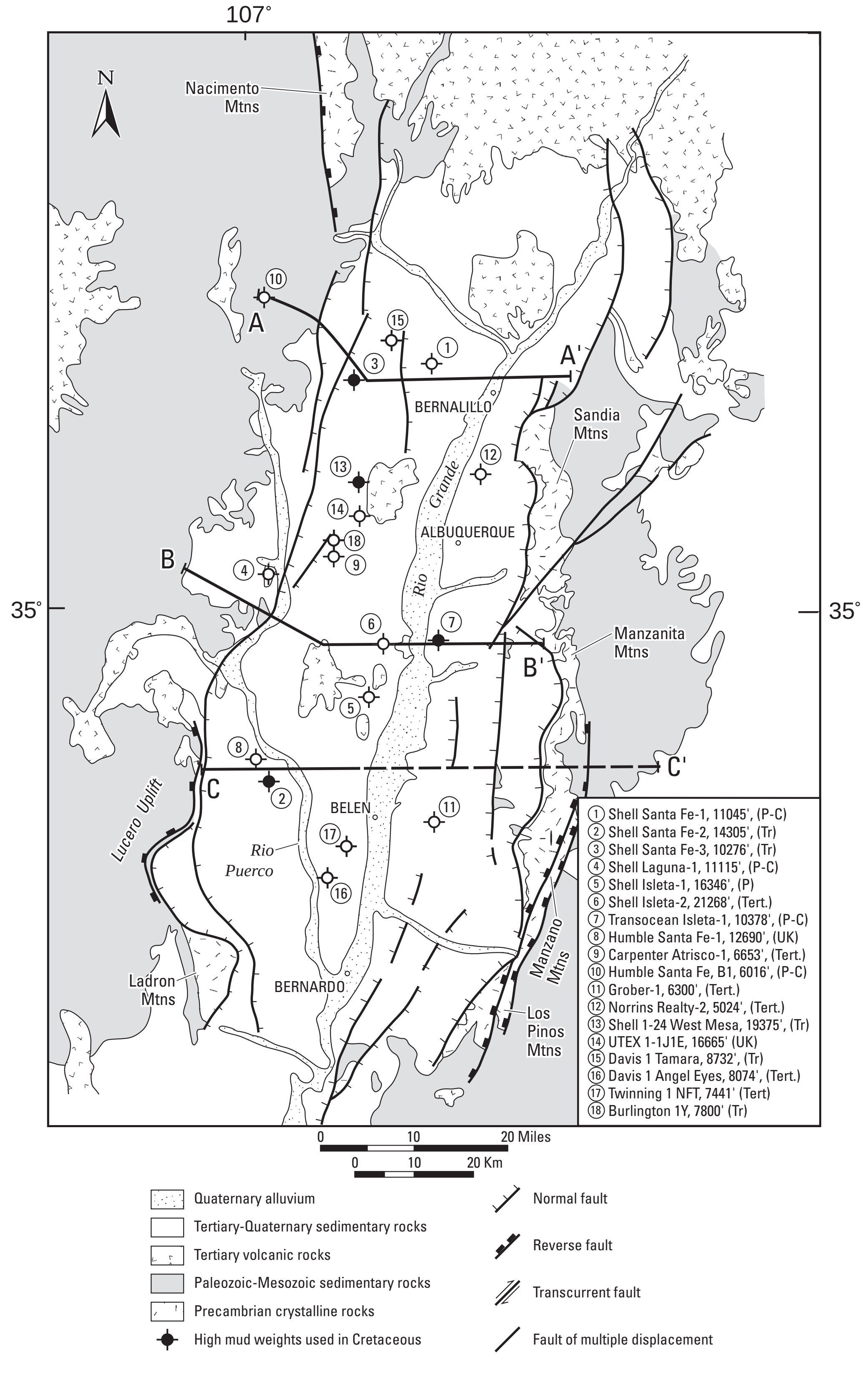


Figure 3. Generalized geologic map of the Albuquerque Basin showing deep drill holes and seismic lines (modified from Russell and Snelson, 1994). Wells in which high (>10 lb) mud weights were used while drilling through the Cretaceous section are also shown. Depths listed are total depths in feet. Cross sections A-A′, B-B′, and C-C′ are shown in figures 4, 5, and 6, respectively.

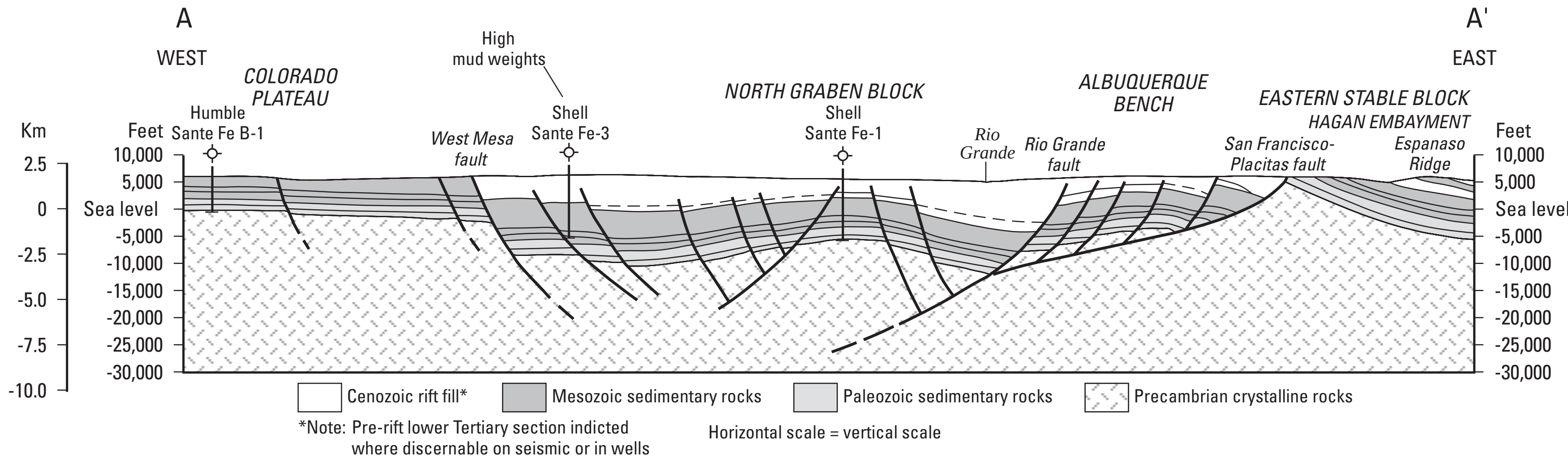


Figure 4. Interpreted west-east cross section A-A' based on seismic data for the northern part of the Albuquerque Basin. Line of section shown on figure 3. High mud weights were used in the Shell No. 3 Santa Fe while drilling the Cretaceous section (modified from Russell and Snelson, 1984).

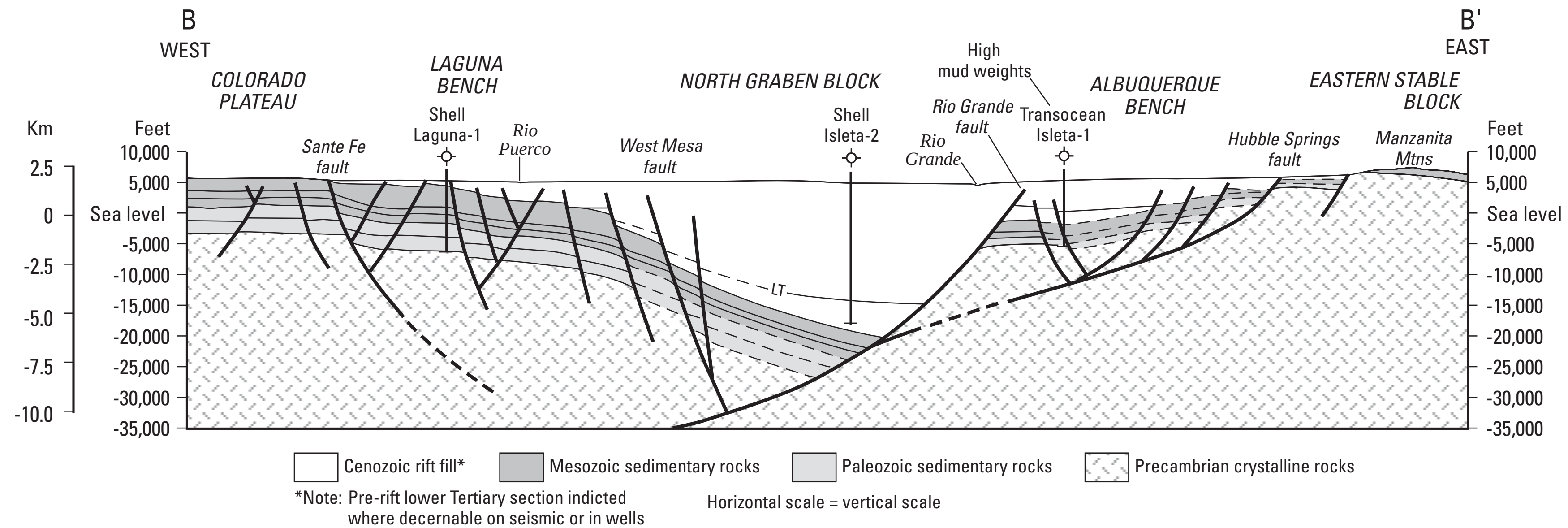


Figure 5. Interpreted west-east cross section B-B' based on seismic data for the central part of the Albuquerque Basin. Line of section shown on figure 3. High mud weights were used in the Transocean No. 2 Isleta while drilling the Cretaceous section (modified from Russell and Snelson, 1984).

