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MINERAL, ENERGY, and GROUND-WATER RESOURCES of SAN JUAN COUNTY, UTAH

by
R.W. Gloyn, C.D. Morgan, D.E. Tabet, R.E. Blackett,
B.T. Tripp, and Mike Lowe

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ABSTRACT

The Utah Geological Survey has summarized information on the known and potential mineral and energy resources in San Juan County. The compilation provides information for use in both short- and long-term land-planning decisions, particularly at the county level, and an indication of the present and future economic impact of mineral and energy development. The report discusses six major commodity groups including: (1) oil and gas, (2) other energy resources (coal, oil-impregnated rocks, geothermal), (3) uranium and vanadium, (4) metallic resources (gold, manganese, copper), (5) industrial rocks and minerals, and (6) ground-water resources. In general, for each group or commodity within a group the following aspects are discussed: (1) known occurrences and characteristics, (2) past production and trends, (3) current production and exploration activity, and (4) geologic potential. Plates accompany each of the major commodity groups and show the location of known resources and areas of geologic potential. In addition to the commodity discussions, the report contains a brief summary of land ownership and status, and concludes with a summary of commodities with the best potential for discovery and possible development.

The report concludes that there is good potential for the discovery of additional occurrences of minerals and energy resources in San Juan County. In addition, some resources are currently being produced or exist in concentration sufficient to support commercial development under favorable market conditions. However, potential for development of most minerals cannot be ascertained at this time based on limited data available for this analysis. Oil and gas have the best potential for new discoveries and development, but the new fields will probably be smaller and more isolated than fields discovered in the past, such as Aneth and Ismay. Coal is present in eastern San Juan County and coal seams are locally of minable thickness. However, factors such as coal quality and adequate rail transportation will hinder development of this resource. There is little or no potential for development of oil-impregnated rock deposits (tar sands) or for discovery of geothermal resources. Uranium and vanadium reserves are present in San Juan County and there is good potential for additional discoveries. However, it is unlikely that uranium will be mined in San Juan County until uranium prices increase sharply above the current $7.00 to $8.00 per pound level. There is good potential for discovery of additional "Lisbon Valley-type" sedimentary copper deposits and speculative potential for discovery of the much larger "leaky reservoir type" sedimentary copper deposits in San Juan County. A large salt and potash resource is present in the evaporite sequence of the Paradox basin in San Juan County, but mining and logistical problems plus competition from established mines will hinder development of this resource. Sufficient sand and gravel, clay, and limestone resources are present to supply existing and anticipated future local needs. Several other industrial mineral resources could exist in concentrations sufficient to support commercial development under favorable market conditions. However, economic value (development potential) of these resources cannot be ascertained due to a lack of resource-specific information on the quality and quantity of the resource base. These mineral resources include: (1) humate, (2) building stone, (3) high-quality limestone, (4) high-quality bentonite, (5) specialty sands and silica, and (7) lightweight aggregate. San Juan County, especially the more populated eastern part, has extensive ground-water resources which are adequate for almost any conceivable future needs.

Most of San Juan County has potential areas for discovery of additional resources, but the greatest potential is in the eastern part of the county. Eastern San Juan County has the best developed infrastructure and the least impact on development by proposed wilderness areas.

INTRODUCTION

In October, 1993, the Utah Department of Natural Resources was asked by San Juan County Commissioners to compile a summary of known and potential mineral and energy resources in the county and to evaluate their potential for development. The purpose of the study was to provide information to: (1) assist in both short- and long-term land planning, and (2) help evaluate the effect of land-planning decisions by other agencies on the development of the known and potential natural resources of the county. Of particular concern to county commissioners was the extensive acreage in the western part of the county being considered for wilderness designation.

The Utah Geological Survey (UGS) assumed responsibility for discussing: (1) known resources, (2) past production and trends, (3) current production and exploration activity, and (4) potential for discovery of additional resources inferred on the basis of favorable geologic conditions.

The Office of Energy and Resource Planning (OERP) assumed responsibility for discussing: (1) the economic and production potential of these resources under current and future economic conditions, and (2) the effect of federal and state regulations, legislation, and land-use policies on the likelihood of developing these resources. The UGS and OERP reports were combined in a briefing document for the San Juan County Commissioners. UGS subsequently decided to release the geologic portion as a Special Study to make it more readily available. The economic analysis part was not included since it is time-sensitive in nature, and since its conclusions and projections are based on current price/demand concepts which can change rapidly.

This Special Study presents a reconnaissance overview based upon readily available information. Information sources include published reports and papers, UGS and Division of Oil, Gas and Mining (DOGM) files and databases, industry contacts and reports, and the knowledge of UGS personnel. For some commodities, such as oil and gas, the information is relatively current and complete. For other commodities, particularly those of little current interest such as uranium, the information is more dated and less complete. And for others, particularly those that have never been developed in San Juan County, such as dimension stone, information is almost nonexistent.

This report is divided into six major commodity groups. Each group may contain several separate resources or commodities. For example, the metallic minerals group includes gold, copper, and manganese. In general, the following items are discussed for each commodity or resource:

Known Occurrences and Characteristics
Past Production and Trends
Current Production and Exploration Activity
Geologic Potential

One or more plates accompany each of the major commodity groups and show the location of known resources and areas of geologic potential. In addition, the report contains a brief summary of land ownership and status and concludes with a summary on those commodities with the best potential for discovery and possible development.

LAND OWNERSHIP AND STATUS

San Juan County is the largest county in Utah. It encompasses 4,944,000 acres, of which 649,867 acres (13.1 percent) are in private surface ownership. Land ownership status in 1977 is shown on plate 1 and surface ownership in 1990 is summarized in table 1 (Utah Office of Planning and Budget, 1992).

Table 1.
Surface ownership in San Juan County, Utah

	Acres	Percentage
Federal Land (total)	2,790,011	56.4
Bureau of Land Management	1,761,009	35.6
National Forest Service	450,707	9.1
National Park Service	578,295	11.7
Tribal Land	1,207,463	24.4
State Land	296,659	6.0
Private Land	649,867	13.1
Total	4,944,000	99.9

Most private land is concentrated in the eastern part of the county along major roads. State land is scattered throughout the county with larger consolidated parcels near the town of Bluff, near Mount Peale, and near Dead Horse Point. Tribal land is the Navajo Indian Reservation mostly south of the San Juan River in the southern part of the county. Federal land constitutes the remainder, with the National Parks and Monuments mostly along the Colorado, San Juan, and Green Rivers and the National Forests around the La Sal and Abajo Mountains.

The Bureau of Land Management (BLM) is the main federal administrative agency for oil and gas, minerals (locatable and leasable), and coal. The agency is responsible for administering these resources on BLM land and on parts of other federal lands with the concurrence of the surface owner or administering agency. For example, the Moab office of the BLM administers oil and gas leases on the Glen Canyon National Recreational Area, the Manti-La Sal National Forest, and a portion of the Navajo Indian Reservation. The agency also administers mining claims on Forest Service and split-estate lands. Any restrictions and/or conditions for leasing or operating on these tribal and non-BLM federal lands are determined by the surface owner or administering agency. For example, National Parks and most of the Navajo Reservation are not open to mineral entry due to restrictions by the surface owners.

A number of areas have been proposed for wilderness designation in San Juan County. The BLM has recommended 11 areas totaling 365,905 acres (U.S. Bureau of Land Management, 1990b). These areas are shown on plate 2 and listed in table 2 (U.S. Bureau of Land Management, 1990a).

Table 2. Bureau of Land Management recommended wilderness	
Mancos Mesa WSA	51,440 acres
Grand Gulch ISA	105,520 acres
Road Canyon WSA	52,420 acres
Fish Creek Canyon WSA	40,160 acres
Mule Canyon WSA	5,990 acres
Dark Canyon ISA	68,030 acres
Butler Wash WSA	24,190 acres
Bridger Jack Mesa WSA	5,290 acres
Indian Creek WSA	6,870 acres
Beind the Rocks WSA (San Juan County portion only)	5,835 acres
South Needles WSA	160 acres

The BLM showed seven other wilderness alternatives in their statewide wilderness final environmental impact statement, (U.S. Bureau of Land Management, 1990a). One alternative, the proposal of the Utah Wilderness Coalition (UWC), is also shown on plate 2. This alternative was included for comparison purposes because it represents the most extensive of the wilderness proposals for San Juan County and could have the greatest potential impact on resource development. To date, no decision has been made by Congress on the status of the BLM-designated Wilderness Study Areas (WSAs). Until that decision is made, all WSAs are managed under the Interim Management Policy and Guidelines for Lands Under Wilderness Review. Other proposed wilderness areas such as those proposed by UWC which are not included in designated WSAs or ISAs (Instant Study Areas) are managed as normal BLM land.

Activity on BLM land in San Juan County is covered by two resource management plans. The Grand Resource Area Management Plan (U.S. Bureau of Land Management, 1985) covers the northeast part of the county, and the San Juan Resource Area Management Plan (U.S. Bureau of Land Management, 1986, 1987, 1989) covers the remainder of the county (figure 1). In these plans, the WSAs occupy a unique position. The plans show how the lands under wilderness review would be managed if Congress releases them from study without designating them as wilderness. However, until released from WSA status, the lands are being managed under the Interim Management Policy and Guidelines for Lands under Wilderness Review. Consequently, for WSAs the BLM management plans and maps do not necessarily reflect current management practice.

The management plans separate BLM lands into four mineral-development categories: (1) areas closed to mineral entry and leasing, (2) open but with no surface occupancy, (3) open with special conditions, and (4) open with standard conditions. For example, for oil and gas leasing in the San Juan Resource Area, 33 percent of BLM land would be available for lease with standard conditions, 46 percent available with special conditions, 15 percent available but with no surface occupancy, and 6 percent unavailable for lease. For minerals in the same area, the BLM recommends that 7 percent of the land be withdrawn from mineral entry, 62 percent be available for location but with special conditions for operations, and 31 percent be available for location under standard conditions. Most restricted areas or areas requiring special conditions were designated to protect riparian/aquatic areas or areas of critical environmental concern (ACEC). Many ACECs overlap with WSAs.

Oil and gas and mineral leases on national forests and national recreation areas are administered by the BLM and are granted subject to conditions stipulated by the United States Forest Service (USFS) and National Park Service (NPS) respectively. These national forest and national recreation area lands are separated into the same four mineral-development categories as BLM lands. For example: for oil and gas leasing in the Monticello area of the Manti-LaSal National Forest using Alternative II would allow 49 percent of the land to be available for leasing with standard conditions, 10 percent would be available with special conditions, 28 percent would be available with no surface occupancy, and 13 percent would be unavailable for leasing. Using Alternative III, the corresponding percentages are: 45 percent, 6 percent, 21 percent, and 28 percent (U.S. Dept of Agriculture, 1992). Although the leases are administered by the BLM, the plan of operations must be approved by the surface owner, i.e. the USFS or NPS.

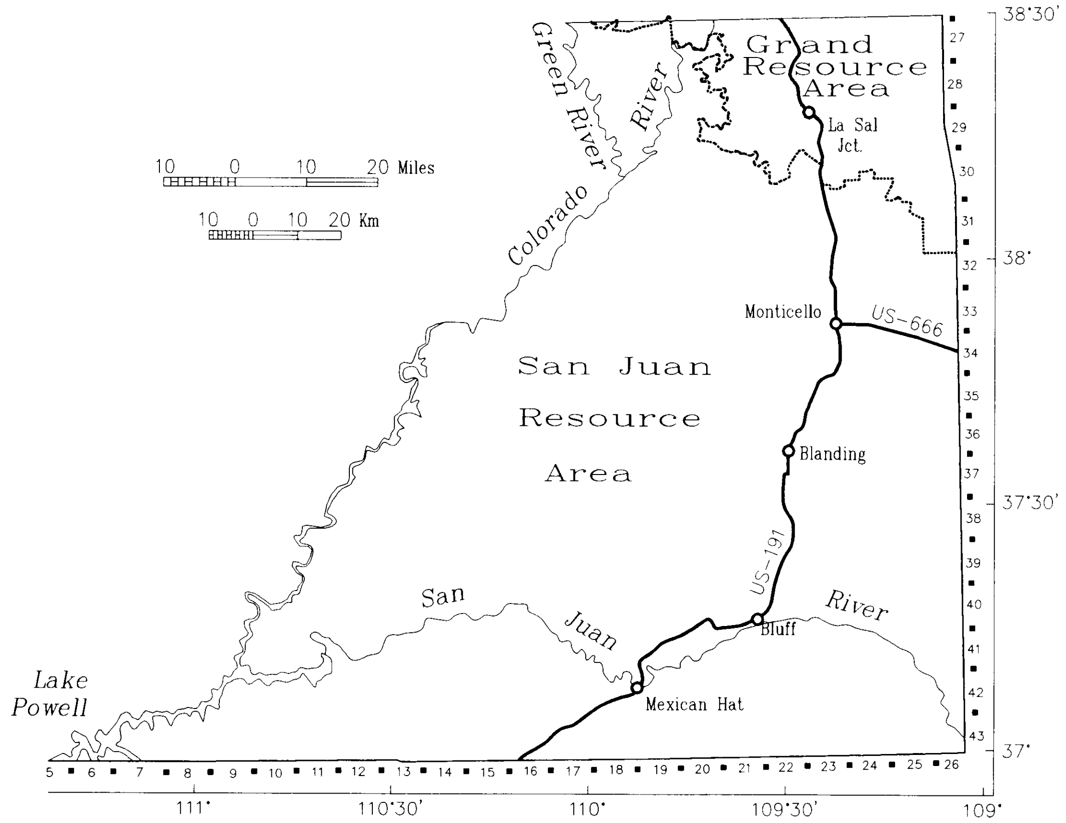


***Figure 1.** Bureau of Land Management resource areas in San Juan County, Utah.*

Leases on tribal lands in San Juan County are granted and conditions stipulated by the Navajo Nation in cooperation with the Bureau of Indian Affairs (BIA). Exploration and production on these lands are managed by the Albuquerque District BLM.

The above summary is very brief and general. For specific information regarding land ownership, availability for development, and conditions and requirements for development, the appropriate state or federal agency should be contacted.

OIL AND GAS RESOURCES

Known Occurrences and Characteristics

San Juan County has significant oil and gas production primarily from the eastern part of the county (plate 3). Over 471 million barrels of oil and 1 trillion cubic feet of gas have been produced in the county (table 3). Annual production is currently over 7 million barrels of oil and 30 billion cubic feet of gas. Total annual value of the oil and gas produced is nearly 200 million dollars. There are 55 active fields with 958 actively producing wells in the county (table 4). Production is from carbonates, sandstones, and shales that range in age from Devonian to Permian (Fallin, 1984; Peterson, 1989). Potential may also exist in older Cambrian and/or Precambrian age rocks (figure 2) (Chidsey and others, 1990; Rauzi, 1990).

Most production is from the Greater Aneth and numerous smaller fields producing from the Ismay and Desert Creek zones in the Pennsylvanian Paradox Formation. The Greater Aneth field produces a low-sulfur, paraffinic oil with API gravity of 40° to 42°; the associated gas has an average heating value of 1,401 BTU/ft^3 (Peterson, 1992). Production from the Greater Aneth and surrounding smaller fields is mostly from porous, carbonate algal mounds and oolitic banks ranging from 10 to 200 feet thick.

The Lisbon field is the second largest producer in the county with production from the Mississippian Leadville Limestone and Devonian McCracken Sandstone Member of the Elbert Formation (Clark, 1978) (figure 2). The oil produced from the Leadville Limestone is a sour-crude (contains hydrogen sulfide) with a gravity of 54° API. The associated gas is a low-BTU gas with an average heating value of 740 BTU/ft^3. Gas produced from the Leadville reservoirs is typically composed of 40 to 100 percent non-hydrocarbon gases. The gases consist mostly of carbon dioxide with lesser amounts of nitrogen and helium. The gas contains over 1 percent helium which is being recovered and sold during the blow-down phase. The oil produced from the McCracken Sandstone is 43° to 50° API gravity and the associated gas has an average heating value of 1,300 BTU/ft^3. The Leadville Limestone and McCracken Sandstone are shallow-shelf deposits that produce from fault-related structural traps (Parker and Roberts, 1963).

Low-BTU gas containing high percentages of nitrogen and/or carbon dioxide has been found in most parts of the county. The highest percentages of non-hydrocarbon gases are in the southeastern portion of the county and decrease to the north and west (Chidsey and Morgan, 1993). Carbon dioxide is the principle non-hydrocarbon gas in the Leadville reservoir in southeastern San Juan County with percentages of nitrogen increasing to the west-northwest. Carbon dioxide reserves may become marketable in the near future as demand increases for use in secondary recovery of oil in the Ismay and Desert Creek reservoirs.

The Cane Creek shale in the Paradox Formation has become a significant exploration play in Grand County (Kane Springs unit) and should become an active play in San Juan County in the near future (Fritz, 1991; Morgan and others, 1991; Morgan, 1992b, 1993a; Grove and others, 1993). Wilson Canyon, a one-well field, is the only field in San Juan County that currently produces from the Cane Creek shale (Mickel, 1978). The oil produced from the Kane Springs unit is low-sulfur, paraffinic oil with API gravity of 36° to 43°; the associated gas has a heating value of 1,205 BTU/ft^3 to 1,471 BTU/ft^3. The Cane Creek is a naturally fractured, self-sourced reservoir composed of interbedded, black, organic-rich shale, dolomite, and silty dolomite (Hite and others, 1984; Grove and others, 1993; Rawlins, 1993).

Other oil and gas fields include Boundary Butte (McEachin and Royce, 1978a, 1978b; Smouse, 1993) and Mexican Hat (Lauth, 1978; Baars, 1993). The Boundary Butte field produces from the Ismay, Desert Creek, and Akah zones of the Paradox Formation. Production from the Paradox Formation at Boundary Butte is primarily gas, with an average heating value of 907 BTU/ft^3, and a minor amount of condensate oil. The field also produces oil from the De Chelly Sandstone of the Permian Cutler Group (also known as Coconino Sandstone). The oil produced from the De Chelly Sandstone is a low-sulfur, 43° API gravity crude. Mexican Hat field is productive from shallow sandstones in the Cutler Group. The oil produced at Mexican Hat has an API gravity of 38° and only minor amounts of associated gas.

Past Production and Trends

Hydrocarbon production began in San Juan County in 1908 when oil was produced from the Mexican Hat field along the San Juan River. Production from this field has been minor and oil and gas did not make a significant contribution to the county until the discovery of the Aneth (1957) and Lisbon (1960) fields. Annual oil production in San Juan County peaked at over 30 million barrels of oil in 1960. Production rapidly declined in the 1960s and leveled off during the 1980s averaging over 8 million barrels of oil annually (figure 3). Over 85 percent of all oil and gas produced in San Juan County has come from the Greater Aneth and Lisbon fields. In 1992, these two fields were responsible for 72 percent of the oil and 80 percent of the gas produced in the county. Over 354 million barrels of oil have been produced from the Greater Aneth field with a current annual production of over 5 million barrels (table 5, figures 4 and 5). Over 49 million barrels of oil have been produced from the Lisbon field with a current annual production of over 250,000 barrels (table 6, figures 6 and 7).

Cumulative gas produced from the Lisbon field is nearly 600 billion cubic feet (BCF) but most of this is recycled gas. Before 1993, gas produced with the oil was separated and most hydro-

Table 3.
Annual and cumulative oil and gas production, San Juan County, Utah. Total value based upon average (state-wide) wellhead price multiplied by the annual production. Production given in barrels (bbls) and thousand cubic feet (MCF).

				Wellhead Price			Cumulative Production	
Year	**Oil (bbls)**	**Gas (MCF)**	**Active Wells**	**Oil (per bbl)**	**Gas (per MCF)**	**Total Annual Value**	**Oil (bbls)**	**Gas (MCF)**
1960	31,929,653	29,097,887	605	$2.61	$0.17	$88,283,035	89,561,132	66,558,818
1961	27,520,921	34,649,402	591	$2.69	$0.16	$79,575,182	117,082,053	101,208,220
1962	24,970,822	36,442,542	577	$2.56	$0.18	$70,484,962	142,052,875	137,650,762
1963	26,267,805	37,412,262	554	$2.64	$0.16	$75,332,967	168,320,680	175,063,024
1964	20,515,546	32,260,565	544	$2.63	$0.14	$58,472,365	188,836,226	207,323,589
1965	17,149,490	30,443,344	511	$2.26	$0.14	$43,019,916	205,985,716	237,766,933
1966	15,946,320	32,789,122	504	$2.64	$0.13	$46,360,871	221,932,036	270,556,055
1967	15,303,956	34,552,502	515	$2.63	$0.15	$45,432,280	237,235,992	305,108,557
1968	13,603,635	33,894,671	493	$2.71	$0.15	$41,950,052	250,839,627	339,003,228
1969	12,887,260	37,512,970	443	$2.80	$0.15	$41,711,274	263,726,887	376,516,198
1970	12,434,894	37,892,928	492	$2.81	$0.16	$41,004,921	276,161,781	414,409,126
1971	11,485,344	39,,334,835	486	$3.04	$0.17	$41,602,368	287,647,125	453,743,961
1972	11,345,630	38,,680,043	479	$2.94	$0.18	$40,318,560	298,992,755	492,424,004
1973	10,676,976	34,,632,761	494	$3.59	$0.19	$44,910,568	309,669,731	527,056,765
1974	10,306,318	29,,446,825	536	$7.39	$0.21	$82,347,523	319,976,049	556,503,590
1975	10,091,330	26,,289,223	542	$8.06	$0.24	$87,645,533	330,067,379	582,792,813
1976	9,839,426	28,,335,982	570	$8.80	$0.51	$101,038,300	339,906,805	611,128,796
1977	9,798,150	29,758,423	569	$8.96	$0.75	$110,110,241	349,704,955	640,887,219
1978	8,682,484	27,065,969	620	$9.98	$0.83	$109,115,945	358,387,439	667,953,188
1979	8,623,143	26,228,460	600	$11.41	$1.14	$128,290,506	367,010,582	694,181,648
1980	7,913,539	26,748,126	607	$19.79	$1.86	$206,360,451	374,924,121	720,929,774
1981	7,935,656	25,,570,063	619	$34.14	$1.87	$318,739,314	382,859,777	746,499,837
1982	8,346,775	27,,942,916	1,036	$30.50	$2.47	$323,595,640	391,206,552	774,442,753
1983	7,506,961	28,,899,201	614	$28.12	$2.56	$285,077,698	398,713,513	803,341,954
1984	8,037,487	29,,580,534	863	$27.21	$3.16	$312,174,509	406,751,000	832,922,488
1985	8,586,399	32,,155,722	984	$23.98	$3.23	$309,764,830	415,337,399	865,078,210
1986	8,622,206	32,,207,130	1,008	$13.33	$2.90	$208,334,683	423,959,605	897,285,340
1987	7,725,908	33,,086,001	1,024	$17.22	$1.82	$198,256,658	431,685,513	930,371,341
1988	8,122,363	34,,163,042	953	$14.24	$1.70	$173,739,621	439,807,876	964,534,383
1989	7,660,883	33,,743,519	960	$18.63	$1.58	$196,037,010	447,468,759	998,277,902
1990	7,774,204	31,,701,985	974	$22.61	$1.64	$227,766,008	455,242,963	1,029,979,887
1991	8,283,384	30,,191,636	997	$19.99	$1.56	$212,683,798	463,526,347	1,060,171,523
1992	7,555,906	30,010,005	985	$19.39	$1.62	$195,125,225	471,082,253	1,090,181,528

Sources: Utah Division of Oil, Gas and Mining production records and Utah Division of Energy Utah Energy Statistical Abstract, 1991.

Table 4.
Oil and gas fields in San Juan County, Utah as of July 1993. Production and active well count is from December 1992, Division of Oil, Gas, and Mining (DOGM) production book.

Field Name	DOGM Number	Discovery Date	Oil (bbls)	Gas (MCF)	Water (bbls)	Number Active wells
Akah	275	1955	493,161	481,236	2,032,820	2
Alkali Canyon	280	1966	3,919	40,085	1,297	0
Anido Creek	285	1961	612,082	424,388	718,051	1
Bannock	287	1989	146,377	496,695	0	1
Big Indian	290	1962	178,160	28,411,576	134,202	2
Bluff	295	1956	1,579,556	3,174,917	78,814	13
Bluff Bench	300	1957	22,905	6,365	26,475	0
Boundary Butte	305	1948	5,274,068	12,315,582	20,186,815	25
Bradford Canyon	310	1983	35,362	318,836	30,704	3
Broken Hills	315	1960	123,942	64,884	170,553	2
Bug	320	1980	1,557,220	3,731,364	3,072,534	14
Cave Canyon	323	1987	1,742,048	3,037,380	654,192	8
Cazado	321	1989	217,209	425,028	255,114	4
Cherokee	324	1989	164,948	2,996,608	638	4
Chinle Wash	325	1957	5,611	2,737,772	87,575	0
Clay Hill	327	1984	876,928	1,239,850	156,391	4
Cleft	330	1963	2,980	—	—	0
Cone Rock	335	1963	133	0	2	0
Cowboy	340	1968	181,999	16,630	12,677	4
Deadman (Ismay)	346	1988	538,225	4,516,434	41,974	2
Deadman Canyon	345	1983	1,076	169,226	2,808	2
Desert Creek	350	1954	2,649,933	2,522,774	1,087,429	4
Gothic Mesa	355	1957	1,823,883	955,891	307,346	16
Grayson	360	1962	5,777	4,876	2,220	0
Greater Aneth	365	1956	367,833,453	331,011,078	928,714,775	591
Hatch	370	1957	14,969	40,891	0	0
Hogan	375	1964	756	775	98	0
Ismay	380	1956	10,417,617	16,855,527	9,874,147	28
Kachina	379	1987	1,840,476	1,741,335	1,770,804	5
Kiva	381	1985	1,934,555	3,015,172	1,474,207	8
Lighting Draw (Ismay)	742	1989	2,039	9,178	1,674	1
Lion Mesa	382	1984	1,624	0	8	2
Lisbon	385	1960	49,933,539	*581,530,776	39,693,817	25
Little Nancy	390	1983	334,646	1,606,234	301,070	9
Little Valley	395	1961	137,848	17,311,939	742,951	1
McCracken Spring	402	1987	300,802	1,208,568	6,595	3
McElmo Mesa	405	1965	2,187,559	2,895,891	5,242,379	3
Mexican Hat	410	1908	178,639	1,546	635	96
Mustang Flat	415	1982	647,890	*9,992,217	15,643	8
Paiute Knoll	425	1974	0	0	0	0
Patterson Canyon	420	1977	512,444	1,556,041	512,728	5
Rabbit Ears	430	1968	54,068	154,717	641,817	0
Recapture Creek	435	1956	2,087,509	3,307,554	246,151	11
Recapture Pocket	437	1987	122,031	137,556	27,512	3
River Bank	440	1967	1,396	8,774	376	0
Road Canyon	401	1989	14,321	23,117	2,109	1
Rockwell Flat	445	1968	618,292	502,425	3,998,309	4
Shafer Canyon	450	1963	67,554	63,805	1,408	0
South Ismay	455	1967	1,073	548	150	1
South Pine Ridge	457	1987	—	—	—	0
Squaw Canyon	460	1980	326,456	805,049	19,251	3
Tin Cup Mesa	465	1983	2,164,258	3,030,757	3,200,080	6

***Table 4** (continued)*

Field Name	DOGM Number	Discovery Date	Oil (bbls)	Gas (MCF)	Water (bbls)	Number Active Wells
Tohonadla	470	1957	1,853,171	781,551	654,805	6
Turner Bluff	475	1957	830,940	602,004	479,116	12
Ucolo	477	1984	78,621	1,081,490	4,169	2
Undesignated 1-40S-24E	—	1991	0	0	0	0
Undesignated 35-41S-25E	—	1992	0	0	0	0
Unnamed 13-38S-23E	487	1987	878	2,683	304	1
Unnamed 15-36S-23E	736	1989	6,251	175,695	1,170	1
Unnamed 16-38S-26E	732	1988	0	0	0	0
Unnamed 18-36S-25E	484	1987	0	3,500	354	1
Unnamed 31-37S-25E	740	1989	1,144	3,566	4,875	1
Unnamed 34-37S-23E	486	1987	6	9,921	14	1
Unnamed 34-37S-25E	741	1989	3,657	9,303	5,453	0
Unnamed 4-41S-23 E	489	1987	3,370	5,252	13,573	0
Unnamed 6-30S-25E	483	1988	3,984	331,904	37	1
Unnamed 7-37S-24E	481	1989	295	129,574	17	1
Unnamed 9-36S-23E	731	1988	3,183	56,745	70	0
Unnamed 9-39S-26E	730	1988	14,276	38,201	7,687	1
Unnamed 9-40S-25E	488	1987	31,407	25,441	4,255	1
Wild Stallion	478	1989	925	135,473	90	1
Wildcat 14-29S-21E	—	1992	0	0	0	0
Wildcat 31-36S-24E	—	1991	2,728	18,819	123	1
Wildcat 31-38S-25E	—	1992	17,014	34,822	242	1
Wildcat 33-39S-25E	—	1991	94	0	0	0
Wilson Canyon	480	1968	80,767	117,967	302	1
Yellow Rock	485	1965	18,205	11,258	194,509	0
County Totals			462,924,232	1,048,468,671	1,026,916,490	958

** = recycled gas*
Source: Utah Division of Oil, Gas and Mining, December, 1992.

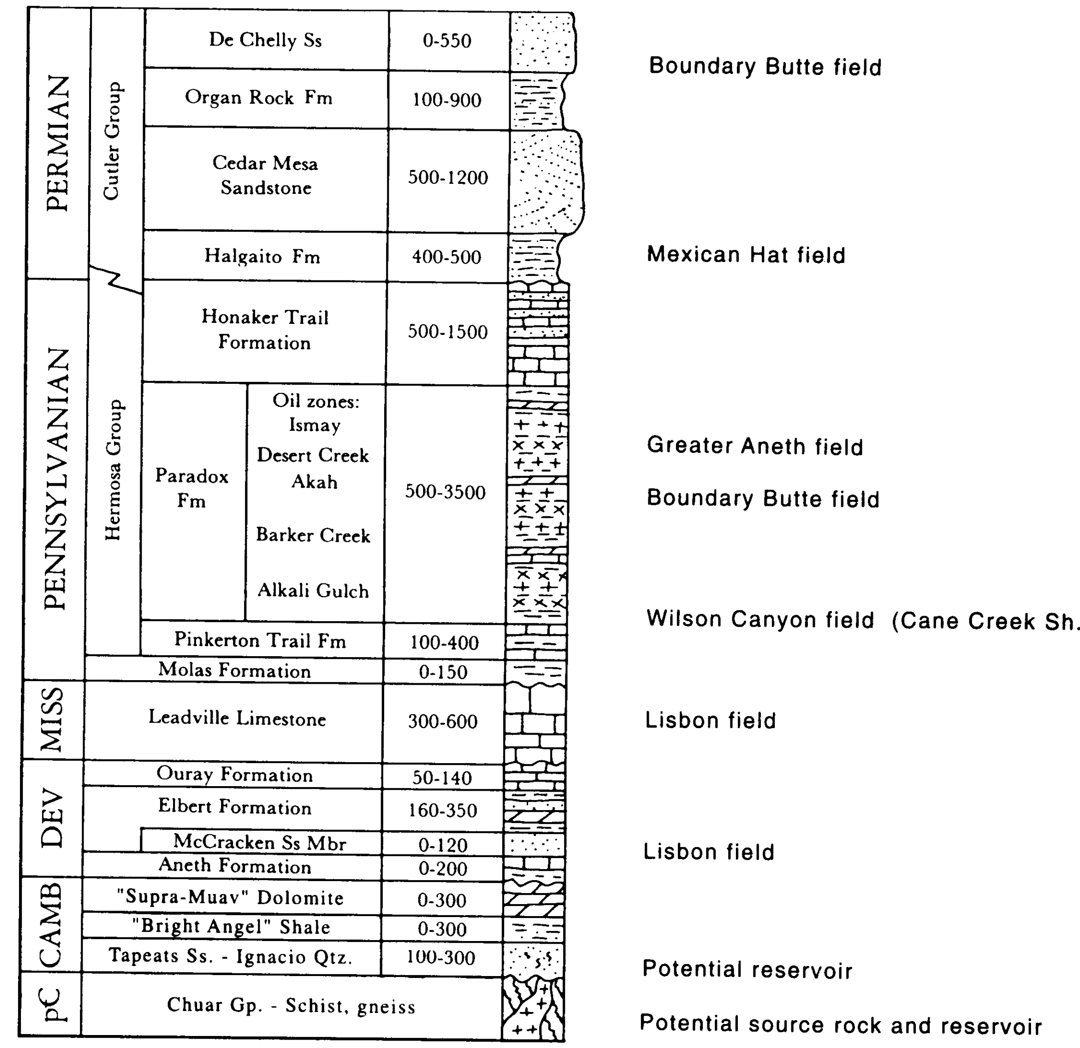


***Figure 2.** Generalized stratigraphic section after Hintze (1988) showing producing and potential oil and gas zones in San Juan County. A field for each producing zone is given as an example. Most fields in San Juan County produce from the Ismay and Desert Creek zones of the Paradox Formation. Over 85 percent of all the oil and gas produced in San Juan County has come from the Greater Aneth and Lisbon fields.*

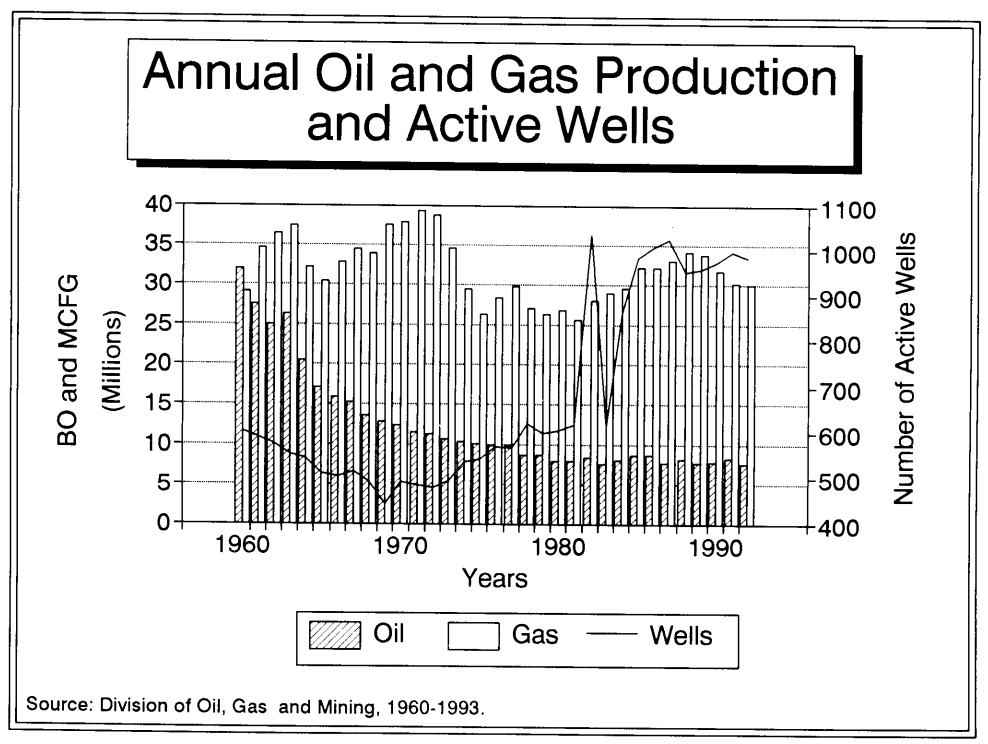


***Figure 3.** Annual oil and gas production and active wells, San Juan County, Utah. Production reported in barrels of oil (BO) and thousands of cubic feet of gas (MCFG).*

Table 5.
Annual and cumulative oil and gas production from the Greater Aneth field, San Juan County, Utah. Production given in barrels (bbls) and thousand cubic feet (MCF).

