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BURLINGTON RESOURCES

SAN JUAN DIVISION

August 12, 1996 *Certified Mail No. Z-382-118-155*

Energy, Minerals and Natural Resources Department
Oil Conservation Division
Attn: Mr. William LeMay
2040 S. Pacheco
Santa Fe, NM 87505

Re: **Name Change Notification**

Dear Mr. LeMay:

This letter is provided to inform you that Meridian Oil Inc. recently had a business name change to Burlington Resources Oil and Gas Company effective July 11, 1996. Please note that UIC permits and discharge plans have not been transferred and no change of ownership has occurred. All UIC permits and discharge plans issued to and currently under review for Meridian Oil Inc. will now be associated with the Burlington Resources Oil and Gas Company name. Attached is a list of UIC permits and discharge plans issued to Meridian Oil Inc. and applications under review.

If you have any questions regarding this notice, please feel free to contact me at (505) 326-9841.

Sincerely,

Keith M. Boedecker

Keith M. Boedecker
Sr. Staff Environmental Representative

cc: OCD - Aztec Office
Keith Baker - BR/File 6.07

OCD ISSUED UIC PERMITS and DISCHARGE PLANS

UNDERGROUND INJECTION CONTROL PERMITS

No.	Injection Well	OCD UIC Permit No.
1.	Ute No. 1	Order SWD-176
2.	San Juan 30-6 No. 112Y	Order SWD-305
3.	Cedar Hill SWD No. 1	Order SWD-337
4.	Pump Canyon	Order SWD-344
5.	Middle Mesa No. 1	Order SWD-350
6.	San Juan 30-6 No. 2	Order SWD-351
7.	San Juan 32-9 No. 5	Order SWD-432
8.	McGrath No. 4	OCD R-7370
9.	Jillson Federal No. 1	OCD R-10168

OCD DISCHARGE PLANS

No.	Facility	OCD Discharge Plan No.
1.	Gobernador Compressor Station	GW-56
2..	Pump Canyon Compressor Station	GW-57
3.	Hart Canyon Compressor Station	GW-58
4.	Manzanares Compressor Station	GW-59
5.	Middle Mesa Compressor Station	GW-77
6.	Rattlesnake Compressor Station	GW-93
7.	Sims Mesa Compressor Station	GW-146
8	Pump Mesa Compressor Station	GW-148
9	Val Verde Gas Plant	GW-169
10	Arch Rock Compressor Station	GW-183
11.	Sandstone Compressor Station	GW-193
12.	Frances Mesa Compressor Station	GW-194

OCD DISCHARGE PLANS UNDER REVIEW

No.	Facility	OCD Discharge Plan No.
1.	Buena Vista Compressor Station	Not Assigned
2.	Cedar Hill Compressor Station	Not Assigned
3.	Quinn Compressor Station	GW-239

nearly 200 ft higher than in the Morrison Formation (Mobil Oil Corporation, 1978, table 2). Although water levels in the Morrison have declined in recent years as a result of uranium-mine dewatering and pumping for Crownpoint's water supply, hydraulic-head differences probably existed prior to development. Because recharge areas for the Dakota and Morrison are at similar altitudes, the head differences probably reflect better lateral flow in the Morrison Formation toward discharge points because of higher transmissivities, better continuity of the sandstones, or both. The fact that hydraulic-head differences persist is an indication that a relatively low vertical permeability exists in the confining layer between the two units.

Very few aquifer tests have been performed on the Dakota Sandstone alone because most wells also produce from other sandstones above or below the Dakota. Dames and Moore (1977) reported transmissivities of 44 and 85 ft^2/d for two tests (19.11.31.131) northeast of Crownpoint (table 5). Results of specific-capacity tests indicate that transmissivity values are generally less than 50 ft^2/d (table 5).

Berg (1979, p. 899) gave reservoir characteristics for the Dakota Sandstone in the Lone Pine oil and gas field near Hospah. Here, fluvial sandstones within the Dakota have the highest hydraulic conductivity, ranging from approximately 0.7 to 1.5 ft/d. A net sandstone thickness of about 70 ft given for the Lone Pine field would give transmissivities of 49 to 105 ft^2/d.

Much lower values of transmissivity can be expected in oil- and gas-producing horizons in deeper parts of the basin. The hydraulic conductivity averages approximately 0.03 ft/d in oil-producing horizons (based on permeability data of Reneau and Harris, 1957, p. 43) and 4×10^{-4} ft/d in gas reservoirs (Deischl, 1973, p. 168).