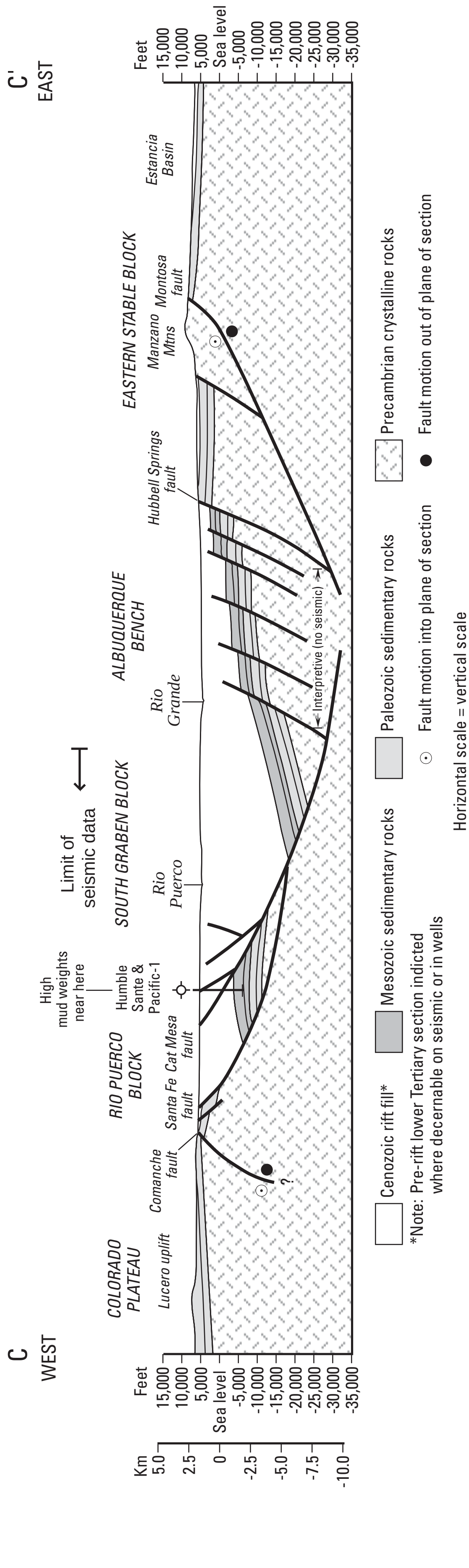


Figure 6. Interpreted west-east cross section C-C' based on seismic data for the southern part of the Albuquerque Basin. Line of section shown on figure 3. The eastern part of the cross section was constructed from geologic inference and is not based on seismic data. High mud weights were used while drilling the Humble No. 1 Santa Fe and Pacific well (modified from Russell and Snelson, 1984).

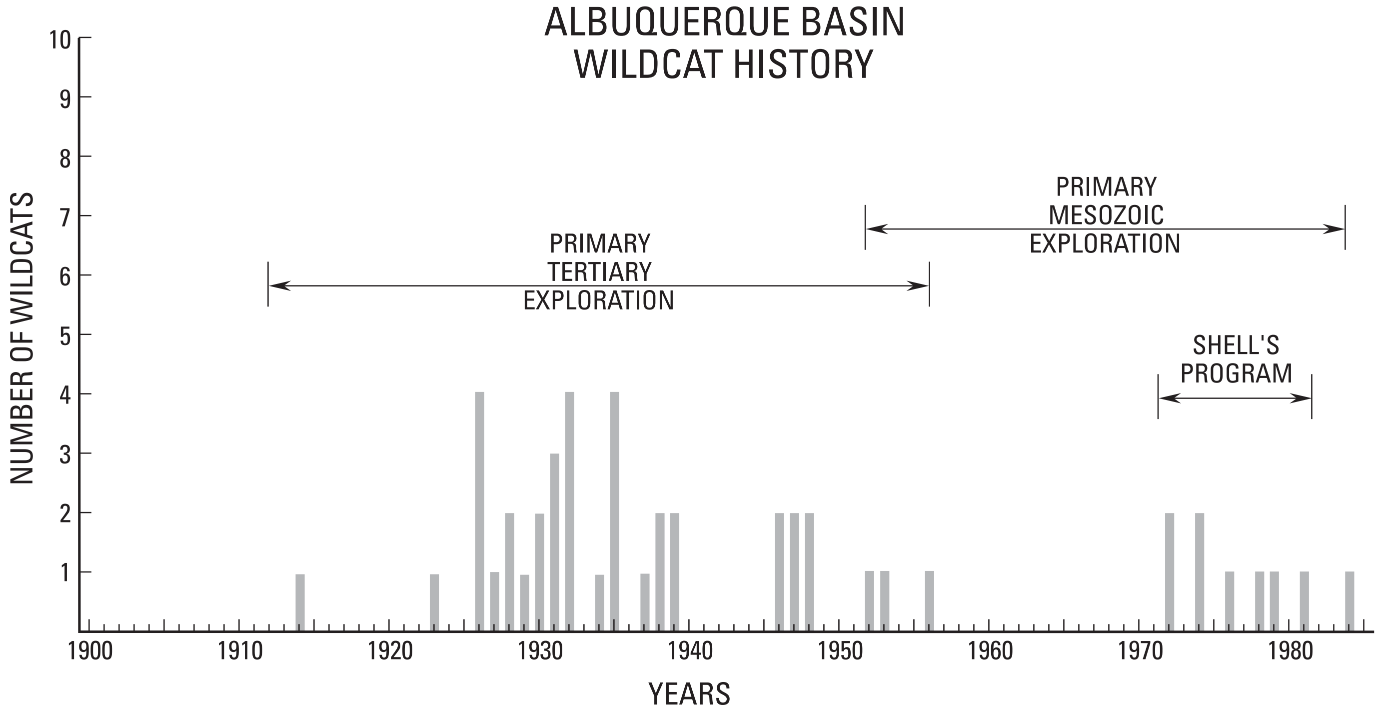
Borehole Temperature Data

Previous investigations have found that there is unusually high heat flow in the vicinity of the Rio Grande rift (Decker, 1969; Reiter and others, 1975; Edwards and others, 1978; Clarkson and Reiter, 1984), although there is some suggestion that the area of high heat flow occurs across a broad area of New Mexico and southern Colorado and is not confined to the immediate vicinity of the rift (Edwards and others, 1978; Clarkson and Reiter, 1984). Many heat-flow measurements in the Albuquerque Basin area, however, have been taken at shallow depths. These heat-flow measurements can be affected by local ground-water convection and hence may not be good measurements of regional heat-flow patterns (Clarkson and Reiter, 1984).

Geothermal gradients calculated from temperatures recorded during logging runs in oil and gas tests are a less precise way to measure variations in heat flow because geothermal gradients vary among different lithologies. Nonetheless, geothermal gradients are commonly used because the data is readily available. Geothermal gradients were calculated by Grant (1982) for eight of the deepest boreholes in the basin. Grant (1982) calculated only one gradient for each hole using the temperature recorded at the bottom of the hole. Here, we calculated geothermal gradients for all the temperatures recorded while these eight holes were being drilled. Figure 7 is a plot of temperature versus depth for the eight drill holes. An average geothermal gradient was also calculated for each drill hole using all of the temperature readings taken. The standard AAPG (American Association of Petroleum Geologists) correction factor was applied to all of the recorded temperatures, and a mean annual surface temperature of 45°F (7°C) was used. A correction factor was applied to the readings because the rocks in the immediate vicinity of the borehole are quenched by comparatively cool mud circulated through the borehole during drilling. The time between when mud circulation stops and the temperature is recorded is seldom long enough for temperatures in the vicinity of the borehole to reequilibrate.