Year	Active Wells	Annual Production Oil (bbls)	Annual Production Gas (MCF)	Cumulative Production Oil (bbls)	Cumulative Production Gas MCF)
1956	—	498,996	347,263	498,996	347,263
1957	—	1,507,487	930,261	2,006,483	1,277,524
1958	—	19,997,521	12,876,942	22,004,004	14,154,466
1959	—	33,922,044	23,267,734	55,926,048	37,422,200
1960	545	10,230,276	26,168,331	66,156,324	65,590,531
1961	507	25,174,568	29,725,377	91,330,892	93,315,908
1962	485	21,557,718	30,260,849	112,888,610	123,576,757
1963	437	21,188,217	27,287,093	134,076,827	150,863,850
1964	423	15,545,013	20,859,049	149,621,840	171,722,899
1965	390	12,138,086	15,152,202	161,759,926	186,875,101
1966	385	10,230,276	10,744,201	171,990,202	197,619,302
1967	369	9,656,868	9,152,241	181,647,070	206,771,543
1968	365	8,976,543	8,165,846	190,623,613	214,937,389
1969	321	8,653,430	7,218,439	199,277,043	222,155,828
1970	372	8,452,420	6,982,759	207,729,463	229,138,587
1971	371	7,860,309	8,370,422	215,589,772	237,509,009
1972	359	7,881,894	6,287,553	223,471,666	243,796,562
1973	368	7,933,005	6,263,658	231,404,671	250,060,220
1974	413	8,156,819	6,288,688	239,561,490	256,348,908
1975	427	8,324,616	6,395,958	247,886,106	262,744,866
1976	460	8,210,263	6,457,308	256,096,369	269,202,174
1977	458	8,258,120	6,694,832	264,354,489	275,897,006
1978	511	7,330,537	6,110,637	271,685,026	282,007,643
1979	493	7,365,479	6,047,021	279,050,505	288,054,664
1980	499	6,740,910	7,314,832	285,791,415	295,369,496
1981	484	6,619,859	5,561,631	292,411,274	300,931,127
1982	489	5,665,809	4,634,680	298,077,083	305,565,807
1983	459	6,047,148	5,310,813	304,124,231	310,876,620
1984	484	6,185,885	5,338,445	310,310,116	316,215,065
1985	673	6,268,247	4,507,683	316,578,363	320,722,748
1986	678	5,692,846	4,033,196	322,271,209	324,755,944
1987	682	5,284,403	3,901,428	327,555,612	328,657,372
1988	586	5,349,447	3,541,521	332,905,059	332,198,893
1989	589	5,340,905	3,376,048	338,245,964	335,574,941
1990	590	5,669,186	3,179,473	343,915,150	338,754,414
1991	595	4,969,049	3,342,620	348,884,199	342,097,034
1992	591	5,216,462	3,003,046	354,100,661	345,100,080

Source: Utah Division of Oil, Gas and Mining, 1956 to 1992.

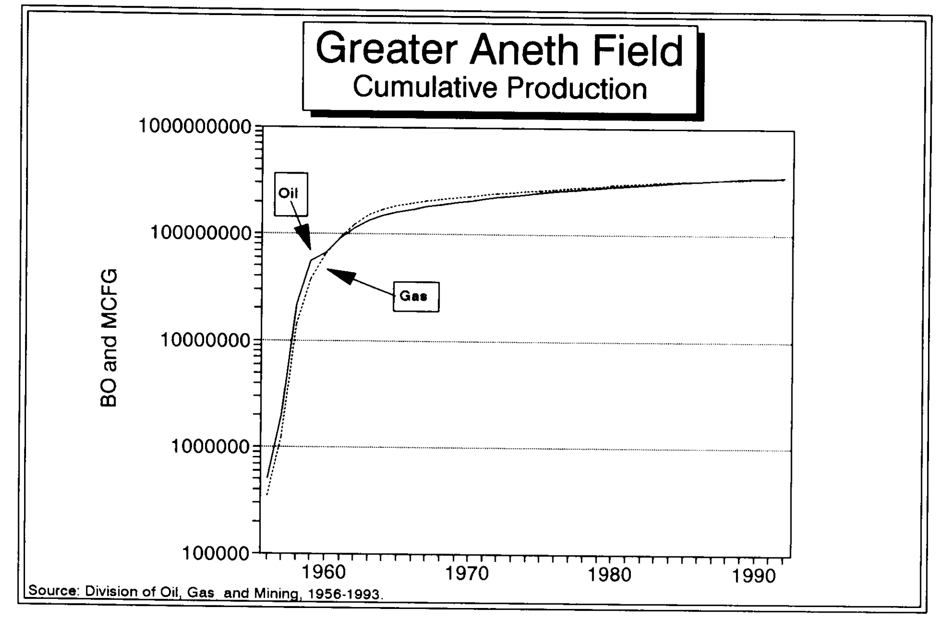


Figure 4. *Cumulative oil and gas production, Greater Aneth field, San Juan County, Utah. Production reported in barrels of oil (BO) and thousands of cubic feet of gas (MCFG).*

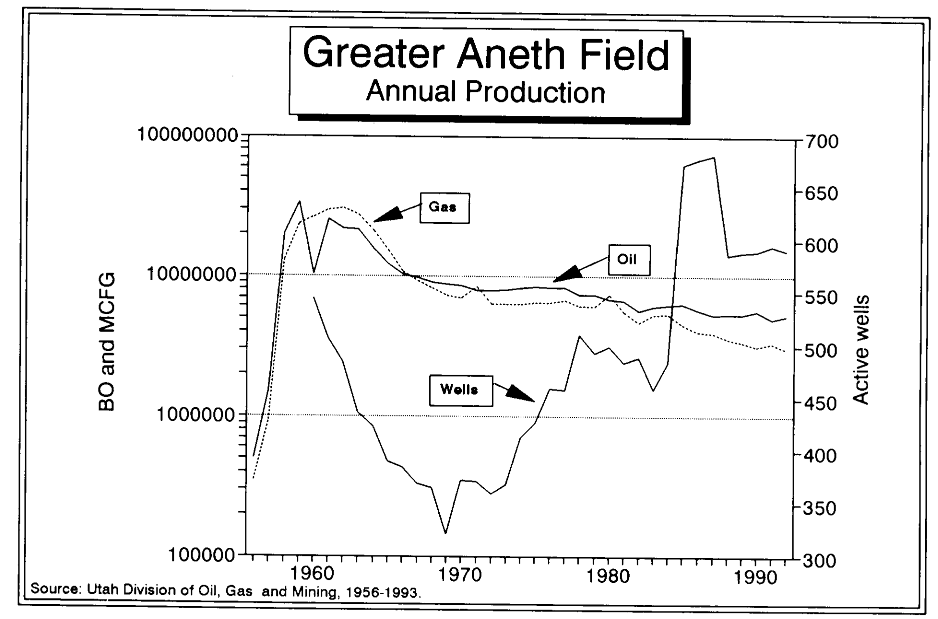


Figure 5. *Annual oil and gas production, and active wells, Greater Aneth field, San Juan County, Utah. Production reported in barrels of oil (BO) and thousands of cubic feet of gas (MCFG).*

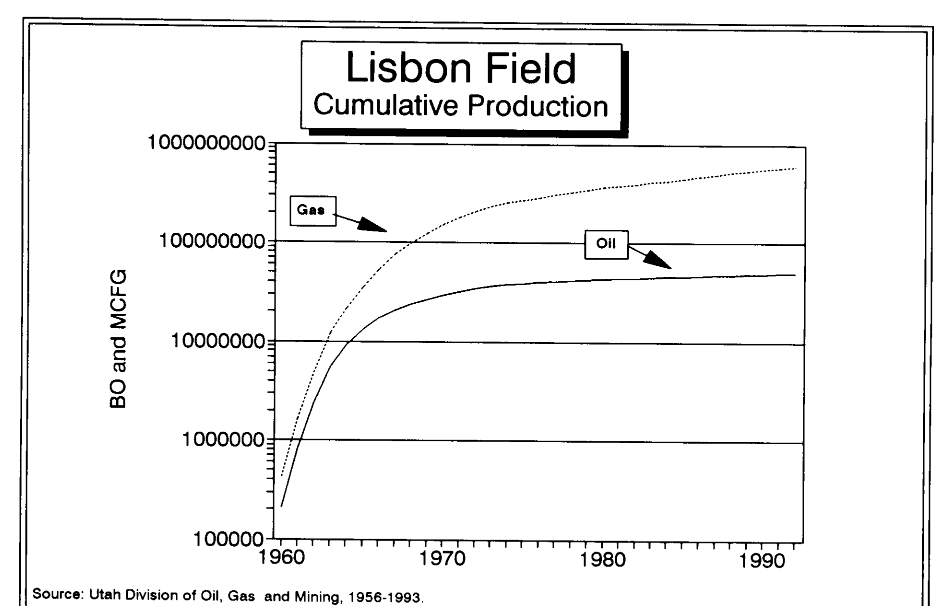


Figure 6. *Cumulative oil and gas production, Lisbon field, San Juan County, Utah. Production reported in barrels of oil (BO) and thousands of cubic feet of gas (MCFG).*

Table 6.
Annual and cumulative oil and gas production from the Lisbon field, San Juan County, Utah. Production reported in barrels (bbls) and thousands of cubic feet (MCF).

Year	Active Wells	Annual Production: Oil (bbls)	Annual Production: Gas (MCF)	Cumulative Prodcution: Oil (bbls)	Cumulative Prodcution: Gas MCF)
1960	8	210,645	425,504	210,645	425,504
1961	14	599,365	1,221,995	810,010	1,647,499
1962	19	1,566,397	3,137,588	2,376,407	4,785,087
1963	18	3,210,900	7,482,603	5,587,307	12,267,690
1964	17	3,541,484	9,070,690	9,128,791	21,338,380
1965	23	3,951,625	14,058,117	13,080,416	35,396,497
1966	20	3,886,404	17,872,272	16,966,820	53,268,769
1967	18	3,621,958	21,660,473	20,588,778	74,929,242
1968	19	3,049,522	22,530,595	23,638,300	97,459,837
1969	19	2,897,245	25,426,334	26,535,545	122,886,171
1970	18	2,828,140	27,216,756	29,363,685	150,102,927
1971	21	2,604,209	27,914,813	31,967,894	178,017,740
1972	20	2,460,333	29,055,996	34,428,227	207,073,736
1973	14	1,932,144	25,100,952	36,360,371	232,174,688
1974	11	1,399,163	19,876,074	37,759,534	252,050,762
1975	13	1,074,580	16,493,206	38,834,114	268,543,968
1976	10	1,002,913	18,004,233	39,837,027	286,548,201
1977	13	954,982	19,436,049	40,792,009	305,984,250
1978	12	874,971	18,168,063	41,666,980	324,152,313
1979	13	827,042	18,857,396	42,494,022	343,009,709
1980	13	717,594	17,078,414	43,211,616	360,088,123
1981	13	588,660	17,153,755	43,800,276	377,241,878
1982	15	524,063	12,700,464	44,324,339	389,942,342
1983	15	629,493	20,117,430	44,953,832	410,059,772
1984	15	415,361	13,904,403	45,369,193	423,964,175
1985	28	658,823	22,445,860	46,028,016	446,410,035
1986	28	603,149	21,899,488	46,631,165	468,309,523
1987	29	549,064	22,799,337	47,180,229	491,108,860
1988	26	572,231	22,916,294	47,752,460	514,025,154
1989	26	544,921	22,529,930	48,297,381	536,554,484
1990	26	415,105	21,635,443	48,712,486	558,189,927
1991	26	302,544	20,408,193	49,015,030	578,598,120
1992	25	254,621	21,120,263	49,269,651	599,718,383

Source: Utah Division of Oil, Gas and Mining, 1956 to 1992.

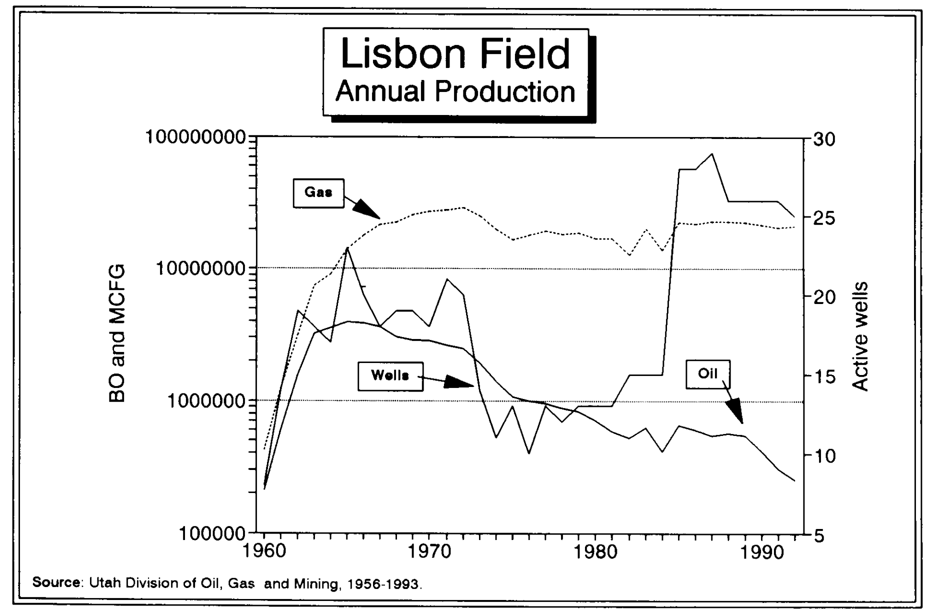


Figure 7. *Annual oil and gas production, and active wells, Lisbon field, San Juan County, Utah. Production reported in barrels of oil (BO) and thousands of cubic feet of gas (MCFG).*

carbon gases were reinjected into the reservoir to maintain pressure to maximize the oil recovery. Starting in 1993, the field began its "blow-down" phase where produced gas is sold and the reservoir pressure begins to deplete. Reinjection records are incomplete, but an average of 2 BCF of gas per year has been produced over the amount reinjected resulting in an estimated 64 BCF of gas being sold or vented from the Lisbon field since 1960. Recoverable gas from the Lisbon field was estimated to be 250 BCF (Clark, 1978). Therefore, approximately 186 BCF of gas may still be produced from the field of which 78 percent (145 BCF) is expected to be hydrocarbon gas. Approximately 1 percent (1.8 BCF) will be helium which will be separated from the hydrocarbon gases and sold. The remainder of the gas will be composed of carbon dioxide, nitrogen, and hydrogen sulfide.

Current Production and Exploration Activity

The majority of the oil and gas produced in San Juan County is from the Ismay and Desert Creek zones in the Paradox Formation (Greater Aneth field), and the Leadville Limestone (Lisbon field) (Morgan, 1993b). Oil production from fields discovered in the 1980s is small compared to production that resulted from the Greater Aneth and Lisbon discoveries (table 4). Although the annual production from San Juan County was level to slowly declining during the early to mid-1980s, the increase in both oil and gas prices more than offset the decline, resulting in a significant increase in the annual total value of oil and gas produced (figure 8).

The largest number of new field discoveries were made in the 1980s (figure 9). The discoveries were a result of an increase in the number of wells drilled (figure 10) due to the dramatic increase in the price of oil. Since 1988, all of the field discoveries have been in Ismay and Desert Creek reservoirs except one minor discovery in the Leadville reservoir (table 7). Since 1985, the miles of seismic lines and number of wells permitted have continued to generally decline (figure 11).

Geologic Potential

San Juan County is an oil-producing area with relatively shallow (3,000 to 6,000 feet) targets and generally high success rates (table 8). There are numerous plays that are productive or have the potential to be productive in San Juan County (table 9, plate 4).

Ismay-Desert Creek Play: The largest number of fields and the majority of the production comes from algal mound and oolitic bank deposits in the Ismay and Desert Creek zones of the Paradox Formation (Morgan, 1993c). The Ismay and Desert Creek reservoirs range from less than 10 feet to over 100 feet thick and are typically at a drill depth of 5,000 to 6,000 feet. The majority of new field discoveries in the county will probably continue to be in the Ismay and Desert Creek reservoirs. Exploration methods primarily involve subsurface mapping of porosity variations combined with high-resolution seismic surveys to identify small, isolated algal mounds. The Ismay-Desert Creek play area covers approximately 2,800 square miles in the eastern portion of the county. The play is limited structurally to the west by the Monument upwarp and stratigraphically to the north near Lisbon Valley.

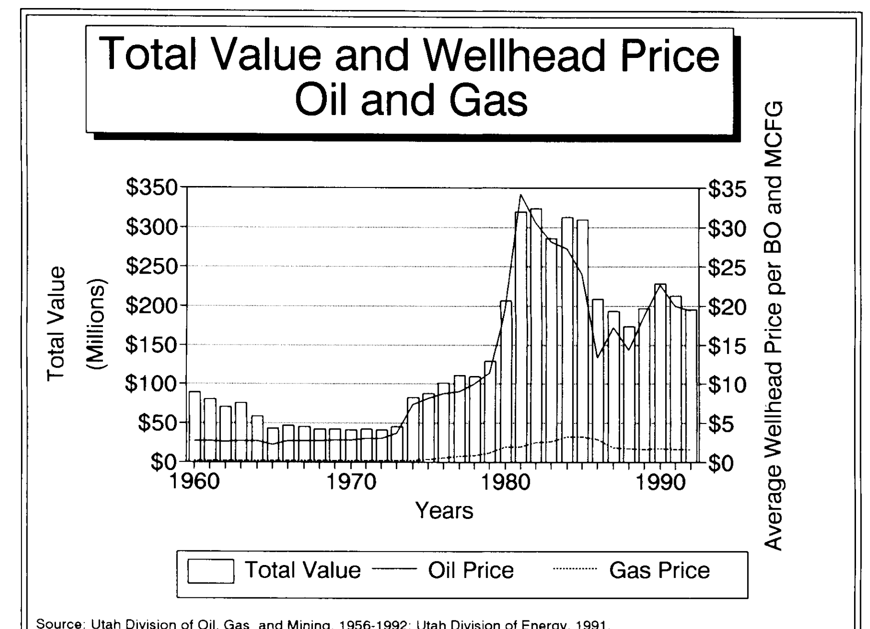


Figure 8. *Total value (wellhead price x annual production) of oil and gas produced, San Juan County, Utah. Wellhead price per barrel of oil (BO) and thousand cubic feet of gas (MCFG).*

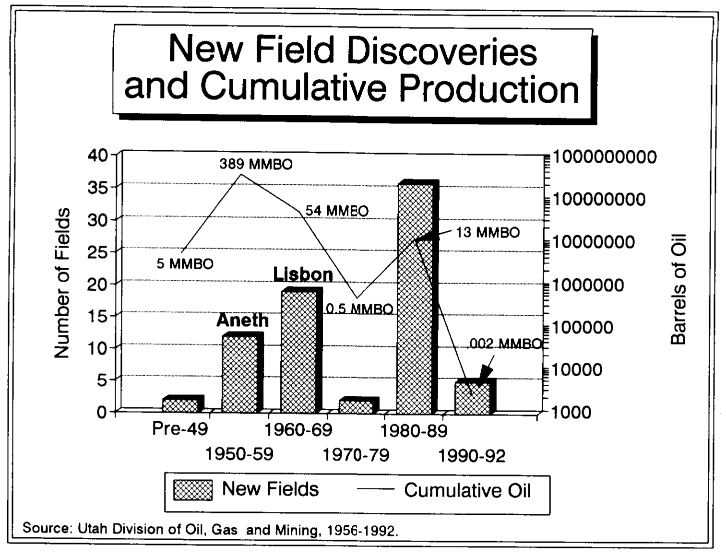


Figure 9. Number of field discoveries and resulting cumulative oil production (as of December 31, 1992) from these fields, San County, Utah.

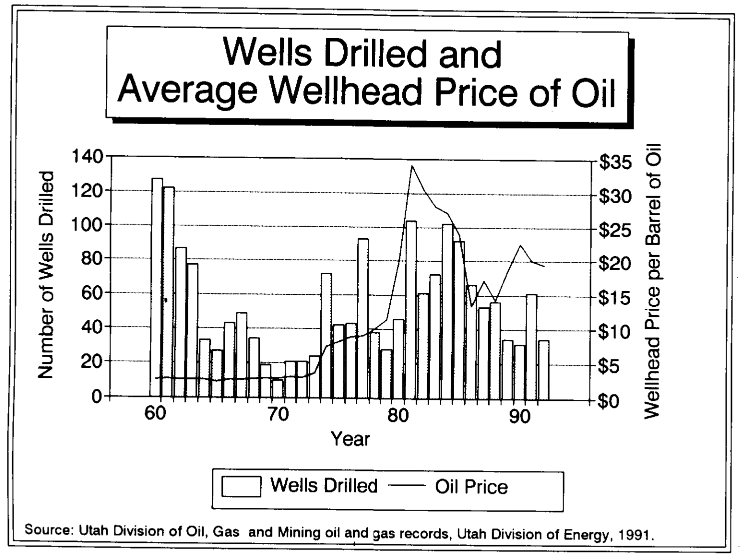


Figure 10. Wells drilled and average wellhead price of oil, San Juan County, Utah.

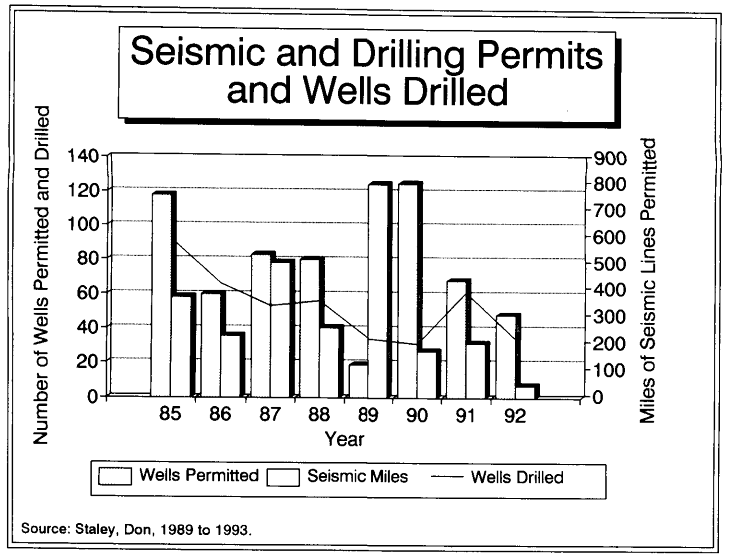


Figure 11. Annual wells permitted, miles of seismic lines permitted, and wells drilled, San Juan County, Utah.

Table 7.
Wildcat discoveries completed during 1990 -1992, San Juan County, Utah. These discoveries have not been given a field designation as of November, 1993.

Location	Operator Well name API Number	Completion Date	Productive Zone (ft)	Initial Potential
T29S R21E NESE Section 14	Giant Expl. and Prod. Hatch Point 1 43-037-31658	9/10/92	Leadville Limestone 7,461-7,738	10 BOPD 200 MCFGPD
T36S R24E SWSW Section 31	Global Natural Res. GNR Bronco Fed. 31-14 43-037-31655	12/23/91	Desert Creek 6,413-6,431	48 BOPD 498 MCFGPD
T38S R25E NENW Section 31	Sunfield Energy Black Bull Fed. 31C 43-037-31663	4/15/92	Desert Creek 5,655-5,753	1483 BOPD 1780 CFGPD
T39S R25E NESE Section 33	Chuska Energy Navajo Canyon 1-33-1 43-037-31546	2/1/91	Ismay-Desert Creek 5,625-5,704	Not reported
T40S R24E NESE Section 1	Chuska Energy NW Cajon 1L-1 43-037-31510	4/28/91	Desert Creek 6,142-6,152	Not reported
T41S R25E NENW Section 35	Chuska Energy North Heron 35C 43-037-31616	3/25/92	Desert Creek 5,560-6,606	Not reported

Source: Staley, 1989 to 1993.

Table 8.
Completions by well type during 1988-1992, San Juan County, Utah.

Type of Completion	1988	1989	1990	1991	1992
Oil wells	22	22	22	36	13
Gas wells	4	1	0	1	0
Service wells	2	2	0	0	1
Temporarily abandoned	1	0	1	3	0
Plugged and abandoned	21	8	8	17	16
Total wells	50	33	31	57	30
Success ratio	54%	74%	71%	65%	45%
Average depth drilled (ft)	5,008	4,576	4,197	4,629	3,847

Success ratio: Successful oil and gas wells divided by total exploration wells drilled. Service wells not included since they are generally water disposal wells, not exploration wells.

Average depth drilled: Average of all exploration wells drilled (both dry and successful).

Source: Staley, 1989-1993.

Table 9.
Primary oil and gas plays in San Juan County, Utah. Plays are listed from most likely to least likely to result in new field discoveries in the near future.

Play Name	Reservoirs	Trap type	Location
Ismay-Desert Creek	Paradox Formation (Pennsylvanian) (Ismay-Desert Creek zones)	Stratigraphic	Blanding basin to Lisbon Valley
Cane Creek shale	Paradox Formation (Pennsylvanian) (Cane Creek shale)	Fractured shale	Montecello - northward
Leadville Limestone	Leadville Limestone (Mississippian)	Structural	County-wide
Paradox	Paradox Formation (Pennsylvanian) (other than Ismay-Desert Creek zones, and Cane Creek shale)		

Table 9 (continued)

Shallow Pennsylvanian-Permian	Cutler & Hermosa Groups (Pennsylvanian & Permian)	Combination	Monument upwarp and southeastern edge of county
McCracken Sandstone	Elbert Formation (McCracken Sandstone Member) (Devonian)	Structural	County-wide
Precambrian source rock	Chuar Group and Tapeats Sandstone (Precambrian and Cambrian)	Combination	Western edge of county

Cane Creek Shale Play: The Cane Creek shale is in the Alkali Gulch zone of the Paradox Formation in northern San Juan County. It currently produces from one vertical well in the Wilson Canyon field. The Cane Creek reservoir is a fractured, organic-rich shale overlain and underlain by salt. The Cane Creek shale is not present in the southern two-thirds of the county and reaches a maximum thickness of over 100 feet in the northern part of the county (Morgan, 1992a, 1993a). The Cane Creek shale reservoir is typically at a depth of 6,000 to 9,000 feet. In the past, only minor production occurred from the Cane Creek shale in Grand and San Juan Counties. Recent advances in horizontal-drilling technology have made it a major play in Grand County. Horizontally drilled Cane Creek wells in the Kane Springs unit (Grand County) are expected to produce 400,000 to 1,000,000 barrels of oil per well (Grummon, 1993). Both Chevron Oil and Meridian Oil horizontally drilled the Cane Creek on Hatch Mesa in northern San Juan County. Although both wells were unsuccessful, additional horizontal drilling and resulting discoveries are highly likely in San Juan County. This play is considered the second most likely to result in new field discoveries in San Juan County in the near future. The Cane Creek play covers approximately 1,600 square miles in northern San Juan County. Drill-hole data show that Cane Creek shale was not deposited south of Monticello.

Leadville Limestone Play: The Leadville Limestone is the second most productive reservoir in San Juan County. It produces from structural traps formed by closure on both anticlines and faults and is currently productive from the Lisbon, Big Indian, and Little Valley fields (Morgan, 1993d). The Leadville Limestone ranges from 200 feet to over 700 feet thick and is typically at a depth of 8,000 to 10,000 feet. A potential for new field discoveries in the Leadville reservoir exists throughout San Juan County. The controlling factor is the ability to seismically identify closed structures at the Leadville horizon.

Paradox Play: Some fields produce from horizons in the Paradox Formation other than the Ismay or Desert Creek zones and the Cane Creek shale. Both structural and stratigraphic traps are possible in the Paradox Formation. The Boundary Butte field is an anticlinal trap with production from the Ismay, Desert Creek, and Akah zones of the Paradox Formation. The Barker Creek zone has produced very minor amounts of oil in San Juan County, but is highly productive in the Colorado and New Mexico portions of the Paradox basin (Reid and Berghorn, 1981). In San Juan County, the Paradox Formation ranges from 500 feet to over 3,000 feet thick and is typically at a depth of 2,000 feet to over 9,000 feet. Stratigraphic traps in shelf carbonates are currently not productive reservoirs but do have some exploration potential. Production from the Paradox Formation is possible anywhere in the county. The controlling factor is the ability to identify structural closure at the Paradox horizon in combination with porous carbonates, or to identify areas where the porous carbonates pinch out, forming a stratigraphic trap.

Shallow Pennsylvanian and Permian Play: Shallow production (200 to 300 feet deep) from sandstones in the Permian Cutler Group occurs at the Mexican Hat field and from the Boundary Butte field at approximately 1,500 feet. Oil shows have also been reported from algal mounds and oolitic bank deposits in the Ismay and Desert Creek zones of the Paradox Formation at shallow depths (2,000 to 3,000 feet) on the Monument upwarp. Potential reservoirs range from a few feet to tens of feet thick. The Monument upwarp is sparsely drilled and that fact, combined with the complex nature of the traps, gives the area substantial exploration potential. The greatest geologic concern is that many of the shallow reservoirs may have been breached and the oil may have migrated out and/or been highly degraded. The primary exploration method for this play is subsurface mapping of porosity trends and paleodepositional patterns using geophysical well log data.

McCracken Sandstone Play: The McCracken Sandstone Member of the Devonian Elbert Formation produces from a structural trap at the Lisbon field. There, the McCracken Sandstone is 8,000 to 9,000 feet deep and slightly over 100 feet thick. A potential for new field discoveries in the McCracken Sandstone reservoir exists throughout San Juan County. The most promising exploration method is seismically identifying closed structures at the Devonian horizon.

Precambrian Source Rock Play: Recent work by the U.S. Geological Survey indicates that rocks of the Late Proterozoic Chuar Group, exposed in the Grand Canyon, are potential source rocks for oil (Reynolds and others, 1988; Palacas and Reynolds, 1989). These rocks contain abundant organic carbon and are thermally within the oil-generating window. Chuar or equivalent rocks underlie some of the Colorado Plateau in Utah and may be present in the western portion of San Juan County. The top of the Precambrian in western San Juan County may be at a depth of 5,000 to 10,000 feet, overlain by 100 to 300 feet of Cambrian sandstone. Oil derived from the Precambrian could be trapped in basal Cambrian sandstones and/or fractured Precambrian rocks. The Precambrian has not been tested in western San Juan County. The Precambrian source rock play has the highest risk and lowest probability of being drilled, but it may have the best possibility for a large field discovery.

COAL, OIL-IMPREGNATED ROCKS, AND GEOTHERMAL RESOURCES

Coal

Known Occurrences and Characteristics

Coal occurrences in San Juan County were known from early reconnaissance geologic surveys (Gregory, 1938). The coal is in the Dakota Sandstone which underlies various mesas including the Sage Plain of San Juan County, Utah, and Dolores and Montezuma Counties, Colorado (Wilson and Livingston, 1980). The Dakota outcrop area is divided into two coal fields (plate 5). The smaller, northern outcrop area (north of Township 31 South) is the La Sal coal field, and the larger, southern outcrop area (south from Township 31 South) is the San Juan coal field (Doelling, 1972, 1982).

The Dakota Sandstone is 92 to 200 feet thick, and averages 138 feet thick under the Sage Plain in east-central San Juan County (figure 12). The Dakota Sandstone consists of three distinct stratigraphic units: (1) a 4- to 134-foot-thick, lower conglomeratic sandstone, (2) a 45- to 122-foot-thick, middle coal-bearing, carbonaceous shale, and (3) an 8- to 35-foot-thick, upper sandstone (Katich, 1958; Wilson and Livingston, 1980).

The middle shale unit of the Dakota Sandstone averages 73 feet thick, and contains several impure, discontinuous coal beds (Gregory, 1938; Doelling, 1969b, 1972). Drilling by AMAX Coal Company during the late 1970s delineated four coal horizons in the Dakota Sandstone in the Sage Plain area (Wilson and Livingston, 1980). The four coal horizons are each separated vertically by 12 to 15 feet of shale and sandstone. The sandstone bodies interbedded with the coals decrease in number and continuity upward through the middle shale while the continuity of the coal horizons improves. Each coal horizon generally contains multiple, lens-shaped beds of coal ranging from 2 to 15 feet thick. Individual coal beds cover an area of 15 square miles or less. Within the San Juan County portion of the Sage Plain, the second lowest coal horizon is the thickest and most continuous.

The coal horizons are exposed around the margins of the Sage Plain plateau. Due to the flat topography of the plateau, the coal horizons are only covered by 35 feet or less of upper Dakota Sandstone and 100 feet or less of Mancos Shale (Doelling, 1972). Therefore, coal deposits present in San Juan County could be surface mined because the maximum amount of overburden above the coal is usually less than 150 feet.

The coal is commonly impure or boney with thinly interlaminated shales, and nearly everywhere contains 30 percent or more ash. No coal sample analyses are available from the La Sal coal field, and only 19 analyses are available from the San Juan coal field (table 10). Using only the coal samples with less than 50 percent ash, the average ash content of 14 samples from the San Juan coal field is 39.99 percent. The high ash content means less combustible material is contained in the coal, and the heating content of the coal is low. The average heat content of the 14 "low-ash" coal samples is only 7,162 Btu/lb. In addition to the high ash and low heat content, the Dakota Sandstone coals have high sulfur contents. The sulfur content of the above 14 samples ranges from 0.52 to 3.80 percent, and averages 1.80 percent. The high ash content of the coal from the San Juan coal field makes determination of its rank difficult. The available analyses have coal ranks falling in the range from subbituminous C to high-volatile A bituminous.

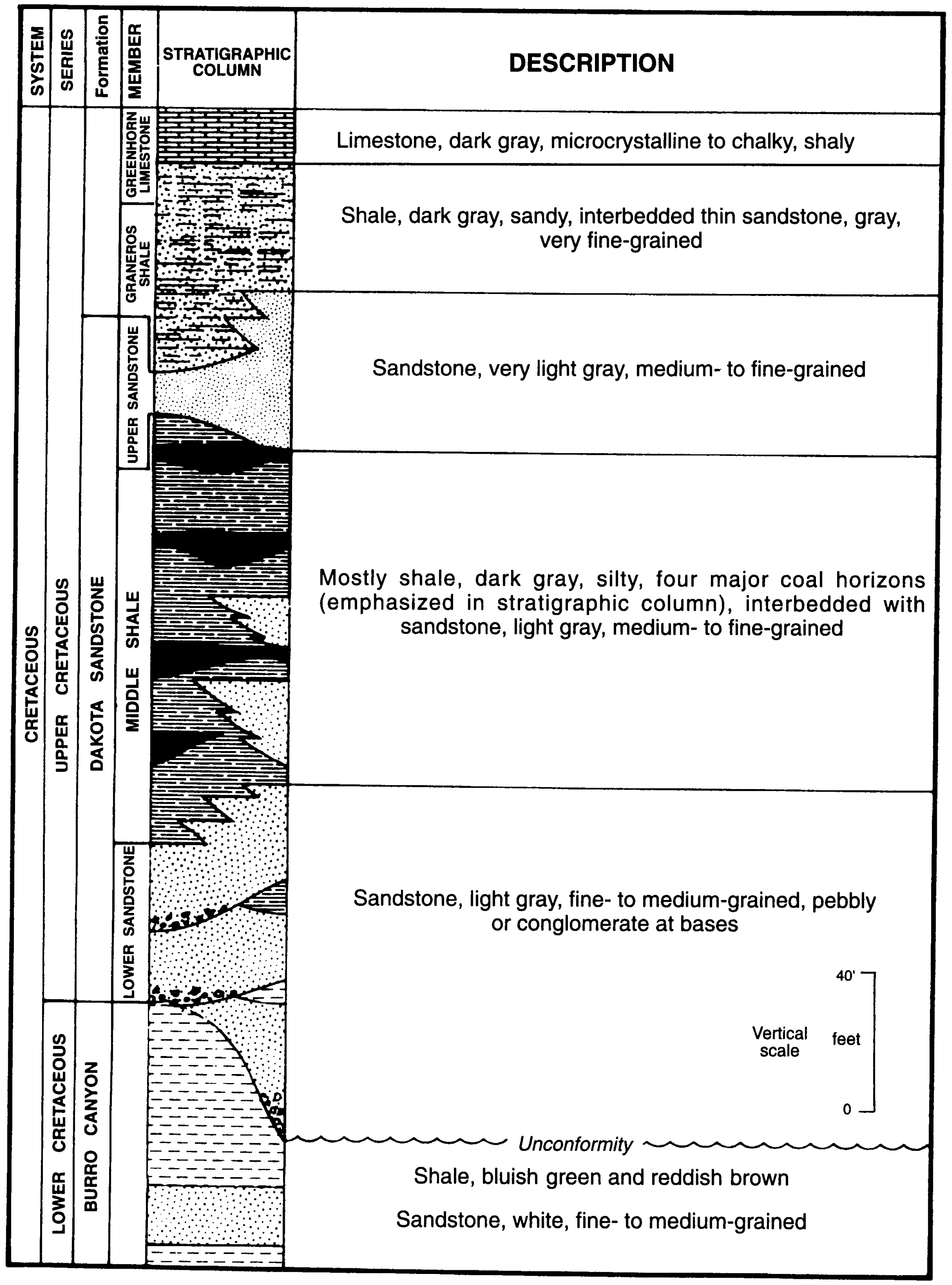


Figure 12. Dakota Sandstone stratigraphic column for the Sage Plain area of Utah (from Wilson and Livingston, 1980).

