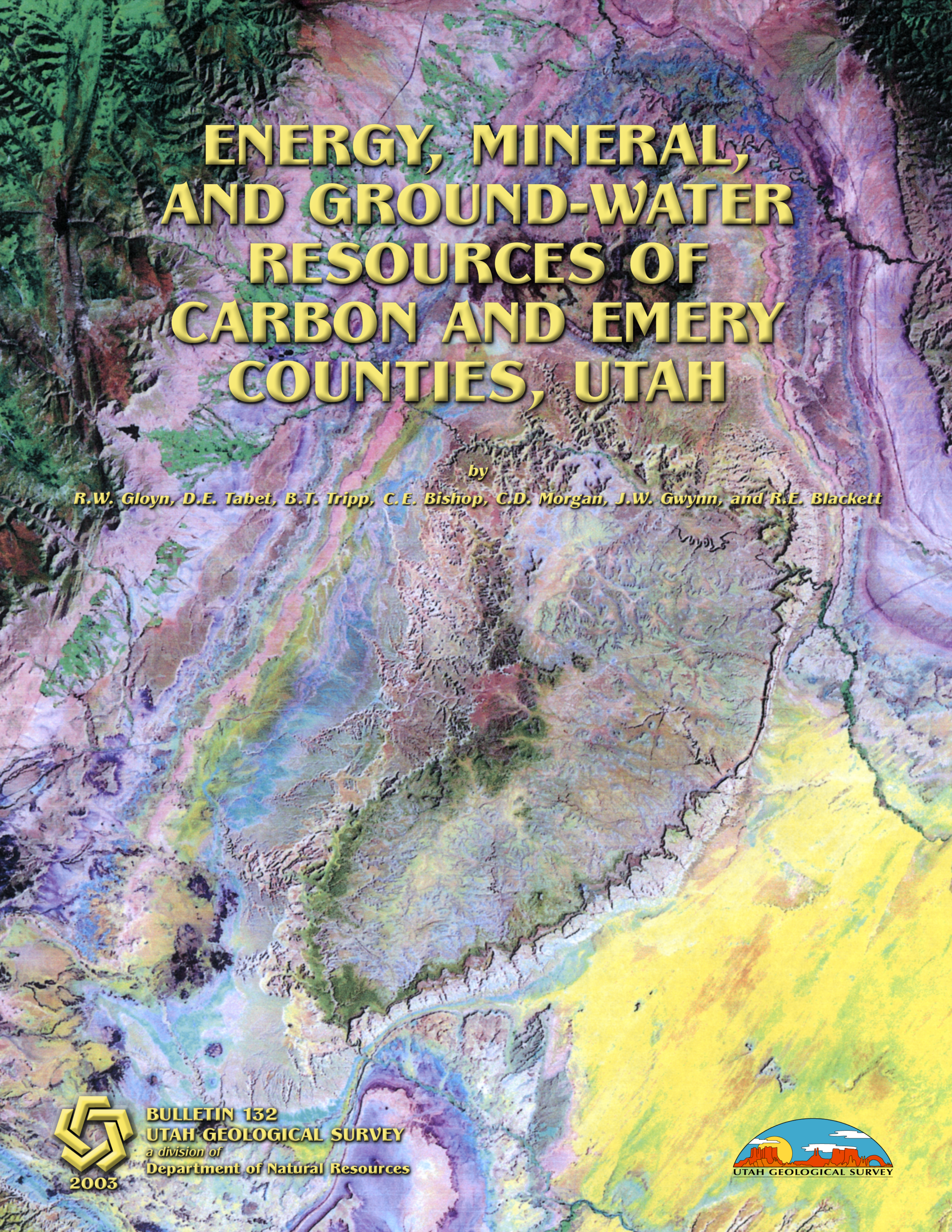

ENERGY, MINERAL, AND GROUND-WATER RESOURCES OF CARBON AND EMERY COUNTIES, UTAH

by

R.W. Gloyn, D.E. Tabet, B.T. Tripp, C.E. Bishop, C.D. Morgan, J.W. Gwynn, and R.E. Blackett

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a division of
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Cover Photo: False color Landsat 7 Thematic Mapper image of the San Rafael Swell and surrounding Wasatch Plateau and Book Cliffs, Utah. Image provided by John C. Dohrenwend, Ph D., Southwest Satellite Imaging, Teasdale, Utah, 84773-0141, dohrenwend@rkymtnhi.com. Used by permission.

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The **UTAH GEOLOGICAL SURVEY** is organized into five geologic programs with Administration and Editorial providing necessary support to the programs. The **ENERGY & MINERAL RESOURCES PROGRAM** undertakes studies to identify coal, geothermal, uranium, hydrocarbon, and industrial and metallic resources; initiates detailed studies of these resources including mining district and field studies; develops computerized resource data bases, to answer state, federal, and industry requests for information; and encourages the prudent development of Utah's geologic resources. The **GEOLOGIC HAZARDS PROGRAM** responds to requests from local and state governmental entities for engineering-geologic investigations; and identifies, documents, and interprets Utah's geologic hazards. The **GEOLOGIC MAPPING PROGRAM** maps the bedrock and surficial geology of the state at a regional scale and at a more detailed scale by quadrangle. The **GEOLOGIC INFORMATION & OUTREACH PROGRAM** answers inquiries from the public and provides information about Utah's geology in a non-technical format. The **ENVIRONMENTAL SCIENCES PROGRAM** maintains and publishes records of Utah's fossil resources, provides paleontological and archeological recovery services to state and local governments, conducts studies of environmental change to aid resource management, and evaluates the quantity and quality of Utah's ground-water resources.

The UGS Library is open to the public and contains many reference works on Utah geology and many unpublished documents on aspects of Utah geology by UGS staff and others.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 databases 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 the Utah Core Research Center which contains core, cuttings, and soil samples from mineral and petroleum drill holes and engineering geology investigations. Samples may be viewed at the Utah Core Research Center or requested as a loan for outside study.

The UGS publishes the results of its investigations in the form of maps, reports, and compilations of data that are accessible to the public. For information on UGS publications, contact the Natural Resources Map/Bookstore, 1594 W. North Temple, Salt Lake City, Utah 84116, (801) 537-3320 or 1-888-UTAH MAP. E-mail: geostore@utah.gov and visit our web site at http:\mapstore.utah.gov.

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ABSTRACT

The Utah Geological Survey has collected and evaluated information on the known and potential energy, mineral, and ground-water resources in Carbon and Emery Counties. This report 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 eight major commodity groups: (1) oil and gas, (2) coal and coal resin, (3) coal-bed methane, (4) other energy resources (oil-impregnated rock, oil shale, geothermal), (5) uranium and vanadium, (6) metallic minerals, (7) industrial rocks and minerals, and (8) 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 locations of known resources and areas of geologic potential. In addition to the commodity discussions, the report contains a brief summary of land ownership status and concludes with a summary of commodities having the best potential for discovery and development.

The report concludes that there is good potential for the discovery and development of additional occurrences of mineral and energy resources in Carbon and Emery Counties. In addition, some resources are present which have tonnage, grade, or quality characteristics that could support commercial development under favorable market conditions or with new technology. However, potential for development of many commodities, particularly some industrial minerals, cannot be ascertained at this time based on limited data available. The most prospective areas for development of additional energy resources are in western Carbon and Emery Counties and in north-central and eastern Carbon County. The most prospective areas for development of additional mineral resources are in eastern and central Emery County.

Natural gas and coal have the best potential for new discoveries and development. Gas has the best potential for significant new discoveries, particularly coal-bed methane gas in the Ferron Sandstone Member of the Mancos Shale of western Carbon and Emery Counties. Lower potential exists for discovery of additional "conventional" or non-Ferron Sandstone Member coal-bed methane gas reservoirs; Tertiary and Upper Cretaceous plays in eastern Carbon and northeastern Emery Counties are the most prospective targets. Potential for significant new oil discoveries is much lower, and most exploration will probably be in northeastern Carbon County.

Coal will continue to be a major economic resource for the next 40 to 50 years. Several new mines are being developed in both the Wasatch Plateau and Book Cliffs coalfields. Production from the Book Cliffs should increase from 4 to nearly 6.5 million tons of coal per year, and production from the Wasatch Plateau should continue at the 20 to 22 million tons per year rate. Although remaining recoverable reserves in both the Wasatch Plateau and Book Cliffs could potentially support 60 to 70 more years of production at current rates, the expected life of both fields is considerably less. Many of the remaining recoverable reserves are in beds less than 6 feet thick or at depths of greater than 2,500 feet and will not be economic to mine under current market conditions. Coal resin is a substantial but unutilized resource in Carbon and Emery Counties. The two counties have large recoverable resin resources, and there is a large market for resin. Unfortunately, resin refiners are unwilling to take Utah coal resin when there are no other coal regions producing resin to guarantee diversity of supply.

There is little potential for near-term development of the other energy resources in Carbon and Emery Counties. There is no geothermal potential, and the known oil shales are too thin and low grade to be developed. Two groups of tar sand deposits are present in Carbon and Emery Counties: a southern group around the San Rafael Swell and a northern group on the south flank of the Uinta Basin. The southern

deposits are either too small or too low grade and are unlikely to be developed. The northern deposits, with the exception the Sunnyside-Jacks Canyon deposit, are also small, low grade, and unlikely to be developed. Only the Sunnyside-Jacks Canyon deposit, containing between 2,500 and 5,000 million in-place barrels of oil, has any chance of development in the foreseeable future. The major obstacle to production is development of an efficient, economical recovery technique that can produce oil that is competitive with that produced by conventional means. Several companies have tested in-situ mining techniques on the Sunnyside deposit with only limited success, and surface mining is only feasible for a small part of the deposit. Even if a new recovery technique were developed, the Sunnyside deposit would have to be competitive with other, better tar sand deposits.

There are known uranium and vanadium reserves in Emery County in and adjacent to the known mines. There is also good potential for additional discoveries of uranium and vanadium particularly on the west side of the San Rafael Swell along channel trends from known deposits and also east of the north Tidwell belt in the San Rafael River mining area. In spite of the known reserves and good potential for additional discoveries, it is unlikely that uranium or vanadium mining will resume in Emery County in the near future. Major obstacles include the current low price for both uranium and vanadium and the lack of nearby mills. Prices of uranium and vanadium would need to nearly double from 2000 levels before the deposits became even marginally economic.

There is little potential in Carbon and Emery Counties for production of base or precious metals. All known copper occurrences not associated with uranium are small and low grade. The grade of the known manganese deposits is 50 percent or less of the grade needed for an economic operation. Known titanium- and zirconium-bearing fossil placer deposits are thinner and lower grade than similar deposits in Wyoming and Montana. Geologic models suggest that “Lisbon Valley-type” sediment-hosted copper deposits could be present adjacent to faults and fractures on the east side of the San Rafael Swell, but there is little supporting evidence and the potential must be considered highly speculative. There is little, if any, obvious potential for precious metal deposits. Minor amounts of gold were recovered from placers along the Green River and similar deposits are probably present along other areas of the Green River and possibly other drainages. Unfortunately, the gold was fine grained, difficult to recover, and all past operations were unsuccessful. Rumors persist about fine-grained, disseminated gold in the Mancos Shale, but until independently confirmed these rumors should be treated with caution.

There is good potential for production of several industrial mineral commodities in Carbon and Emery Counties. Substantial deposits of gypsum are present in the Summerville and Carmel Formations, particularly on the west side of the San Rafael Swell. Several companies are currently developing their holdings, and sufficient resources are present along the outcrop trend to support a number of other gypsum mines. Market conditions, transportation costs, and land-use restrictions will determine the extent of future gypsum development. Valuable deposits of humate are present in southwestern Emery County and are being developed for use as both a nutritional trace element supplement for humans and as a soil amendment and fertilizer by a number of small operators. Further development, particularly for use as fertilizer, will require developing markets. There has been little production of construction materials (sand and gravel and crushed stone) in Carbon and Emery Counties. This situation is not expected to change in the near future. Carbon and Emery Counties have very limited resources of good-quality sand and gravel, and development of crushed stone for aggregate will depend on the cost of importing the needed aggregate material from outside the two counties. Carbon and Emery Counties contain several other industrial rocks and minerals that could be developed including silica sand, dimension stone, flagstone, and limestone for coal mine rock dusting. 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.

Good-quality ground water is scarce in Carbon and Emery Counties, and most water users depend on surface water from springs, streams, and reservoirs for their supply. Only a few formations have potential to supply large amounts of moderate to good-quality water and only in selected parts of the counties. Potential units include the: (1) Najavo Sandstone, (2) Ferron Sandstone, (3) Star Point Sandstone and lower Blackhawk Formation, (4) Dakota Sandstone, and (5) White Rim Sandstone. Most of the better areas for developing the ground-water resource in these units are remote from the population, farming and industrial areas. Most water used in Carbon and Emery Counties will likely continue to come from surface sources.

INTRODUCTION

In April 1995, the Utah Geological Survey (UGS) entered into an agreement with the University of Utah to provide information on the energy, mineral, and ground-water resources of Carbon and Emery Counties as part of a contract with the Division of Community Development to develop a digital database for Carbon, Emery, Grand, and San Juan Counties. The study of Carbon and Emery Counties was an outgrowth of a previous study done for San Juan County (Gloyn and others, 1995). Additional similar studies are planned for other natural resource-rich counties in Utah.

This report describes known and potential energy, mineral, and ground-water resources of Carbon and Emery Counties and evaluates their potential for development. The purpose of the study is to provide information to: (1) assist the counties in both short- and long-term land planning, (2) aid industry in exploration and development of these resources, (3) assist other natural resource personnel, particularly government personnel, in understanding the past, current and future importance of the various resources, and (4) help evaluate the effects of land-planning decisions of other agencies, particularly the Bureau of Land Management (BLM) and U.S. Forest Service (USFS). The report presents an overview based upon readily available information including published documents, UGS and Utah 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 or coal, 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 had little, if any, exploration or development activity, information is scant.

This report is divided into eight major commodity groups: (1) oil and gas, (2) coal and coal resins, (3) coal-bed methane, (4) other energy (oil-impregnated rock, oil shale, geothermal), (5) uranium and vanadium, (6) metallic minerals, (7) industrial rocks and minerals, and (8) ground water resources. Each group may contain several separate resources or commodities. For example, the metallic mineral group includes copper, gold, manganese, and titanium-zirconium, and the "other energy" group includes tar sands, oil shale, and geothermal. 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, and
Potential for Additional Discoveries and/or Development.

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

LAND OWNERSHIP AND STATUS

Emery and Carbon Counties are the seventh and nineteenth largest counties in Utah, respectively. Emery County encompasses 2,850,356 acres or 5.4 percent of the state and Carbon County encompasses 947,632 acres or 1.8 percent of the state. Surface ownership status in 1999 is shown on plate 1 and summarized in table 1. In most cases, the mineral estate (mineral ownership) belongs to the surface estate but some tracts have split ownership. For most of the tracts with split ownership, the mineral rights or partial mineral rights have been retained by the Utah School and Institutional Trust Lands Administration and the surface rights are private or U.S. Forest Service.

Most private land in Emery County is along major roads in the western part of the county, and most private land in Carbon County is around the towns of Price, Helper, and Wellington and as several large parcels in the central and northern Book Cliffs and northern Wasatch Plateau coalfields. State land is scattered throughout both counties with several large consolidated parcels north and southwest of Price, north of Wattis, southeast of Columbia, and south of Cedar Mountain. Federal land constitutes the remainder with National Forests in the extreme western part of the counties along the Wasatch Plateau.

The U.S. Bureau of Land Management (BLM) is the main federal administrative agency for oil and gas, minerals (locatable, leasable, and saleable), and coal. The agency is responsible for administrating these resources on BLM land and on selected parts of other federal lands with the concurrence of the surface owner or administrating agency. For example, the Price office of the BLM administers oil and gas and coal leases and minerals (locatable and leasable) on BLM land, and the Salt Lake office administers oil and gas and coal leases on U.S. Forest Service (USFS) land (Manti-La Sal National Forest) in Carbon and Emery Counties. The BLM also administers mining claims on USFS and split-estate lands where the Federal Government owns the mineral rights. Any restrictions and/or conditions for leasing or operating in the National Forest are determined by the USFS. Table 2 lists the acreage held under current oil and gas leases, current coal leases, and active mining claims (locatable minerals) on federal land in Carbon and Emery Counties.

Table 1. *Surface ownership in Carbon and Emery Counties, Utah (Utah Office of Planning and Budget, written communication, 1999).*

	Carbon County		**Emery County**	
	Acres	**Percent**	**Acres**	**Percent**
Federal Land (total)	450,162	47.5	274,808	79.8
U.S. Bureau of Land Management	419,835	44.3	2,062,072	72.3
U.S. Forest Service	30,327	3.2	210,652	7.4
National Park Service	-	-	2,085	<0.1
Utah State Land	123,887	13.1	335,085	11.8
Private Land	373,511	39.4	240,425	8.4
Total	947,632	100.0	2,850,356	100.0

Table 2. *Acreage in Carbon and Emery Counties, Utah, held for mineral and energy resources on federal land as of September 30, 1999 (Utah State Office, Bureau of Land Management, written communication, 1999).*

	Carbon County	**Emery County**
Oil and gas leases	238,053 acres	251,072 acres
Coal leases	318,681 acres	354,708 acres
Mining claims	11,000 acres (approximate)	21,000 (estimated)

Over half of the acreage in Carbon County and 20 percent of the acreage in Emery County is not held by the Federal Government. This non-federal acreage belongs to either private land holders including individuals and corporations or the Utah School and Institutional Trust Lands Administration (SITLA). Much of this land is or could be available for lease or purchase under conditions set by the owner. Leases on private land would require negotiation with the owner. Leases including rental payments and royalties for state land are more standardized but do vary according to the use of the land or commodity sought and developed. More information on leasing or purchase of state land can be obtained from the School and Institutional Trust Land Administration, 675 East 500 South, Suite 500, Salt Lake City, Utah, 84102-2818, phone 801 538-5100.

A number of areas have been proposed for wilderness designation in Carbon and Emery Counties. The BLM has recommended eight areas totaling 452,173 acres (U.S. Bureau of Land Management, 1990b). These areas are shown on plate 2 and listed in table 3.

The BLM showed seven other wilderness alternatives in their statewide wilderness Final Environmental Impact Statement (U.S. Bureau of Land Management, 1990a). To date (January 2002), 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 the Utah Wilderness Coalition (UWC) which are not included in designated WSAs or ISAs (Instant Study Areas), are managed as normal BLM land.

The U.S. Geological Survey (USGS) and U.S. Bureau of Mines (USBM) performed geologic studies on many of the WSAs. USGS reports include those by Soulliere and others (1988), Bartsch-Winkler and others (1990), and Cashion and others (1990). USBM reports include those by Martin (1987), McDonnel (1988), Benjamin (1989), Close (1989), Lipton (1989), Munts (1989), and Neuman (1989).

In 1996, the BLM began a re-inventory of BLM lands in Utah under a directive from the U.S. Secretary of the Interior to determine if additional areas, not included in designated WSAs, had wilderness characteristics. The results of the study were published in 1999 (U.S. Bureau of Land Management, 1999) and substantially increased the amount of land in Carbon and particularly Emery County considered to have wilderness characteristics. Many of the "newly found" wilderness areas were adjacent to designated WSAs, but others were in areas separate from the WSAs. The BLM wilderness inventory areas are listed in table 4 and shown on plate 2. Plate 2, however, does not name the wilderness inventory areas that were separate from the WSAs. These re-inventoried areas with "wilderness characteristics" have no new legal status and their inclusion in the re-inventory does not change the management of any of these lands. An Environmental Impact Statement (EIS) study and/or Federal Land Policy and Management Act (FLPMA) planning processes are required before the tracts can be submitted to Congress for designation as WSAs. If designated as WSAs by Congress, then the tracts will be managed under the Interim Management Policy and Guidelines for Lands Under Wilderness Review; until that time they should be managed as normal BLM land.

Activity including resource exploration and development on BLM land in Carbon and Emery Counties is covered by two resource management plans (figure 1). The San Rafael Resource Management Plan (U.S. Bureau of Land Management, 1991) covers the western and southern part of Emery County, and the Price River Management Framework Plan (U.S. Bureau of Land Management, 1983) covers all of Carbon County and the northeastern part of Emery County (figure 1). Although the Price River Management Framework Plan is dated, it has been amended several times. The BLM has no plans to write a new management plan for either area in the near future (Price office of BLM, verbal communication, 1996). In these plans, the WSAs occupy a unique position. The plans show how land 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-leasing categories: (1) areas closed to mineral entry or leasing, (2) areas open but with no surface occupancy, (3) areas open with special conditions, and (4) areas open with

Table 3. *U.S. Bureau of Land Management recommended wilderness in Carbon and Emery Counties, Utah (U.S. Bureau of Land Management, 1990a, 1990b).*

Wilderness Study Area (WSA)	Acres
Crack Canyon WSA	25,335
Desolation Canyon WSA (Carbon and Emery County portion only)	16,894
Horseshoe Canyon North WSA (Emery County portion only)	18,580
Mexican Mountain WSA	46,750
Muddy Creek WSA	31,400
San Rafael Reef WSA	59,170
Sid's Mountain/Sid's Cabin WSA	79,644
Turtle Canyon WSA	27,960

Table 4. *Wilderness Study Areas (WSAs) and U.S. Bureau of Land Management inventory areas with wilderness characteristics in Carbon and Emery Counties, Utah.*

Name of Area (WSA Number) (Location notes)	**Total WSA acreage**	**BLM Proposed Action acreage**	**BLM Inventory Wilderness Characteristic acreage (Includes wilderness acreage of adjacent WSA)**
Horseshoe Canyon North WSA (060-045) (<10% in Wayne Co.)	20,500	20,500	See Labyrinth Canyon
San Rafael Reef WSA (060-029A)	59,170	59,170	101,120
Crack Canyon WSA (060-028A)	25,335	25,335	See below
Muddy Creek WSA (060-007)	31,400	31,400	See below
Muddy Creek/Crack Canyon (approximately 71,000 acres in Wayne Co.)			271,785
Devils Canyon WSA (060-025)	9,610	0	19,550
Sid’s Mountain/ Sid’s Cabin WSA (060-023)	80,530	79,644	109,800
Mexican Mountain WSA (060-054)	59,600	46,750	106,500
Jacks Canyon WSA (060-068A2)	7,500	0	11,160
Desolation Canyon WSA (060-068A1) (approximately 87,000 acres of WSA in Grand Co.) (in re-inventory approximately 94,720 acres in Grand, 20,500 acres in Duchesne, and 64,000 acres in Uintah Counties)	290,845	224,850	502,065
Turtle Canyon WSA (060-067)	33,690	27,960	42,410
Upper Muddy Creek			20,300
Hondu Country			22,400
Mussentuchit Badlands (approximately 5% in Sevier Co.)			26,500
Cedar Mountain			17,300
Wildhorse Mesa (approximately 27,200 acres in Wayne Co.)			54,000
Labyrinth Canyon (approximately 43,520 acres in Wayne Co.)			112,800
Limestone Cliffs (>95% in Sevier Co.)			27,600

Note: Total WSA acreage and Proposed Action acreage figures do not include acreage of non-BLM inholdings. BLM Wilderness Inventory acreage figures generally include acreage of some to all non-BLM inholdings.

standard conditions. For example, for oil and gas leasing in the San Rafael Resource Area, 48 percent of the BLM land is open for leasing with standard conditions, 32 percent open with special conditions, 15 percent open with no surface occupancy, and 5 percent unavailable for lease. For locatable minerals in the same area, the BLM recommends 82 percent be available for location with standard conditions and 18 percent be available with special conditions. Only 1,780 acres were closed to mineral entry. Most of the areas requiring special conditions were designated to protect ripar-

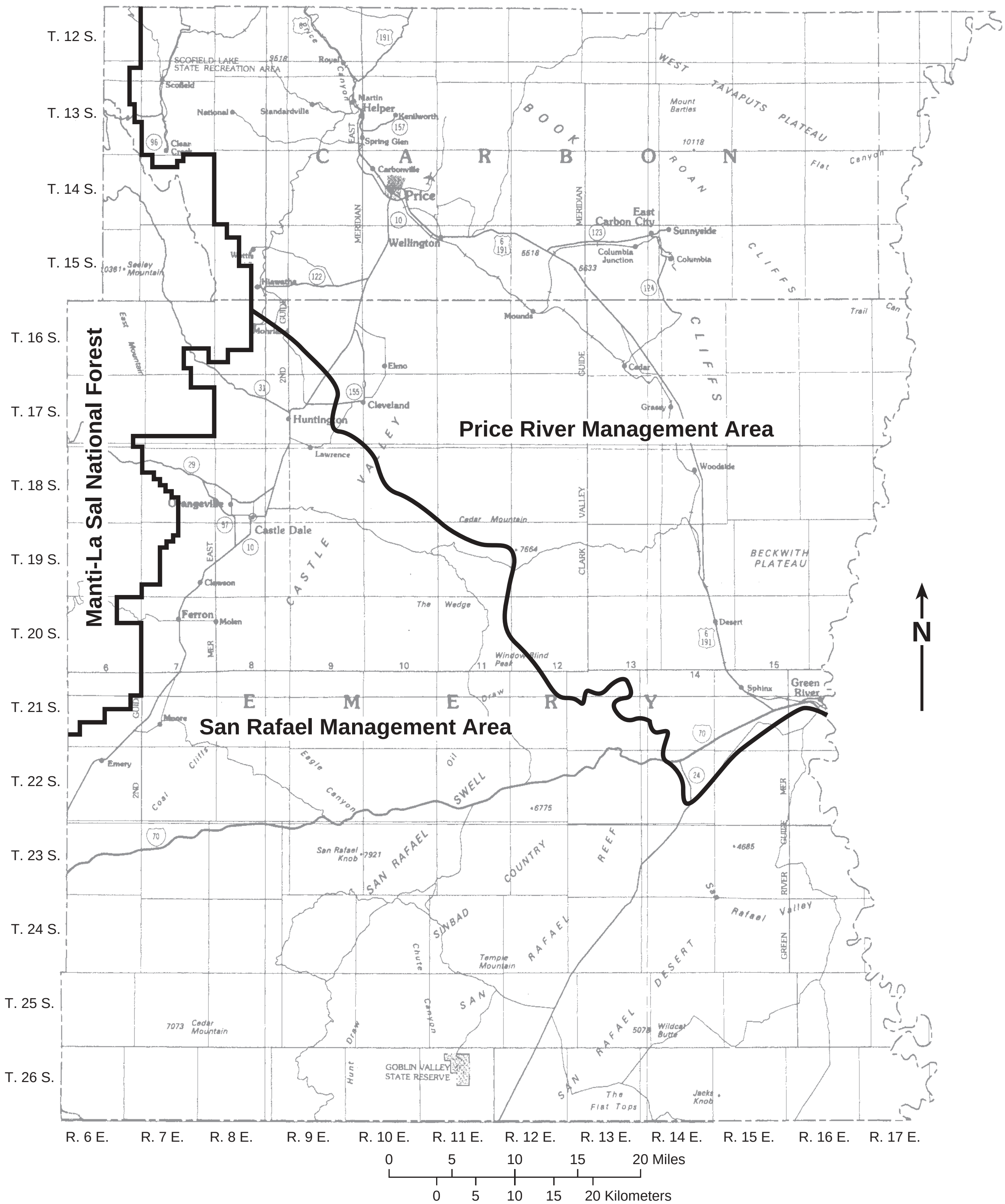


Figure 1. *U.S. Bureau of Land Management administrative management areas in Carbon and Emery Counties, Utah.*

ian/aquatic areas or Areas of Critical Environmental Concern (ACECs). Many ACECs overlap with WSAs. The two BLM management plans do not cover USFS or National Park Service (NPS) lands because these lands are administered by the state BLM office.

Oil and gas and mineral leases on National Forests are administrated by the BLM and are granted subject to conditions stipulated by the USFS. These National Forest lands are separated into roughly the same four mineral development categories as for BLM land. In the Manti North and Manti South areas of the Manti-La Sal National Forest, which cover parts of Carbon, Emery, Sanpete, Utah, and Sevier Counties, the USFS recommends alternative III. Under alternative III, 43 percent of the land is available for leasing with standard conditions, 8 percent available with special conditions, and 49 percent available with no surface occupancy (U.S. Department of Agriculture, 1992). Over 75 percent of the land designated as no-surface occupancy was excluded because of steep slopes and unstable soil conditions. Although the leases are administered by the BLM, the plan of operations must be approved by the USFS.

Interested parties should contact the appropriate state or federal agency for specific information regarding land ownership, availability for development, and conditions and requirements for development. For most state land contact the School and Institutional Trust Land Administration, 675 East 500 South, Suite 500, Salt Lake City, Utah, 84102-2818, phone 801-538-5100.

For federal land contact the Utah State office of the Bureau of Land Management, 324 South State, Salt Lake City, Utah, 84111, phone 801-539-4031.

GENERAL GEOLOGY AND GEOLOGIC HISTORY

Stratigraphy

Over 16,000 feet (5,200 m) of Permian to Tertiary sedimentary rocks are exposed in Carbon and Emery Counties and are underlain in the subsurface by an additional 3,500 to 4,000 feet (1,150-1,300 m) of Cambrian and Devonian to Permian sedimentary rocks. The oldest rocks are exposed in central Emery County near the center of the San Rafael Swell. The youngest sedimentary rocks (Late Cretaceous to early Tertiary) are exposed in western Carbon and Emery Counties in the Wasatch Plateau, and in northern and eastern Carbon County in the Uinta Basin. The four generalized stratigraphic sections shown in figure 2 roughly correspond to the northwestern, southwestern, southeastern, and northeastern parts of the two-county area. Comparison of these sections gives some idea of the variations in lithology and thickness of the different formations and members.

The stratigraphic column can be divided into 18 generalized lithostratigraphic sequences; in most areas these sequences are separated by major unconformities. These packages are described below in table 5.

A few intrusive rocks are present in Carbon and Emery Counties; they consist of thin dikes usually from 1 to 10 feet (0.3-3.2m) wide and simple to composite sills up to 100 feet (33 m) thick. Most of the dikes are diabase but several nephelenites and mica-rich lamprophyres (minette) have been described (Tingey, 1989). The sills are diabase, shonkinite, or syenite or combinations of these (Gartner and Delaney, 1988). Nearly all of the intrusive diabase dikes and sills are located in southwestern Emery County and are of Pliocene age (Gartner and Delaney, 1988). The nephelenites and lamprophyres are located mostly in northwestern Carbon County and have late Oligocene (24 Ma) and late Miocene (6-8 Ma) ages (Tingey, 1989). Most of the nephelenite and lamprophyre dikes trend roughly east-west, and most of the younger diabase dikes trend north to N. 20° W. (Gartner and Delaney, 1988; Tingey, 1989).

Structure

Most of the sedimentary units in Carbon and Emery Counties are relatively flat lying with dips of less than 6° to 10°, commonly less than 4°, except around the San Rafael Swell and in isolated fault blocks. On the steep east flank of the San Rafael Swell (San Rafael Reef), Triassic to Jurassic units dip 10° to over 35° east to southeast before flattening out to the east; within the center of the Swell the Permian to Lower Triassic units dip 1° to 4° west and northwest; and along the west flank the Triassic to Jurassic units dip generally 3° to 10° west. In the Wasatch Plateau and Castle Valley in western Emery County, Cretaceous units dip 2° to 8° west or northwest. In the Book Cliffs and Roan Cliffs in northern and eastern Carbon County, Cretaceous to early Tertiary units dip 3° to 10° north or northeast into the Uinta Basin.

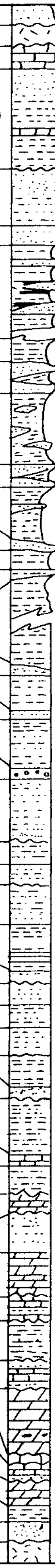
Geologic History

The Cambrian and Devonian to middle Mississipian sequences (sequences 1 and 2, table 5) represent repeated transgressions and regressions of a Paleozoic ocean located in what is now Nevada and western Utah and are separated by a major Early Devonian-age unconformity that removed all units above the Middle Cambrian. The middle Mississippian to Permian sequence (sequence 3, table 5) has highly variable rock types and extreme changes in total thickness. This variation is largely due to repeated transgressions and regressions of a Paleozoic ocean to the west and south coupled with Pennsylvanian and Permian tectonic activity that formed several uplifts and basins in southeastern Utah. The middle Mississippian to Permian sequence can be divided into five subunits that are commonly but not invariably separated by unconformities. During this time, most of Carbon and Emery Counties were on a broad shallow shelf with deeper basins to the southeast and northwest and scattered uplifts or positive areas. Over the uplifts (Piute Platform/ Emery High) the lower three subunits are missing; within the basins the lower three subunits are present and conformable. The subunits from lowest to highest are: (1) transgressive regressive sandstone-limestone, sandstone, or shale unit (Humbug and Molas Formations), (2) a multiple transgressive-regressive sequence of shale, shaley sandstone, and limestone (Doughnut and Pinkerton Trail Formations), (3) a cyclic sequence of sandstone and limestone or shale, limestone, and evaporites (Callville Limestone, Paradox and Honaker Trail Formations), (4) an alternating sequence of sandstone and dolomite or shale, siltstone, and dolomite that became sandier upward overlain by a thick sandstone or

Northwestern Carbon County

HELPER - PRICE - WELLINGTON

Period	Group / Formation	Formation / Member	Feet	Notes
Q	Alluvium & pediment deps		0-100	
TERT	Alkalic diabase dikes & sills		0-5 wide	8 m.y. 18 m.y. 24 m.y.
TERT	Flagstaff Limestone		220-280	
	North Horn Formation		1040-2170	North Horn & Price River Fms thin eastward as they pass over the northern end of the San Rafael Swell thus dating its rise
CRETACEOUS	Mesaverde Group	Price River Fm	270-1150	
CRETACEOUS	Mesaverde Group	Castlegate Ss	180-290	
CRETACEOUS	Mesaverde Group	Blackhawk Formation	1000-1500	Sunnyside Ss & coal; Kenilworth Ss & coal; Aberdeen Ss & coal; Spring Canyon Ss
CRETACEOUS	Mancos Shale	Shale tongue	120-350	Storrs Ss
CRETACEOUS	Mancos Shale	Star Point Ss Mbr	300-20	Panther Ss
CRETACEOUS	Mancos Shale	Shale tongue	800-1300	*Baculites*
CRETACEOUS	Mancos Shale	Emery Ss Member	120-180	*Desmoscaphites*
CRETACEOUS	Mancos Shale	Shale tongue	350-850	*Placenticeras*; *Baculites codyensis*
CRETACEOUS	Mancos Shale	Upper Garley Cyn M	30-60	
CRETACEOUS	Mancos Shale	Shale tongue	80-110	
CRETACEOUS	Mancos Shale	Lower Garley Cyn M	40-70	*Placenticeras*
CRETACEOUS	Mancos Shale	Blue Gate Shale Member	2500 ±	Shell Oil-North Springs 27-15S-9E; Shell Oil - Miller Creek 26-15S-10E; Pan Am-Farnham Dome 7-15S-12E; Pure Oil-Washboard 12-16S-9E; Pure Oil-Desert Lake 1-17S-10E
CRETACEOUS	Mancos Shale	Ferron Ss Member	100-10	
CRETACEOUS	Mancos Shale	Tununk Sh Mbr	200-300	
CRETACEOUS	Dakota Sandstone		0-30	
CRETACEOUS	Cedar Mtn Fm	Upper member	150-750	
CRETACEOUS	Cedar Mtn Fm	Buckhorn Cg Mbr	0-50	
JURASSIC	Morrison Formation		800 ±	
JURASSIC	Summerville Formation		120-180	J-5 unconformity
JURASSIC	Curtis Formation		140-180	J-3 unconformity
JURASSIC	Entrada Formation		150-950	
JURASSIC	Carmel Formation		300-700	
JURASSIC	Page Sandstone		70	J-2 unconformity
JURASSIC	Navajo Sandstone		150-300	
JURASSIC	Kayenta Formation		120-200	
JURASSIC	Wingate Sandstone		300-400	
TRIASSIC	Chinle Fm	Upper member	200-300	bentonitic
TRIASSIC	Chinle Fm	Moss Back Mbr	20-60	Tr-3 unconformity
TRIASSIC	Moenkopi Fm	Upper member	550-700	
TRIASSIC	Moenkopi Fm	Sinbad Ls Mbr	50	
TRIASSIC	Moenkopi Fm	Black Dragon Mbr	250-350	Tr-1 unconformity
PERM	Black Box Dolomite		170	
PERM	White Rim Sandstone		500-700	
PERM	Pakoon Dolomite		650-800	
IP	Callville Limestone		250-300	
MISS	Doughnut Formation		600-700	
MISS	Humbug Formation		400-500	
MISS	Redwall Dolomite		750-970	
D	Pinyon Peak Ls		20	
D	Ouray Formation		110-160	
Є	Cambrian dolomite		350	
Є	Ophir Shale		200	
Є	Tintic Quartzite		210	
pЄ	Crystalline basement		-	



Northeastern Carbon County

SUNNYSIDE - WOODSIDE AREA

Period	Formation	Member	Feet	Notes
Q	Alluvial, colluvial, pediment and terrace deposits		0-200	
TERTIARY	Green River Formation		3200 +	Edge of Uinta Basin; Tar sands
TERTIARY	Colton Formation (formerly Wasatch)		900-3000	Roan Cliffs varicolored ss, sh thicken to southeast
TERTIARY	Flagstaff Limestone		0-30	
	North Horn Formation		100-500	
CRETACEOUS	Price River Fm	Bluecastle Ss Mbr	100-300	
CRETACEOUS	Price River Fm	Mudstone member	100-400	Book Cliffs
CRETACEOUS	Castlegate Sandstone		80-300	
CRETACEOUS	Blackhawk Fm	Upper mudstone	100-200	
CRETACEOUS	Blackhawk Fm	Sunnyside Member	100-190	Principal coal beds
CRETACEOUS	Blackhawk Fm	Lower mudstone	150-200	
CRETACEOUS	Blackhawk Fm	Kenilworth Mbr	110-220	coal
CRETACEOUS	Blackhawk Fm	Mancos tongue	200	
CRETACEOUS	Blackhawk Fm	Aberdeen Mbr	0-10	
CRETACEOUS	Mancos Shale (main body)		3400	*Scaphites hippocrepis*; *Baculites aquilaensis*; *Scaphites warreni*
CRETACEOUS		Ferron Ss Mbr	10-50	
CRETACEOUS		Tununk Sh Mbr	400	*Collignoniceras*
CRETACEOUS	Dakota Sandstone		0-60	*Pycnodonte newberryi*
CRETACEOUS	Cedar Mtn Fm	Upper mudstone	110-350	
CRETACEOUS	Cedar Mtn Fm	Buckhorn Cg Mbr	10-80	
JURASSIC	Morrison Fm	Brushy Basin M	150-250	
JURASSIC	Morrison Fm	Salt Wash Ss M	50-250	
JURASSIC	Summerville Formation		150-200	chocolate torte beds
JURASSIC	Curtis Formation		130-180	
JURASSIC	Entrada Sandstone		150-450	
JURASSIC	Carmel Formation		200-500	gypsum
JURASSIC	Page Sandstone		50 ±	J-2 unconformity
JURASSIC	Navajo Sandstone		320-350	
JURASSIC	Kayenta Formation		50-100	
JURASSIC	Wingate Sandstone		310-440	
TRIASSIC	Chinle Fm	Upper member	200-230	Pan-Am Dragerton 11-15S-13E
TRIASSIC	Chinle Fm	Moss Back Ss Mbr	40-50	Reserve Oil-Cedar Siding 21-16S-13E
TRIASSIC	Moenkopi Fm	Upper member	450-600	Forest-Arnold-Little Park 25-16S-14E
TRIASSIC	Moenkopi Fm	Sinbad Ls Mbr	50 ±	
TRIASSIC	Moenkopi Fm	Black Dragon Mbr	300-450	
PERM	Black Box Dolomite		140	"Kaibab"
PERM	White Rim Sandstone		600-650	"Coconino"
PERM	Pakoon Dolomite		800	"Oquirrh" of some well logs
IP	Callville Limestone		550	
M	Doughnut Formation		850-250	
M	Humbug Formation		400-180	
M	Redwall Dolomite		800-0	
D	Ouray-Elbert Fms		120-0	formations truncated on southeast flank of Uncompahgre Uplift
Є	Cambrian carbonate		350-0	
Є	Ophir Shale		150-0	
Є	Tintic Quartzite		170-0	
	Precambrian crystalline basement			

Figure 2a. *Generalized stratigraphic sections of formations in Carbon and Emery Counties (after Hintze, 1993).*

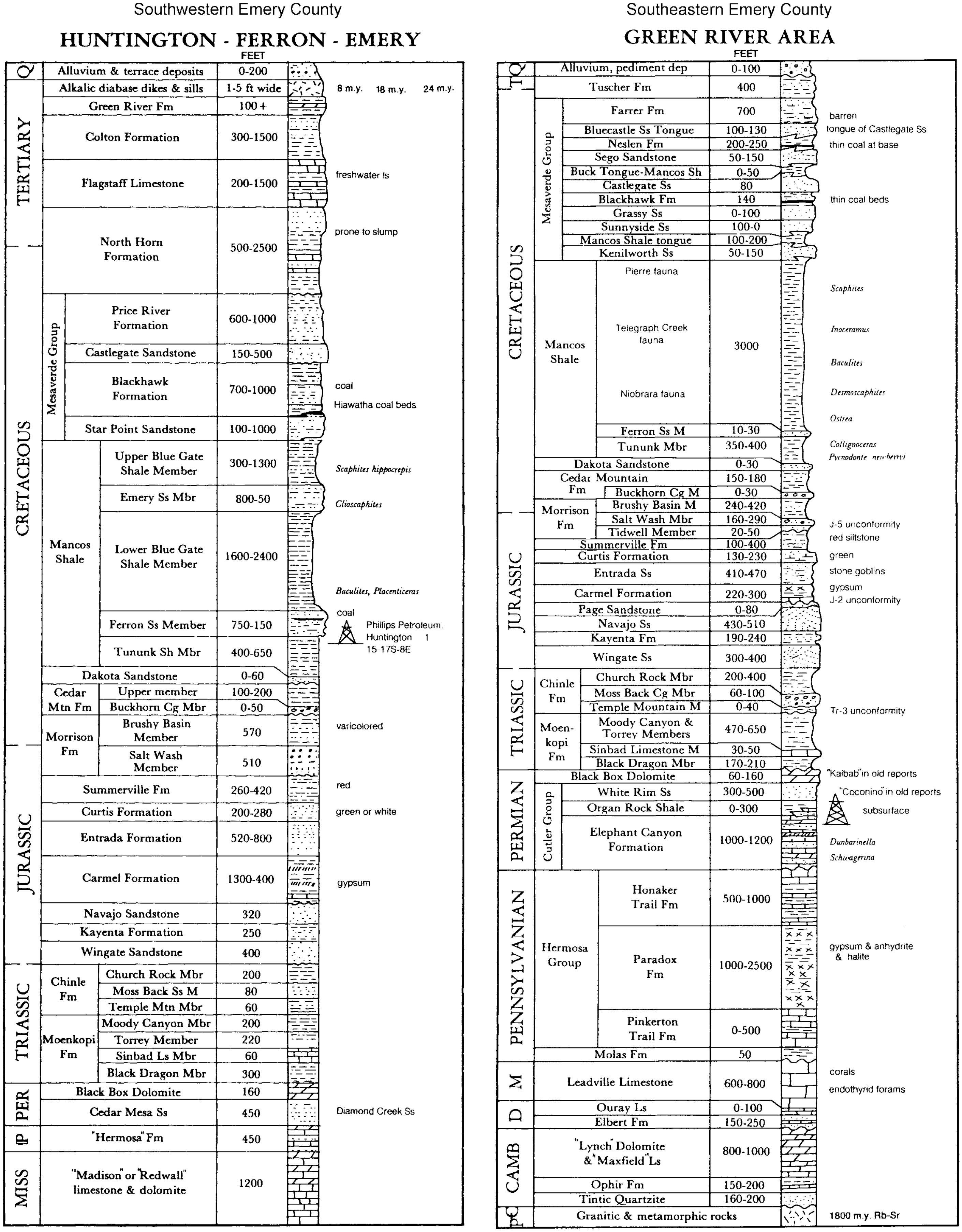


Figure 2b. *Generalized stratigraphic sections of formations in Carbon and Emery Counties (after Hintze, 1993).*

Table 5. *Major lithostratigraphic sequences in Carbon and Emery Counties.*

Sequence Number	Age	Formations	Description
1	Middle Cambrian 555-525 my (million years)	Tintic Quartzite, Ophir Shale, Lynch Dolomite, Maxfield Limestone	Marine transgressive sequence with progressive deposition of sandstone, shale, and dolomite on crystalline Precambrian basement
2	Devonian to middle Mississippian 364-335 my	Elbert Formation, Ouray and Redwall (Leadville) Limestones	Multiple transgressive-regressive sequence of mostly shallow-shelf carbonate rocks bounded by unconformities
3	Middle Mississippian to early Permian 330-260 my	See text	Complex sequence of marine sandstone, shale, limestone, dolomite, and gypsum/halite with highly variable thicknesses (see text for additional detail)
4	Early Triassic 243-239 my	Moenkopi Formation	Coastal plain-marginal marine shale, mudstone, and minor sandstone with thin marine limestone
5	Late Triassic 228-212 my	Chinle Formation	Continental sequence of fluvial sandstone and conglomerate and flood-plain to lacustrine siltstone and mudstone
6	Early Jurassic 208-187 my	Wingate Sandstone, Kayenta Formation, Navajo Sandstone	Two thick eolian sandstone sections with minor limestone separated by a section of fluvial sandstone, siltstone, and mudstone
7	Middle Jurassic 185-165 my	Page Sandstone, Carmel Formation, Entrada Sandstone	Transgressive sequence of eolian sandstone and beach-shoreface-subtidal sandstone and siltstone overlain by an oscillating sequence of sabkha-intertidal mudflat-shallow marine mudstone, gypsiferous mudstone, dolomite, and limestone (Page Sandstone and lower Carmel Formation) followed by a regressive sequence of similar sabkha-tidal flat-shallow marine units (upper Carmel Formation) (Bagshaw, 1977) and tidal flat mudstone and beach-delta-marginal marine sandstone and/or eolian sandstone (Entrada Sandstone)
8	Middle Jurassic 165-163 my	Curtis and Summerville Formations	Transgressive-regressive sequence of shallow marine glauconitic sandstone, siltstone, and mudstone (Curtis Formation) (Smith, 1976) and tidal flat sandstone, siltstone, and gypiferous mudstone (Summerville Formation) (Stanton, 1976)
9	Late Jurassic 154-141 my	Morrison Formation	Fluvial-flood-plain-lacustrine conglomerate, sandstone, shale, and mudstone (locally bentonitic) and minor lime stone
10	late Early Cretaceous 114-99 my	Cedar Mountain Formation	Fluvial-flood-plain-lacustrine conglomerate, sandstone, shale, and mudstone (locally bentonitic) and minor lime stone
11	Late Cretaceous 98-93 my	Dakota Formation	Thin transgressive-regressive sequence of marginal marine-beach-delta sandstone, shale, and coal
12	Late Cretaceous 93-85 my	Mancos Shale	Thick sequence of marine shale and sandstone with several locally thick, deltaic sandstone-mudstone-coal members (Ferron, Emery, and Garley Canyon Members of Mancos Shale).
13	Late Cretaceous 85-76 my	Blackhawk Formation, Castlegate Sandstone, Price River Formation and other formations of Mesaverde Group	Cyclic sequence of marginal marine to deltaic sandstone, siltstone, and coal
14	Late Cretaceous to Paleocene 74-61 my	North Horn Formation	Fluvial to lacustrine sandstone, shale, and mudstone
15	Paleocene 61-57.5 my	Flagstaff Formation	Flood-plain to lacustrine mudstone and limestone
16	late Paleocene to early Eocene 57.5-54 my	Colton Formation	Fluvial sandstone, siltstone, and mudstone
17	Eocene 54-44 my	Green River Formation	Lacustrine mudstone, limestone, marl, and oil shale with interbedded fluvial deltaic sandstone and mudstone
18	Quaternary 100,000 -0 years	Unnamed	Eolian, fluvial, and colluvial surficial cover, mostly fine-grained sand and silt but also some coarser-grained sand and gravel

sandy shale (Pakoon Dolomite-Cedar Mesa Formation-White Rim Sandstone or Elephant Canyon-Organ Rock Shale-White Rim Sandstone), and (5) a fairly uniform, widespread transgressive shallow shelf dolomite or limestone (Black Box Dolomite). The middle Mississippian to Permian sequence is 2,800 to 3,000 feet (920-985 m) thick in northern Carbon County, 700 to 1,000 feet (230-330 m) thick in western Emery County over the Emery High, and 2,500 to 4,500 feet (820-1,475 m) thick in southern and eastern Emery County. A major period of erosion spanning nearly all of the Late Permian (Tr-1 unconformity) separates this sequence from the sequences described below.