WATER QUALITY AND USE—Specific conductance increases from less than 2,000 μmhos near recharge areas to more than 10,000 μmhos in deeper parts of the basin (fig. 67, sheet 7, pocket). In those areas where data are available, the specific conductance of water from the Dakota is generally higher than that of water from the underlying Morrison Formation. Scattered stock and domestic wells produce water from the Dakota Sandstone. Many of the wells that produce from the Dakota, however, are also completed in overlying or underlying rocks or both.

Morrison Formation (Late Jurassic)

The Morrison Formation is the uppermost Jurassic unit present in the basin and is a major source of both uranium and water in the Grants uranium region. This unit lies at depths of 1,500–3,000 ft on the marginal platforms but dips to depths of nearly 9,000 ft in the basin center (figs. 68 and 69, sheet 7, pocket).

GEOLOGIC CHARACTERISTICS—This sequence of nonmarine sandstone, mudstone, and minor limestone was defined by Eldridge (Emmons and others, 1896) for exposures at the town of Morrison, Jefferson County, Colorado. The Morrison consists of four members (in ascending order): the Salt Wash Sandstone Member, the Recapture Shale Member, the Westwater Canyon Sandstone Member, and the Brushy Basin Shale Member.

The Salt Wash Sandstone Member, named by Lupton (1914) for exposures 30 mi southeast of the town of Green River, Grand County, Utah, is restricted to the extreme northwest part of the San Juan Basin. The Salt Wash consists of sandstone and mudstone with lenses of conglomerate. The sandstone is a fine-grained, mature subarkose (tables 8 and 9). This member is approximately 200 ft thick near the Four Corners, but thins southward, pinching out completely just north of Toadlena. In the subsurface, east and southeast of the Four Corners, the Salt Wash intertongues with and grades laterally into the upper part of the Bluff Sandstone (Sears and others, 1974).

The Recapture Shale Member was named by Gregory (1938) for exposures near the town of Bluff, San Juan County, Utah, and redefined by Stokes (1944). This member is present more or less throughout the San Juan Basin and consists mainly of interbedded, red shale and white sandstone. Thickness is approximately 125–150 ft in the north, 125–300 ft in the east and southeast (Sears and others, 1974). Like the Salt Wash, the Recapture also thins southward and southeastward, pinching out south of Gallup and southeast of Grants (Granger, 1968).

The Westwater Canyon Sandstone Member was named by Gregory (1938) and redefined by Harshbarger and others (1957) for exposures south of Blanding, Utah. This sequence of sandstone, conglomeratic sandstone, and mudstone is both the major ore horizon and principal aquifer in the Grants uranium region (fig. 70). The Westwater Canyon consists mainly of fine- to medium-grained, immature to submature, arkose to lithic arkose (tables 8 and 9). The member thins southward and eastward and has an average thickness of 250 ft (Sears and others, 1974; Kelly, 1977).

The Brushy Basin Shale Member, also named by Gregory (1938) for exposures near Blanding, Utah, is an interval of mudstone, sandstone, conglomeratic sandstone, and limestone. The sandstone is generally fine, mature to supermature arkose to subarkose (tables 8 and 9). The major ore-bearing sandstone in the Brushy Basin has been named the Jackpile ore-bearing bed for exposures in the Jackpile mine near Laguna, New Mexico (Freeman and Hilpert, 1956). Flesch (1974) described what he believed to be a correlative sandstone near San Ysidro to the north. Sandstones from the

Figure 70—WESTWATER CANYON MEMBER OF MORRISON FORMATION EXPOSED ON NORTHWEST SIDE OF NM-53, APPROXIMATELY 1.5 MI SOUTHWEST OF INTERSECTION WITH NM-509. View to northwest in SW¼ sec. 21, T. 13 N., R. 9 W.

Brushy Basin are fine- to medium-grained, submature to supermature arkose to subarkose. Average thickness of the Brushy Basin Shale Member is 185 ft; this member is not present in the southwest part of the basin (Sears and others, 1974).

The Morrison Formation generally intertongues with the underlying Cow Springs Sandstone or Bluff Sandstone. Total thickness of the Morrison ranges from 330 to 915 ft (fig. 71, sheet 7, pocket).

HYDROLOGIC PROPERTIES—The potentiometric surface of ground water in the Westwater Canyon Sandstone Member is shown in fig. 72 (sheet 7, pocket). In 1978, a combined discharge of about 16,000 gpm was produced from uranium mines in the Morrison Formation (J. G. Dudley, geohydrologist, New Mexico Environmental Improvement Division, personal communication, 1979). These and other withdrawals have caused water-level declines as shown in fig. 73.