Geothermal gradients calculated from different logging runs in the same drill hole were surprisingly consistent (table 4). For instance, the eight individual geothermal gradients calculated for the Shell No. 1 Isleta hole varied from 1.77°F/100 ft to 2.48°F/100 ft (3.23°–4.52°C/100 m). If only the six deepest temperatures are used, variation is only from 1.95°F/100 ft to 2.15°F/100 ft (3.56°–3.92°C/100 m). Shallower temperature readings in boreholes are generally less reliable than deeper readings, largely because of the greater times required for borehole temperatures to reequilibrate once mud circulation is stopped. Average geothermal gradients for the eight drill holes varied from 1.7°F/100 ft to 2.3°F/100 ft (3.1°–4.2°C/100 m) (table 4). These values are not significantly different from geothermal gradients throughout northern New Mexico (Geothermal Gradient Map of North America, 1976).

Table 2. Histogram showing exploration activity in the Albuquerque Basin from 1900 to 1984 (modified from Black, 1999).



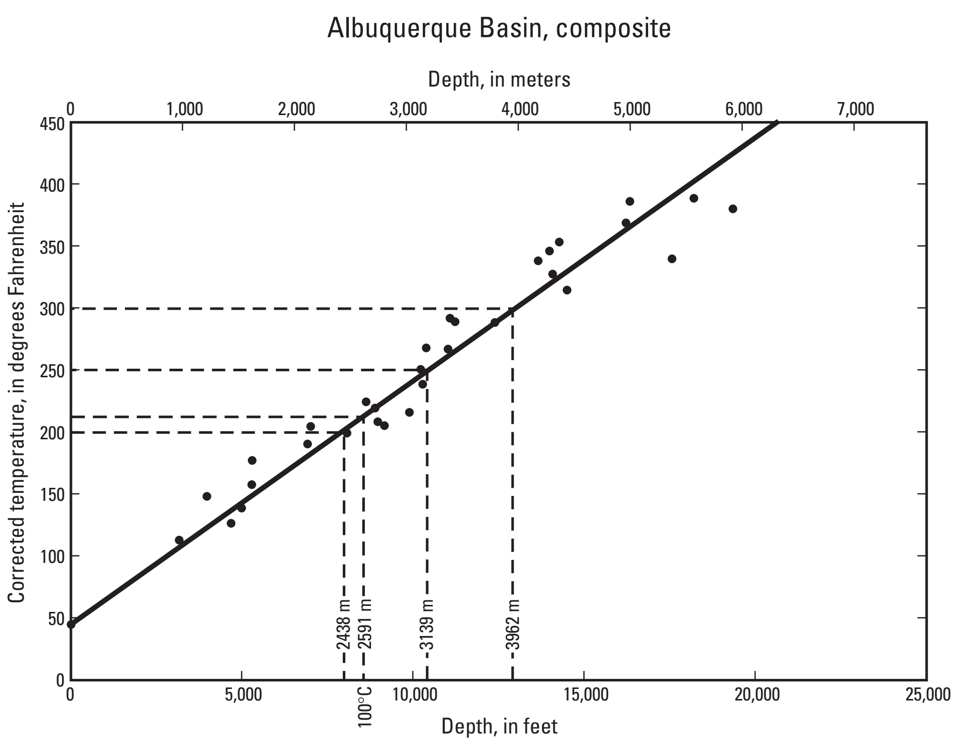


Figure 7. Plot of bottom-hole temperatures versus depths for all wells listed in table 3. The gradients plotted are based on uncorrected bottom-hole temperatures and a mean annual surface temperature of 45°F (9°C). A best-fit line through the data points is shown. The average uncorrected geothermal gradient for the entire Albuquerque Basin is about 2.0°F/100 ft (3.67°C/100 m).

Table 3. List of deep oil and gas tests in the Albuquerque Basin with formation tops reported by Petroleum Information, Inc.

Well no.	Well name	Location	Total depth in feet (meters)	Formation	Depth in feet (meters)	Depth in ft (m) (Lozinski, 1994)
4	Shell	8-9N-1W	11,115 (3,647)	Gallup Ss. (Cretaceous)	2,632 (802)	
	1 Laguna			Dakota Ss. (Cretaceous)	3,555 (1,084)	
	Wilson			Morrison Fm. (Jurassic)	3,950 (1,204)	
				Granite (Precambrian)	11,102 (3,384)	
2			(4,360)	(Eocene-Oligocene)		(1,460)
	2 Santa Fe			Galisteo-Baca Fms., (Eocene)		7,598 (2,316)
				Top Cretaceous		8,238 (2,510)
				Mesaverde Group (Cretaceous)	11,030 (3,362)	
				Mancos Shale (Cretaceous)	13,298 (4,053)	
				Todilto Limestone (Jurassic)	13,928 (4,245)	
				Entrada Ss. (Jurassic)	13,954 (4,253)	
				Chinle Fm. (Triassic)	14,058 (4,285)	
10			(3,868)	p Cretaceous		8,501 (2,591)
	1 Santa Fe					
3			(3,132)	(Eocene-Oligocene)		gnized
	3 Santa Fe			Galisteo-Baca Fms., (Eocene)		3,996 (1,218)
				Top Cretaceous		4,068 (1,240)
				Menefee Fm. (Cretaceous)	4,144 (1,263)	
				Point Lookout Ss. (Cretaceous)	6,138 (1,871)	
				Gallup Ss. (Cretaceous)	7,404 (2,257)	
				Dakota Ss. (Cretaceous)	8,731 (2,661)	
				Morrison Fm. (Jurassic)	9,078 (2,767)	
1			(3,367)	(Eocene-Oligocene)		gnized
	1 Santa Fe			Galisteo-Baca Fms., (Eocene)		2,969 (905)
				Top Cretaceous		3,642 (1,110)
				Menefee Fm. (Cretaceous)	3,644 (1,111)	
				Point Lookout Ss. (Cretaceous)	4,378 (1,334)	
				Dakota Ss. (Cretaceous)	6,600 (2,012)	
				Morrison Fm. (Jurassic)	6,907 (2,105)	
13			(5,906)	(Eocene-Oligocene)		(2,603)
	West Mesa			Galisteo-Baca Fms., (Eocene)		15,709 (4,788)
				Top Cretaceous		16,818 (5,126)
				Point Lookout Ss. (Cretaceous)	16,817 (5,126)	
				Gallup Ss. (Cretaceous)	18,082 (5,511)	
				Mancos Shale (Cretaceous)	18,130 (5,526)	
				Dakota Ss. (Cretaceous)	18,888 (5,757)	
14			(5,079)	(Cretaceous)	(5,027)	
5			(4,982)	(Eocene-Oligocene)		(2,679)
	1 Isleta			Galistero-Baca Fms., (Eocene)		10,551 (3,216)
				Top Cretaceous		12,041 (3,670)
				Menefee Fm. (Cretaceous)	12,110 (3,691)	
				Gallup Ss. (Cretaceous)	13,090 (3,990)	
				Mancos Shale (Cretaceous)	13,265 (4,043)	
				Chinle Fm. (Triassic)	13,808 (4,209)	

Burial Reconstructions for the Albuquerque Basin

Isopach maps of Tertiary rocks in the Albuquerque Basin were constructed using well data from Lozinsky (1994) in order to better understand the subsidence history of the basin and to help define the deepest parts of the basin where a basin-centered gas accumulation is likely to occur. The isopach maps were constructed using only drill-hole data, and no attempt was made to incorporate seismic information. The maps are thus very generalized and do not show thickness variations that result from the stair-step faulting within the basin. The first isopach map is of the combined Eocene Galisteo and Baca Formations (fig. 8). Although these units predate the onset of subsidence in the basin, they nonetheless thicken somewhat toward the deep trough of the basin. The second isopach map

Table 4. Bottom-hole temperatures recorded during logging runs for selected deep tests in the Albuquerque Basin.