Past Production and Trends

Two small mines were developed during the 1920s in the San Juan coal field near the Utah-Colorado state line. Very small amounts of coal were mined for local consumption, but all mining activity had ceased by 1948 (Doelling, 1972). These two Utah mines are the Crepo mine (section 22, T. 34 S., R. 26 E.) and the Rasmussen mine (section 35, T. 33 S., R. 26 E.). Gregory (1938) also mentions another coal mine one mile east of the Utah state line in Colorado.

During the late 1970s, the energy crisis prompted renewed interest in domestic coal deposits and AMAX Coal and Arjay Petroleum examined the San Juan coal field. AMAX drilled 31 coal exploration holes across the Sage Plain in Utah and Colorado as part of a regional assessment project (Wilson and Livingston, 1980). Arjay Petroleum (unpublished data in UGS files) drilled 195 holes in the vicinity of Eastland, Utah. Arjay Petroleum estimated that 77 million tons of coal, at an average strip ratio of 5.6 to 1, were recoverable by surface mining in their exploration area. Although AMAX and Arjay Petroleum demonstrated that the San Juan coal field contains significant surface-minable coal resources, they concluded that development of these resources is limited by poor coal quality and lack of rail transportation (Wilson and Livingston, 1980).

Current Production and Exploration Activity

There is no current coal production or exploration activity in

Table 10.
Quality of Dakota Sandstone coals in San Juan County, Utah.
(all values except heat content are in percent)

LOCATION	MOISTURE	ASH	*VM	*FC	SULFUR	Btu/lb
Not available	4.96	66.13	15.16	13.75	1.05	2,740
Not available	4.11	48.84	19.98	27.07	1.16	5,557
Sec 35 T33S R26E	2.70	30.90	24.10	42.30	2.0	9,300
Sec 35 T33S R26E	4.30	11.10	32.30	52.30	3.8	12,480
Sec 06 T34S R25E	3.97	52.99	19.47	23.57	1.75	5,402
Sec 06 T34S R25E	4.41	39.12	23.71	32.76	1.28	6,136
Sec 14 T34S R25E	5.13	38.04	19.47	37.36	1.82	5,725
Sec 21 T34S R25E	4.47	45.49	22.5	27.54	2.04	6,309
Sec 23 T34S R25E	3.19	47.48	20.1	29.23	2.4	6,033
Sec 25 T34S R25E	3.79	43.94	22.01	30.26	1.54	6,656
Sec 26 T34S R25E	3.98	36.93	23.63	35.46	3.17	7,879
Sec 26 T34S R25E	2.46	53.97	20.35	23.22	0.62	5,582
Sec 27 T34S R25E	3.73	46.53	21.49	28.25	1.41	6,177
Sec 33 T34S R25E	5.65	49.03	22.82	22.50	1.24	5,681
Sec 03 T34S R26E	3.71	39.99	22.35	33.95	1.22	7,652
Sec 03 T34S R26E	3.36	42.72	22.29	31.62	0.52	7,259
Sec 15 T35S R25E	4.44	39.77	23.69	32.10	1.61	7,425
Sec 09 T35S R25E	4.63	51.75	10.94	32.68	0.74	5,434
Sec 09 T35S R25E	4.48	58.59	20.29	16.64	0.48	4,303
Minimum	2.46	11.10	10.94	13.75	0.48	2,740
Maximum	5.65	66.13	32.30	52.30	3.8	12,480
Average	4.08	44.38	21.40	30.13	1.57	6,512
Standard Deviation	0.78	11.26	4.03	8.50	0.84	1,961

**VM = Volatile matter *FC = Fixed carbon*
Source: Tabet and others, in preparation

the coal fields of San Juan County, nor any known plans for coal exploration and development.

Geologic Potential

The strata containing coal in San Juan County are well defined, and the discovery of new coal-bearing strata is unlikely. At least two companies have attempted to define areas underlain by thick, potentially economic deposits of coal. The available data indicate that the thickest coal is near Eastland. However, full results of the company investigations are not known and large areas remain unexplored.

Although the coal deposits are apparently thick enough to be mined, marketing factors such as product quality and adequate rail transportation hinder development of San Juan County coal deposits. The creation of new technology to clean the coal may alleviate the high ash and sulfur problems, but availability of rail transport remains a development constraint unless the coal is used locally.

Oil-Impregnated Rocks

Known Occurrences and Characteristics

Ritzma (1979) identified two deposit of oil-impregnated rocks, the White Canyon and Mexican Hat deposits, in San Juan County (plate 5). The White Canyon deposit is in Triassic or possibly Permian rocks while the Mexican Hat deposit is in Pennsylvanian rocks.

The White Canyon deposit is described by Thaden and others (1964) as oil-impregnated rock within the Hoskinnini Member of the lower part of the Triassic Moenkopi Formation. This member consists of reddish-brown, very fine- to coarse-grained sandstone interbedded with grayish-orange sandstone. Northwest from White Canyon, this cliff-forming member thins from a maximum of 110 feet to a feather edge near Glen Canyon on the Colorado River. The oil-impregnated rocks in White Canyon occur near the pinch-out area of the Hoskinnini Member of the Moenkopi Formation.

Oil impregnation within the Hoskinnini Member is not pervasive, but is confined to selected beds (Thaden and others, 1964). The bitumen is confined primarily to coarse-grained, weakly calcareous beds. The contrast between the usual reddish-brown color of the Hoskinnini sandstone and the light-brown weathering of the oil-impregnated beds gives the unit a striped appearance in the area of interest. The amount of bitumen is highly variable, but it tends to increase to the northwest toward the pinch-out zone of the Hoskinnini sandstone.

As defined by Ritzma (1979), the White Canyon oil-impregnated rock deposit is a linear body trending northeasterly through parts of Townships 34 and 35 South and Ranges 15 and 16 East. He estimated the deposit to contain 12 to 15 million barrels of in-place oil, but this estimate has not been verified by surface or subsurface exploration. The oil-impregnated zone varies from zero to a few tens of feet thick. Overburden ranges from zero at the outcrop to 480 feet thick under the mesa top (U.S. Bureau of Land Management, 1984). The grade of the White Canyon oil-impregnated rocks has not been determined. The one analysis of the sulfur content of the contained oil showed a high sulfur content of 2.73 percent (Ritzma, 1979). According to Ritzma (1979), this high sulfur content is apparently typical of oil in similar deposits in southeastern Utah.

The Mexican Hat deposits are more minor occurrences than an actual deposit. They represent localized seeps of oil from limestones and sandy limestones of the Pennsylvanian Honaker Trail Formation along the banks of the San Juan River near Mexican Hat, Utah. Ritzma (1979) classified the Mexican Hat occurrences as medium to small, and estimated the contained oil at 0.4 to 0.5 million barrels. However, the discontinuous nature of the host units and the very localized nature of the oil impregnation suggests that the deposits are of limited extent. Seeps were also described by Gregory (1938) for locations along the bottom of San Juan Canyon near Mexican Hat, at the head of Honaker Trail, and near the mouth of Johns Canyon (plate 5). Gregory ascribes the seeps to the movement of oil along fractures, joints, and faults in oil-bearing rocks near the crests of anticlines.

Exploration and Production History

There has been no production from the two oil-impregnated rock deposits of San Juan County, but oil is produced from similar reservoirs down-dip from the Mexican Hat seeps in the Mexican Hat oil field. Previous work on the oil-impregnated rock deposits has consisted only of reconnaissance surveys; no detailed delineation work (drilling and laboratory analysis) has been reported. However, the U.S. Bureau of Land Management (1984) delineated a 10,536-acre Special Tar Sand Study Area covering the known area of the White Canyon deposit. This designation provides developers of this deposit special tax considerations. To date, no companies have expressed interest in leasing or developing the White Canyon deposit.

Current Production and Exploration Activity

No oil-impregnated rock exploration or production activity is being conducted in San Juan County, and there are no known plans for such activity.

Geologic Potential

Reconnaissance surveys of the county have found no indications of additional oil-impregnated rock deposits. The Mexican Hat deposits are small and have little or no development potential. The White Canyon deposit is estimated to be larger in size, but its grade, quality, and extent are uncertain.

LOW-TEMPERATURE GEOTHERMAL RESOURCES

Known Occurrences and Characteristics

Low-temperature geothermal waters, at temperatures between 20 and 36°C (68 to 97°F) have been recorded from 9 springs and 21 wells in San Juan County (table 11). Although low-temperature geothermal waters have been identified, there is no evidence for moderate- to high-temperature (greater than 90°C) systems. Because San Juan County is situated within the Colorado Plateau geologic province where heat-flow through the earth's crust is generally low, no high-temperature geothermal resources would be expected within reasonable drilling depths.

Data from low-temperature wells, springs, and collector wells in San Juan County are summarized in table 11. Total dissolved solids (TDS) content in the water from the shallow wells and springs is generally low and the water would be classified as fresh (0 to 1,000 mg/L) to brackish (1,000 to 10,000 mg/L) by Freeze and Cherry (1979). Higher TDS water comes from wells in the southeastern part of the county where oil field waters are collected as a by-product of petroleum production. These waters have TDS contents ranging from saline (10,000 to 100,000 mg/L) to brine (more than 100,000 mg/L).

The low-temperature wells and springs listed in table 11 have been developed by oil and mining companies, as well as by government agencies and individuals. These wells and springs were developed as water sources for agricultural, industrial, and domestic uses, not for thermal uses.

Exploration and Production History

No exploration for geothermal resources has been conducted in San Juan County other than regional geothermal assessments. In addition, no direct-use thermal application of the low-temperature geothermal waters is known.

Current Production and Exploration Activity

No geothermal exploration or production activity is being conducted in San Juan County, and there are no known plans for such activity.

Geologic Potential

Depth data from 16 of the 18 wells in the database show that all the wells are relatively shallow, with the deepest well measuring only 2,021 feet deep. Fitting a linear trend through the depth versus temperature data yields the following equation which has an 84 percent correlation coefficient with the data:

$$\text{Temperature (°C)} = 0.0082\ \text{Depth (meters)} + 18.267$$

With this temperature gradient of 8.2°C per kilometer, a well would need to be drilled to 32,700 feet before the water temperature would reach 100°C. Usually temperature gradients throughout the Colorado Plateau region are two to three times higher than this value (Kron and Stix, 1982). The thermal gradient from the present database, which includes only shallow wells, may in

Table 11.
Low-temperature (20°- 50°C) wells and springs in San Juan County, Utah.
(data from Blackett, 1994, OFR-311)

SOURCE NAME	TYPE	LOCATION	TEMP (°C)	DEPTH (m)	FLOW(L/min)	TDS (mg/L)	REFERENCE
Warm Spring	S	S30, T35S, R14E	25.5	0.0	189.00	1,860	Feltis, 1966
Wexpro Company	W	S07, T36S, R26E	22.0	573.0	26.50	766	USGS, 1992
Energy Fuels Nuclear	W	S22, T37S, R22E	24.0	554.7	900.93	260	USGS, 1992
Energy Fuels Nuclear	W	S28, T37S, R22E	23.0	573.0	—	227	USGS, 1992
Energy Fuels Nuclear	W	S33, T37S, R22E	24.5	615.7	821.43	235	USGS, 1992
National Park Service	W	S29, T38S, R11E	21.0	320.0	75.71	86	USGS, 1992
National Park Service	W	S21, T39S, R26E	21.0	434.0	110.00	1,070	Bliss, 1983
BIA 12R-163	S	S33, T39S, R26E	22.7	0.0	—	1,760	Bliss, 1983
City of Bluff	W	S25, T40S, R21E	20.0	251.5	14.01	—	USGS, 1992
City of Bluff	W	S30, T40S, R22E	20.0	251.5	227.12	482	USGS, 1992
Bureau of Land Management	W	S27, T40S, R23E	21.0	204.8	329.33	1,820	USGS, 1992
Texaco	W	S15, T40S, R24E	20.0	335.3	321.76	—	USGS, 1992
Texaco	W	S17, T40S, R24E	20.0	281.9	495.89	2,550	USGS, 1992
unnamed	W	S17, T40S, R24E	31.0	NA	—	2,310	USGS, 1992
unnamed	C	S22, T40S, R24E	36.0	—	—	84,700	USGS, 1992
BIA 12T-312	W	S01, T40S, R25E	21.7	427.0	7.60	3,550	Bliss, 1983
BIA 12R-173	S	S05, T40S, R25E	20.0	0.0	0.40	2,890	Bliss, 1983
Texaco	W	S19, T40S, R26E	20.5	237.4	677.59	11,400	USGS, 1992
unnamed	C	S20, T40S, R26E	24.0	—	—	184,000	USGS, 1992
unnamed	C	S21, T41S, R24E	31.5	—	—	95,000	USGS, 1992
Texaco	W	S04, T41S, R25E	20.0	335.3	33.31	3,090	USGS, 1992
Navajo Tribe	W	S12, T41S, R25E	21.0	219.5	0.38	2,120	USGS, 1992
BIA 8A-293	S	S19, T42S, R06E	25.0	0.0	—	460	Feltis, 1966
BIA 2A-104	S	S35, T42S, R09E	21.1	0.0	40.00	264	Bliss, 1983
BIA 8A-281	S	S14, T42S, R17E	23.3	0.0	7.60	2,490	Feltis, 1966
BIA 8A-229	S	S23, T43S, R16E	21.0	0.0	—	944	Bliss, 1983
BIA 8A-260	S	S29, T43S, R19E	22.2	0.0	15.00	597	Bliss, 1983
Navajo Tribe	W	S15, T43S, R23E	20.0	154.8	12.49	145	USGS, 1992
BIA 94-57	S	S32, T43S, R23E	20.0	0.0	1.90	—	Bliss, 1983
unnamed	W	S12, T43S, R24E	24.0	NA	—	—	USGS, 1992

W = well, S = spring, C = collection facility part reflect mixing of cooler meteoric waters with the warmer connate waters, but it does indicate a generally low thermal gradient in San Juan County.

The low temperature of the known occurrences does not indicate any favorable targets for high-temperature geothermal exploration and production. However, low-temperature waters, such as those known in San Juan County, could be used for space heating using geothermal heat pumps.

URANIUM AND VANADIUM RESOURCES

Known Occurrences and Characteristics

Uranium and vanadium occurring with copper, have been mined over the past century in San Juan County. The deposits are in three ages of host rocks – the Permian Cutler Formation, the Triassic Chinle Formation, and the Jurassic Morrison Formation. Characteristics of the uranium deposits in these host rocks, modified from Doelling (1969c) and Woodward-Clyde Consultants (1983), are presented in table 12. Locations of uranium-vanadium mining areas and deposits within the various rock units are shown on plate 7.

Cutler Hosted Deposits: Fluvial sandstone and mudstone units within the upper part of the Permian Cutler Formation contain copper-, uranium-, and vanadium-bearing minerals. Mines within these units are located in the Lisbon Valley - Big Indian Wash region and in a north-south belt between Cane Creek and Indian Creek. In the Lisbon Valley - Big Indian Wash area, the mines include from north to south: La Sal No. 2, Reprise, School Section 2, Big Buck 4A, Big Buck 5, Big Buck 6, Bacardi, Velvet, and Uranerz, (Chenoweth, 1990b).

Chinle Hosted Deposits: Widely scattered uranium and vanadium deposits have been mined from fluvial sandstones within the Shinarump and Moss Back Members of the Triassic Chinle Formation. In southern and central San Juan County, the Shinarump Member is the basal member of the Chinle Formation and rests unconformably on top of the lower Triassic Moenkopi Formation. In northern and eastern San Juan County, the Moss Back Member is the basal Chinle unit. It rests uncomformably on the Moenkopi Formation and locally, where the Moenkopi has been eroded, on sandstones of the Permian Cutler Formation.

Table 12.
Characteristics of uranium-vanadium deposits in the Cutler, Chinle, and Morrison Formations.
(after Doelling, 1969c; and Woodward-Clyde Consultants, 1983)

CHARACTERISTIC	MORRISON	CHINLE	CUTLER
Host Rocks	Salt Wash Sandstone Member, in sandstone lenses at any stratigraphic level. Upper Jurassic and lower Cretaceous.	Basal sandstone of the Shinarump, Monitor Butte, or Moss Back Member overlying the Moenkopi Formation. Triassic.	Discontinuous arkosic lenses interbedded with mudstone. Permian.
Thickness and Texture	Largest deposits in lenses over 40′ thick. When multiple lenses cluster, most ore found in a single lens.	Ore confined to channel sandstone lenses, especially those 300 to 1,000′ wide and over 40′ thick, except in Lisbon Valley and Big Indian Wash.	Ore bodies occur in both thin and thick arkose lenses (up to 28′ thick). Arkose lenses are usually coarse grained, porous, cross-bedded, and lenticular.
Size and Shape of Ore Bodies	Aligned parallel to sedimentary trends; most are roughly tabular and oval in plan. Ore bodies are commonly up to 9′ thick, 50′ wide, and 20′ long. Sinuous ore bodies may range to 300′ long and average 5′ thick.	Maximum 20′ thick by few hundred feet wide, by over 1,000′ long. Parallel sedimentary trends and roughly tabular in plan. Irregular where channels are complex.	Deposits are small, occur as blebs, pods, and irregularly shaped, low-grade bodies.
Mineralogy	Uranium-vanadium type, consists of uraninite and montroseite in primary deposits, and carnotite, tyuyamunite, vanadium clays or mica, and corvusite in oxidized zone.	Copper-uranium mineralization occurs in western part of San Juan County, uranium-vanadium in eastern part. Primary ores are found in deeper mines.	Mainly copper-uranium mineralization, but vanadium is also present. Minerals include carnotite, becquerelite, and copper sulfides.
Alteration Color	Generally white to brown. Mudstone, normally purplish, is greenish gray near ore.	Underlying Moenkopi usually bleached near ore.	Ore exists only in light-colored arkosic lenses.
Relation of Ore to Host Rocks	Ore minerals fill pore spaces and replace interstitial clay, cementing materials, and organic matter. Ore deposits occur along margins and middle of thick sandstone lenses.	Ore minerals fill pore spaces, replace interstitial clay, cement, and organic matter. Ore bodies lie along margins of channels (Shinarump Member), especially in the deepest scours. Large Lisbon Valley deposits lie near the base of the Moss Back Member.	Ore minerals occur as concretions and disseminations in arkose and along bedding planes in adjoining mudstone.

In the Monument Valley (Arizona and Utah) and White Canyon districts (plate 7), mines in the Shinarump Member have yielded significant amounts of uranium and vanadium from localized channels cut into the underlying Moenkopi Formation. Deposits in these districts range from less than 1,000 tons to greater than 500,000 tons with most deposits in the range of 5,000 to 10,000 tons. Uranium grades averaged about 0.25 to 0.30 percent U_3O_8 for both districts, but ores from Monument Valley were much richer in vanadium (0.65 vs. 0.04 percent V_2O_5) and lower in copper than those from the White Canyon district. Uranium ores from White Canyon contained from 0.3 to 1.3 percent copper (Chenoweth, 1991, 1993). The Shinarump-hosted deposits are generally linear to amoeba shaped and consist of closely spaced lenticular ore pods which are generally concordant with bedding. Individual ore pods are from a few to several hundred feet long and from less than one foot to 12 feet thick (Malan, 1986).

In the Lisbon Valley area, some of the largest, high-grade uranium-vanadium ore bodies in the country have been mined from fluvial sandstone units of the Moss Back Member. In this area the Moss Back Member lies unconformably either on very thin remnants of the Moenkopi Formation, or directly on the Cutler Formation. Deposits in the Lisbon Valley area range from 500 to 1,500,000 tons. Average grade of the mined ore was 0.37 percent U_3O_8 and 0.34 percent V_2O_5. The deposits are irregular, amoeba-shaped masses concordant with the bedding of the host rocks. They range from less than one foot to over 45 feet thick with an average thickness of 6 feet (Chenoweth, 1990b). Deposits in the Interriver, Cane Creek, and Indian Creek regions are also contained mainly within the Moss Back Member of the Chinle Formation.

Uranium-lead age dating on uraninite ores from the Shinarump yielded ages from 70 to 210 Ma suggesting that some mineralization may have begun shortly after deposition of host strata, and some long after (Shawe and others, 1991).

Morrison Hosted Deposits: Numerous uranium and vanadium deposits are present in the Salt Wash Member of the Jurassic Morrison Formation in eastern San Juan County. The deposits are concentrated in nine main areas as shown on plate 7. Most of the mines and prospects occur in drainages (Montezuma Canyon, La Sal) or along the edges of mesas (Dry Valley) where the favorable host unit is exposed.

Most of the ore has been mined from tabular bodies containing as much as tens of thousand of tons of ore. Roll-shaped and convoluted ore bodies are typically smaller with up to several thousand tons of ore (Shawe and others, 1991). In San Juan County, the tabular ore bodies are from 2 to over 10 feet thick, 10 to several hundred feet wide, and 50 to more than 600 feet long. Some of the larger ore bodies occur in the Paradox area along La Sal Creek (Doelling, 1969c). Ore grades average from 0.15 to 0.32 percent U_3O_8 and from 0.30 to more than 1.50 percent V_2O_5, (Thamm and others, 1981). Some ore bodies show a zonal arrangement with a high-grade core surrounded by lower grade material. Ore bodies are commonly enriched in a variety of other metals including copper, lead, zinc, molybdenum, and silver.

A large amount of uranium has been produced from the Salt Wash Member to the east and north of San Juan County in western Colorado and in Grand County, Utah. This production came from the Uravan mineral belt, an indistinct arcuate-shaped zone from 2 to 8 miles wide and over 70 miles long. Within this belt the uranium-vanadium deposits have closer spacing, larger size, and higher grade than those in the adjacent areas (Thamm and others, 1981). The location of the belt is thought to correspond to particularly favorable host rocks which formed at the toe or "leading edge" of a broad alluvial plain. Most of the deposits in San Juan County are not considered part of the Uravan mineral belt, although the group of deposits north of Ucolo could represent a southern extension of the belt.

Shawe and others (1991) suggest that ore deposition involved a combination of two phases of alteration by epigenetic fluids and intense reducing conditions around carbonized plant debris. The fluids caused alteration of the rocks and deposition of uranium-vanadium minerals at solution-pore water interfaces. Based on geologic relationships, the age of the later stage of alteration and ore deposition is most likely early Tertiary. Uranium-lead age dating of Uravan ores, however, suggests a range of deposition from about 70 to 115 million years.

Past Production and Trends

Uranium and vanadium ores have been mined in San Juan County since the early 1900s. Early uses of uranium included coloring glass and as glazes for ceramics, and later for the associated radium for medical research. Vanadium was also used for coloring glass and ceramics. From 1943 to 1970, uranium from the Colorado Plateau was mined for nuclear weapons, and since then for nuclear power plants (Chenoweth, 1990a). Vanadium is used today mainly for strengthening steel alloys (Shawe and others, 1991). Cumulative uranium and vanadium production from San Juan County, compiled from Chenoweth (1990b, 1991, 1993), Thamm and others (1981), and from the Utah Geological Survey's UMOS database, is summarized in table 13.

Table 13.
Uranium and vanadium production in San Juan County, Utah by mining area (generalized from Chenoweth, 1990a, 1990b, 1991, 1993; Thamm and others, 1981; and Utah Geological Survey UMOS database, November, 1993).

District/Area	lbs U_3O_8	lbs V_2O_5
Lisbon Valley Area[1]	79,560,000	534,000
White Canyon District	11,069,000	216,000
Interriver, Cane Creek, Indian Creek Areas	3,276,000	195,000
Paradox (La Sal)[2] District	6,426,000	28,878,000
Dry Valley Area	1,525,000	12,662,000
Montezuma Canyon Area	88,000	775,000
Monument Valley District	323,000	533,000
Cottonwood Wash Area	896,000	5,664,000
Bluff-Butler Wash Area	53,000	—
Abajo Area	7,000	1,000
Total	103,223,000	49,458,000

[1] Includes 1.6 million lbs U_3O_8 in Big Indian Wash region not listed by Chenoweth.
[2] Includes Browns Hole and Brumley Ridge.

Figure 13 shows combined annual production of uranium from 1948 through 1988 in the Lisbon Valley area, and the White Canyon, and Monument Valley mining districts — areas where detailed production figures are available.

Until about 1910, carnotite ores in the Uravan mineral belt were mined for use as a coloring agent for glass and ceramic glazes. From 1910 until the early 1920s, ores were mined for their radium content, from which vanadium was recovered as a by-product. From the early 1930s to about 1944, the ores were mined for their vanadium content for use in steel making. In 1947, the Atomic Energy Commission (AEC) created a market for uranium and mining in the Uravan belt focused again on production of uranium with vanadium as a by-product.

In 1952, while prospecting for uranium in the Cutler Formation, Charles A. Steen discovered a large high-grade uranium deposit in the Moss Back Member of the Chinle Formation at the Mi Vida mine in Lisbon Valley. This major discovery sparked new exploration that eventually made Lisbon Valley Utah's premier uranium mining area (table 13). Mines were established throughout San Juan County with production reaching a maximum between about 1958 and 1960. In the early 1960s, the AEC began restricting ore purchases, and ceased all purchases in 1970. The private market for uranium strengthened in the 1970s with development of nuclear power. Declining markets in the 1980s, due to overproduction and a general non-acceptance of nuclear power forced mines and mills to close. Presently, other than three permitted small mines, no uranium-vanadium mines or mills are operating in San Juan County. The only active mill is the White Mesa mill near Blanding run by Energy Fuels Nuclear Inc.

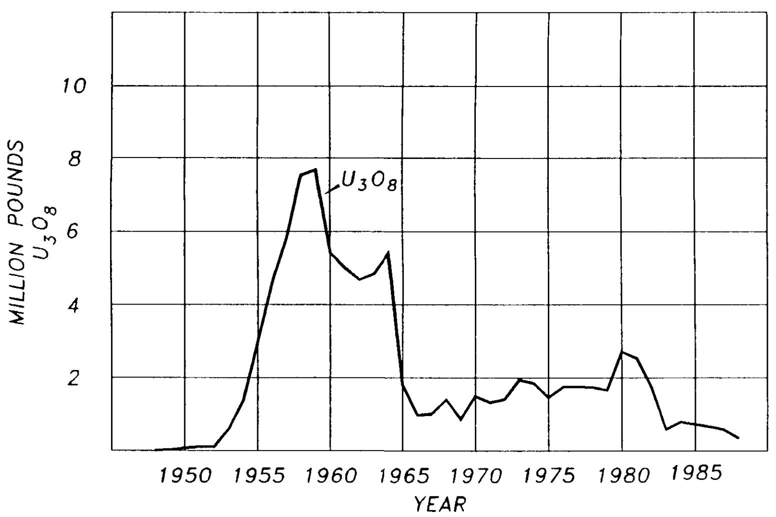


Figure 13. Annual production of uranium in the Lisbon Valley area, and White Canyon and Monument Valley mining districts, San Juan County, Utah (after Chenoweth, 1990b, 1991, 1993).

Annual production records of the U.S. Department of Energy's Grand Junction, Colorado office show that during the period 1948 through 1982, nearly 111 million pounds of U_3O_8 were produced in Utah (Chenoweth, 1990a). Of this total, mines in San Juan County produced 83 percent. Roughly 78 percent of the San Juan County production came from Lisbon Valley, while 12 percent came from White Canyon. Over 60 million pounds of vanadium, produced mainly as a by-product, have been mined in conjunction with uranium ores in San Juan County. During the late 1980s and early 1990s, stronger vanadium markets led to vanadium and by-product uranium production from mines in the Morrison Formation of the Uravan belt and eastern San Juan County. However, weaker vanadium markets forced the White Mesa mill to stand-by status and supporting mining operations to close until 1995 when the mill resumed processing ore.

Current Production and Exploration Activity

In late 1993, the Utah Department of Natural Resources, Division of Oil, Gas, and Mining (DOGM) recorded seven active "notice of intent to explore" (NOIs) permits for uranium/vanadium in San Juan County. Active NOIs included four in the Paradox area, one in Lisbon Valley, one north of Dry Valley, and one in the White Canyon area. DOGM also listed only three "small" uranium/vanadium mines with active mining permits and lists no "regular" mines with active permits. For uranium-vanadium mines, fifteen "regular" mines and nine "small" mines had permits under suspension. Small mines are those that disturb five acres or less of land; regular mines disturb more than five acres. Active status mines are those that reported some activity to DOGM during the past year. Suspended status mines are those that reported no activity during the past year. The locations and names of these mines are shown on plate 6.

At a market price of $10.00 per pound of concentrate, uranium requirements of U.S. utilities are now met by low-cost (solution mining) domestic producers and foreign imports. During the late 1980s until 1990, a stronger vanadium market encouraged production from a number of mines in the Morrison Formation. Since 1990, the vanadium market has softened and mining has been suspended at most operations. Much higher prices for uranium and vanadium will be required before the uranium-vanadium mining industry in San Juan County is again viable. Chenoweth (1990b) estimates that a price of $20.00 to 30.00 per pound U_3O_8 would be required.

Geologic Potential

The principal sources of uranium and vanadium in San Juan County have been ore bodies in the Moss Back Member of the Chinle Formation in Lisbon Valley, the Shinarump Member of the Chinle Formation in the White Canyon district, and the Salt Wash Member of the Morrison Formation in the Paradox and Dry Valley regions. Lesser production has come from the Cutler Formation in the Lisbon Valley area.

Chenoweth (1990a, 1990b, 1993) suggests that developed reserves remain in the White Canyon-Red Canyon area (White Canyon district), in the southern part of the Lisbon Valley in the Cutler Formation including a drill-indicated reserve of 2.5 million pounds of U_3O_8 at the Uranerz deposit, and in the Paradox region in the Morrison Formation. Reserves also exist at most of the "regular mines" with permits under suspension (plate 6).

However, many unexplored, but still prospective areas exist beneath moderate to deep cover in much of San Juan County. For Shinarump-hosted deposits, potential exists along established channel trends in the White Canyon district between White and Red Canyons, in the southern Elk Ridge area, and near Round Mountain both east and west of Stevens Canyon. There is little potential in the Monument Valley area because resources in the Utah part were essentially mined out by the late 1960s during the Atomic Energy Commission procurement years.

For Moss Back-hosted deposits potential exists on the down-dropped block northeast of the Lisbon Valley fault. Deep uranium mineralization is present in the Moss Back Member at the Lisbon mine and similar deposits could be expected to the southeast. On the southwest side of the Lisbon Valley fault, there is potential for Cutler-hosted deposits. These deposits are not restricted to a well-defined belt and could exist outside of the well-drilled Moss Back trend.

For Salt Wash-hosted deposits potential exists in the Paradox - Browns Hole area, south of the known mines in the Dry Valley area, and in the area north of Ucolo. The area north of Ucolo is particularly interesting because it could represent a southern continuation of the Uravan mineral belt. There is also potential for Salt Wash deposits under moderate to deep cover over most of eastern San Juan County. However, discovery of such deposits could require much close-spaced drilling because of their small lateral extent.

METALLIC RESOURCES

There are reported occurrences of gold, copper, and manganese in San Juan County (plate 8). With the exception of the copper deposits along the Lisbon Valley fault, all of these occurrences have proved to be small and uneconomic. In addition, lead, zinc, molybdenum, copper, and several other metals are found associated with the sedimentary-hosted uranium-vanadium deposits. With the exception of copper, all of these metals occur in quantities too small to be considered even as by-products of uranium-vanadium mining.

Gold

Known Occurrences and Characteristics

Three types of gold occurrences are known in San Juan County. Most are small and have had only minor, if any, production (Doelling, 1969b). The three types include gold veins and lodes in the Blue Mountain district of the Abajo Mountains (Witkind, 1964), disseminations in Jurassic-Triassic sedimentary rocks (Butler and others, 1920; Phillips, 1985) and recent placers (Johnson, 1973; Doelling, 1975). The lode gold mines and main areas of placer mining are shown on plate 8.

Gold Veins and Lodes: Based on descriptions by Witkind (1964) the gold veins and lodes can be divided into gold-pyrite-lode and quartz vein categories.

The gold-pyrite lodes occur at or near the margins of laccoliths on the east side of the Abajo Mountains. The lodes usually develop at the intrusive-sedimentary rock contact and consist of pyrite with some base metals. Mines in this category include the Dream mine and Marvin tunnel, Dixon's mine, Viking mine, Alma mine, and other unnamed prospects. Only at the Dream mine was gold reported to be recovered (Witkind, 1964).

Gold-quartz-fissure-vein deposits are present on the east and west sides of the Abajo Mountains. They consist of thin quartz vein or veinlet zones with free gold and occasional base metal sulfides. According to Witkind (1964), the veins occur in shatter zones adjacent to intrusive stocks. The properties were developed by short adits, generally less than 100 feet long, and small prospect pits. Mines in this category include the Gold Queen, Danish Girl, and Bluebird mines in sections 11 and 13, T. 34 S., R. 22 E. and the Duckett mine in section 18, T. 34 S., R 22 E. The Gold Queen mine produced most of the small quantities of gold reported from the area.

Disseminations in Sedimentary Rocks: Widespread anomalous gold values are reported for Permian to Jurassic sedimentary rocks over much of San Juan County, particularly in the Chinle and Wingate Formations and the Navajo Sandstone (Butler and others, 1920; Gregory and Moore, 1931; Phillips, 1985). Values of 0.01 to 0.02 ounces gold/ton or higher have been reported, but are most likely exaggerations. Values of 0.001 to 0.004 ounces gold/ton are more realistic estimates, even for the better occurrences (Lawson, 1913). This disseminated gold is most likely the source for much of the gold in some of the recent placer deposits, particularly those on the San Juan River (Gregory, 1938).

Placer Deposits: Recent placer gold deposits are found along Johnson Creek and Recapture Creek south of the Blue Mountain district, along the San Juan River from Montezuma Creek to the Colorado River, and along the Colorado River from White Canyon to the Arizona border (Johnson, 1973). In the Colorado and San Juan Rivers, gold is found in numerous bars along the river (plate 8). These bars were placer mined between 1880 and 1890. Total production from these placers in San Juan County was small, probably less than 2,000 ounces.

The gold occurs in recent river gravels and bars and in older terrace sands and gravels as much as 150 to 200 feet above the present river level. The very small size of the gold flakes (0.05 to 0.1 mm diameter) makes them difficult to recover. The gold reportedly was distributed throughout the gravel with the richest zones in thin clay streaks or seams. The higher bars or terraces showed better values, particularly on the upstream side (Utah Geological and Mineral Survey, 1966). Some of the gold is found in streaks of heavy minerals which may make up to 6 percent of some sand bars (Doelling, 1969b). Production from individual bars was small with one of the best producers, the California bar, producing only 500 - 600 ounces. Grades were in the 0.03 to 0.05 ounces/cubic yard range. Lake Powell now covers all of the reported placer occurrences in San Juan County along the Colorado and lower San Juan Rivers. Occurrences in the Montezuma Creek area of the San Juan River are still accessible, as well as those along Johnson and Recapture Creeks.