Transmissivity of the Morrison Formation does not exceed 500 ft ^{2}/d (table 5, fig. 74). The highest values occur in the southern part of the basin northeast of Gallup and southeast of Ambrosia Lake. Values of transmissivity have been previously reported by Kelly (1977) and Jobin (1962). Because the grain size and percentage of sand in the Westwater Canyon Member decreases toward the northeast (Ridgely and others, 1978, p. 37; Sears and others, 1974, plate XXIII), transmissivity can be expected to decrease in that direction. Transmissivity data shown in fig. 74 (sheet 7, pocket), although not conclusive, tend to confirm this trend.

WATER QUALITY AND USE—Some of the lowest specific conductances for ground water in the San Juan

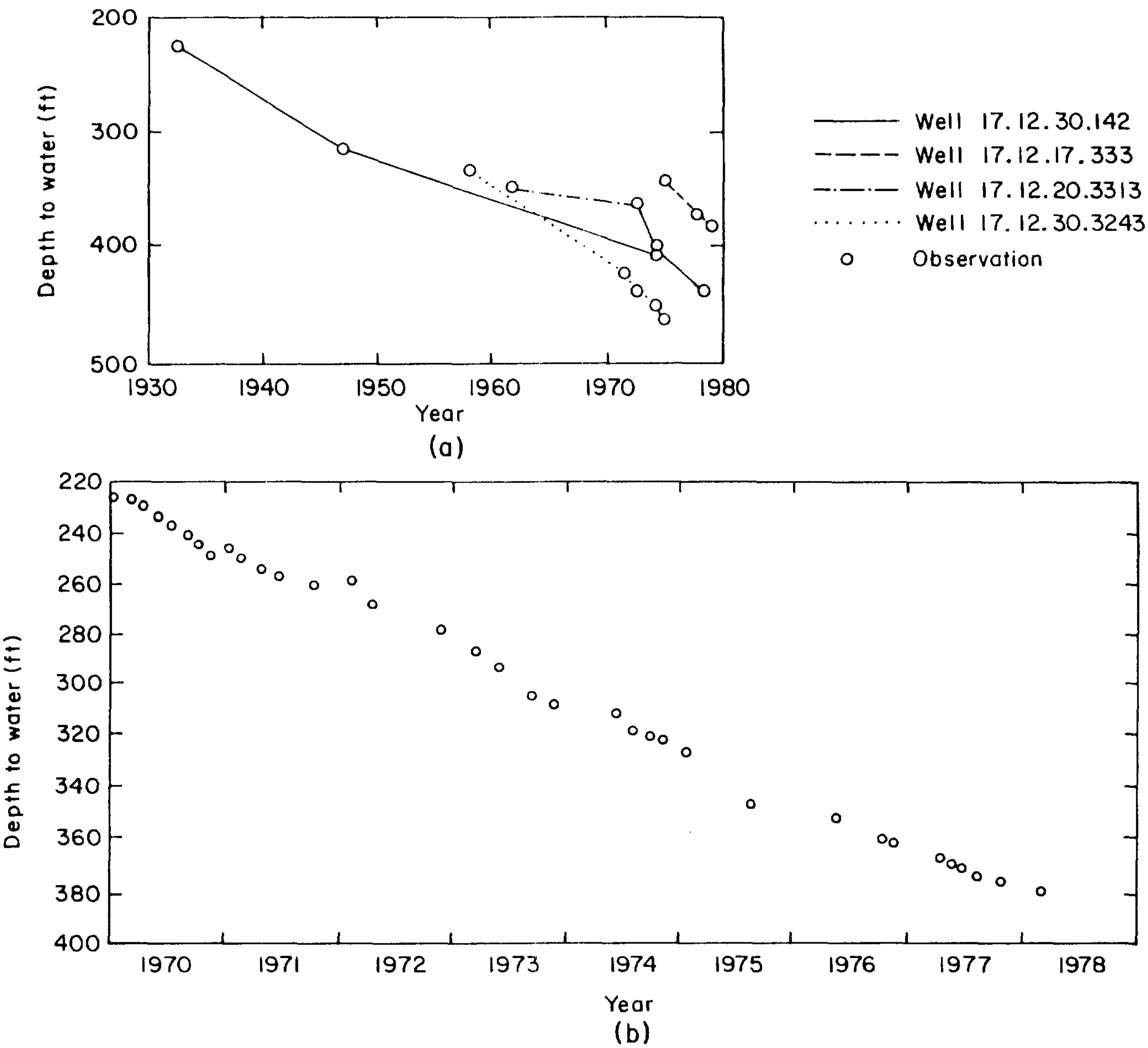

Figure 73—WATER-LEVEL DECLINES IN DAKOTA SANDSTONE AND MORRISON FORMATION.
a) Morrison Formation near Crownpoint
b) Dakota and Morrison at abandoned mine shaft (16.16.17.2141); water level in 1968 before dewatering of Church Rock mines reported at 114 ft below land surface (Hiss, 1977, p. 53).