[Geothermal gradients listed are average values for the entire hole calculated from uncorrected bottom-hole temperatures assuming a mean annual surface temperature of 45˚F (7˚C). Locations shown on figures 3, 8, 9, and 10]

No.	Well name	Location	Depth in feet (meters)	Bottom-hole temperature in ˚F (˚C)	Geothermal gradient in ˚F/100 ft (˚C/100 m)	Average gradient for well in ˚F/100 ft (˚C/100 m)
4	Shell 1	8-9N-1W	3,989 (1216)	147 (63)	2.56 (4.7)	2.3 (4.2)
	Laguna Wilson		11,107 (3,385)	292 (144)	2.23 (4.07)	
2			(972)	(44)	2.1 (3.83)	(4.01)
	Santa Fe		7,011 (2,137)	204 (96)	2.27 (4.14)	
			8,654 (2,638)	224 (107)	2.07 (3.78)	
			11,238 (3,425)	289 (143)	2.17 (3.96)	
			14,011 (4,271)	347 (175)	2.16 (3.94)	
			14,305 (4,360)	354 (179)	2.16 (3.94)	
7			(1,615)	(69)	2.11 (3.85)	(3.83)
	1 Isleta		9,175 (2,797)	205 (96)	1.74 (3.17)	
			10,378 (3,163)	267 (131)	2.14 (3.90)	
3			(1,434)	(52)	1.72 (3.14)	(3.47)
	Santa Fe		8,994 (2,714)	208 (98)	1.81 (2.01)	
			10,276 (3,132)	238 (114)	1.88 (3.43)	
1			(2,114)	(87.8)	2.09 (3.81)	(3.83)
	Santa Fe		11,045 (3,367)	267 (131)	2.01 (3.67)	
13			(5,359)	(172)	1.69 (3.08)	(3.1)
	West Mesa		19,350 (5,898)	381 (194)	1.74 (3.17)	
5			(1,623)	(81)	2.48 (4.52)	(3.83)
	Isleta		8,080 (2,463)	198 (92)	1.77 (3.23)	
			8,909 (2,715)	219 (104)	1.95 (3.56)	
			10,250 (3,124)	250 (121)	2 (3.64)	
			12,396 (3,778)	288 (142)	1.96 (3.58)	
			13,675 (4,168)	339 (171)	2.15 (3.92)	
			14,100 (4,298)	328 (164)	2.01 (3.67)	
			16,346 (4,982)	387 (197)	2.09 (3.81)	
6			(1,524)	(59)	1.86 (3.39)	(3.47)
	Isletta		9,926 (3,025)	215 (102)	1.71 (3.12)	
			14,525 (4,427)	315 (157)	1.86 (3.39)	
			16,254 (4,954)	370 (188)	2 (3.64)	
			18,227 (5,556)	390 (199)	1.89 (3.45)	

(fig. 9) represents the combined thickness of the Galisteo and Baca Formations and the overlying "unit of Isleta No. 2 well" as defined by Lozinsky (1994). The unit is thought to be late Eocene to late Oligocene in age and thus spans the onset of rifting in the Albuquerque Basin. By the late Oligocene, more than 8,200 ft (2,499 m) of sediments and volcanic rocks (present-day thickness) had accumulated along the developing deep basin trough west of Albuquerque (fig. 9). The last isopach map includes all Tertiary and younger rocks and unconsolidated sediments (fig. 10). More than 21,000 ft (6,400 m) of sediments and volcanic rocks have accumulated along the deep basin trough from the Tertiary to the present.

Burial reconstructions were made for three deep dill holes in the Albuquerque Basin from the time of deposition of the Cretaceous Dakota Sandstone to the present. The Dakota Sandstone, the Point Lookout Sandstone, and the Menefee Formation are present in three of the wells. These wells, the Shell No. 3 Santa Fe, the Shell No. 1 Santa Fe, and the Shell No. 1-24 West Mesa (fig. 3, table 1) were modeled using BasinMod version 7.01 developed by Platte River Associates in order to determine the timing of hydrocarbon generation. The Shell No. 3 Santa Fe and No. 1 Santa Fe are near cross section A-A2 in a comparatively shallow area in the northern part of the basin. The Shell No. 1-24 West Mesa well is in a much deeper part of the basin farther to the south.

The data used for the burial reconstructions is shown on the stratigraphic charts in figure 11. The Cretaceous stratigraphy of the Albuquerque Basin is similar to that of the San Juan Basin to the north (Molenaar, 1988b). Principal Cretaceous stratigraphic units used in the burial reconstructions are the Dakota Sandstone, the Point Lookout Sandstone, and the top of the Menefee Formation. These units have not been placed

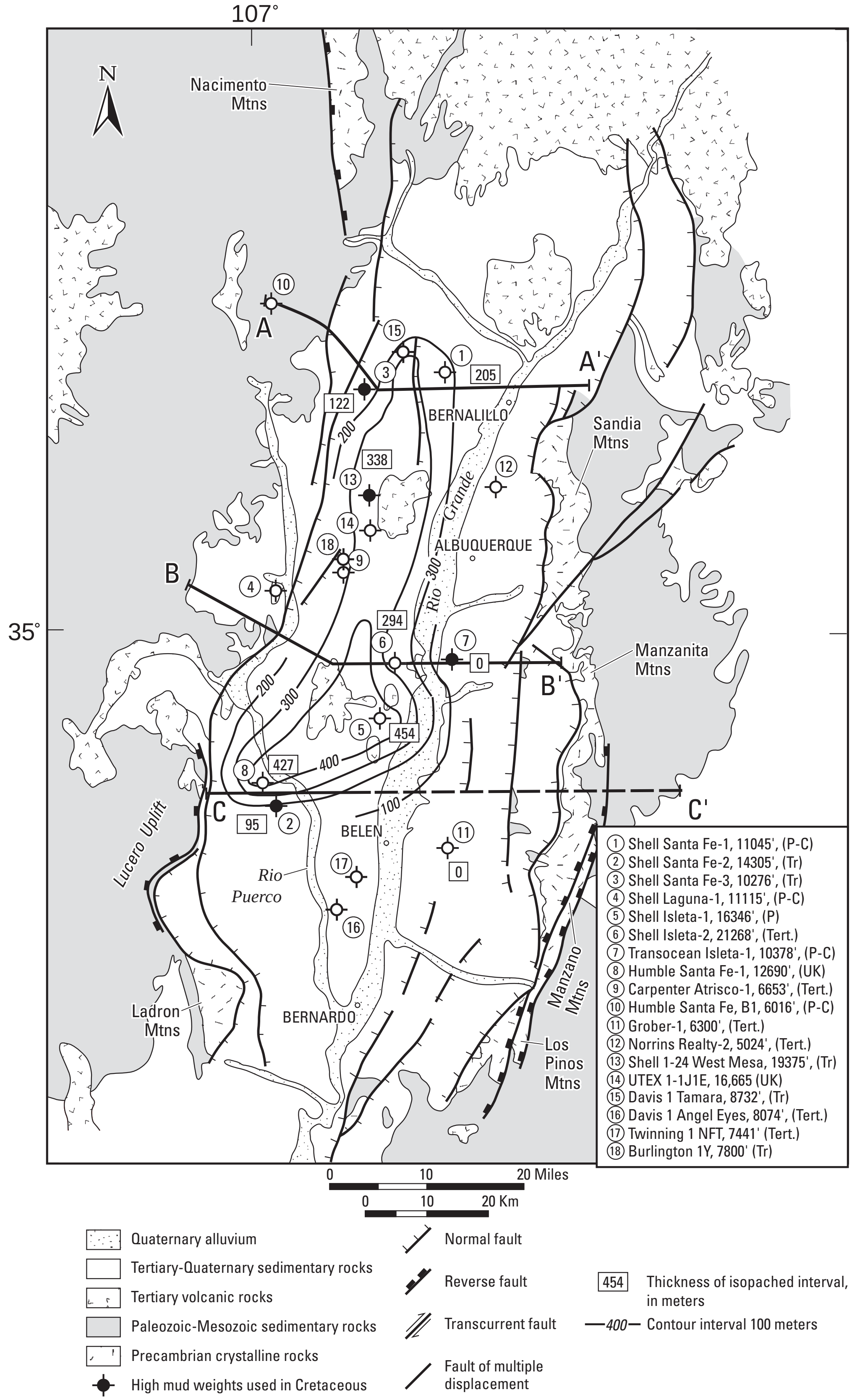


Figure 8. Isopach map of the combined Eocene Galisteo and Baca Formations, Albuquerque Basin, constructed using data from Lozinski (1994, his table 1).