Past Production and Trends

Only about 3,000 ounces of gold have been produced from San Juan County and immediately adjacent areas (Doelling, 1969b). Most of this production came from sand bars along the San Juan and Colorado Rivers. Most of this placer production took place between 1880 and 1890 when there were several "gold rushes" in the county. These rushes were based more on speculation and exaggeration than fact and produced little gold.

Only very minor production was from the gold veins and lodes and most of this was from the Dream and Gold Queen mines. This production is estimated at less than 1,000 ounces and most likely less than 300 ounces. Most development was prior to 1910, although intermittent work continued at the Dream mine until 1943.

Several attempts were made to mine the gold disseminated in sedimentary rocks around the turn of the century, most notably near Paria, Arizona and at Spenser's Camp on the San Juan River in Utah; all were unsuccessful.

Current Production and Exploration Activity

There has been very little recent gold activity in San Juan County. Between 1975 and 1993 only five NOI permits have been filed for precious metals with DOGM. DOGM issued only nine Small Mine Permits for precious metals of which five were still active in late 1993 (plate 6). Current gold activity appears to be concentrating on outcrop areas of the Navajo Sandstone and Kayenta Formations and on small stream drainages far away from known gold occurrences. All of the activity is by individuals or small companies. It is also likely that there has been some very minor placer activity on the upper San Juan River near Montezuma Creek.

Geologic Potential

There is limited potential for discovery or development of significant gold deposits in San Juan County. All of the known deposits have been small and uneconomic. In fact, for most gold occurrences significantly more money was spent on development than was ever made from production. There may be some potential in and around the Abajo and La Sal Mountains for distal or proximal skarn, intrusive breccia, or stockwork deposits (plate 8). The potential is highly speculative and based on occurrences of such deposits around similar intrusives in Montana and Colorado. However, in view of the limited number of gold occurrences, both lode and placer in these areas, the potential must be ranked as low.

MANGANESE

Known Occurrences and Characteristics

A number of small manganese deposits are found in Jurassic to Cretaceous sedimentary rocks along the Lisbon Valley fault system (Baker and others, 1952; Weir and Puffet, 1981). The largest and most numerous occurrences are in the Muleshoe Wash area northwest of La Sal Junction (plate 8). A southern group of deposits (section 30, T. 28 S., R. 23 E.) consists of thin (less than 1 foot thick) layers of manganese oxide in limestone near the upper contact of the Navajo Sandstone. These manganese-stained horizons are from 10 to 550 feet long (Baker and others, 1952) and do not appear to be related to faults. A northern group of deposits (section 19, T. 28 S., R. 23 E. and section 24, T. 28 S., R. 22 E.) consist of "irregular, blanket-like pods, a few tens to few hundreds of feet across and less than 1 foot thick adjacent to faults" (Weir and Puffet, 1981). These deposits consist of manganese oxide impregnations and void fillings in the Entrada Sandstone immediately above the unconformity with the Navajo Sandstone. Manganese oxide zones, up to 10 feet wide, also occur along a series of subparallel fault and fracture zones in the Navajo Sandstone. These veins pinch out with depth, generally within 30 feet of the surface. Other smaller and lower grade manganese deposits are present in the Burro Canyon Formation at the northwest end of Lisbon Valley (Weir and Puffet, 1981). Weir and Puffet (1981) believe that these Lisbon Valley manganese deposits were formed after the copper deposits which are found further south.

Past Production and Trends

The San Juan manganese deposits were probably prospected about the turn of the century and were further developed during World Wars I and II. The size of the workings and neighboring dumps near Muleshoe Wash suggest that some material was shipped from these deposits during the war periods (Weir and Puffet, 1981). The only recorded production was one shipment of 35 tons of ore averaging 32.1 percent manganese.

Current Production and Exploration Activity

Known manganese deposits are small and uneconomic. No recent exploration activity for manganese in San Juan County is known and the potential for discovery of any economic deposits is minimal.

COPPER

Known Occurrences and Characteristics

A number of copper occurrences in sedimentary rocks are known in San Juan County, mostly along the Lisbon Valley anticline (Weir and others, 1961). The location of the main occurrences are shown on plate 8. The occurrences consist of chalcocite, covellite, djurleite, chalcopyrite, and their oxidized equivalents (malachite, azurite, tenorite, and native copper). These minerals occur as coatings on fractures, as pore fillings in sandstone, and as replacements of plant fragments (Doelling, 1969c). The copper mineralization is disseminated in favorable beds with the higher concentrations along fractures and around gray carbonaceous shale pods and lenses. The host units are sandstones, conglomerates, and occasionally limestones and are Pennsylvanian to Cretaceous in age.

The best deposits (Big Indian, Blackbird [Centennial] and GTO) are stratiform deposits in permeable sandstones of the Dakota and Burro Canyon Formations adjacent to the Lisbon Valley fault. The deposits are elongate parallel to the fault and mineralization extends down dip along favorable beds. The grade and intensity of mineralization decreases away from the faults. The deposits are up to 2,000 to 3,000 feet long, up to 800 to 1,200 feet wide, and 10 to 30 feet thick (Weir and Puffet, 1981). Deposits may be stacked, with copper mineralization present in several sandstone beds separated by shales. In the Centennial Pit area, mineralization occurs over a stratigraphic thickness of 300 feet (Sindor Incorporated, 1990). Grades are variable, commonly in the range of 1 to 2 percent copper.

Other deposits occur in the sandstones and limestones of the Hermosa Group, in sandstones of the Kayeta Formation, and in sandstones of the Cutler Group, particularly where the sandstones are bleached.

The deposits are thought to be Laramide or younger in age (Breit and others, 1987). They are thought to have formed when saline, oxidizing, copper-rich fluids were reduced by indigenous or introduced reductants in the host sandstones or by fluid mixing with reducing ground water (Morrison and Parry, 1986). The source of the saline fluids was most likely the Pennsylvanian Paradox Formation and the source of the copper was redbeds in the Permian Cutler Group and younger formations. The fluid became oxidized due to wall rock interaction with the redbeds. The faults and fractures of the Lisbon Valley fault system provided channel ways for the fluids. The initiation of fluid flow is thought to be due to the Laramide orogeny (Breit and others, 1987) or variations in hydraulic head from the La Sal, San Juan, or Abajo Mountains (Morrison and Parry, 1986).

Past Production and Trends

Copper was discovered in Lisbon Valley in 1881, and commercial quantities have been produced intermittently, particularly during World War II and in the early 1970s. Nearly all of the production has come from the Big Indian (Blue Jay), Blackbird (Pioneer or Centennial), GTO, and Sentinel areas. Production initially came from inclined shafts and drifts and later from open pits. By 1960, over 150,000 tons of 1.5 percent copper with minor silver had been produced from the Big Indian mine and nearly 5,000 tons of over 2.0 percent copper from the Blackbird mine. Some of the early production from the Blackbird mine averaged over 8.0 percent copper (Weir and others, 1981).

In 1960, Micro Copper Corporation mined some copper in the Lisbon Valley area. From 1967 to 1973, Keystone-Wallace Resources operated a copper oxide heap leach precipitation plant (Peterson and Gloyn, 1994). "From 1970 to 1973, Keystone Wallace Resources produced 25 million pounds of copper using a sulfuric-acid-leaching process. The operation was successful until significant quantities of chalcocite were encountered in the pits" (Sindor Incorporated, 1990). More recent activity has been confined mostly to exploration and metallurgical testing.

Recent Exploration and Production Activity

In the mid-1970s, Centennial Development optioned the Blackbird (Centennial), GTO, and Sentinel properties from Keystone Wallace and subleased to Noranda in 1973. Noranda conducted extensive exploration and feasibility studies. Drill-indicated resources of 10 million tons at 0.73 percent copper in the Centennial Pit area, and 3.8 million tons at 0.35 percent copper in the Sentinel area were delineated at this time (Sindor Incorporated, 1990 and figure 14). Kelmine acquired the lease in 1985, completed feasibility studies for the high-grade portion of the Centennial Pit and obtained a mine and plant permit. Kelmine subsequently transferred the lease to MLP Associated Ltd. who optioned the property to Sindor Resources Incorporated in 1989. Sindor did some drilling and begin mine permitting, but later dropped the property because of lack of financing (Peterson and Gloyn, 1994). Kennecott subsequently acquired the property and drilled several holes, some up to 1,600 feet deep, before dropping the property. Summo Minerals Corporation currently leases the property.

Much of the recent exploration and drilling has been concentrated in the Centennial and GTO Pit areas in section 36, T. 30 S., R. 25 E. and section 1, T. 31 S., R. 25 E. (figure 14). Additional work has been concentrated to the northwest in and around the Sentinel Pit. In late 1994, Summo Minerals Corporation announced recalculated open pittable reserves of over 38 million tons based on pre-1994 drilling (The Mining Record, December 28, 1994). The breakdown of reserves is shown in table 14.

Summo Minerals drilled 68 additional step out-holes in 1994 to increase the reserve . Results from this drilling have not been included in the above summary . A feasibility study for an open-pit, heap-leach operation is expected to be completed in early 1995.

In addition to the known pittable resource of nearly 38 million tons, there are potentially large, higher grade deeper resources. Drilling near and southeast of the GTO pit intersected copper mineralization of 3.0 to over 5.8 percent copper at depths of 400 to 600 feet and mineralization is found at depths of 700 feet in the Centennial Pit area (Sindor Incorporated, 1990).

Geologic Potential - Known Areas and Targets

There is excellent potential for discovery of additional sedimentary-hosted copper deposits along the Lisbon Valley fault and adjacent subparallel fault and fracture zones in the Lisbon Valley and the McIntyre graben to the south (plate 8). The area has known deposits, favorable host units, recognized fault "feeders," and numerous and widespread copper occurrences. In addition to the deposits in the Burro Canyon and Dakota Formation host units, there is also potential in the underlying sandstones of the Cutler Group, the Glen Canyon Group, and the Chinle, Bluff, and Entrada Formations particularly if there has been reduction of these sandstones by gas or liquid hydrocarbons. With introduced reductants, the deposits could be large.

Geologic Potential - New Areas and Targets

Using the Lisbon Valley conceptual model, which requires a feeder, additional potential areas include zones along and adjacent to the Shay graben, the Bridger Jack graben, the Verdure Creek graben zone, and faults in and around Bridger Jack - Flat Iron Mesas (plate 8). These areas have potential fault feeders and favorable host rocks. However, the relative absence of copper occurrences makes the potential of these areas much lower than the Lisbon Valley area.

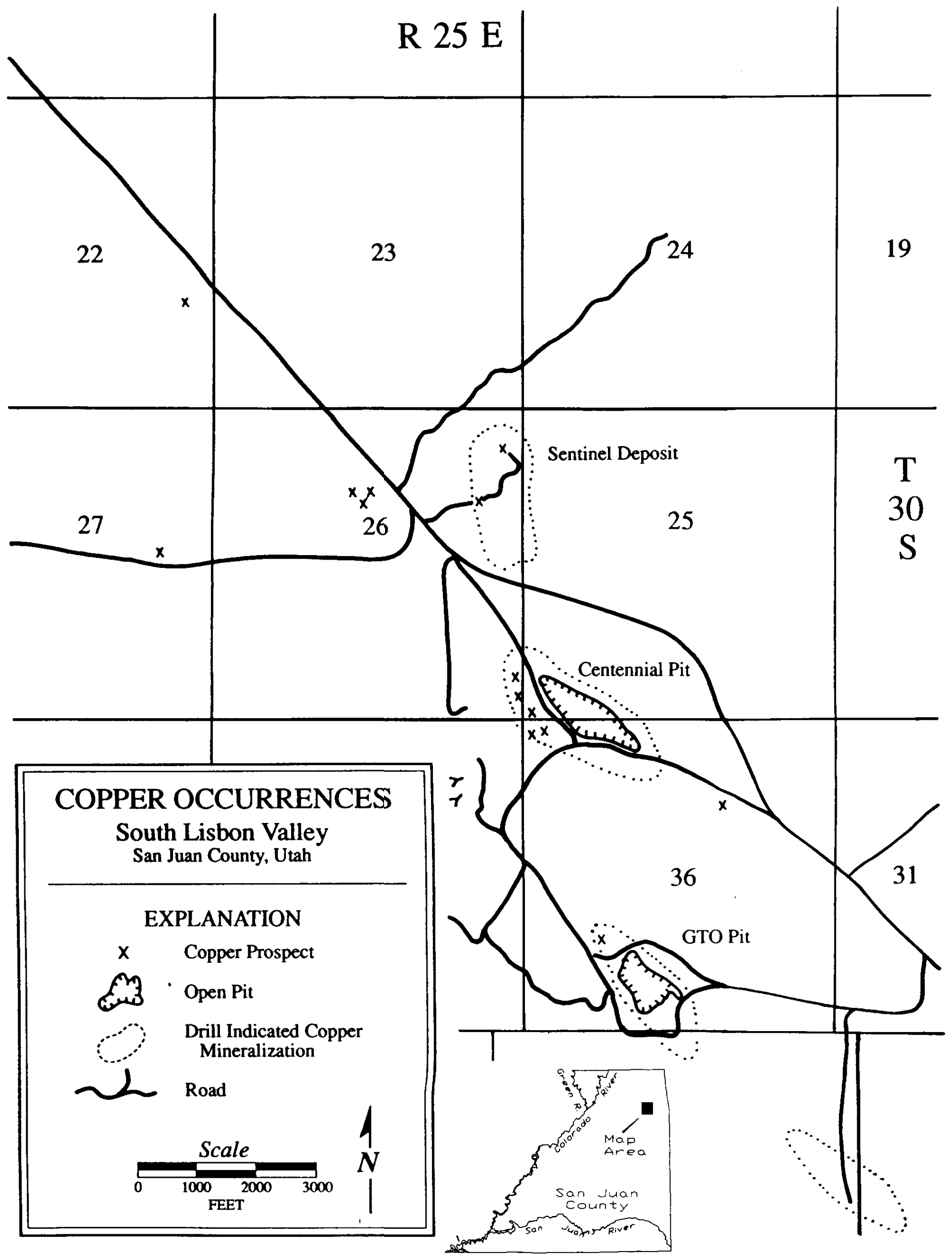


Figure 14. Copper occurrences, southern Lisbon Valley, San Juan County, Utah.

Table 14. Open pittable copper reserves in southern Lisbon Valley.					
Deposit	Cut-off Grade	Tons Ore	Grade	Strip Ratio	Category
Centennial	0.1%	25,846,000	0.466%Cu	1.77	Diluted Proven
Sentinel	0.1%	6,272,130	0.314%Cu	0.31	Diluted Proven
GTO	0.3%	6,340,000	0.720%Cu	5.40	Nondiluted Proven, Possible & Probable

Using a leaky reservoir conceptual model (Dzezkazagan model) (Kirkham, 1989), there could be some potential in northwestern San Juan County, particularly over gas fields or anticlines, and in southeastern San Juan County over oil and gas fields (plate 8). In this model, hydrocarbon or hydrogen sulfide leakage from below would cause reduction of Permian to Jurassic redbeds and precipitation of copper minerals would occur where metal-bearing oxidized solutions inherent in the redbeds encounter this reduced "front." If present, such deposits could be very large. Potential constraints, particularly in the Aneth area, could be the depth to the mineralized zones.

There is also a remote possibility for lead-zinc deposits in the Mississippian Leadville Limestone and in limestone algal mounds and oolitic banks of the Pennsylvanian Paradox Formation. These deposits might form when brines from the deep Paradox basin encounter favorable limestone hosts near the basin margins. The potential is still only conceptual, but sphalerite and galena are known from oil-well drill cuttings. Even if the concept is demonstrated, most potential host rocks would be at depths of 2,000 feet or greater making development less likely and more expensive.

INDUSTRIAL ROCK AND MINERAL RESOURCES - KNOWN

The industrial rock and mineral potential of San Juan County is difficult to evaluate because of the lack of industrial mineral studies done for the area. San Juan County has not been well examined because there is only small, local demand for industrial minerals and export potential is limited by the lack of a railroad. This situation could change; commodity use patterns change constantly and the entrepreneurial ability of mineral producers can lead to development of niche markets. Because specific information on industrial minerals in San Juan County is scarce, this section of the report will not follow the same format as the other sections; industrial mineral resource data will be divided into known resources (those with some recent history of production) and potential resources (those with potential for production under a reasonable demand/price scenario).

Construction materials for local use are the primary industrial mineral commodities produced in San Juan County. These commodities include: sand and gravel, bentonite, and crushed limestone. Small amounts of ornamental stone and semiprecious gemstones have also been produced in the county. The location of these commodities is shown on plate 9.

Sand and Gravel

San Juan County has adequate sand and gravel resources present in old river terrace, stream channel, and pediment deposits (Utah Department of Highways, 1968). The bedrock sources for the sand and gravel in these deposits are crucial in determining their quality. The best bedrock sources for aggregate in the county are well-indurated sandstone, non-cherty limestone and dolomite, conglomerate, and some granitic rocks.

According to Kiersch (1955b) sand and gravel derived from the Triassic Shinarump Conglomerate Member of the Chinle Formation is of excellent quality and this source rock unit is present in much of central and western San Juan County. Unfavorable bedrock sources for concrete aggregate include rhyolite, dacite, and andesite (Kierch 1955b), tuffaceous rocks, and cherty carbonates because they contain minerals which react unfavorably with cement during curing. Fortunately, these rock types are rare in San Juan County.

The larger sand and gravel pits are shown on plate 9. Plate 9 also shows areas identified by the BLM as having known sand and gravel deposits and areas favorable for sand and gravel. Undoubtedly there are additional sand and gravel resources in San Juan County, particularly along drainages. The BLM granted rights-of-way for eight sand and gravel deposits to be used in highway construction (table 15) and 11 sand and gravel pits to supply material to local communities (table 16). Some, but not all, of these areas are shown on plate 9. Kiersch (1955b) and the Utah Department of Highways (1968) contain site specific data on existing and potential sand and gravel pit sites.

Table 15. Sand and gravel rights-of-way granted by the BLM for highway construction in San Juan County, Utah (U.S. Bureau of Land Management, 1987).		
Site Name	Location	Size (acres)
Mexican Hat A	Sec. 20, T. 41 S., R. 19 E.	160
Mexican Hat B	Sec. 29, T. 41 S., R. 19 E.	217.20
Cottonwood Wash	Sec. 14, 23, T. 37 S., R. 21 E.	80
McCray Mesa	Sec. 01, T. 39 S., R. 22 E. Sec. 06, 07, T. 39 S., R. 23 E.	40 151.54
Bluff A	Sec. 24, T. 40 S., R. 23 E. Sec. 19, T. 40 S., R. 22 E.	77.62
Bluff B	Sec. 26, T. 40 S., R. 21 E.	10
Hatch Wash	Sec. 01, T. 28 S., R. 22 E. Sec. 03 T. 29 S., R. 23 E. Sec. 10, T. 30 S., R. 23 E.	160 80
Blanding	Sec. 13, 24, T. 36 S., R. 22 E.	140

Table 16. Community sand and gravel pits designated by the BLM in San Juan County, Utah (Bureau of Land Management, 1987)		
Site Name	Location	Size (acres)
Buck	Sec. 27, T. 40 S., R. 21 E.	100
Bluff	Sec 27, 28, T. 40 S., R. 22 E.	153.74
Airport	Sec. 5, 8, T. 40 S., R. 21 E.	224.27
Lem's Draw	Sec. 24, T. 36 S., R. 22 E.	160
Gray Ridge	Sec. 36, T. 40 S., R. 23 E.	256.74
Spring Creek	Sec. 8, 9, T. 33 S., R. 23 E.	440
Bluff Bench	Sec. 26-28, 34-35, T. 40 S., R. 23 E.	920
Bucket Canyon	Sec. 35, T. 40 S., R. 23 E.	173
Brown's Canyon	Sec. 18, 19, T. 37 S., R. 23 E.	60
Recapture	Sec. 13, T. 36 S., R. 22 E.	60
Mexican Hat	Sec. 1, T. 42 S., R. 18 E.	37.5

Bentonite

Several geologic units have potential for bentonite production in San Juan County: the Triassic Petrified Forest and Monitor Butte Members of the Chinle Formation, the Cretaceous Brushy Basin and Westwater Canyon Members of the Morrison Formation, and the Cretaceous Mancos Shale (figure 15). The Petrified Forest Member probably has the best potential for development of clay for local engineering uses.

Bentonite is ubiquitous in the Petrified Forest and Monitor Butte Members of the Chinle Formation throughout San Juan County, but the thickness and purity of the bentonite is quite variable. The Petrified Forest Member typically consists of claystone and clayey sandstone with occasional limestone-pebble conglomerates (Stewart and others, 1959). The Petrified Forest Member thins (and becomes sandier) to the northeast in San Juan County, becoming very thin near Monticello (Stewart and Wilson, 1960). The bentonite in the Petrified Forest Member along Chinle Creek southeast of Mexican Hat (plate 9) is roughly 40 feet thick. The bentonite of the Petrified Forest Member was examined and sampled at Lee's Ferry a few miles south of the Utah state line. The clay is 120 feet thick there but six samples taken had a maximum swell of only 202 percent with an average swell of 130 percent (Kiersch, 1955a).

The Monitor Butte Member consists mostly of bentonitic claystone and clayey sandstone interstratified with small sandstone lenses 1 to 10 feet thick. The sandstone lenses typically form 5 to 20 percent of most outcrops but may be absent (Stewart and others, 1959). The member thins (and becomes sandier) to the northeast in San Juan County and is absent northeast of Monticello. The best locations for bentonite as noted by Doelling (1969b) were Monument Valley, Clay Hills, and near Comb Ridge.

The upper part of the Brushy Basin Member of the Morrison Formation consists largely of volcanic ash altered to clay. The unit shows a zonation in clay mineralogy with primarily bentonite in eastern San Juan County changing to illite eastward into Colorado (Owen and others, 1989). Numerous samples taken from the upper Brushy Basin at Lisbon Valley by Owen and others (1989) contained more than 90 percent bentonite. Samples taken from the undifferentiated Brushy Basin at Montezuma Creek also averaged more than 90 percent bentonite. Two operations have produced clay from the Brushy Basin Member. The Butterfield bentonite mine, located near Aneth (plate 9), produced 5,000 cubic yards of clay from the Brushy Basin in 1977 and may have produced in other years. The Grand County Water Conservancy District mined 400 cubic yards of clay in 1989 and 1,872 cubic yards of clay in 1992 from the Spanish Valley clay pit of northernmost San Juan County (Utah Division of Oil, Gas and Mining unpublished data) (plate 9). The Spanish Valley clay pit is probably located in the Brushy Basin Member.

The Westwater Canyon Member of the Morrison Formation is predominantly a cross-stratified sandstone but locally contains silty, greenish-gray interbedded claystone. The distribution pattern of bentonite in the claystone is unknown.The Mancos Shale consists of dark-grey marine shale with interbedded sandstone. The distribution and purity of bentonite in the shale is unknown.

Bentonite is currently produced in San Juan County and there

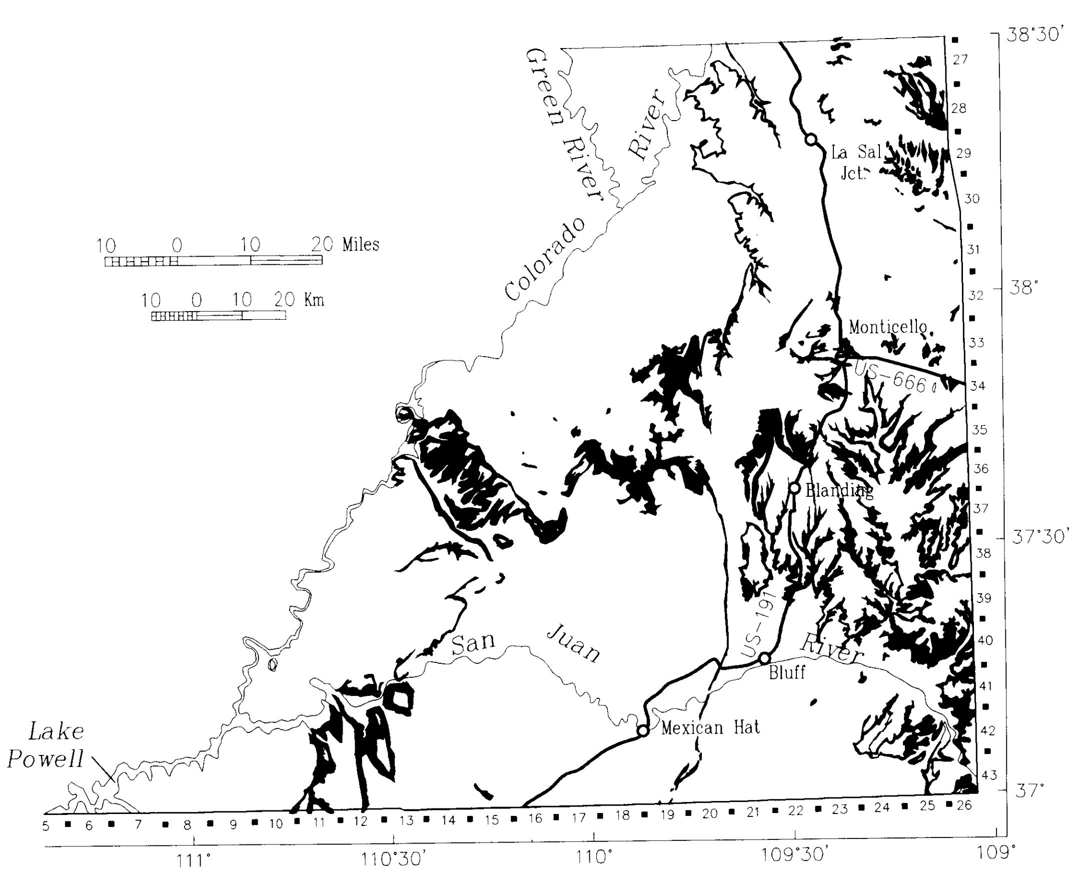


***Figure 15.** Outcrops of formations with potential for bentonite production in San Juan County, Utah.*

is potential for additional production. The most likely immediate use for additional bentonite is for engineering uses such as reservoir, ditch, and landfill lining. More exploration and testing is necessary to determine potential for oil well drilling mud, foundry bonding clay, and fuller's earth. If found suitable for these higher unit-value uses, the clay could be exported to customers in the West.

Limestone

The lacustrine limestones of the Jurassic Navajo Sandstone and the marine limestones of the Pennsylvanian Honaker Trail Formation (formerly the Rico Formation) contain small amounts of relatively high-quality limestone. Thin, discontinuous limestone units are present in the thick sandstones of the Navajo Sandstone. Near Shonto, Arizona (25 miles south of the Utah state line), these limestone units contain 96 to 98 percent $CaCO_3$. These Navajo Sandstone deposits are also well exposed at Mexican Water, Arizona (5 miles south of the Utah state line) where they are relatively pure but very thin, only one to two feet thick (Kiersch, 1955a). The Honaker Trail Formation consists of marine limestone and interbedded shale, siltstone, and fine-grained sandstone. It has potential for production of high-calcium limestone from the Mexican Hat area and from outcrops in the San Juan River Canyon (figure 16). At Mexican Hat, the favorable limestone is four feet thick, assays 92.1 percent $CaCO_3$, and is strip minable. Outcrops of several other thin, favorable limestones in the Honaker Trail in the San Juan River Canyon range from 1 to 4 feet thick, assay as high as 91 percent $CaCO_3$, but would have to be mined by underground methods (Kiersch, 1955a).

Three companies are currently developing limestone operations in San Juan County, all in the Honaker Trail Formation. Holliday Construction has opened a small prospect on Comb Ridge to obtain limestone to test for possible use as riprap and armor plating on DOE uranium mill tailings burials in the area. Such engineering use of limestone does not require that the stone have a high-calcium content, any massive, resistant, unfractured rock could be used. Immediately to the west, Western Industrial Minerals has proposed a new quarry to provide both scrubber limestone for power plants and rock dust for coal mines in the Four Corners area; these uses require a high-calcium limestone. Further north, Cotter Corporation is opening a quarry in section 36, T. 29.5 S., R. 24 E. at the north end of Lisbon Valley. The limestone is in the Honaker Trail and is reported to be 15 feet thick (verbal communication Dick White, August, 1994). The quarry is scheduled to produce between 20,000 to 30,000 tons per year (TPY) to be used as scrubber limestone for the power plant in Nucla, Colorado. High-calcium limestone is rare enough on the Colorado Plateau that even though these planned developments are not prime limestone deposits they could be mined and shipped to users in the Four Corners region.

Gemstones/Ornamental Stone

Semi-precious gemstones present in San Juan County include petrified wood containing opal and agate, chalcedony, garnet, fossilized dinosaur bone, and azurite. The Chinle Formation contains abundant decorative petrified wood which has been cut and polished for use as decorative items and jewelry. It is widely distributed across much of San Juan County. Deep red to black pyrope garnet have been recovered from volcanic vent deposits of the Mule Ear and Moses Rock occurrences near Mexican Hat (plate 9). Although they are used in jewelry and as abrasives, the amount of material known to be present is so small that a commercial venture is unlikely. The size of these volcanic vents at depth is uncertain so there is some potential for larger quantities of garnets to be present. The percentage of garnets of gem quality is also quite low (Kiersch, 1955a). Spessartite garnets were also produced at an unspecified place in San Juan County in 1908 (Sterrett, 1908). Fossilized dinosaur bone is often associated with Chinle and Morrison Formation outcrops; some of this bone is replaced by chalcedony and has been cut and polished into semi-precious gemstones (Austin, 1991). Deep blue azurite coats fractures in the Dakota Sandstone along the Lisbon Valley fault zone near La Sal. The one-inch-thick deposits have been mined and the azurite shaped into ornamental stones (Doelling, 1969b). The Big Indian copper mine reportedly produced 7,200 pounds of malachite and azurite from 1982 to 1984 (Hampson, 1993); the good-quality crystals were sold as mineral specimens with the poorer material being marketed as paint pigment. Production of fossil wood has a regulatory ceiling. The federal government and the state of Utah control the amount of fossil wood that can be gathered by private collectors. Vertebrate and invertebrate fossils can only be removed from state and federal land by permit.

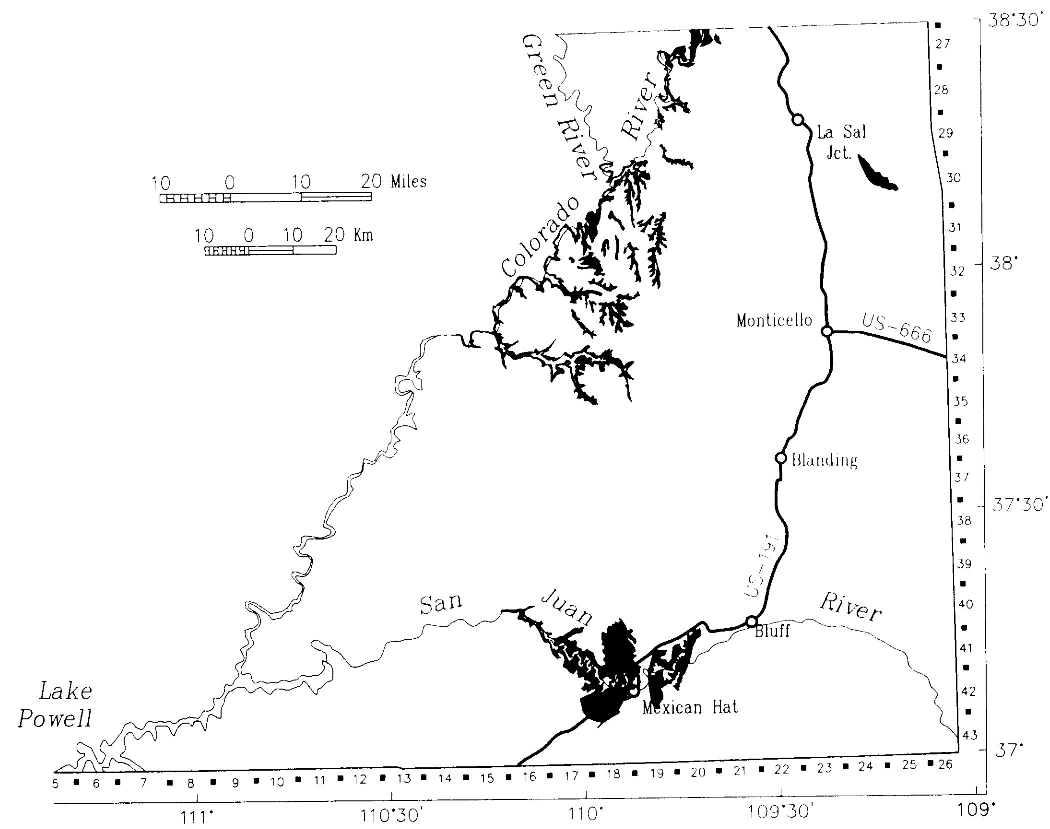


***Figure 16.** Outcrops of the Permian Elephant Canyon Formation (Rico Limestone), and selected Pennsylvanian Honaker Trail Formation outcrops, known sources of high-calcium limestone, in San Juan County, Utah*

INDUSTRIAL ROCK AND MINERAL RESOURCES -POTENTIAL

San Juan County contains many commodities that may be produced (and possibly exported) in the future depending on increased demand in the region and on the entrepreneurial ability of mineral companies. Quality and quantity data are sparse for most of these commodities and it was often necessary to extrapolate information on a commodity restricted to a particular stratigraphic unit from a nearby county or state. Much geological work remains to be done in San Juan County to adequately characterize these resources. Information on potential resources is presented below by commodity in rough order of probable export potential based on our present knowledge and is summarized in table 17 in alphabetical order. The discussion of bedded salt and brines follows the standard format since more information is available for these commodities.

Humate

Weathered coal and carbonaceous shales and mudstones of the Cretaceous Dakota Sandstone have potential for sale as humate, a natural soil conditioner. No known exploration for humate has taken place in San Juan County, but studies were done on humate in the Dakota Sandstone near Westwater, in Grand County, Utah.

Baker Associates proposed an open pit operation there in 1982 to produce 1.12 million metric tons of humate from a 250 acre site (U.S. Bureau of Land Management, 1985). They submitted one analysis of the humate to the U. S. Bureau of Land Management (BLM) for inclusion in their Environmental Assessment; it showed an adequate humic acid content of 25.56 percent. Occurrences in San Juan County are expected to be similar. Humate has been produced for roughly 20 years from several mines in the slightly younger Cretaceous Meneffee Formation in the San Juan basin of northwestern New Mexico (Hoffman, Verploegh, and Barker, 1994).

The value of humate is determined by the contained humic acid (including humic, ulmic, and fulvic acid) (Siemers and Waddell, 1977). Deleterious material possibly present in the coal includes: cadmium, lead, mercury, arsenic, selenium, uranium, and thorium. These toxins are present in humate, but they are not usually concentrated enough to be of concern; Siemers and Wadell (1977) found no deleterious concentrations of these elements in the New Mexico humate samples that they analyzed.

Doelling (1972) reported that the Dakota Sandstone is 30 to 200 feet thick in the San Juan and La Sal coal fields and contains thin, discontinuous coal seams generally thinner than 4 feet. The quality of humate rather than the thickness is the most important factor for development and the higher quality humates would not necessarily be associated with the thickest coals. The better quality humate should occur close to the surface where the coal and carbonaceous shale has been upgraded by weathering. The outcrop limits of the coals and carbonaceous shales in the Dakota Formation in San Juan County are shown in plate 5.