Basin are associated with the Morrison Formation. Values of less than 1,000 μmhos occur in the Crownpoint-Church Rock area and near the Chuska Mountains between Tohatchi and Shiprock (fig. 75, sheet 7, pocket).

The specific conductance of Morrison water may exceed 10,000 μmhos in the northeast part of the study area and near outflow points. A sharp transition is apparent in the northwest part of the basin where water flowing toward the San Juan River from the northeast merges with flow from the Chuska Mountains. A relatively high conductance might be expected near the Rio Puerco as a result of flow from the northwest and possibly from vertical leakage from deeper units.

The Morrison Formation is the source of the public water supply for the village of Crownpoint. The city of Gallup also has numerous wells that are completed in both the Gallup Sandstone and the Morrison Formation (West, 1957, table 4). Several wells south of Crownpoint also produce water from the Morrison for domestic use. Numerous flowing wells, some of which are converted uranium-test holes, produce water for stock and domestic use along the western edge of the basin between Crownpoint and Shiprock.

Cow Springs-Bluff Sandstone (Late Jurassic)

These two formations are treated together because they are closely related stratigraphically and probably behave as a single unit hydraulically.

GEOLOGIC CHARACTERISTICS—The name "Cow Springs Sandstone" is generally credited to Harshbarger and others (1951). The type area is the north face of Black Mesa near Cow Springs Trading Post, Coconino County, Arizona. This unit intertongues with the Summerville Formation and the lower part of the Morrison Formation. Although not analyzed separately in this study, the Cow Springs is generally a fine-grained, arkosic sandstone (fig. 76). It is 240 ft thick at Lupton, Arizona, just across the state line, southwest of Gallup (Harshbarger and others, 1951).

The Bluff Sandstone was named by Baker and others (1936) for exposures along the San Juan River at the town of Bluff, San Juan County, Utah. Harshbarger and others (1957, p. 3) believed the Bluff to be "a tongue of the Cow Springs but because of its homogeneous and mappable character and its areal extent, it [was] considered a separate formation and assigned to the San Rafael Group." The Bluff is a medium-grained, mature arkose (tables 8 and 9). Thickness reportedly ranges from a few feet to approximately 300 ft (Harshbarger and others, 1957). In our study, thickness was not determined separately for the Bluff unit. Observed thickness of the Cow Springs-Bluff Sandstone and Summerville Formation combined (fig. 77, sheet 6, pocket) ranges from 60 to 200 ft.

The Cow Springs and Bluff generally display an intertonguing relationship with both the underlying Summerville Formation and the overlying Recapture Shale Member of the Morrison Formation.

HYDROLOGIC PROPERTIES—The water in the Cow Springs-Bluff has an origin and flow pattern similar to the water in the overlying Morrison Formation, but significant hydraulic-head differences exist between the two units in some areas. For example, Mercer and Cooper (1970, p. 78) reported that in the Munoz 1 test hole north of Gallup (16.18.17.122) the water level in the Cow Springs Sandstone was nearly 200 ft higher than the water level in the overlying Morrison Formation.

Figure 76—COW SPRINGS SANDSTONE, NORTHWEST OF CHURCH ROCK MINE ROAD, 1.5 MI NORTH OF CHURCH ROCK. View to northwest in SE¼ sec. 1, T. 15 N., R. 17 W.

Although the Cow Springs-Bluff is a fairly thick and continuous sequence consisting predominantly of sandstone, the transmissivity is relatively low. Jobin (1962, p. 55) reported transmissivities of about 50 ft²/d for this aquifer in most of the San Juan Basin, increasing to as much as 300 ft²/d near the Four Corners. These values appear high when compared with a value of 3 ft²/d (Cooley and others, 1969, p. 46) for one aquifer test at an unspecified location and a yield of less than 2 gpm reported by Mercer and Cooper (1970, p. 471) in the Munoz 1 test hole.

WATER QUALITY AND USE—The specific conductance of water from the Cow Springs-Bluff probably is less than 2,000 μmhos in or near outcrops on the southern and western margins of the basin. No data are available for greater depths except in the Gallup area where Mercer and Cooper (1970, p. 78) reported a value of 4,300 μmhos. No wells are known to derive their water exclusively from this aquifer and those wells tapping this unit are also completed in the underlying Entrada or overlying Morrison.