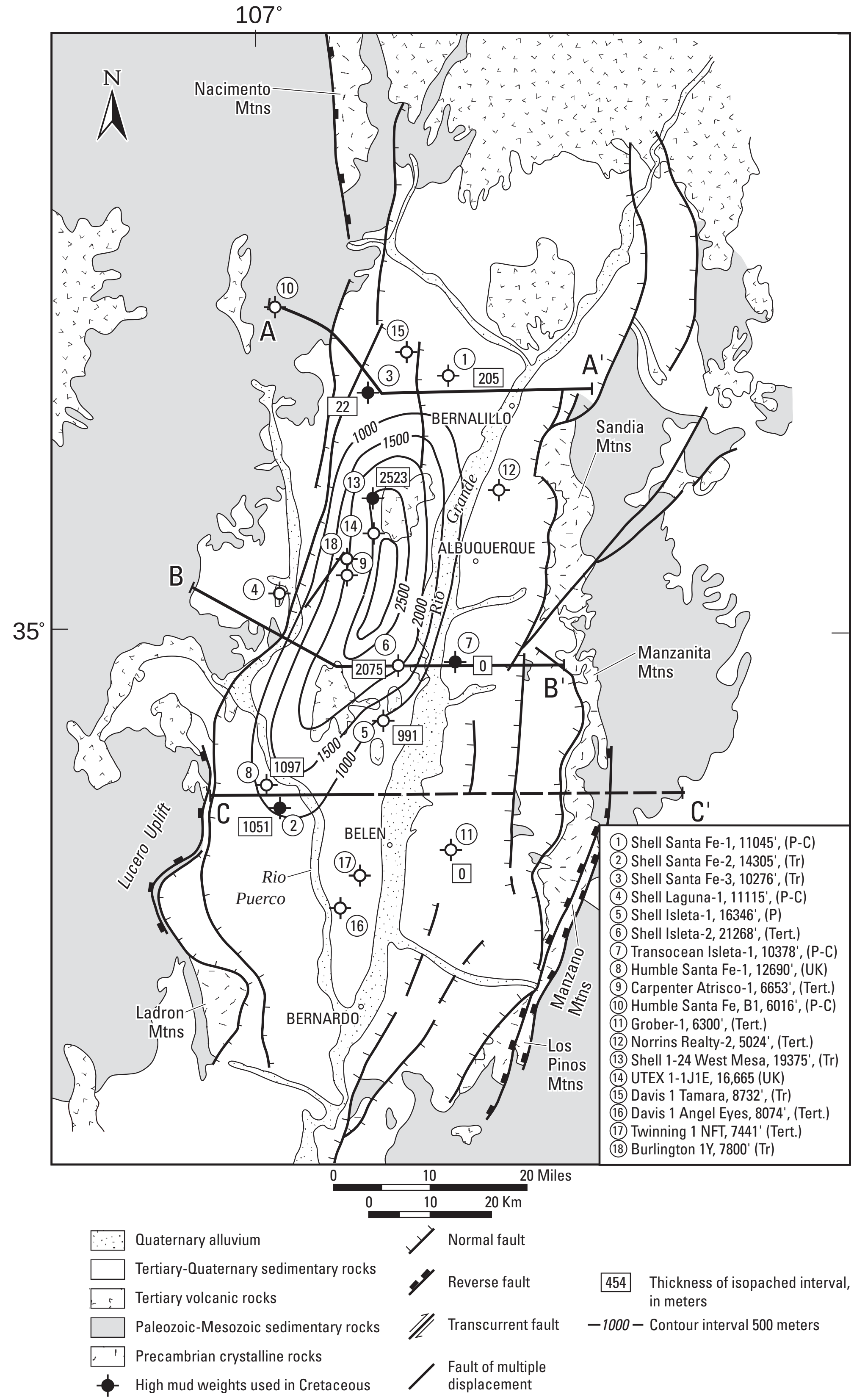


Figure 9. Isopach map of the combined Eocene Galisteo and Baca Formations and unnamed “unit of Isleta No. 2 well” (upper Eocene to upper Oligocene?) of Lozinski (1994) in the Shell No. 2 Isleta well in sec. 16, T. 8 N., R. 2 E. All thickness data used is from Lozinski (1994, his table 1). The isotherm assumes that the average present-day geothermal gradient of 2.0°F/100 ft (3.67°C/100 m) (see fig. 8).

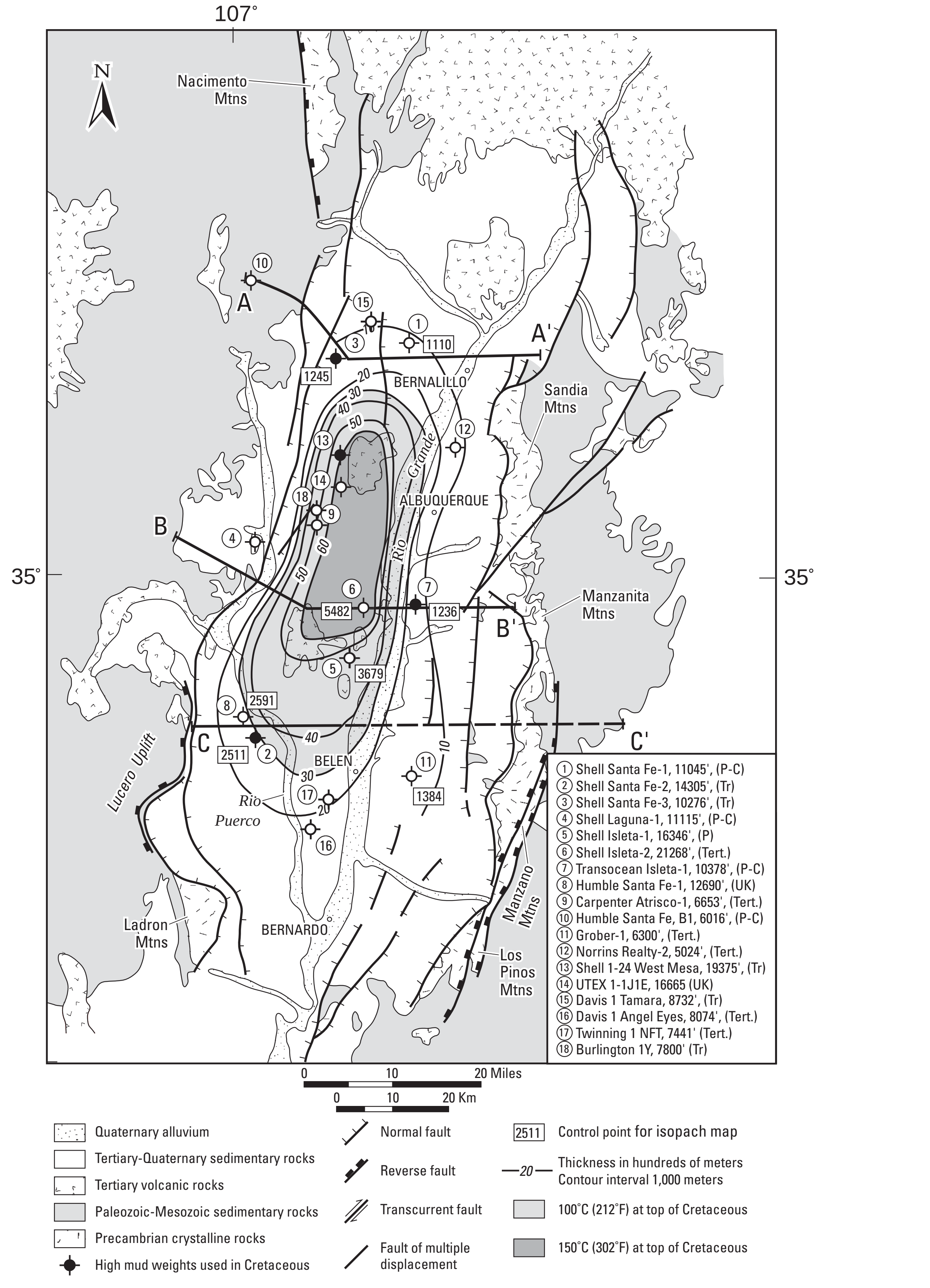


Figure 10. Isopach map of the total present-day thickness of Tertiary rocks in the Albuquerque Basin using subsurface drill-hole data of Lozinski (1994, his table 1). Tertiary faults are ignored, and, hence, the isopach map is generalized. The approximate areas where the top of the Cretaceous has achieved temperatures of 100°C and 150°C (212°F and 302°F) at the present are shaded. The isotherms assume an average present-day geothermal gradient of 2.0°F/100 ft (3.67°C/100 m) (see fig. 7).

within the standard Western Interior Cretaceous biozones in the area of the Albuquerque Basin but have been extensively studied in the San Juan Basin to the north. In the eastern part of the San Juan Basin, the Dakota Sandstone is within the *Acanthoceras amphibolum* biozone (Dane, and others, 1966), which has been dated at about 95 million years (Obradovich, 1993). The Point Lookout Sandstone falls near the top of the *Scaphites hippocrepis* zone (Gill and Cobban, 1966), which is dated at about 81.5 million years (Obradovich, 1993). The top of the Menefee Formation in the Albuquerque Basin is assumed to be in the *Baculites obtusus* ammonite zone, which is about the age of the top of the Menefee in the easternmost part of the San Juan Basin (Gill and Cobban, 1966). Age of the *Baculites obtusus* zone is 80.5 million years (Obradovich, 1993).