Bedded Salt

Known Occurrences and Characteristics

Bedded potash (sylvite and carnallite), salt (halite), and magnesium salts (carnallite) of the Paradox Formation underlie a large part of San Juan County (plate 10). The Pennsylvanian Paradox Formation contains 29 stacked salt layers (not all of which are found at any one point in the basin) separated by clastic interbeds (figure 17). The salt-bearing zone is about 4,000 feet thick. Roughly 10 percent of the thickness of this unit is potash,

Table 17.
Potential for production of industrial rocks and minerals in San Juan County, Utah

COMMODITY	DEPOSIT SIGNIFICANCE	MARKET FOR COMMODITY	RECENT EXPLORATION	RECENT PRODUCTION	NOTES
Barite	low	slight decline	no	no	These occurrences are insignificant compared to Nevada bedded barite deposits and could probably only be produced as byproduct of vanadium or copper mining. The barite market closely tracks the oil and gas drilling industry which is currently depressed.
Bentonite	medium	static	yes	yes	There are large deposits but they are predominantly Ca-rich or low-swelling bentonites which are worth less than Na-rich or high-swelling bentonites. The viability of these deposits depends on the amount of domestic oil and gas drilling. Work should be done to determine the suitability of bentonite in this area for use as foundry bond clay and fuller's earth.
Building stone	low	slight growth	no	no	There is scant information on building stone in San Juan County but unusual varieties could have good potential.
Common clay	medium	slight growth	no	no	San Juan County is a long way from an urban center; however in the long term, brick manufacturers will be overrun by urbanization and have to move operation to more rural areas.
Crushed stone	low	static	no	no	Crushed stone is important for local use but there is little export potential.
Fireclay	low	slight decline	no	no	Fireclay as a refractory is being replaced by alumina and magnesia but this material has some potential for use in ceramics such as china and sanitary ware.
Gemstones and ornamental stone	low	solid growth	yes	yes	There is potential to attract rockhounds and for small production of decorative items such as aquarium ornaments.
Gypsum	medium	slight growth	yes	no	Gypsum is a very low unit value commodity and generally must be located close to existing wallboard plants to be economical. Some potential exists for shipment of agricultural gypsum to California.
Humate	medium	solid growth	yes	no	Production of this commodity is very subject to entrepreneurial skill.
Lightweight aggregate	medium	static	no	no	There probably are large volumes of material suitable for this purpose in San Juan County. Distance to market will be the major problem since the material is used primarily in high-rise building construction in major cities.
Limestone	medium	solid growth	yes	yes	While San Juan County has limited deposits of limestone, what material is present has good potential due to a lack of limestone in this region in general. There is current and potential demand for limestone for cement raw material or flue gas desulfurization at regional plants.
Salt (bedded)	high	static	no	yes[1]	Potash production in this area will be partially controlled by the current price for potash from the giant Saskatchewan, Canada deposits. Magnesuim production has been proposed several times in the Paradox basin but no production has taken place; the increasing use of lightweight magnesium in automobiles could improve the economics of this commodity. Halite is most likely to be produced as a byproduct of potash or magnesium production.
Salt (brine)	high	static	yes[2]	no	There is moderate potential to produce magnesium, lithium, bromine, and boron as byproducts of potash production. Brines from oil and gas production wells have potential for byproduct minerals production.
Sand and gravel	low	slight growth	no	yes	These deposits are important for local use but have no export potential.
Specialty sand and silica	moderate	static	yes[3]	no	The highest potential for this commodity is as oil and gas well hydrofracture sand which comprises only about 5% of the specialty sand market. Glass making and metal casting uses the bulk of specialty sands; these industries are unfortunately located far from San Juan County.

continued on next page

Table 17 (continued)

COMMODITY	DEPOSIT SIGNIFICANCE	MARKET FOR COMMODITY	RECENT EXPLORATION	RECENT PRODUCTION	NOTES
Zeolites	moderate	slight growth	yes	no	Speculative potential exists, however, high-purity zeolites have not been reported from this area. Additionally the zeolite industry, which has enormous promise, is still very small.

[1] *Potash and halite are produced by Moab Salt Company at Cane Creek, a few miles north of the San Juan County line.*
[2] *U.S. Borax examined potential production of lithium and magnesium from existing wells in Grand County.*
[3] *Claims were recently staked in the remote San Rafael Swell for specialty sands.*

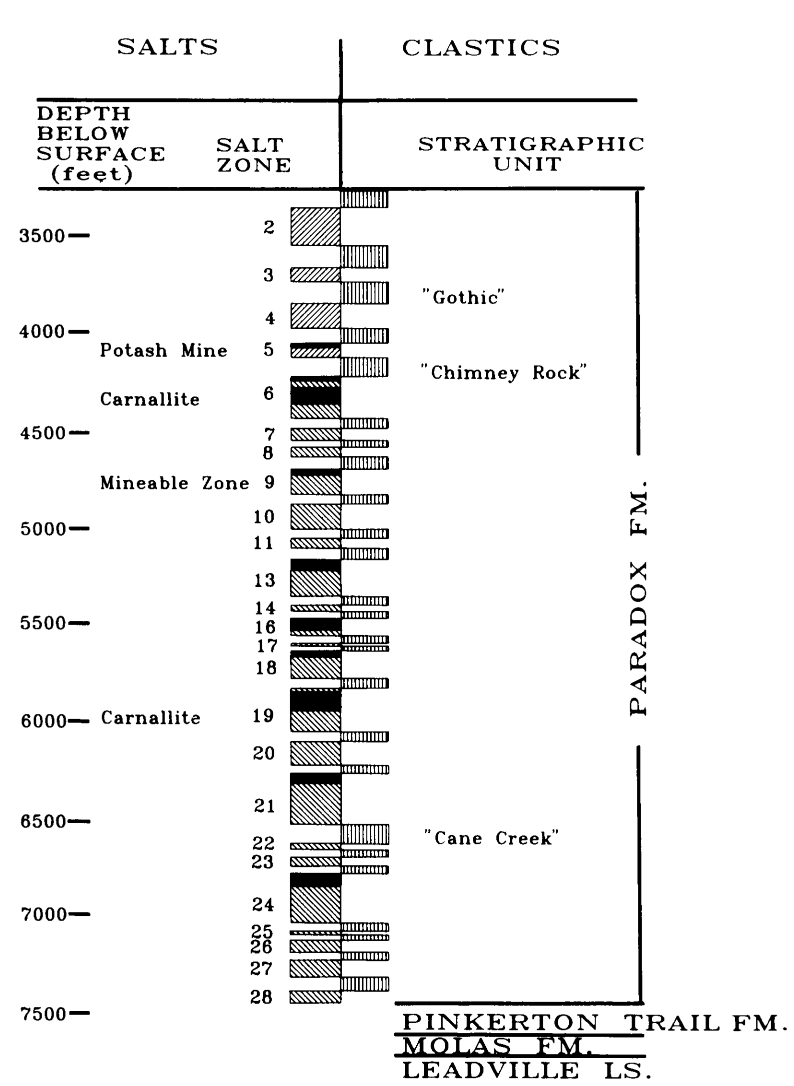


Figure 17. *Detailed salt stratigraphy of the Paradox Formation in the Cane Creek anticline area, Moab Drilling Company (Government Whitecloud No. 1) well, sec. 14, T. 26 S., R. 20 E. (modified from Hite, and others, 1972). Halite units indicated by diagonal hatched pattern, shaly units by vertical hatched pattern, and potash by solid black. Salt units are not always distinguishable; salt units 1, 12, 15, and 29 were not recognized at this well. Salt stratigraphy in San Juan County is very similar except that a potash unit is present in salt 27 in San Juan County but not in Grand County at the White Cloud No. 1 well.*

25 percent is shale, and 65 percent is halite. Eight to 10 potash beds underlie various parts of the county and have an aggregate thickness of roughly 220 to 460 feet (Hite and others, 1972). Lewis (1965) estimated known potash reserves in the Paradox basin to be 254 million tons potassium oxide (K_2O) with inferred reserves of 161 million tons K_2O. These numbers are based on subsurface mining with minimum potash bed thickness of 4 feet, a minimum K_2O grade of 14 percent, and a cutoff depth of 4,000 feet. Solution minable resources are much greater.

Past Production and Trends

Potash and salt production from the Paradox Formation began in 1964 at the Cane Creek anticline, in Grand County, just north of the San Juan County line. The location of Moab Salt Company's Cane Creek mine was selected because the salt beds are nearest the surface in the salt anticlines and the salt is thickened by folding. The mine was initially a conventional room and pillar operation. In 1970, problems with explosive gas pockets, high mine temperatures, and a contorted ore zone dictated a change to solution mining of the original workings (Phillips, 1975).

Current Production and Exploration Activity

The Cane Creek mine is still producing both potash and by-product salt by solution mining and solar evaporation. All production, as of 1993, came from salt unit 5, but salt unit 9, which contains a thick potash interval, is an additional potential resource. This mine reported the following annual production of combined salt and potash (in short tons): 1990 - 485,102; 1991 - 410,628; 1992 - 445,363; 1993 - 410,067 (Utah Division of Oil, Gas and Mining unpublished data). Moab Salt Company plans to eventually mine the potash resources of salt unit 9 approximately 1,000 feet below the current mine in salt unit 5. They plan to rehabilitate and deepen the shaft originally used for the mining of salt unit 5; potash and halite would be mined by room and pillar methods to expose enough surface area for later conversion to solution mining. Moab Salt Company projects a remaining mine life of 30 years (Morgan and others, 1991). There is no known current exploration or development for bedded salt in San Juan County.

There are both negative and positive factors affecting future saline mineral development in San Juan County. Thick overburden, transportation problems, and competition from mines in New Mexico and Canada may hinder development of saline resources in San Juan County. Thick overburden covers most of the resource, increasing mining costs. San Juan County also lacks a railhead. A new mine in San Juan County would have to compete not only with mines in New Mexico, but also with a very well established and aggressive Canadian potash industry which is producing from a salt resource much larger than that in the Paradox basin. On the positive side, Paradox evaporites represent a world-class deposit of a material for which no substitute exists and since recovery of this resource depends on evaporating water from a natural or solution mining brine, the hot, dry summers of San Juan County are ideal.

Geologic Potential

The most favorable areas in San Juan County to produce potash and salt are where the salt is thick, at shallow depth, and uncontorted. Plate 10 shows that these criteria are met in north and central San Juan County. The major potash zones, however, are restricted to the area of San Juan County north of a northwest trending line drawn through Monticello. Many of the shallow areas in this region are uplifts or anticlines in which the salt is often contorted, making underground and solution mining difficult. The U.S. Geological Survey originally designated the Cane Creek and Lisbon Valley areas as Known Potash Leasing Areas (KPRA) due to thin overburden and thickened salt in these areas. Experience with potash mining in a salt anticline in Grand County has shown that production from salt anticlines can be difficult. Solution mining may actually be more productive in areas of greater overburden but less contorted, more predictable salt beds. Butte Resources' Ten Mile area potash project in Grand County is based on this concept.

Brines

Known Occurrences and Characteristics

A thick zone of saline water containing potassium, sodium, magnesium, and trace elements underlies the eastern portion of San Juan County in the same area as the bedded salt of the Paradox Formation. Devonian to Cretaceous strata contain brine, but Mississippian to Permian strata contain the highest concentrations (table 18) and host most of the resource.

The depth to the brine zone is controlled by stratigraphy and geologic structure as well as the amount of surface water infiltration. The concentration and composition of the brine varies laterally and vertically. Mayhew and Heylmun (1966) evaluated oil-field brines from 200 wells in the Paradox basin and determined that the brines become more concentrated toward the deeper part of the basin (figure 18). They projected commercial possibilities for extraction of magnesium, potassium, bromine, boron, and lithium. Gwynn (1993, personal communication) is completing a more detailed study on the variations in brine chemistry. He has compiled a database of Paradox basin brine chemical analyses (Gwynn, in preparation). Gwynn's work also shows that potash and sodium increase in concentration with increasing depth in the Paradox basin. Magnesium is most concentrated in Paradox Formation brines in the shallow parts of the basin and decreases rapidly in concentration in the deeper parts of the basin to the south (Gwynn, 1993, personal communication). Howells (1990) prepared a map showing the elevation of the base of the saline water.

Past Production and Trends

Oil and gas fields have produced the only brine from San Juan County (as a waste product). Cumulative production by field is shown in table 4. This brine has all been reinjected or otherwise disposed of; no salt has yet been recovered.

Current Activity and Potential

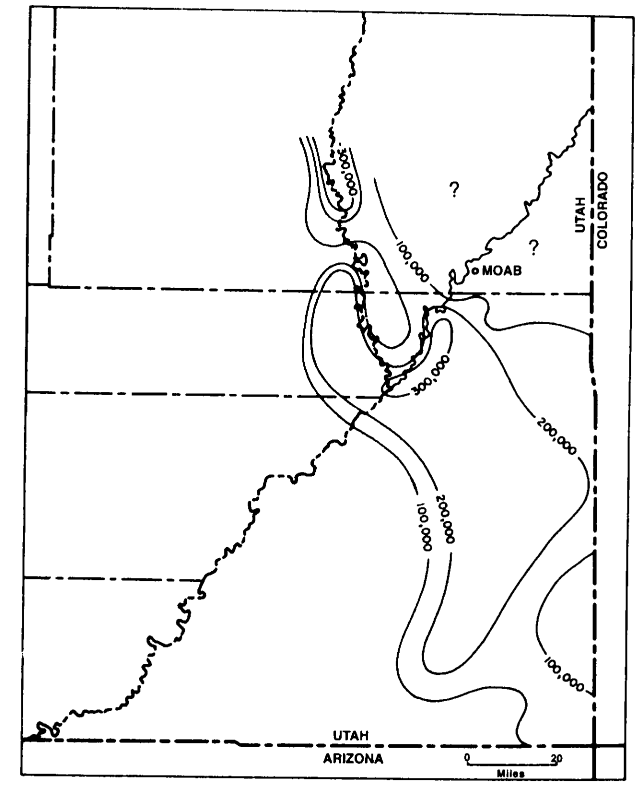
While brine in San Juan County has good long-term potential for solar potash, magnesium, and salt production, its most immediate market is likely to be as a drilling fluid for use in oil and gas drilling in the Paradox basin. Concentrated brine must be used when drilling holes which penetrate salt horizons to avoid enlarging the wellbore. Additionally, the trend toward weight reduction in automobile manufacture may stimulate magnesium demand, which would improve the economics of San Juan County brine production.

Building Stone

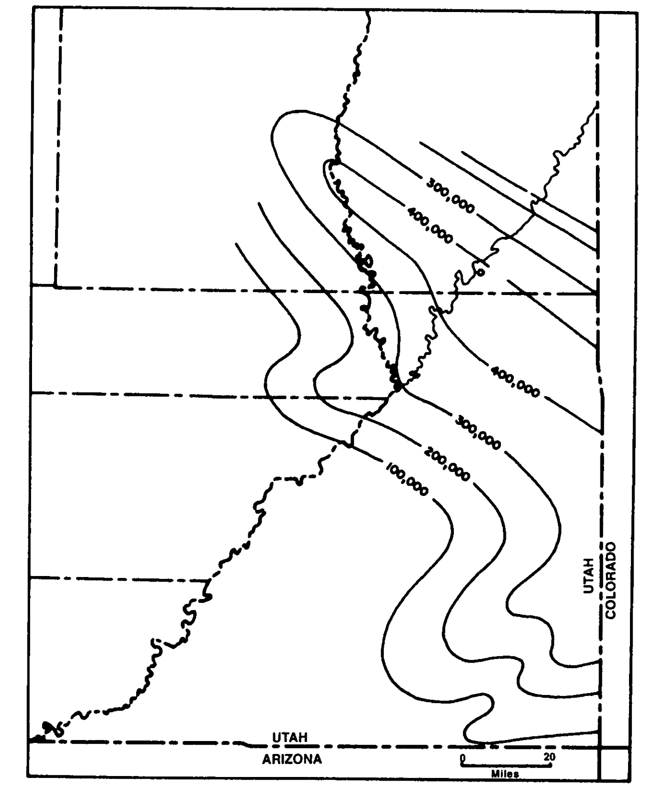
Massive and flaggy sandstone and granitic rock are the building stones with the highest potential for production in San Juan County. Reddish-brown and buff, ripple-marked sandstones are produced profitably at Torrey, Utah from the Triassic Moenkopi Formation. Similar stones of Permian, Triassic, and Jurassic age occur in abundance in most of San Juan County. The Torrey operation consists of quarrying large blocks from massively bedded sandstones and then sawing and carving or splitting the stone. Flaggy to thin-bedded sandstones are also being produced in the state. Near Park City, red and tan sandstones are produced in sizable quantities for residential and commercial construction. Characteristics desirable in flagstone

Table 18.
Generalized chemical analyses of brine in Paradox basin stratigraphic units (numbers before slashes are average concentrations[in mg/l except for lithium which is reported in parts per million]; numbers after slashes are the number of samples averaged) (from Gwynn, J.W., in preparation)

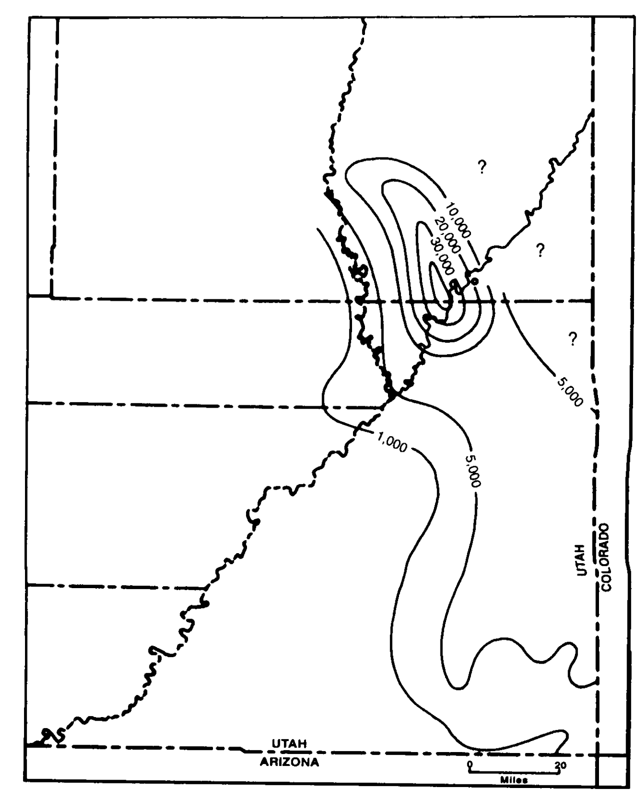
Stratigraphic unit	Total dissolved solids	Na	K	Mg	Li
Cretaceous	981 / 32	146 / 32	3 / 25	43 / 32	0 / 0
Jurassic	1,722 / 50	474 / 51	10 / 36	27 / 51	0 / 0
Jurassic/Triassic (Navajo Sandstone)	1,478 / 149	418 / 149	14 / 112	15 / 146	0 / 0
Triassic	4,600 / 16	1,017 /16	53 / 3	104 / 16	0 / 0
Permian	15,593 / 34	4,629 / 34	59 / 19	274 / 34	1 / 2
Pennsylvanian	139,442 / 281	38,292 / 259	462 / 121	2,896 / 259	3 /2
Mississippian	106,630 / 93	37,082 / 90	573 / 28	969 / 90	38 / 2



Concentration of brine from Mississippian rocks (total dissolved solids, in parts per million)



Concentration of brine from Pennsylvanian rocks (total dissolved solids, in parts per million)



Concentration of magnesium in Pennsylvanian brines (parts per million)

Figure 18. *Variations in subsurface brine chemistry in San Juan County, Utah (from Mayhew and Heylmun, 1966).*

include uniform thin bedding, large size of slabs (few joints and faults), and attractive color, texture, and color banding. Thin-bedded and well-cemented sandstone of Permian through Jurassic age in San Juan County could have some potential for use as flagstone. The granites of the Abajo and La Sal Mountains should also be evaluated for building stone potential. An unusual granite can be profitably quarried in large blocks and shipped significant distances. Characteristics of granites currently in vogue include: red, black, blue, or green color and decorative flow banding.

Specialty Sands and Silica

Unlithified dune sand and sandstones of San Juan County have potential for production of hydrofracture sand, glass sand, engine traction sand, and as a source of silica. Several units have potential and should be sampled: the Permian Cedar Mesa and De Chelly sandstones, Triassic Hoskinnini Sandstone; the Jurassic Wingate, Navajo, and Entrada Sandstones and the Bluff Sandstone Member of the Morrison Formation; Cretaceous Dakota Sandstone and eolian dunes. Sparse information is available on the quality of these units; however, Ketner (1964) gives the following general analyses:

Table 19.
Average elemental analyses of selected sandstones of Utah.

Formation	No. of Samples	Al	Fe	Mg	Ca	Na	K	Ti	Mn
Dakota Sandstone	7	0.8	0.3	0.04	0.08	0.03	.02	0.05	0.001
Bluff Sandstone Member (Morrison Formation)	5	1.0	.3	.2	1.0	.08	.7	.05	.02
Entrada Sandstone	12	.8	.3	.4	.7	.1	.8	.04	.008
Carmel	4	2.0	1.0	.7	2.0	.2	1.0	.1	.02
Navajo Sandstone	5	1.0	.2	.08	.3	.1	.7	.04	.008
Kayenta Formation	3	1.0	.4	.7	1.0	.3	1.0	.06	.03

Meeting glass sand specifications is difficult; the iron content should be below 0.15 percent (Mills, 1983). Few sands or sandstones are naturally this pure but beneficiation might improve the quality enough to make these formations usable. It is more likely that these units could provide quality hydrofracture sand or engine traction sand.

Lightweight Aggregate

Shales containing organic matter or sulfur-bearing minerals are found in abundance in San Juan County and can be thermally expanded into bloated shale, a valuable lightweight aggregate. Samples of clay from the Chinle Formation of northern Arizona exhibited bloating when fired, possibly indicating some potential for this unit in San Juan County (Kiersch, 1955b). One purple clay mottled with green swelled to 1,000 percent of its original volume. The Mancos Shale was generally unsatisfactory due to its high carbonate content, but some samples showed promise (Kiersch, 1955b). Additionally, low-grade coal of the Dakota Sandstone can be sintered to produce lightweight aggregate (Kiersch, 1955b). Anderson (1960) evaluated the bloating shale potential of shaly formations in northern Utah and concluded that any organic shale which would evolve a gas at the same temperature at which its constituent clays melted and became plastic might have potential for manufacture of lightweight aggregate. Lightweight aggregate is sometimes used in place of sand and gravel because it has thermal and sound insulating properties and is light, which reduces the amount of structural steel needed in a building.

Common Clay and Fireclay

Clays of the Triassic-age Moenkopi Formation, Petrified Forest Member of the Chinle Formation, and the Cretaceous-age Brushy Basin Member of the Morrison Formation, Dakota Sandstone, and Mancos Shale have good potential for producing common clay and lower potential for producing fireclay in San Juan County. Kiersch (1955a) examined and analyzed clays from several of these formations in northern Arizona for use in common clay applications. He rated the Moenkopi clay as good, the Chinle clay as fair to good, the Morrison clay as fair, and the Mancos clay as fair. Van Sant (1964) examined and sampled clay beds associated with coal of the Dakota (?) Sandstone at three localities just south of Monticello (plate 9) for refractory clay potential. The outcrops examined tended to be thin and mainly suitable for manufacture of common clay products, but one four-inch-thick unit outcropping six miles southwest of Monticello was judged suitable for high-duty refractory use. Doelling (1969b) mentions that high-duty refractory clays are found in the Dakota Sandstone in nearby Garfield County. Good-quality refractory clays are often found under coal seams because humic acids associated with the coal leach underlying shales of many soluble minerals leaving the resistant alumina; high alumina content correlates with the refractory grade of the clay.

Zeolites

The Brushy Basin Member of the Morrison Formation contains zeolites in eastern San Juan County. The predominant mineral found is clinoptilolite with a smaller amount of analcime. A substantial amount of the volcanic ash originally present in this saline, alkaline-lake deposit has been altered to zeolites (Turner-Peterson, 1987). The economic potential is unknown. The few individual samples taken by Turner-Peterson contained only about 30 percent clinoptilolite (Turner-Peterson, personal communication); but saline-alkaline lake deposits can contain very pure beds of zeolites. There is a high probability that additional exploration could reveal purer deposits. Clinoptilolite has promising applications in agriculture, livestock feed, wastewater treatment, and chemical processes.

Crushed Stone

Crushed stone for aggregate could be obtained in large quantities from the limestones and dolomites, well-indurated sandstones, conglomerates, and granitic rocks of the county. Quality sources of crushed stone must have adequate compressive strength, crush to uniform equidimensional particles without generating excessive fines, and be chemically unreactive with cement.

Gypsum

The Pennsylvanian Paradox Formation, the Permian Cedar Mesa Sandstone, and the Triassic Moenkopi Formation contain gypsum in San Juan County. The Paradox Formation contains significant quantities of gypsum but is only exposed at a few places in the county. A thin, lower gypsum unit is exposed along the San Juan River near Grand Gulch, but no data are available on thickness or purity. A gypsum bed in the middle part of the Paradox Formation is reported to be up to 40 feet thick at an outcrop near Lime Creek, north of Mexican Hat (plate 9) (Withington, 1964). The same unit is exposed on the Colorado River near Cataract Canyon, but no information is available on thickness or purity. Gypsum found in the Cedar Mesa Sandstone southeast of Mexican Hat on the west side of Comb Ridge is impure, usually containing only about 50 percent gypsum with selected samples assaying 80 to 91 percent gypsum (Kiersch, 1955a). The Moenkopi Formation is reported to contain gypsum at two places in San Juan County; at the Colorado River near Cataract Canyon and south of Mexican Hat near Gypsum Creek. Neither occurrence was reported as being extensive (Withington, 1964).

Barite

A small amount of barite was reported as a gangue mineral associated with uranium-vanadium-copper mineralization at the Happy Jack mine (Trites and Chew, 1955). The Happy Jack mine is in west-central San Juan County near the western county line (plate 9). Three other uranium mines (the Honey Bee #1, the Moon Shine, and the Lisbon), in northern San Juan County (plate 9), also contain barite as a gangue mineral.

Agricultural Minerals

Several of the minerals present in San Juan County are used in agriculture and animal husbandry; their presence together in the same region makes it more likely that they can be profitably produced. Zeolites, humate, and potash could be incorporated together into potting soil. Zeolites, limestone, humate, and potash could be mixed in poultry and animal feed.

GROUND-WATER RESOURCES

Characteristics of Major Aquifer Systems

In San Juan County, ground water has been withdrawn over the past century primarily from two types of aquifers: fractured bedrock and unconsolidated deposits. The characteristics of geologic units in San Juan County, along with their hydrologic properties and significance, are presented in table 20. The principal aquifers are discussed below.

Fractured-Bedrock Aquifers

The post-Precambrian sedimentary rocks in San Juan County have a maximum known thickness of about 10,000 feet (Avery, 1986). All of the rocks in San Juan County can be water bearing to some degree, depending on their permeability, thickness, and location with respect to recharge areas. The permeability (a measure of the amount, size, and interconnection of void spaces) of bedrock aquifers depends both on primary permeability due to interconnected void spaces between rock particles, and secondary permeability due to rock fractures (faults and joints). Some of the better water-yielding rock units are grouped into aquifer systems. The major water-yielding rock units in San Juan County have been grouped together into six aquifers. From oldest to youngest (in order of decreasing depth at any given location), these aquifer systems are the Redwall aquifer (Howells, 1990) and the P, C, N, M, and D aquifers (Avery, 1986). These aquifers are not laterally or vertically homogenous and, although they are treated individually in the following discussion, little is known about the interaction between the aquifers or the degree to which they are isolated or perched due to confining beds (Avery, 1986). In general, the shallowest aquifers are best because they commonly contain higher quality water than deeper aquifers and are more easily accessible.

Redwall aquifer: The Redwall aquifer, probably the most widespread, continuous aquifer in San Juan County, consists of the Redwall (Leadville) Limestone and permeable intervals and facies in the overlying Molas and Pinkerton Trail Formations (Howells, 1990) (table 20). Except in areas of Tertiary intrusive rocks, these formations underlie all of San Juan County. Burial and diagenesis have generally reduced the porosity and permeability of these rocks to the point where they yield water only where fractured or where systems of solution channels have developed. The Redwall Limestone is more than 500 feet thick near the Grand Canyon (Cooley and others, 1969).

P aquifer: The P aquifer consists of permeable beds in the undifferentiated Cutler Group (mostly in the northeast part of San Juan County) and the Cedar Mesa Sandstone of the Cutler Group (Avery, 1986) (table 20, plate 11). Thackston and others (1981) include permeable intervals in the "Rico Formation" and the upper two-thirds of the Honaker Trail Formation of the Hermosa Group as part of the P aquifer. Sandstone units of the P aquifer range from 20 feet thick east of the La Sal Mountains to more than 1,200 feet thick at some locations west of the Abajo Mountains. Based on previously published data, Avery (1986) calculated a hydraulic conductivity (a measure of the ability to transmit a specific fluid, in this case water) of 0.02 foot per day for a well in the P aquifer in Canyonlands National Park.

C aquifer: The C aquifer consists of the DeChelly Sandstone of the Cutler Group (table 20, plate 11) (Avery, 1986). The C aquifer is generally present only south of the San Juan River (Avery, 1986; Howells, 1990). The C aquifer is about 200 feet thick in southern San Juan County near the Utah-Arizona state line, but thins northward to zero near the San Juan River (Cooley and others, 1969). Cooley and others (1969) report hydraulic conductivities ranging from 0.6 to 5.4 feet per day and well yields ranging from 3 to 200 gallons per minute for the C aquifer.

N aquifer: The N aquifer consists of the Wingate Sandstone, the Kayenta Formation, the Navajo Sandstone, the Carmel Formation, and the Entrada Sandstone, except south of the San Juan River where the Entrada Sandstone is not considered part of the N aquifer (table 20, plate 12) (Avery, 1986). Where units making up the N aquifer are fully preserved and saturated, the aquifer is generally between 750 and 1,250 feet thick (Avery, 1986). The N aquifer "is the main source of domestic and livestock water in San Juan County" (Howells, 1990). Most water-well drillers try to complete their wells in the N aquifer in areas where the D aquifer is not saturated (Avery, 1986). Cooley and others (1969) report hydraulic conductivities ranging from 0.4 to 66.2 feet per day and well yields ranging from 5 to 170 gallons per minute for the Navajo Sandstone portion of the N aquifer.

M aquifer: The M aquifer consists of the Bluff Sandstone and Salt Wash, Recapture, and Westwater Canyon Members of the Morrison Formation (table 20, plate 13) (Avery, 1986). Water in the M aquifer is generally under water-table conditions where it appears (Howells, 1990). Where the M aquifer is overlain by the relatively impermeable Brushy Basin Member, the water may be under confined conditions (Howells, 1990). The M aquifer has a total thickness of about 400 feet near the Utah-Arizona state line where all four units making up the aquifer are present; northward, the stratigraphic section thins and the aquifer is only about 150 feet thick near La Sal where only the Salt Wash Member is present (Avery, 1986). Cooley and others (1969) report hydraulic conductivities ranging from 0.01 to 2.0 feet per day for the Westwater Canyon portion of the M aquifer, and well yields ranging from 6 to 19 gallons per minute for the Salt Wash, Recapture, and Westwater Canyon portions of the M aquifer.

D aquifer: The D aquifer consists of the Burro Canyon Formation and the Dakota Sandstone (table 20, plate 14); these formations cap the highest mesas in eastern San Juan County (Avery, 1986). Ground water in the D aquifer is generally under water-table conditions, but where the aquifer is overlain by the Mancos Shale or low-permeability unconsolidated deposits, ground water may be under confined conditions (Howells, 1990). The D aquifer ranges from 150 to 400 feet thick; aquifer thickness decreases with distance from the flanks of the Abajo and La Sal Mountains due to erosion. In some areas, such as east of Monticello and near Blanding, the aquifer consists primarily of the Burro Canyon Formation because the Dakota Sandstone is thin (Avery, 1986). Where present, the D aquifer has been tapped by numerous wells and is a common target for water-well drillers because of its shallow depth (Avery, 1986). Cooley and others report hydraulic conductivities ranging from 0.09 to 3.4 feet per day and well yields ranging from 3 to 36 gallons per minute for the Dakota Sandstone portion of the aquifer.

Unconsolidated Aquifers

Unconsolidated sediments, deposited primarily as thin veneers over bedrock, provide water to wells at many locations in San Juan County (table 20, plate 15). These unconsolidated sediments have a wide range of hydrologic characteristics which vary primarily due to grain size, sorting, and bedding. Unconsolidated deposits in San Juan County rarely exceed 200 feet, and probably average less than 50 feet thick (Doelling, 1969a). Types of unconsolidated deposits include: wind-blown silt and sand, stream alluvium (including terrace gravels), alluvial-fan deposits, pediment-mantle deposits, talus, landslide deposits, colluvium, and glacial outwash and till.

These unconsolidated deposits are generally mixtures of gravel, sand, silt, and clay and exhibit varying degrees of stratification and sorting (Doelling, 1969a). Permeability and hydraulic conductivity generally increase with increased grain size and sorting. Wind-blown silt and sand deposits in San Juan County are usually highly permeable because they are very well sorted. Stream alluvium may have a wide range of hydraulic characteristics because the deposits contain both highly permeable stream-bed gravels and low-permeability overbank clays. Glacial till generally has a low permeability, primarily due to poor sorting.

Although unconsolidated deposits provide water to springs and wells at many locations in San Juan County, they are a major source of water only in southern Spanish Valley in the northern portion of the county and along the San Juan River in the southern portion of the county. Stream alluvium in Spanish Valley is more than 360 feet thick in some places (Sumsion, 1971; Avery, 1986); most wells in this valley range from 30 to 300 feet deep. The thickness of stream alluvium in the San Juan River Valley is not well defined; most wells range from about 20 to 60 feet deep (Sumsion, 1975). Wells in alluvium in Spanish Valley have highly variable yields, ranging from 8 to 1,000 gallons per minute (Sumsion, 1971). Alluvium in the San Juan River Valley yields relatively large quantities of water to wells, ranging from 66 to 250 gallons per minute.

Recharge and Discharge

The areally extensive bedrock aquifers all receive recharge through infiltration of precipitation and stream flow in one or more of the following recharge areas: (1) the La Sal and Abajo Mountains, and, probably, Navajo Mountain in Utah; (2) the southwestern flank of the Uncompahgre Plateau in Colorado; (3) the San Juan Mountains of Colorado and the Carrizo Mountains and Black Mesa of Arizona; (4) the Henry Mountains of Garfield County, Utah; and (5) the topographically highest outcrops of each aquifer within San Juan County for aquifers above the Paradox Formation of the Hermosa Group (Howells, 1990). In general, most recharge occurs in areas with elevations greater than 8,000 feet because this is where most precipitation falls.