The Early and Late Triassic sequences (sequences 4 and 5, table 5) represent: (1) an early oscillating transgression and regression of the western ocean over a broad tidal flat, (2) a period of widespread erosion (Tr-3 unconformity) covering most of the Middle Triassic (10-12 my), and (3) later fluvial sandstone and mudstone deposition by north- and northwest-flowing streams from source areas to the south and possibly west in the Mogollon Highlands. The Early Jurassic sequence (sequence 6, table 5) represents incursions of large areas of windblown sand (ergs) over the older or contemporaneous sandstones and mudstones. The dominant wind direction was to the south and southeast and the ergs advanced from the northwest. This sequence is bracketed by two major unconformities: the J-0 at the base of the sequence representing possibly 6 to 8 million years, and the J-3 at the top also representing possibly 6 to 8 million years (Pipiringos and O'Sullivan, 1978).

The early Middle Jurassic sequence (sequence 7, table 5) represents the incursion and later retreat of the Sundance sea from the north along the relatively narrow northwest-trending Carmel-Twin Creek seaway (Kocurek and Dott, 1983). Eolian and sabkha-tidal to subtidal environments predominated in Carbon and Emery Counties, but marine environments were present to the north and west (Blakey and others, 1983). The late Middle Jurassic sequence (sequence 8, table 5) represents a subsequent incursion and retreat of the Sundance sea from the northeast with deposition of marine followed by tidal flat sediments (Kocurek and Dott, 1983). A regional unconformity (J-5) is at the top of this sequence.

The Late Jurassic and Early Cretaceous fluvial-floodplain sequences (sequences 9 and 10, table 5) were deposited by north-, northeast-, and east-flowing streams with sediment derived from source areas associated with Late Jurassic (Elko orogeny) or Early Cretaceous (Sevier orogeny) tectonism. The two sequences are separated by an unconformity representing nearly 20 million years (Kirkland and others, 1997). The four Late Cretaceous sequences (sequences 11 to 14, table 5) are associated with incursion and subsequent westward filling of the Western Interior Seaway that extended from the Arctic to Mexico during the Late Cretaceous. The first sequence represents the initial marginal marine deposits; the second sequence represents the deep-water marine deposits with fluvial and deltaic wedges derived from thrust-belt highlands to the west; the third sequence represents mostly fluvial and deltaic deposits with subordinate interbedded marine shales; and the fourth sequence represents almost exclusively fluvial flood-plain deposits (Fouch and others, 1983). No major unconformities separate the four sequences although numerous unconformities are present that are mostly related to variation in basin subsidence and sediment supply.

The Laramide orogeny affected much of the Rocky Mountain region between the Late Cretaceous and late Eocene. The most obvious result of the orogeny was the formation of large, generally elongate uplifts and intervening subsiding basins. In the Colorado Plateau region of Utah, uplift began as early as Late Cretaceous and continued episodically until late Eocene time. Uplifts include the San Rafael Swell, the Circle Cliffs uplift, and the Uinta Mountains. The uplifts were source areas for the fluvial and lacustrine deposits in the adjacent low areas and basins.

The three Paleocene to Eocene sequences (sequences 15 to 17, table 5) are related to two large lakes that developed in Utah during the early Tertiary. The Paleocene lake, Lake Flagstaff, occupied a large area in central Utah between the Sevier orogenic belt and Laramide-age uplifts such as the San Rafael Swell and Circle Cliffs farther south. Lacustrine and fluvial sedimentation was confined to western Emery County and western and northern Carbon County. The Eocene lake, Lake Unita, was somewhat smaller and occupied an area between the Sevier-orogenic belt and Laramide-age uplifts to the south and north (San Rafael Swell and Uinta Mountains). Variations in the rates of basin subsidence and sediment supply resulted in complex interfingering of lacustrine marl and shale and fluvial sandstone and siltstone. Rocks associated with Lake Uinta and its margins are not preserved in most of Emery County except for a small area in extreme northeastern Emery County and are restricted to the northern and eastern parts of Carbon County along the Book and the Roan Cliffs.

Regional uplift during the early Tertiary was followed in the late Tertiary by the establishment of the Colorado River drainage. Extensive erosion followed with over 10,000 feet (3,250 m) of section removed in some areas, and the area is still being eroded today. Diabase dikes and diabase-syenite composite sills were intruded in the Paleocene. Oligocene and Miocene volcanism occurred to the west and south, but the only expression of this volcanism in Carbon and Emery Counties is a few small dikes. Crustal extension beginning in middle Miocene time formed a series of north-south-trending faults in the western part of the two counties. Continued erosion and local deposition during the Quaternary produced the alluvial, colluvial, eolian, and fluvial units of sequence 18.

PHYSIOGRAPHY

The physiography of Carbon and Emery Counties reflects the geologic structure and rock types of the area. Major physiographic areas are shown in figure 3. The major physiographic feature is the large northeast-trending San Rafael Swell, a domical anticlinal uplift developed during the Laramide orogeny. The flanks are composed of resistant Triassic and Jurassic sandstone beds that form "reefs" or flatirons. The San Rafael Swell is surrounded by low-lying areas underlain by non-resistant, generally shaley units of Middle Jurassic to Cretaceous age that form the Salt Wash-Castle Valley area on the west, the Tidwell Wash-Grassy Wash area on the northeast, and the San Rafael Desert on the southeast. These low areas are rimmed by cliffs and mesas of more resistant Late Cretaceous to Eocene fluvial and deltaic sandstone and lacustrine limestone that form the Wa-

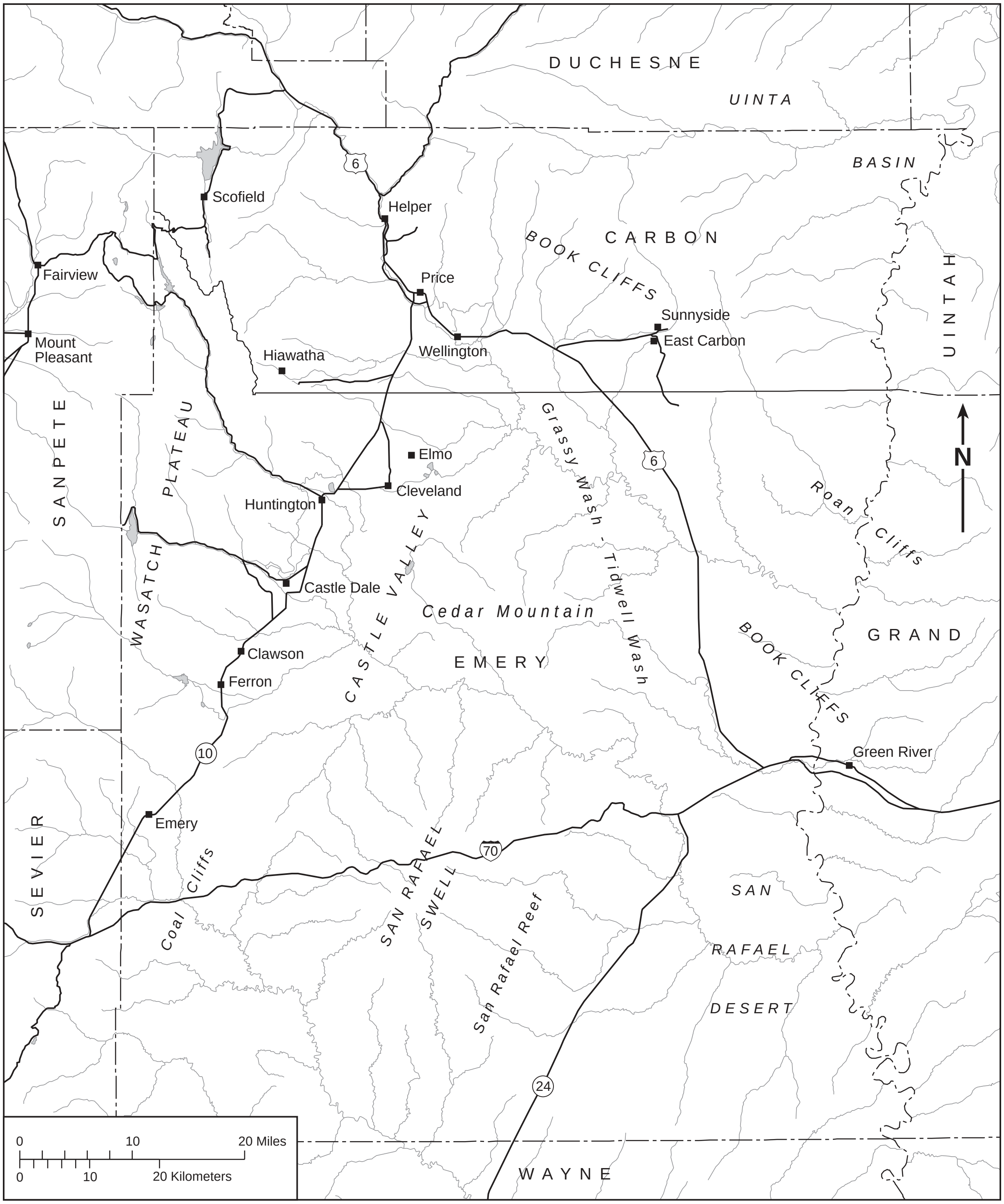


Figure 3. *Location of major physiographic features in Carbon and Emery Counties, Utah.*

satch Plateau on the west and the Book and Roan Cliffs on the north and northeast. The Uinta Basin is located north and east of the Book and Roan Cliffs. Two other prominent physiographic features are present: the Coal Cliffs, which are formed by thick, resistant sandstone beds of the Ferron Sandstone Member of the Mancos Shale; and Cedar Mountain, which has been preserved as a mesa because of a capping of resistant conglomerate of the Cedar Mountain Formation.

OIL AND GAS RESOURCES

Hydrocarbon Resources

Known Occurrences and Characteristics

The Utah Division of Oil, Gas and Mining (DOGM) lists one oil and 16 hydrocarbon gas fields in Carbon and Emery

Counties (table 6). These fields are shown on plate 3 with North Spring included with Drunkards Wash field and Indian Creek included with Flat Canyon field. There are 11 active fields with 496 producing wells in Carbon County and six active fields with 155 producing wells in Emery County (table 6). Six of the fields have produced some oil (table 6). Production in Carbon County is from carbonate, sandstone, shale, and coal reservoirs that range in age from Triassic to Tertiary and occur at depths of 1,300 to 6,500 feet (400-2,000 m). Production in Emery County is from carbonate, sandstone, and shale reservoirs that range in age from Permian to Cretaceous and occur at depths of 1,500 to 7,200 feet (460-2,200 m).

Most of the hydrocarbons produced in Carbon and Emery Counties are from the Cretaceous Ferron Sandstone Member of the Mancos Shale, the Triassic Moenkopi, and the Tertiary Green River and Wasatch (Colton) Formations with minor production from the Permian Kaibab Formation (Black Box Dolomite) and Cretaceous Mesaverde Group.

Ferron reservoirs: Fields that produce from the Ferron Sandstone include Clear Creek, Ferron, Flat Canyon, Buzzard Bench, Helper, North Spring, and Drunkards Wash. The first three fields are sandstone reservoirs. Drunkards Wash, Helper, North Spring, and Buzzard Bench produce from coal beds and are discussed in the coal-bed gas section of this report. Two other fields, Marsing Wash and Service Berry, were initially designated as separate fields are now included in the Drunkards Wash field. Miller Creek field is another Ferron discovery but has never produced.

The gas in the Ferron reservoirs is thought to be self-sourced biogenic gas from coal beds, mudstone beds, or both (Walton, 1954). However, some high-gravity oil has been produced from the Ferron Sandstone Member in the southern part of the Flat Canyon field that could have been derived from the Mancos Shale west of the field or from a deeper, more mature, pre-Cretaceous source rock (Sprinkel, 1993, Sprinkel and others, 1997).

Clear Creek field: Clear Creek field production is from lenticular, fluvial sandstone interbedded with alluvial to delta-plain siltstone and shale, as well as deltaic and shoreface sandstone interbedded with marine shale in the Ferron Sandstone (Edson and others, 1954; Walton, 1954, 1963; Preston, 1961a; Tripp, 1989, 1991a, 1993a; Sprinkel, 1993). Individual producing sandstone beds are from 10 to 20 feet (3-6 m) thick, but may be stacked over a stratigraphic interval of 700 feet (210 m). The net pay thickness is approximately 200 feet (60 m) (Tripp, 1993a). The Clear Creek field is developed on a complexly faulted, doubly plunging anticline (figure 4). Traps are both structural and stratigraphic. The gas is nearly 98 percent methane with a heating value of 990 to 1,002 British thermal units per cubic foot (Btu/ft^3) (29.6-29.9 kilojoules per cubic meter [kJ/m^3]) (Edson and others, 1954). The high production rate for some wells from low-permeability sandstone suggests that fracture permeability is important.

Ferron field: Ferron field production is from lenticular, deltaic sandstone interbedded with marine shale in the Ferron Sandstone (Quigley, 1961; Tripp, 1989, 1990, 1991b, 1993b). Individual producing beds are typically 10 to 20 feet (3-6 m) thick. The Ferron field is developed on a doubly plunging anticline with two closures at the Ferron horizon (figure 5). Traps are both structural and stratigraphic. The gas is 95 percent methane with a heating value of 1,040 Btu/ft^3 (31.0 kJ/ft^3) (Quigley, 1961).

Oil has also been produced in the Ferron field from shallow-water, shelf carbonate in the underlying Permian Kaibab Formation (Black Box Dolomite). Net pay thickness (perforated interval) ranges from 16 to 50 feet (5-15 m). The trapping mechanism is structural, stratigraphic, and hydrodynamic (Tripp, 1991b). The oil was green, had 42° API gravity, and a pour point less than 5° Fahrenheit (-15° C) The associated gas (29 percent methane, about 11 percent ethane and longer chain hydrocarbons, 7 percent nitrogen, and 52 percent carbon dioxide) has a heating value of 581 Btu/ft^3 (17.3 kJ/m^3) (Moore and Sigler, 1987).

Flat Canyon field: Flat Canyon field production is from lenticular, fluvial to deltaic sandstone in the Ferron Sandstone with minor production from sandstone in the deeper Cretaceous Dakota Sandstone (Seeley, 1961; Tripp, 1993c). Individual producing beds are typically 10 to 20 feet (3-6 m) thick with a net pay interval of 100 to 200 feet (30-60 m) in the Ferron and approximately 100 feet (30 m) in the Dakota. The Flat Canyon field is on the crest and southern limb of the northeast-trending Flat Canyon anticline. The trap is both structural and stratigraphic.

The average composition of gas produced from the Ferron Sandstone at Flat Canyon field is 89 percent methane and 5 percent ethane, and about 6 percent propane and longer chain hydrocarbons with a heating value of 1,139 Btu/ft^3 (34 kJ/m^3) (Moore and Sigler, 1987). Some gas was produced at Flat Canyon field from the Dakota Sandstone that was 86 percent methane with a heating value of 1,151 Btu/ft^3 (34.4 kJ/m^3). Some 56° API gravity oil has been produced from the Ferron Sandstone (table 6).

Buzzard Bench field: The first wells drilled in the Buzzard Bench field produced from lenticular, fluvial to deltaic sandstone in the Ferron Sandstone. Since 1995 the wells have been completed in the coals of the Ferron Sandstone. Buzzard Bench field is discussed further in the coal-bed gas section of this report.

Moenkopi reservoirs: Grassy Trail Creek is the only field with significant production from the Triassic Moenkopi Formation in Carbon and Emery Counties. The Last Chance field (now shut in) tested minor amounts of gas from the Moenkopi, and a well in Buzzard Bench produced 132 barrels of oil (BO) (21 m^3) from the Moenkopi in 1982 before the area was designated as a field.

Grassy Trail Creek field: Grassy Trail Creek field production is from three zones in the middle to lower Moenkopi Formation: two zones of silty sandstone in the Torrey Member, interpreted to be tidal channels, and one zone of dolomitic sandstone in the deeper Polack Member, interpreted to be estuary fill (Peterson, 1972; Lutz and Allison, 1991; Allison and others, 1993). The producing beds are typically less than 10 to 20 feet (3-6 m) thick and the net pay thickness is from 21 to 36 feet (6.4-11.0 m) (Allison and others, 1993). Production from the Moenkopi reservoirs is stratigraphically controlled and enhanced by natural fractures and minor faulting (figure 6). Fractures are 100 to 200 feet (30-60 m) apart (Lutz and Allison, 1991). Seventy-seven short radius laterals have been drilled from 18 vertical boreholes to take advantage of the fracture permeability.

The oil is 40° API gravity with a pour point of less than 5° Fahrenheit (< -15°C) (Wenger and Morris, 1971). Asso-

Table 6. *Oil and gas fields in Carbon and Emery Counties, Utah as of June 30, 2001. Active well count and most production is from June 2001 DOGM monthly production book for individual fields. Total is from June 2001 DOGM monthly production book for individual counties. Unassigned is difference between sum of individual fields and county total. Farnham Dome, Gordon Creek, and Woodside fields (plate 3) are non-hydrocarbon gas reservoirs and are discussed later. Assignment of Drunkards Wash production and well count to either Carbon or Emery County from Staley (2001).*

CARBON COUNTY

Field Name	DOGM Number	Discovery Date	Oil (bbl)	Gas (Mcf)	Water (bbl)	Number Active Wells
Castlegate	013	1992	0	3,227,075	8,102,048	13
Clear Creek (also in Emery Co.)	010	1951	0	93,024,581	3,858	11
Drunkards Wash (also in Emery Co.)	048	1991	0	232,669,588	91,102,364	360
Dry Creek	046	1988	1,826	1,358,694	0	1
Grassy Trail Creek (also in Emery Co.)	025	1961	147	0	0	0
Helper	018	1993	0	17,647,835	5,864,106	92
Marsing Wash (now part of Drunkards Wash)	014	1983	0	Included in Drunkards Wash	Included in Drunkards Wash	Included in Drunkards Wash
Miller Creek	030	1983	0	0	0	4
Nine Mile	035	1962	0	703,349	0	1
North Spring	049	1989	0	110,253	23,525	1
Peters Point	040	1953	135,855	5,506,221	5,353	9
Prickly Pear	016	1978	0	264,219	0	1
Service Berry (now part of Drunkards Wash)	008	1983	0	Included in DrunkardsWash	Included in Drunkards Wash	Included in Drunkards Wash
Stone Cabin (also in Duchesne Co.)	045	1961	22	988,446	2	3
Unassigned			-120	-19,805,724	3,525	
TOTAL			**137,730**	**336,080,058**	**105,136,507**	**496**

EMERY COUNTY

Field Name	DOGM Number	Discovery Date	Oil (bbl)	Gas (Mcf)	Water (bbl)	Number Active Wells
Buzzard Bench	132	1984	0	7,319,317	13,787,586	52
Clear Creek (also in Carbon Co.)	010	1951	0	22,351,973	0	0
Drunkards Wash (also in Carbon Co.)	048	1991	0	4,336,485	3,528,554	57
Ferron	135	1957	38,470	11,553,006	8,163	16
Flat Canyon	011	1953	15,094	9,024,772	8,869	6
Grassy Trail Creek (also in Emery Co.)	025	1961	552,837	155,525	97,521	20
Indian Creek (production reported with Flat Canyon)	100	1981				
Last Chance	145	1935	0	750	0	4
Unassigned			509	20,315,927	5,764	
TOTAL			**606,910**	**75,057,755**	**17,436,457**	**155**

Note: Unassigned numbers for oil and water for Emery County may reflect production from wells classified as "wildcat" or possibly Carbon County oil production from Grassy Trail field. Unassigned numbers for oil and water for Carbon County may reflect production from wells classified as "wildcat" or possibly failure to assign some Grassy Trail field production to Carbon County. Unassigned numbers for gas in Carbon and Emery Counties probably reflect problems in separating Drunkards Wash production between Carbon and Emery Counties.

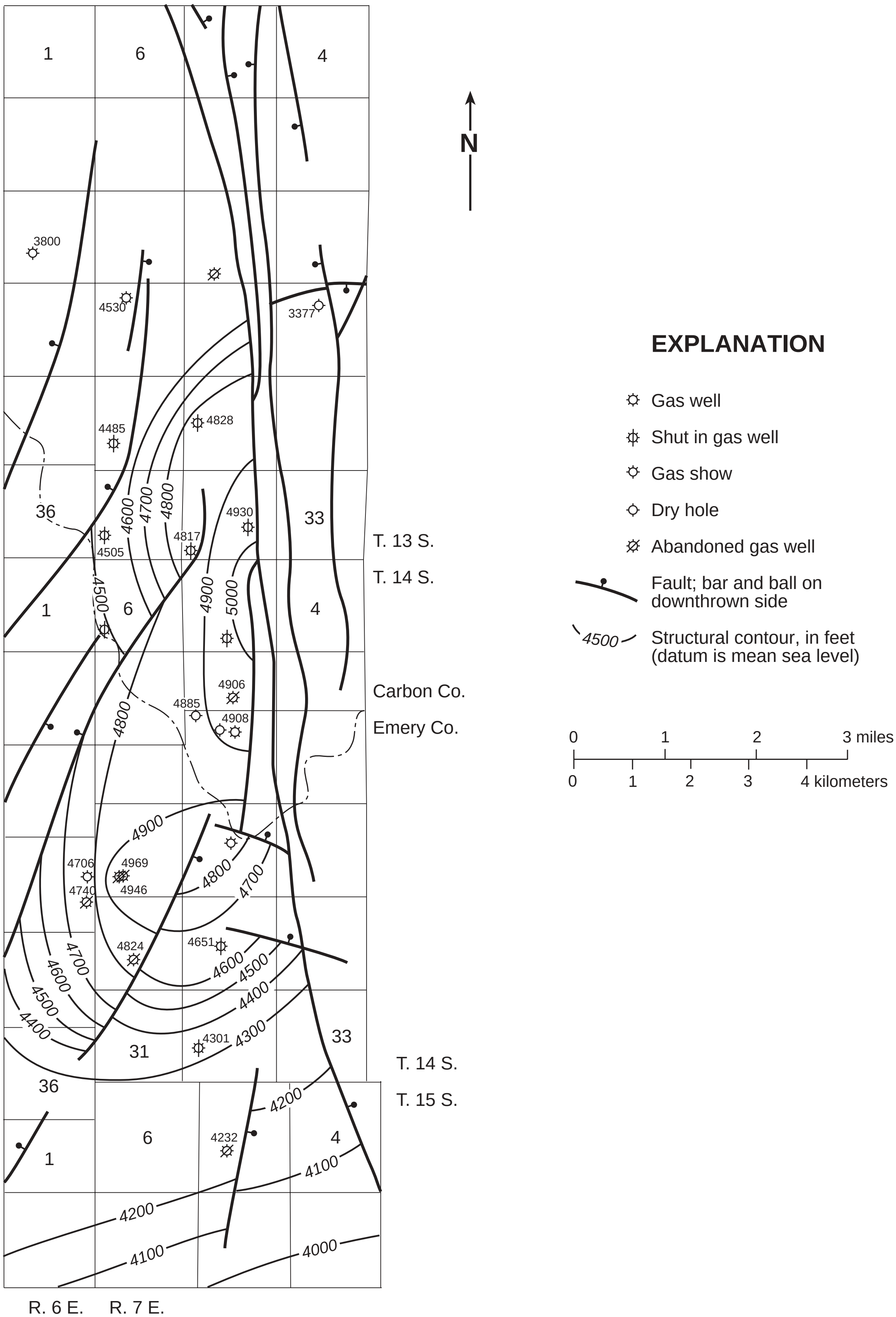


Figure 4. *Structure contours on the top of the Ferron Sandstone, Clear Creek field, Carbon and Emery Counties, Utah; contour interval 100 feet (modified from Tripp,1993a).*

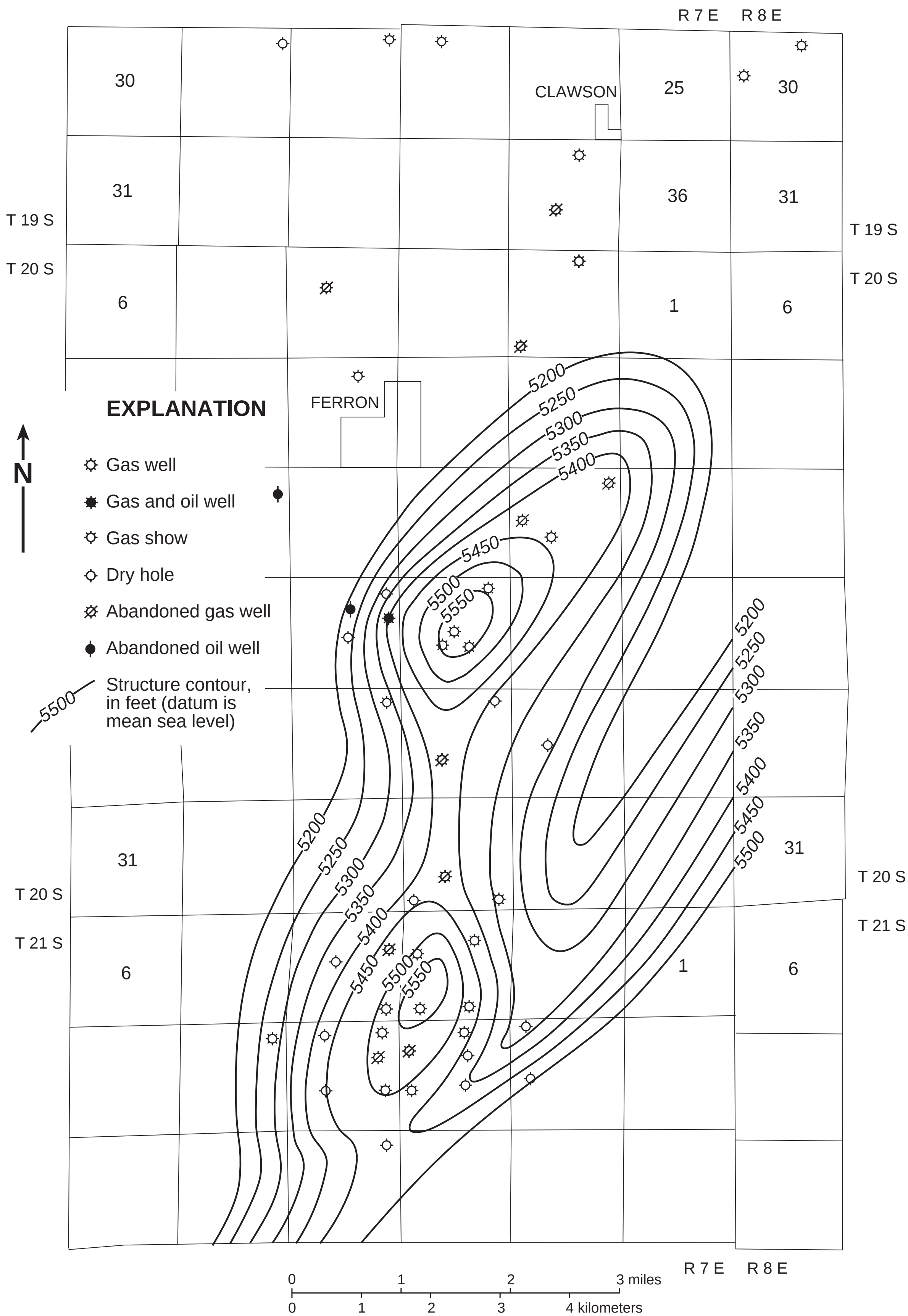


Figure 5. Structure contours on the top of the Ferron Sandstone, Ferron field, Emery County, Utah; contour interval 50 feet (modified from Tripp, 1993b).

ciated gas composition is 28 percent methane, about 8 percent ethane and longer chain hydrocarbons, 61 percent nitrogen, and 5 percent carbon dioxide; the heating value of the gas is 417 Btu/ft^3 (12.5 kJ/m^3) (Moore and Sigler, 1987).

Last Chance field: Wells in the Last Chance field are completed in fine- to medium-grained, lenticular, channel sandstone and carbonate of the middle to upper Moenkopi Formation (Jackson, 1993). Net pay thickness is from 10 to 40 feet (3-12 m) for the sandstone reservoirs and 10 to 20 feet (3-6 m) for the carbonate reservoirs. The field is located along the crest of the northwest-trending South Last Chance anticline with about 80 feet (24 m) of closure above the gas-water contact.

The gas is composed of 64 to 88 percent methane, 4 to 5 percent carbon dioxide, and 12 to 31 percent nitrogen and has a heating value of 660 to 850 Btu/ft^3 (19.8-25.4 kJ/m^3). Jackson (1993) describes the field as a "remote, under-pressured, relatively low-Btu and low-volume gas field with minimal chance of development in the foreseeable future."

Mesaverde reservoirs: Fields producing gas from the Cretaceous Mesaverde Group include Prickly Pear and Castlegate. The Prickly Pear field produces from sandstone reservoirs in the Mesaverde, but the Castlegate field produces methane from coal beds in the Blackhawk Formation of the Mesaverde Group. The characteristics of coal-bed methane fields are discussed in a subsequent section of this report.

Tertiary reservoirs: Fields with production from the Tertiary Green River and Wasatch (Colton) Formations include the Peters Point, Stone Cabin, Dry Creek and Nine Mile fields.

Peters Point field: The Peters Point field produces from thin, lenticular, fluvial to deltaic sandstone beds in both the Green River and Wasatch Formations (Hendel, 1957; Preston, 1961b). Individual producing beds are typically 20 to less than 10 feet (6 to <3 m) thick. Peters Point field is a combination structural and stratigraphic trap on the crest and flanks of the northwest-trending Jack Canyon anticline, where sandstone beds pinch out along the flanks of the anticline (figure 7).

The average composition of gas produced from the Wasatch reservoirs at Peters Point field is 93 percent methane and 5 percent ethane; the heating value of the gas is 1,079 Btu/ft^3 (32.2 kJ/m^3) (Moore and Sigler, 1987). The oil is 28° API gravity with a pour point of 80° Fahrenheit (27° C) (Picard, 1956). Nearly 0.2 billion cubic feet gas (BCFG) (5.6 million cubic meters [MMm^3]) has been produced from the Dakota Sandstone out of a single well in the Peters Point field in addition to the production from the Tertiary reservoirs.

Dry Creek, Nine Mile, and Stone Cabin fields: Dry Creek, Nine Mile, and Stone Cabin fields (Preston, 1961c; Langenwalter, 1993) are situated along the northwestern plunge of the Jack Canyon anticline and contain reservoirs and traps similar to the Peters Point field. Dry Creek, Nine Mile, and Stone Cabin production is more than 3.05 BCFG (86 MMm^3), mostly from Wasatch reservoirs. The average composition of gas produced from the Wasatch at Stone Cabin field is 86 percent methane and 6 percent ethane with the remainder consisting of nitrogen, propane, and longer chain hydrocarbons. The gas has a heating value of 1,105 Btu/ft^3 (31.2 kJ/m^3) (Moore and Sigler, 1987). These fields produce mostly gas, but minor amounts of oil (<2,000 BO [<318 m^3]) have been produced from the Wasatch at the Dry Creek field.

Past Production and Trends

Carbon County: Hydrocarbons were first discovered and produced in Carbon County from the Ferron Sandstone at the Clear Creek field. The Clear Creek field was discovered in 1951 and is the second-most productive field in the two counties behind Drunkards Wash. The first oil was discovered and produced in Carbon County from the Green River and Wasatch Formations at Peters Point field. The Peters Point field was discovered in 1951 and is the largest oil producer in Carbon County.

Carbon County has significant gas and some oil production. Nearly 340 BCFG (9,629 MMm^3) and more than 146,000 barrels of oil (BO) (23,214 m^3) have been produced in the county as of December 30, 2000 as reported by DOGM in their annual county production reports (table 7). However, cumulative production to December 30, 2000 for Carbon County as reported by DOGM in their December 2000 monthly production book was only 293 Bcf (8,298 MMm^3) and 137,648 BO (21,886 m^3), about 47 Bcf (1,331 MMm^3) lower. The differences between the two numbers according to Staley (2001) is because the pre-1985 and some later annual county production numbers were not or have not yet been corrected and amended after being published or released. The monthly production book numbers are more accurate. Annual production (2000) was more than 75 BCFG (2,122 MMm^3) (table 7). The annual value (2000) of the hydrocarbon production is more than 248 million dollars (table 7). The annual oil and gas production and number of active wells for Carbon County are shown in figure 8 and the total value and well-head price of oil and gas in Carbon County are shown in figure 9.

Most of the gas production in Carbon County has been from the Clear Creek, Helper, and Drunkards Wash fields. The Clear Creek field is nearing depletion, however, and the majority of the gas produced in Carbon County now comes from the Drunkards Wash and Helper fields (refer to the coal-bed methane discussion) which have produced over 250 BCFG (7,075 MMm^3) from coal beds in the Ferron Sandstone as of June 30, 2001. Most of the oil production in Carbon County is from Peters Point field where over 135,000 BO (21,465 m^3) has been produced from the Tertiary reservoirs as of June 30, 2001.

Emery County: Hydrocarbons were first discovered in Emery County with the completion of a gas well in Last Chance field in 1935 (Hager, 1954; Shannon, 1961; Riggs, 1983; Jackson, 1993). The only production from Last Chance field is 750 thousand cubic feet of gas (MCFG)(21,225 m^3) gauged during testing of the Moenkopi Formation. There is no pipeline in the area, and the field has never been commercially produced. The first commercial production of hydrocarbons was from the Ferron Sandstone reservoir at Clear Creek field which is in both Carbon and Emery Counties. The first oil was discovered at the Ferron field in 1957, but the first production was from the Grassy Trail Creek field. More oil has been produced from Grassy Trail Creek than any other field in Carbon or Emery County.