The thickness of the interval from the top of the Dakota Sandstone to the top of the Point Lookout Sandstone varies from 2,071 ft (631 m) in the Shell No. 1-24 West Mesa well to 2,593 ft (790 m) in the Shell No. 3 Santa Fe well (table 3). This is similar to the San Juan Basin, where Law (1992) reported thicknesses of 2,020 ft (616 m) and 2,200 ft (671 m) for the same interval (Law, 1992, figs. 6 and 7). The interval from the top of the Point Lookout to the top of the Cretaceous interval varies much more widely—from 0 ft in the Shell No. 1-24 Mesa well to 2,070 ft (631 m) in the Shell No. 3 Santa Fe well (table 3). This variation is due to differences in the amount of section removed beneath the Cretaceous-Tertiary unconformity. The same interval in the two wells cited by Law (1992) in the San Juan Basin varies from 2,980 ft (908 m) for the well on the south flank of the basin to 4,020 ft (1,225 m) for the well near the basin trough.

As in the Albuquerque Basin, different amounts of erosion beneath the Cretaceous-Tertiary unconformity in the San Juan Basin are largely responsible for this variation. Law (1992) estimated that about 300 ft (90 m) of section had been removed beneath the Cretaceous-Tertiary unconformity at a location near the basin trough, for a total original thickness of 4,320 ft (1,317 m) for the post Point Lookout section. Law also estimated that about 750 ft (230 m) of section had been removed beneath the unconformity at the location on the south flank of the basin, for a total original thickness of 3,730 ft (1,137 m) of post-Point Lookout Cretaceous rocks. For the Albuquerque Basin reconstructions, we assume an original thickness of 4,000 ft (1,220 m) of post-Point Lookout Sandstone Cretaceous rocks.

Figure 11 shows the sediment thicknesses and ages used in the burial reconstructions of the three wells. Age of the oldest rocks above the Cretaceous-Tertiary unconformity is Eocene (Lozinsky, 1994). An age of 50 million years is assumed for the oldest Eocene strata at all three wells modeled. These Eocene strata are also present on the flanks of the Albuquerque Basin and predate the onset of rifting. It is assumed that downcutting of Cretaceous strata beneath the unconformity began at the end of the Cretaceous (66 Ma) and continued at an even pace until 50 million years ago. For two wells, the Shell No. 3 Santa Fe and the Shell No. 1 Santa Fe, continuous deposition at a constant rate is assumed from 50 Ma to the present. Somewhat more data is available for the Shell 1-24 West Mesa well. According to Lozinski (1994), 1,109 ft (338 m) of strata were deposited by late Eocene time (40 Ma). An additional 7,169 ft (2,185 m) of strata was deposited between 40 Ma and the end of the Oligocene, at 25 Ma. The remaining 8,540 ft (2,603 m) of fill was deposited between 25 Ma and the present. Geothermal gradients used are 1.9°F/100 ft for the No. 3 Santa Fe well, 2.1°F/100 ft for the Santa Fe No. 1 well, and 1.7°F/100 ft for the 1-24 West Mesa well.

The burial reconstructions indicate that, in two of the wells (the Shell No. 3 Santa Fe and the Shell No. 1 Santa Fe), potential source rocks in the Mancos Shale and overlying Cretaceous section are immature and have not generated significant hydrocarbons (figs. 12, 13). In the third well, the Shell No. 1-24 West Mesa, hydrocarbon generation began at the base of the Mancos Shale about 20 million years ago (figs. 14, 15). Cretaceous source rocks had not generated significant amounts of hydrocarbons prior to the onset of rifting and creation of the Albuquerque Basin in the Oligocene. The onset of significant hydrocarbon generation in the Shell No. 1-24 West Mesa well corresponds to a temperature of about 212°F (100°C). Using an average geothermal gradient of 2.0°F/100 ft (3.3°C/100 m) for the basin, this temperature would occur at a depth of about 8,350 ft. (2,545 m). The Cretaceous section has been buried to this depth over a large area of the Albuquerque Basin (fig. 10).

Formation Pressures

Basin-centered gas accumulations are typically abnormally overpressured or abnormally underpressured, with overpressuring the result of volume increases during hydrocarbon generation and underpressured conditions developing during uplift and cooling. Because the Albuquerque Basin is currently at maximum burial and heating, it is unlikely that any basin-centered accumulation there would be underpressured. If overpressured conditions exist in the basin, then a basin-centered accumulation may be present. The most reliable formation-pressure information is obtained from drill-stem tests. Only 2 of the 10 deepest wells in the basin had a reliable drill-stem test in the Cretaceous section. The Dakota Sandstone was tested in the Shell 1 Laguna-Wilson Trust well (fig. 3) at a depth of 3,600 to 3,651 ft (1,097–1,113 m). The test recovered 48 barrels of water. Shut-in pressures indicate a normal hydrostatic fluid pressure gradient of 0.43 psi/ft. The Shell No. 1 Santa Fe well also tested the Dakota Sandstone, but at a much greater depth of 6,720 to 6,753 ft (2,048–2,053 m). This test recovered 5,172 ft (1,576 m) of water. Shut-in pressures indicate a fluid-pressure gradient of 0.43 psi/ft (normal hydrostatic pressure). The normally pressured water in the shallow test would be expected, as a basin-centered accumulation would not be expected at this depth. The deeper water test at more than 6,700 ft (2,400 m) is problematical. Active gas