Entrada Sandstone (Late Jurassic)

The Entrada Sandstone forms the distinctive red cliffs at Red Rock State Park east of Gallup and along the southern basin margin north of I-40. Depth to the top of the Entrada ranges from generally less than 4,000 ft on the marginal platforms to 9,310 ft in the basin center (figs. 78 and 79, sheet 6, pocket).

GEOLOGIC CHARACTERISTICS—This unit was named by Gilluly and Reeside (1926) for exposures in the northern part of the San Rafael Swell, in southeast Utah. Nomenclature of the Entrada in New Mexico has had a problematical history. Strata now included in the Entrada at Fort Wingate, on the southern margin of the basin, were originally named the Wingate Sandstone by

Dutton (1885). After intermediate revisions by various workers, Baker and others (1947) finally replaced the Wingate there with the Entrada; the Wingate is no longer recognized in the San Juan Basin (Green and Pierson, 1977; O'Sullivan, 1977). In the San Juan Basin, the Entrada consists of three members: a lower sandstone member (named the Iyanbito Member by Green, 1974), a middle siltstone member, and an upper sandstone member (Harshbarger and others, 1957). The Iyanbito Member is present only in the southern part of the basin. The middle and upper members are generally present throughout the basin. The upper member is generally a fine-grained, mature to supermature, subarkose to lithic arkose (tables 8 and 9). Thickness of the upper member is approximately 167 ft along the Church Rock mine road (fig. 80), 135 ft north of Prewitt, and 133 ft at Haystack Mountain; at San Ysidro the combined thickness of upper and middle Entrada is 115 ft (Stone, 1979a). The thickness of the Entrada based on subsurface data is mapped in fig. 81 (sheet 6, pocket). The Entrada conformably to unconformably overlies the Chinle Formation.

HYDROLOGIC PROPERTIES—Transmissivity, as indicated by a few specific-capacity tests, is less than 50 ft^2/d along the southern edge of the basin but more than 100 ft^2/d near the basin center (J. W. Shomaker, consulting geologist, personal communication, 1974). Values of hydraulic conductivity ranging from 0.5 to 5 ft/d in oil wells (Fassett and others, 1977, p. 24), would substantiate transmissivities of 100 ft^2/d or more. Jobin (1962, p. 42) reported a similar range of from 130 to 350 ft^2/d for the Entrada in the study area.

WATER QUALITY AND USE—In many places in or near recharge areas, water in the Entrada has a specific conductance less than 1,500 μmhos (fig. 82, sheet 6, pocket). Specific conductance increases to more than 10,000 μmhos in deeper parts of the basin.

In an elongate area between Bisti and San Ysidro, the Entrada produces oil from several fields (Fassett and others, 1977, p. 23). Large quantities of saline water that has a specific conductance of between 10,000 and 20,000 μmhos are produced with the oil. Test wells in this area produce water similar in quality to that of water produced from oil wells.

A well at Sanostee produced fresh water from the Entrada, but the water was unusable because of associated oil and gas (Halpenny and Harshbarger, 1950, p. 19). Domestic and stock wells in the area between Smith Lake and Mariano Lake produce much of their water from the Entrada Sandstone. Generally, however, water from the Entrada is not suitable for drinking, especially in deeper parts of the basin.

Figure 80—ENTRADA SANDSTONE NORTHWEST OF CHURCH ROCK MINE ROAD, 0.5 MI NORTH OF CHURCH ROCK. View to north in NE¼ SE¼ sec. 11, T. 15 N., R. 17 W.

Deeper deposits (pre-Jurassic)

Although there has been extensive drilling for petroleum in the San Juan Basin, most of these wells bottom in the Cretaceous section, and thus little is known of the deeper deposits of the area. The pre-Jurassic rocks are generally too deep to play a significant part in the energy-resource development or to be used extensively for water supply. The following general statements are included merely for completeness.

CHINLE FORMATION (TRIASSIC)—The Chinle Formation crops out in a considerable area at the southern margin of the basin, forming a broad valley between the northern flank of the Zuni Mountains and the red cliffs of the Entrada Sandstone. The Chinle Formation was first described by Gregory (1917). Subdivisions proposed by Stewart (1957) for southeast Utah are generally applied in New Mexico, but not all members are present (fig. 83). Other members have been recognized on the east side of the basin by Wood and Northrop (1946). The Chinle consists of mudstone, sandstone (often pebbly), and limestone. Total thickness of the formation is reportedly 700–1,500 ft (Molenaar, 1977a). The Chinle disconformably overlies the San Andres Limestone.

Aquifer tests of the Sonsela Sandstone Bed of the Petrified Forest Member of the Chinle northeast of Prewitt (well 13.10.18.212) gave a transmissivity of >100 ft^2/d. Specific conductances of water from the Sonsela and the shallower Correo Sandstone Bed of the Petrified Forest Member at this well exceed 10,000 μmhos. Generally, water quality deteriorates rapidly with depth, making the water unacceptable for stock or domestic use, except in or very near outcrop areas.