Emery County has significant gas production and some oil production. More than 51 BCFG (1,443 MMm^3) and over 605,000 BO (96,200 m^3) have been produced in the county as of December 30, 2000 as reported by DOGM in their annual county production reports (table 8). However,

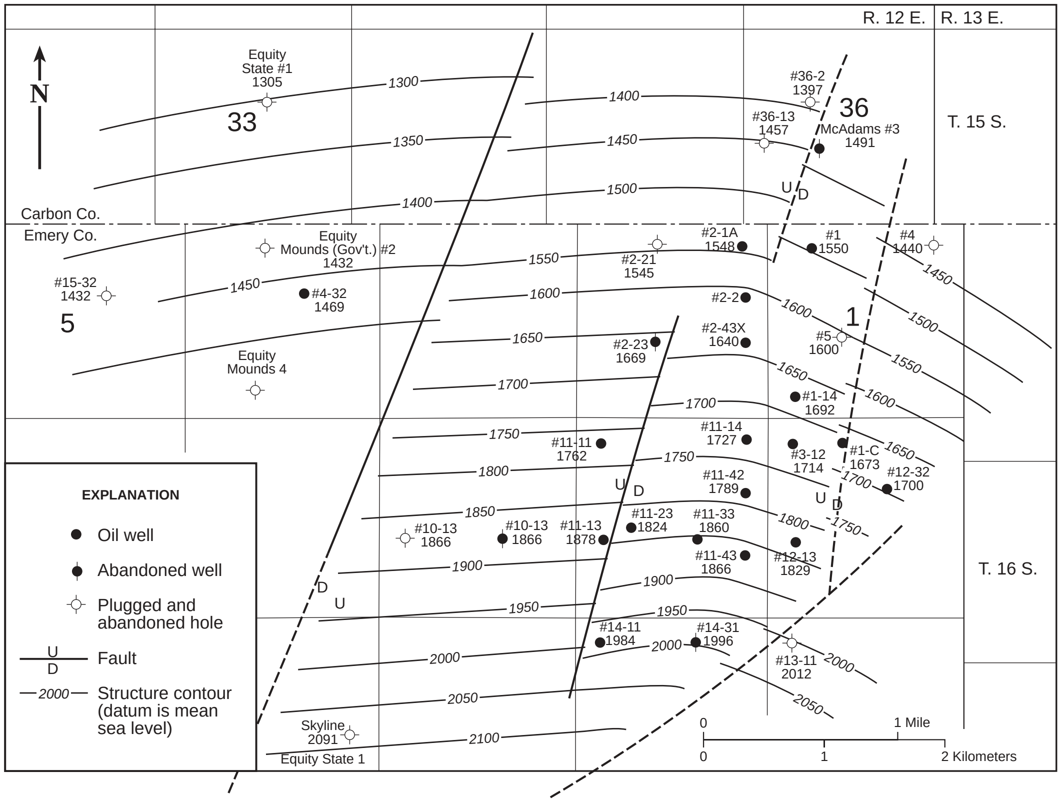


Figure 6. *Structure contours on the top of the A zone, Torrey Member of the Moenkopi Formation, Grassy Trail Creek field, Carbon and Emery Counties, Utah; contour interval 50 feet, faults are inferred (from Lutz and Allison, 1991).*

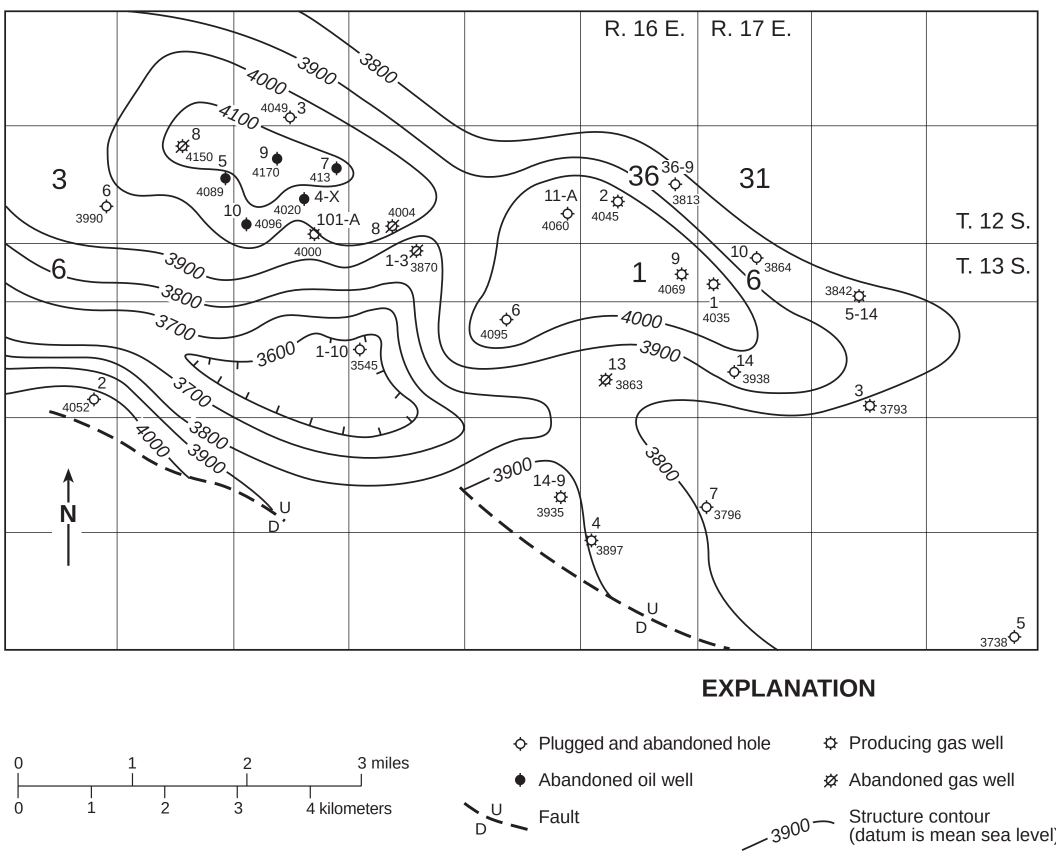


Figure 7. *Structure contours on the top of the Wasatch Formation, Peters Point field, Carbon County, Utah; contour interval 100 feet, faults from Weiss and others (1990).*

Table 7. *Annual and cumulative oil and gas production, Carbon County, Utah. Total value based on average (statewide) wellhead price multiplied by the annual production. Production given in barrels (bbls) and thousand cubic feet (Mcf). Source: Utah Division of Oil, Gas and Mining Annual Production by County (through 2000).*

Year	Annual Production		Active Wells	Wellhead Price		Total Annual Value	Cumulative Production	
	Oil (bbl)	Gas (Mcf)		Oil (per bbl)	Gas (per Mcf)		Oil (bbl)	Gas (Mcf)
1960	0	12,222,228	15	$2.61	$0.17	$2,077,779	0	77,317,765
1961	0	9,413,620	15	$2.69	$0.16	$1,506,179	0	86,731,385
1962	3,724	7,194,141	17	$2.56	$0.18	$1,304,479	3,724	93,925,526
1963	5,646	7,914,346	17	$2.64	$0.16	$1,281,201	9,370	101,839,872
1964	3,897	5,637,377	17	$2.63	$0.14	$799,482	13,267	107,477,249
1965	1,997	3,754,411	25	$2.26	$0.14	$530,131	15,264	111,231,660
1966	2,357	2,672,601	27	$2.64	$0.13	$353,661	17,621	113,904,261
1967	0	1,831,930	26	$2.63	$0.15	$274,790	17,621	115,736,191
1968	0	1,670,221	26	$2.71	$0.15	$250,533	17,621	117,406,412
1969	0	1,119,204	24	$2.80	$0.15	$167,881	17,621	118,525,616
1970	0	882,956	24	$2.81	$0.16	$141,273	17,621	119,408,572
1971	0	434,212	23	$3.04	$0.17	$73,816	17,621	119,842,784
1972	0	366,825	21	$2.94	$0.18	$66,029	17,621	120,209,609
1973	0	260,553	26	$3.59	$0.19	$49,505	17,621	120,470,162
1974	1,272	191,408	28	$7.39	$0.21	$49,596	18,893	120,661,570
1975	17,237	180,007	26	$8.06	$0.24	$182,132	36,130	120,841,577
1976	17,493	171,004	33	$8.80	$0.51	$241,150	53,623	121,012,581
1977	20,161	634,983	39	$8.96	$0.75	$656,880	73,784	121,647,564
1979	14,981	479,446	40	$11.41	$1.14	$717,502	112,321	122,844,752
1980	12,806	524,813	49	$19.79	$1.86	$1,229,583	125,127	123,369,565
1981	8,833	359,561	46	$34.14	$1.87	$973,938	133,960	123,729,126
1982	6,547	542,906	46	$30.50	$2.47	$1,540,661	140,507	124,272,032
1983	3,940	403,622	12	$28.12	$2.56	$1,144,065	144,447	124,675,654
1984	0	214,624	34	$27.21	$3.16	$678,212	144,447	124,890,278
1985	0	227,256	40	$23.98	$3.23	$734,037	144,447	125,117,534
1986	0	92,877	40	$13.33	$2.90	$269,343	144,447	125,210,411
1987	0	39,589	42	$17.22	$1.82	$72,052	144,447	125,250,000
1988	639	315,639	47	$14.24	$1.70	$545,686	145,086	125,565,639
1989	527	182,210	44	$18.63	$1.58	$297,710	145,613	125,747,849
1990	155	141,539	48	$22.61	$1.64	$235,629	145,768	125,889,388
1991	28	236,419	48	$19.99	$1.56	$369,373	145,796	126,125,807
1992	53	328,039	59	$19.39	$1.62	$532,451	145,849	126,453,846
1993	122	1,060,347	103	$17.45	$1.85	$1,963,771	145,971	127,514,193
1994	164	4,933,449	147	$16.38	$1.54	$7,600,198	146,135	132,447,642
1995	27	12,379,993	161	$17.53	$1.35	$16,713,464	146,162	144,827,635
1996	0	17,124314	166	$21.54	$1.42	$24,316,526	146,162	161,951,949
1997	0	22,760,216	204	$18.56	$1.86	$42,334,002	146,162	184,658,165
1998	0	31,903,361	257	$12.54	$1.73	$55,192,815	146,162	216,615,526
1999	527	50,175,216	357	$17.69	$1.93	$96,847,490	146,689	266,790,742
2000	211	75,586,077	455	$28.51	$3.42	$248,244,380	146,900	339,376,819

Does not include CO_2 production from Farnham Dome field.

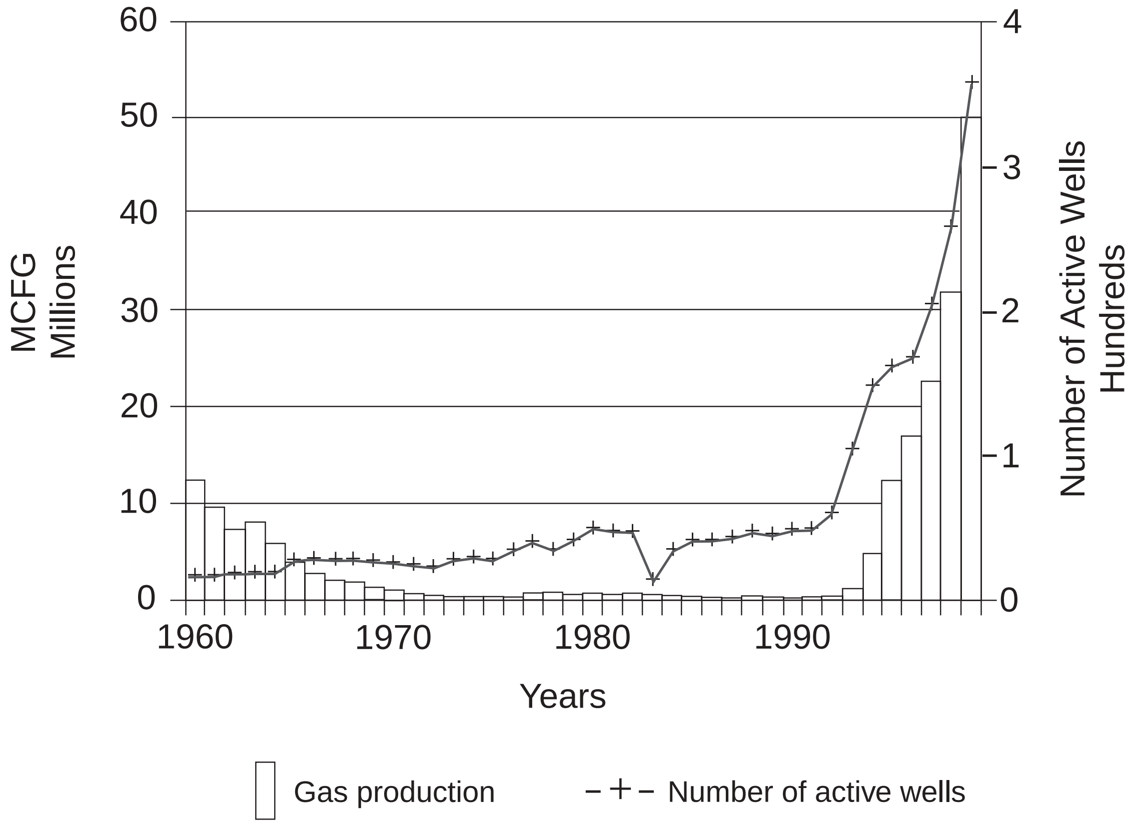


Figure 8. *Annual gas production and number of active wells in Carbon County, Utah from 1960 to 1999, annual oil production volumes too small to show. Data source is Utah Division of Oil, Gas and Mining.*

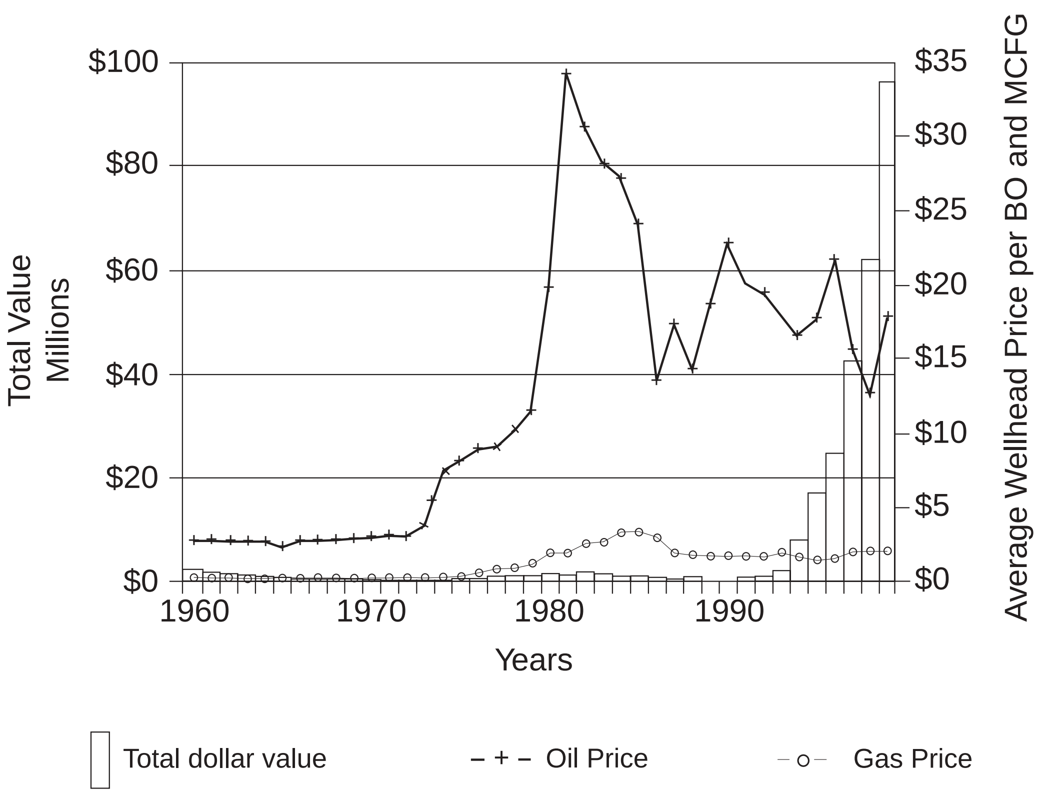


Figure 9. *Total value and wellhead price of oil and gas production in Carbon County, Utah from 1960 to 1999, annual wellhead price is a statewide average calculated by the Utah Energy Office. Total value is the annual wellhead price times the annual volume produced as reported by the Utah Division of Oil, Gas and Mining.*

cumulative production to December 30, 2000 for Emery County as reported by DOGM in their December 2000 monthly production book was 71.5 BCFG (2,025 MMm^3) and 604,177 BO (96,064m^3), nearly 20 BCFG (566 MMm^3) higher. The explanation for the differences is because the pre-1985 and some later annual county production numbers were not or have not yet been corrected and amended after being published or released. The monthly production book numbers are more accurate. Annual production (2000) is more than 4.0 BCFG (113 MMm^3) and over 3,200 BO (509 m^3) (table 8). The annual value (2000) of the oil and gas produced is nearly 14 million dollars (table 8). The annual oil and gas production and number of active wells for Emery County are shown in figure 10 and the total value and wellhead price of oil and gas in Emery County in figure 11.

Most conventional gas production is from the Ferron (Quigley, 1961; Tripp, 1989, 1990, 1991b, 1993b) and Flat Canyon (Seeley, 1961; Tripp, 1993c) gas fields which have produced more than 11 and 9 BCFG (311 and 255 MMm^3) (DOGM June 2001 monthly production book), respectively, from the Ferron Sandstone. Coal-bed methane production is from the Emery County portion of the Drunkards Wash field (4.3 BCFG [122 MMm^3]) and the Buzzard Bench field (7.3 BCFG [206 MMm^3]) (DOGM June 2001 monthly production book). Most oil production is from the Grassy Trail Creek field which has produced more than 500,000 BO (79,500 m^3) from the Moenkopi Formation (DOGM May 2001 monthly production report).

Current Production and Exploration Activity

The majority of the gas currently produced in Carbon and Emery Counties is from sandstone and coal beds in the Ferron Sandstone. Oil production in Carbon County is from the Green River and Wasatch Formations. Oil production in Emery County is from the Moenkopi Formation. Gas production had been declining in both counties but dramatically increased in Carbon County beginning in 1993 (table 7) with the exploitation of coal-bed methane from the Ferron Sandstone and Blackhawk Formation. The number of wells and resulting success have increased during this same period (table 9). Oil production continues to decline in Carbon and Emery Counties. Since 1980, all new field discoveries in the two counties have been gas producers (table 10).

Since 1989, only a few miles of seismic lines have been permitted in Carbon and Emery Counties, indicating that structural traps have not been a significant exploration target in this area. Few wells had been permitted until drilling for coal-bed methane began (figure 12). Drilling for oil and gas (other than coal-bed methane) will likely continue to be minimal unless a new play is discovered.

Potential for Additional Discoveries and/or Development

Carbon and Emery Counties have produced oil and gas from both shallow and deep reservoirs, ranging in age from Tertiary to Permian. There are numerous plays that are productive or have the potential to be productive (table 11, plate 4).

Ferron play: Sandstone and coal beds in the Cretaceous Ferron Sandstone contain the largest number of fields and produce the majority of the gas in the two-county area. Individual beds in the Ferron are typically 10 to 20 feet (3-6 m) thick and are at depths of 1,500 to 6,500 feet (460-2,000 m). Early discoveries were structural traps with gas contained in the sandstone beds. More recent discoveries are stratigraphic traps with gas entrapped in the coal beds. The majority of new field discoveries in Carbon and Emery Counties will probably continue to be in Ferron reservoirs. Exploration companies initially explored by mapping surface structures. Today, the most common exploration method is subsurface mapping of coal-bed and sandstone thicknesses and structure. The Ferron play area covers more than 1,800 square miles (4,600 km^2) in western Emery County, and western and northeastern Carbon County. In western Emery County, the play is limited on the east by the outcrop of the Ferron. In eastern Carbon County the play is limited on the south by the depositional pinchout of porous sandstone and coal beds.

Tertiary play: Oil and gas are produced from the Tertiary Green River and Wasatch (Colton) Formations in several fields in the Roan Cliffs area of eastern Carbon County. The Tertiary reservoirs typically consist of several sandstone beds usually from 20 feet to less than 10 feet (6-3 m) thick and are at depths of 1,300 to 5,000 feet (400-1,500 m). Production from Tertiary reservoirs in Carbon County is from combination traps where sandstone beds pinch out along a series of structural closures on the Jack Canyon anticline from Peters Point to Stone Cabin. The most common exploration method for Tertiary reservoirs in this area is subsurface thickness and structure mapping of individual beds to identify potential hydrocarbon traps. The Tertiary play area covers nearly 800 square miles (2,000 km^2) in eastern Carbon County and a small portion of northeastern Emery County. The play is limited to the south due to outcrop of the Green River and Wasatch (Colton) Formations along the Book Cliffs.

Mesaverde play: Minor volumes of gas are produced from sandstone beds and an increasing amount comes from coal beds in the Cretaceous Blackhawk Formation of the Mesaverde Group. Mesaverde reservoirs consist of several sandstone and coal beds typically less than 10 feet to 20 feet (3-6 m) thick. Producing reservoirs are at depths of 4,000 to 6,500 feet (1,200-2,000 m). Sandstone beds in the Mesaverde have produced very small volumes of gas from wells drilled along the Jack Canyon anticline. Gas production from coal beds in the Blackhawk is from the Castlegate field. The most common exploration method for Mesaverde reservoirs in this area is subsurface thickness and structure mapping of individual sandstone and coal beds to identify potential hydrocarbon traps. The play area covers more than 1,300 square miles (3,200 km^2) in northern and eastern Carbon and northeastern Emery Counties. The play is limited to the south due to outcrop of the Mesaverde along the Book Cliffs in central and eastern Carbon and Emery Counties and low methane content in coals in the Wasatch Plateau in western Carbon and Emery Counties.

Moenkopi play: Oil is produced from the Triassic Moenkopi Formation at Grassy Trail Creek field, the largest oil field in Emery County. The Moenkopi reservoirs consist of shallow-marine sandstone deposits, probably tidal channels and estuary fill, (Lutz and Allison, 1991). The sandstone beds are typically less than 10 feet to 20 feet (3-6 m) thick and occur at a depth of approximately 3,900 feet (1,200 m). Grassy Trail Creek is the only field currently producing from the Moenkopi, but drilling oil shows, seeps, and tar sands have been reported throughout the region, and 132 BO (21 m^3) was produced from the Buzzard Bench field during

Table 8. *Annual and cumulative oil and gas production, Emery County, Utah. Total value based on average (statewide) wellhead price multiplied by the annual production. Production given in barrels (bbls) and thousand cubic feet (Mcf). Source: Utah Division of Oil, Gas and Mining Annual Production by County (through 2000).*

Year	**Annual Production**		**Active Wells**	**Wellhead Price**		**Total Annual Value**	**Cumulative Production**	
	Oil (bbl)	**Gas (Mcf)**		**Oil per (bbl)**	**Gas (per Mcf)**		**Oil (bbl)**	**Gas (Mcf)**
1960	0	1,642,464	3	$2.61	$0.17	$279,219	11,077	22,681,686
1961	0	103,084	11	$2.69	$0.16	$16,493	11,077	22,784,770
1962	32,716	77,897	11	$2.56	$0.18	$97,774	43,793	22,862,667
1963	20,956	101,497	11	$2.64	$0.16	$71,563	64,749	22,964,164
1964	22,855	227,152	11	$2.63	$0.14	$91,910	87,604	23,191,316
1965	23,755	1,175,683	13	$2.26	$0.14	$218,282	111,359	24,366,999
1966	16,149	1,342,965	27	$2.64	$0.13	$217,219	127,508	25,709,964
1967	11,171	1,135,400	32	$2.63	$0.15	$199,690	138,679	26,845,364
1968	8,722	723,186	23	$2.71	$0.15	$132,115	147,401	27,568,550
1969	6,311	641,854	27	$2.80	$0.15	$113,949	153,712	28,210,404
1970	3,937	949,793	22	$2.81	$0.16	$163,030	157,649	29,160,197
1971	4,655	527,689	23	$3.04	$0.17	$103,858	162,304	29,687,886
1972	3,453	511,483	17	$2.94	$0.18	$102,219	165,757	30,199,369
1973	1,261	451,514	17	$3.59	$0.19	$90,315	167,018	30,650,883
1974	488	406,627	16	$7.39	$0.21	$88,998	167,506	31,057,510
1975	291	335,487	16	$8.06	$0.24	$82,862	167,797	31,392,997
1976	0	264,397	15	$8.80	$0.51	$134,842	167,797	31,657,394
1977	336	265,542	16	$8.96	$0.75	$202,167	168,133	31,922,936
1978	0	161,089	16	$9.98	$0.83	$133,704	168,133	32,084,025
1979	1,225	141,784	49	$11.41	$1.14	$175,611	169,358	32,225,809
1980	2,265	137,399	49	$19.79	$1.86	$300,386	171,623	32,363,208
1981	2,707	105,744	20	$34.14	$1.87	$290,158	174,330	32,468,952
1982	27,847	114,753	64	$30.50	$2.47	$1,132,773	202,177	32,583,705
1983	132,420	108,824	15	$28.12	$2.56	$4,002,240	334,597	32,692,529
1984	61,311	256,924	47	$27.21	$3.16	$2,480,152	395,908	32,949,453
1985	54,024	927,210	49	$23.98	$3.23	$4,290,384	449,932	33,876,663
1986	26,884	781,747	51	$13.33	$2.90	$2,625,430	476,816	34,658,410
1987	22,085	286,518	51	$17.22	$1.82	$901,766	498,901	34,944,928
1988	17,168	504,789	76	$14.24	$1.70	$1,102,614	516,069	35,449,717
1989	12,937	636,862	72	$18.63	$1.58	$1,247,258	529,006	36,086,579
1990	11,441	777,013	69	$22.61	$1.64	$1,532,982	540,447	36,863,592
1991	11,889	1,438,400	67	$19.99	$1.56	$2,481,565	552,336	38,301,992
1992	11,551	1,256,481	68	$19.39	$1.62	$2,259,473	563,887	39,558,473
1993	11,429	1,203,269	68	$17.45	$1.85	$2,425,484	575,316	40,761,742
1994	8,623	873,199	65	$16.38	$1.54	$1,485,971	583,939	41,634,941
1995	5,744	703,166	69	$17.53	$1.35	$1,049,966	589,683	42,338,107
1996	4,771	778,051	80	$21.54	$1.42	$1,207,599	594,454	43,116,158
1997	3,354	926,911	103	$18.56	$1.86	$1,786,304	597,808	44,043,069
1998	2,921	1,345,422	110	$12.54	$1.73	$2,364,208	600,727	45,388,491
1999	1,649	2,317,596	121	$17.69	$1.93	$4,502,131	602,376	47,706,087
2000	3,279	4,042,810	145	$28.51	$3.42	$13,919,894	605,655	51,748,897

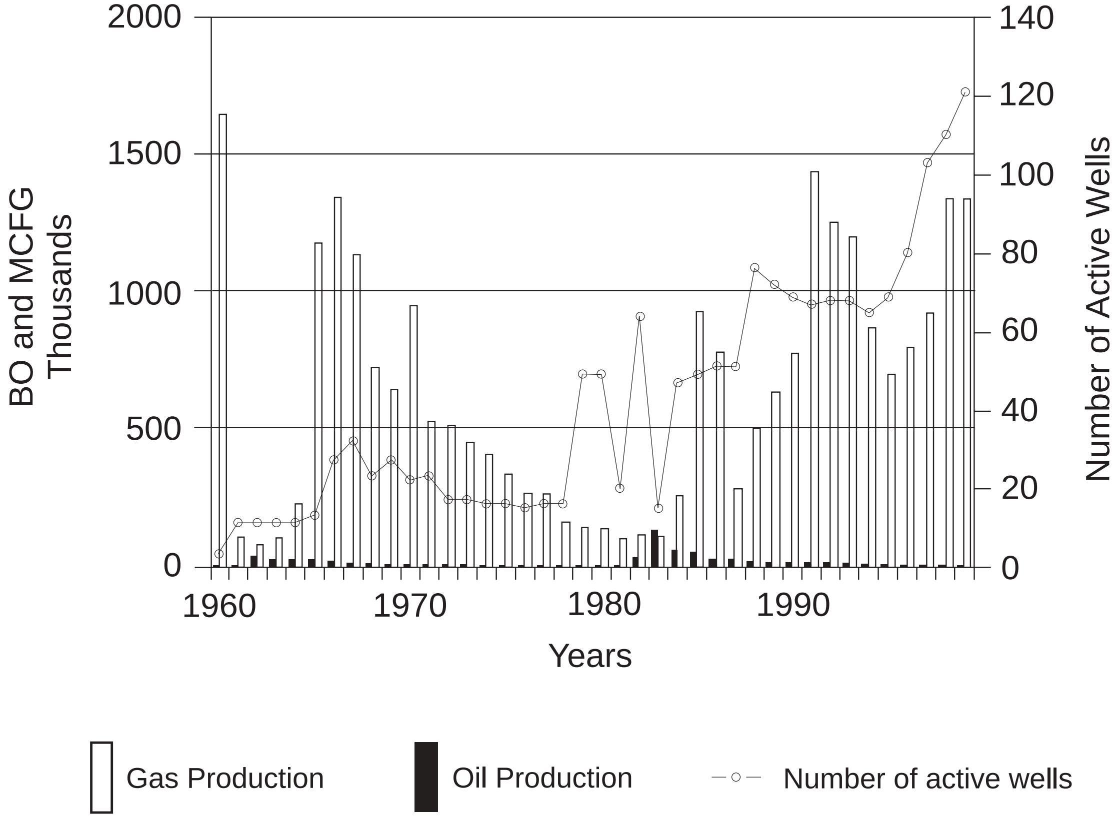


Figure 10. *Annual oil and gas production and number of active wells in Emery County, Utah from 1960 to 1999. Data source is Utah Division of Oil, Gas and Mining.*

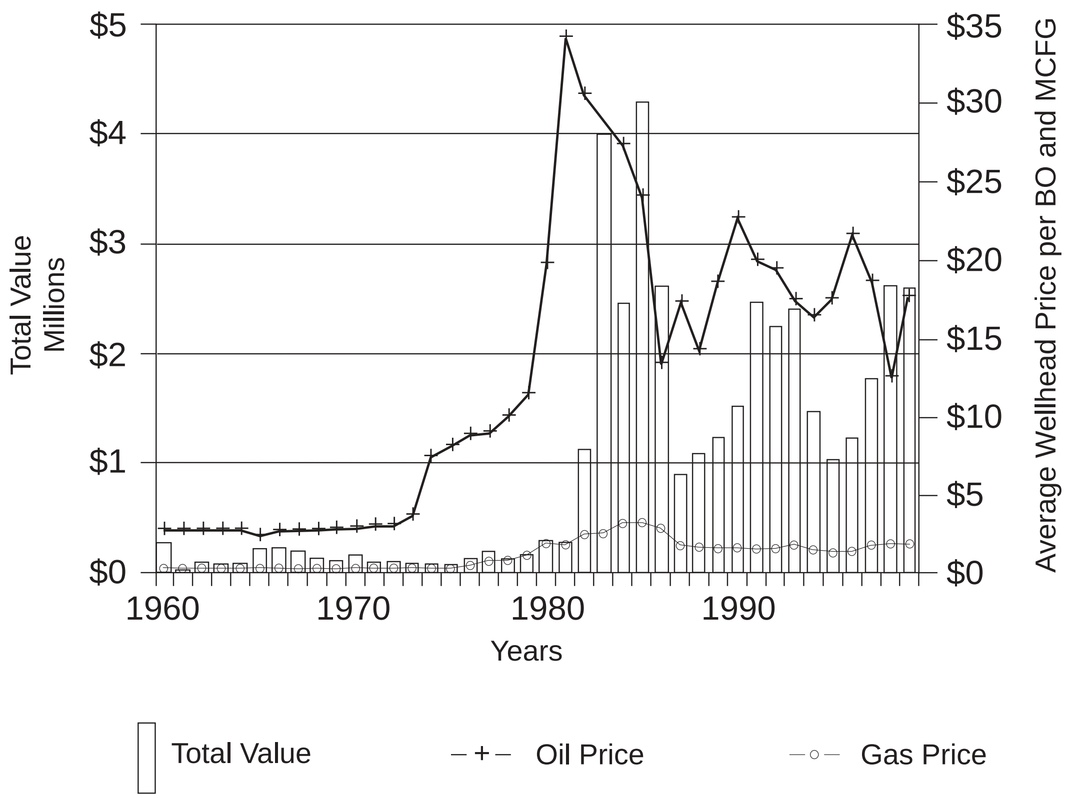


Figure 11. *Total value and wellhead price of oil and gas production in Emery County, Utah from 1960 to 1999, annual wellhead price is a statewide average calculated by the Utah Energy Office. Total value is the annual wellhead price times the annual volume produced as reported by the Utah Division of Oil, Gas and Mining.*

Table 9. Completions by well type during 1988-1998, Carbon and Emery Counties, Utah. Source: Utah Division of Oil, Gas and Mining.

Type of Completion	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Oil wells	0	0	0	0	0	0	0	0	0	0	0
Gas wells	1	1	5	0	13	45	42	21	20	59	84
Service wells	0	0	0	0	0	0	1	0	3	4	0
Temporarily abandoned	1	0	0	0	0	0	0	0	0	0	0
Plugged and abandoned	1	4	1	1	1	3	1	3	2	2	0
Stratigraphic tests	0	0	0	0	5	0	4	0	0	0	0
Total Wells	3	5	6	1	19	48	48	24	25	65	84
Success Ratio (excluding stratigraphic tests)	33%	20%	83%	0%	93%	94%	98%	88%	92%	97%	100%
Average Depth Drilled (ft)	3,808	3,162	5,267	1,932	2,591	3,539	2,769	2,189	4,340	3,270	3,126

Table 10. New field discoveries completed during 1980-1999, Carbon and Emery Counties, Utah. Source: Utah Division of Oil, Gas and Mining.

Location of Discovery Well	Field Designation	Discovery Date	Productive Zone (ft)	Initial Potential
34 T15S R9E	Marsing Wash	1983	Ferron not reported	not reported
16 T15S R9E	Service Berry	1983	Ferron 2,576-2,680	440 MCFG
36 T18S R7E	Buzzard Bench	1983	Ferron 1,951-1,989	44 MCFG
27 T12S R15E	Dry Creek	1988	Wasatch 5,004-5,026	3,888 MCFG 16 BC
10 T15S R8E	North Spring	1988	Ferron 3,790-3,848	1,000 MCFG 0 BW
25 T14S R9E	Drunkards Wash	1991	Ferron 1,592-1,690	48 MCFG 78 BW
11 T12S R10E	Castlegate	1992	Blackhawk 4,210-4,482	0 MCFG 686 BW
23 T13S R10E	Helper	1994	Ferron not reported	234 MCFG 56 BW

MCFG - Thousand cubic feet of gas
BC- Barrels condensate
BW- Barrels water

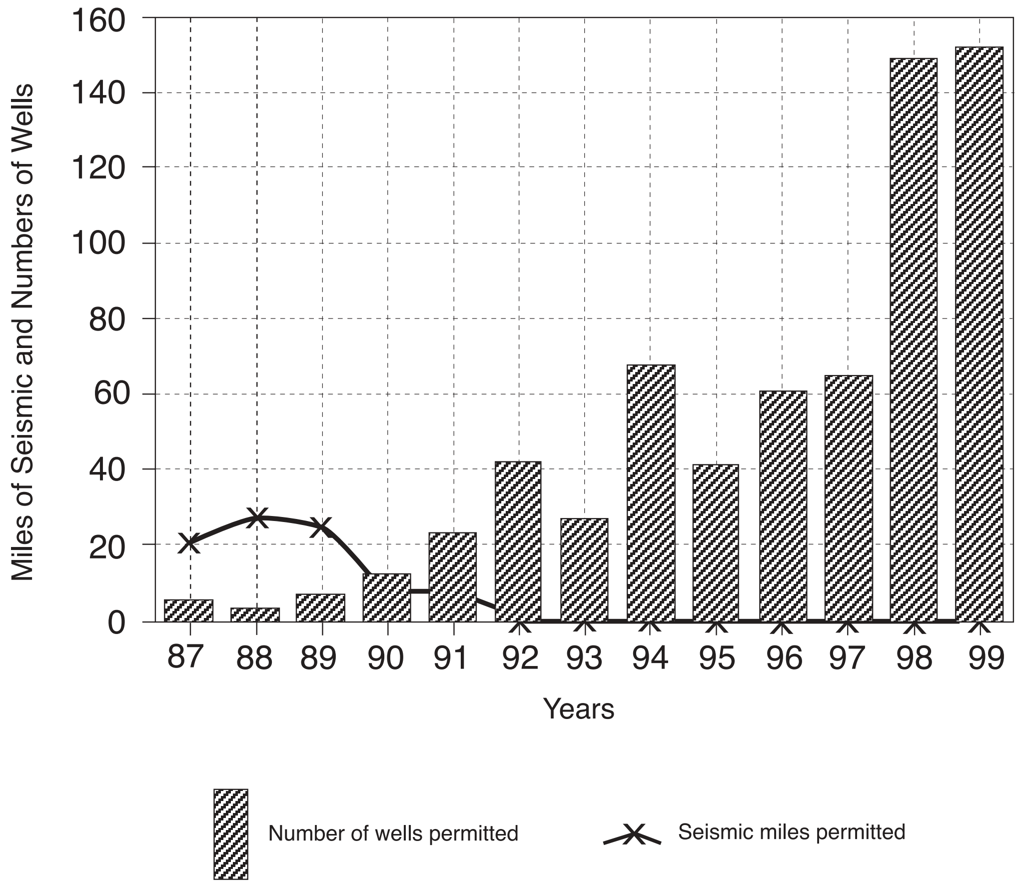


Figure 12. *Miles of seismic and number of wells permitted in Carbon and Emery Counties, Utah. Data source is Utah Division of Oil, Gas and Mining.*

Table 11. *Primary oil and gas plays in Carbon and Emery Counties, Utah. Plays are listed from most likely to least likely to result in new field discoveries.*

Play Name	Reservoir(s)	Trap Type	Location
Ferron	Ferron Sandstone sandstone and coal beds	Structural and stratigraphic	West Emery and Carbon, and northeast Carbon
Tertiary	Green River and Wasatch (Colton) Formations	Combination	East Carbon and northeast Emery
Mesaverde	Mesaverde Group sandstone and coal beds	Combination	North Carbon and northeast Emery
Moenkopi	Moenkopi Formation	Stratigraphic	Area-wide excluding San Rafael uplift[1]
Kaibab	Kaibab Formation (Black Box Dolomite)	Structural and possibly Stratigraphic	Area-wide excluding San Rafael uplift[1]
Dakota, Cedar Mountain, and Morrison	Dakota, Cedar Mountain, and Morrison Formations	Combination	Carbon and northeast, northwest, and west-central Emery
Paradox	Paradox Formation	Stratigraphic	East Emery
Leadville	Leadville (Redwall) Limestone	Structural	Area-wide
Entrada	Entrada Sandstone	Structural	East Carbon and Emery

[1]San Rafael uplift for this table is defined as the area of the uplift where the Moenkopi or older formations are exposed.

1982. The most common exploration method for Moenkopi reservoirs in this area is subsurface thickness and structure mapping of depositional facies and individual beds to identify potential hydrocarbon traps. The play area covers all of Carbon and Emery Counties except the portion of the San Rafael Swell where Moenkopi and older rocks are exposed.

Kaibab play: More than 38,000 BO was produced from the Permian Kaibab Formation (Black Box Dolomite) at Ferron field. The Kaibab reservoir consists of dolomitic limestone deposited in a shallow-water shelf environment (Kiser, 1976). Production from the Kaibab is believed to be structural, but oil shows and subsurface mapping indicate a potential for stratigraphic and hydrodynamic traps as well (Goolsby and others, 1988; Tripp, 1993d). The most common exploration method for Kaibab reservoirs in this area is subsurface thickness and structure mapping of depositional facies and porosity trends, and determining ground-water flow patterns to identify potential hydrocarbon traps. The play covers all of Carbon and Emery Counties excluding the portion of the San Rafael uplift defined by the outcrop of Moenkopi and older rocks.

Dakota, Cedar Mountain, and Morrison play: The Cretaceous Dakota, Cedar Mountain, and Jurassic Morrison Formations are important producing reservoirs in Grand County (Noe, 1993). The Dakota, Cedar Mountain, and Morrison play has not been a major producer in Carbon or Emery County, even though it has gas shows throughout the region, and some gas was produced from the Dakota at Flat Canyon field. Two wells were completed as Dakota-Cedar Mountain producers along the Range Creek anticline (sections 6 and 8, T. 18 S., R. 16 E.) during the early 1980s. But due to the rugged terrain, remoteness of the area, and the lack of a gas pipeline nearby, the discovery was never exploited. Many of the anticlines, such as Clear Creek and Ferron, have reservoir-quality sandstone beds in the Dakota, Cedar Mountain, and Morrison but are not productive. Thermal maturity of potential source rock may be a major problem with the play in Carbon and Emery Counties (Sprinkel, 1993). The Dakota, Cedar Mountain, and Morrison reservoirs are fluvial sandstone deposits typically less than 10 feet to 40 feet (3-12 m) thick that occur at a depth of 7,000 feet (2,100 m). Production from the Dakota, Cedar Mountain, and Morrison reservoirs is from combination traps consisting of multiple, lenticular channel deposits across anticlinal folds. The most common exploration method for Dakota, Cedar Mountain, and Morrison reservoirs in this area is subsurface thickness and structure mapping of individual beds to identify potential hydrocarbon traps. The play covers more than 2,500 square miles (6,500 km^2) in nearly all of Carbon County and northeastern and northwestern Emery County. The play is limited to the area underlain by the Dakota, Cedar Mountain, and Morrison Formations.

Paradox play: The Pennsylvanian Paradox Formation is productive in Grand and San Juan Counties but is not productive in Carbon or Emery County. The Paradox reservoirs consist of carbonate algal mounds, grainstone bank deposits, and fractured shale (Cane Creek shale for example). Individual reservoirs typically are less than 10 feet to more than 100 feet (3-30 m) thick and may be found at depths from 5,000 to 9,000 feet (1,500-2,700 m) (Morgan and Chidsey, 1991). Production from the Paradox is commonly stratigraphically controlled. The most common exploration method for Paradox reservoirs in this area is subsurface thickness mapping of depositional facies and individual beds to identify potential hydrocarbon traps. The play covers a little more than 500 square miles (1,300 km^2) in eastern Emery County. The play is limited by the original depositional extent of the Paradox Formation.

Leadville play: The Mississippian Leadville (Redwall) Limestone is productive in Grand and San Juan Counties (Morgan, 1993a, 1994) but is not productive in Carbon or Emery County. The Leadville reservoir varies from limestone to dolomitic limestone to dolomite. It ranges in thickness from less than 10 feet to more than 1,000 feet (3-300 m). Production from the Leadville is structurally controlled. Unfortunately, the known structures in Carbon and Emery Counties have been tested and the Leadville was found to be nonproductive. A better understanding of source and migration of hydrocarbons may lead to less obvious but productive structures. The most common exploration method for Mississippian reservoirs in this area is subsurface structure mapping to identify potential hydrocarbon traps. The play covers all of Carbon and Emery Counties.

Entrada play: The Jurassic Entrada Sandstone is productive in Grand County (Morgan, 1993b) but is not productive in Carbon or Emery County. The Entrada is an eolian sandstone that ranges in thickness from less than 10 feet to more than 450 feet (3-140 m). Production from the Entrada is structurally controlled. The most common exploration method for Entrada reservoirs in this area is subsurface structure mapping to identify potential hydrocarbon traps. The play area covers approximately 300 square miles (800 km^2) in eastern Carbon and northeastern Emery Counties. The play is limited to the west by facies change from porous dunal, eolian sandstone to intertidal and shoreline siltstone and shale deposits of the Arapien Shale.

Carbon Dioxide and Helium Resources

Known Occurrences and Characteristics

Carbon dioxide (CO_2) was produced at Farnham Dome field from the Jurassic Navajo Sandstone from 1931 through 1979 (Morgan and Chidsey, 1991). In addition, carbon dioxide-rich gas (greater than 50 percent CO_2) has been tested from the Jurassic Navajo, Triassic Moenkopi, and Permian Kaibab (Black Box Dolomite) and White Rim Formations (Chidsey and Morgan, 1993; plate 3). Most of the CO_2-rich gas in Emery County contains a high percentage of nitrogen (N_2) except at Farnham Dome and Gordon Creek fields.

Helium-rich gas (1 percent or more He) has been tested from the Triassic Moenkopi, Permian Kaibab (Black Box) and White Rim, and Devonian Elbert Formations (Chidsey and Morgan, 1993). Helium-rich gas in Carbon and Emery Counties is associated with CO_2 and N_2.

Navajo reservoirs: Carbon dioxide-rich gas (99 percent CO_2) was produced at Farnham Dome field from the Jurassic Navajo Sandstone. Farnham Dome is a doubly-plunging, north-south-trending anticline with more than 300 feet (90 m) of closure at the Navajo horizon. The Navajo is 270 to 330 feet (80-100 m) thick at Farnham Dome and represents an eolian depositional environment.

Moenkopi reservoirs: Tests of CO_2- and/or He-rich gas from the Triassic Moenkopi Formation have been reported from Gordon Creek field (99 percent CO_2) and Sunnyside unit (1.2 percent He).