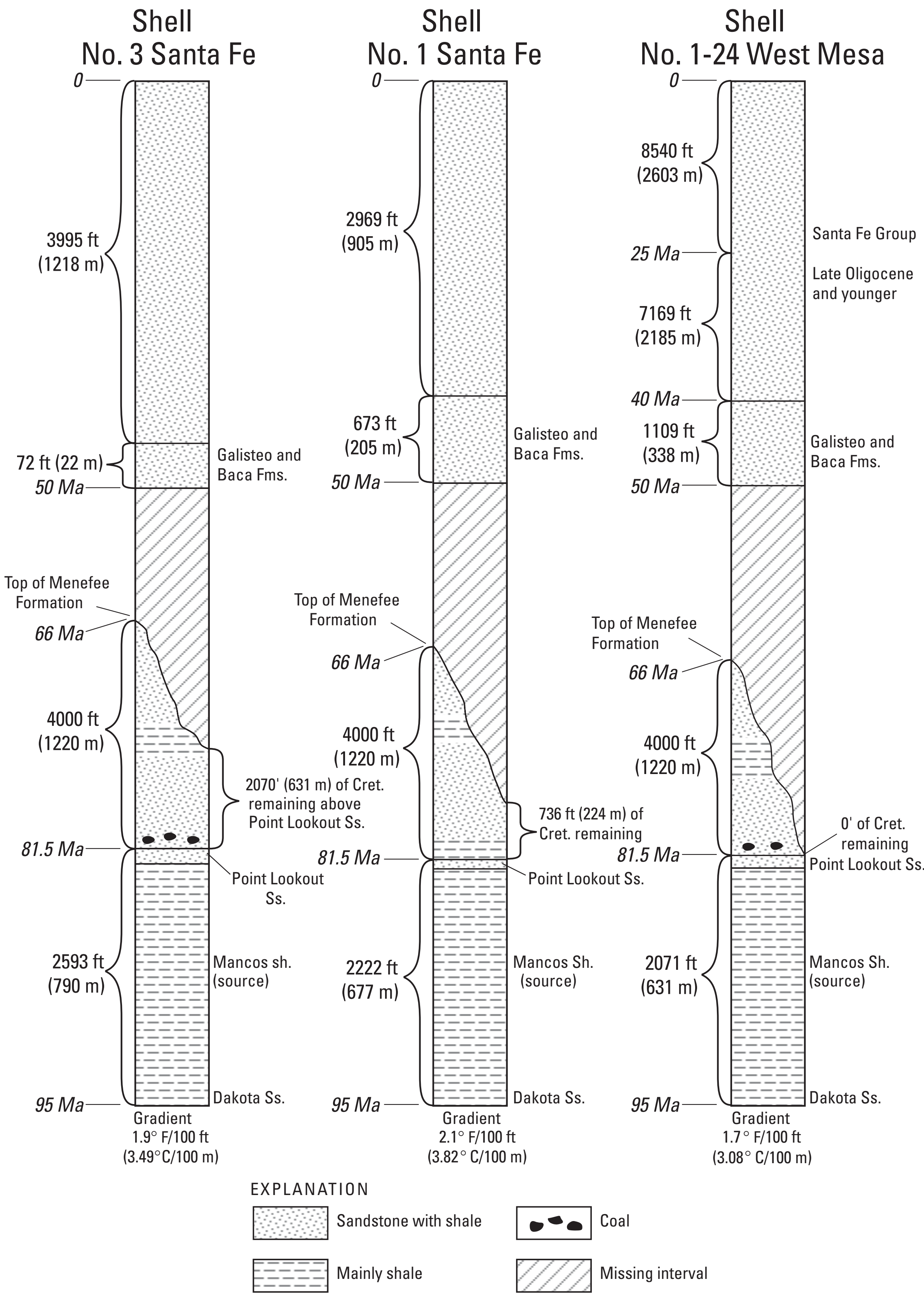


Figure 11. Stratigraphic diagrams showing present-day thicknesses and ages of rocks from the Dakota Sandstone to the present in the three wells used for burial reconstructions. Location of wells shown on figures 3, 8, 9, or 10. Vertical scale is variable.

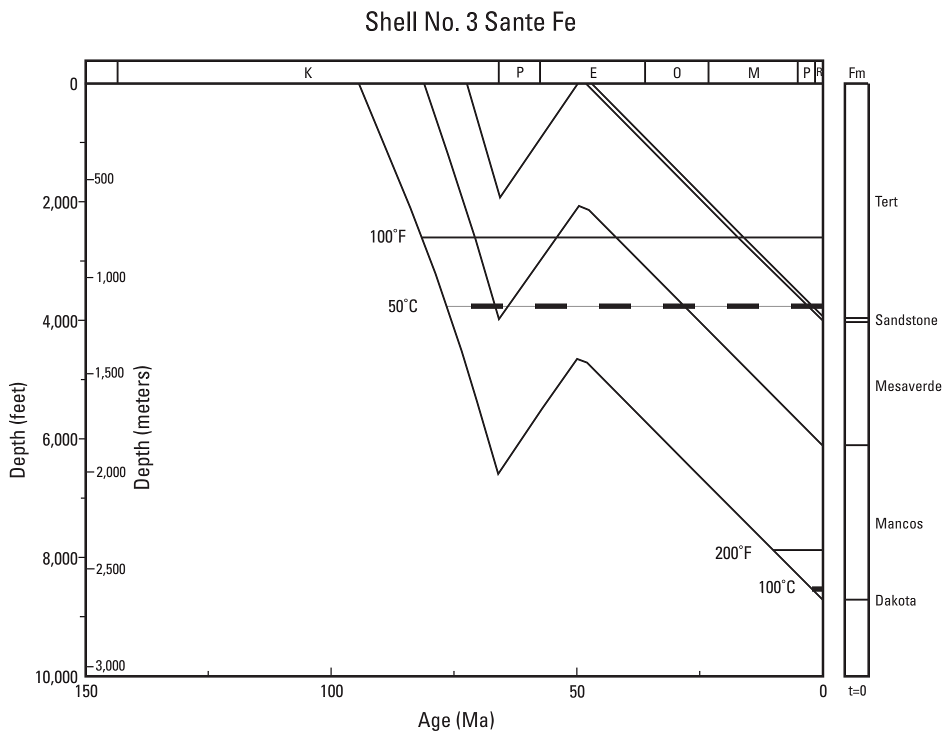


Figure 12. Burial reconstruction showing depths and temperatures for the Shell No. 3 Santa Fe well in sec. 28, T. 13 N., R. 1 E. Location of well shown on figures 3, 8, 9, or 10.

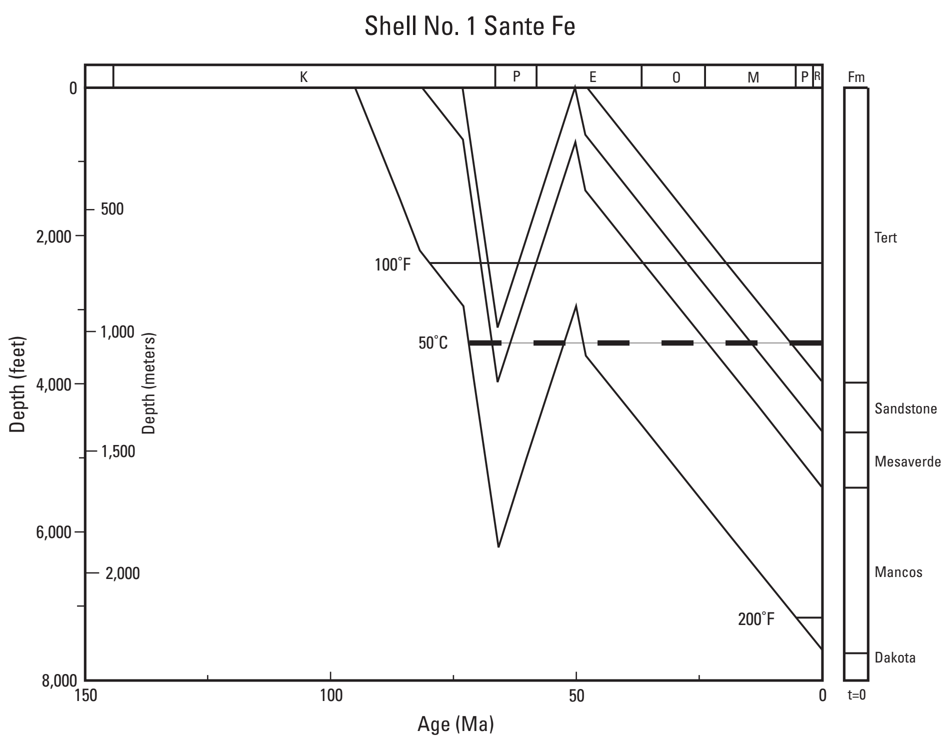


Figure 13. Burial reconstruction showing depths and temperatures for the Shell No. 1 Santa Fe well in sec. 18, T. 13 N., R. 3 E. Location of well shown on figure 3.

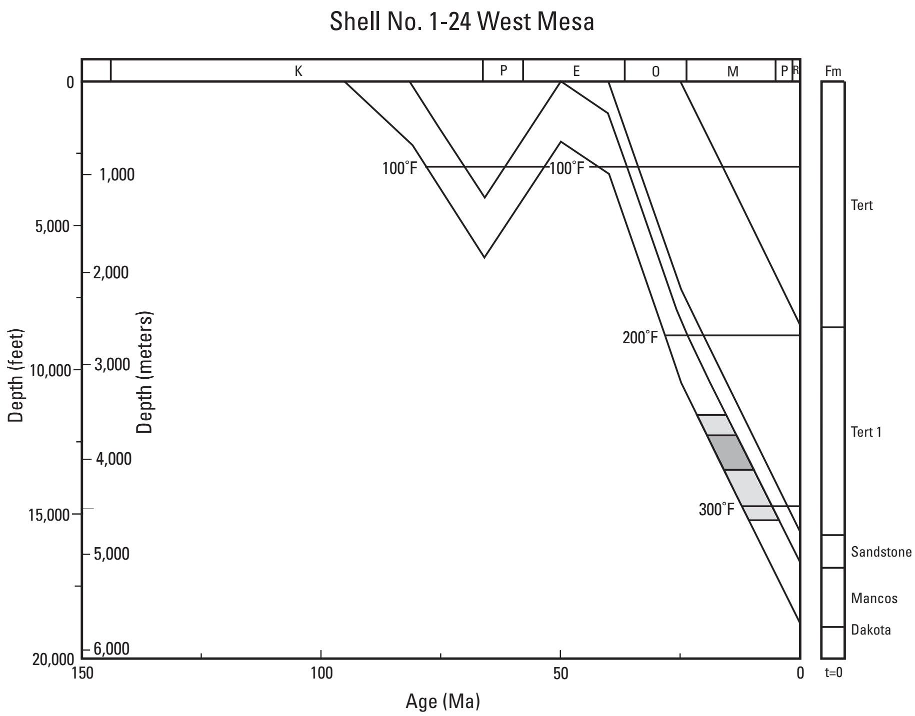


Figure 14. Burial reconstruction showing depths and temperatures in for the Shell No. 1-24 West Mesa well in sec. 24, T. 11 N., R. 1 E. Location of well shown on figure 3. Light shaded area brackets period of gas generation by Cretaceous source rocks. Dark shaded area brackets period of peak gas generation by Cretaceous source rocks.