GLORIETA SANDSTONE-SAN ANDRES LIMESTONE (PERMIAN)—These formations are grouped because they intertongue and behave as a single unit hydraulically. The Glorieta Sandstone and overlying San Andres Limestone form the northern flank of the Zuni uplift. The Glorieta Sandstone, named by Keyes (1915) for exposures on Glorieta Mesa, San Miguel County, New Mexico, consists of fine- to medium-grained, quartzose sandstone. Baars and Stevenson (1977, fig. 4) gave a thickness map for the Glorieta that shows that it thins northward and northeastward, pinching out at approximately the latitude of Lybrook and Nageezi. The San Andres Limestone was named by Lee (Lee and Girty, 1909) for exposures in Rhodes Canyon, San Andres Mountains, Socorro County, New Mexico. The San Andres Limestone consists of thin-bedded dolostone, massive, micritic limestone (often fossiliferous), and fine-grained clastic rocks (Baars and Stevenson, 1977). The San Andres also thins northward and pinches out in the southern part of the San Juan Basin (Baars, 1962). The Glorieta Sandstone conformably overlies the Yeso Formation.

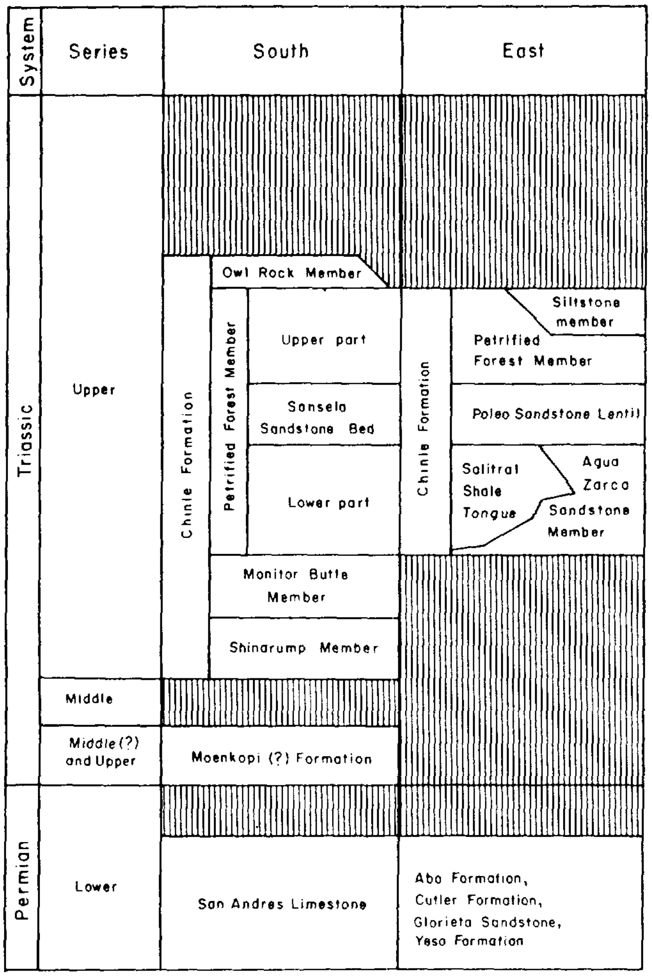

Figure 83—Stratigraphic nomenclature and correlation of Triassic and adjacent deposits in San Juan Basin (modified from O'Sullivan, 1977).

In the Grants–Bluewater area, dissolution of carbonate rocks has caused relatively high transmissivities. Gordon (1961, table 8) reported values ranging from 60,000 to 450,000 ft²/d. Near Fort Wingate, the transmissivity is considerably lower, ranging from 5 to 3,700 ft²/d (Shomaker, 1971, p. 36). A transmissivity of 90 ft²/d for a well at Smith Lake may be typical for areas away from outcrops and not subjected to dissolution of carbonates. The Glorieta-San Andres yielded less than 1 gpm to a test hole drilled by Sohio north of Laguna (L. Jacobson, geologist, Sohio, personal communication, 1975), indicating a very low transmissivity for this aquifer in the southeast part of the study area.

The specific conductance of water from this aquifer ranges from 500 to 3,300 μmhos in the Grants–Bluewater area (Gordon, 1961, table 10) and from 800 to 3,500 μmhos near Fort Wingate (Shomaker, 1971, p. 46). The Smith Lake well yielded water with a specific conductance of 960 μmhos. Iron and manganese concentrations in this well are relatively high, making the water unsuitable as a domestic supply unless it is treated (Robert Mayers, engineer, U.S. Public Health Service, personal communication, 1976). The Glorieta-San Andres aquifer is the principal source of water along I-40 between Grants and Gallup. The city of Grants derives its water from this aquifer.