Gordon Creek field is a doubly plunging, northeast-southwest-trending anticline with 500 feet (150 m) of closure on the base of the Cretaceous Emery Sandstone Member of the Mancos Shale which is exposed at the surface (Peterson, 1961). A test of the Sinbad Limestone Member of the Moenkopi Formation gauged a flow of 8,500 thousand cubic feet of gas per day (MCFGPD) (240 Mm^3/day) from a depth of 10,890 to 10,980 feet (3,320-3,345 m). The Sinbad is a fine grained, dense carbonate deposited in a nearshore marine environment. Natural fractures may be an important part of the reservoir permeability.

Permian reservoirs: Tests of CO_2- and/or He-rich gas from the Permian Kaibab Formation (Black Box Dolomite) and White Rim Sandstone of the Cutler Group have been reported from the Farnham Dome (98 percent CO_2), Ferron (61 percent CO_2), Gordon Creek (99 percent CO_2), and Woodside (1.51 percent He) fields. The Kaibab is 100 to 125 feet (30-38 m) thick in the Woodside area and consists of silty, cherty, dolomitic limestone. The Kaibab represents an epicontinental marine transgression. The average pay thickness is estimated to be 30 feet (10 m). The White Rim is a coastal dune sandstone deposit typically 400 to 650 feet (120-200 m) thick in the Woodside to Gordon Creek area.

The Woodside field is an asymmetric, doubly plunging, north-south-trending anticline. Mapping by Gilluly (1929) indicated 800 feet (240 m) of vertical closure. The Woodside field was established as U.S. Helium Reserve No. 1 on March 21, 1924. Tests of the Permian Kaibab Formation (Black Box Dolomite) flowed at rates as high as 1,000 MCFGPD (28,320 m^3/day). The gas consisted of 61 percent N_2, 32 percent CO_2, 6 percent hydrocarbons, and 1.51 percent He. The field was never produced and was dropped as a helium reserve in 1954. Minor shows of oil and gas have been reported at Woodside from the Jurassic Entrada, Triassic Chinle and Moenkopi, and Pennsylvanian Paradox Formations.

Elbert reservoirs: Gas was tested in the Temple Springs 1 well from the Devonian Elbert Formation at a depth of 4,670 to 4,741 feet (1,423-1,445 m). A rate of 2,837 MCFGPD (80,344 m^3/day) was gauged and the gas composition was reported to be 97 percent N_2 and 2.8 percent He. The well was plugged and abandoned.

Past Production and Trends

The only commercial production of CO_2 in Carbon and Emery Counties was from the Farnham Dome field from 1931 through 1979. Carbon dioxide was produced from the Jurassic Navajo Sandstone, transported by a surface pipeline, and used for making dry ice in the town of Wellington. Nearly 5 BCFG (142 MMm^3) was produced from Farnham Dome before the dry ice plant was shut down, eliminating the market for the CO_2.

The primary use for CO_2 is in tertiary oil recovery. The oil reserves in Carbon and Emery Counties are not large enough to justify the construction of a pipeline. Also, the large percentage of associated N_2 reduces the value of the reserves because of the high cost to separate out the N_2. Recently, a number of small (typically 1 to 2 square miles [2-3 km^2]) waterflood units have been established in Duchesne and Uintah Counties to extract more oil from the Green River Formation. If these waterfloods are followed by a tertiary-oil-recovery (TOR) program, a market use for CO_2 found in Carbon and Emery Counties may become available. Water-alternating-gas and huff-and-puff are TOR methods that require small enough quantities of CO_2 that it can be brought in by truck, eliminating the need for expensive pipelines.

Helium has not been produced in Carbon or Emery Counties. The nearest He production is from the Lisbon field (T. 30 S., R. 24 E.) in San Juan County. Helium-rich gas in Carbon and Emery Counties is associated with CO_2 and N_2. Extracting He from other gases is a very expensive process and is generally done only in conjunction with the exploitation of large hydrocarbon reserves.

Current Production and Exploration Activity

Carbon dioxide and helium are not produced in Carbon or Emery County. Currently there is no known exploration activity for these two gases in Carbon or Emery County.

Potential for Additional Discoveries and/or Development

Carbon dioxide: Carbon dioxide-rich gas has been tested from the Jurassic Navajo, Triassic Moenkopi, and Permian Kaibab (Black Box Dolomite) and White Rim Formations. Also, some Mississippian-aged carbonate reservoirs in Carbon and Emery Counties may contain large quantities of CO_2-rich gas. Most of the CO_2-rich gas in Emery County contains a high percentage of N_2 which greatly reduces the value of the CO_2. Farnham Dome and Gordon Creek fields in Carbon County contain 99 percent pure CO_2. The reservoirs in Carbon County have the greatest potential for exploitation if a market for the CO_2 can be found.

Helium: Helium-rich gas has been tested from the Triassic Moenkopi, Permian Kaibab (Black Box) and White Rim, and Devonian Elbert Formations. Helium-rich gas in Carbon and Emery Counties is associated with CO_2 and N_2, greatly increasing the cost to extract the He. Helium is usually extracted from hydrocarbon gases as a by-product. Currently, there are no known He-rich reservoirs in Carbon or Emery County that have sufficient hydrocarbons to make He an economical resource.

COAL AND COAL RESIN RESOURCES

Coal Resources

Carbon and Emery Counties include all or part of three of the state's 22 coalfields: the Wasatch Plateau, Book Cliffs, and Emery coalfields (figure 13). These three coalfields, each of which originally contained a resource of over 2 billion short tons (1.8 billion metric tons) of minable coal, make up nearly half of the coal resources of the state's six major fields, and together contain about one-third of the state’s coal resources (table 12).

Carbon and Emery Counties have numerous thick coal zones, many in excess of 15 feet (4.6 m) thick. However, most of the coal zones are lenticular and commonly split into several thinner beds that thin rapidly or even disappear over a distance of a few miles. The lenticular nature of the coal,

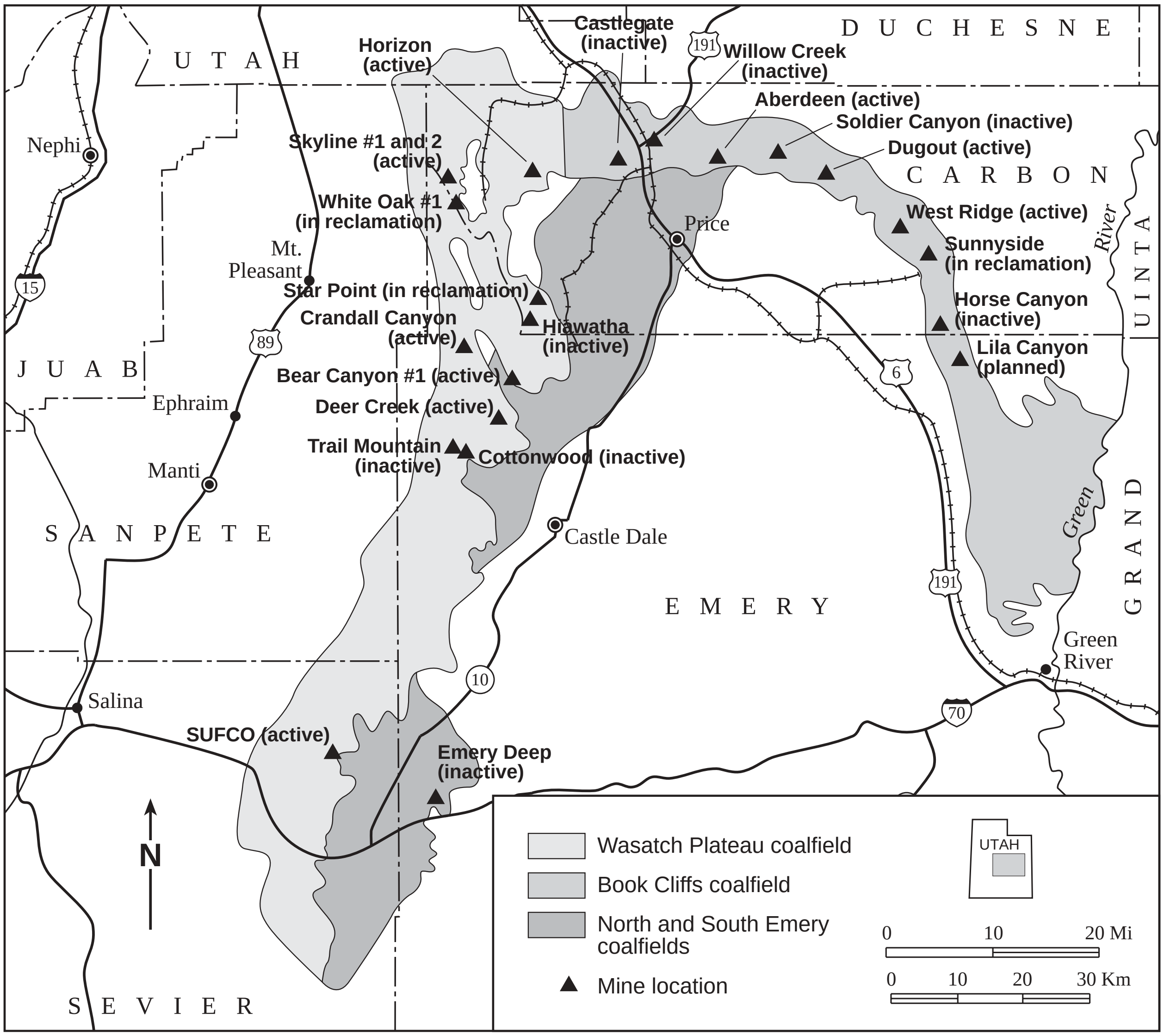


Figure 13. *Coalfields and permitted coal mines in Carbon, Emery, and Sevier Counties, Utah.*

Table 12. *Original minable resources of major Utah coalfields (in billions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; from Doelling, 1972; Anderson, 1983).*

Coalfield	Identified Resources	Hypothetical Resources	Total
Alton	1.870	0.279	2.149
* Book Cliffs	3.527	0.157	3.684
* Emery	1.430	0.635	2.065
Kaiparowits Plateau	7.878	7.320	15.198
Kolob	2.014	—	2.014
* Wasatch Plateau	6.379	3.888	10.267
TOTAL	23.098	12.279	35.377

* field has resources in Carbon or Emery County

rapid lateral changes in the nature of floor and roof strata, intertonguing stratigraphic relations of the coal-bearing rocks, and faulting make correlation of individual coal beds difficult. The average thickness of the coal beds included in the resource estimates given above is slightly greater than 6 feet (1.8 m). At present, nearly all operations in Carbon and Emery Counties are mining beds thicker than 6 feet (1.8 m).

The heat content of Carbon and Emery Counties' bituminous coal is high compared with that of the subbituminous coals typically produced in Montana, New Mexico, and Wyoming. Typical as-received heat contents range from 11,500 to 12,900 British thermal units (Btu) per pound (6,388-7,166 kcal/kg) of coal. Sulfur content is generally low (< 1 weight percent), but there are some areas with medium (1 to 2 weight percent) sulfur, particularly in the Emery coalfield. Near-surface coal quality is commonly degraded by oxidation, or the coal may be burned for a considerable distance away from the outcrop.

The coal-bed isopach maps included in this report (figures 16-25) were compiled from a variety of published sources and augmented by unpublished data on file at the UGS. The published sources include Speiker (1925), Fisher (1936), Davis and Doelling (1977), AAA Engineering and Drafting (1979a through 1979bb), Doelling and others (1979), Nethercott (1979), Anderson (1983), Bunnell (1987), Carroll (1987), and Russon (1987). After the coal geology section of the report was completed, additional studies on the coal resources of the area have been completed or are in-progress. The UGS in conjunction with the USGS (National Coal Resource Data System) has completed studies on the northern Wasatch Plateau and the Book Cliffs and are currently (2002) evaluating on the southern Wasatch Plateau. Recent published information on the northern Wasatch Plateau includes Tabet and others (1999), and Kirschbaum, Roberts, and Biewick (2000).

Known Occurrences and Characteristics

Book Cliffs coalfield: The Book Cliffs coalfield extends 70 miles (112 km) across northern Carbon and eastern Emery Counties, with an average width of 4 miles (6.4 km) (Doelling, 1972). The field parallels a line of the Union Pacific Railroad, which gives mine operators in this field a distinct transportation advantage over the mine operators in other Utah coalfields. The coal beds in the Book Cliffs field occur in the Upper Cretaceous Blackhawk Formation. The Blackhawk Formation consist of six members: the Spring Canyon, Aberdeen, Kenilworth, Sunnyside, Grassy, and Desert, in ascending order (Taylor and Lovell, 1995). The first four members are the major coal-bearing units in the Book Cliffs coalfield. The lower members successively thin and pinch out to the east and south, causing a general thinning of the Blackhawk Formation (figure 14).

The coal beds dip north and east at an average of 4 to 8 degrees in the Book Cliffs, but locally dips may be as high as 15 degrees (Doelling, 1972). Overburden increases rapidly north from the outcrop under an increasingly thick cover of younger Cretaceous and Tertiary sedimentary rocks. The area of minable resources (less than 3,000 feet [900 m] of cover) is limited to a band about 4 to 5 miles (6.4 -8.0 km) downdip from the outcrop (see plate 5). Significant faulting is present only in the Sunnyside and Woodside areas, but the faults are generally sufficiently wide-spaced there to accommodate mining operations.

Coal Geology: The Book Cliffs field has been subdivided into four mining areas named, from west to east, Castlegate, Soldier Canyon, Sunnyside, and Woodside (figure 15). Major coal beds, or groups of beds, in ascending order in the Castlegate area include the Spring Canyon coal group (figure 16), the Castlegate coal group (figure 17), and the Kenilworth bed (figure 18). In the Soldier Canyon and Sunnyside areas, the major coal beds are the Gilson bed (figure 19a) and Rock Canyon bed (figure 19b) of the Kenilworth coal group,

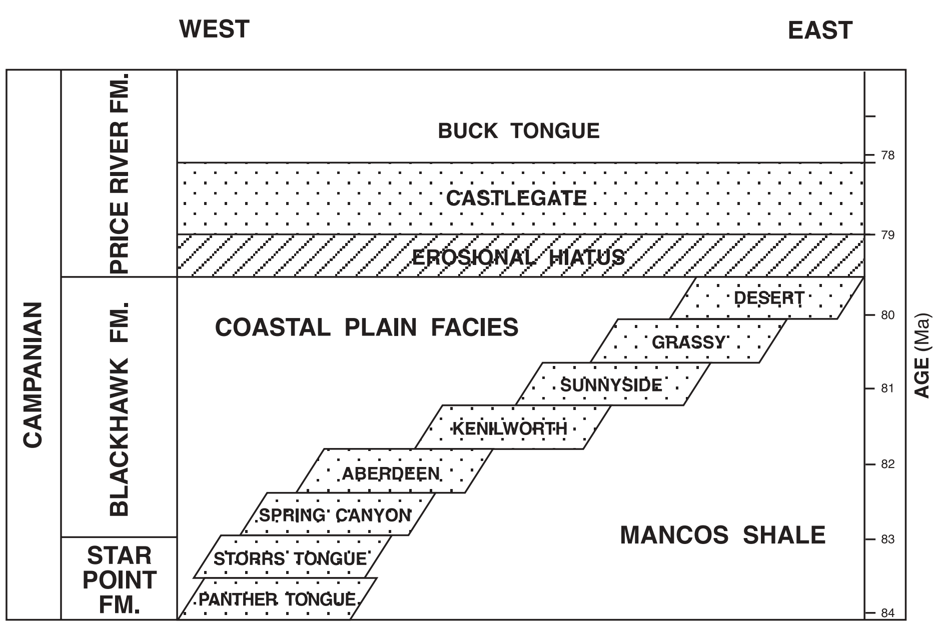


Figure 14. *Spatial distribution of the six members of the Blackhawk Formation in the Price-Woodside area of central Utah (modified from Taylor and Lovell, 1995).*

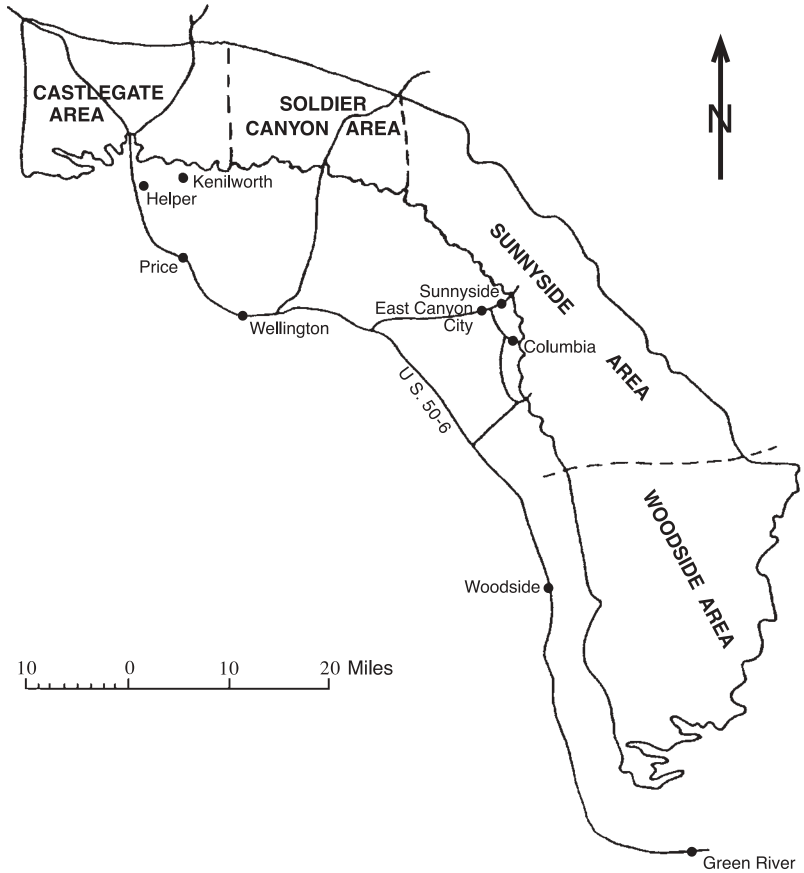


Figure 15. Location of four mining areas in Book Cliffs coalfield (modified from Doelling, 1972).

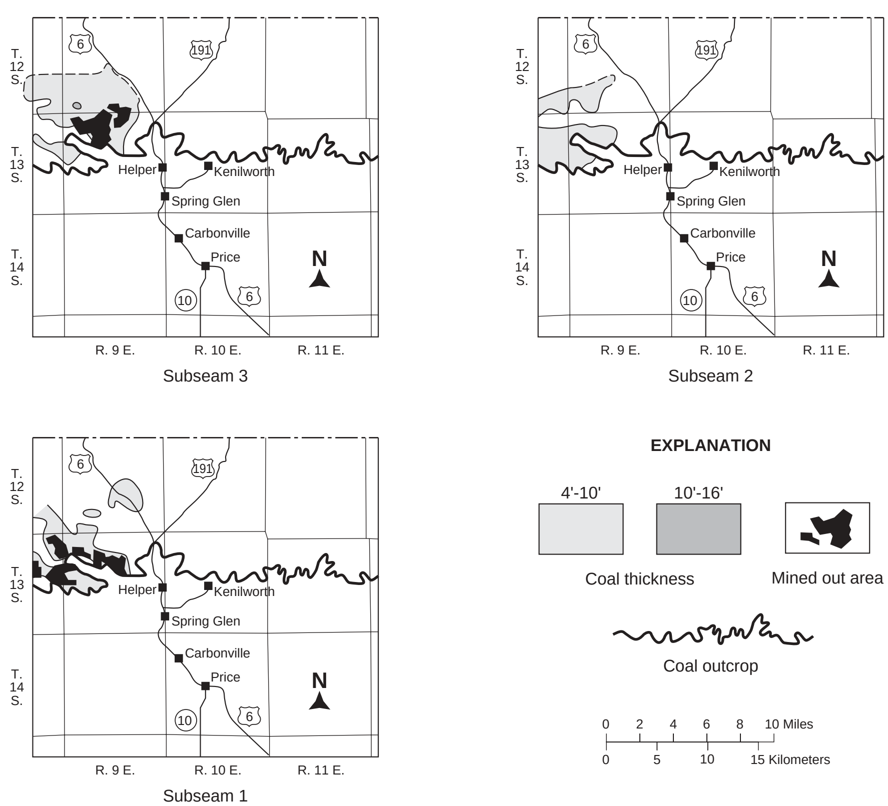


Figure 16. Total coal isopachs of Spring Canyon coal group in Castlegate area, Book Cliffs coalfield, Carbon County, Utah.

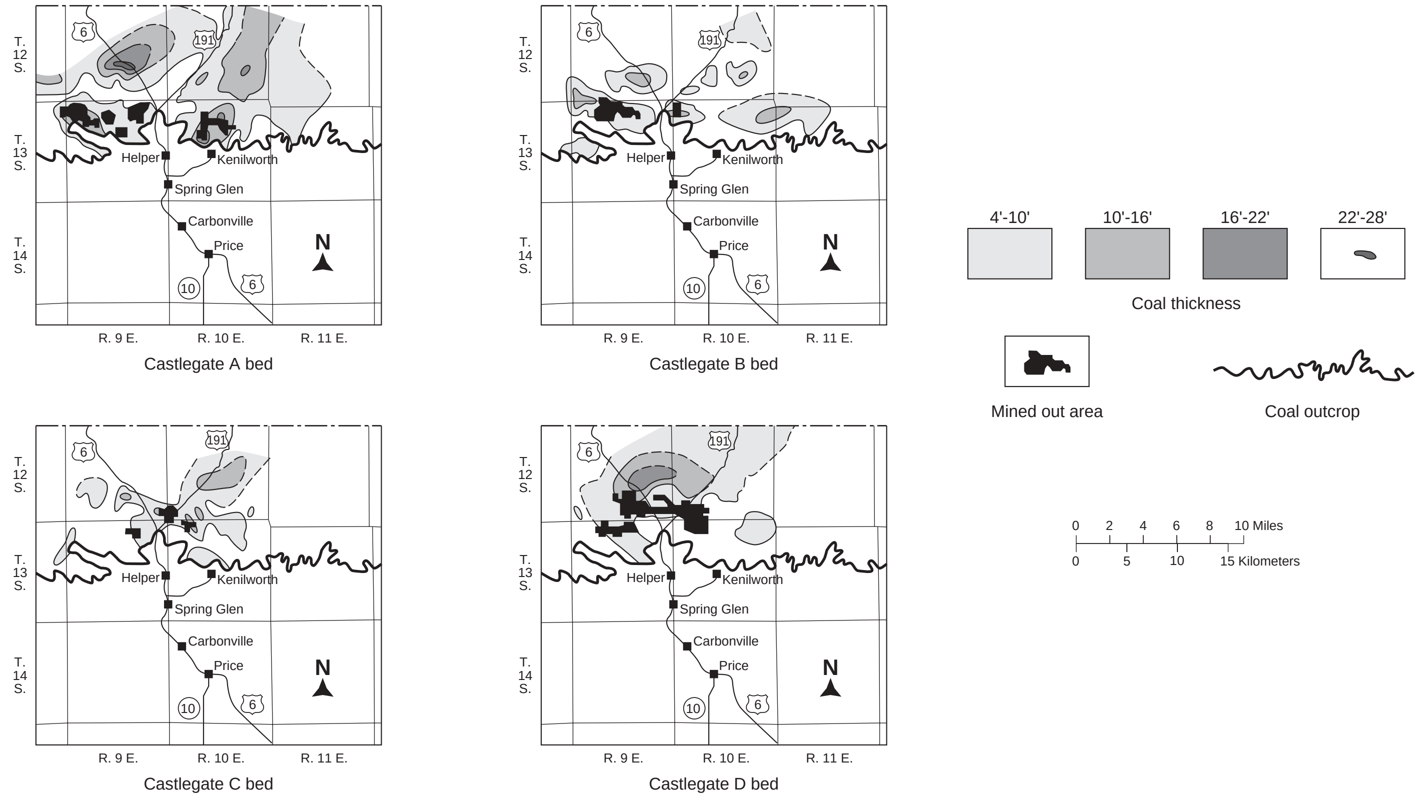


Figure 17. *Total coal isopachs of Castlegate coal group in Castlegate area, Book Cliffs coalfield, Carbon County, Utah.*

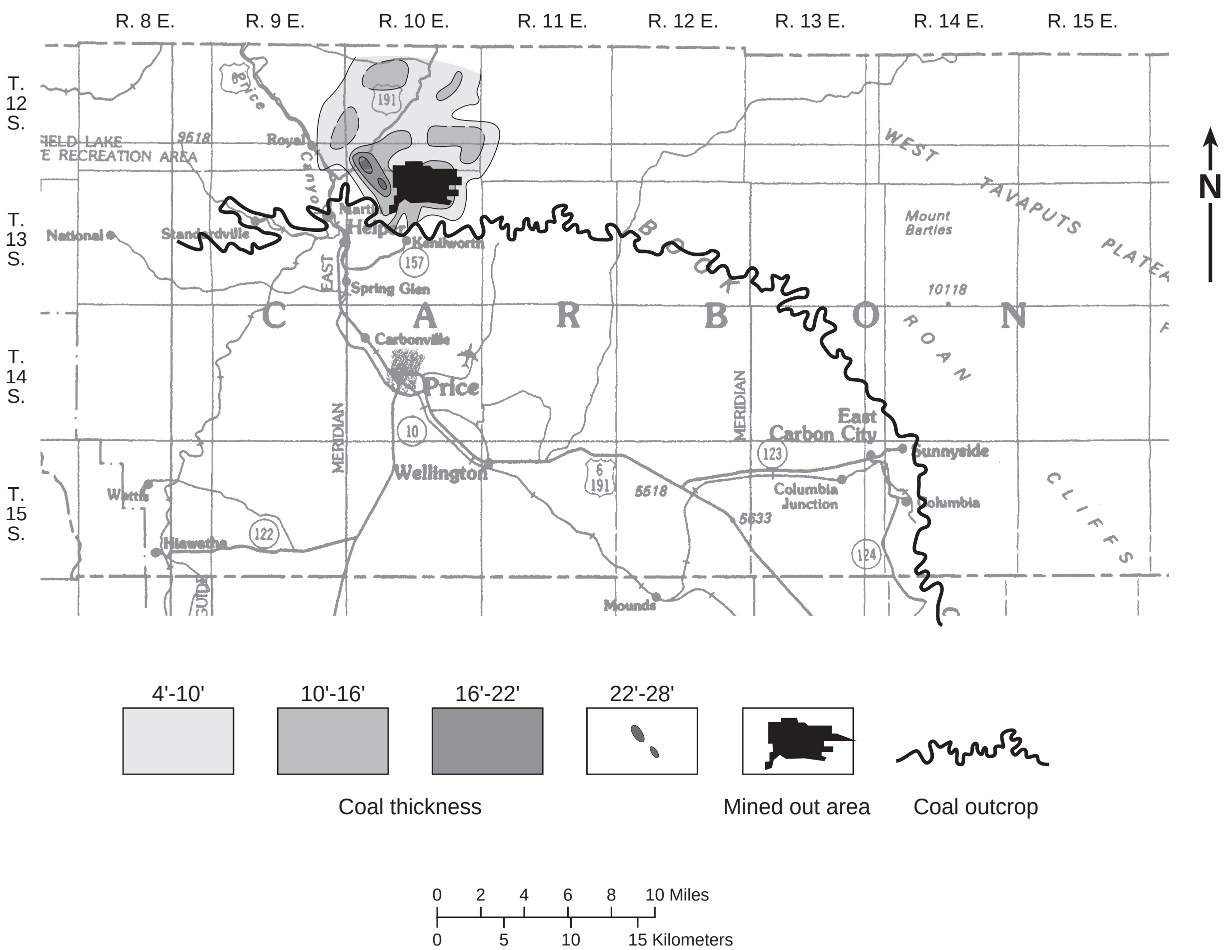


Figure 18. *Coal isopach of Kenilworth bed in Castlegate area, Book Cliffs coalfield, Carbon County, Utah.*

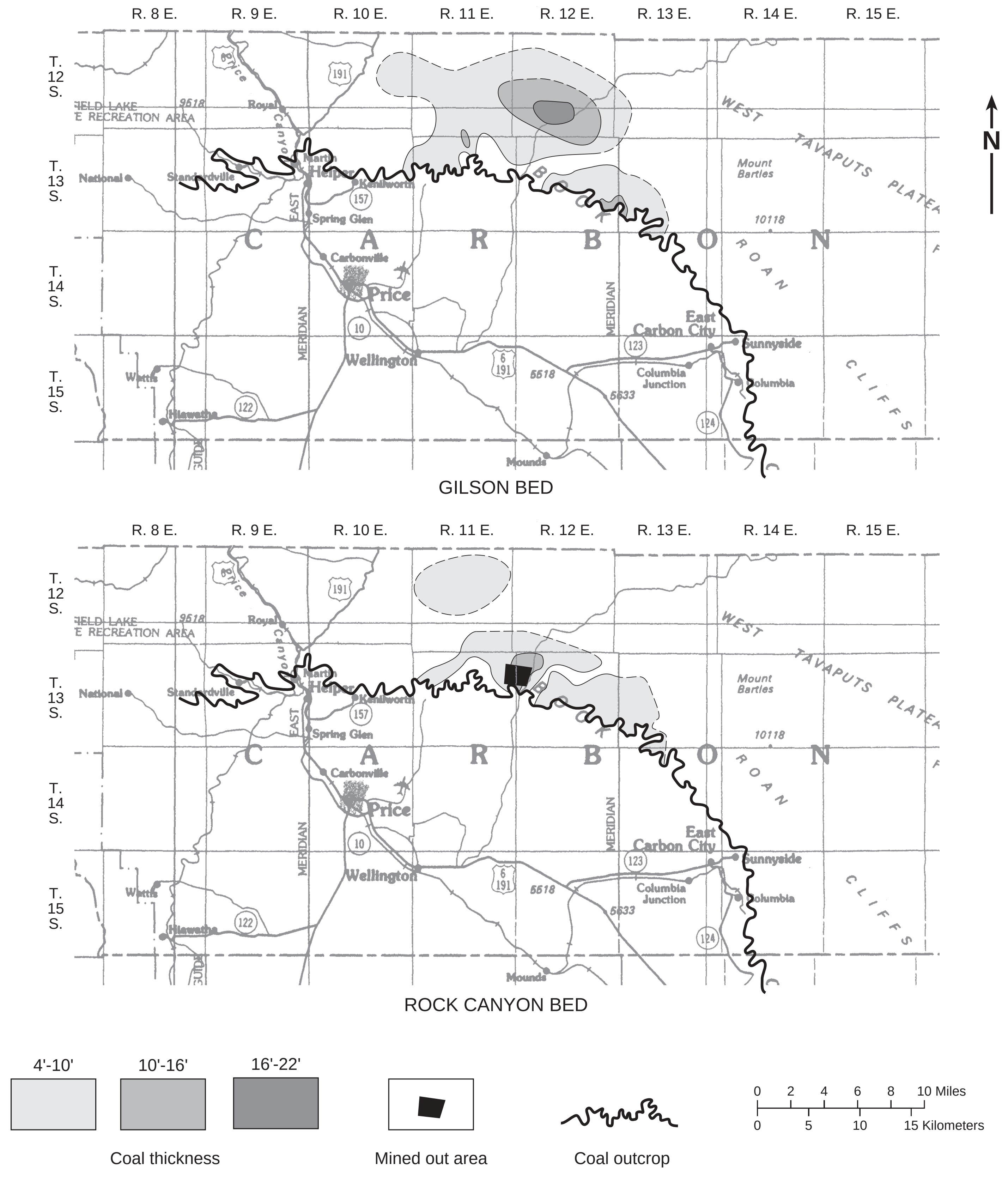


Figure 19. *Coal isopachs of Gilson and Rock Canyon beds (Kenilworth group) in Soldier Canyon-Sunnyside area, Book Cliffs coalfield, Carbon County, Utah.*

and the Sunnyside bed (figure 20). Finally, in the Woodside area only the Sunnyside bed is present (figure 20). The coal beds are typically lenticular and commonly split into several thinner benches or thin rapidly over a distance of a few miles. The minable thickness range of the major beds for each of the various Book Cliffs coal areas are listed in descending stratigraphic order in table 13.

Table 13. *Thickness range of minable coal beds of the Book Cliffs coalfield by mining area (modified from Doelling, 1972).*

Castlegate Area beds	**Thickness Range (ft)**
Castlegate D	4 to 18
Kenilworth	4 to 28
Castlegate C	4 to 12
Castlegate B	4 to 12
Castlegate A	4 to 16
Subseam 1 (Spring Canyon)	4 to 8
Subseam 2 (Spring Canyon)	4 to 8
Subseam 3 (Spring Canyon)	4 to 10
Soldier Canyon Area beds	**Thickness Range (ft)**
Sunnyside	4 to 10
Rock Canyon	6 to 12
Gilson	4 to 18
Sunnyside Area beds	**Thickness Range (ft)**
Sunnyside	4 to 16
Rock Canyon (NW only)	4 to 8
Gilson (NW only)	4 to 14
Woodside Area beds	**Thickness Range (ft)**
Sunnyside	4 to 10
Rock Canyon (NW only)	4 to 8
Gilson (NW only)	4 to 14

Coal Quality: Coal from the Book Cliffs field generally has high heat contents, low ash contents, and low to moderate sulfur contents. The rank of the coal ranges from high-volatile C bituminous to high-volatile A bituminous, with the higher rank coals found in the eastern part of the field. The coal beds in the Sunnyside and Woodside areas are particularly noted for their good coking quality. Coal-quality statistics for seven coal zones or beds from the Book Cliffs coalfield that have 30 or more proximate analyses or 10 or more ultimate analyses are given in tables 14 to 20 (data taken from an unpublished Utah Geological Survey database).

The statistics indicate that the coal beds of the Book Cliffs coalfield are quite uniform in quality. The mean proximate analytical values show the coal beds are all low in sulfur (0.4 - 1.0 percent), low in ash (5.8 - 7.7 percent), low in moisture (4.10 - 5.33 percent), and high in heating value (12,512 - 12,910 Btu/lb [6,951 - 7,172 kcal/kg]) on an as-received basis.

Coal Resources: The Book Cliffs coalfield is one of Utah's six major coalfields with a major coalfield defined as one having original minable resources in excess of 2 billion short tons (1.8 billion metric tons) (Tabet, 1995). The minable resources include only coal beds at least 4 feet (1.2 m) thick with less than 3,000 feet (900 m) of overburden. The most recent coal resource estimates for most of the Book Cliffs field are those of Doelling (1972), with some revisions by Anderson (1983) for the Pine Canyon quadrangle. Anderson's coal resource estimate for the Pine Canyon quadrangle is somewhat lower than Doelling's earlier estimate, resulting in a lower overall resource estimate for the Book Cliffs coalfield. The original in-place coal resources of the Book Cliffs coalfield are separated by county in table 21. About 90 percent of the Book Cliffs coal resources occur in Carbon County.

Nearly half of the coal resources in the Book Cliffs coalfield are found in the Castlegate area at the western end of the field, where there are more thick coal beds. A tally of the Book Cliffs field's coal resources by mining area is given in table 22.

Wasatch Plateau coalfield: The Wasatch Plateau coalfield extends southwest about 90 miles (145 km) from western Carbon County, through western Emery County, and into eastern Sanpete and Sevier Counties (Doelling and Smith, 1982) (figure 13). Doelling and Smith (1982) expanded the field to include the formerly separate Mt. Pleasant and Salina Canyon coalfields as parts of a "larger" Wasatch Plateau coalfield. The field, as they defined it, is 13 to 22 miles (21-35 km) wide. The eastern edge of the field is bounded by the outcrop of the coal-bearing Blackhawk Formation, and the western edge is bounded by a series of faults near the western margin of the Wasatch Plateau in Sanpete and Sevier Counties. Carbon and Emery Counties contain roughly the northeastern half of the “larger” Wasatch Plateau coalfield. Only the northern third of the field is directly served by rail transportation. One spur leaves the main line of the Union Pacific Railroad at the town of Colton and heads 15 miles (24 km) southwest to serve the mines near the town of Scofield. Three other spurs branch off at the town of Helper, two running 5 miles (8 km) west, and one running 20 miles (32 km) south. The longest one, which runs south to the town of Hiawatha, served the Star Point # 2 mine of RAG Coal Company. Shipment of coal from the southern end of the field requires an truck haul 55 miles (88 km) westward to a loadout on a branch of the Union Pacific Railroad west of the town of Levan.

Coal Geology: Most of the coal in the Wasatch Plateau field is found in the lower third of the Blackhawk Formation (Sanchez and others, 1983a, b; Sanchez and Brown, 1983, 1986, 1987; Brown and others, 1987; Sanchez and Ellis, 1987). Over 20 individual beds have been identified that contain coal more than 4 feet (1.2 m) thick. The northern portion of the field has a greater number of thick beds than the southern portion. Major coal-bed groups of the northern and central Wasatch Plateau from Carbon and Emery Counties include (in ascending order) the Hiawatha zone (consisting of the Accord Lakes, Axel Anderson, Cottonwood, and Flat Canyon beds) (figure 21); the Blind Canyon zone (figure 22); the Wattis zone (figure 23); and the Castlegate A and D zones (figure 24). The reported thickness range of minable coal for the major zones of the northern and central parts of the Wasatch Plateau field in Carbon and Emery Counties is given in table 23.

The coal beds generally dip gently to the west, but are cut by several major north-south-trending fault zones with displacements ranging from a few to several hundred feet. These normal faults offset the coal beds and interfere with mining; however, there is usually sufficient room between the faults to conduct mining (Doelling, 1972).

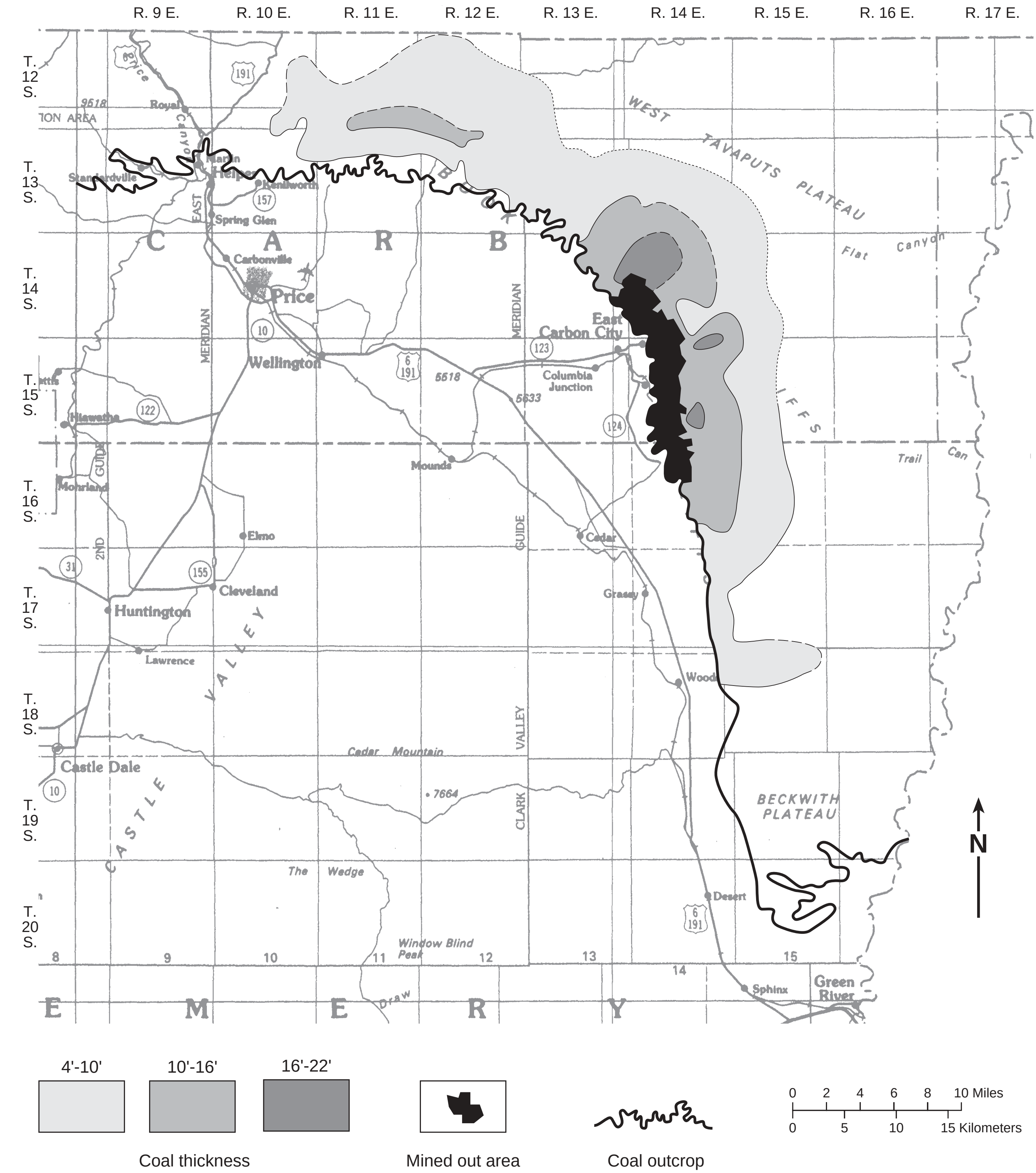


Figure 20. Total coal isopach of Sunnyside group in Soldier Canyon-Sunnyside area, Book Cliffs coalfield, Carbon County, Utah.