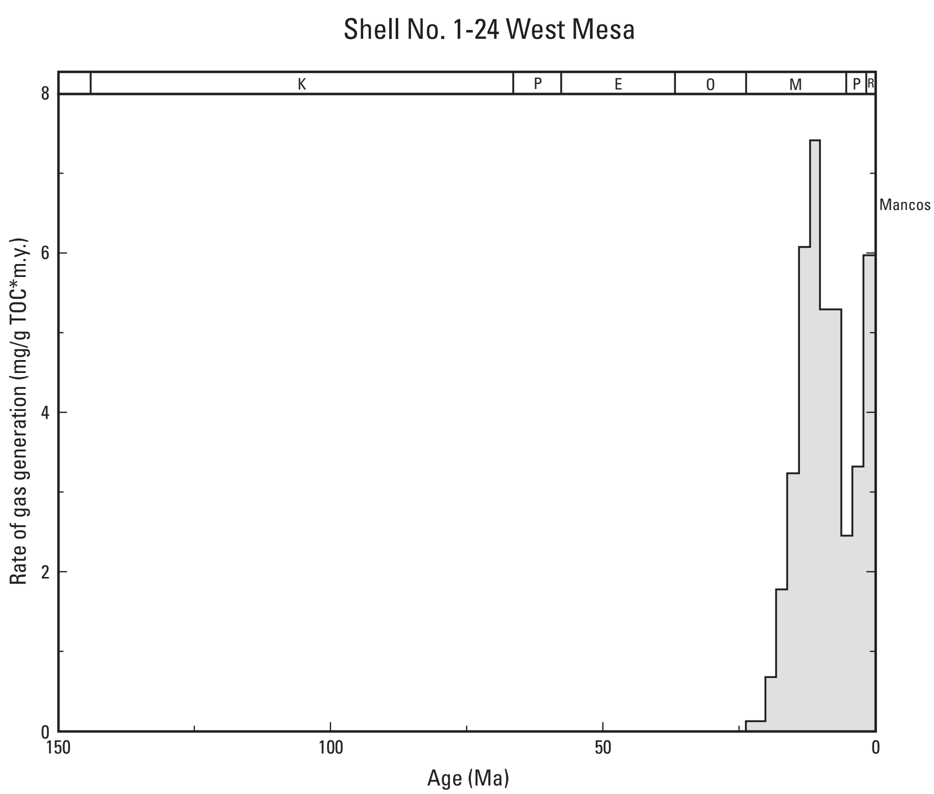


Figure 15. Rate of gas generation in milligrams (mg) per gram (g) of total organic carbon (TOC) per million years (m.y.) at the base of the Cretaceous Mancos Shale in the Shell No. 1-24 West Mesa well (sec. 24, T. 11 N., R. 1 E). The second peak, which began about 5 Ma, is due to the breakdown of oil to gas. Location of well shown on figures 3, 8, 9, or 10.

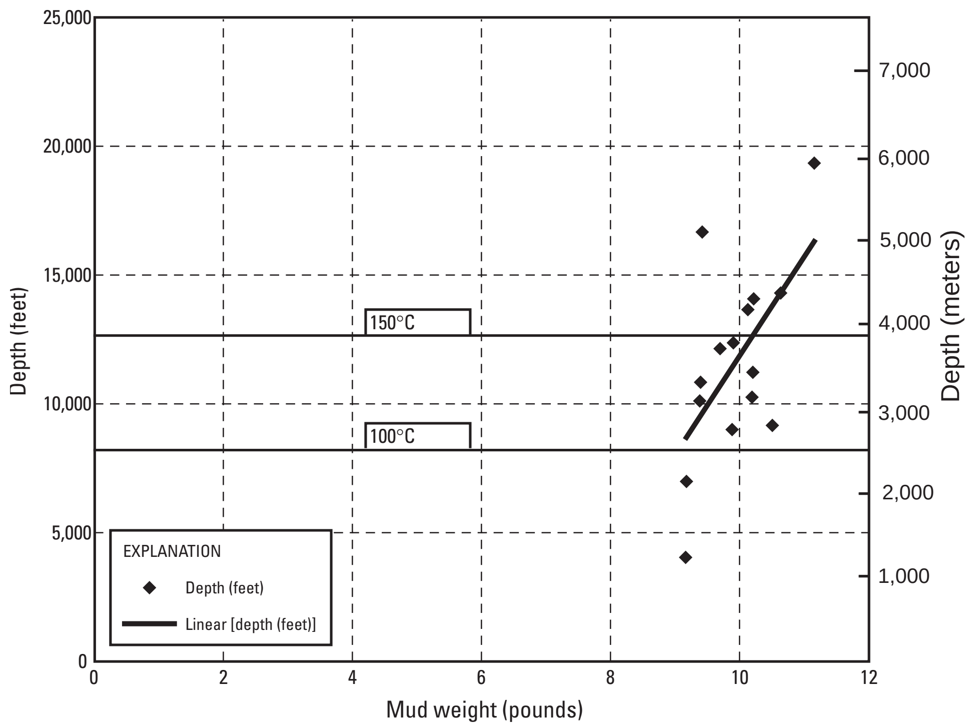


Figure 16. Graph of mud weight versus depth for the eight wells listed in table 4. Approximate depth to the 100°C and 150°C (212°F and 302°F) isotherms were calculated assuming an average geothermal gradient of 2.0°F/100 ft (3.67°C/100 m) for the entire Albuquerque Basin. Heavy line is best-fit linear relationship between mud weight and depth.

Table 5. List of mud weights recorded during logging runs for selected deep tests in the Albuquerque Basin.

[Locations shown on figures 3, 8, 9, and 10]

Well no.	Well name	Location	Depth in ft (m)	Mud weight (lb)
4	Shell 1 Laguna Wilson	8-9N-1W	3989 (1,216)	9.2
2	Shell 2 Santa Fe	29-6N-1W	11,238 (3,425)	10.2
			14,305 (4,360)	10.6
10	Humble 1 Santa Fe	18-6N-1W	10,095 (3,077)	9.4
			10,853 (3,308)	9.4
			12,160 (3,706)	9.7
7	Transocean 1 Isleta	8-8N-3E	9,175 (2,797)	10.5
3	Shell 3 Santa Fe	28-13N-1E	8,994 (2,741)	9.9
			10,276 (3,132)	10.2
1	Shell 1 Santa Fe	18-3N-3E	6,937 (2,114)	9.2
13	Shell 1-24 West Mesa	24-11N-1E	19,350 (5,898)	11.1
14	Utex 1-1J1E	1-10N-1E	16,665 (5,079)	9.4
5	Shell 1 Isleta	7-7N-2E	12,396 (3,778)	9.9
			13,675 (4,168)	10.1
			14,100 (4,298)	10.2

generation and the presence of a basin-centered gas accumulation might be expected at this depth.

Less reliable formation-pressure information can be obtained from mud weights measured during drilling. A continuous record of mud weights used is typically recorded on mud logs made while drilling. Spot recordings of mud weights at the time of logging runs are listed on the header information on geophysical logs. Table 5 is a list of mud weights from log headers for nine of the deepest wells in the basin. Mud weights versus depth for these wells is plotted on figure 16. A mud weight of 10 lb corresponds to a pressure gradient of 0.519 psi/ft, or moderate overpressuring. High mud weights—indicating overpressuring—were used while drilling through the Cretaceous section in five of the deeper wells in the basin.

Conclusions

It appears likely that the deep central portion of the Albuquerque Basin contains a basin-centered gas accumulation that is developing at the present time. The area contains a largely intact Cretaceous section similar to the Cretaceous interval that contains a basin-centered accumulation in the nearby San Juan Basin. High mud weights are typically used while drilling the Cretaceous interval in this area, suggesting some degree of overpressuring. Gas shows have been reported while drilling through the Cretaceous interval throughout this area. Attempts to complete gas wells in the Cretaceous have resulted in subeconomic quantities of gas, primarily because of low permeabilities. Little water has been reported. All of these characteristics are typical of basin-centered gas accumulations in other Rocky Mountain basins. Burial reconstructions suggest that large amounts of gas are being generated by Cretaceous source rocks at the present time. This is different from other Rocky Mountain basins where rates of gas generation have declined significantly since regional uplift and downcutting began about 10 million years ago. This regional uplift was offset in the Albuquerque Basin by rapid subsidence.

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