Unconsolidated aquifers are generally recharged by precipitation, stream flow, and springs discharging from bedrock aqui-

Table 20.
Characteristics of the major geologic units and their hydrologic characteristics and significance, San Juan County, Utah.
(modified from Howells, 1990 and Avery, 1986; stratigraphic nomenclature after Hintze, 1988)

Era	System	Series	Group formation, or rock unit	Maximum reported thickness (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Cenozoic	Quaternary	Pleistocene and Holocene	Alluvial and eolian deposits	360	Silt, sand, and gravel in stream valleys and floodplains. Windblown silt and sand on upland areas, benches, and broad valleys. Sand and gravel deposits on benches along major streams. Poorly sorted angular to well-rounded sand, pebbles, and boulders on dissected pediment surfaces surrounding the Abajo Mountains.	Low to moderate permeability. Yields small quantities of water to shallow wells in the San Juan River valley.	Unconsolidated aquifers (plate 11)
					Talus, slope wash, and block rubble.	Springs in the Abajo Mountains issue from this unit.	
					Dissected deposits of poorly sorted silt, sand, and gravel.		
					Well-rounded and well-sorted deposits; mostly glacial outwash.		
					Unsorted, unstratified, morainal deposits.		
	Tertiary	Eocene and Oligocene	Intrusive igneous rocks (stocks, laccoliths, dikes, and sills)	5,000+	The intrusives of the Abajo Mountains are mostly quartz diorite to diorite porphyry, but include granodiorite and quartz monzonite. The intrusives of the La Sal Mountains are mostly diorite porphyry, but include soda syenite, syenite, and monzonite porphyry.	Very low permeability. Known to yield water only where jointed, fractured, or faulted. Water yielded is fresh.	
Mesozoic	Cretaceous	Upper Cretaceous	Mesaverde Group	30 (?)	A regressive sequence of continental fluvial, deltaic, and swamp deposits of shale, siltstone, sandstone, and coal beds that interfinger with the upper part of the Mancos Shale. In San Juan County this unit is represented only by a small, thin bed of sandstone in the La Sal Mountains.	Insignificant; too small in areal extent.	
			Mancos Shale	800 (?)	Marine shale that contains a few thin beds of sandstone or limestone. The Mancos Shale has three members: The Blue Gate Member at the top, a shale that contains thin beds of bentonite or shaly sandstone and limestone; the Ferron Sandstone Member in the middle, a fine-grained, thin-bedded sandstone and sandy shale; and the Tununk Member at the base, a mudstone and shale that contains some thin bentonite beds. The Mancos Shale is gradational with, and laterally interfingers with, the overlying Mesaverde Group. The Mancos Shale underlies much of northeastern San Juan County, but is typically not present south of Blanding and west of Comb Ridge.	Very low permeability; a barrier to the movement of water unless fractured. Water in the Mancos Shale, or in alluvium or colluvium derived from it, is saline. The Ferron Sandstone Member is too thin and too small in areal extent to have any hydrologic significance.	
		Upper Cretaceous	Dakota Sandstone	250	The Dakota Sandstone includes continental deposits at the base and marine sediment at the top. The Dakota is quartzitic, sometimes conglomeritic, fluvial to near-shore marine sandstone that contains interbedded non-marine shale and thin beds of low-grade coal. The formation locally contains a coarse conglomerate at the base. The Dakota Sandstone underlies much of eastern San Juan County, but is typically not present west of Comb Ridge north of the San Juan River, or west of Desert Creek south of the San Juan River.	Generally very low to low permeability except where faulted or fractured. Ground water in the Dakota Sandstone usually is under water-table conditions, although in some areas, particularly where the Dakota is overlain by Mancos Shale or by clayey alluvium or colluvium, ground water may be under artesian conditions. Because the areal distribution of the formation is fragmented, flow systems are local. The Dakota Sandstone and Burro Canyon Formation make up the D aquifer. Water in the D aquifer ranges from fresh to moderately saline. The Dakota Sandstone yields fresh to slightly saline water in most areas, but water may be more saline where recharge has been in contact with Mancos Shale or with alluvium or colluvium derived from Mancos Shale. The Dakota Sandstone is a major source of potable water near Monticello and La Sal.	D aquifer (plate 12)

***Table 20** (continued)*

Era	System	Series	Group formation, or rock unit	Maximum reported thickness (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Mesozoic	Cretaceous	Lower Cretaceous	Cedar Mountain Formation/ Burro Canyon Formation	200	The Cedar Mountain and Burro Canyon Formations are believed to be contemporaneous. The Cedar Mountain Formation is a fluvial deposit that consists of two members. The upper member is composed of swelling clay and mudstone containing many limestone nodules and a few scour-fill sandstone beds. The lower member, the Buckhorn Conglomerate Member, is a scour-and-fill sandstone that contains granule- to cobble-sized conglomeratic material. The Cedar Mountain interfingers laterally with and grades into the Burro Canyon Formation at about the present location of the Colorado River. The Burro Canyon is a fluvial deposit of quartzose sandstone and conglomerate interbedded with generally nonbentonitic siltstone, shale, and silty and sandy mudstone, that contains a few thin beds of limestone. These formations (usually the Burro Canyon) underlie much of eastern San Juan County, but are typically not present west of Comb Ridge north of the San Juan River, or west of Desert Creek south of the San Juan River.	Generally very low to low permeability except where faulted or fractured. The Cedar Mountain Formation is limited in areal extent; and thus, is hydrologically insignificant. Where the Burro Canyon Formation is water-bearing, ground water usually is under water-table conditions, though in some areas it is under artesian conditions. Because the areal distribution of the formation is fragmented, flow systems are local, and water quality is variable. The Burro Canyon Formation and the overlying Dakota Sandstone make up the D aquifer. The Burro Canyon Formation is a major source of potable water around Blanding and on the Sage Plain, east of Monticello.	D aquifer (plate 12)
	Jurassic	Upper Jurassic	Morrison Formation	1,350+	Continental deposits of mostly fluvial shale, siltstone, mudstone, and sandstone that contain a few beds of fresh-water limestone. In the northern half of the county, the Morrison Formation is composed of two members. The upper member, the Brushy Basin Member, is laminated, bentonitic mudstone and siltstone that contains a few lenses of chert-pebble conglomerate and sandstone. The basal member is the Salt Wash Member, which is correlative with the Bluff Sandstone Member in the southern part of the county. The Salt Wash Member is a fine- to medium-grained, sometimes conglomeritic sandstone interbedded with mudstone. The Salt Wash contains thin beds of calcareous and gypsiferous shale and has thin beds of limestone near the base of the member. The Bluff Sandstone Member, an eolian deposit that contains minor interbeds of fluvial material, is a massive, mostly fine- to medium-grained sandstone. The Bluff Sandstone Member is 350 feet thick near the town of Bluff, thins northward to zero thickness near Blanding, and thins southward to about 20 feet near the Arizona state line. In the southern half of the county the Morrison Formation thickens and is further divided; the Recapture and Westwater Canyon Members separate the Salt Wash and correlative Bluff Sandstone Members from the Brushy Basin Member. The Westwater Canyon Member is a lenticular, fine- to coarse-grained, arkosic sandstone and conglomerate that contains some interbedded sandy shale and mudstone. The Westwater Canyon Member interfingers with and grades into the lower part of the Brushy Basin Member between Monticello and Blanding. The Recapture Member is a fine- to medium-grained, calcareous and gypsiferous sandstone and interbedded siltstone and mudstone that thins and grades into the underlying Salt Wash Member to the northeast. The Morrison Formation underlies much of eastern San Juan County; it is typically not present west of Comb Ridge and Nokaito Bench.	The Bushy Basin Member has very low permeability (average less than 10 millidarcies) and is a barrier to the movement of water except where faulted or fractured. The Brushy Basin Member is the confining bed between the D and M aquifers. The Salt Wash, Recapture, Westwater Canyon, and Bluff Sandstone Members make up the M aquifer. The Salt Wash, Recapture, and Westwater Canyon Members have low permeabilities (samples ranged from 263 to 813 millidarcies). The Bluff Sandstone has low to moderate permeability (samples ranged from 430 to 3,240 millidarcies). Water in the aquifer is usually under water-table conditions where the units that make up the Morrison aquifer crop out, but where the units are overlain by the Brushy Basin Member or by relatively impermeable beds within the Morrison Formation below the Brushy Basin, the water may be under artesian conditions. Water in the Bluff Sandstone Member is under artesian conditions southeast of the Abajo Mountains; wells near Montezuma Creek and near the town of Bluff may flow. Water from the Morrison Formation ranges from fresh to moderately saline in most of the area, but south of T. 35 S., Salt Lake Base Line and Meridian, water may be very saline locally.	M aquifer (except the Brushy Basin Member) (plate 13)
		Middle Jurassic	Wanakah (formerly Curtis and Summer-ville) Formation	200	The Wanakah (formerly called the Curtis and Summerville Formations) consists of a marginal-marine, tidal-flat, and fluvial facies (Summerwille), and a marine facies (Curtis). The marginal-marine, tidal flat and fluvial facies consists of calcareous and gypsiferous, laminated shale, and very fine- to fine-grained sandstone containing an irregular zone of chert (and, locally, limestone) concretions near its top. The marine facies consists of glauconitic, fine- to coarse-grained sandstone and siltstone that contain thin beds of shale	Very low to low permeability; a barrier to the movement of water except where faulted or fractured. The Wanakah Formation is the confining bed between the M and N aquifers.	

***Table 20** (continued)*

Era	System	Series	Group formation, or rock unit	Maximum reported thickness (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Mesozoic	Jurassic	Middle Jurassic	Wanakah (formerly Curtis and Summerville Formation	200	and locally contain thin lenses of conglomerate. The marine facies grades southward, eastward, and upward into the marginal-marine, tidal-flat, and fluvial facies. Both facies thicken toward the northwest. Both facies have largely been removed from the county by erosion west of Comb Ridge. Small scattered remnants of the marine facies are found near the Colorado River in the northwestern part of the county. The marginal-marine, tidal-flat, and fluvial facies is typically present east of Comb Ridge and Nakaito Bench.		
		Middle Jurassic	Entrada Sandstone Carmel Formation	550 (Entrada) 164 (Carmel)	The Entrada Sandstone is the shoreward, shallow-marine, coastal-dune, and continental-eolian facies, and the Carmel Formation is the marine facies formed by a cycle of advance and retreat of ancient sea. The Entrada Sandstone contains a topmost unit of medium-grained, well-sorted sandstone believed to have been a coastal-dune complex; a middle unit of very fine- to medium-grained, massive sandstone of eolian and, possibly, shallow-marine origin; and a basal unit of poorly bedded, sandy siltstone and silty sandstone deposited in a shallow-marine environment. The Carmel is a silty shale, siltstone, and sandstone that contains gypsum and thin beds of limestone. The Carmel Formation thickens westward. The Carmel and Entrada typically underlie much of the area east of Comb Ridge and Nokaito Bench, but to the west, most of these formations have been removed by erosion except for scattered remnants near the Colorado River west of Navajo Mountain.	Very low to low permeability. Both the lower unit of the Entrada Sandstone and the Carmel Formation are barriers to the movement of water except where faulted or fractured. Permeability of samples from the Entrada ranged from 26 to 1,445 millidarcies, but generally was about 250 millidarcies. Where the Entrada Sandstone is overlain by other formations, water in the Entrada commonly is under artesian conditions. Wells flow in the Blanding Basin. Water from the Entrada Sandstone is fresh to moderately saline, but south of T. 35 S., Salt Lake Base Line and Meridian, it may be very saline locally. Permeability of samples from the Carmel ranged from 1 to as much as 54 millidarcies, though most samples were less than 10 millidarcies. The largest permeability was found where the Carmel locally contained relatively clean sandstone beds. The Entrada, Navajo, and Wingate Sandstones and the Carmel and Kayenta Formations make up the N aquifer, except south of the San Juan River where the Entrada Sandstone is not considered part of the N aquifer.	N aquifer (plate 14)
	Triassic (?) and Jurassic	Upper Triassic (?) and Lower Jurassic	Navajo Sandstone	1,250	Well-rounded, well-sorted, massive, fine- to medium-grained eolian sandstone. The Navajo Sandstone thins eastward and northward and intertongues with the underlying Kayenta Formation in southwestern Utah. The Navajo Sandstone locally contains beds of cherty, dolomitic, freshwater limestone that probably were deposited in playa lakes. Some geologists believe that the Navajo is a nearshore, shallow-marine, and coastal-dune complex deposit or a tidal-dominated shallow-marine shelf deposit. The Navajo Sandstone is thickest south of the San Juan River. The formation underlies most of the area east of Comb Ridge and east of R. 20 E., Salt Lake Base Line and Meridian, north of the Abajo Mountains; west of there, it has been removed by erosion except in areas west of Piute Creek and within a band 10 to 17 miles wide near the Colorado River, south of T. 35 S., Salt Lake Base Line and Meridian.	Low permeability. Permeability of samples of the Navajo Sandstone ranged from about 200 to 665 millidarcies. Wherever the Navajo is overlain by other formations, particularly the Carmel or Wanakah Formations, water in the Navajo usually is under artesian conditions. In the Blanding Basin, wells flow. The Navajo Sandstone is the major unit making up the N aquifer and is the major source of potable ground water in the county. Water from the formation generally is fresh to moderately saline, but south of T. 35 S., Salt Lake Base Line and Meridian, it may be very saline to briny locally.	N aquifer (plate 14)
	Triassic	Upper Triassic	Kayenta Formation	339	Very fine- to fine-grained, irregularly bedded, locally conglomeratic, fluvial sandstone, siltstone, and shale, that contain beds of mudstone or lacustrine limestone. The Kayenta Formation thins southeastward to a thickness of about zero in the southeastern corner of the county. The Kayenta intertongues with the overlying Navajo Sandstone in southwestern Utah. The formation underlies most of the area east of Comb Ridge and east of R. 20 E., Salt Lake Base Line and Meridian, north of the Abajo Mountains. It also is found west of Copper Canyon and in scattered areas near the Colorado River.	Very low to low permeability; somewhat of a barrier to the movement of water except where faulted or fractured. Permeability of samples of the Kayenta Formation ranged from 30 to 295 millidarcies. The Kayenta is a semipermeable, leaky confining bed within the N aquifer. Water from the Kayenta generally is fresh to moderately saline, but south of T. 35 S., Salt Lake Base Line and Meridian, it may be very saline to briny locally.	N aquifer (plate 14)

Table 20 (continued)

Era	System	Series	Group formation, or rock unit	Maximum reported thickness (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Mesozoic	Triassic	Upper Triassic	Moenave Formation Wingate Sandstone	650	The Moenave Formation has a basal member of fine- to coarse-grained, friable sandstone, siltstone, and mudstone, and an upper member of medium-grained, micaceous sandstone that contains some siltstone. The Wingate Sandstone is a well-sorted, very fine- to medium-grained, calcareous, massively bedded, well-cemented, eolian sandstone. In the southwestern part of the county, the fluvial Moenave Formation interfingers with the Wingate Sandstone. The Moenave thickens to the southwest, whereas the Wingate is thickest south of the San Juan River and thins northward. The Moenave Formation is present west of Copper Canyon. The Wingate Sandstone underlies most of the county east of Comb Ridge and east of R. 20 E., Salt Lake Base Line and Meridian, north of the Abajo Mountains. It also is found in scattered areas near the Colorado River and west of Copper Canyon.	Very low to low permeability except where faulted or fractured. Permeability of samples of Wingate Sandstone ranged from 65 to 340 millidarcies. The Wingate Formation is the lowest part of the N aquifer. Water from the Wingate is fresh to moderately saline, but locally it may be very saline to briny.	N aquifer (plate 14)
			Chinle Formation	2,000	The Chinle Formation usually has siltstone and conglomeratic sandstone near the top, floodplain or lacustrine, bentonitic mudstone and marly mudstone in the middle, and fluvial, conglomeratic sandstone and mudstone in the lower part. The Chinle Formation underlies most of the area east of Comb Ridge and east of R. 20 E., Salt Lake Base Line and Meridian, north of the Abajo Mountains. It also occurs in scattered areas near the Colorado River and along the Arizona state line, and west of Copper Canyon.	Very low to low permeability; a barrier to the movement of water except where jointed, faulted, or fractured. Permeability of samples of sandstone beds in the lower part of the Chinle ranged from 3 to 1,000 millidarcies. The Chinle Formation is a confining bed between the N and P (or C) aquifers. Water from the basal sandstone of Chinle ranges from fresh to briny.	
		Lower and Middle Triassic	Moenkopi Formation	2,500+	A marginal marine deposit that grades from tidal-flat, deltaic, and fluvial beds in the eastern part of the county to a shallow-water, marine limestone facies in the western part of the county. The Moenkopi Formation has an upper unit of shaly siltstone, thin, flaggy sandstone, and thick, massive sandstone that, in the northwest, contains a thin, marine limestone bed. The lower unit is interbedded thin, commonly contorted, beds of fine- to medium-grained, micaceous, silty sandstone and shaly siltstone that locally contain gypsum beds. In the northeastern part of the county the formation may contain arkosic conglomerate. The Moenkopi Formation is thickest adjacent to the major salt anticlines in the northeastern part of the county because the salt diapirs were rising and their anticlinal crests were being eroded as the Moenkopi was being deposited. The Moenkopi is found throughout the county except where it has been eroded from the Monument upwarp, in the central portion of the county, and from the crests of the salt anticlines.	Commonly very low permeability; a barrier to the movement of water except where faulted or fractured. The average permeability of the Moenkopi Formation has been estimated as less than 5 millidarcies.	
Paleozoic	Permian	Lower Permian	Toroweap Formation/ Kaibab Limestone Cutler Group	10,000+	The Cutler Group is mostly fluvial arkose and arkosic fanglomerate, conglomerate, and finer grained continental and nearshore marine clastics. In the eastern and central parts of the county, fluvial deposition prevailed through most of the Permian, but in the southwestern and western parts of the county, marine, eolian, and fluvial deposition from meandering streams occurred. The coarsest beds are adjacent to the Uncompahgre Plateau where the Culter Group is undifferentiated. Within 40 miles to the southwest of the Uncompahgre Plateau, grain size decreases enough so that formations within the Cutler Group can be distinguished. The topmost unit commonly is an unnamed sequence of fluvial siltstone, mudstone, and shale that contain some interbedded sandstone. This unit is the fluvial and nearshore marine equivalent of the Kaibab Limestone. The Kaibab is a cherty, dolomitic marine limestone. The next lower formation within the Cutler Group is the White Rim Sandstone, a fine- to coarse-grained, well-sorted sandstone that is the nearshore	Very low to low permeability except where faulted or fractured. Shaly beds are barriers to the movement of water except where faulted or fractured. The permeability of sandstone beds in the Cutler Group ranges from less than 2 to more than 900 millidarcies. The undifferentiated Cutler Group and the Cedar Mesa Sandstone, where water bearing and permeable, are part of the P aquifer; the DeChelly Sandstone, where water bearing and permeable, is defined as the C aquifer. The P aquifer generally exists north of the San Juan River and the C aquifer generally exists south of the San Juan River. The Organ Rock and Halgaito Formations are confining beds within the P aquifer. West of Comb Ridge, flow systems in the Cutler Group probably are local and water-table condi-	The Cutler Group (plate 15) contains the C aquifer and the P aquifer

Table 20 (continued)

Era	System	Series	Group formation, or rock unit	Maximum rported thickess (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Paleozoic	Permian	Lower Permian	Toroweap Formation/ Kaibab Limestone Cutler Group	10,000+	and sandbar-complex facies of the Toroweap Formation. The Toroweap is a massive, marine, limy sandstone and, farther west, it is largely carbonate. The next lower formation, present south of Blanding, is the DeChelly Sandstone, a fine-grained, mostly eolian sandstone. The Organ Rock Formation, which underlies the DeChelly Sandstone, is shale, siltstone, and fine-grained sandstone that laterally grades into the coarser arkosic facies of the undifferentiated Cutler Group to the northeast. As far east as the eastern edge of the Monument upwarp, the Organ Rock Formation is underlain by the Cedar Mesa Sandstone, a fine- to coarse-grained sand-stone that had been deposited in a shallow-marine foreshore environment. The Cedar Mesa Sandstone is underlain by the marine Elephant Canyon Formation in the west and by the Halgaito Formation in the east. The Elephant Canyon Formation, formerly called the Rico Formation in northern San Juan County, is limestone and dolomite beds that contain sandstone, siltstone, and shale beds in the middle and siltstone and sandstone near the top. The Halgaito Formation is a fluvial red bed sequence of fine- to medium-grained, thin-bedded, arkosic sandstone, siltstone, and mudstone. The Halgaito Formation contains a few thin, lenticular beds of limestone near the base. The Cutler Group underlies all of the county except where removed by erosion on the crests of the salt anticlines and in the deeper canyons (plate 15).	tions are predominant. Water in the Culter Group ranges from fresh to briny.	The Cutler Group (plate 15) contains the C aquifer and the P aquifer
	Pensylvanian and Permian	Upper Pennsylvanian and Lower Permian	Rico Formation	900	Not recognized by Hintze (1988) in southern San Juan County, the Rico Formation has been renamed the Elephant Canyon Formation of the Cutler Group in northern San Juan County. The Rico Formation includes normal marine carbonate deposits, associated nearshore and shoreline deposits, and coastal-plain fluvial deposits of fine- to medium-grained, calcareous sandstone, partly gypsiferous, micaceous siltstone and sandy shale, and thin- to thick-bedded, cherty limestone. The formation underlies the entire county except where eroded on the crests of salt anticlines and in the deeper canyons.	Very low permeability; probably a barrier to the movement of water except where faulted or fractured. Except at outcrops, water from the Rico Formation is moderately saline to briny. Permeable units in the Rico Formation are considered part of the P aquifer by Thackston and others (1981).	
	Pennsylvanian	Middle and Upper Pennsylvanian	Hermosa Group	15,000+	Deposited in an environment that ranged from marine shoal and shelf to hypersaline evaporite basin, the Hermosa Group has been divided into three formations. The top and bottom formations, the Honaker Trail and Pinkerton Trail Formations, are similar in lithology. They commonly are thin- to thick-bedded limestone and dolomite that contain beds of fine-grained micaceous sandstone and siltstone, sandy shale, and occasional thin interbeds of shale and anhydrite; reefs and algal bioherms are common. The middle formation, the Paradox Formation, contains a thick sequence of evaporite deposits interbedded with shale, carbonate, and fine-grained sandstone and siltstone in what was the deepest part of the Paradox basin, and limestone and dolomite interbedded with shale and fine-grained sandstone to the west and south of the evaporite sequence. Toward the Uncompahgre Plateau, all three members interfinger with coarse arkosic sediments. The Hermosa Group is thickest in the salt anticlines in the northeastern part of the county.	Very low to high permeability. Evaporites are a barrier to the movement of water. Carbonate rocks, except reefs and bioherms, usually are barriers to the movement of water except where faulted or fractured or where solution channels have developed. Reef and biohermal deposits may be highly permeable and can have porosities of as much as 30 percent. Except at outcrops, water from the Hermosa Group usually is moderately saline to briny. Dissolved-solids concentrations can exceed 400,000 milligrams per liter. Permeable intervals in the upper two-thirds of the Honaker Trail Formation are considered part of the P aquifer by Thackston and others (1981). Permeable intervals and facies in the Pinkerton Trail Formation of the Hermosa Group are part of the Redwall aquifer.	
		Lower and Middle Pennsylvanian	Molas Formation	290	A continental deposit, the Molas Formation commonly is a regolith that developed on a karst surface. The formation is siltstone, silty shale, and calcareous sandstone and contains some thin-bedded limestone. Locally the Molas is conglomeratic, particularly near the base.	Very low to low permeability; probably a barrier to the movement of water except where faulted or fractured. Permeable intervals and facies are part of the Redwall aquifer.	
	Mississippian	Lower and Upper Mississippian	Redwall (Leadville) Limestone	828	Deposited on a broad, relatively flat, shallow-water, marine shelf, this formation is called the Redwall Limestone by some geologists, the Leadville Limestone by others. Many geologists, including Hintze (1988), call it the	Very low to low permeability except where faulted or fractured or where solution channels have developed. Water from the Redwall (Leadville) Limestone	Redwall aquifer

Table 20 (continued)

Era	System	Series	Group formation, or rock unit	Maximum reported thickness (feet)	Description	Hydrologic characteristics[1] and significance	Aquifer system
Paleozoic					Redwall in the western part of the Leadville in the eastern part of the area. The upper part of the formation is dense, thin-bedded, sometimes oolitic, limestone; the lower part is massive, cherty dolomite that locally contains thin beds of limestone near the top and also may contain thin beds of shale. In the eastern part of the county, the formation may contain a sandstone facies. Throughout much of the county, particularly in the western half, the upper part of the Redwall Limestone is a thin-bedded silty and clayey carbonate rock that is named the Horseshoe Mesa Member.	probably is moderately saline to briny. This unit is the major part of the Redwall aquifer.	Redwall aquifer
Paleozoic	Devonian	Upper Devonian	Ouray Limestone	300	Deposited in a quiet-water, shallow-marine environment, the Ouray Limestone is a dense, commonly oolitic limestone that locally contains partings of shale. Contact with the underlying Elbert Formation is gradational.	Very low to low permeability except where faulted or fractured or where solution channels have developed. Water in the formation probably is moderately saline to briny.	
Paleozoic	Devonian		Elbert Formation	420	Deposited in a shallow-water, in part intertidal, marine-shelf environment, the Elbert Formation is a thin-bedded, sandy dolomite that contains sandy shale. In the southeastern part of the county, the basal Elbert Formation contains a shoal and offshore bar facies, the McCracken Sandstone Member. The McCracken Sandstone Member is a fine- to medium-grained, poorly sorted, tightly cemented sandstone, commonly glauconitic, with streaks of sandy dolomite.	Very low to low permeability except where faulted or fractured or where solution channels have developed. Water in the formation is moderately saline to briny.	
Paleozoic	Devonian		Aneth Formation	249	Argillaceous marine limestone and dolomite, commonly anhydritic and slightly glauconitic, and calcareous shale.	Very low to low permeability except where faulted or fractured or where solution channels have developed. Water in the formation is moderately saline to briny.	
Paleozoic	Cambrian	Upper Cambrian	Ignacio Quartzite equivalent	730	A basal transgressive marine deposit of thin-bedded, slightly friable sandstone.	Very low permeability except where faulted or fractured. Water in the formation is moderately saline to briny.	
Paleozoic	Cambrian	Upper Cambrian	Lynch Dolomite	1,300	Massive marine dolomite and interbedded shale.	Probably very low in permeability except where faulted or fractured or where there are solution channels. Water in the formation is very saline or briny.	
Paleozoic	Cambrian	Middle Cambrian	Muav Limestone	650	Massive marine limestone that locally contains partings of shale.	Probably very low in permeability except where faulted or fractured or where there are solution channels. Water in the formation probably is very saline or briny.	
Paleozoic	Cambrian		Bright Angel Shale	450	The Bright Angel Shale is shale interbedded with fine-grained sandstone, siltstone, dolomite, and limestone. The formation grades from carbonate to shale to siltstone and sandstone from west to east.	Probably very low permeability; a barrier to the movement of water except where faulted or fractured.	
Paleozoic	Cambrian		Tapeats Sandstone	400	Fine- to coarse-grained, tightly cemented sandstone that is silty and shaly at the top. The formation thickens eastward from the southwestern corner of the county.	Probably very low permeability except where faulted or fractured. Water in the formation is very saline or briny.	
Precambrian			Igneous and metamorphic rocks		Undifferentiated igneous and metamorphic rocks.	Very low permeability; a barrier to the movement of water except where jointed, faulted, or fractured.	

[1]Ranges of permeablility are defined as follows:

Range	Permeability, in millidarcies
Very low	Less than 185
Low	185 to 1,850
Moderate	1,850 to 18,500
High	18,500 to 185,000
Very high	More than 185,000

fers. Stream flow is a particularly important source of recharge to the unconsolidated aquifers in the San Juan River Valley and Spanish Valley. The unconsolidated aquifer in Spanish Valley also receives recharge from subsurface flow through bedrock (Sumsion, 1971).

Regional movement of water to San Juan County aquifers is generally north from Arizona, west from Colorado, and southwest from the Uncompahgre Plateau (Howells, 1990). Groundwater movement may vary locally from this regional pattern due to variations in recharge or discharge. In addition, faults and fractures permit movement, mostly vertical, of water between aquifers (Howells, 1990). Aquifers discharge water to other aquifers if there is sufficient interconnection via fractures or pore spaces and the hydraulic head in the discharging aquifer is greater than that of the receiving aquifer. Where the hydraulic head is sufficient and the aquifers are sufficiently permeable, then water may be discharged to the ground surface as a spring.

Water Quality

Water in recharge areas is fresh and mostly of calcium-bicarbonate or calcium-magnesium-bicarbonate type (Howells, 1990). Total dissolved solids generally increase with increasing depth and distance from outcrop (recharge) areas (Howells, 1990), and presumably with proximity to evaporite deposits. Additional information regarding the character and distribution of saline waters in the Paradox basin, including San Juan County, can be found in Gwynn (in preparation).

In this report water salinity is classified based on concentration of dissolved solids in milligrams per liter (mg/L) as follows: fresh, 0 to 1,000 mg/L; slightly saline, 1,000 to 3,000 mg/L; moderately saline, 3,000 to 10,000 mg/L; very saline, 10,000 to 35,000 mg/L; and briny, more than 35,000 mg/L (Howells, 1990). Drinking water and ground-water protection regulations classify water, based largely on total-dissolved-solid concentrations, as follows: class IA (pristine ground water), less than 500 mg/L; class II (drinking water quality ground water), 500 to 3,000 mg/L; class III (limited use ground water), 3,000 to 10,000 mg/L; and class IV (saline ground water), more than 10,000 mg/L. Class IA and II waters are considered suitable for drinking water, provided concentrations of individual contaminants do not exceed state and federal ground-water quality standards. Class III water is generally suitable for drinking water only if treated, but can be used for some agricultural or industrial purposes without treatment.

Fractured-Bedrock Aquifers

Redwall aquifer: The Redwall aquifer contains very saline to briny, sodium-chloride-type water; total-dissolved-solid concentrations are as high as 350,000 mg/L near evaporite deposits in the Hermosa Group, but decrease away from these deposits to less than 6,500 mg/L (Howells, 1990). The average total-dissolved-solid concentration for 26 well-water samples collected from the Redwall aquifer as part of a study of saline waters of the Paradox basin was approximately 80,000 mg/L (Gwynn, in preparation).

P aquifer: Total-dissolved-solid concentrations in the P aquifer increase from 1,000 mg/L in recharge areas north of Monticello (Avery, 1986) to more than 10,000 mg/L where the aquifer is deep and far from recharge areas (Howells, 1990).

C aquifer: Near Aneth, where the DeChelly Sandstone is about 2,500 feet below the ground surface, the C aquifer contains moderately saline to briny, sodium-chloride-type water (Avery, 1986).

N aquifer: Water in the N aquifer is commonly fresh to moderately saline, but near Aneth, where the aquifer is at its greatest depth, the aquifer contains very saline to briny, sodium-chloride-type water (Howells, 1990).

M aquifer: Water in the M aquifer is commonly fresh to moderately saline but, with increasing distance from surface-recharge areas, salinity increases and the water changes from calcium magnesium bicarbonate to sodium-bicarbonate-type (Howells, 1990).

D aquifer: The D aquifer commonly contains fresh, calcium bicarbonate- or calcium-magnesium-bicarbonate-type water; however, particularly where recharged by runoff from areas underlain by the Mancos Shale or sediments eroded from the Mancos, the aquifer contains slightly to moderately saline, calcium-magnesium-sulfate- or sodium-bicarbonate-type water.

Unconsolidated Aquifers

Total-dissolved-solid concentrations in water in alluvium in Spanish Valley ranges from 169 to 1,020 mg/L (Sumsion, 1971). Water levels and the chemical quality of water in the San Juan River Valley is closely related to river discharge; water levels in wells and the quality of water in the alluvium decrease with decreasing stream discharge.

SUMMARY

San Juan County has good potential for discovery and development of additional mineral and energy resources. The most prospective areas are in the eastern part of the county. Fortunately, this part of the county has better developed infrastructure (roads, pipelines, and services) and fewer uncertainties on the exploration and development status of federal lands.

Oil and gas have the best potential of all mineral and energy resources in San Juan County for significant new discoveries and development and would have the greatest economic impact on the county. There are numerous petroleum plays that are productive or have the potential to be productive in San Juan County. The Ismay/Desert Creek play is the most likely to have new discoveries. The play area covers approximately 2,800 square miles in the eastern part of the county. New discoveries are quite likely, but the new fields will probably be smaller and more isolated than fields discovered in the past, such as Aneth and Ismay.

The Cane Creek fractured shale play is the second most likely to have discoveries. The play area covers approximately 1,600 square miles in northeastern San Juan County north of Monticello. The expected size of the discoveries is difficult to predict since it depends on the size, number, and distribution of fractures. However, horizontally drilled Cane Creek wells to the north in Grand County are expected to produce between 400,000 and 1,000,000 barrels of oil per well.

There are a number of other plays which are productive at some fields in San Juan County but are currently productive only within small areas. The likelihood of discoveries from these plays is considered as moderate; certainly less than for the Ismay-Desert Creek or Cane Creek plays. The plays and play areas are:

1) Leadville Limestone Faulted Anticlines: All of county
2) Paradox Formation Structures and Pinchouts: All of county
3) Cutler and Hermosa Group Structures: Central and extreme southeastern part of county
4) McCracken Sandstone Structures: All of county

There is also a possibility of discovering Precambrian-sourced oil in Precambrian and basal Cambrian sandstones in western San Juan County. However, no holes have been drilled to test this concept in the county. This play has the highest risk and lowest probability of being drilled, but it may have the best possibility for a large field discovery. If the play concept is successful to the west in Kane and Garfield Counties, the chance for exploration in San Juan County could be greatly increased.

Coal deposits are present in the Dakota Sandstone in the La Sal and San Juan coal fields. These coal fields cover approximately 750 square miles in eastern San Juan County. Although the coal seams are locally of sufficient thickness to be mined, market factors such as coal quality and adequate rail transportation will hinder development. New technology to clean the coal may alleviate the high-ash and high-sulfur problems, but lack of transport remains a constraint unless the coal is used locally.

Two deposits of oil-impregnated rock are known in San Juan County at White Canyon and Mexican Hat. The Mexican Hat deposit is small and has no development potential. The White Canyon deposit is larger, but the grade, quality, and extent of the deposit are yet to be determined. If an economic process is developed for extracting oil from tar sands, many other deposits in Utah will be developed before White Canyon. Using the material as asphalt road paving is also unlikely since the deposit is remote from population centers.

There is no potential for high-temperature geothermal resources in San Juan County. This lack of potential is not unexpected since the Colorado Plateau geologic province has low heat flow and no known high-temperature geothermal resources. However, some low-temperature waters could be used for space heating using geothermal heat pumps.

Numerous uranium deposits and occurrences are known in San Juan County in the Permian Cutler, Triassic Chinle, and Jurassic Morrison Formations. Known reserves exist in the Cutler Formation in the Lisbon Valley area, in the Chinle Formation in the White Canyon-Red Canyon area, and in the Morrison Formation in the Paradox-Dry Valley region. Many unexplored, but still prospective, areas exist beneath moderate to deep cover in much of San Juan County. Within these favorable units, the more prospective areas for additional discoveries are located near existing mines, and districts. The northeastern part of the county is more favorable because the deposits are commonly larger and more continuous than those in western San Juan County. All of the regular and most of the small-mine permits for uranium and vanadium (both current and suspended) are in this eastern area.

Some of the more prospective areas for the major host units include:

1) Cutler-Hosted Deposits: Southwestern side of Lisbon Valley
2) Moss Back (Chinle)-Hosted Deposits: Northeastern side of Lisbon Valley
3) Shinarump (Chinle)-Hosted Deposits: White Canyon district, southern Elk Ridge area, near Round Mountain both east and west of Stevens Canyon
4) Salt Wash (Morrison)-Hosted Deposits: Paradox-Browns Hole area, southeast of Dry Valley area, north of Ucolo

Although both known uranium-vanadium reserves and good potential exist in San Juan County, it is not expected that a viable uranium industry will exist in San Juan County until there is a significant price increase for uranium above the current $7.00 to 8.00 per pound level.

Potential exists for discovery of additional metallic mineral deposits in San Juan County. The best potential is for "Lisbon Valley type" sedimentary copper deposits, particularly in the Lisbon Valley area.

A resource of nearly 38 million tons of copper ore is known in the Dakota and Burro Canyon Formations in the Lisbon Valley area. There is evidence of nearby deeper, higher-grade copper mineralization. The area is currently being evaluated and explored by Summo Minerals Corporation. In addition to the known resources, the area has excellent potential for additional discoveries to both the northwest and southeast along and adjacent to the Lisbon Valley fault. There is moderate potential for discovery of similar deposits along and adjacent to the Shay graben, the Bridger Jack graben, the Verdure Creek graben, and near Bridger Jack and Flat Iron Mesas. Apparently little exploration has been done for sedimentary copper in these areas.

Speculative potential also exists for "leaky reservoir type" copper deposits in Permian to Jurassic redbeds in northwestern and southeastern San Juan County, particularly near oil and gas fields. There has been little, if any, exploration for this target type but, if present, such deposits could be very large.

Low potential exists for the discovery of skarn, breccia-hosted, or stockwork gold deposits around the Abajo and La Sal Mountains, based on analogies with gold occurrences associated with similar intrusive rocks in Colorado and Montana.

The industrial rock and mineral potential of San Juan County has not been studied in detail, and only a few commodities have been produced, mostly for local use. These commodities include sand and gravel, clay (bentonite), and limestone.