Table 14. *Coal-quality statistics for Subseam 1 bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	7.1	20.8	4.3	2.2	71
Btu/lb	12,833	13,900	7,045	920	72
Fix. Carbon (%)	44.6	50.0	33.9	2.3	70
Vol. Matter (%)	44.19	48.5	31.4	2.6	70
Sulfur (%)	1.0	2.1	0.3	0.4	63
Moisture (%)	4.10	24.50	0.62	2.97	73

Table 15. *Coal-quality statistics for Castlegate A bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	5.8	10.9	3.0	1.3	124
Btu/lb	12,819	14,460	11,840	432	116
Fix. Carbon (%)	47.37	54.50	28.34	2.72	117
Vol. Matter (%)	41.85	64.31	38.30	2.78	117
Sulfur (%)	0.6	5.2	0.3	0.5	117
Moisture (%)	4.9	10.3	1.2	1.8	124
Carbon (%)	74.39	80.70	70.19	2.29	34
Hydrogen (%)	5.7	6.4	5.0	0.3	34
Nitrogen (%)	1.4	1.6	0.9	0.1	34
Oxygen (%)	12.5	16.5	9.5	1.9	34
Chlorine (%)	0.01	0.08	0.00	0.02	14

Table 16. *Coal-quality statistics for Castlegate B bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	6.3	12.8	3.8	1.1	233
Btu/lb	12,910	13,902	11,608	286	235
Fix. Carbon (%)	46.8	50.5	39.4	1.5	231
Vol. Matter (%)	42.9	46.4	38.7	1.2	231
Sulfur (%)	0.4	1.0	0.2	0.2	228
Moisture (%)	4.1	10.4	0.9	1.3	238
Carbon (%)	73.46	76.90	69.62	1.91	20
Hydrogen (%)	5.60	6.06	5.10	0.27	20
Nitrogen (%)	1.4	1.6	1.3	0.1	20
Oxygen (%)	13.0	15.1	11.0	1.3	20
Chlorine (%)	---	---	---	---	--

Table 17. *Coal-quality statistics for Kenilworth bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	6.88	13.19	4.10	1.42	133
Btu/lb	12,783	14,360	11,629	302	129
Fix. Carbon (%)	46.99	53.34	40.97	1.93	129
Vol. Matter (%)	41.9	46.3	35.7	1.8	130
Sulfur (%)	0.38	0.70	0.10	0.11	117
Moisture (%)	4.2	8.1	1.9	1.2	133
Carbon (%)	74.2	80.5	71.8	2.6	15
Hydrogen (%)	5.7	6.0	5.0	0.2	15
Nitrogen (%)	1.4	1.5	1.2	0.1	15
Oxygen (%)	12.48	15.72	10.00	1.49	15
Chlorine (%)	---	---	---	---	--

Table 18. *Coal-quality statistics for Gilson bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	7.19	14.20	2.67	2.11	171
Btu/lb	12,594	13,642	11,648	421	172
Fix. Carbon (%)	49.69	55.45	44.00	1.81	167
Vol. Matter (%)	38.5	44.3	30.9	1.6	167
Sulfur (%)	0.49	1.29	0.05	0.13	154
Moisture (%)	4.62	8.50	2.07	1.11	178
Carbon (%)	74.31	78.48	65.90	3.07	13
Hydrogen (%)	5.17	6.10	4.32	0.40	13
Nitrogen (%)	1.45	1.61	1.30	0.09	13
Oxygen (%)	10.68	13.40	5.56	2.21	13
Chlorine (%)	0.03	0.08	0.0	0.03	8

Table 19. *Coal-quality statistics for Rock Canyon bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	7.7	11.8	3.3	1.8	56
Btu/lb	12,512	13,676	11,390	416	55
Fix. Carbon (%)	49.0	53.8	45.2	1.6	55
Vol. Matter (%)	38.41	43.18	34.25	1.28	55
Sulfur (%)	0.7	2.4	0.3	0.4	55
Moisture (%)	4.83	7.90	1.95	1.07	56

Table 20. *Coal-quality statistics for Lower Sunnyside bed of the Blackhawk Formation, Book Cliffs coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	6.5	11.9	3.5	1.3	149
Btu/lb	12,745	14,220	9,527	490	150
Fix. Carbon (%)	50.3	74.3	41.6	3.1	143
Vol. Matter (%)	37.3	44.7	5.8	4.5	145
Sulfur (%)	0.8	3.0	0.1	0.3	142
Moisture (%)	5.33	15.17	1.90	1.67	161
Carbon (%)	73.1	81.6	62.2	2.8	31
Hydrogen (%)	5.46	5.86	4.30	0.35	31
Nitrogen (%)	1.5	1.6	1.2	0.1	31
Oxygen (%)	12.6	22.8	5.7	2.8	31
Chlorine (%)	0.01	0.07	0.00	0.03	6

Table 21. *Original, in-place, minable coal resources of the Book Cliffs coalfield by county (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; modified from Doelling, 1972, and Anderson, 1983).*

County	Demonstrated	Inferred	Total
Carbon	2,356.7	820.1	3,176.8
Emery	350.5	—	350.5
Total	2,707.2	820.1	3,527.3

Table 22. *Original in-place, minable coal resources (demonstrated and inferred) of the Book Cliffs coalfield by mining area (in millions of short tons, for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; modified from Doelling, 1972, and Anderson, 1983).*

Mining Area	Resources
Castlegate	1,652.4
Soldier Canyon	725.6
Sunnyside	1,077.3
Woodside	72.0
Total	3,527.3

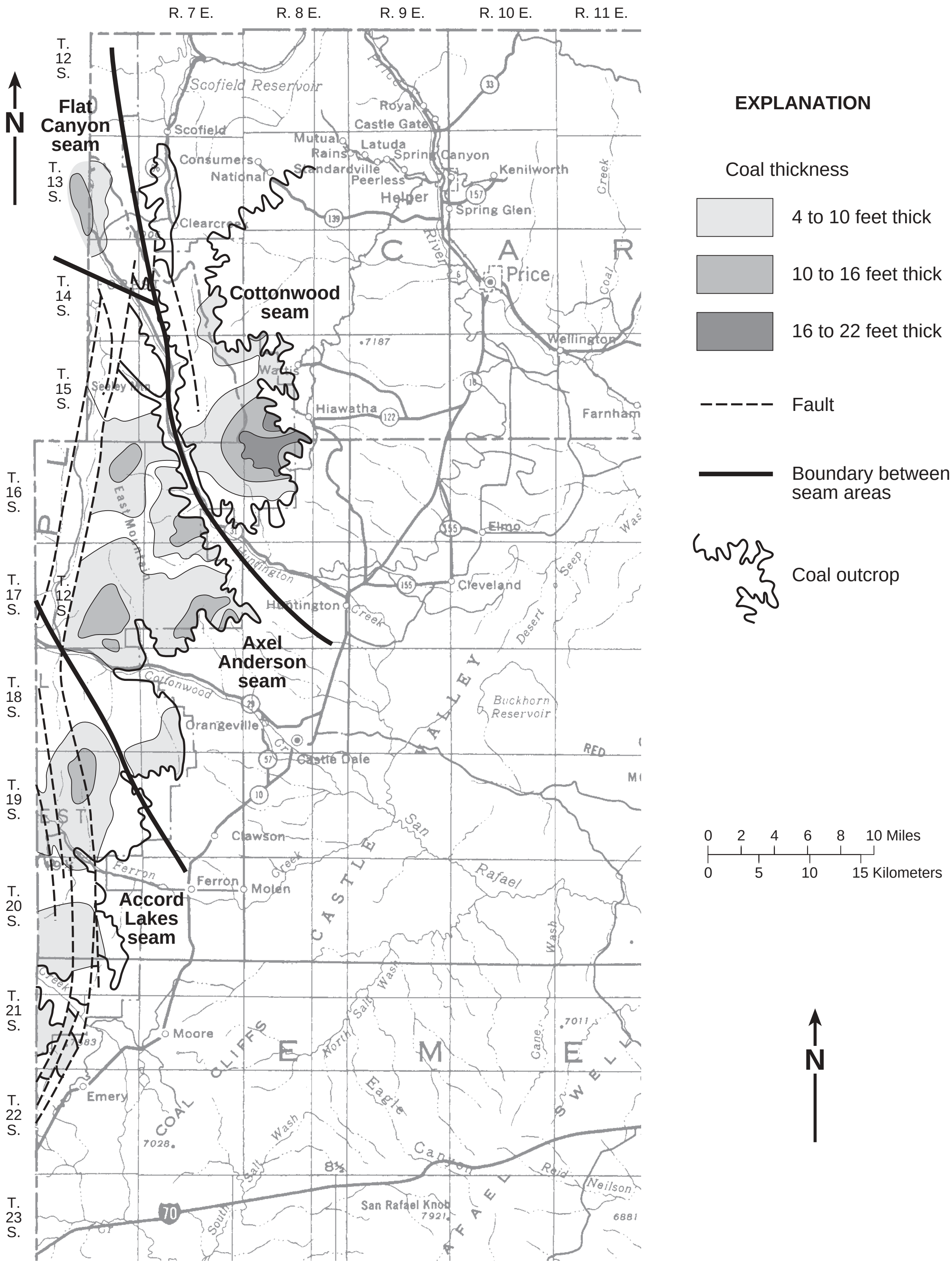


Figure 21. *Total coal isopach of Hiawatha zone, Wasatch Plateau coalfield, Carbon and Emery Counties, Utah (includes Acord Lakes [south], Axel Anderson [central], Cottonwood [north-central], and Flat Canyon [north] beds).*

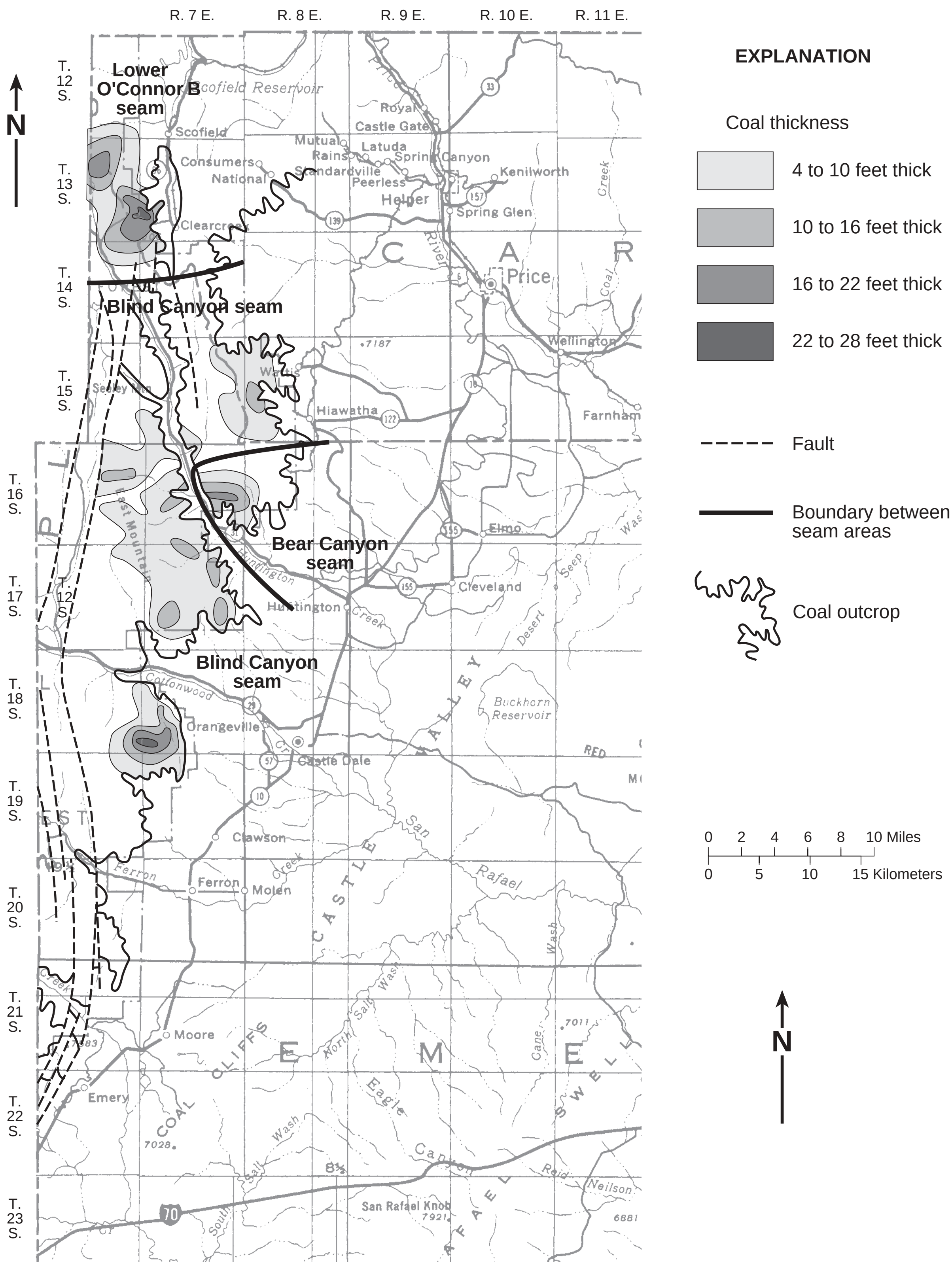


Figure 22. *Total coal isopach of Blind Canyon zone, Wasatch Plateau coalfield, Carbon and Emery Counties, Utah (includes Bear Canyon [east-central] , and Lower O'Connor B [north] beds).*

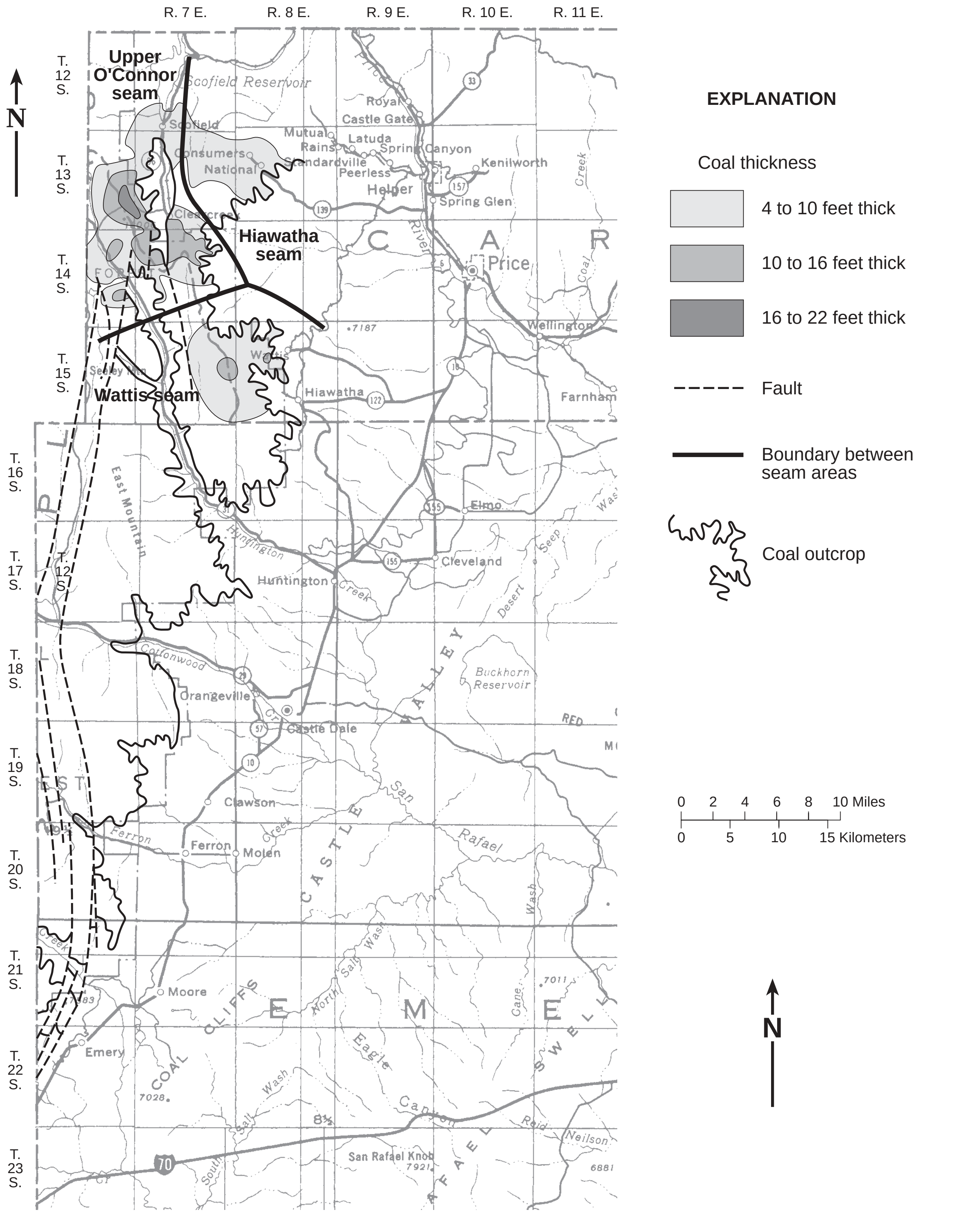


Figure 23. *Total coal isopach of Wattis-Upper O'Connor zones, Wasatch Plateau coalfield, Carbon and Emery Counties, Utah (includes Hiawatha bed of Jump Creek quadrangle).*

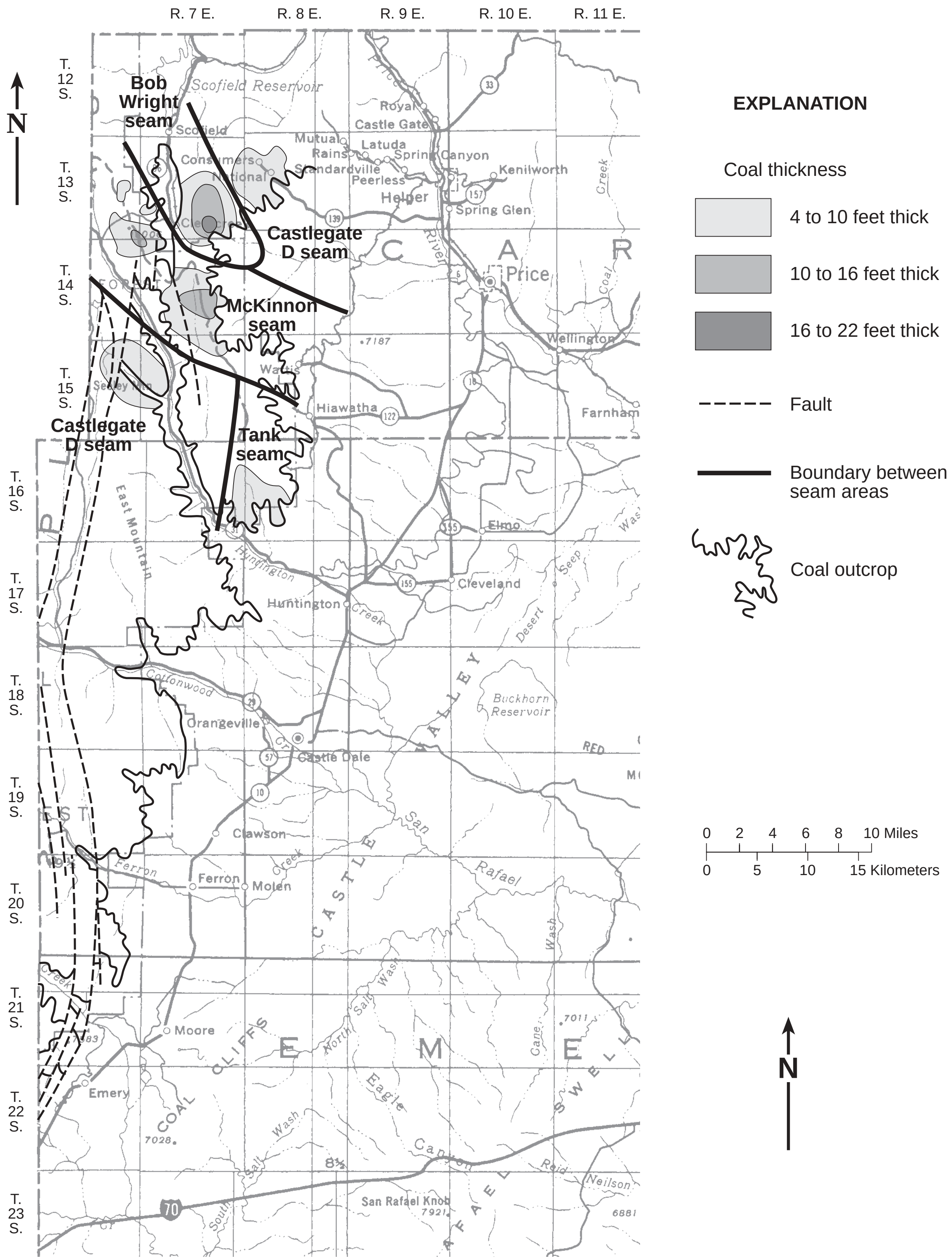


***Figure 24.** Total coal isopach of Castlegate A and D zones, Wasatch Plateau coalfield, Carbon and Emery Counties, Utah (includes McKinnon, Bob Wright [Castlegate A] and Tank [Castlegate D] beds).*

Coal Quality: Coal of the Wasatch Plateau field is generally good quality, with low ash and sulfur contents, and high heat contents (Keith, 1989). Most of the coals are high-volatile C bituminous in rank, although locally some coals in the northern part of the field are high-volatile B bituminous.

The Wasatch Plateau coal beds are often resin-rich with resin contents of 2 to 15 percent. Although not presently used, the resin has been historically recovered as a by-product for use in adhesives, in paints and coatings, and as a binder in printing ink (Tabet and others, 1995a). Coal quality statistics are summarized in tables 24 to 27 for four Wasatch Plateau field coal beds that have a sample population of more than 30 proximate analyses, and usually more than 20 ultimate analyses (UGS unpublished coal quality database). Those four Wasatch Plateau coal beds are the Blind Canyon, Castlegate A, Hiawatha, and Upper Hiawatha.

The Wasatch Plateau coal beds have similar mean proximate and ultimate analytical values, but the Upper Hiawatha bed shows the greatest differences in quality. This bed is slightly higher in ash and moisture and slightly lower in heat content, fixed carbon, and volatile matter than the other three beds. In general, the coals of the Wasatch Plateau decrease slightly in rank and heat content from north to south.

Coal Resources: The Wasatch Plateau is one of Utah's six major coalfields. Doelling (1972) estimated that the Carbon and Emery portions of the field alone contained 4.8 billion short tons (4.3 billion metric tons) of in-place minable coal resources (table 28). Doelling defined the minable coal as beds greater than 4 feet (1.2 m) thick and buried under less than 3,000 feet (900 m) of cover. Approximately three-fourths of all the minable coal in this field lies in Carbon and Emery Counties: 46 percent in Emery County, and 28 percent in Carbon County.

Emery coalfield: The Emery coalfield was originally defined from surface exposures of the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale (Lupton, 1916). The surface exposures cover an area 25 miles (40 km) long and 2 to 10 miles (3-16 km) wide near the Sevier Emery County border (figure 13). This area lies about 45 miles (72 km) southwest of Price, which is the site of the nearest rail loadout. The original field is bounded on the east by an erosional escarpment and on the west by a fault zone (Doelling, 1972). Surface exposures show the coal thinning and disappearing to the north; however, recently published drilling data show that similar thick coal beds also occur in the Ferron Sandstone in the subsurface extending northward all the way to Price (Bunnell and Holberg, 1991; Tabet and others, 1995b). The presently defined northern boundary of the field is near Price but could potentially extend farther north into the Uinta Basin. Future exploration along the subsurface Ferron Sandstone trend will expand the known coal resources of the Emery coalfield.

Coal Geology: The coal of the Emery field occurs in the 300- to 900-foot-thick (90 to 274 m) Ferron Sandstone Member of the Mancos Shale. Where exposed in the south, this unit contains 13 coal beds, seven of which exceed 4 feet (1.2 m) in thickness. Lupton (1916) gave the beds letter designations from A to M in ascending order of occurrence. Beds I and J are the most important, and the separation between them is minimal in many areas, resulting in a single bed up to 25 feet (7.6 m) thick (Doelling, 1972). The dip of the coal beds varies from 2 to 12 degrees to the west, with most beds dipping at 4 to 7 degrees. Faulting is minor and presents little difficulty to mining. In the southern end of the field, 76 percent of the reserves are under less than 1,000 feet (300 m) of cover, and very thin overburden in some areas makes surface mining possible (plate 8). The reported thickness ranges of the major coal beds in the Emery coalfield (see figure 25) are given in table 29 in descending stratigraphic order.

Coal Quality: The quality of coal from the Emery field, particularly the sulfur and ash contents, is quite variable throughout the field. Generally, the sulfur and ash contents of the coals from this field are somewhat higher than those for coals from the Book Cliffs and Wasatch Plateau coalfields. The rank of coal is considered to be high-volatile C bituminous where fresh and unweathered. Shallow coal beds are often oxidized or burned for a considerable distance away from the outcrop. Summary coal-quality statistics for several beds from the Emery coalfield are shown in tables 30 to 34 (data from an unpublished UGS database).

Coal Resources: Estimated original, in-place, minable coal resources for the southern portion of the Emery coalfield are 1.4 billion short tons (1.3 billion metric tons)(Doelling, 1972). Emery County contains 58 percent of the minable coal resources of the Emery coalfield, or 830.5 million short tons (755.0 million metric tons) (table 35). No coal resource estimates have been published for the northern, more deeply buried portion of the field, but Bunnell and Holberg (1991) indicate the resources in this area are substantial.

Past Production and Trends

Introduction: Historically, most Utah coal production has come from underground mines in central Utah, and future production will probably continue to come predominantly from this region. The three major coalfields of central Utah, and Carbon and Emery Counties, are the Book Cliffs field, the Wasatch Plateau field, and the Emery field.

Book Cliffs coalfield: The Book Cliffs coalfield is the second most important field in the state and has produced a total of 284.3 million short tons (258.5 million metric tons) from 1889 through 1999 (Jahanbani, 2000). Annual production for the period 1982 to 1998 is shown in figure 26. During the 1990s, annual coal production from this field remained in the 2 to 4 million short ton (1.8 to 3.6 million metric ton) per year range. In 1999 production from this field came from three mines, and totaled 2.92 million short tons (2.65 million metric tons), or about 11 percent of the state's production.

Wasatch Plateau coalfield: The Wasatch Plateau coalfield covers parts of Carbon, Emery, Sanpete, and Sevier Counties. Overall, this field has both the greatest annual and cumulative coal production of any coalfield in Utah (Jahanbani, 2000). Coal in this field was first developed in Carbon County during the late nineteenth century. Over the years, production has expanded from the northern, Carbon County part, of the field to the central and southern parts of the field in Emery and Sevier Counties. The Sanpete County portion of the field is generally deep and has not been mined. Cumulative production from over 80 mines through 1999 has totaled 478.8 million short tons (435.3 million metric tons). Annual production for the period 1982 to 1998 is shown in figure 27.

Table 23. *Thickness range of minable coal beds of the Wasatch Plateau coalfield by area (modified from Doelling, 1972).*

Northern Wasatch Plateau zones	Thickness Range (ft)
Castlegate D (Tank)	4 to 8
Castlegate A (Bob Wright-McKinnon)	4 to 16
Wattis (Upper O'Connor of Scofield area)	4 to 20
Blind Canyon (Lower O'Connor B of Scofield area)	4 to 24
Cottonwood (Lower O'Connor A of Scofield area)	4 to 20
Axel Anderson (Flat Canyon of Scofield area)	4 to 14
Central Wasatch Plateau zones	**Thickness Range (ft)**
Wattis	4 to 10
Blind Canyon (Bear Canyon -Third)	4 to 24
Axel Anderson	4 to 14
Acord Lakes	4 to 10

Table 24. *Coal-quality statistics for the Blind Canyon bed of the Blackhawk Formation, Wasatch Plateau coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	7.1	18.3	2.3	2.3	144
Btu/lb	12,844	13,966	10,800	463	142
Fix. Carbon (%)	44.96	50.08	37.50	2.12	136
Vol. Matter (%)	42.8	48.4	37.5	1.7	139
Sulfur (%)	0.52	1.10	0.29	0.14	130
Moisture (%)	5.13	8.37	1.20	1.11	145
Carbon (%)	72.74	80.50	67.69	3.15	21
Hydrogen (%)	5.72	6.66	4.69	0.48	21
Nitrogen (%)	1.3	1.6	0.6	0.2	20
Oxygen (%)	11.81	16.50	8.82	1.94	21
Chlorine (%)	0.01	0.03	0.00	0.01	8

Table 25. *Coal-quality statistics for the Castlegate A bed of the Blackhawk Formation, Wasatch Plateau coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	6.0	13.5	2.8	2.0	103
Btu/lb	12,206	14,170	10,475	593	93
Fix. Carbon (%)	45.2	53.5	28.3	2.7	95
Vol. Matter (%)	41.6	54.3	36.6	2.5	95
Sulfur (%)	0.59	1.60	0.31	0.18	81
Moisture (%)	7.3	14.1	3.6	1.8	105
Carbon (%)	72.1	79.0	67.5	3.1	17
Hydrogen (%)	5.75	6.31	5.30	0.26	17
Nitrogen (%)	1.4	1.6	1.1	0.1	17
Oxygen (%)	14.8	20.3	11.4	2.8	17
Chlorine (%)	0.0	0.0	0.0	0.0	4

Table 26. *Coal-quality statistics for the Hiawatha bed of the Blackhawk Formation, Wasatch Plateau coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	6.67	25.72	0.05	1.98	521
Btu/lb	12,689	14,530	9,073	487	521
Fix. Carbon (%)	45.64	54.40	31.26	1.89	502
Vol. Matter (%)	42.0	47.4	4.4	2.3	509
Sulfur (%)	0.63	4.06	0.29	0.25	479
Moisture (%)	5.55	14.24	0.70	1.58	537
Carbon (%)	71.60	81.88	51.38	6.05	58
Hydrogen (%)	5.51	6.30	3.89	0.51	58
Nitrogen (%)	1.3	1.7	0.3	0.2	58
Oxygen (%)	12.18	17.18	9.25	2.18	58
Chlorine (%)	0.05	0.13	0.00	0.04	22

Table 27. *Coal-quality statistics for the Upper Hiawatha bed of the Blackhawk Formation, Wasatch Plateau coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	8.99	25.09	2.79	5.07	34
Btu/lb	11,503	12,396	9,443	750	29
Fix. Carbon (%)	45.28	51.95	34.66	4.03	30
Vol. Matter (%)	37.73	44.52	33.10	2.45	32
Sulfur (%)	0.54	1.46	0.28	0.24	34
Moisture (%)	8.04	12.9	2.66	1.87	31
Carbon (%)	64.90	69.75	53.09	4.80	22
Hydrogen (%)	4.59	5.20	3.99	0.32	22
Nitrogen (%)	1.13	1.44	0.96	0.12	22
Oxygen (%)	11.07	18.0	9.22	1.67	22
Chlorine (%)	0.01	0.11	0.00	0.02	21

Table 28. *Original, in-place, minable resources for the Carbon and Emery Counties portion of the Wasatch Plateau coalfield (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; based on Doelling, 1972).*

County	T. 12 to 15 S. R. 6 to 8 E.	T. 16 to 18 S. R. 6 to 8 E.	T. 19 to 21 S. R. 6 to 8 E.	Total
Carbon	1,816.8	—	—	1,816.8
Emery	798.5	1,865.1	285.4	2,949.0
Total	2,615.3	1,865.1	285.4	4,765.8

Table 29. *Thickness range of minable coal beds of the Emery coalfield (modified from Doelling, 1972).*

Emery Field Beds	Thickness Range (ft)
M bed	0 to 4
J bed	0 to 13
I bed	3 to 30
G bed	3 to 6
F bed	0 to 4
C bed	3 to 20
A bed	3 to 16

Table 30. *Coal-quality statistics for the A bed, Ferron Sandstone Member of the Mancos Shale, southern Emery coalfield (as-received basis).*

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	13.22	29.33	4.70	8.76	10
Btu/lb	11,979	13,529	9,504	1,393	10
Fix. Carbon (%)	46.32	51.01	37.88	4.38	10
Vol. Matter (%)	37.04	41.97	28.65	4.63	10
Sulfur (%)	0.78	1.46	0.37	0.33	10
Moisture (%)	3.43	5.10	2.60	0.87	10
Carbon (%)	66.63	74.84	53.44	7.70	9
Hydrogen (%)	4.85	5.50	3.88	0.66	9
Nitrogen (%)	1.25	1.47	0.88	0.17	9
Oxygen (%)	10.48	15.50	8.52	2.46	9
Chlorine (%)	0.03	0.06	0.00	0.02	8

Table 31. Coal-quality statistics for the C bed, Ferron Sandstone Member of the Mancos Shale, southern Emery coalfield (as-received basis).

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	14.54	23.60	6.60	6.81	6
Btu/lb	11,275	12,300	9,965	913	6
Fix. Carbon (%)	43.42	47.90	39.60	3.39	6
Vol. Matter (%)	37.79	40.70	33.40	2.79	6
Sulfur (%)	1.26	2.10	0.66	0.63	6
Moisture (%)	4.25	5.21	2.30	1.14	6
Carbon (%)	64.98	68.60	58.90	4.48	4
Hydrogen (%)	5.30	5.70	4.80	0.42	4
Nitrogen (%)	1.18	1.30	1.00	0.15	4
Oxygen (%)	14.65	16.40	12.70	1.74	4
Chlorine (%)	—	—	—	—	—

Table 32. Coal-quality statistics for the G bed, Ferron Sandstone Member of the Mancos Shale, southern Emery coalfield (as-received basis).

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	14.15	39.09	3.74	9.40	12
Btu/lb	11,630	13,319	8,020	1,520	12
Fix. Carbon (%)	43.48	50.49	29.69	5.71	12
Vol. Matter (%)	38.06	43.81	25.72	4.62	12
Sulfur (%)	1.03	2.22	0.09	0.83	7
Moisture (%)	4.30	8.80	3.14	1.60	12
Carbon (%)	61.96	72.81	44.81	9.43	7
Hydrogen (%)	4.67	5.10	3.35	0.64	7
Nitrogen (%)	1.24	1.52	1.06	0.18	7
Oxygen (%)	10.06	18.90	5.35	4.28	7
Chlorine (%)	0.03	0.06	0.00	0.03	7

Table 33. Coal-quality statistics for the I bed, Ferron Sandstone Member of the Mancos Shale, southern Emery coalfield (as-received basis).

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	8.20	17.26	4.01	2.95	47
Btu/lb	12,179	13,139	8,467	889	43
Fix. Carbon (%)	47.4	51.9	37.3	2.9	46
Vol. Matter (%)	38.91	43.89	34.30	1.72	46
Sulfur (%)	1.12	6.58	0.31	1.11	46
Moisture (%)	5.5	16.7	2.8	2.4	47
Carbon (%)	68.58	73.8	61.25	3.87	13
Hydrogen (%)	5.2	5.7	4.8	0.3	13
Nitrogen (%)	1.26	1.35	1.10	0.07	13
Oxygen (%)	13.06	18.80	5.82	3.42	13
Chlorine (%)	0.05	0.07	0.03	0.02	2

Table 34. Coal-quality statistics for the Ferron zone, Ferron Sandstone Member of the Mancos Shale, northern Emery coalfield (dry basis).

	Mean	Maximum	Minimum	Standard Deviation	Sample Population
Ash (%)	21.8	85.9	4.6	14.4	427
Btu/lb	12,689	13,417	11,786	—	3
Fix. Carbon (%)	43.7	61.2	4.6	9.6	427
Vol. Matter (%)	34.5	57.1	9.5	5.5	427
Sulfur (%)	1.97	10.08	0.21	1.44	426
Carbon (%)	67.04	78.26	40.50	7.82	354
Hydrogen (%)	4.95	6.32	2.22	0.55	354
Nitrogen (%)	1.24	2.03	0.42	0.25	354
Oxygen (%)	7.91	15.65	0.20	1.53	355
Chlorine (%)	—	—	—	—	—

Table 35. *Original, in-place, minable coal resources for the southern Emery coalfield by county (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; from Doelling, 1972).*

County	Demonstrated	Inferred	Total
Emery	441.763	388.781	830.544
Sevier	234.792	365.050	599.842
Total	676.555	753.831	1,430.386

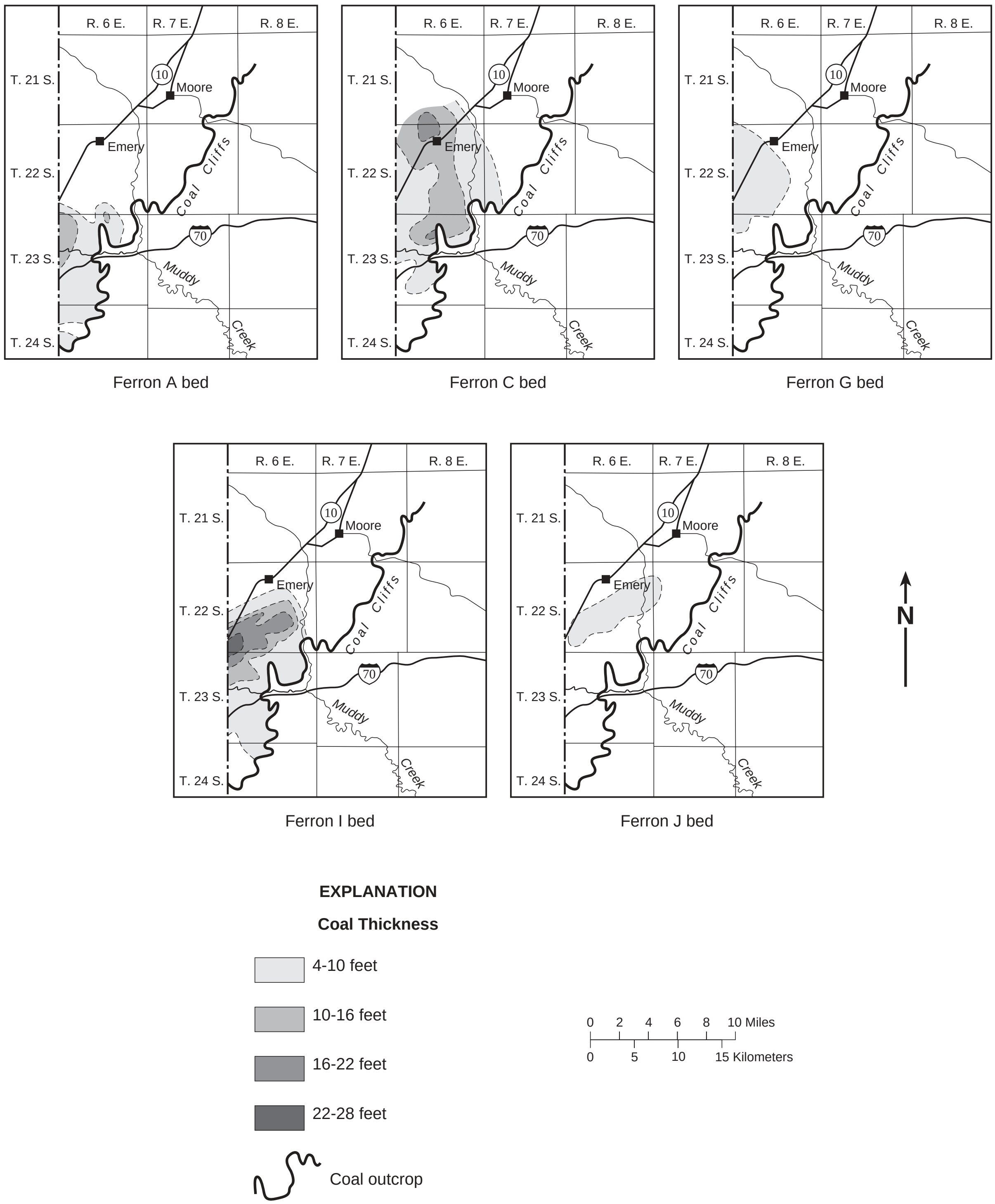


Figure 25. *Total coal isopach for Ferron coal beds in southern Ferron coalfield, Emery County, Utah (modified from Ryer, 1981).*

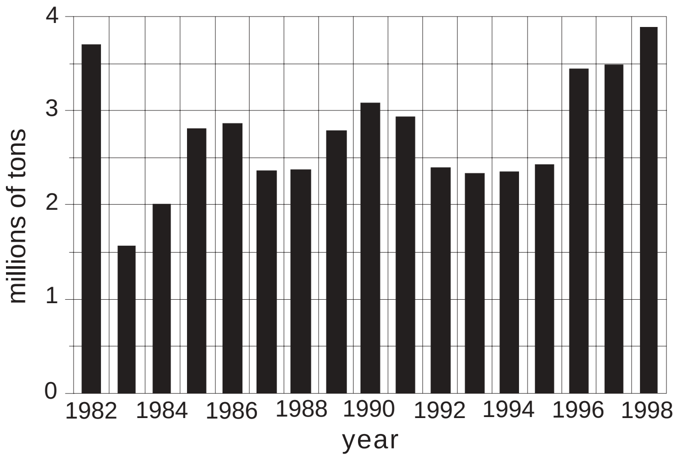


Figure 26. *Annual coal production, Book Cliffs coalfield, Utah, 1982 to 1998 (from Jahanbani, 2000).*

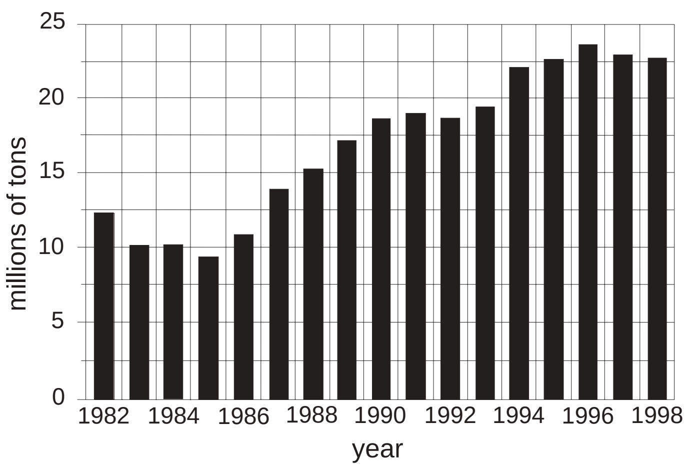


Figure 27. *Annual coal production, Wasatch Plateau coalfield, Utah, 1982 to 1998 (from Jahanbani, 2000).*

In 1999, the ten active mines in the field produced 23.57 million short tons (21.43 million metric tons) of coal, or about 89 percent of the state's total. Production from this field has increased rapidly since the mid-1980s, doubling since 1987.

Emery coalfield: The Emery coalfield's last active mine ceased production in 1990 when Consolidation Coal Company idled its Emery mine. Through 1994, this mine's activity was limited to shipping a very small quantity of coal from its stockpile, and in 1995, Consolidation Coal decided to seal the portals of the mine and limit maintenance to pumping water to keep the mine from flooding.

Production from the Emery coalfield has been erratic, but generally decreased from 1982 to 1990 (figure 28). Falling coal prices and the lack of nearby rail transportation have undoubtedly hindered large-scale development of the abundant coal resources of this field.