YESO FORMATION (PERMIAN)—Lee (Lee and Girty, 1909) named the Yeso Formation for exposures of sandstone, red beds, and gypsum on Mesa del Yeso, Socorro County, New Mexico. According to Baars and Stevenson (1977), the marine evaporites of the Yeso thicken south from a line roughly connecting Gallup and Albuquerque but are missing north of this line. The Yeso of the San Juan Basin is, therefore, almost exclusively an interval of red beds. The Yeso conformably overlies the De Chelly Sandstone.

The Yeso Formation is largely untested. A test of a well near Grants, which was drilled to determine the feasibility of injecting wastes from a uranium-processing mill, gave a transmissivity of 850 ft²/d for the Yeso Formation (West, 1972, p. 16). Water from the well had dissolved-solids concentrations of between 3,000 and 4,000 mg/L (West, 1972, p. 13).

DE CHELLY SANDSTONE (PERMIAN)—The De Chelly Sandstone was named by Gregory (1915) for exposures in the Canyon de Chelly, Apache County, Arizona. The boundaries and correlation of this unit have been the subject of a lengthy debate. Recent drilling in the San Juan Basin has generally confirmed what Baars (1962) had advocated nearly 20 years ago: that the sandstone known as the Meseta Blanca Member of the Yeso Formation in the Albuquerque region and the De Chelly Sandstone of the Four Corners region are one and the same (Baars and Stevenson, 1977). The De Chelly consists of highly crossbedded, clean, eolian sandstone. Its thickness ranges from 800 ft in the southwest corner of San Juan County to less than 100 ft northeast of a line roughly connecting La Plata and Cuba (Baars and Stevenson, 1977, fig. 2). The De Chelly conformably overlies the lower Cutler and Abo Formations.

Cooley and others (1969, p. 47) reported transmissivities for this aquifer ranging from 40 to 100 ft²/d. Water from the De Chelly, in places, has dissolved-solids concentrations of less than 500 mg/L (Harshbarger and Repenning, 1954, p. 15). Springs yielding as much as 80 gpm near Toadlena (Harshbarger and Repenning, 1954, p. 12) supply stock and domestic water to local users.

LOWER CUTLER/ABO FORMATION (PERMIAN)—A sequence of arkosic red beds overlies the Pennsylvanian strata throughout the San Juan Basin. In the northern part of the basin, these red beds are termed the lower Cutler Formation, and in the south they are termed the Abo Formation. The Abo was named by Lee (Lee and Girty, 1909) for exposures in Abo Canyon at the south end of the Manzano Mountains, Valencia and Torrance Counties, New Mexico. The Cutler was named by Cross and Howe (Cross and others, 1905) for exposures along Cutler Creek, near Ouray, Ouray County, Colorado. Thickness of the lower Cutler/Abo Formation ranges from 1,800 ft, where differentiated in the northeast part of the basin, to 200 ft, southeast of Gallup (Baars and Stevenson, 1977, fig. 1). The lower Cutler/Abo disconformably overlies various Pennsylvanian strata.

The lower Cutler/Abo Formation is largely untested as a source of water. West (1972, p. 13) reported a hydraulic conductivity of approximately 4×10^{-2} ft/d and a dissolved-solids concentration of 9,000 mg/L for water from the Abo near Grants. Water from the Abo near Fort Wingate has a dissolved-solids concentration of about 4,600 mg/L (Shomaker, 1971, table 5). Anderholm (1979) reported on two springs issuing from sandstones in the Abo in the Cuba quadrangle; one of these, developed by the U.S. Forest Service, is a major source of drinking water for residents of Cuba.

PENNSYLVANIAN STRATA—The stratigraphy of the Pennsylvanian deposits in the San Juan Basin is complex and the nomenclature applied to them differs from area to area (fig. 84). These deposits consist mainly of marine carbonate rocks and associated, very fine to medium, clastic terrigenous rocks. Although they crop out in most of the uplifts surrounding the basin, little is known of them in the basin subsurface, except where local structure has prompted petroleum exploration (such as at Tocito dome, northwest San Juan County). Thickness generally ranges from 2,500 ft in the northwest to <1,000 in the southeast and <500 in the east (Jentgen, 1977, fig. 2). The Pennsylvanian strata disconformably overlie deeper units.