San Juan County has adequate sand and gravel resources present in old river terrace, stream channel, and pediment deposits. The better quality sand and gravel resources were derived from well-indurated sandstone, non-cherty limestone and dolomite, conglomerate, and some granitic rock.

Several geologic units, mostly in eastern San Juan County, contain bentonite. Two operations currently mine bentonite in San Juan County for use as clay liners in reservoirs and landfills. Potential exists for additional production of bentonite for similar engineering uses and also for higher unit-value uses such as drilling mud or fuller's earth which require better quality bentonite. Additional testing is needed to determine its suitability for these higher unit-value uses.

Two stratigraphic units, the Navajo Sandstone and the Honaker Trail Formation, contain small amounts of limestone which assay as high as 92 percent $CaCO_3$. High-calcium limestone is rare on the Colorado Plateau and these occurrences could provide both scrubber limestone for power plants and rock dust for coal mines in the Four Corners area.

One small quarry in San Juan County intermittently produces building stone, but there is good potential for additional operations. Possible sources include Permian, Triassic, and Jurassic sandstones and intrusive granitic rocks.

In addition to these commodities, San Juan County contains other industrial rocks and minerals that could conceivably be developed. Quantity and quality data for most of these industrial rocks is limited and much additional geologic work is needed to adequately characterize these resources. Potential resources in rough order of probable export potential are listed below:

1) Humate from weathered low-grade coal in the Dakota Sandstone,
2) Potash and salt from the Paradox Formation,
3) Potash, magnesium, salt and other commodities such as boron, lithium and bromine from saline brines,
4) Specialty sands from Recent eolian dunes and Permian to Cretaceous sandstones,
5) Light-weight aggregates from shales in the Chinle Formation and organic shales and mudstones in the Dakota Sandstone,
6) Common and fire clay from shales of the Triassic Moenkopi and Chinle Formations, and from shales of the Cretaceous Morrison Formation, Dakota Sandstone, and Mancos Shale,
7) Zeolites from the Brushy Basin Member of the Morrison Formation.

San Juan County has a large salt and potash resource contained in the evaporite sequence of the Paradox basin. Estimated known and inferred potash resources for the Paradox basin are over 400 million tons of potassium oxide (K_2O) based on a minimum bed thickness of 4 feet, a minimum grade of 14 percent K_2O, and a cutoff depth of 4,000 feet. Salt (halite) resources are substantially greater, estimated to be 2 to 3 billion tons. The most favorable areas in San Juan County to produce potash and salt are in the northern and central parts of the county where the salt is thick, at shallow depths, and undeformed. However, thick overburden, transportation problems, and competition from mines in New Mexico and, particularly Canada, may hinder development of this resource.

There may also be some potential for recovering high-value commodities such as lithium, boron, and bromine from saline brines. Unfortunately, there are few brine assays for these elements and it is impossible to evaluate the economic potential or viability for extraction of these elements from oil well or other brines. Potassium and magnesium are also contained in these brines, but commercial development would have to compete with more traditional or established producers.

San Juan County has extensive ground-water resources which are adequate for almost any conceivable future requirements. The more populated eastern part of the county has excellent ground-water resources. One of the two major aquifers, the N aquifer, consisting of Triassic to Jurassic sandstones, or the D aquifer, consisting of the Dakota Sandstone and Burro Canyon Formation, is present at relatively shallow depths over most of eastern San Juan County. These aquifers are from 200 to over 1,250 feet thick, contain good-quality water, particularly at shallow depths, and can be prolific producers. Good-quality water is also obtained from unconsolidated deposits in this area.

The main aquifers in central San Juan County are the P and C aquifers of the Cutler Group and the unconsolidated deposits. The bedrock Cutler aquifers can be relatively thick and potentially quite prolific with yields up to 200 gallons per minute. In most of central San Juan County, flow systems probably are local; water-table conditions are predominant; and water quality is relatively good.

The main aquifers in western San Juan County are the N aquifer and unconsolidated sediments. The N aquifer is over 1,000 feet thick, at relatively shallow depths, potentially quite prolific with yields of up to 170 gallons per minute, and commonly contains good quality water.

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Plate 1. Land Ownership Status

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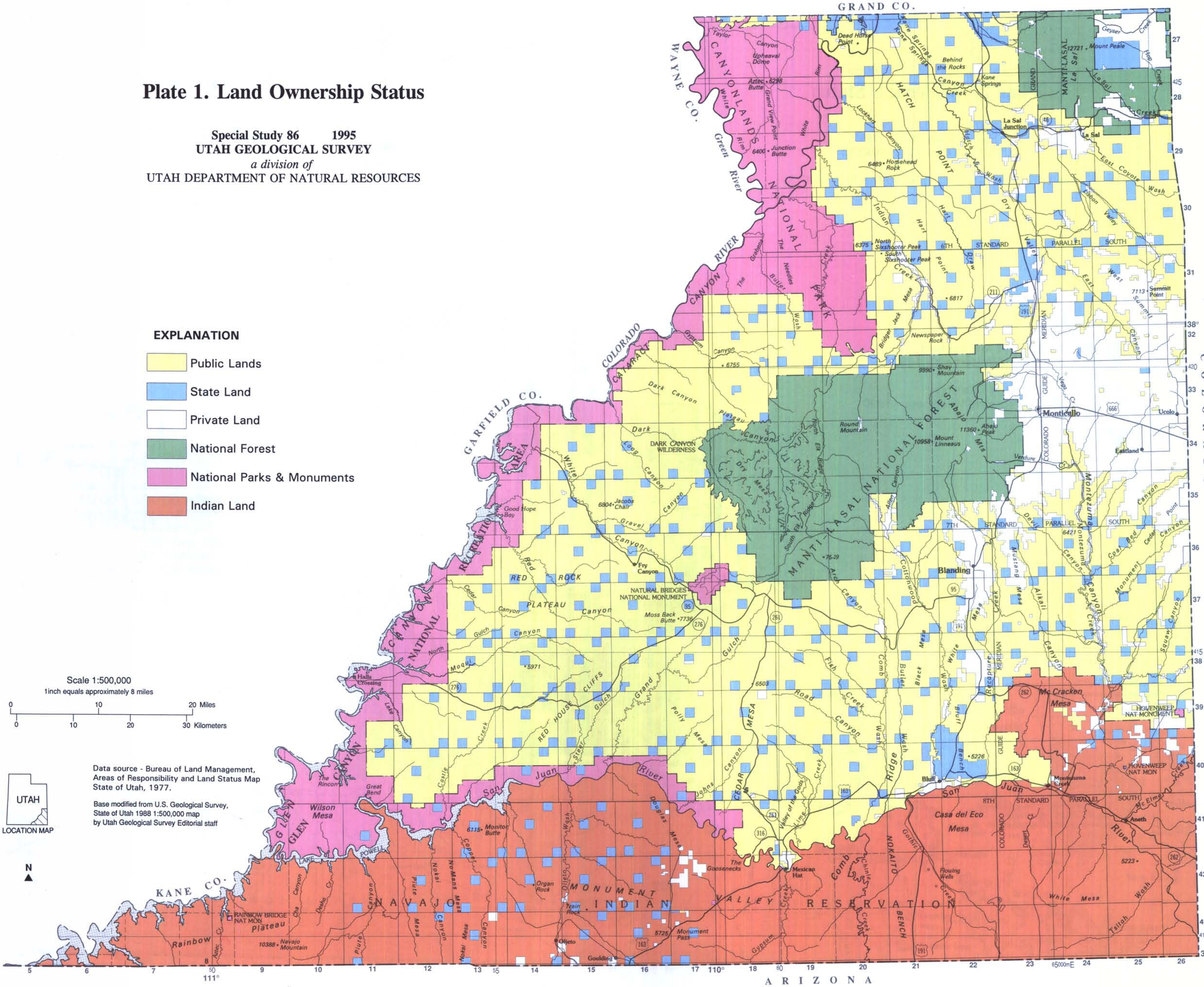

Data source - Bureau of Land Management, Areas of Responsibility and Land Status Map State of Utah, 1977.

Base modified from U.S. Geological Survey, State of Utah 1988 1:500,000 map by Utah Geological Survey Editorial staff

Plate 2. Wilderness Status

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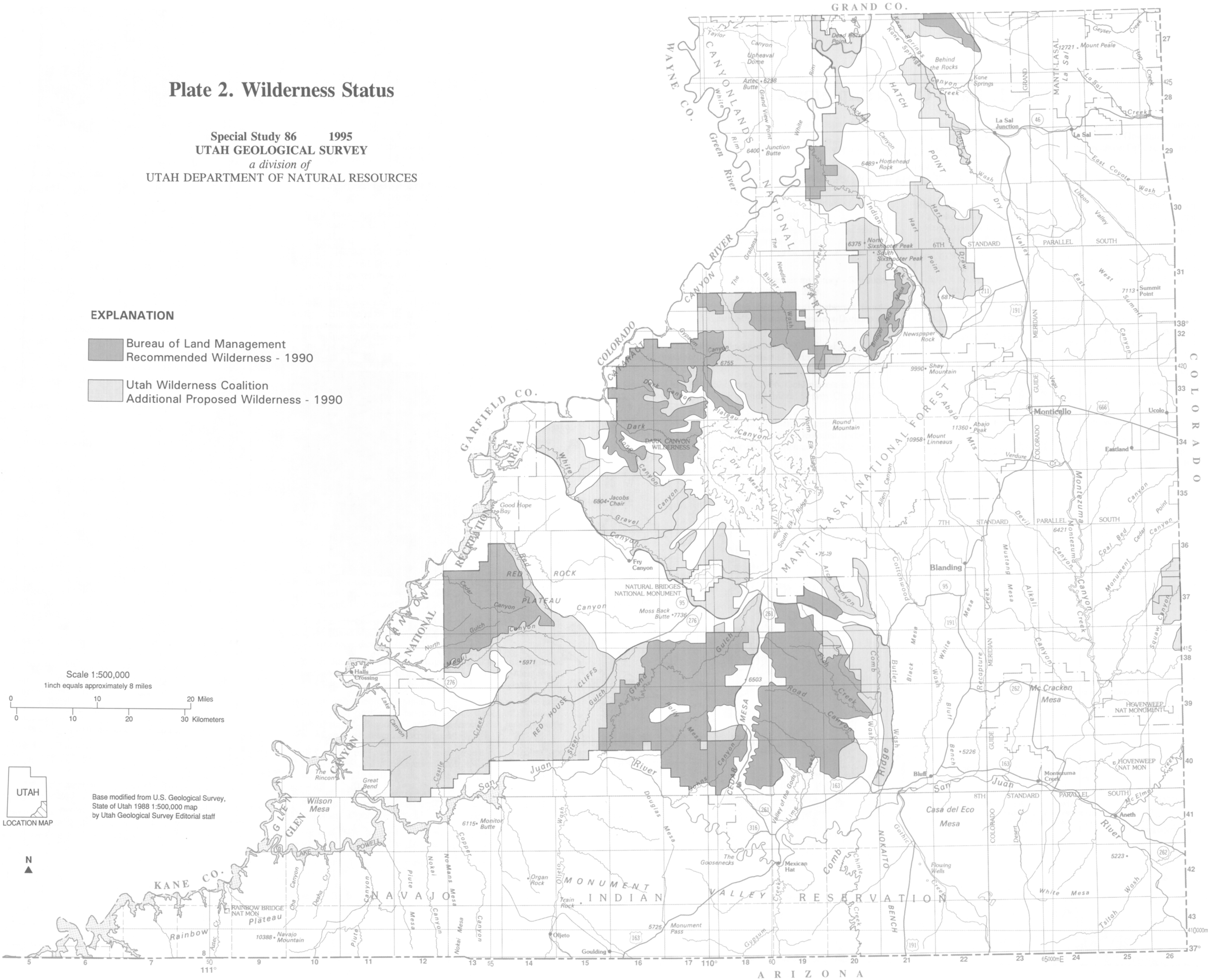

EXPLANATION

- Bureau of Land Management Recommended Wilderness - 1990
- Utah Wilderness Coalition Additional Proposed Wilderness - 1990

Scale 1:500,000
1inch equals approximately 8 miles
0 10 20 Miles
0 10 20 30 Kilometers

Base modified from U.S. Geological Survey, State of Utah 1988 1:500,000 map by Utah Geological Survey Editorial staff

Plate 3. Oil and Gas Fields and Pipelines

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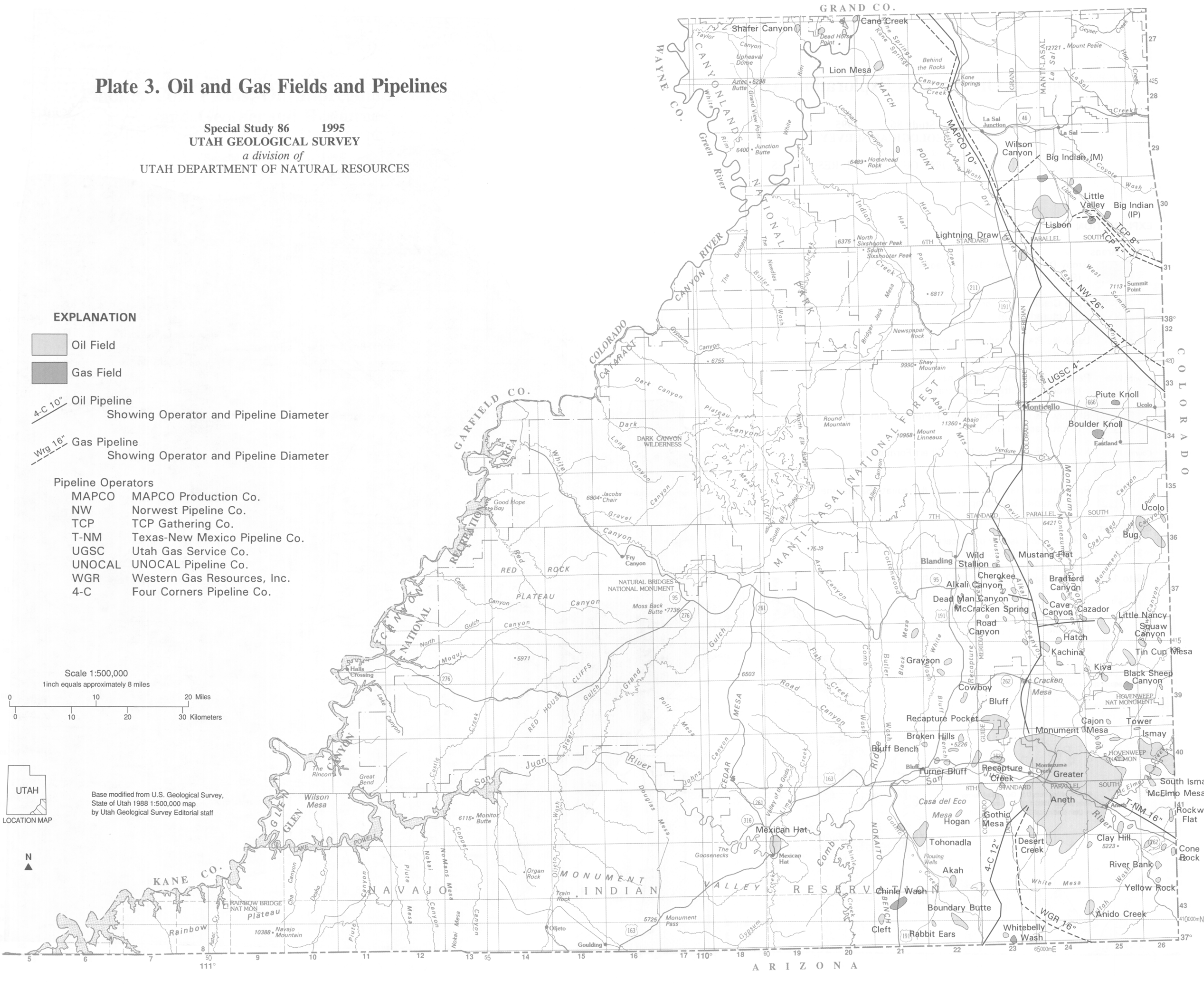

EXPLANATION

Oil Field

Gas Field

4-C 10" Oil Pipeline
Showing Operator and Pipeline Diameter

Wrg 16" Gas Pipeline
Showing Operator and Pipeline Diameter

Pipeline Operators

MAPCO	MAPCO Production Co.
NW	Norwest Pipeline Co.
TCP	TCP Gathering Co.
T-NM	Texas-New Mexico Pipeline Co.
UGSC	Utah Gas Service Co.
UNOCAL	UNOCAL Pipeline Co.
WGR	Western Gas Resources, Inc.
4-C	Four Corners Pipeline Co.

Scale 1:500,000
1inch equals approximately 8 miles

0 10 20 Miles
0 10 20 30 Kilometers

UTAH
LOCATION MAP

Base modified from U.S. Geological Survey, State of Utah 1988 1:500,000 map by Utah Geological Survey Editorial staff

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Plate 4. Oil and Gas Exploration Areas

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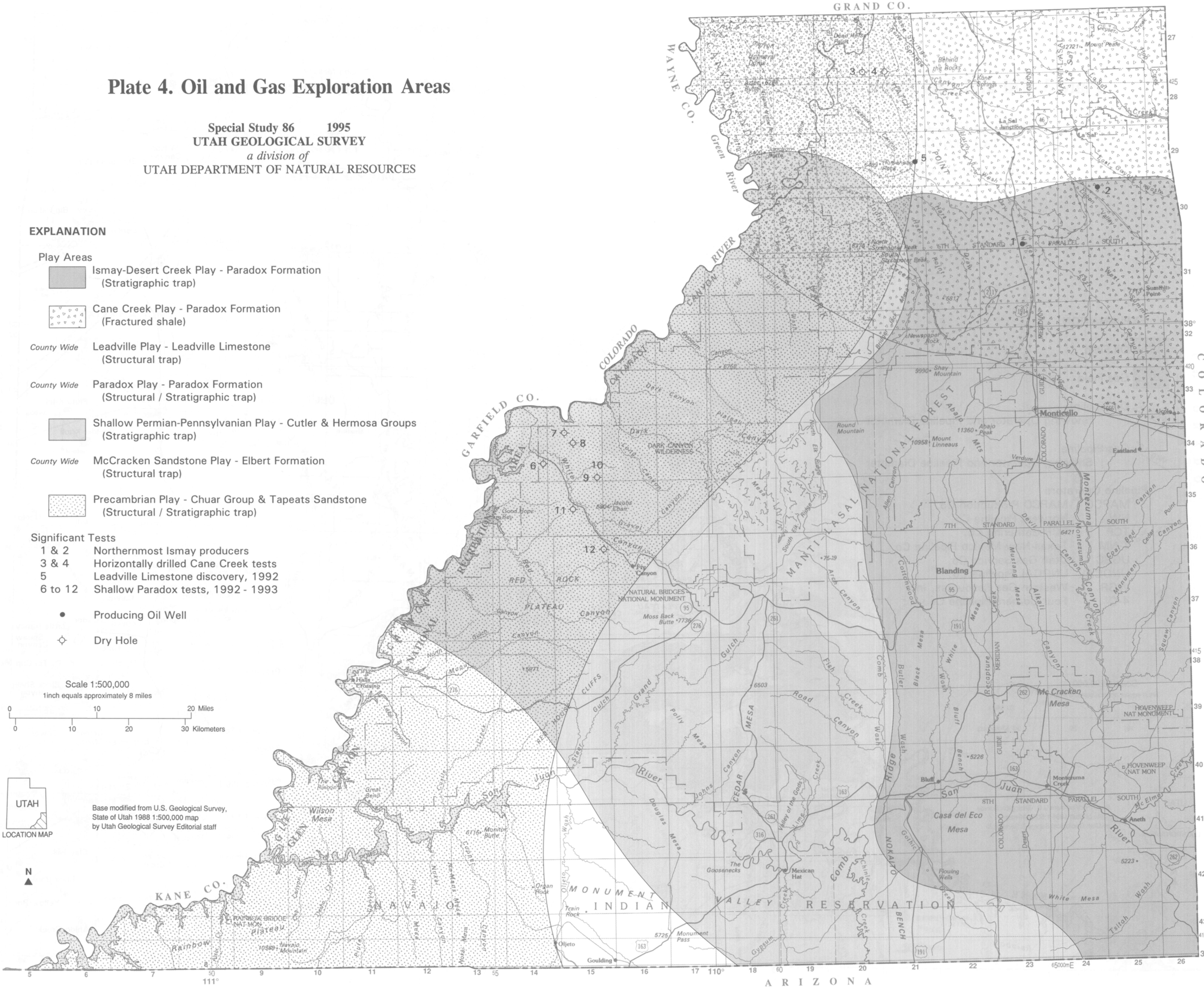

Plate 5. Coal Fields, Oil-Impregnated Rocks, and Geothermal Resources

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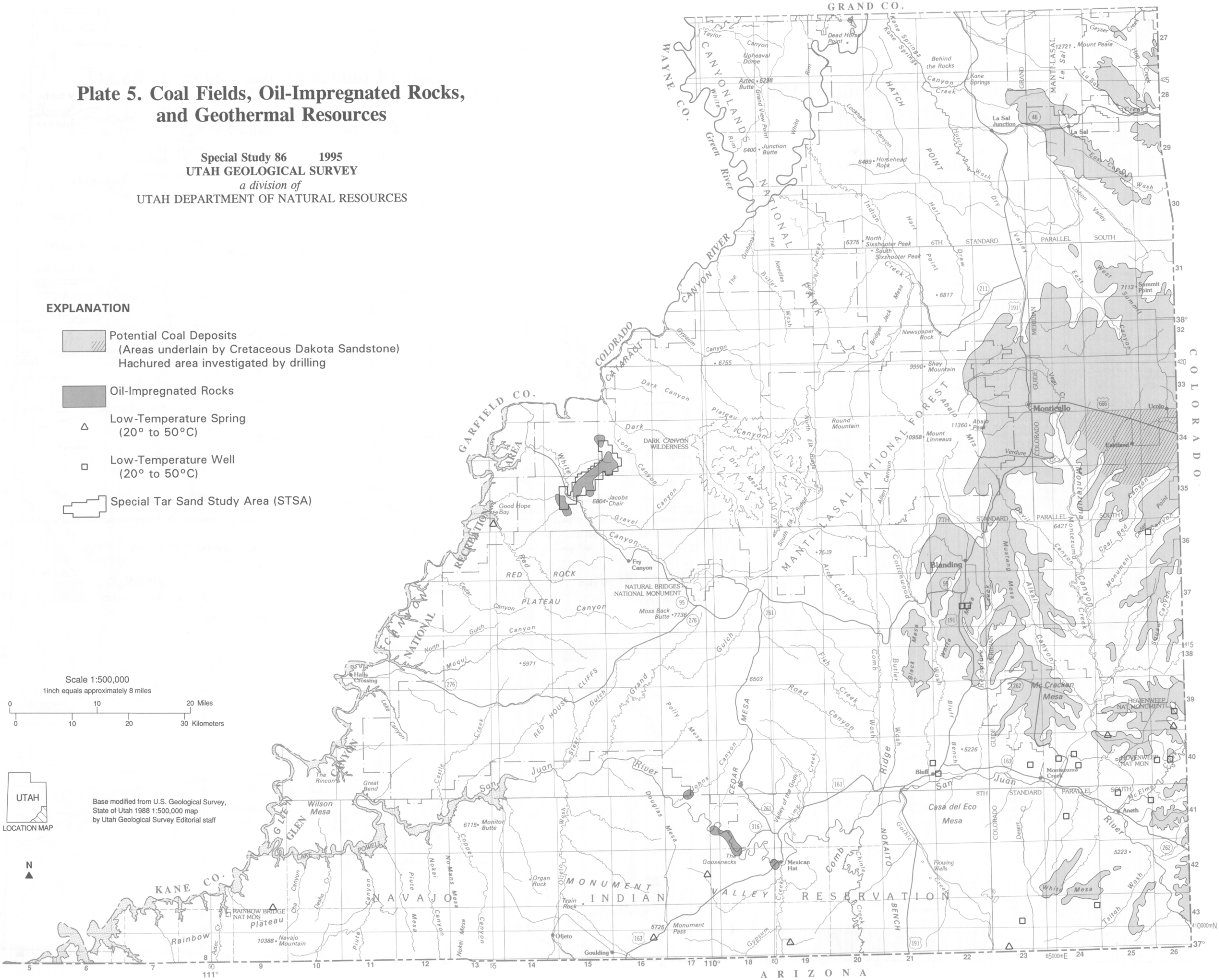

Plate 6. Active and Permitted Mines as of March 1994

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EXPLANATION

ACTIVE SMALL MINE PERMITS

NAME	OPERATOR	MINERAL
WINDFALL/MAYBE #2	JOHN K. BROWN	U,V
BIG INDIAN JR.	SANDFILL CORP.	CU
SPANISH VALLEY CLAY	GRAND CTY WCD	CLAY
SLUSH PROJECT	WRS MINING CO.	?
PRINCE MINE	PAUL SCHOFIELD	AU
FRISCO MINE	SLICK ROCK MINING CO.	U
JOKER #1/BRADFORD CYN	GLEN A. SHUMWAY	V
TUCSON #6	JOHN STEVENSON	AU,AG,PT
SURPRISE #34	ALAN LEVIN	AU,AG,PT
BOB #4	DAN QUALLS	AU,AG,PT
SHUMWAY PERMITTED	KENNETH D.SHUMWAY	?
MANCOS LODE CLAIMS	J & J MINING CO.	AU
YELLOWSTONE LODE CLAIMS	TERRY SHUMWAY	?
MOON #4	WESTERN IND. MINERALS	LS
LIME RIDGE QUARRY	HOLLIDAY CONSTRUCTION	LS

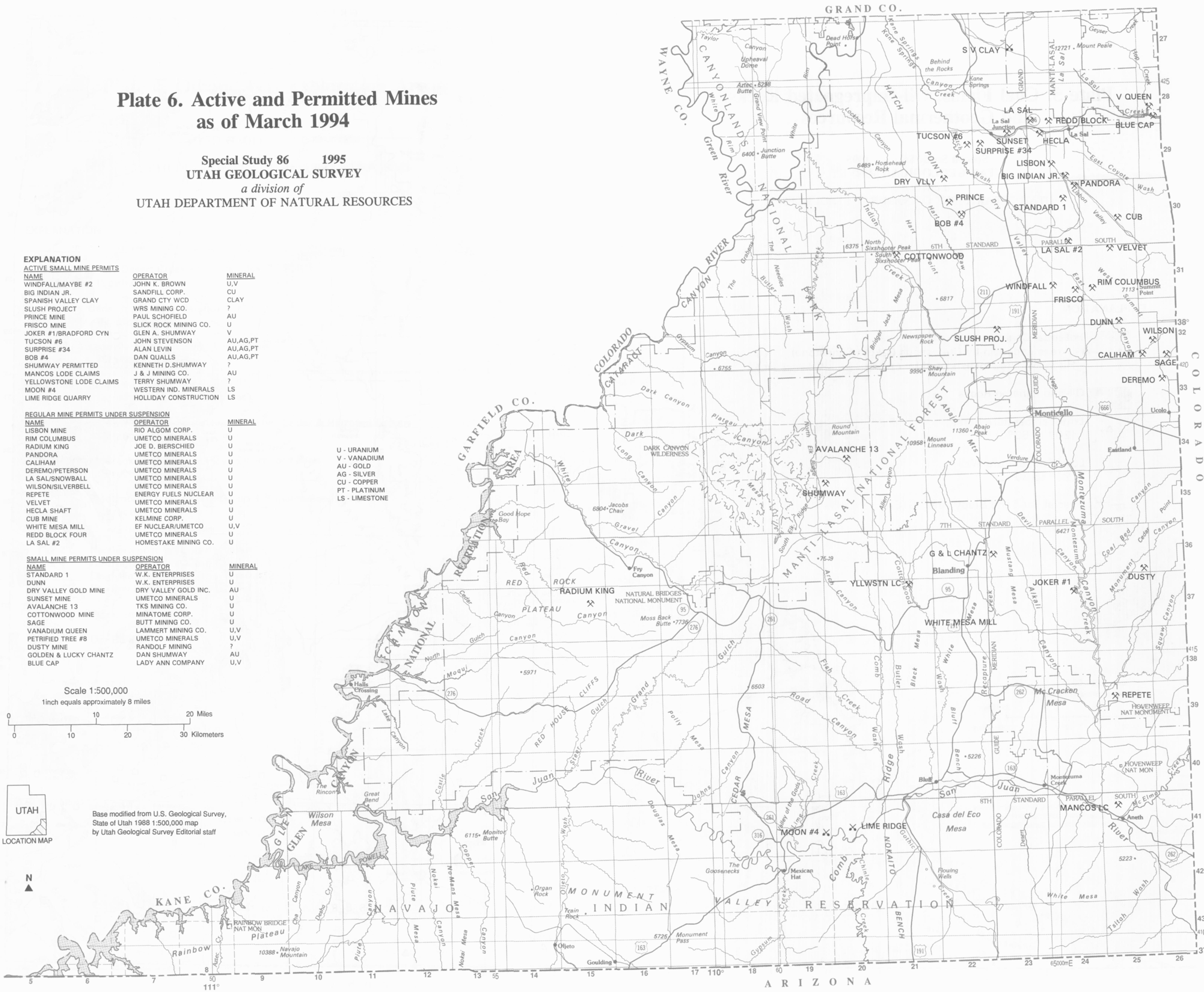
REGULAR MINE PERMITS UNDER SUSPENSION

NAME	OPERATOR	MINERAL
LISBON MINE	RIO ALGOM CORP.	U
RIM COLUMBUS	UMETCO MINERALS	U
RADIUM KING	JOE D. BIERSCHIED	U
PANDORA	UMETCO MINERALS	U
CALIHAM	UMETCO MINERALS	U
DEREMO/PETERSON	UMETCO MINERALS	U
LA SAL/SNOWBALL	UMETCO MINERALS	U
WILSON/SILVERBELL	UMETCO MINERALS	U
REPETE	ENERGY FUELS NUCLEAR	U
VELVET	UMETCO MINERALS	U
HECLA SHAFT	UMETCO MINERALS	U
CUB MINE	KELMINE CORP.	U
WHITE MESA MILL	EF NUCLEAR/UMETCO	U,V
REDD BLOCK FOUR	UMETCO MINERALS	U
LA SAL #2	HOMESTAKE MINING CO.	U

SMALL MINE PERMITS UNDER SUSPENSION

NAME	OPERATOR	MINERAL
STANDARD 1	W.K. ENTERPRISES	U
DUNN	W.K. ENTERPRISES	U
DRY VALLEY GOLD MINE	DRY VALLEY GOLD INC.	AU
SUNSET MINE	UMETCO MINERALS	U
AVALANCHE 13	TKS MINING CO.	U
COTTONWOOD MINE	MINATOME CORP.	U
SAGE	BUTT MINING CO.	U
VANADIUM QUEEN	LAMMERT MINING CO.	U,V
PETRIFIED TREE #8	UMETCO MINERALS	U,V
DUSTY MINE	RANDOLF MINING	?
GOLDEN & LUCKY CHANTZ	DAN SHUMWAY	AU
BLUE CAP	LADY ANN COMPANY	U,V

U - URANIUM
V - VANADIUM
AU - GOLD
AG - SILVER
CU - COPPER
PT - PLATINUM
LS - LIMESTONE



Scale 1:500,000
1inch equals approximately 8 miles
0 10 20 Miles
0 10 20 30 Kilometers

Base modified from U.S. Geological Survey, State of Utah 1988 1:500,000 map by Utah Geological Survey Editorial staff

Plate 7. Uranium and Vanadium Resources

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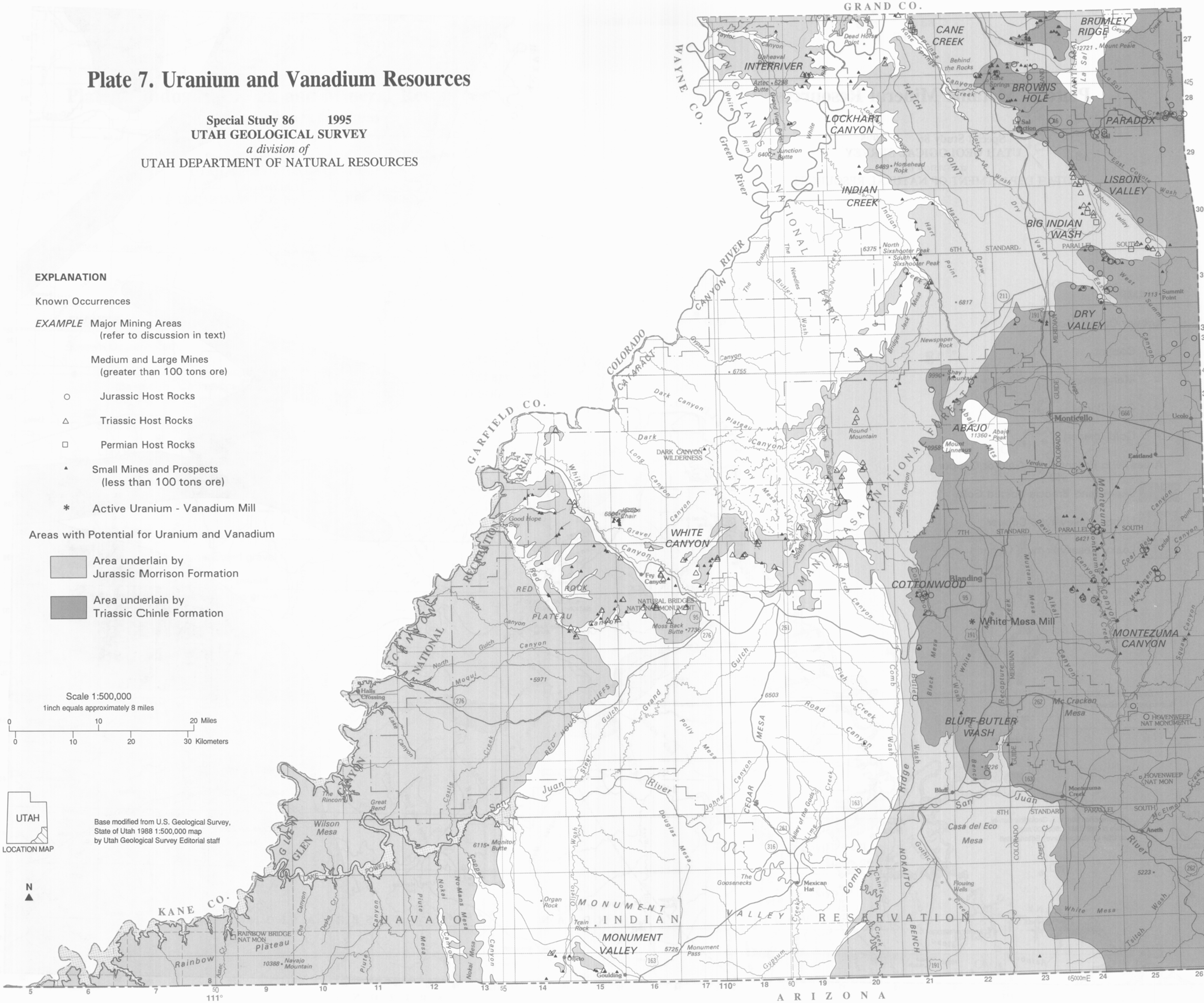

EXPLANATION

Known Occurrences

EXAMPLE Major Mining Areas (refer to discussion in text)

Medium and Large Mines (greater than 100 tons ore)

○ Jurassic Host Rocks

△ Triassic Host Rocks

□ Permian Host Rocks

▲ Small Mines and Prospects (less than 100 tons ore)