Current Production and Exploration Activities

According to the Utah Energy Office, the state's 2000 coal sales reached 27.63 million short tons (25.06 million metric tons) from production of 26.92 million short tons (24.41 million metric tons) (Jahanbani, 2001). Increased

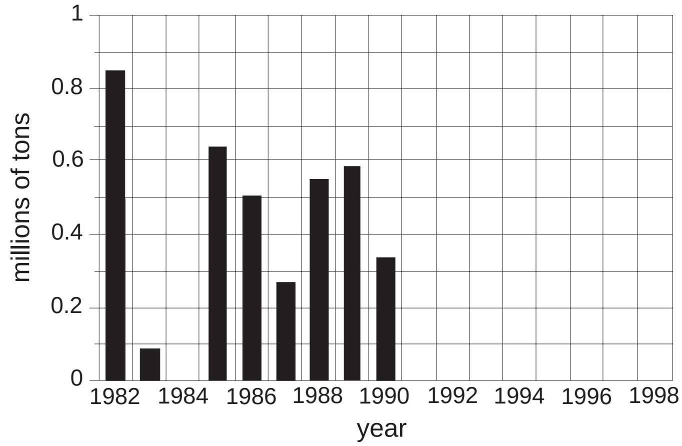


Figure 28. *Annual coal production, Emery coalfield, Utah, 1982 to 1998 (from Jahanbani, 2000).*

demand for Utah coal has not yet translated to higher prices, and the average price paid per ton of coal edged lower again in 2000. Most of the present coal tonnage comes from large, highly productive mines equipped with longwall mining machines; five of Utah's mines rank among the top 20 of the nation's largest underground coal mines.

Coal industry structure: The Utah coal industry is highly competitive and production has become concentrated among fewer, but larger, mines. In 1982, for example, 29 coal mines were operated by 16 companies, but by 2000 there were only 12 coal mines operated by six parent companies, and all of the operating mines were in either the Book Cliffs or the Wasatch Plateau coalfield. The six parent coal companies operating Utah mines in 2000 were Andalex Resources Incorporated, Canyon Fuel Company LLC (Arch Coal), CO-OP Mining Company, Interwest Mining Company, Lodestar Energy Incorporated, and Plateau Mining Company (RAG Coal).

Andalex Resources Incorporated: Andalex Resources has operated coal mines in Utah since 1980, when it opened the Tower Division to operate the Aberdeen, Apex, and Pinnacle mines in the Book Cliffs field northeast of Price. Mining at this division is currently limited to a longwall operation at the Aberdeen mine. In late 1994, Nevada Power sold Andalex Resources its 50 percent interest in Genwal Resources which operated the Crandall Canyon mine in the Wasatch Plateau coalfield. Since buying a 50 percent stake and assuming the role of operator at that mine, Andalex has expanded the production capacity of the mine by leasing an additional 18 million short tons (16.4 million metric tons) of recoverable federal coal reserves and installing a longwall mining machine. In 1996, Andalex Resources also expanded the coal-handling capacity of its Wildcat loadout facility to 3.5 million short tons (3.2 million metric tons) per year to handle the company's growing production. Production from Andalex's Tower Division mine (Aberdeen) and the Crandall Canyon mine for 2000 was 1.58 million short tons (1.43 million metric tons) and 3.88 million short tons (3.52 million metric tons), respectively. These two mines accounted for 20.3 percent of Utah's 2000 coal production.

In addition to these existing mines, Andalex Resources is constructing a new mine on the B Canyon property purchased in early 1997 from British Petroleum Company. The new mine, named West Ridge, is located in the Book Cliffs coalfield northwest of the town of Sunnyside. Construction on this new 3-million-short-ton-per year (2.7 million metric ton) mine began in 1999, and the longwall machine was installed in 2001. Development work produced 0.53 million short tons (0.48 million metric tons) of coal in 2000. The coal is trucked to Andalex's existing Wildcat loadout near Helper.

Canyon Fuel Company LLC: In March 1998, ARCO Coal Company sold its 65 percent interest in the Canyon Fuel Company LLC to Arch Coal Company (the remaining 35 percent is owned by Itochu Corporation). Canyon Fuel owns three Utah coal operating companies and a 9 percent interest in the Los Angeles Export Terminal Company. The three operating companies owned by Canyon Fuel are: the Soldier Creek Coal Company, the Southern Utah Fuel Company, and the Utah Fuel Company.

Soldier Creek Coal Company operated the Soldier Canyon mine in the Book Cliffs coalfield, and produced 0.57 million short tons (0.52 million metric tons) of coal in 1998, its last year of production. The Soldier Creek Coal Company has shifted production to its new 2-million short-ton-per-year (1.8 million metric ton) Dugout Canyon mine, which is located on state coal leases a few miles east of the Soldier Canyon mine. Initial coal production from the new mine began in 1998 and totaled 0.17 million short tons (0.15 million metric tons) from the Rock Canyon coal bed; 2000 production increased to 0.50 million short tons (0.45 million metric tons). The Gilson bed will also be mined in the future.

Southern Utah Fuel Company operates the SUFCO mine in the Sevier County portion of the Wasatch Plateau coalfield. This longwall mine produced 5.91 million short tons (5.36 million metric tons) of coal from the Upper Hiawatha bed in 2000. In May 1999, to ensure an extended productive life for the SUFCO mine, Canyon Fuel leased The Pines federal coal tract. This tract, which lies directly east of the SUFCO mine, adds approximately 70 million short tons (63.6 million metric tons) of additional recoverable coal to the mine's reserve base.

Utah Fuel Company operates one longwall mine in the northern part of the Wasatch Plateau coalfield: the Skyline No. 1 mine near Scofield. The Skyline mine produced 3.02 million short tons (2.73 million metric tons) of coal in 2000 from the Lower O'Connor bed. The recoverable coal reserves of the Utah Fuel Company were augmented by the acquisition in May 1996 of the Winter Quarters federal lease tract containing about 28 million short tons (25.5 million metric tons) of minable reserves. In 1998, the company applied for 2,612 acres (1,057 ha) of additional federal coal to the west of its holdings in a tract known as the Flat Canyon tract; the tract may be offered for sale in 2002.

The 2000 production from all of the Utah coal mines controlled by Canyon Fuel Company totaled 9.43 million short tons (8.55 million metric tons). This amounted to 35.0 percent of Utah's total 2000 coal production. These mine properties were estimated to contain 300 million short tons (272.7 million metric tons) of recoverable coal according to a news release announcing the Canyon Fuel Company purchase by Arch Coal Company.

CO-OP Mining Company: CO-OP Mining Company, a family-owned company, operates the Bear Canyon No. 1 mine. This room-and-pillar mine lies in the Emery County portion of the Wasatch Plateau coalfield. In 2000, production from this mine was 1.06 million short tons (0.96 million metric tons), or 3.9 percent of the state's total production. As with other Utah coal operators, CO-OP Mining recently added to its coal reserves by purchasing the Mohrland property from the Intermountain Power Agency in early 1997. This nearly 3,000-acre (1,214 ha) tract lies due east of the Bear Canyon No. 1 mine, but is separated from it by a major fault. The Mohrland property also includes an existing loadout on the Utah Railway. CO-OP's recoverable coal reserves are estimated to be in excess of 30 million short tons (27.3 million metric tons).

Plateau Mining Company: Plateau Mining Company was sold to RAG International Mining Company of Essen, Germany in mid-1999. Plateau Mining has been the operator of the Star Point mine complex in the Wasatch Plateau coalfield for a number of years. Production at the Star Point No. 2 mine for 2000 was 0.09 million short tons (0.08 million metric tons). Coal reserves for longwall mining at the Star Point mine complex are depleted so the company planned to develop a new mine in the Book Cliffs coalfield north of Helper. In April 1996, Plateau Mining received its permit for the 5-million-short-ton-per-year (4.5 million metric ton) Willow Creek mine from the Utah Division of Oil, Gas and Mining, and the first coal was produced in September 1996. Coal production for the Willow Creek mine in 2000 totaled 1.35 million short tons (1.22 million metric tons), but the mine was sealed in August 2000 when the second fire in three years broke out in the gob behind the longwall mining area. The Willow Creek mine has remained sealed since then and is apparently for sale. The Star Point mine was permanently closed in April 2000 when its reserves were exhausted. Plateau's coal production from both of its mines in 2000 totaled 1.44 million short tons (1.30 million metric tons) and accounted for 5.3 percent of the state's total for that year.

Interwest Mining Company: Interwest Mining Company, a subsidiary of PacifiCorp, operates two longwall mines in the Emery County portion of the Wasatch Plateau coalfield. Interwest Mining purchased the Trail Mountain mine from ARCO Coal Company in 1992 and idled the mine until the second half of 1995, when longwall reserves at the company's Cottonwood mine were depleted. The Trail Mountain mine resumed full operation in 1996 using a longwall machine and produced 4.17 million short tons (3.78 million metric tons) of coal in 2000 from the Hiawatha bed. Although Interwest Mining applied in 1992 to lease the Cottonwood Canyon federal tract containing an additional 75 million short tons (68.2 million metric tons) of recoverable coal in the Hiawatha bed to the north and west of the Trail Mountain mine, it later dropped its interest in this tract. In April 2000, the company announced that it would close the Trail Mountain mine in April 2001 when the coal reserves in its existing leases were exhausted.

Interwest Mining's second operation, the Deer Creek mine, produces coal from the Blind Canyon bed. Longwall production from this mine in 2000 totaled 4.26 million short tons (3.86 million metric tons). Total 2000 production for the Interwest Mining Company operations was 8.43 million short tons (7.65 million metric tons), or 31.3 percent of the state's total.

Lodestar Energy Incorporated: In July 1999, Lodestar Energy Incorporated, a subsidiary of the Renco Group, acquired the Wasatch Plateau coalfield properties of both White Oak

Mining and Construction and Horizon Coal Corporation from Scott and Tod Kiscaden. White Oak had purchased the properties of Valley Camp of Utah, Incorporated from the Quaker State Oil Company in September 1993. White Oak had resumed production at the Belina No. 2 mine (Lower O'Connor bed), which had been shut down since the expiration of Valley Camp's last contract in June 1992. White Oak's coal production from the Belina mine has declined somewhat since 1993, and in 2000 totaled 0.57 million short tons (0.51 million metric tons). The Belina mine's reserves will be exhausted in early 2001, and the company has announced plans to move production to its companion operation, the Horizon mine.

The Horizon Coal Corporation began permitting a new mine to develop coal reserves behind the abandoned Blue Blaze/Consumers Mine in the Gordon Creek area in 1997. Production at the Horizon mine began in early 1998 and totaled 0.11 million short tons (0.10 million metric tons). Permitting problems delayed full mine development, and production for 1999 was only 0.05 million short tons (0.04 million metric tons); the mine was idled in 2000. When permitted, full production capacity of the mine is expected to be 1.5 million short tons (1.36 million metric tons) per year. To allow for an extended life of the new mine, Horizon Coal leased about 1,288 acres (497 hectares) of federal coal in 1998 in the Beaver Creek tract. This tract, which lies to the north of existing Horizon holdings, contains an additional 6 million short tons (5.5 million metric tons) of coal in the Hiawatha bed. Total coal production from the White Oak and Horizon operations amounted to about 2 percent of Utah's total coal production for 2000.

Coal markets: Utah coal is shipped to utility and industrial markets mainly in the western United States, including the states of Utah, California, Nevada, Washington, Arizona, Idaho, and Colorado. Starting in 1994 the Federal Clean Air Act of 1990 required the implementation of a new phase of emission standards which resulted in increased shipments of Utah's low-sulfur coal to markets in the eastern and central United States. Those eastern and central states receiving Utah coal in 2000 included Illinois, Missouri, Nebraska, Pennsylvania, Tennessee and Wisconsin (Jahanbani, 2001). Utah's high-quality, bituminous coals also have a significant export market to several Pacific Rim countries. Increased demand for Utah's high-quality coal has caused production to increase about 22 percent from 1993 to 1999. This rapid growth in production has caused coal companies to look for ways to expand production at existing operations and to look for new opportunities to open mines in both previously mined and unmined areas of central Utah.

The market segments served by Utah coal operators in 2000, listed in decreasing order, included the electric utility, industrial, Pacific Rim export, and residential/commercial segments. Statistical data from the Utah Office of Energy and Resource Planning (Jahanbani, 2001) on coal sales and mines from 1996 to 2000 are summarized in table 36.

Potential for Additional Discoveries and/or Development

Book Cliffs coalfield: Although production from this field has been relatively steady since the early 1990s, it appears that production will grow with the renewed interest in developing the abundant coal resources of this field. Three new mines in this field had been planned by three separate companies. Unfortunately, Plateau Mining's plans for a 5 million-short-ton-per-year (4.5 million metric ton) mine are uncertain after the new mine experienced two serious mine fires in a three-year period. The mine is currently sealed. As of 2000, Canyon Fuels has begun development of the new 3.5 million-short-ton-per-year (3.18 million metric ton) Dugout Canyon mine east of Soldier Canyon. Installation of a longwall machine at the Dugout Canyon mine is planned for mid-2001. Finally, Andalex Resources purchased the B Canyon property northwest of the town of Sunnyside from British Petroleum and began initial production at the 3 million short-ton-per-year (2.73 million metric ton) West Ridge mine in October 1999. Installation of the West Ridge longwall machine is planned for mid-2001. At full production, these new mines could push annual coal production from the Book Cliffs field to a record 6.5 million short tons (5.91 million metric tons).

Original in-place coal reserves for the Book Cliffs field are estimated to be 3,527.3 million short tons (3,206.7 million metric tons)(Doelling, 1972; and Anderson, 1983). Modifying Doelling and Smith's (1982) estimate of the remaining recoverable coal reserves in the Book Cliffs coalfield to account for the lowered coal-reserve estimate of Anderson (1983), and accounting for the coal produced from 1982 through 2000 results in remaining recoverable coal reserves for the Book Cliffs field of 745.5 million short tons (676.3 million metric tons) (table 37). Reserves are sufficient to provide about 240 years of production at 2000 production

Table 36. *Utah coal sales, 1996-2000 (figures are in millions of short tons; 1 short ton equals 0.909 metric ton).*

	1996	1997	1998	1999	2000*
Total Sales	27.816	25.407	26.974	26.180	27.624
Electric Utilities	19.205	18.909	20.516	20.072	20.915
Industrial	2.832	2.829	3.429	3.359	3.531
Pacific Rim (export)	5.468	3.513	2.735	2.567	2.960
Residential/Commercial	0.311	0.156	0.294	0.182	0.223
No. of Mines	13	15	15	13	12
No. of Operators	9	10	10	10	10
Ave. Price/ton	$18.50	$18.34	$17.83	$17.36	$16.93

*estimated values

rates, but only 115 years if production increases to the 6.5 million-short-tons-per-year (5.91 million metric tons) rate of the planned mines. In addition, a significant portion of the remaining reserves lie under deep cover (> 2,500 feet [762 m]) or are less than 6 feet (1.8 m) thick, and may not be minable using current mining technology.

Wasatch Plateau coalfield: Original in-place minable resources in the Wasatch Plateau coalfield were calculated by the Utah Geological Survey (Doelling, 1972) to be 6,379 million short tons (5,799 million metric tons). Carbon County contains 1,817 million short tons (1,652 million metric tons) (28 percent) of those resources, and Emery County contains 2,949 million short tons (2,681 million metric tons) (46 percent) (table 38). Reported mine recoveries in a particular seam are generally 50 percent or more, but the amount of original, in-place coal lost at property boundaries, or due to inadequate stratigraphic separation of beds, faulting, past mining techniques, and oxidation brings the actual historical recovery rate closer to 28 percent. The remaining recoverable resources in the Wasatch Plateau field are estimated at 1,312 million short tons (1,190 million metric tons) of coal after subtracting mined-out coal areas, and assuming a future recovery rate similar to historical levels of 28.4 percent. The remaining resources are sufficient for about 57 more years of production at 2000 annual rates; however, production from this field has been increasing. Current mining practices only occasionally reach depths of 2,500 feet (762 m) and do not include seams thinner than 6 feet (1.8 m), so the expected life of the Wasatch Plateau field is considerably less than the 57 years indicated by Doelling's resource estimates.

Emery Coalfield: Original in-place resources for the Emery coalfield were estimated to be 2,065 million short tons (1,877 million metric tons), of which 1,430.4 million short tons (1,300.4 million metric tons) was considered the minable reserve base (table 39) (Doelling,1972). Recoverable coal resources for this field were estimated at 427.5 million short tons (388.6 million metric tons) (Doelling and Smith, 1982). Cumulative coal production for the field through 1999 was 9.5 million short tons (8.6 million metric tons), all from the Emery County portion of the field. Subtracting out the produced coal leaves the Emery field with remaining recoverable coal reserves of 418.0 million short tons (380.0 million metric tons).

Coal Resin Resources

Coal resin, or resinite, is a potentially valuable product used by the ink, plastics, paint, and other industries that has been produced as a by-product of coal mining in Carbon and Emery Counties in the past but is not currently being produced. The resinite-bearing coal beds are found in the Upper Cretaceous Blackhawk Formation in the Wasatch Plateau and Book Cliffs coalfields. The vertical stacking and intertonguing relationships of the various resin-bearing coals and marine sandstone units of the Blackhawk Formation are shown in figure 29.

Coal is composed of macerals, which are components derived from the disaggregation of plant material. Macerals

Table 37. *Recoverable coal reserve budget for the Book Cliffs coalfield by county (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; modified from Doelling and Smith, 1982).*

County	Original Reserve Base	Original Recoverable Reserves	Production (through 2000)	Remaining Reserves
Carbon	3,176.8	931.0	262.9	668.1
Emery	350.5	102.7	25.3	77.4
Total	3,527.3	1,033.7	288.2	745.5

Table 38. *Recoverable coal reserve budget for Wasatch Plateau coalfield by county (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; (modified from Doelling and Smith, 1982).*

County	Original Reserve Base	Original Recoverable Reserves	Production (through 2000)	Remaining Reserves
Carbon	1,816.8	516.7	143.0	373.7
Emery	2,949.0	838.7	279.2	559.5
Sevier	1,613.1	458.8	79.6	379.2
Total	6,378.9	1,814.2	501.8	1,312.4

Table 39. *Recoverable coal reserve budget for the Emery coalfield by county (in millions of short tons for coal beds ≥ 4 feet thick and with ≤ 3,000 feet of overburden; modified from Doelling and Smith, 1982).*

County	Original Reserve Base	Original Recoverable Reserves	Production (through 1999)	Remaining Reserves
Emery	830.5	248.2	9.5	238.7
Sevier	599.8	179.3	0.0	179.3
Total	1,430.4	427.5	9.5	418.0

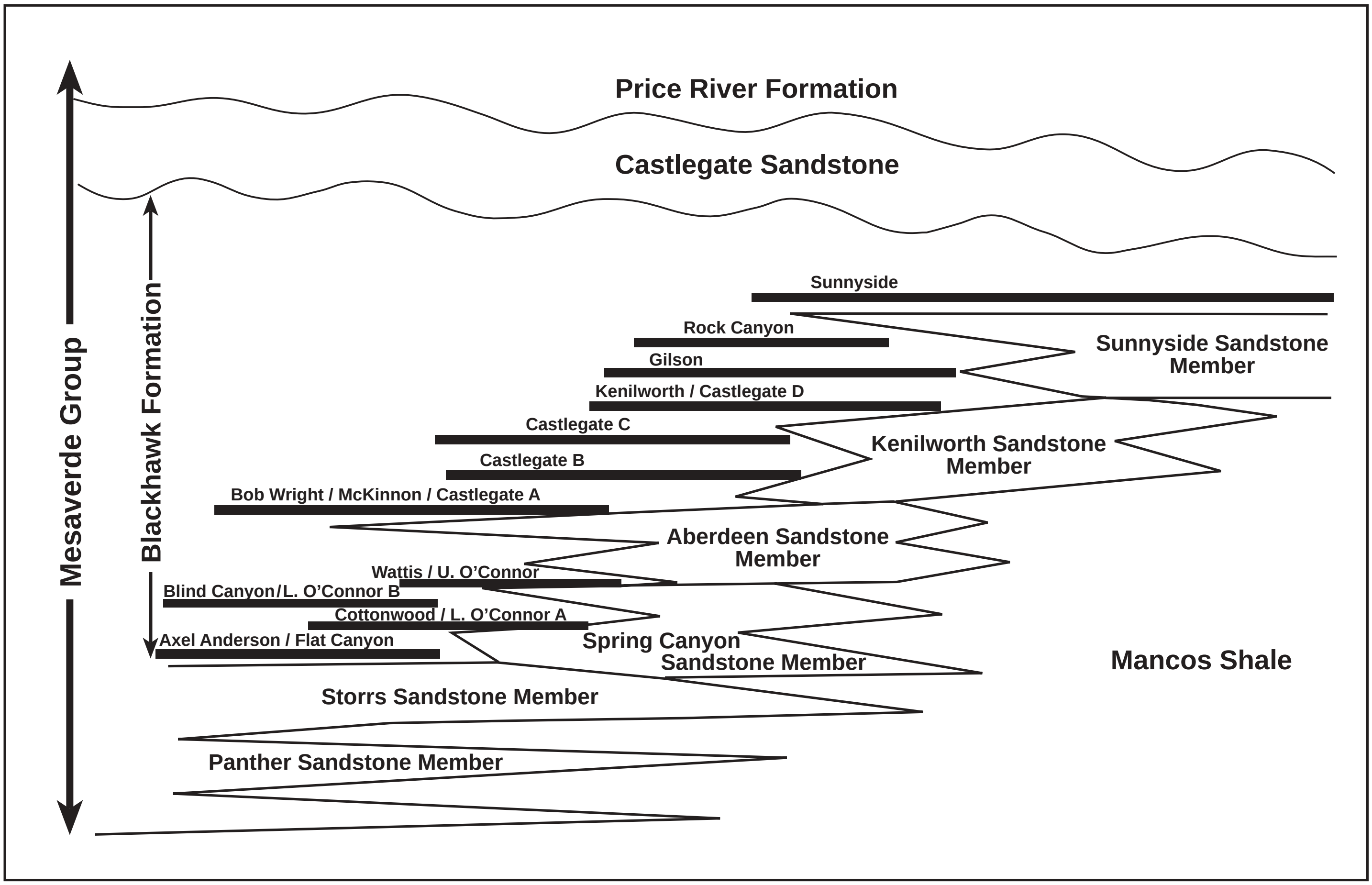


Figure 29. *Diagrammatic cross section showing stacking of sandstone bodies and coal beds of the Blackhawk Formation, central Utah.*

are classified into three major groups: vitrinite (woody material), inertinite (carbonized plant matter), and exinite (waxy or sticky plant coatings or secretions). The term resinite is used by coal petrographers for a subgroup of the exinite macerals. Poinar (1991) defines resinite as semi-fossilized or fossilized resin found in association with coal.

Although resinite, or coal resin, forms a small percentage of almost all coals, it is particularly abundant in coals from some western U.S. states, especially coals from Utah (Crelling and others, 1982). Resinite in coal generally occurs either as fine, disseminated grains associated with the coaly matrix (occluded), or as coarse, ovoid bodies and veins filling cleats (non-occluded) (Poinar, 1991). Cleat-filling resinite commonly shows flow structures and coal inclusions, and is thought to be secondary, mobilized by increased heat and pressure during the bituminous coalification step (Crelling and others, 1982). Resinite is rarely found in anthracite or other high rank coals, because the resinite macerals are altered and destroyed by the extreme heat and pressure involved in the higher stages of coalification (Poinar, 1991).

Known Occurrences and Characteristics

Physical properties of resinite: Resinite is a heterogenous mixture of organic compounds derived from plant resin that varies in color in hand specimens from yellow to amber to light brown to dark brown. Under microscopic examination resinite fluoresces green to dark orange. Yu (1991) concluded that the microscopic color of resinite darkens with increasing thermal alteration. He postulated that thermal alteration changed both the resinite chemistry and its light-absorption characteristics.

Resinite is a glassy, brittle substance with conchoidal fracture. It has a melting point of 302 to 392°F (150 to 200°C), and a Mohs hardness of about 2.5 (Yu, 1991). In sub-bituminous and bituminous coals, resinite is characterized by a density of 62.43 to 79.91 lbs/ft^3 (1.00 to 1.29 g/cm^3), which is considerably lower than that of the other coal macerals (vitrinite 79.29 to 89.27 lbs/ft^3 [1.27 to 1.43 g/cm^3], and inertinite >96.64 lbs/ft^3 [1.55 g/cm^3]). This density difference permits resinite to be separated from coal using flotation or gravity methods.

Chemical properties of resinite: The resinite coal maceral is a hydrogen-rich, volatile-rich fraction of coal (Yu, 1991; Yu and others, 1991). Yu (1991) found that the lightest colored resinite (macroscopically) had the highest volatile-matter content, and that the darker colored resinites contained incrementally greater amounts of fixed carbon, but at most no more than a few percent. The average proximate analysis for two resinite samples from the Hiawatha bed shows that this maceral fraction is almost completely composed of volatile matter (table 40). For comparison purposes, table 40 also lists proximate analyses for two raw coal samples (Buranek and Crawford, 1943; Yu and others, 1992) and for one sample of coal from which the resin was removed (Klepetko, 1947).

Table 40. *Proximate analyses of four raw coal and coal fraction samples from the Wasatch Plateau coalfield.*

Sample Type	Bed Name	Moisture(%)	Ash(%)	Volatile Matter(%)	Fixed Carbon(%)	Btu/lb
Resinite[1]	Hiawatha	0.21	0.12	93.60	5.07	18,312
Raw coal[1]	Hiawatha	1.45	11.51	44.40	42.64	15,538
Raw coal[1]	Blind Canyon	4.6	5.3	40.1	49.9	13,290
Coal(minus resin)[2]	Blind Canyon	—	8.33	42.59	49.08	13,132

[1] reported on as-received basis
[2] reported on a dry basis

An understanding of how the chemistry of the coal changes before and after resinite removal would ideally come from analyses of the differing coal products derived from a single source. Although the samples in table 40 should not be directly compared because they are not from a single source, the analyses show that the resinite is distinctly different in composition from the raw coal. Further, the coal quality of the Blind Canyon bed appears to be only slightly changed when the small fraction of resinite is removed from the raw coal. However, additional sampling and testing is needed to determine more precisely how the coal quality changes when the resin fraction is removed. Coals with higher resinite contents would probably have greater quality changes when the resinite was removed.

Four ultimate analyses of the resinite from Utah coals are given in table 41. The first three resinite samples were analyzed in the 1920s (Steele, 1924; Benson, 1925), when the standard analytical procedures did not include testing for nitrogen and sulfur. The last resinite and the one "whole" coal analyses are from Yu and others (1991).

Comparison of the ultimate analyses for the "whole" coal and the extracted resinite samples show that the resinite is richer in hydrogen and generally depleted in oxygen. The resinite may also be depleted in nitrogen and sulfur in comparison with the "whole" coal.

Resinite concentration in Utah coal: The study of resinite in Utah coal began in the 1920s (Steele, 1924; Benson, 1925). The resinite content of coal from 27 mines was determined by the Utah Geological Survey (UGS) (Sommer and others, 1991) as part of a cooperative program with the University of Utah to establish a coal sample bank. Resinite and coal-rank data from Sommer and others (1991) are listed in table 42.

The resinite content of all 27 samples averages 2.5 percent, and varies from 0.7 to 7.4 percent. Resinite contents show much variability from mine to mine, and from samples taken from the same bed. In general, coal beds of lower rank tend to have higher resinite contents than those of higher rank. For example, the lower rank Wasatch Plateau field coals tend to have higher resinite contents (average of 3.0 percent) than coals from the Book Cliffs field (average of 1.7 percent). The highest resinite contents are generally 2.5 to 3 times the average value, and come from the Castlegate A, Blind Canyon, and Wattis beds of the Wasatch Plateau coalfield (table 42).

Additional resinite-content analyses have been compiled by the UGS in a comprehensive statewide coal petrographic database that includes data from drill core as well as mine samples (Hucka and others,1997). This database contains resinite analyses for 257 samples from the Wasatch Plateau and Book Cliffs coalfields (table 43).

Table 43 presents basic resinite-content statistics for individual coal seams in the database with five or more analyses. The resinite contents from the UGS database (table 43) show some differences from those reported by Sommer and others (1991) (table 42). Resinite contents in table 43 show a broader range of values, from 0.2 to 28.3 percent of the coal, and the average resinite content (3.09 percent) is slightly higher. Coalbeds listed in table 43 that have above average resinite contents are the Hiawatha, Upper Hiawatha, Blind Canyon, and all four Castlegate beds (Hucka and others, 1997). The Wattis bed, which had a high resinite content in table 42, was not included in table 43 because it had fewer than five analyses. However, the two analyses available for the Wattis bed were both higher than the 3.09 percent resinite average.

Because coal resin is brittle and easily crushed, it is preferentially concentrated with the fine-sized coal fraction during mining. Consequently, the U.S. Fuel Company produced coal resin at its northern Wasatch Plateau mine by processing only the coal fines. Coal fines from this mine contained 8 to 9 percent resin (Buranek and Crawford, 1943). The elevated concentration of resinite in the fine-coal fraction also appears in analyses of different size fractions from two grab samples collected by the UGS from the waste and coal stockpiles at the Star Point #2 mine of Cyprus Plateau Mining Company (table 44). Coal waste is generated from the wash plant reject material and from run-of-mine product with too much rock dilution.

The elevated resinite concentration apparent in the fine fraction of the two grab samples suggests that: (1) simple screening could be useful in helping concentrate resinite, and (2) resinite could be produced from the coal waste piles as well as from mined coal.

Resinite resources: The coal beds of the lower Blackhawk Formation in the Wasatch Plateau and western Book Cliffs coalfields have the highest resinite content, and offer the most potential for resinite recovery. These coal beds include the Hiawatha, Upper Hiawatha, and Blind Canyon beds above the Spring Canyon Sandstone Member, and the Wattis and Castlegate A, B, C, and D beds above the Aberdeen Sandstone Member of the Blackhawk Formation. Coal resources for the above-mentioned beds have been estimated by Doelling (1972), Sanchez and others (1983a, 1983b), Sanchez and Brown (1983, 1986, 1987), Sanchez and Ellis (1987), and Brown and others (1987). Their estimates of in-place, original coal resources and an estimate of the associated resinite resources are summarized in table 45.

In table 45 the recoverable resinite is assumed to be 25 percent of the total resinite contained in the in-place coal

Table 41. Ultimate analyses of resinite and whole coal samples from the Wasatch Plateau coalfield (reported on a dry, ash-free basis).

Sample Type	Bed Name	Carbon(%)	Hydrogen(%)	Oxygen(%)	Nitrogen(%)	Sulfur(%)	Density(g/cm^3)
Resinite	Castlegate A	80.4	9.4	10.2	—	—	0.99
Resinite	Hiawatha	82.62	10.14	6.81	—	—	1.03
Resinite	Hiawatha	83.61	10.10	5.86	—	—	1.03
Resinite	Hiawatha	85.21	10.72	3.50	0.37	0.20	1.04
Coal	Hiawatha	81.45	6.74	9.71	1.44	0.66	1.31

Table 42. Resinite content and coal rank of 27 Utah mine samples (from Sommer and others, 1991). For coal rank: hvCb = high volatile C bituminous; hvBb = high volatile B bituminous.

Coalfield	Mine Name	Bed Name	Resinite (%)	Coal Rank
Wasatch Plateau	Star Point #2	Blind Canyon	3.2	hvCb
Wasatch Plateau	Deer Creek	Blind Canyon	4.4	hvCb
Wasatch Plateau	King #4	Blind Canyon	3.0	hvCb
Wasatch Plateau	Belina #1	U. O'Connor	1.2	hvCb
Wasatch Plateau	Skyline #1	U. O'Connor	0.7	hvCb
Wasatch Plateau	Skyline #3	L. O'Connor	0.8	hvCb
Wasatch Plateau	Belina #2	L. O'Connor	1.4	hvCb
Wasatch Plateau	Beaver Cr. #9	Hiawatha	3.3	hvCb
Wasatch Plateau	King #6	Hiawatha	2.9	hvCb
Wasatch Plateau	Crandall Cyn.	Hiawatha	1.4	hvCb
Wasatch Plateau	Bear Cyn. #1	Hiawatha	1.1	hvCb
Wasatch Plateau	Cottonwood	Hiawatha	1.8	hvCb
Wasatch Plateau	SUFCO	U. Hiawatha	2.1	hvCb
Wasatch Plateau	Bear Cyn. #1	U. Hiawatha	2.4	hvCb
Wasatch Plateau	Star Point #2	Wattis	7.3	hvCb
Wasatch Plateau	Gordon Cr. #7	Castlegate A	7.4	hvCb
Wasatch Plateau	Beaver Cr. #8	Castlegate A	6.8	hvCb
Book Cliffs	Aberdeen	Castlegate A	2.8	hvCb
Book Cliffs	Castlegate #3	Sub Seam #3	2.3	hvCb
Book Cliffs	Pinnacle	Pinnacle	1.4	hvCb
Book Cliffs	Pinnacle	Gilson	2.0	hvBb
Book Cliffs	Soldier Cyn.	Rock Canyon	1.4	hvBb
Book Cliffs	Apex	L. Sunnyside	0.9	hvBb
Book Cliffs	Sunnyside #1	L. Sunnyside	1.4	hvAb
Book Cliffs	Soldier Cyn.	Sunnyside	1.6	hvBb
Book Cliffs	Sunnyside #3	U. Sunnyside	1.1	hvBb
Emery	Emery	Upper I	2.5	hvBb

Table 43. *Statistics on resinite content (percent) of various beds in the Wasatch Plateau and Book Cliffs coalfields. Average weighted by number of samples.*

Wasatch Plateau coalfield

Field Area	Bed Name	Mean	Minimum	Maximum	Std. Dev.	Samples
Entire	Hiawatha	3.23	0.6	28.3	3.88	49
Entire	U. Hiawatha	3.60	0.8	25.7	4.57	28
Central	Blind Canyon	5.33	0.9	14.5	3.87	16
North	U. O'Connor	1.24	0.6	4.0	0.80	15
North	L. O'Connor	1.92	0.2	5.8	1.51	19
North	Castlegate A	5.34	1.1	7.5	2.33	5

Book Cliffs coalfield

Field Area	Bed Name	Mean	Minimum	Maximum	Std. Dev.	Samples
West	Castlegate A	4.25	1.2	12.9	2.97	16
West	Castlegate B	5.74	1.7	16.2	4.59	7
West	Castlegate C	5.43	2.7	11.5	3.76	7
West	Castlegate D	5.31	1.7	17.8	4.05	14
West	Subseam 3	2.55	1.0	7.2	1.58	11
West	Kenilworth	2.09	1.1	3.5	0.77	7
Central	Rock Canyon	1.96	0.8	4.3	0.87	19
Central	Gilson	1.44	0.5	5.0	0.93	24
East	L. Sunnyside	1.24	0.8	2.1	0.40	10
East	U. Sunnyside	2.15	0.9	3.0	0.68	10
Both Fields	Weighted Ave.	3.09	0.9	13.8		257

Table 44. *Percent resinite contained in grab samples from the waste pile and coal stockpile at the Star Point #2 mine, Wasatch Plateau coalfield. Stockpile combines production from the Wattis (85 percent) and Blind Canyon (15 percent) beds (Tabet and others, 1995).*

Resinite Type	Stockpile -20 mesh	Stockpile +20 mesh	Waste Pile -20 mesh	Waste Pile +20 mesh
Green (primary)	12.8	4.8	7.3	3.3
Yellow (primary)	0.3	0.5	0.4	0.2
Orange (primary)	0.1	0.2	0.3	0.1
Exsudatinite (secondary)	0.2	0.2	0.3	0.0
Fluorinite (secondary)	0.0	0.0	0.0	0.1
Bituminite (secondary)	0.1	0.0	0.0	0.0
Total Resinite (%)	13.5	5.7	8.3	3.7

Table 45. *Coal and resinite resources of selected beds in the Wasatch Plateau and westernmost Book Cliffs coalfields (in millions of short tons; 1 short ton = 0.9091 metric tons).*

	Southern Wasatch Plateau		Northern Wasatch Plateau			Western Book Cliffs		TOTAL
	Hiawatha	Upper Hiawatha	Hiawatha	Blind Canyon	Castlegate A	Spring Canyon Grp.	Castlegate Grp	
Original Resources	409.0	22.5	1,131.1	246.8	283.4	371.0	332.4	2,796.2
Resinite Content (%)	3.2	3.6	3.2	5.3	5.3	2.5	5.0	—
Original Resinite	13.1	0.8	36.2	13.1	15.0	9.3	16.6	104.1
Recoverable Resinite	3.3	0.2	9.0	3.3	3.7	2.3	4.1	25.9

resources. This percentage was calculated based on the following premise. Although historical coal mining recovery rates in Utah are close to 30 percent, modern longwall mining techniques commonly provide recovery rates in excess of 50 percent. The coal recovery rate used in this resource estimate was a compromise figure of 50 percent of the in-place coal. Traditional froth flotation separation techniques have historically recovered only 50 percent of the resinite from the mined coal (Benemelis, 1990); however, new flotation techniques can recover 90 percent of the resinite (Miller and Ye, 1989; Yu, 1991). This study conservatively chose the 50 percent resinite recovery rate from traditional flotation methods for resource calculation purposes. Using these assumptions the total recoverable resinite from the target coalbeds is 25.9 million short tons (23.5 million metric tons), or 51.8 billion pounds (23.5 billion kg). New flotation techniques could dramatically increase Utah's recoverable resinite resources, but to date they have not been demonstrated on a commercial scale.

Coal mining has occurred in areas underlain by the target beds for over a century, and has probably disturbed about 25 percent of the original coal reserves in those areas. Subtracting 25 percent for past mining from the original 25.9 million short tons (23.5 million metric tons) of recoverable resinite leaves a remaining recoverable resinite resource of 19.4 million short tons (17.6 million metric tons), or 38.8 billion pounds (17.6 billion kg).

The above resource estimate was made on a field-wide basis and does not represent resources in specific coal leases. Because the resinite contents of Utah coals show significant variation from sample to sample, coal beds within any specific lease area considered for resinite production should be sampled and analyzed to determine the expected range and average resinite content for that area.

Past and Current Production Trends

Resinite production from Utah is currently at an impasse because miners cannot find resin refiners to process their product, and resin refiners are not likely to build new capacity without the guarantee of a large, steady supply of resin concentrate feedstock. From 1947 to 1979, when Utah resinite was being produced, this low-cost resin was readily accepted as a substitute for other higher cost synthetic and natural resins (Miller, 1988). For example, during this period the U.S. Fuel Company produced up to 80,000 pounds (36,287 kg) of resinite concentrate (55 percent resinite) per month as a by-product from its wash plant (Doelling, 1972). However, this plant was dismantled when the mine closed in 1993. Utah resinite also had a local resin-refining outlet until the solvent extraction plant at Bauer in Tooele County burned down in 1979 and was not rebuilt.

This lack of refining capacity lead to the early demise of a recent resin-production start-up effort by Cyprus Plateau Mining Company. During early 1993, the company added a coal resin recovery circuit to its Star Point mine wash plant, and was producing 10,000 pounds (4,536 kg) of resinite concentrate a month. Unfortunately, resinite production by Cyprus Plateau Mining was curtailed shortly after inception when a resin refiner could not be found to purify the resin concentrate. Cyprus Plateau's attempts to find a refiner were probably hurt by the fact that the coal reserves at that resin-rich mine would be exhausted by 2000.

Market Potential

Benemelis (1990) summarized some of the potential markets for resinite. Resin from coal competes in the market place with other natural and synthetic resins, and gilsonite. A major market for resinite is the ink industry. The annual U.S. consumption of various types of resin in the production of black ink is about 750 million pounds (340 million kg) (Benemelis, 1990). Resins used in making black ink may contain up to 15 percent coal resin, which corresponds to 112.5 million pounds (51 million kg) of coal resin that potentially could be used annually for black-ink production in the U.S.

The worldwide resin market is large and expanding. Additional customers for coal resin in the ink industry exist in international markets, and in some colored-ink markets. Other markets for coal resin are the adhesive, rubber, varnish, coatings, and plastics industries. Recently, it has been proposed that coal resin could be used as feedstock for high-density jet fuels (Miller, 1988), and for environmental clean-up and abatement work (F. Djahanguiri, U.S. Bureau of Mines, verbal communication, 1992). Yu (1991) states that the total annual U.S. consumption of various hydrocarbon resins in 1988 was 1.5 billion pounds (0.7 billion kg), one-third of the worldwide consumption of 4.5 billion pounds (2.0 billion kg).

Utah coal operators that could produce and refine resinite would probably find that their low-cost product could displace other high-cost resins in the market place. At present, a shortage of resin-refining capacity poses a significant bottleneck in getting Utah resinite to the end users in the ink, plastic, and varnish industries. Restarting the coal resin industry in Utah will require a cooperative effort between several resin-supplying mining companies and a resin refiner so that the miners are assured an outlet for their resin concentrate and the refiner is assured a diversified, large, steady supply of feedstock material.

COAL-BED GAS RESOURCES

Coal miners have long known that methane in coal beds poses a serious risk of explosion, and this was one problem that eventually lead to the creation of the U.S. Bureau of Mines (USBM) in 1910 (Irani and others, 1977). Early research by the USBM focused on quantifying the amount of methane released during mining and finding solutions to alleviate the health and safety problems created by the gas (Diamond and Levine, 1981). During late 1970s, after two interruptions in petroleum supply from the Middle East, the U.S. Department of Energy (DOE) and the Gas Research Institute (GRI) began research on new and unconventional sources of natural gas. Based on the USBM's measurements of large volumes of methane in coal beds, DOE and the GRI sponsored studies to quantify the amount of methane present in coal beds and to develop techniques to economically produce this gas. The DOE completed preliminary coal-bed gas resource estimates for all major coal basins in the U.S. by 1982. These early studies focused subsequent research and development efforts on five basins: (1) Black Warrior (Alabama), (2) Central Appalachian (West Virginia, Virginia, Kentucky and Tennessee), (3) Northern Appalachian (Pennsylvania, West Virginia and Ohio), (4) Piceance (Colorado), and (5) San Juan (Colorado and New Mexico) (ICF Resources, 1990). Utah's coal-bed gas potential was discounted because little was known of the methane content of its deep coal resources.

Two coalfields in Carbon and Emery Counties, the Book Cliffs, and Emery fields, have coal beds with high gas contents and proven coal-bed gas production. Gas contents for coals in the Wasatch Plateau coalfield are lower and, to date, have not produced commercial coal-bed gas.

Federally funded coal-bed gas research in Utah began in the late 1970s, and mostly involved studies by the Utah Geological Survey (UGS) to measure the gas content of coals in the Utah's major coalfields (Davis and Doelling, 1976, 1977; Doelling and others, 1979; Smith, 1981, 1986; Keith and others, 1990 a,b,c,d; Keith and others, 1991; and Bishop, 2001 a,b,c,d,e,f). Mountain Fuel Resources, Inc. was also funded by the DOE to do some gas production testing of the coals of the Book Cliffs field (Allred and Coates, 1980, 1982).

Interest in the coal-bed gas potential of the Blackhawk Formation in the Book Cliffs coalfield began in the late 1970s with the drilling of several test wells by Mountain Fuel. However, it was not until 1990 that an attempt was made to recover gas from deep, unmined coal beds. A five-well pilot program by Cockrell Oil Company lead to the development of the Castlegate field which produced from 1990 to 1997, when the field was plugged and abandoned mainly due to dewatering problems. The J.M. Huber Corporation re-opened the field in 1999 and production resumed in 2000.