West (1972, p. 13) reported an average hydraulic conductivity for Pennsylvanian rocks near Grants of approximately 6×10^{-4} ft/d. In the central part of the basin, these rocks are relatively tight and have not readily yielded water to drill stem tests (David Versteeg, geologist, Amoco Production Co., personal communication, 1979).

Water produced with oil from the Pennsylvanian units in several fields near the Four Corners is highly mineralized; total-dissolved-solids concentrations range from 35,000 to 150,000 mg/L (David Versteeg, personal communication, 1979). On or near outcrop areas in Colorado, dissolved-solids concentrations are commonly less than 500 mg/L (Brogden and Giles, 1976). An oil well north of San Ysidro, known as Warm Spring, formerly flowed warm water from the Magdalena Group. A specific conductance of 15,700 µmhos obtained for this water (Trainer, 1978, p. 79), may reflect general water quality in Pennsylvanian units in the basin.

OLDER PALEOZOIC ROCKS—Cambrian, Devonian, and Mississippian deposits are present in the extreme north and northwest parts of the San Juan Basin (Stevenson and Baars, 1977; Armstrong and Mamet, 1977). These strata are the least well known in the area, but because of their great depth, they are of little interest as potential aquifers.

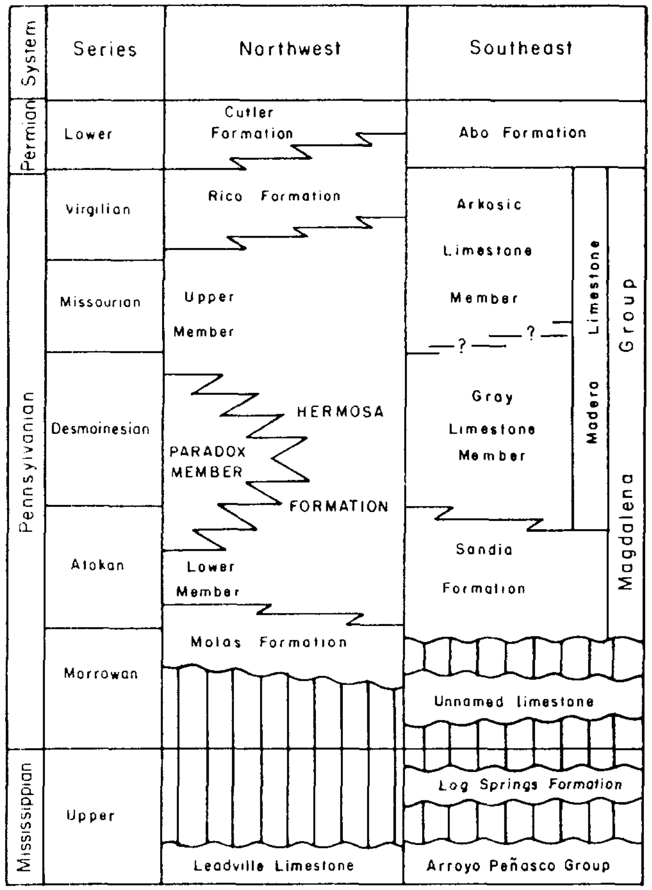

Figure 84—STRATIGRAPHIC NOMENCLATURE AND CORRELATION OF PENNSYLVANIAN AND ADJACENT DEPOSITS IN SAN JUAN BASIN (after Jentgen, 1977).

Hydrogeology

Hydrogeology may be defined as the science that uses geologic principles to interpret hydrologic phenomena (May, 1976); as such, the term "hydrogeology" is not synonomous with ground-water hydrology. Assessing the hydrogeology of an area or aquifer involves delineating the geologic controls of the occurrence, movement, and quality of its ground water.

Basic principles

A major control on the characteristics of a ground-water-flow system is topography; it determines the location of recharge and discharge areas, the direction of ground-water flow, and the hydraulic gradient. Topography is the result of structural and geomorphic processes acting on the local stratigraphic column. Structure provides the elevation and general configuration of the recharge area: cuesta, fault block, or plateau, for example. Geomorphic processes acting through time determine the extent to which these structural features have been modified by erosion or deposition. The local stratigraphic sequence is of utmost importance; the topographic expression of a block of crystalline rock is markedly different from that of a sequence of alternating marine sandstones and shales.

In the case of sandstone aquifers, like those that prevail in the San Juan Basin, minor controls may also be exerted by the texture, geometry, and orientation of the aquifers, or permeability zones within them. Texture includes both grain size and sorting. These parameters affect the size and degree of interconnection of pores, which in turn influence hydraulic conductivity. Geometry includes the dimensions of the aquifer (thickness, width, and length) and their interrelationships. Geometry primarily depends on the depositional origin of