* Active Uranium - Vanadium Mill

Areas with Potential for Uranium and Vanadium

Area underlain by Jurassic Morrison Formation

Area underlain by Triassic Chinle Formation

Plate 8. Metallic Mineral Resources

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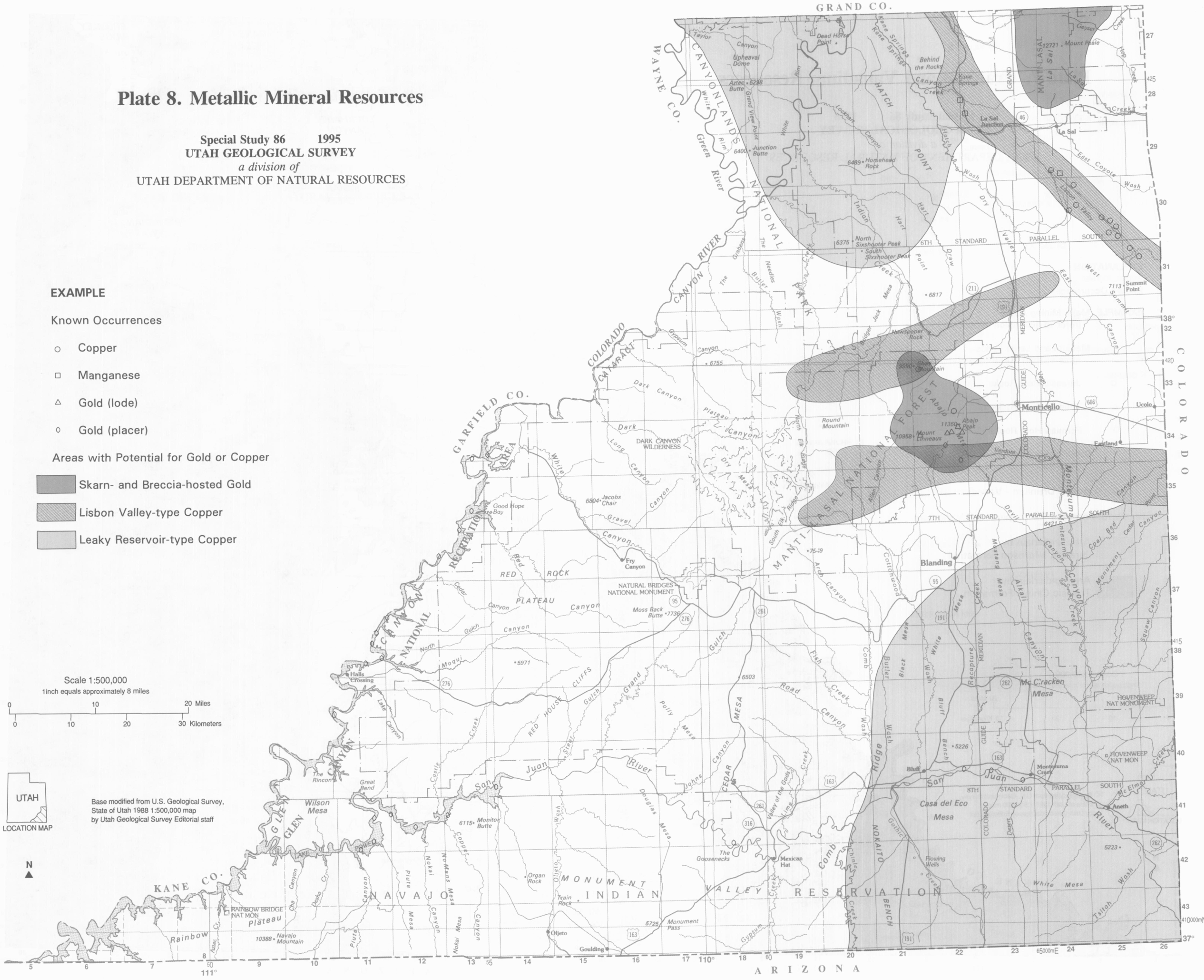

Plate 9. Industrial Rock and Mineral Resources
(excluding saline resources)

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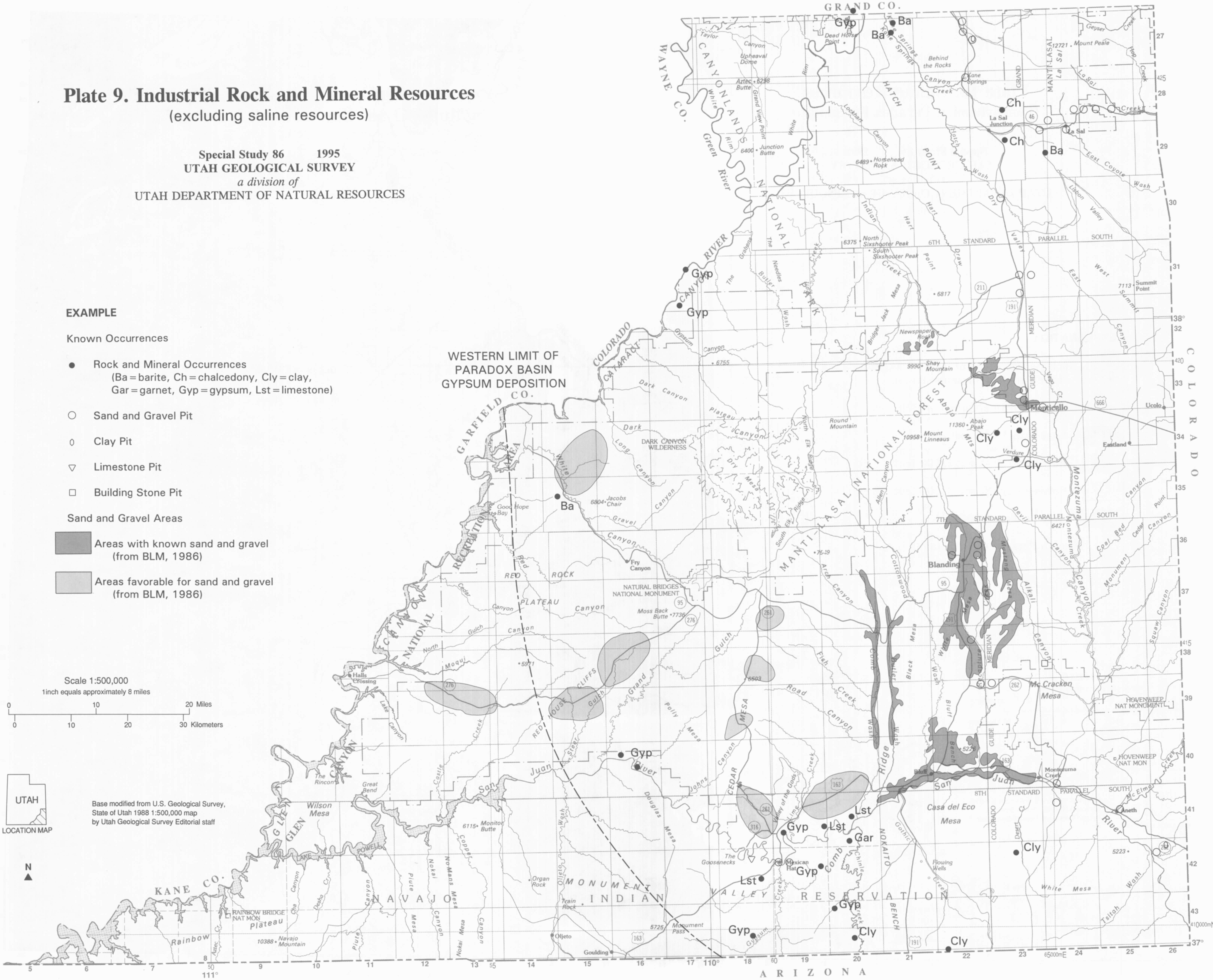

Plate 10. Saline Resources
(Pennsylvanian Paradox Formation)

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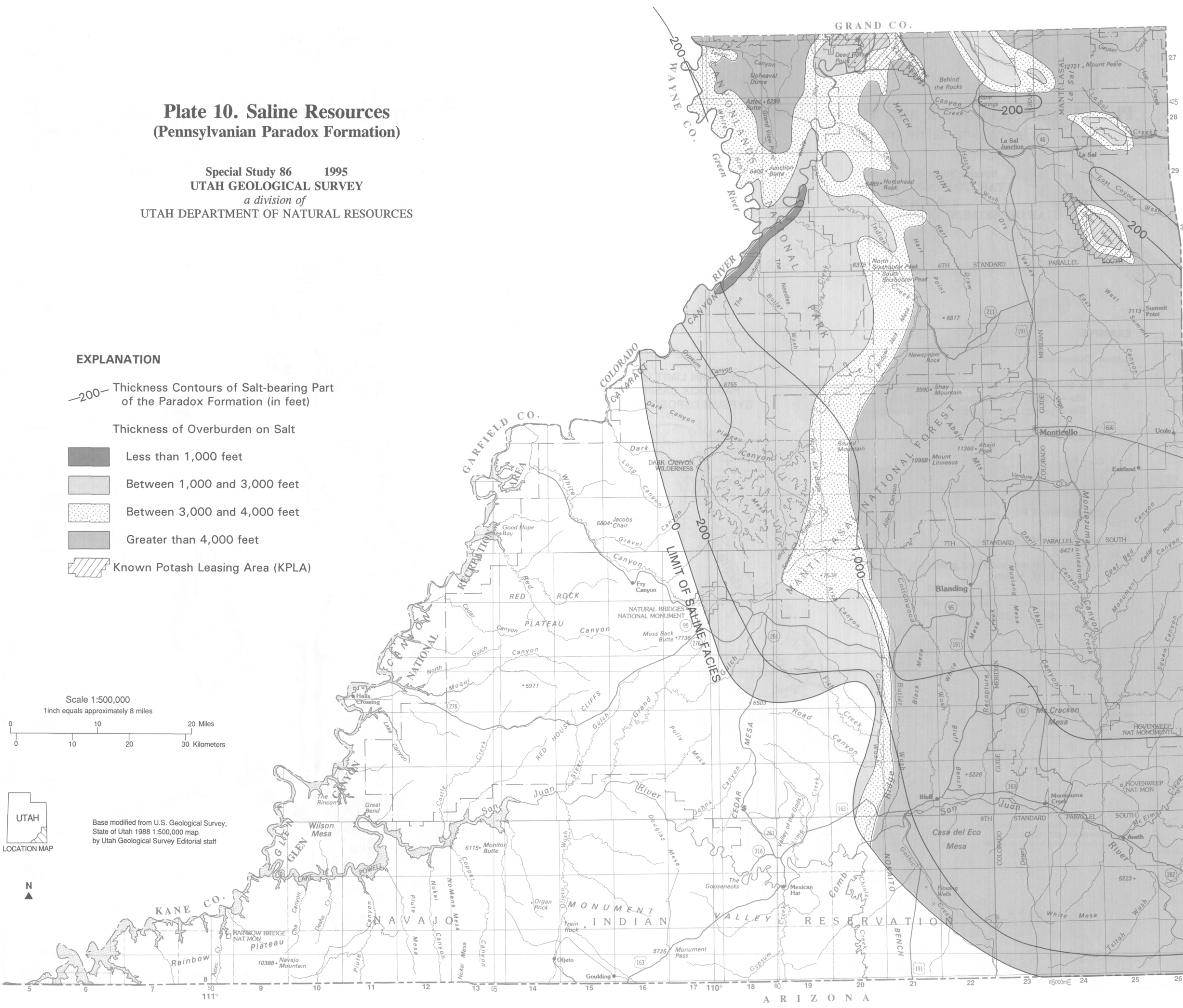

Plate 11. Areal Extent of the Cutler Group Containing the P Aquifer and the C Aquifer

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EXPLANATION

Areas underlain by the Cutler Group

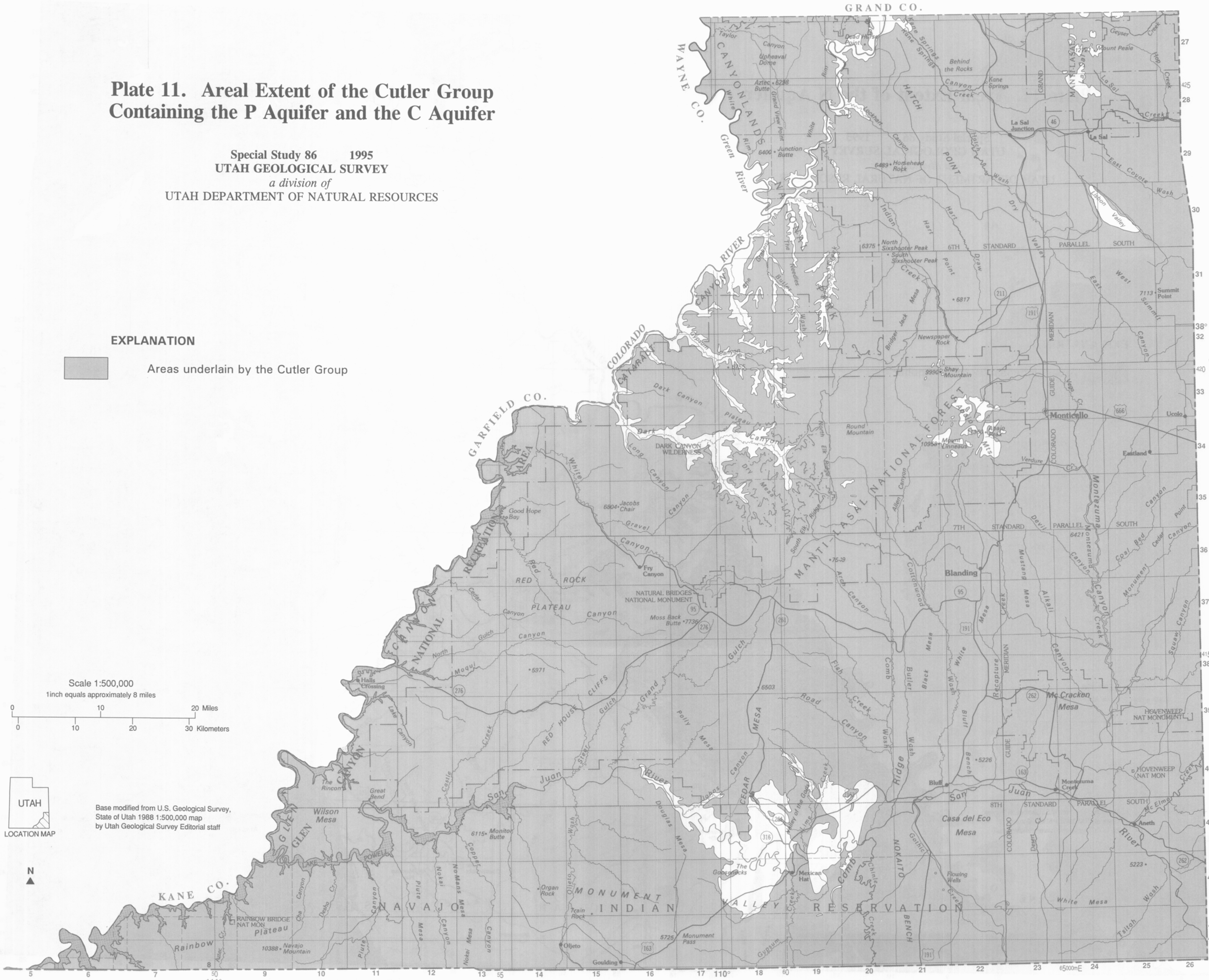

Plate 12. Areal Extent of the N Aquifer

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EXPLANATION

Areas underlain by the N Aquifer

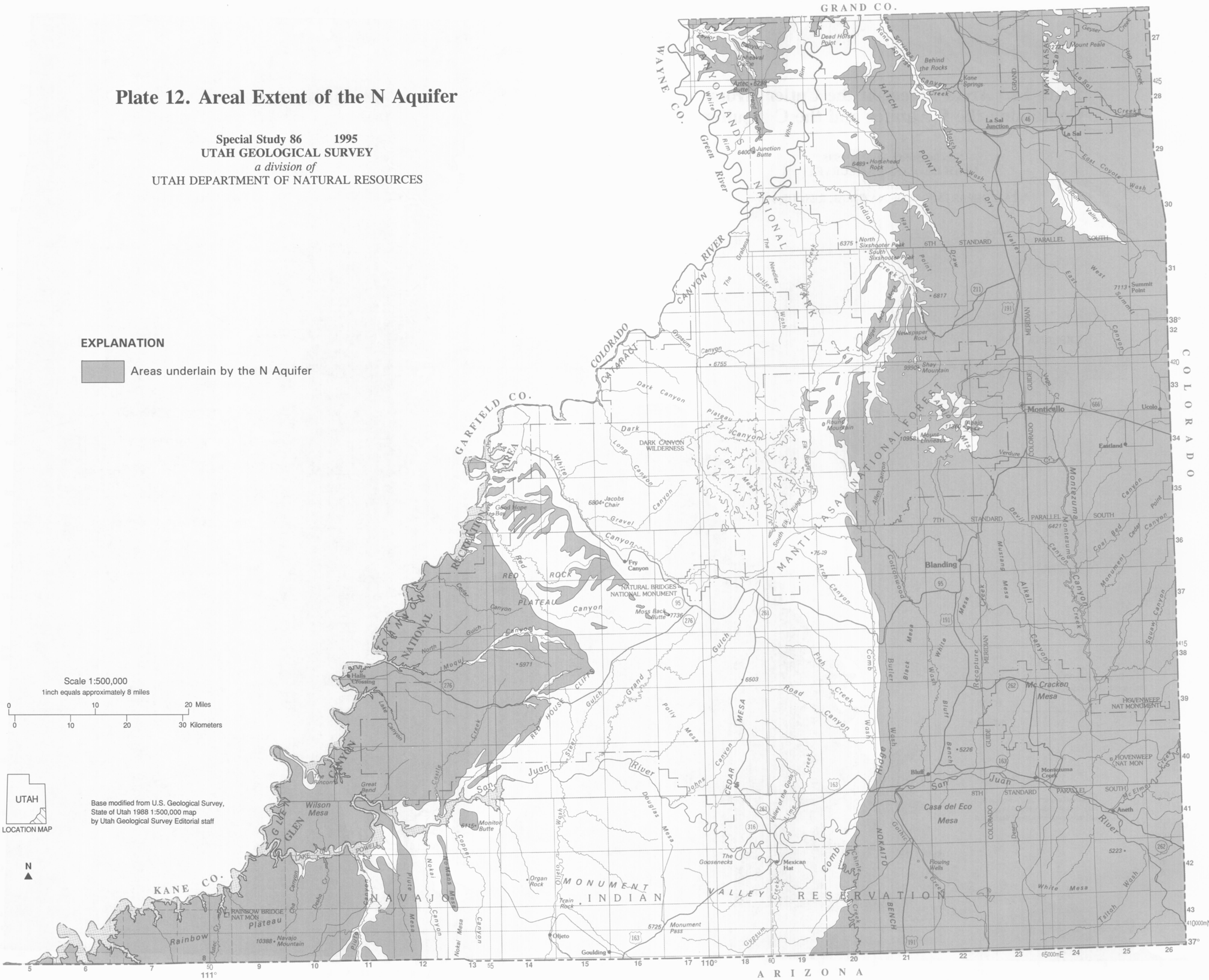

Plate 13. Areal Extent of the M Aquifer

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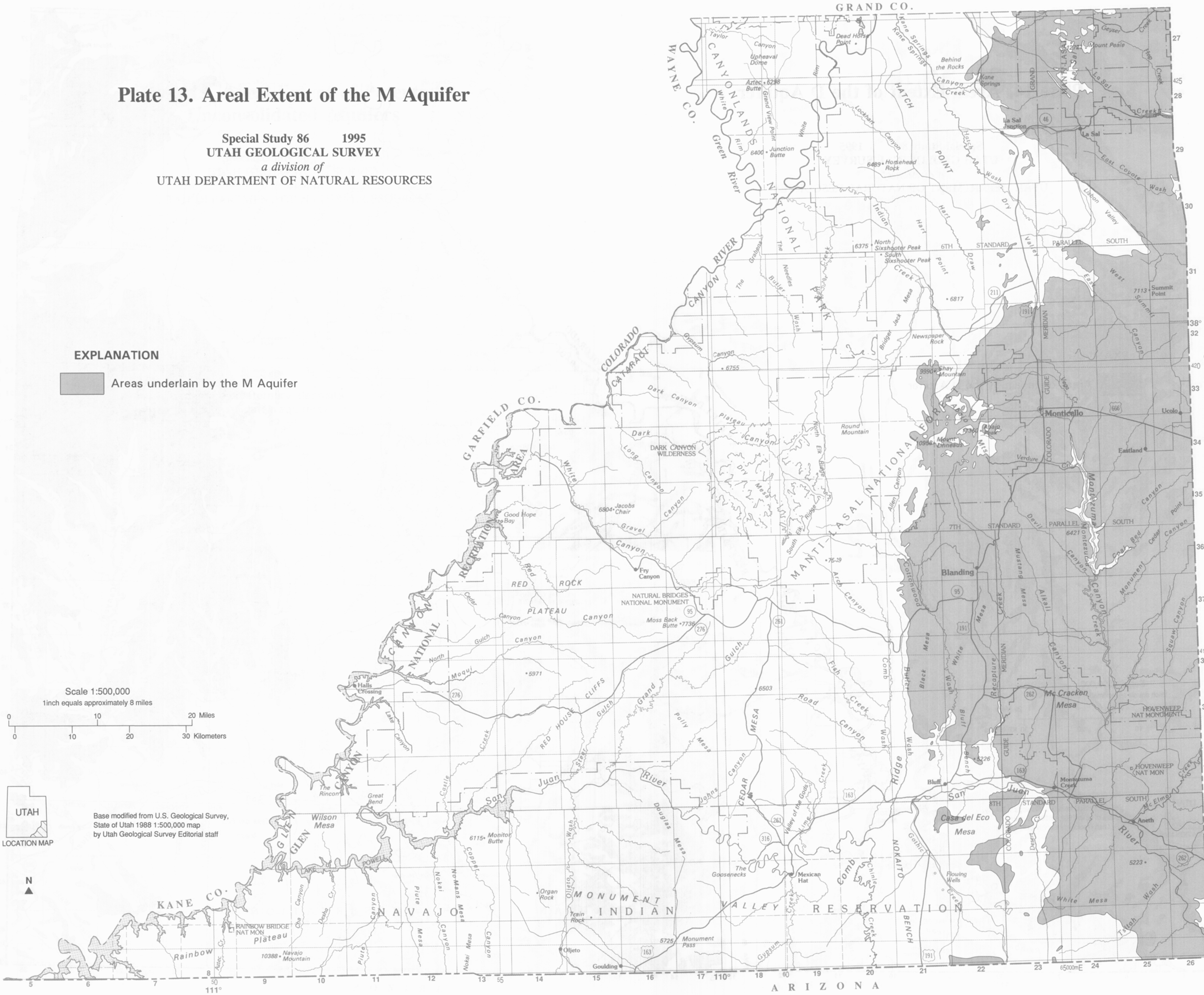

Plate 14. Areal Extent of the D Aquifer

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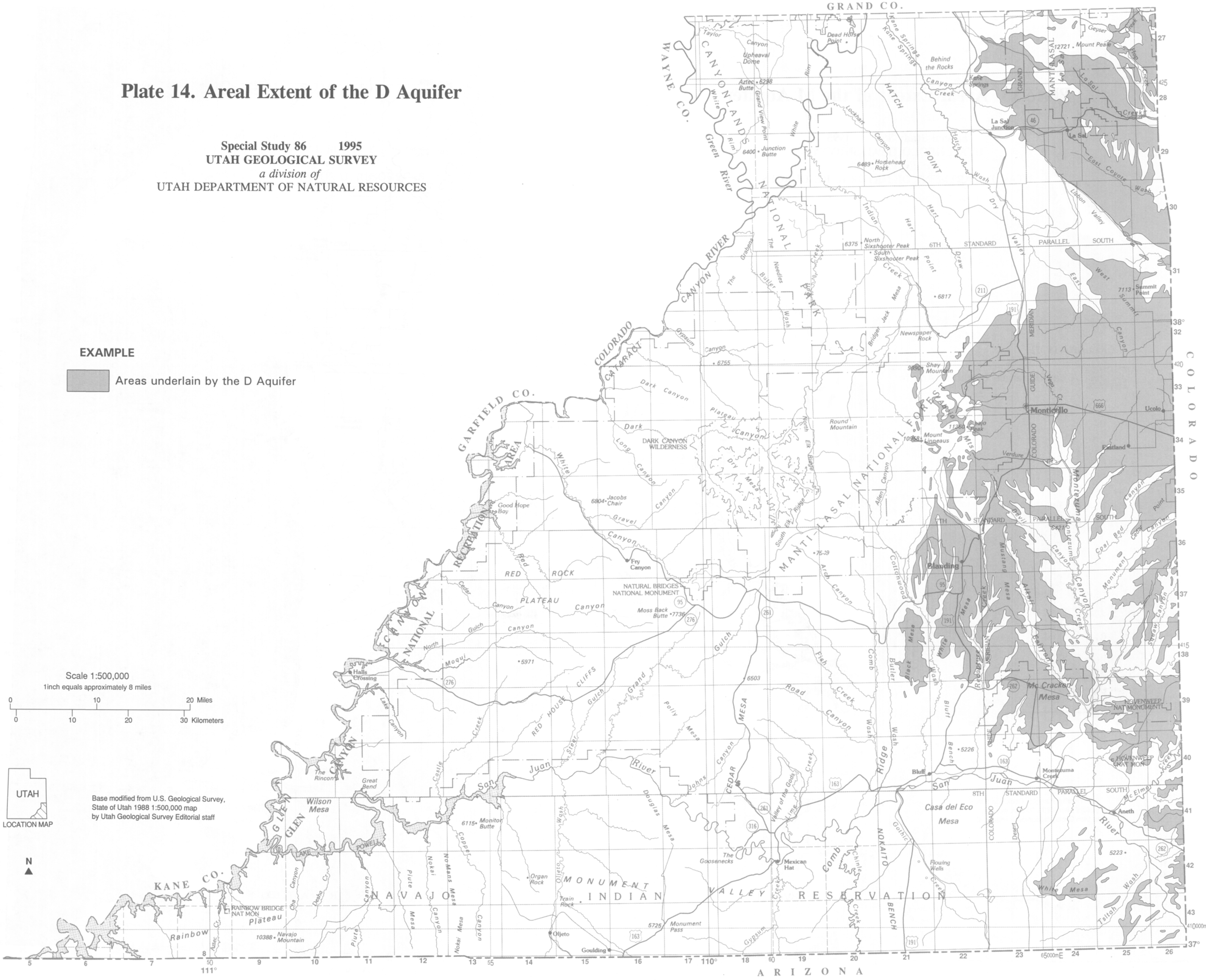

Plate 15. Areal Extent of Potential Unconsolidated Aquifers

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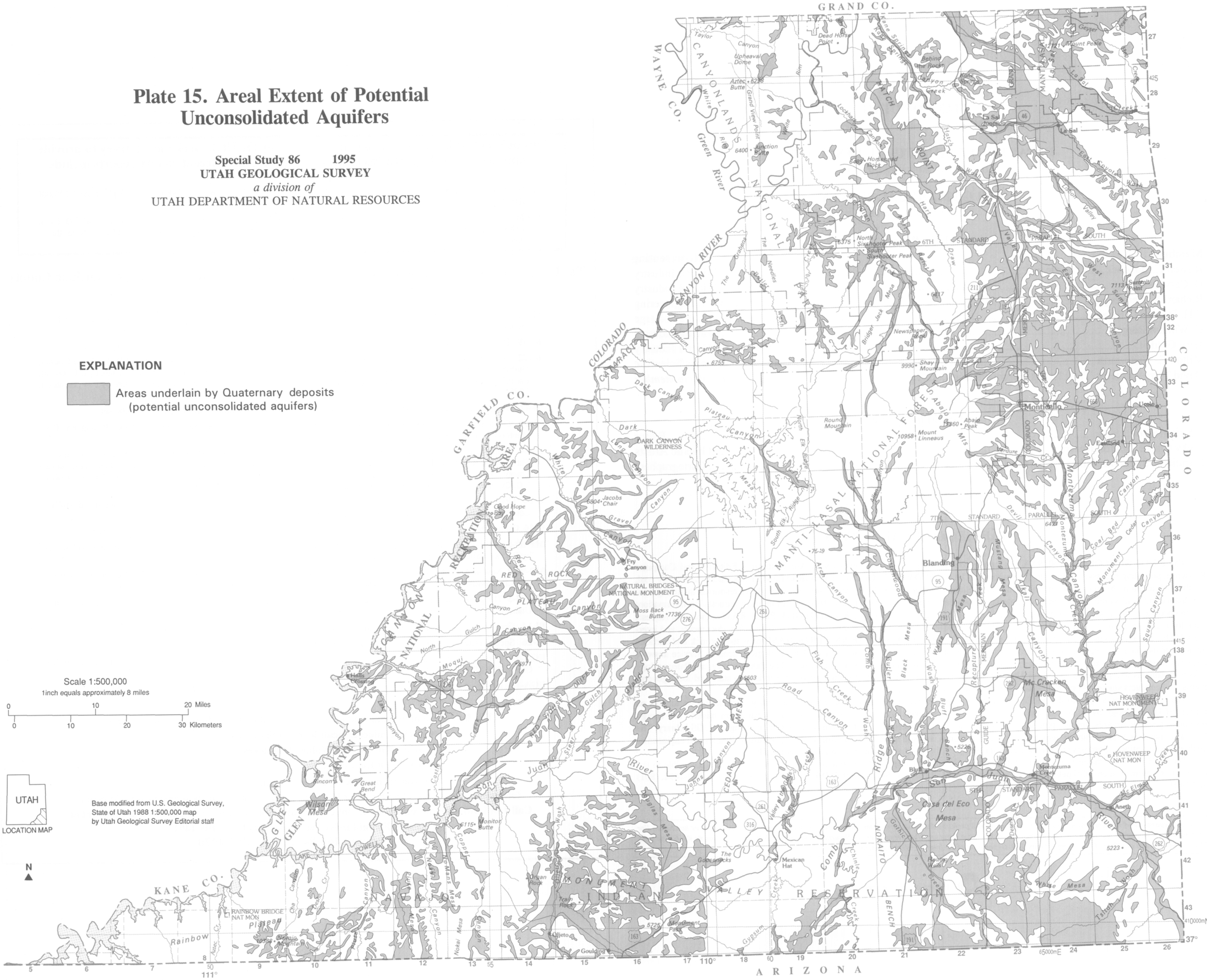

EXPLANATION

Areas underlain by Quaternary deposits (potential unconsolidated aquifers)

Scale 1:500,000
1inch equals approximately 8 miles
0 10 20 Miles
0 10 20 30 Kilometers

UTAH
LOCATION MAP

N

Base modified from U.S. Geological Survey, State of Utah 1988 1:500,000 map by Utah Geological Survey Editorial staff

UTAH GEOLOGICAL SURVEY

The **UTAH GEOLOGICAL SURVEY** is organized into three geologic programs with Administration, Editorial, and Computer Resources providing necessary support to the programs. The **ECONOMIC GEOLOGY PROGRAM** undertakes studies to identify coal, geothermal, uranium, hydrocarbon, and industrial and metallic resources; to initiate detailed studies of the above resources including mining district and field studies; to develop computerized resource data bases, to answer state, federal, and industry requests for information; and to encourage the prudent development of Utah's geologic resources. The **APPLIED GEOLOGY PROGRAM** responds to requests from local and state governmental entities for engineering-geologic and ground-water investigations; and identifies, documents, and interprets Utah's geologic hazards and ground-water resources. The **GEOLOGIC MAPPING PROGRAM** maps the bedrock and surficial geology of the state at a regional scale by county and at a more detailed scale by quadrangle. The Geologic Extension Service answers inquiries from the public and provides information about Utah's geology in a non-technical format. The Paleontology and Paleoecology Section maintains and publishes records of Utah's fossil resources, provides paleontological recovery services to state and local governments, and conducts studies of environmental change to aid resource management.

The UGS Library is open to the public and contains many reference works on Utah geology and many unpublished documents on aspects of Utah geology by UGS staff and others. The UGS has several computer data bases with information on mineral and energy resources, geologic hazards, stratigraphic sections, and bibliographic references. Most files may be viewed by using the UGS Library. The UGS also manages a sample library which contains core, cuttings, and soil samples from mineral and petroleum drill holes and engineering geology investigations. Samples may be viewed at the Sample Library or requested as a loan for outside study.

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This publication is part of an ongoing program by the Utah Geological Survey to provide comprehensive geologic studies of the counties of Utah. Recent county reports include:

B-115 Geology and mineral resources of Box Elder County, Utah, by H.H. Doelling, 1980, 251 p., 3 pl., scale 1:125,000 $20.00

B-124 The geology of Kane County, Utah; geology, mineral resources, geologic hazards, by H.H. Doelling and F.D. Davis with sections on petroleum and carbon dioxide by C.J. Brandt, 1989, 192 p., 10 pl., 1:100,000 $15.00 (Note: the 10 plates may also be purchased in a separate package as Map 121 for $7.00)

The Utah Geological Survey Bookstore carries many other publications relating to San Juan County. A few are listed here.

MO-2 Eastern and northern Utah coal fields: Vernal, Henry Mountains, Sego, La Sal-San Juan, Tabby Mountain, Coalville, Henrys Fork, Goose Creek and Lost Creek, by H.H. Doelling and R.L. Graham, 1972, 409 p. $40.00

B-119 Petroleum resources of the Paradox Basin, 1984, by K.M. Clem and K.W. Brown, 1984, 162 p, 4 pl. $15.00

B-122 Salt deformation in the Paradox region: Geology of Salt Valley anticline and Arches National Park, Grand County, Utah by H.H. Doelling; Evidence for Quaternary deformation in the Salt Valley anticline, southeastern Utah, by C.G. Oviatt; Late Cenozoic gravity tectonic deformation related to the Paradox salts in the Canyonlands area of Utah, by P.W. Huntoon; 1988, 93 p. $9.50

M-47 Oil-impregnated rock deposits of Utah, by H.R. Ritzma, scale 1:1,000,000, two plates, 1979 $5.00/set

M-87 Geologic map of Capitol Reef National Park and vicinity, Utah, (Garfield, San Juan Cos.) by G. Billingsley, P.W. Huntoon, and W.J. Breed, 5 pl., scale 1:62,500, 130" x 30", 1987 $8.00

SS-64 Contributions to Quaternary geology of the Colorado Plateau (San Juan Co.) by G.E. Christenson, C.G. Oviatt, J.F. Shroder and R.E. Sewell, 1985, 85 p. $5.00 Quaternary geology of the Montezuma Creek-Lower Recapture Creek area, San Juan County, Utah, by G.E. Christenson; Late Quaternary geomorphic changes along the San Juan River and its tributaries near Bluff, Utah, by C.G. Oviatt; Mass movement in the La Sal Mountains, Utah, by J.F. Shroder and R.E. Sewell

C-84 Geological considerations for oil and gas drilling on State potash leases at Cane Creek anticline, Grand and San Juan Counties, Utah, by C.D. Morgan, W.A. Yonkee, and B.T. Tripp, 1991, 24 p. $4.00

C-86 Oil and gas drilling in Utah, 1990, by T.C. Chidsey Jr., C.D. Morgan, and M.D. Laine, 30 p., 1994 $5.00

MP-89-5 Multi-characteristic correlation of upper Cretaceous volcanic ash beds from southwestern Utah to central Colorado, by B.J. Kowallis, E.H. Christensen, and A. Deino, 22 p., 9/1989 $3.75

MP-92-2 New 40Ar/39Ar ages of intrusive rocks from the Henry and La Sal Mountains, Utah, by S.T. Nelson, M.T. Heizler, and J.P. Davidson, 24 p., April 1992 $4.50

MP-93-3 The geology and production history of the uranium deposits in the White Canyon mining district, San Juan County, Utah, by W.L. Chenoweth, 26 p., 1 pl., 1:125,000, Ap. 1993 $6.00

PI-14 Geologic resources of San Juan County, Utah, by S.N. Eldredge, 30 p., December 1992 $2.50

PI-26 Special issue on Utah (reprint of Rocks & Minerals Utah Special) 62 p., 1994 $3.50

UGA-17 Geology and hydrology of hazardous-waste, mining-waste, waste-water and repository sites in Utah, edited by G.E. Cordy, 1989, 233 p. $15.00

UGA-18 Energy and mineral resources of Utah, edited by M.L. Allison, (1990 field trip) 1991, 222 p. $12.00

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