Interest in the coal-bed gas potential of the Ferron Sandstone Member of the Mancos Shale in the Emery coalfield began with a five-well pilot program near Price in 1992. From its initial five-well pilot program, River Gas Corporation (now Phillips Petroleum) has expanded development to a level, as of June 30, 2001, where the Drunkards Wash field contains 417 producing wells. An additional 16 producing wells were completed in 2000 in the Drunkards Wash area by the Marathon Oil Company. Development of the Ferron Sandstone coal-bed gas play has also expanded as Texaco Exploration and Production, Incorporated and Anadarko Petroleum Corporation have developed coal-bed gas reserves in the Buzzard Bench (52 wells) and Helper (92 wells) fields, respectively, elsewhere along the play as of June 2001. The location of these fields is shown on plate 3. Anadarko also is developing an area known as Clawson Springs, southwest of Drunkards Wash, and plans to complete 32 wells in 2001.

Known Occurrences and Characteristics

Book Cliffs and Wasatch Plateau Coalfields

Coal thickness: The coal geology of the Book Cliffs and Wasatch Plateau coalfields is discussed in detail in the coal resources section of this report, and only certain points are repeated here that relate particularly to coal-bed gas potential. The map of total net coal thickness within the Blackhawk Formation (plate 6) shows that the greatest accumulation of coal occurs in the area northeast of the town of Scofield, where more than 50 feet (15 m) of coal is found in up to 10 coal beds. The area with 30 or more feet (9 m) of net coal in the Blackhawk Formation extends eastward along the Book Cliffs to approximately Soldier Creek Canyon (plate 6). South of this area in the Wasatch Plateau coalfield the Blackhawk Formation coal deposits have a total net thickness less than 30 feet (9 m), except in a few local areas. East of Soldier Creek Canyon the total net coal in the Blackhawk Formation is generally less than 20 feet (6 m) thick. In the extreme eastern parts of Carbon and Emery Counties, near the Green River, the total net coal in the Blackhawk Formation is less than 10 feet (3 m) thick.

Coal depth: Plate 5 shows that Blackhawk Formation coals in Carbon and Emery Counties commonly lie at depths of less than 2,500 feet (762 m), and many of those areas have been, or will be, drained of gas by mining activity. In unmined areas some of the coal-bed gas could be recovered prior to or during mining. In those areas with past or current mining, much of the coal down to 2,500 feet (762 m) of cover has already been drained of gas. It is also difficult to recover gas economically from coals with more than 6,000 feet (1,829 m) of overburden (Rice and others, 1995), so only those coals at depths between 2,500 and 6,000 feet (762 and 1,829 m) should be considered as potential gas reservoirs in the Book Cliffs and Wasatch Plateau coalfields. Unfortunately, there is only sparse information on the coals and their gas contents at these depths. Coals in this depth range are found mostly in Sevier and Sanpete Counties on the western side of the Wasatch Plateau, and in the northern part of the Book Cliffs field, mainly in northern Carbon, southern Utah and Wasatch, and southwestern Duchesne Counties.

Coal-bed gas content: According to Smith (1985), the gas content from 92 samples of Blackhawk Formation coals in the Wasatch Plateau coalfield range from no gas to 64 cubic feet of gas per ton (ft^3/ton) of coal (0.0 to 2.0 cubic centimeters of gas per gram [cm^3/g] of coal). Results for individual coal beds are shown in table 46. The average gas content for the 97 samples is 7.7 ft^3/ton (0.25 cm^3/g), a very low gas content. The low gas content is thought to be mostly due to loss to the atmosphere from coals exposed in canyons in the highly dissected Wasatch Plateau. In addition, the coals probably initially contained less gas. Coal rank and vitrinite reflectance data of in-mine samples (Hucka and others, 1997) indicate that these coals are lower rank and would generate less gas than coals in either the Book Cliffs or Emery coalfields. Smith (1985) classifies the Wasatch Plateau coals as low-gassy 0 to 32 ft^3/ton (0-1 cm^3/g).

Smith (1985) reported the Blackhawk coals of the Book Cliffs coalfield have gas contents of no gas to 352 ft^3/ton (0 to 11.0 cm^3/g), based on desorption analyses of 103 coal core samples. The average gas content measured for the 103 Book Cliffs coals tested by Smith (1985) is about 100 ft^3/ton (3.1 cm^3/g). Results for individual coal beds are shown in table 47.

During the period from 1979 to 1981, Mountain Fuel Resources Inc., with joint funding from the DOE, drilled three coal-bed gas test wells in the Whitmore Park area about 23 miles (37 km) northeast of Price, Utah. Gas desorption tests were done on 14 coal core samples from these wells and showed gas contents ranging from 169 to 443 ft^3/ton (5.3 to 13.9 cm^3/g). The average gas content for these 14 core samples was 346 ft^3/ton (10.8 cm^3/g). The Mountain Fuel core samples were collected from generally greater depths (2,664 to 3,099 feet [812 to 945 m]) and farther from the outcrop than the samples reported by Smith (1985), which probably accounts for the higher gas contents reported by Mountain

Table 46. Coal-bed gas content of coal beds in Wasatch Plateau coalfield (modified from Smith, 1985). (u) = upper split of the bed.

Coal Bed	Number of samples	Avg. depth (ft)	Depth range (ft)	Average gas content(ft^3/ton)	Range of gas content(ft^3/ton)
Bear Canyon	3	1,190	971 - 1,314	5.1	0.3-13.2
Blind Canyon	7	970	185 - 1,762	12.2	0.0 - 19.3
Flat Canyon	2	1,484	1,368 - 1,600	2.6	0.0 - 5.1
Hiawatha	25	956	89 - 1,671	11.2	0.0 - 53.0
Hiawatha (u)	18	1,030	791 - 1,825	3.2	0.0 - 10.9
Ivie	3	721	595 - 813	0.0	0.0
Ivie (u)	2	179	82 - 277	3.8	3.5 - 4.2
McKinnon	2	475	200 - 750	14.4	3.2 - 25.7
Muddy	2	1,167	744 - 1,590	6.4	0.0 - 12.8
O'Connnor	15	892	326 - 1,995	8.3	0.0 - 57.0
O'Connor (u)	9	901	605 - 1,384	14.1	0.0 - 64.2
Unknown	4	1,098	924 - 1,432	0.0	0.0

Table 47. Coal-bed gas content of coal beds in Book Cliffs coalfield (from Smith, 1985).

Coal Bed	Number of samples	Avg. depth (ft)	Depth range (ft)	Average gas content(ft^3/ton)	Range of gas content(ft^3/ton)
Beckwith	1	653	653		3.2 —
Castlegate A	23	1,573	194 - 3,355	112.4	6.4 - 301.7
Castlegate B	9	736	316 - 1,234	67.4	28.9 - 231.1
Castlegate C	8	878	198 - 3,292	86.7	22.5 - 340.3
Castlegate D	9	786	149 - 1,431	73.8	22.5 - 179.8
Fish Creek	1	1,728	1,728	6.4	—
Gilson	8	1,601	476 - 3,097	112.4	0.0 - 301.7
Kenilworth	6	2,048	766 - 3,177	186.2	3.2 - 353.1
Rock Canyon	9	1,630	404 - 2,867	99.5	9.6 - 240.8
Subseam 1	4	1,951	1,395 - 2,821	221.5	70.6 - 301.7
Subseam 2	6	1,654	937 - 2,188	102.7	16.0 - 269.6
Subseam 3	4	1,625	963 - 2,222	41.7	12.8 - 73.8
Sunnyside	9	1,106	396 - 2,720	57.8	3.2 - 170.1
Unknown	6	1,040	284 - 2,081	122.0	57.8 - 260.0

Fuel. Smith (1985) classifies the Book Cliffs coals as moderately gassy (32 to 160 ft^3/ton [1 to 5 cm^3/g]) to highly gassy (greater than 160 ft^3/ton [5 cm^3/g]).

Coal-bed gas resources: The Wasatch Plateau coalfield appears to hold little promise for coal-bed gas development in Carbon or Emery County because the coals there are mostly thin, of low rank, and low in gas content. The portion of the Book Cliffs coalfield that is most prospective for coal-bed gas production lies mainly in northwestern Carbon County, where the coals are thickest, at moderate depths, and have high gas contents.

The coal-bed gas resources of the Book Cliffs and Wasatch Plateau coalfields have been estimated a number of times since 1984, and using different assumptions each time, the resource estimates have changed (Adams and Kirr, 1984; Gloyn and Sommer, 1993; Rice and others, 1995). The first two studies used the coal resource estimates for each field and multiplied them by an estimated gas content value for the coals in that field to arrive at the in-place coal-bed gas resources. These coal-bed gas resource estimates have included coal resources that are buried under less than 1,000 feet (305 m) of cover; however, these coals typically have been drained of most contained gas, either by past mining or through natural processes. In addition, the earliest coal-bed gas resource estimates did not include gas from coal resources that lie between 3,000 and 6,000 feet (914 and 1,829 m) deep. Conversely, Gloyn and Sommer's (1993) gas resource estimate included coal resources down to 9,000 feet (2,743 m), while it now appears that the depth cutoff for economic coal-bed gas production is approximately 6,000 feet (1,829 m). Rice and others (1995) used a more statistical approach to gas-play analysis to derive their gas-resource estimate. They defined the play area, broke the play into drillable play cell units, then statistically assigned the play cell units a resource potential based on geologic and engineering factors, and finally determined play resources by estimating the number of cells units that would contain economic quantities of gas.

Wasatch Plateau Coalfield: Adams and Kirr (1984) estimated the resource to range from 29.9 to 74.1 billion cubic feet (Bcf) (0.85 to 2.10 billion m^3) of gas for coal beds at least 4 feet (1.2 m) thick and down to a depth of 3,000 feet (914 m). Gloyn and Sommer (1993) extrapolated the 4-foot-thick (1.2 m) coal re-sources down to at least 9,000 feet (2,743 m) and used a higher gas content range that resulted in an increased in-place coal-bed gas resource estimate of 900 to 1,500 Bcf

(25.5 to 42.5 billion m^3) of gas for the Wasatch Plateau coalfield. No known exploration specifically for coal-bed gas has taken place in the Wasatch Plateau coalfield and no coal-bed gas reserves have been proven for this field in Carbon or Emery County. The deeper portion of the Wasatch Plateau, which is more prospective for coal-bed gas, lies in Sanpete and Sevier Counties.

Book Cliffs Coalfield: Various estimates for the in-place coal-bed gas resources of the Book Cliffs are given in table 48. The in-place coal-bed gas resources of the Book Cliffs coalfield were first estimated by Adams and Kirr (1984) to range from 193.1 to 1,211.8 Bcf (5.5 to 34.3 billion m^3) of gas in Blackhawk Formation coal beds greater than 4 feet (1.2 m) thick and with less than 3,000 feet (914 m) of cover. This resource estimate used coal-bed gas contents ranging from 52 to 328 ft^3/ton (1.69 to 10.62 cm^3/g) of coal.

Gloyn and Sommer (1993) added new in-place coal-bed gas resources for the coal deposits deeper than 3,000 feet (914 m). They extrapolated shallow coal resources down to depths of 9,000 feet (2,743 m) and used a higher estimated gas content range of 350 to 400 cubic feet of gas per ton (10.9 to 12.5 cm^3/g) of coal. With these new assumptions they revised the in-place coal bed gas resource estimate for the Book Cliffs field upward to a range of 4,400 to 5,000 Bcf (124.6 to 141.6 billion m^3) of gas. This estimate is optimistic because most of the Book Cliffs field coals from the surface down to 2,000 feet (610 m) of cover will be mined or drained of gas by mining, and should not be considered in coal-bed gas estimates, and gas resources below 6,000 feet (1,829 m) will be costly to produce.

The U.S. Geological Survey (Rice and others, 1995) analyzed the coal-bed gas potential of the Book Cliffs' play in the assessment of the oil and gas resources of the United States. They defined various play factors on occurrence and productivity of the Book Cliffs coal reservoirs and estimated that the recoverable gas resource ranges from 1,304 to 2,746 Bcf (36.9 to 77.8 billion m^3), with a mean coal-bed gas resource estimate of 1,941 Bcf (55.0 billion m^3). The estimate of Rice and others (1995) covers coal resources at depths from 500 to 6,000 feet (152 to 1,829 m), with net coal thicknesses ranging up to 68 feet (21 m), and assumes a drilling success rate of 80 percent. Each well on 160-acre (65-hectare) spacing would have recoverable gas resources ranging from 0.02 to 6.0 Bcf (0.6 to 169.9 million m^3). The mean recoverable gas resource per well was estimated to be 1.4 Bcf (39.6 million m^3) per well on 160-acre (65 hectare) spacing (Rice and others, 1995). In comparison, Ruhl and Meibos' (1997) estimate that the recoverable gas resources for wells with 160-acre (65-hectare) spacing in the Castlegate field area are 1.7 Bcf (48.1 million m^3) per well, based on an average coal thickness of 40 feet (12 m). If the recoverable gas is assumed to be 60 percent of the in-place gas, we can infer that the coal has a gas content of about 250 ft^3/ton (7.8 cm^3/g).

Coal-bed gas composition: Coal-bed gas from the Blackhawk Formation is only produced from the Castlegate field at the northwest end of the Book Cliffs coalfield in Carbon County. The compositions of the coal-bed gas produced from several wells in the Book Cliffs field are given in table 49. The dry nature of these gases, as indicated by the predominance of methane over other gases, indicates that these gases are coal-bed derived.

Table 48. *Various estimates of coal-bed gas resources for the Book Cliffs coalfield.*

Source (date)	Depth range (feet)	Gas content	Gas resource estimate
Adams and Kirr (1984)	0 to 3,000	52 to 328 ft^3/ton	193 to 1,212 Bcf ^{I}
Gloyn and Sommer (1993)	0 to 9,000	350 to 400 ft^3/ton	4,400 to 5,000 Bcf ^{I}
Rice and others (1995)	500 to 6,000	0.02 to 6.0 Bcf/well	1,340 to 2,746 Bcf ^{R}

^{I} = in-place; ^{R} = recoverable

Table 49. *Composition (by percentage) of Blackhawk Formation coal-bed gas from the Book Cliffs coalfield (from Allred and Coates, 1980, and Rice and others, 1995).*

Sample Area	Carbon Dioxide CO_2	Methane C1	Ethane C2	Propane C3	Butane C4	Pentane C5	C1/C1-C5	Location
Castlegate field	10.0	89.0	1.0	0.0	0.0	0.0	0.99	12S, 10E
Whitmore Park	2.2	97.7	0.1	0.0	0.0	0.0	0.99	12S, 12E
Whitmore Park	1.7	98.1	0.1	0.1	0.0	0.0	0.99	12S, 12E
Whitmore Park	1.3	98.5	0.1	0.1	0.0	0.0	0.99	12S, 12E
Whitmore Park	1.4	98.2	0.2	0.2	0.0	0.0	0.99	12S, 12E
Whitmore Park	4.3	95.2	0.4	0.1	0.0	0.0	0.99	12S, 12E
Whitmore Park	4.1	95.5	0.3	0.1	0.0	0.0	0.99	12S, 12E
Whitmore Park	3.3	96.3	0.3	0.1	0.0	0.0	0.99	12S, 12E
Whitmore Park	2.4	96.9	0.4	0.3	0.0	0.0	0.99	12S, 12E
Whitmore Park	2.2	97.0	0.4	0.3	0.1	0.0	0.99	12S, 12E

Emery Coalfield

Coal thickness: The coal geology of the Emery coalfield is discussed in detail in the coal resources section of this report and readers are referred to that section for more detailed discussion of stratigraphy and coal quality. Only the coal geology information pertinent to the coal-bed gas resources is discussed below. A map of total net coal in the Ferron Sandstone (plate 7) shows the cumulative thickness of all individual coal beds 1 foot (0.3 m) thick or greater. The 10-foot (3 m) isochore line defines a northeast-trending, 6- to 10-mile-wide (10 to 16 km) band of thick coal called the Ferron coal-bed gas "fairway" (Tabet and others, 1996). Although the thick-coal fairway appears on the map as a continuous band that runs southwesterly for about 80 miles (129 km) starting near the city of Price, it actually consists of coals formed by two delta systems that were deposited at slightly different times (Hale, 1972).

The coal deposits of the older, northern Vernal delta can be traced from Price at least as far south as the town of Orangeville, Utah. South of there drilling data are sparse and the correlation of units is problematic. There are two distinct areas of thin coal about 8 to 12 miles (13-19 km) apart in the northern part of the coal-bed fairway which correspond to areas of thick sand in the Ferron which were mapped by Tripp (1989) as deltaic systems (plate 7). The thicker coal deposits in the northern part of the Ferron fairway near Price comprise three to six beds which locally total as much as 48 feet (15 m) thick, and average about 24 feet (7 m) thick (Burns and Lamarre, 1997).

The younger, southern part of the Ferron coal fairway was deposited as part of the Last Chance delta (Hale, 1972) in the area mainly southwest of the town of Emery (plate 7). The distribution of coal at the southern end of the fairway shows distinct, northeast-trending pods of thick coal that correspond to interdeltaic areas of the more lobate Last Chance delta. The thickest total net coal recorded in the southern area is in excess of 50 feet (15 m), and the average net thickness is about 30 feet (9 m). Figure 25 shows the thickness of several coal beds in the southern part of the Ferron fairway. Burning of the coal along the outcrop at the southern end of the fairway has obscured the original thickness of the coal.

Coal depth and reflectance data: Plate 8 shows the depth to the top of the Ferron Sandstone Member of the Mancos Shale in parts of Carbon and Emery Counties. The 1,000-foot (305 m) contours show that the depth to the Ferron Sandstone increases westward and northward from the outcrop to over 8,000 feet (2,438 m) beneath the Wasatch Plateau and Book Cliffs. Depth contours were generally not drawn within the various grabens cutting the study area because of limited drilling data.

Tabet and others (1996) plotted the vitrinite reflectance values for coals in the Ferron Sandstone (figure 30). Each data point on their map has either an individual vitrinite reflectance reading for a single coal bed, or a range of vitrinite reflectance values where reflectance was measured for more than one coal bed. Wells with multiple reflectance values indicate that individual coal beds responded differently to the thermal maturation process. For contouring purposes, the maximum vitrinite reflectance value in a well was used at each site to reflect the maximum level of thermal maturity. With two exceptions, the vitrinite reflectance data show increasing values to the west as depth increases. The reflectance values are lowest, about 0.5 percent, along the outcrop and increase to a maximum value of 0.71 percent under the deeper parts of the Wasatch Plateau.

The reflectance data suggest that the Ferron coals are in the early maturation stage for thermogenic methane generation, and should only have generated a gas content of about 80 to 150 ft^3/ton (2.5 to 4.7 cm^3/g) of coal according to Kaiser and others (1995). Coal thermoplastic properties, elemental analysis, and burial history modeling suggest higher levels of thermal maturity in the Drunkards Wash area than is indicated by vitrinite reflectance (Quick and Tabet, 1999), corresponding to a high volatile A bituminous rank reported for these coals (Lamarre, 1999). The significance of the "suppressed" vitrinite reflectance is unknown at the present time. Carbon isotope analyses of Ferron coal-bed-gas samples by the U.S. Geological Survey, however, also indicate a thermogenic to mixed thermogenic-biogenic origin.

Coal-bed gas content: Only a limited number of coal-bed gas content analyses have been reported from the Ferron Sandstone coals, and most of those analyses were from shallow core samples (Smith, 1985; Burns and Lamarre, 1997). The 51 shallow coal cores from the southern "Last Chance" part of the Ferron fairway have reported gas contents ranging from no gas to 150 ft^3/ton of coal (0 to 4.7 cm^3/g), with an average gas content of about 15 ft^3/ton of coal (0.47 cm^3/g). Some of the southern core samples were taken near the outcrop and may not be representative of the gas content of more deeply buried coals.

According to Burns and Lamarre (1997), the gas content of the Ferron coals from the northern "Vernal delta" area range from 200 to 501 ft^3/ton of coal (6.25 to 15.66 cm^3/g). Smith (1985) classifies these coals as highly gassy. Highly gassy coal beds can be commercially produced as demonstrated by the various companies that have produced gas from wells in the northern Ferron fairway.

Coal-bed gas resources: Most of the Emery coalfield that is prospective for coal-bed gas exploitation lies in Carbon and Emery Counties, with a small portion in Sevier County. Based on Doelling's (1972) estimate of coal resource and gas contents of 2 to 10 ft^3/ton (0.06 to 0.32 cm^3/g), Adams and Kirr (1984) estimated the in-place coal-bed gas resource of the Emery coalfield to range from 2.7 to 13.9 Bcf (76.5 to 393.6 million m^3) (see table 50). They noted that 75 percent of Doelling's coal resource is under less than 1,000 feet (305 m) of cover, but did not include any coal resources for the northern, "Vernal delta" part of the Ferron Sandstone trend.

Gloyn and Sommer (1993) provided resource estimates for both the northern (Vernal delta) and southern (Last Chance delta) portions of the Emery coalfield. They estimated the coal resources to depths of 9,000 feet (2,743 m) at 5.0 billion short tons (4.5 billion metric tons) for each part of the field, but used different gas contents for the different parts of the field. They assumed a gas content of 150 to 200 ft^3/ton (4.86 to 6.48 cm^3/g) for the southern part of the field, and assumed a gas content of 400 to 500 ft^3/ton (12.96 to 16.20 cm^3/g) for the northern part of the field. Using these assumptions, they estimated an in-place coal-bed gas resource of 800 to 1,000 Bcf (22.7 to 28.3 billion m^3) of gas for the southern part of the Emery field, and an estimate of 2,000 to 2,500 Bcf (56.6 to 70.8 billion m^3) of gas for the northern part of the field.

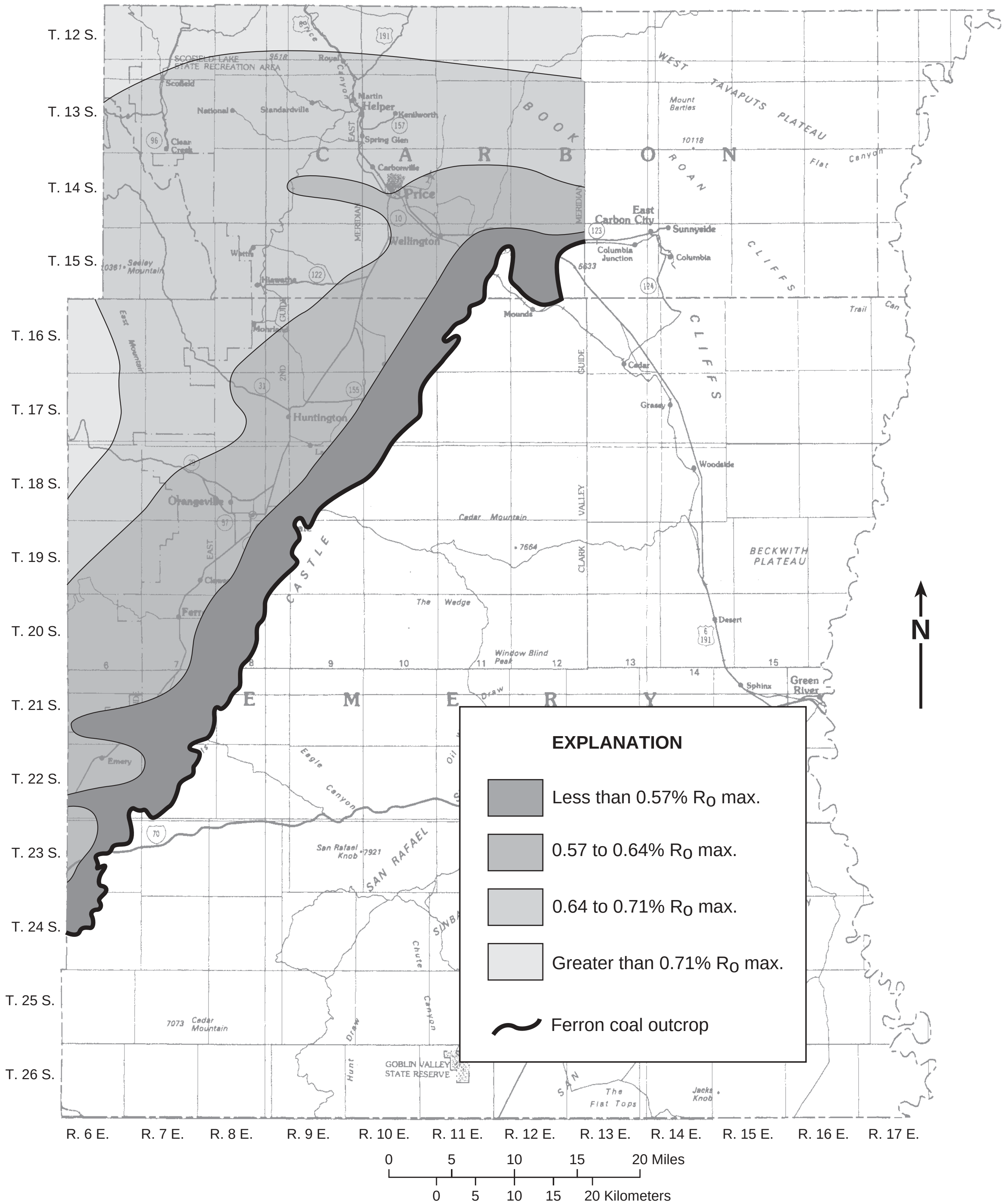


Figure 30. *Vitrinite reflectance contours (in percent R_o max.) for coal beds in Ferron Sandstone Member, Mancos Shale, Carbon and Emery Counties, Utah (from Tabet and others, 1996).*

Rice and others (1995) estimated the ultimate recoverable gas resources in the Emery coalfield play, a 396 square-mile area (1025 km^2) where coals are 500 to 6,000 feet (152 to 1,829 m) below the ground surface. They statistically estimated the recoverable coal-bed gas from wells drilled on 160-acre (65 hectare) spacing in the play area by assuming that 70 percent of the wells drilled would be successful and that successful wells would produce between 0.05 and 3.7 Bcf (1.4 and 104.8 million m^3) of gas per well, with a mean recovery of 0.92 Bcf (26.1 million m^3) of gas. Using these parameters, Rice and others (1995) estimated the recoverable gas resources for the Emery field to range from 551 to 984 Bcf (15.6 to 27.9 billion m^3) of gas, with a mean recoverable gas estimate of 748 Bcf (21.2 billion m^3). Companies developing the northern part of the Emery field now estimate the average recoverable gas resources per 160-acre (65 hectare) well to be 1.8 to 2.6 Bcf (50.9 to 73.6 million m^3) (Tabet and Burns, 1996; Don Wallette, Phillips Petroleum Company, verbal communication, 2001), or at least twice the 0.92 Bcf mean value per well estimated by Rice and others (1995).

Coal-bed gas composition: Coal-bed gas from the Ferron Sandstone Member of the Mancos Shale has been produced from the Drunkards Wash, Helper, and Buzzard Bench fields in the northern part of the Emery coalfield but, to date, only three Drunkards Wash field gas samples have been analyzed (Vito Nuccio, USGS, verbal communication, 1996). The Ferron coal-bed gas differs from the gas produced from Ferron Sandstone reservoirs in having significantly higher nitrogen and carbon dioxide contents, and a generally dry gas composition (high C1/C1-C5 ratio; see table 51).

The USGS also determined the carbon isotopic composition of these three coal-bed gas samples. The samples' del 13C values range from -46.68 to -50.07 (Nuccio, written communication, 1996); values of del 13C of -1.0 to -50.0 indicate a thermogenic gas, or a gas generated from thermal maturation of organic matter. Values of del 13C between -50.0 and -60.0 indicate a mixture of thermogenic and biogenic gas, and values from -60.0 to -99.0 indicate gas of biogenic origin.

Past and Current Production and Trends

Book Cliffs and Wasatch Plateau Coalfields

Mountain Fuel Resources was the first company to evaluate the gas production potential of coal beds in the Blackhawk Formation by drilling and testing three wells in the Whitmore Park area northeast of Price, Utah during the late 1970s and early 1980s (Allred and Coates, 1980, 1982). Mountain Fuel measured the gas contents of seven coal beds, and tested different completion and hydraulic stimulation techniques to determine the most economic method of producing coal-bed gas in central Utah. None of the Blackhawk Formation test wells produced enough gas to be brought into commercial production.

The first successful attempt to produce coal-bed gas in Utah from the Blackhawk Formation began in 1983 as a gas-recovery program at the Soldier Canyon mine. The mine operator decided to try to recover and sell the gas rather than simply vent it to the atmosphere. As a result of the program, gas production from the mine increased from 213 Mcf (6,032 m^3) per day in 1983 to about 1,500 Mcf (42,480 m^3) per day in 1993 before the program was discontinued (Tangren and others, 1993). The gas was produced from gob areas and horizontal boreholes drilled into the coal ahead of mining. The gas was brought to the surface via a vertical borehole by a rotary screw compressor. At the surface the gas was dewatered and cleaned of impurities before compression and sale.

The first commercial project to recover gas from deep, unmined coal beds in Utah was a five-well pilot program by Cockrell Oil Corporation in 1990 testing coals of the Book Cliffs coalfield north of Price. This initial program led to the development of the 25-well Castlegate coal-bed gas field by Pacific Gas and Electric, which purchased the rights to Cockrell's project area in 1993. The Castlegate field, which has approval to drill up to 124 wells, was sold in August 1994 to Anadarko Petroleum Corporation, which continued to operate the field until the end of 1997.

Anadarko ceased production from the Castlegate field at the end of 1997. According to production records kept by the Department of Natural Resources' Division of Oil, Gas and Mining (DOGM), cumulative production from the field from its inception in 1990 through December 1997 was 2.95 Bcf (83.5 million m^3) of gas and 7.54 million barrels (1,119 million liters) of water. One of the original 25 gas wells, the Shimmin Trust 10-11, was later converted to a saltwater disposal well, with produced water injected into tongues of the Star Point Sandstone, which lies directly below the Blackhawk Formation.

Several problems contributed to the 1997 shutdown of the Castlegate field (Stephen K. Ruhl, Anadarko Petroleum Corporation, verbal communication, 1998). According to production records kept by DOGM, the average production of gas from the wells in this field was relatively constant, ranging between 59 and 102 Mcf (1,671 and 2,889 m^3) per day (see table 52). The fact that gas and water production levels remained nearly constant over the life of the field indicates that improper well completion techniques hampered effective dewatering and the ability to reach maximum gas production.

Poor design of the water injection well also may have caused disposed water to recirculate back to producing wells. Water production only declined from an early maximum of 176 barrels (27,981 liters) of water per day to 120 barrels (19,078 liters) of water per day. Cumulative water production was highest from wells in the area about 1 mile (1.6 km) updip (south) from the injection well site, indicating that some of the disposed water was migrating back up into the Blackhawk Formation from the underlying Star Point Sandstone.

The Castlegate field was purchased by the J.M. Huber Corporation in 1999. As of June 2001, thirteen of the abandoned wells had been re-completed as producing wells according to DOGM records.

Emery Coalfield

Three major companies were actively testing and producing coal-bed gas in the Emery coalfield in the 1990s. Exploration and testing of coal-bed gas had been done earlier by several companies but no coal-bed gas wells were developed. The earliest exploration campaign was begun by River Gas Corporation in late 1992. Anadarko Petroleum Corporation began exploration in 1993 and Texaco Explor-

Table 50. *Various estimates of coal-bed gas resources for the Emery coalfield.*

Source (date	Depth range (feet)	Gas content	Gas resource estimate
Adams and Kirr (1984)	0 to 3,000	64 to 320 ft^3/ton	2.7 to 13.9 Bcf [I]
Gloyn and Sommer (1993)	0 to 9,000	150 to 500 ft^3/ton	2,800 to 3,500 Bcf [I]
Rice and others (1995)	500 to 6,000	0.05 to 3.7 Bcf/well	551 to 984 Bcf [R]

[I] = in-place; [R] = recoverable

Table 51. *Composition (by percentage) of Ferron Sandstone coal-bed gas from the Emery coalfield (gas analyses from Vito Nuccio, USGS).*

Site Number	Nitrogen	Dioxide	Methane	Ethane	Propane	Butane	Pentane	C1/C1-C5	Location
River Gas 25-9-1	5.5	2.1	91.7	0.3	0.0	0.0	0.0	0.99	14S, 9E
River Gas 27-9-30	3.2	1.4	94.8	0.1	0.0	0.0	0.0	0.99	14S, 9E
River Gas 12-15-37	3.0	2.2	94.4	0.1	0.0	0.0	0.0	0.99	15S, 9E

Table 52. *Annual production statistics for the Castlegate field from various operators (data derived from Utah Division of Oil, Gas and Mining records; Mcf = thousand cubic feet).*

Year	Number of Wells	Gas(Mcf)	Water(bbl)	Average Days/Well	Average Gas/Well/Day
1994	24	439,371	1,746,070	309	59 Mcf
1995	25	782,128	1,719,989	349	93 Mcf
1996	24	870,596	1,432,596	348	102 Mcf
1997	24	571,404	946,622	327	77 Mcf
1998	0	0	0	0	0 Mcf
1999	0	0	0	0	0 Mcf
2000	9	139,844	423.531	325	70 Mcf

ation and Production, Incorporated started in 1995. The coal-bed gas exploration and development activities of these companies in the Emery coalfield are summarized below.

River Gas Corporation (now owned by Phillips Petroleum Corporation): Starting in late 1992, River Gas began a coal-bed-gas development program in the Cretaceous Ferron Sandstone coals to the west and south of Price. The program was initiated with the completion of five wells in 1992. River Gas gradually expanded the newly designated Drunkards Wash gas field by drilling 28 additional wells in 1993, and further drilling added 39 more gas wells in 1994 to bring the total to 72 producing gas wells at the end of 1994.

In August 1994, the Bureau of Land Management (BLM) began work on an Environmental Impact Statement (EIS) covering a 10-township area to evaluate the impacts of River Gas' plan to drill as many as 1,000 additional coal-bed gas wells near Price. Because River Gas' early drilling in the area had been confined to state and private lands, most of these lands had already been drilled. Consequently, during preparation of the EIS, development drilling in the Drunkards Wash area slowed dramatically as the BLM would not allow extensive drilling on federal lands until the EIS was completed. River Gas completed only 18 new gas wells in 1995; in 1996 development dropped further to four new gas wells, but also included the construction of two new water disposal wells and a water evaporation pond. During 1997, development drilling was limited to 10 new gas wells, which brought total field development to 113 producing gas wells. Based on the development alternative approved by the BLM in the Final EIS, a total of 550 gas wells will be allowed in the Price coal-bed-gas project area.

Annual production from the Drunkards Wash field is shown from 1993 through December 2000 in table 53. These production figures indicate that continued and expanded dewatering has improved the daily productivity of an average Drunkards Wash field well from 1993 levels of 180 Mcf (5,097 m^3) per day per well to 2000 levels of more than 500 Mcf (>14,158 m^3) per day per well. Through December 2000, the field had total cumulative gas production of 191.4 Bcf (5.4 billion m^3), which made it the eighth largest gas field in Utah based on cumulative production. Annual 2000 gas production for the 349-well Drunkards Wash field was 66.1 Bcf (1.9 billion m^3). This annual volume made Drunkards Wash the third most productive gas field in Utah for 2000 behind the Anschutz Ranch East field (49 wells) at 70.7 Bcf (2.0 billion m^3) in Summit County, and the Natural Buttes field (1,219 wells) at 67.3 Bcf (1.9 billion m^3) in Uintah County.

In September 2000, River Gas Corporation's 25 percent interest in the Drunkards Wash coal-bed gas project was sold to Phillips Petroleum Corporation. Phillips, which will remain operator of the field, reportedly paid about $0.57 per thousand cubic feet ($0.02 per m^3) of gas reserves. The remaining 75 percent interest is owned by Texaco and Capital Partners.

Anadarko Petroleum Corporation: Anadarko has been testing the gas production capability of Ferron coals in various parts of the Emery coalfield since 1993. The company started with three test wells in 1993, two at the northern end of the Emery coalfield, and one at the southern end. Anadarko tested the coal-bed gas potential of the central part of the Emery coalfield in late 1995 with a single well.

The coal-bed gas potential of the southern part of the Emery coalfield was tested by Anadarko's A-1 Ferron-Federal well, which was drilled in February 1994 about 3 miles (4.8 km) west of the town of Emery, Utah. Cores were taken from this well at depths between 2,496 and 3,008 feet (761 and 917 m), but the well was abandoned in March 1994, and no test results have been released.

The coal-bed gas potential of the central portion of the Emery coalfield was tested by Anadarko's A-1 Grimes Wash-Federal well, which was located about 5 miles (8 km) northwest of Castle Dale, Utah, in section 10, T. 18 S., R. 7 E. This 3,685-foot-deep (1,123 m) well reported production of 474 Mcf (13,424 m^3) of gas and 3,582 bbls (569,476 liters) of water for 27 days in December 1995. The Grimes Wash well and surrounding lease area were sold to Texaco in 1996.

Anadarko's major testing and development efforts in the Emery coalfield have been concentrated at the northern end near the town of Helper, Utah. Anadarko's first two wells in the area, the A-1 and B-1 Helper, were completed during late 1993. These two wells produced 10 and 3 million cubic feet (0.3 and 0.08 million m^3) of gas, respectively, before being shut-in. During the summer of 1994, the BLM completed an Environmental Assessment permitting Anadarko to drill four additional wells around the A-1 Helper well, on leases covering parts of five sections in T. 13 and 14 S., R. 10 E. These wells were brought into production in early 1995. Anadarko produced gas from its five-well Helper field in T. 13 S., R. 10 E. throughout 1995. Average daily gas production per well varied from 161 Mcf (4,560 m^3) of gas per day to 218 Mcf (6,174 m^3) of gas per day. Anadarko's other well in the area, the B-1 Helper, was shut-in starting in 1995.

No Anadarko wells were completed in the Helper area in 1995, but one new well was added in 1996 in the northeast quarter of section 26, T. 13 S., R. 10 E. Gas production from the field was curtailed from March through July of 1996.

During 1997, Anadarko completed 20 new gas wells in T. 14 S., R. 10 E., bringing to 26 the total number of gas wells producing in the Helper area. Production figures for the Helper field are listed in table 54. Anadarko has announced plans for a total of 69 wells in the Helper area. However only 16 of these 69 wells fall within the area covered by the completed River Gas EIS. To allow for full development of Anadarko's Helper coal-bed gas project a new EIS was begun in early 1997 and completed in early 1999. This EIS approved an additional 65 wells in the area. As of December 2000, Anadarko had 79 producing gas wells in the Helper field of the Ferron coal-bed gas play.

Texaco Exploration and Production, Incorporated: Texaco, an early wildcat driller in the Price area, and most recently a partner with Phillips Petroleum on the Drunkards Wash field development, renewed its individual exploration efforts in the Ferron Sandstone coal-bed gas reservoirs with three widely spaced wildcat wells in 1995. The northernmost well, the 10-1 L M Lemmon, lies about 15 miles (24 km) southwest of River Gas' Drunkards Wash project and about 2 miles (3 km) west of the town of Huntington. It was completed in March 1995 at a total depth of 2,161 feet (659 m) and tested at 75 Mcf (2,124 m^3) of gas and 209 bbls (32,750 liters) of water per day. The second well, the 26-2 Federal, lies nine miles southwest of the first well near the Buzzard Bench field, about four miles west of the town of Castle Dale. It was completed in February 1995 at a total depth of 3,181 feet (970 m) and tested at 150 Mcf (4,248 m^3) of gas and 227 bbls (36,089 liters) of water per day. The third well, the 21-3 Federal, is about 3 miles (5 km) due north of the town of Ferron in T. 19 S., R. 7 E. It was also completed in February 1995 at a total depth of 2,655 feet (809 m) and tested at 300 Mcf (8,496 m^3) of gas and 41 bbls (6,518 liters) of water per day.

In early 1996, Texaco completed five more widely spaced wildcats to further test the extent of the coal-bed fairway. Based on the results of the various wildcat wells, Texaco decided later in 1996 to begin production testing of the Ferron coal-bed gas in T.18 S., R. 7 E. In addition, Texaco purchased Anadarko's Grimes Wash well and surrounding lease areas in the township and renamed the Grimes Wash well the Utah Federal P10-47. Other production testing in T.18 S., R. 7 E. consisted of completing an additional 10 wells in three clusters around the early wildcats. At the end of 1996, Texaco had completed a total of 20 Ferron gas wells, and one cluster of six wells had been brought into production (see table 55). In addition to its 1996 gas wells, Texaco also completed a water disposal well (SWD-1) in section 24, T. 18 S., R. 7 E., in the Navajo Sandstone at 7,295 feet (2,223 m).

Drilling for coal-bed gas by Texaco in 1997 consisted of 23 new wells in the central portion of T. 18 S., R. 7 E., with the majority of wells on private and state lands. A total of 43 coal-bed gas exploration wells had been drilled or purchased by Texaco in the Ferron trend as of the end of 1997, and 31 of Texaco's 43 Ferron gas wells had been in production for at least a month. In early 1997, Texaco joined Anadarko Petroleum Corporation, Chandler and Associates, and Questar Pipeline Company in preparing a broader coal-bed gas EIS to analyze the impacts from development of the gas resources in the central and northern parts of the trend. The EIS recommended approval for an additional 222 coal-bed gas wells for the central portion of the Ferron trend, which is controlled predominantly by Texaco. As of December 2000, Texaco had 45 producing gas wells in the area west of Castle Dale, Utah along the Ferron coal-bed gas play.

Potential for Additional Discoveries and/or Development

Book Cliffs and Wasatch Plateau Coalfields

Development of the Castlegate field has proven commercial quantities of gas in the Book Cliffs coalfield. This field is currently (2001) being redeveloped by the J. M. Huber Company, and has BLM approval to add at least 100 new wells. Cumulative production from the field through 2000 was 3.09 Bcf (87.5 million m^3) of gas and 7.96 million barrels (1,265 million liters) of water. Through December 2000, an average of 0.14 Bcf (4.0 million m^3) of gas had been recovered from each Castlegate field well, in contrast to an original estimate that primary recoverable gas reserves per well were 1.7 Bcf (48.1 million m^3) over an estimated 20-year life (Ruhl and Meibos, 1996).

Table 53. *Annual production statistics for Drunkards Wash field of Phillips Petroleum Company (data derived from Utah Division of Oil, Gas and Mining records).*

Year	Number of Wells	Gas (Mcf)	Water (bbl)	Average Days/Well	Average Gas/Well/Day
1993	32	856,600	1,628,703	108	180 Mcf
1994	71	4,179,519	4,176,519	340	313 Mcf
1995	89	11,090,504	5,722,803	360	404 Mcf
1996	93	15,769,873	6,244,750	363	487 Mcf
1997	113	21,417,492	7,461,293	352	596 Mcf
1998	178	30,123,019	15,640,142	355	631 Mcf
1999	263	47,667,262	20,020,506	361	606 Mcf
2000	349	66,056,039	21,848,818	361	524 Mcf

Table 54. *Annual production statistics for the Helper field of Anadarko Petroleum Corporation (data derived from Utah Division of Oil, Gas and Mining records).*

Year	Number of Wells	Gas (Mcf)	Water (bbl)	Average Days/Well	Average Gas/Well/Day
1995	5	337,388	92,567	345	196 Mcf
1996	6	90,403	47,117	171	163 Mcf
1997	26	543,817	262,209	359	151 Mcf
1998	39	1,659,541	875,966	361	144 Mcf
1999	71	2,836,252	949,119	356	188 Mcf
2000	79	7,188,957	2,139,098	360	253 Mcf

Table 55. *Annual production statistics for the Ferron coal-bed gas wells of Texaco Exploration and Production, Incorporated (data derived from Utah Division of Oil, Gas, and Mining records).*

Year	Number of Wells	Gas (Mcf)	Water (bbl)	Average Days/Well	Average Gas/Well/Day
1995	1	474	3,582	27	18 Mcf
1996	6	246,777	403,069	254	254 Mcf
1997	28	385,115	926,624	299	117 Mcf
1998	37	766,692	2,917,768	331	65 Mcf
1999	37	1,158,130	4,439,902	350	90 Mcf
2000	45	1,780,690	5,362,432	350	113Mcf

Outside the Castlegate field, at least 100 square miles (259 km^2) in Carbon County, in T. 12 S., R. 8 -13 E., have potential for coal-bed gas production where the Blackhawk Formation coals are between 2,500 and 6,000 feet (762 and 1,829 m) deep, and have a net thickness of at least 10 feet (3 m). This 100-square-mile (259 km^2) area, which possesses the best development potential, could accommodate 400 wells on a 160-acre (65 hectare) spacing. These wells, added to the 125 wells from the Castlegate field area, means the Book Cliffs coalfield could potentially have 525 producing coal-bed gas wells. If all of these wells were to each produce 0.5 to 1.7 Bcf (14.2 to 48.1 m^3) of recoverable gas, then the Book Cliffs field, almost wholly within Carbon County, could contain 262 to 892 Bcf (7.4 to 25.3 billion m^3) of recoverable coal-bed gas resources.

The Wasatch Plateau coalfield appears to have little to no development potential for coal-bed gas within Carbon and Emery Counties. The coal in this field within these two counties is generally under less than 2,500 feet (762 m) of cover, is slightly lower in rank than the coal of the Book Cliffs field, is commonly faulted, and has been highly dissected by canyons. All of these factors contribute to the low measured-gas contents for Blackhawk coals of the Wasatch Plateau field. No exploration has been conducted for coal-bed gas and no coal-bed gas resources have been delineated for this field.

Emery Coalfield

Recent coal-bed-gas drilling in the northern and central portions of this field has been confined to Castle Valley, the area below the escarpments of the Book Cliffs and Wasatch Plateau. The Ferron coals occur at relatively shallow depths in Castle Valley, ranging from about 1,000 to 4,500 feet (305 to 1,372 m). Approximately 211,000 acres (85,392 ha) of the Ferron coal-bed fairway fall within the 1,000- to 4,500-foot (305 to 1,372 m) depth range. If the Castle Valley portion of the Ferron coal-bed fairway were drilled on a 160-acre (65 hectare) spacing pattern, it could potentially contain about 1,300 gas wells. As of December 2000, there were 488 producing coal-bed gas wells in Ferron coals, 348 by Phillips Petroleum, 45 by Texaco, Incorporated, 79 by Anadarko Petroleum, and 16 by Marathon Oil. Drilling plans announced by three companies in 1997 indicated that a total of about 819 coal-bed gas wells will ultimately be drilled in the Castle Valley portion of the Ferron fairway; 550 by Phillips, 200 by Texaco, and 69 by Anadarko. Other companies with small scattered holdings have not released drilling plans, and drilling may not be permitted by the BLM in some areas to preserve wildlife habitat, so the total number of coal-bed gas wells likely to be completed in Castle Valley is about 1,000.

If all the potential 1,000 coal-bed gas wells in the Castle Valley area were drilled and completed, and achieved a daily production equal to Phillips Petroleum's current wells at around 600 Mcf (16,992 m^3) per day per well, then the area's wells could produce 600,000 Mcf (17.0 million m^3) per day of coal-bed gas. On an annual basis (345 production days/year) this would be about 207 Bcf (5.9 billion m^3) for the 1,000 wells. In comparison, the state's largest current gas producing field, Anschutz Ranch East, had annual production of about 70.7 Bcf (2.0 billion m^3) for 2000. If the 1,000 potential coal-bed gas wells in the Castle Valley portion of the Emery coal field each contain 2.0 to 2.6 Bcf (56.6 to 73.6 million m^3) of recoverable gas reserves per well (estimate per well for Drunkards Wash; Tabet and Burns, 1996), then the total recoverable gas reserves for that portion of the field would range from 2,000 to 2,600 Bcf (56 to 74 billion m^3).

Some of the deeper portions of the Ferron trend may contain gas that can be recovered economically, but such production has not been tested or proven to date. The area covering the deeper portion of the Emery coalfield within Carbon and Emery Counties would allow drilling of at least 700 more coal-bed gas wells on 160-acre (65 hectare) spacing. Drilling to tap the gas resource held in the deeper coals of the Emery field would need to be conducted in a way that would not interfere with coal mining operations in the higher Blackhawk Formation coals. There is lower potential in the shallower, southern half of the Ferron coalfield. Recent Utah Geological Survey research indicates that the northern half of the Ferron field has the best potential for economic quantities of coal-bed gas, while the southern half appears to be undersaturated and no attempt has been made to assign a resource potential to this southern area.

Other Potential

The Emery Sandstone Member of the Mancos Shale, which lies stratigraphically between the Ferron Sandstone Member of the Mancos Shale and the Blackhawk Formation, is also known to be a coal-bearing unit within western Carbon and Emery Counties. Little is known about the extent or distribution of coal in this unit; the coal beds in this unit are not known to crop out anywhere in the two-county area, but have been observed on well logs from several oil and gas test wells drilled on the Wasatch Plateau. Emery Sandstone coal beds are known to be as much as 20 feet (6 m) thick and occur at depths between 2,000 and 5,000 feet (610 and 1,524 m), which are reasonable for gas production. In particular, such coal beds are reported in the abandoned Cockrell Oil Corporation Scofield No. 1 well located in section 30, T. 12 S., R. 8 E. No information has been released on the gas content of these coal beds, but the Emery Sandstone coals deserve further testing.

OIL-IMPREGNATED ROCK, OIL SHALE, AND GEOTHERMAL ENERGY RESOURCES

Oil-Impregnated Rock Resources

Fifteen oil-impregnated rock deposits and several additional minor occurrences are known in Carbon and Emery Counties (table 56). These deposits contain an estimated 4,660 to 7,475 million barrels (741-1189 m^3) of oil, but most are low grade and unlikely to be developed in the near future. No exploration or development work was being conducted on these deposits as of December 2000 (Jim Kohler, BLM, verbal communication, 2000). The location of these deposits is shown on plate 9 and certain characteristics are summarized in table 56.

The Sunnyside deposit is the largest and richest oil-impregnated deposit in the two counties. Most of the oil-impregnated rock exploration and development in the two counties has been on the Sunnyside deposit, and it is considered to be the only deposit to have any potential for development at the present time.

In the following sections a general overview of the deposits is given first, followed by a more detailed discussion of the Sunnyside deposit.

Known Occurrences and Characteristics

General: Oil-impregnated rock deposits occur in five main areas in Carbon and Emery Counties (plate 9):

(1) south flank of the Uinta Basin (Sunnyside, Minnie Maud Creek, and Cottonwood-Jacks Canyon deposits);
(2 north part of San Rafael Swell (Red Canyon, Black Dragon, Wickiup, and Cottonwood Draw deposits);
(3) south part of San Rafael Swell (Justensen Flats, Family Butte, Flat Top, Chute Canyon, Temple Mountain,and San Rafael Swell deposits);
(4) Nequoia Arch; and
(5) Sweetwater Dome.

The deposits occur in a variety of host rocks ranging in age from Permian to Eocene (table 56 and figure 31). The Uinta Basin deposits are in Paleocene to Eocene rocks and the San Rafael Swell deposits are mostly in Triassic to Jurassic rocks with a few occurrences in Permian rocks.

Major host units and depositional environments include:

(1) medium- to fine-grained, fluvial channel sandstones and marginal marine (lacustrine) deltaic sandstones (Green River and Colton Formations, Torrey Member of Moenkopi Formation);
(2) medium- to fine-grained, shallow marine to shoreface sandstones (Black Dragon Member of Moenkopi Formation, White Rim Sandstone);
(3) medium- to coarse-grained, fluvial channel sandstones (Moss Back Sandstone Member of Chinle Formation, Kayenta Formation);
(4) shallow water to tidal flat marine limestones (Black Box Dolomite, Sinbab Limestone Member of Moenkopi Formation); and
(5) fine- to medium-grained, eolian sandstones (Wingate and Navajo Sandstones).

***Table 56.** Summary of oil-impregnated rock deposits of Carbon and Emery Counties, Utah (arranged roughly north to south then west to east).*

DEPOSIT NAME	HOST FORMATION	GROSS OIL IN PLACE (Million Barrels)	GRADE (Gallons/short ton)	ANALYSIS OF EXTRACTED OIL	COMMENTS
MINNI MAUD CREEK (Indian Cyn, Lake Cyn)	Garden Gulch & Parachute Cr. Mbrs. of Green River & Colton (Wasatch) Fms. (Paleocene/Eocene)	10-15 (Ritzma, 1979)	No information	No information	Medium-sized deposit, 0.5-3.5 sq. mi., 1-4 principal pay zones, 5-15 ft net pay zone, 0->500 ft overburden, formerly part of Argyle Cyn. deposit.
SUNNYSIDE (Tidwell, Rideout)	Upper Colton (Wasatch) Fm., and basal Green River Fm., undivided. (Paleocene/Eocene)	5,200-5,850 (Oblad and others, 1987), > 6,000 (Lewin & Assoc., 1984) 3,500-4,000 (Koch, 1982)	13.08 -28.43 (Clem, 1985) 20.5 Avg (Oblad and others, 1987) 25-28 (13 Avg) (Campbell & Ritzma, 1979)	83.3% C, 10.8% H, 0.7% N, 0.6% S, 4.4% O (Oblad and others, 1987)	Giant deposit, 35-90 sq. mi., 3-12 principal pay zones, 15-550 ft net pay zone, 0-500 ft overburden, previous exploration and development
COTTONWOOD-JACKS CANYON. (Continuation of the Sunnyside deposit)	Green River Fm., deltaic facies. (Eocene)	20-25 (Ritzma, 1979)	No information	No information	Medium-size deposit
RED CANYON (Woodward Wash)	Torrey Mbr. of Moenkopi Fm (Triassic)	60-80 (Ritzma, 1979)	9.5 (3.9% tar) (Blakey, 1979)	72.39% C, 11.81% H, 2.57% S (Blakey, 1977)	Large deposit
WICKIUP	Moenkopi Fm. (undifferentiated). (Triassic)	60-75 (Ritzma, 1979)	No information	No information	Large deposit
COTTONWOOD DRAW	Black Dragon Mbr. of Moenkopi Fm. (Triassic)	75-80 (Ritzma, 1979)	6.6-40.3 (2.7-5.0% tar) (Oblad and others, 1987)	68.06-68.85% C, 10.95-11.60% H, 1.6-3.2% S (Blakey, 1977)	Large deposit
BLACK DRAGON (Black Box Jackass Bench)	Black Dragon Mbr. of Moenkopi Fm (Triassic)	100-125 (Ritzma, 1979) 55-91 (Tripp, 1985).	6-40.3 (2.4-16.8% tar) (Blakey, 1977)	70.17-67.36% C, 11.25-10.41% H, 5.08-2.84% S (Blakey, 1977)	Large deposit, 70 sq. mi., 0-47 ft net pay, about 100 ft of overburden
JUSTENSEN FLAT (Copper Globe)	Navajo Ss. and Kayenta Fm. (Jurassic)	Minor (Ritzma, 1979)	No information	No information	Minor deposit
SAN RAFAEL SWELL (miscellaneous localities unnamed [San Rafael Swell south group])	Moss Back Ss. Mbr. of Chinle Fm. (Triassic) Black Box Dolomite (Permian)	Minor (Ritzma, 1979)	No information	No information	Minor deposit
FAMILY BUTTE (San Rafael Swell south group)	Torrey Mbr. of Moenkopi Fm. (Triassic)	100-125 (Ritzma, 1979)	9.4-26.4 (8.1-11.0% tar) (Blakey, 1977)	68.15-69.32% C, 10.8-11.4% H, 3.46-3.65% S (Blakey, 1977)	Large deposit
FLAT TOP (San Rafael Swell south group)	Moss Back Mbr. of Chinle Fm. (Triassic)	0.25-0.5 (Ritzma, 1979)	No information	No information	Minor deposit
CHUTE CANYON (San Rafael Swell south group)	Torrey Mbr. of Moenkopi Fm. (Triassic)	50-60 (Ritzma, 1979)	No information	No information	Large deposit
TEMPLE MOUNTAIN (San Rafael Swell south group)	Moss Back Mbr. of Chinle Fm. (Triassic) and Wingate Ss. (Jurassic)	Minor	No information	No information	Minor deposit
NEQUOIA ARCH Northern portion, southern portion mainly in Wayne County	White Rim Ss. (Permian)	730 (measured) north - 310 south - 420 160 (speculative) north - 130 south - 30 (Lewin and Assoc., 1984).	7.18 (estimated)(range of 500 to 530 barrels per acre-foot, (Lewin and Assoc., 1984) Conversion based on factor of “barrels per acre foot x .014047"	No information	Giant deposit, measured and speculative resource values determined from drill hole information.
SWEETWATER DOME	Curtis Fm. and Entrada Ss. (Jurassic)	0.1-0.12 (Ritzma, 1979)	No information	No information	Minor deposit, about 1.5 sq. mi.

Reserve estimates are based on limited drilling and sampling and should be considered as very preliminary. Many may overestimated overall size and/or grade of the resource.

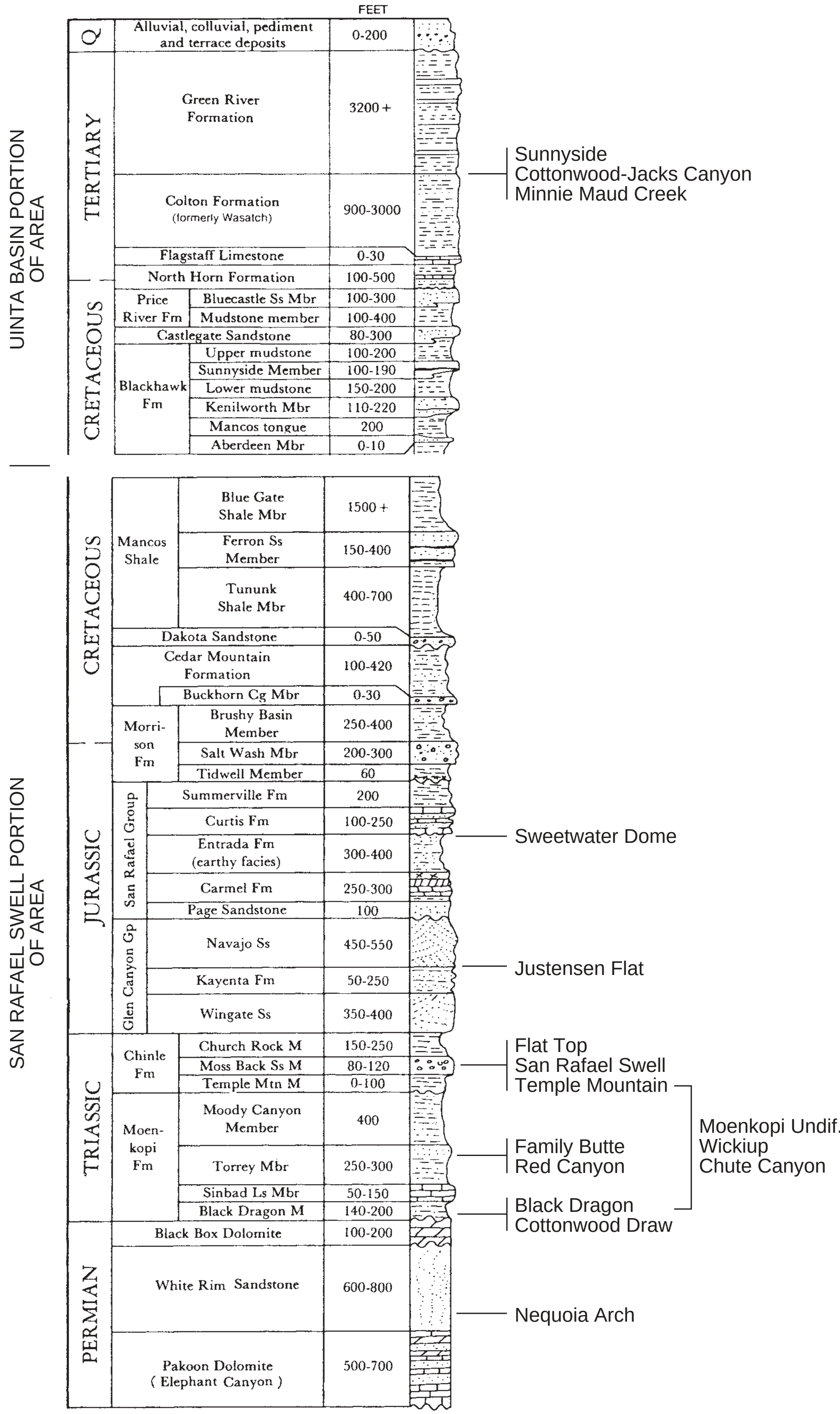


Figure 31. *Generalized stratigraphic section showing oil-impregnated rock units in Carbon and Emery Counties, Utah (after Hintze, 1993). Sunnyside-Woodside and San Rafael Swell, West Flank sections combined to represent Uinta Basin (northern) and San Rafael Swell (southern) tar sand areas.*

The largest and richest deposits are in the fluvial channel sandstone/marginal marine deltaic sandstone and shallow marine to shoreface sandstone environments. The host units are usually enclosed by or interbedded with mudstone, siltstone, and shale which are rarely impregnated with bitumen. The deposits consist of dense, viscous hydrocarbon (bitumen) filling pores, vugs, and cavities in the host units. The amount of contained bitumen is highly variable depending on porosity, permeability, and degree of saturation (percentage of pores/cavities filled). In general, units with higher porosity and permeability contain more bitumen, but the degree of saturation can vary drastically both vertically and laterally over distances of a few centimeters. Lateral variations, dependent in part on facies variation, are particularly difficult to predict. Typical saturation values for bitumen-impregnated deposits in Carbon and Emery Counties range from 10 to over 70 percent (Campbell and Ritzma, 1979).

Individual deposits contain from 1 to 32 pay zones. Individual pay zones range in thickness from 2 to 350 feet (0.6-110 m). Most pay zones in the San Rafael Swell deposits are from 4 to 20 feet (1.2-6 m) thick in the better parts of the deposits, but pay zones in the Sunnyside deposit are much thicker, usually from 25 to 250 feet (8-80 m) (Clem, 1985). Net pay thickness (aggregate thickness of bitumen-bearing units) ranges from 2 to nearly 50 feet (0.6-15 m) in the San Rafael Swell deposits and from 15 to 600 or more feet (5-180 m) in the southern Uinta Basin deposits. Gross pay thickness (thickness between uppermost and lowermost bitumen-bearing horizon) ranges from less than 20 to nearly 70 feet (6-20 m) in the San Rafael Swell deposits and from about 20 feet to nearly 1,900 feet (6-580 m) (Gwynn, 1986) in the southern Uinta Basin deposits. Contained oil ranges from 0.1 to over 42 gallons per short ton. Deposits in the San Rafael Swell and southern Uinta Basin show similar oil content ranges, but average values are higher for the Uinta Basin deposits. For example, the Sunnyside deposit averages 14.3 gallons per ton (Campbell and Ritzma, 1979), but the Black Dragon deposit averages less than 7 gallons per ton (Tripp, 1985). Most other San Rafael Swell deposits are even lower grade.

The oil-impregnated rock deposits represent degraded oil fields. Hydrocarbons generated from organic-rich source rocks migrated along and up permeable zones until confined by structural or stratigraphic traps. Later degradation of the trapped oil by biodegradation or water washing (dissolution by meteoric waters) caused the loss of the lighter, more volatile, hydrocarbons resulting in density and viscosity increases in the residual hydrocarbons. Biodegradation and water washing occur when crude oil contacts bacteria- and oxygen-laden meteoric water at low temperatures and usually at shallow depths. The source rock for the oil-impregnated rock deposits on the south flank of the Uinta Basin is thought to be carbonaceous siltstones and shales of the Parachute Creek and Douglas Creek Members of the Green River Formation. The source rock for the deposits in the San Rafael Swell is not known but is most likely Paleozoic shales or possibly even Triassic shales. Biomarkers from San Rafael Swell deposits are different from Uinta Basin deposits and indicate two distinct source rocks for the deposits (Jim Palacas, USGS, verbal communication, 1995).

Sunnyside deposit: The Sunnyside deposit and adjacent Cottonwood-Jacks Canyon deposit are located in T. 13-14 S. and R. 13-15 E. (figure 32). The Sunnyside deposit is the near-outcrop, highly saturated part and the Cottonwood-Jacks Canyon is the downdip, less saturated part. The deposits are included in the Sunnyside and vicinity Designated Tar Sands Area (DTSA). Oil-impregnated rocks are exposed along the Roan Cliffs for a distance of 9 miles (14.5 km) between Nine Mile Creek to the head of Rock Creek and to the east in drainages of Stone Cabin Canyon, Cottonwood Canyon, Jack Canyon, and Flat Canyon.

The Sunnyside oil-impregnated deposit occurs within the lower part of the Green River Formation (Eocene) in the marginal lacustrine (deltaic) facies and in the upper part of the Colton (Wasatch) Formation (Paleocene-Eocene) in the meandering stream/fluvial facies (Banks, 1981; Schenk and Pollastro, 1987). The units dip northeastward at 3 to 12 degrees. The fluvial sandstones of the Colton Formation are lenticular, limited in lateral extent, and exhibit varying degrees of porosity and permeability. Many of the fluvial sandstones exhibit channel downcutting and basal conglomerates, and the thicker sandstone bodies represent several stacked channels (Schenk and Pollastro, 1987). Sandstone units within the Green River Formation show greater lateral continuity but generally lower porosity and permeability values. Considerable intertonguing of the lithologically similar Green River and Colton Formations is common (Covington, 1976), making it difficult to distinguish between the two formations. Clem (1985) measured three sections in the west-central portion of the Sunnyside deposit. These sections show the lithologic variability of the units and their relationships.

Up to 32 saturated beds have been identified from surface mapping (Clem, 1985), but usually only 3 to 12 principal pay zones are present (Ritzma, 1979). Medium- to very-fine-grained sandstone and occasionally siltstone are the main host lithologies. These bitumen-bearing beds are interbedded with mudstone, shale, siltstone, and limestone that do not contain significant bitumen (Schenk and Pollastro, 1987). Individual bitumen-bearing beds range in thickness from 0.5 to 350 feet (0.2-110 m), but most are between 30 and 150 feet (9-50 m) thick. Net pay thickness varies from 15 to nearly 600 feet (5-180 m) (Ritzma, 1979) within a gross pay thickness of 1,000 to 1,900 feet (300-580 m) (Gwynn, 1986). In the better areas, up to 60 percent of the gross pay thickness is variably impregnated with bitumen. The degree of bitumen saturation is quite variable both vertically and horizontally. Vertical changes from “barren” to “highly rich” may occur rapidly at bed boundaries or over several tens of feet within more homogeneous host units. Horizontal changes from “barren” to “highly rich” may occur within a few hundred feet along strike (Clem, 1985). Channeling, irregular thickness, pinch-out and interfingering with neighboring beds make correlation of individual beds very difficult (Clem, 1985). Reservoir and bitumen properties are summarized in table 57.

Two zones of saturation have been identified in the subsurface. The upper zone crops out in several drainages and may have a gross thickness of up to 1,000 feet (300 m). The lower zone, 800 to 900 feet (250-275 m) below the upper zone, is between 1,300 and 1,900 feet (400-580 m) thick (Gwynn, 1986). To the west along the Roan Cliffs, there is no distinction between these two zones and the intervening barren zone is missing.

The west-central part of the Sunnyside deposit is very rich and contains approximately 600,000 barrels (95,400 m^3)

Table 57. *Reservoir and bitumen properties for the Sunnyside deposit.*

Property	Range	Mean
Porosity (volume percent)	3.7-35.6[1] 10-28[3]	23.1[1] 25-30[2] 24[3]
Permeability (millidarcies)	0-537[1] 150-650[2] 800-1,000[3]	570[2]
Grade (gallons/short ton)	0.3-32.0[1]	14.3[1] 21.2[2]
Bitumen content (weight percent)	0.1-11.7[1]	5.4[1] 9.0[2]
Oil Saturation (percent pore space)	2.0-90.0[1]	51.8[1] 55.0[2] 50.0[3]
Water Saturation (percent pore space)	0-97.0[1]	20.9[1] 5.0[2]
Bitumen Gravity (degrees API)	7.6-9.2[1]	8.6[1]
Bitumen Viscosity (centipoise)	—	100,000[3] at reservoir temperature
Bitumen sulfur content (weight percent of extracted bitumen)	0.50-0.60[1]	0.55[1] 0.70[3]

Sources: [1] Campbell and Ritzma (1979) [2] Covington (1976) [3] Lewin and Associates (1984)

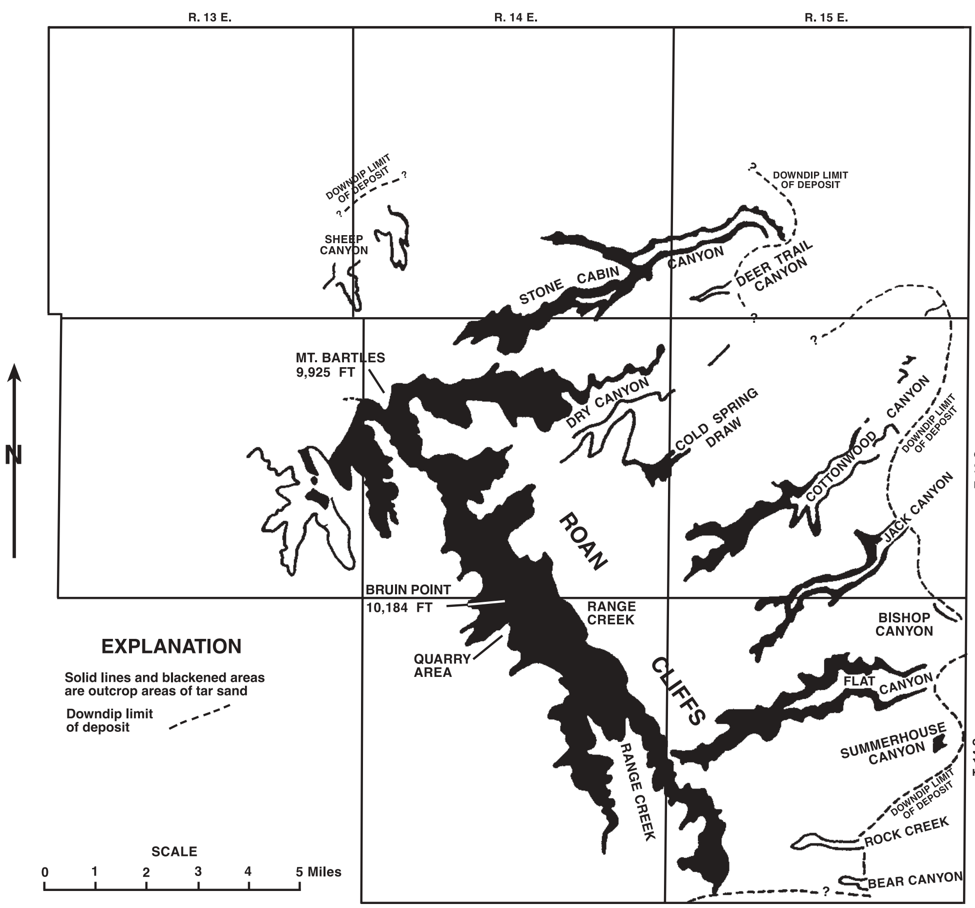


Figure 32. *Outcrop distribution of oil-impregnated sandstones, Sunnyside-Jacks Canyon deposit Carbon County, Utah (from Holmes and others, 1948, and Ritzma, 1984a)*

of oil per acre. This area extends for about 2 miles (3.2 km) along the outcrop near Bruin Point (figure 32). The large, in-place resource is due to both the high saturation (over 1,000 barrels of oil per acre-foot) and the considerable pay thickness of 200 to 500 feet (60-150 m). The richness of the deposit decreases gradually to the north and east away from the outcrop. This rich portion of the deposit corresponds to a well-developed delta complex. Table 58 gives several in-place reserves estimates for the Sunnyside-Cottonwood/Jacks Canyon deposit. The majority of the overburden within the Sunnyside deposit ranges from 0 to 328 feet (0-100 m). Within the central portion of the deposit (T. 14 S., R. 15, 16 E.), overburden is between 328 to 656 feet (100-200 m) thick, and near the center of T. 14 S., R. 16 E. overburden is between 656 and 984 feet (200-300 m) thick.

Past Production and Exploration Activity

Although the deposits have been studied and sampled by many workers (Holmes and others, 1948; Holmes and Page, 1956; Covington, 1963, 1964, 1965, 1976; Ball Associates, 1965; Ritzma, 1973, 1979, 1984a, 1984b; Glassett and Glassett, 1976; Blakey, 1977; Campbell and Ritzma, 1979, 1982; Utah Energy Office, 1980; Koch 1982; Lewin and Associates, 1984; Clem, 1985; Covington and Young, 1985; Gwynn, 1986; Tripp, 1985; Schenk and Pollastro, 1987; Blackett, 1996; and others), there has been little exploration or drilling on any of the deposits except the Sunnyside occurrence. Most of the work has been confined to mapping the tar sand outcrops, measuring the stratigraphic section and estimating oil content, and limited sampling and analysis. Some drilling was done on several of the San Rafael Swell deposits by Kirkwood Oil and Gas and Cities Service (Bishop and Tripp, 1993), but no additional work was done. Only the Sunnyside deposit has been even partially evaluated and tested.

The Sunnyside deposit was mined from 1892 to about 1894, when about 1,000 short tons (900 metric tons) was removed, and again from 1902 to 1903, during which time an additional 1,000 short tons (900 metric tons) was removed. A new quarry was opened by the Utah Asphalt Company which removed about 3,000 short tons (2,700 metric tons) between 1915 and 1917. Between 1927 and 1948, operations were more or less continuous (Holmes and Page, 1956; Ball Associates, 1965). Between 1931 and 1945, the material was used for paving in Utah and five other western states (Campbell and Ritzma, 1979). By about 1948, 335,000 short tons (304,000 metric tons) of oil-impregnated rock had been quarried (Holmes and others, 1948).

In 1956, Gulf Oil Corporation drilled the No. 1 Nutter Ranch well in section 24, T. 13 S., R. 14 E., SLBL & M, apparently as a “conventional” oil well. This well was cased and produced some heavy oil for a short time. The hole was drilled to a depth of 2,685 feet (818 m) and intersected about 100 feet (30 m) of oil saturation in the Green River Formation (Petroleum Information Corporation, Denver, Colorado).

Between 1955 and 1965, Signal Oil & Gas Company explored the economic feasibility of an in-situ mining operation. They initially drilled a stratigraphic test well in section 4, T. 14 S., R. 14 E., to a total depth of 1,450 feet (442 m). The well penetrated most of the oil-impregnated sandstone with the following results (Covington, 1976):

a. total thickness of oil-impregnated sand	645 feet (200 m),
b. net oil sand, thickness	366 feet (112 m),
c. average oil saturation	55 percent,
d. average porosity	25 percent, and
e. average permeability	0.75 -1.75 darcies.

A secondary purpose of the well was to determine if liquid oil existed in a downdip direction from the outcrop (Covington and Young, 1985).

Table 58. *In-place reserve estimates for the Sunnyside-Cottonwood/Jacks Canyon deposit (in millions of barrels of oil).*

Reference	Measured	Indicated	Inferred/Conjectured	Total
Holmes and others (1946)	410 (includes indicated)	included in measured	318	728
Ball Associates (1965)	—	—	—	2,500-3,000
Ritzma (1979)	1,250	1,750	500-1,000	3,500-4,000
Lewin and Associates[1] (1984)	4,400 (includes indicated)	included in measured	1,700	6,100
Ritzma (1984a, b)	1,800	2,200	1,200-1,850	5,200-5,850

[1] Includes Cottonwood-Jacks Canyon in inferred/conjectured category.

Subsequently, during 1966 to 1967, Signal drilled three horizontal holes in the cliff face of the old Utah Rock Asphalt Quarry for steam-soak extraction tests. The holes were 370 feet long and consisted of a central production well and two surrounding steam injection wells (Covington, 1976). Total oil production from the test was 560 barrels of bitumen with an average oil/steam ratio of 0.042 (Lewin and Associates, 1984). The project was later abandoned.

In about 1964, the Sunnyside deposit was core drilled by the Shell Oil Company and the Atlantic Refining Company (Covington, 1965). Shell Oil Company drilled six core tests in section 3, T. 14 S., R. 14 E. (Covington and Young, 1985). In 1966, Shell did an experimental (five-spot) in-situ steam-flood test. They determined that the natural vertical fractures in the formation prevented the build-up of sufficient pressure or energy in the formation to drive the oil, and Shell terminated the test in 1967 (Lewin and Associates, 1984). Other drilling during the mid-1960s included three core holes drilled by Texaco in section 22, T. 13 S., R. 14 E. (455 feet [139 m]), section 23, T. 13 S., R. 14 E. (826 feet [252 m]), and section 31, T. 13 S., R. 15 E. (730 feet [222 m]) (Covington and Young, 1985).

In the early to mid-1980s, AMOCO Minerals Company did additional core drilling coupled with geophysical logging, and laboratory Soxhlet (hot-solvent) extraction tests to determine weight-percent oil in the rock. Results are still confidential. During 1982, Enercor did preliminary studies of mining feasibility on their leases (Covington and Young, 1985).

In November 1982, Chevron Resources Company signed an operating agreement with Great National Tar Sands Corporation (GNC) of Dallas, Texas for the development of 2,000 acres of the Sunnyside deposit. Ore was shipped to the company's Salt Lake City pilot plant where the extraction process was being perfected (Covington and Young, 1985). The project did not proceed to commercial development and was apparently abandoned. Covington and Young (1985) reported that GNC drilled at least seven holes in and around the highly saturated area near Bruin Point.

In 1973, a tar sands research and development program was started at the University of Utah (Department of Fuels, Chemical, and Metallurgical Engineering) which focused on surface mining bitumen recovery processes with emphasis on water-assisted and thermal recovery technologies, upgrading of the bitumens, and characterization of the native bitumens and liquid hydrocarbon products (Hupka and Oblad, 1984). The objective of the effort was to develop the scientific and engineering base necessary for commercialization of Utah's tar sand deposits (Oblad and others, 1987). Some 36 publications, eight final reports, 16 theses and dissertations, and seven patents resulted from this work (Oblad and others, 1987).

Current Production and Exploration Activities

There is no current exploration or development work being done on the property, although work is continuing both at the University of Utah and by private concerns to develop more efficient and economical techniques to recover the oil from the Sunnyside and other oil-impregnated rock deposits in Utah.

Potential for Additional Discoveries and/or Development

Additional exploration and drilling around and downdip from the known deposits would certainly improve and refine the current resource estimates and better delineate the areas of higher oil saturation. However, it is unlikely that significant, new, high-grade, oil-impregnated rock deposits will be found.

The major obstacle to production from the Sunnyside oil-impregnated rock deposit is the lack of an efficient, economical recovery technique that is competitive with oil produced by conventional means. Two known recovery techniques and their advantages and drawbacks are discussed briefly below. Additional information is found in Oblad and others (1987) which reviews the tar sand research and development work conducted by the University of Utah, including work on bitumen recovery, processing and utilization, and characterization, and provides an extensive listing of theses and dissertations, final reports, patents, and publications.

Potential Oil-Recovery Methods

There are two basic categories of recovery methods for oil-impregnated rock deposits: in-situ, and mining. In-situ recovery uses several combustion methods and a variety of steam-flood processes to provide the energy to mobilize the oil. Heat, steam, or air are introduced into the oil-impregnated zone through a series of injection wells that heat, mobilize, or combust the bitumen. The resulting mobilized oil is subsequently removed through production wells. Generally, from two to five injection wells are needed for each production well. Heating also reduces the oil's viscosity, enabling it to move more easily. The mining method of oil recovery involves conventional mining of the oil-impregnated rock from the deposit, transport to the processing facility, removal of the oil or bitumen from the rock, and upgrading of the bitumen to a usable feed stock for further refining.

Major advantages of the in-situ method include lower capital and operating costs and less surface disturbance. The main disadvantages are: (1) lower overall recovery of in-place reserves, possibly as low as 10 percent due to variability in porosity, permeability, and degree of saturation of oil-impregnated units causing unpredictable fluid-flow paths which could conceivably miss the rich zones, (2) limited flexibility in modifying techniques or procedures, (3) limited control over ground-water contamination (lost solvent or mobilized hydrocarbons), and (4) the need for large quantities of good-quality water.

Major advantages of the mining method include better overall recovery of the in-place reserves, extraction of the oil under more controllable conditions, and more flexibility in modifying mining or extraction procedures to meet changing conditions. The main disadvantages are higher capital and operating costs, disposal of the “spent” host rock, shallow depth cutoff, higher reclamation costs, and greater environmental impacts.

In-situ methods of oil recovery have been tried at Sunnyside with only limited success. Covington (1976) states that problems associated with thermal recovery by steam injection or fire flooding are: (1) the lenticularity of the sands, (2) the fact that bitumen-rich sandstones grade vertically, laterally, and in a downdip direction into lean to barren sandstones, often within several hundred feet, (3) the lack of a nearby, adequate supply of large volumes of good-quality water, and (4) lack of local markets. The lack of a nearby source of good-quality water is a major obstacle. Water from the Price River is fully appropriated, as is water from the Grassy Trail Creek. The area is also generally closed to drilling new water wells (Kent Jones and Mark Page, Utah Division of Water Rights, verbal communication, 1995).

Fractures in the host unit can seriously influence the effectiveness of using in-situ methods of recovery. During the steam-flood experiments by Shell Oil Company at Sunnyside, the natural vertical fractures in the formation prevented the build-up of sufficient pressure or energy to drive the oil (Lewin and Associates, 1984).

Large-scale surface mining would only be feasible for a small portion of the Sunnyside deposit; the near-surface, richest portion. Marchant and Koch (1984) suggest that an ore:waste ratio (net ore thickness:overburden plus interburden thickness) should be 1:1 or greater even for the significantly richer Canadian deposits. Ore (greater than 30 percent saturation) to waste ratios for four sections reported by Clem (1985) in the richest portion of the deposit are 0.6 to 1, 1.02 to 1, 0.34 to 1, and 3.4 to 1. The ratios decrease to the north and west downdip.

Underground mining is not practical. Estimated direct mining costs using efficient longwall or room-and-pillar methods are greater than the average contained oil even at a price of $25.00 per barrel.

It is unlikely that any of the oil-impregnated rock deposits in Carbon and Emery Counties will be developed in the near future. The Sunnyside deposit has the best potential for development but will require improvements in recovery technology and/or a significant increase in the price of oil to be feasible. Even with improvements in technology or oil-price increases, other better deposits in Utah, most notably in Uintah County, will probably be developed long before the Sunnyside deposit.

Oil Shale Resources

Known Occurrences and Characteristics

Oil shale of the Eocene-age Green River Formation crops out in the northeastern part of Carbon and Emery Counties. It occurs in a triangular-shaped, stream-dissected area and underlies nearly 250 square miles (650 km^2) mostly in northeastern Carbon County (figure 33). However, only about half of this area can be considered a significant resource because the oil shale thickness and kerogen content decrease to the southwest. A good dividing line would be the 15-gallon-per-ton saturation line as shown on figure 33. A small part of the oil shale in Carbon County is within the U.S. Naval Oil Shale Reserve No. 2 (NOSR) which comprises T. 12 and 13 S., R. 18 and 19 E. The NOSR was withdrawn from development by presidential order on December 6, 1916 (Pruitt, 1961). In early 2000, an agreement was announced to return the Naval Oil Shale Reserve No. 2 to the Ute Indian Tribe. The agreement will allow the Tribe to develop the resource but will require them to return an 8 percent royalty to the federal government to help pay for removal of uranium mill tailings at the Atlas mill site in Moab.

Oil shale in Carbon County consist of two zones of lacustrine, kerogen-rich, magnesian marlstone in the Green River Formation deposited in ancient Lake Uinta. The main zone is at the contact of the Middle Member (Douglas Creek Member of earlier publications) and the Upper Member (Parachute Creek Member of earlier publications) (Weiss and others, 1990). This zone contains the laterally extensive Mahogany bed, a well-known marker bed. The second, less significant, zone is present 30 to 80 feet (9-24 m) above the main zone. The zones strike northwest and dip about 1 to 1.5° northeast (104-125 feet per mile[19.7-23.6 m/km]).

The Middle Member is composed mainly of sandstone; siltstone; shale; and oolitic, algal, and ostracodal limestone. Locally it contains a few oil shale beds, but they are thin and less widespread than those in the Upper Member. They have little economic significance except for the uppermost beds in the northwestern Uinta Basin in Duchesne County.

The Upper Member is composed mainly of marlstone, oil shale, siltstone, sandstone, and tuff. Lithologic units are mostly thin, even bedded, and laterally continuous. In the northeastern Uinta Basin, the member is composed mostly of thin-bedded marlstone, oil shale, and tuff, all deposited in a deep-water or more distal to the shoreline environment. In the southwestern part of the Unita Basin, the member is composed mostly of siltstone and sandstone with only a few oil shale or tuff interbeds and was deposited in a shallow-water or more proximal to the shoreline environment.

The lower part of the overlying Uinta Formation (Evacuation Creek Member of earlier publications) occurs as residual patches capping some of the higher ridges in Carbon County. It contains some marlstones with appreciable amounts of organic matter but has no thick oil shale beds.

Trudell and others (1982) described seven principal oil shale units in the Upper Member in ascending order: L1, Mahogany, and units I through V. Only two oil shale units are present in Carbon or Emery County; the main or Mahogany zone and the upper zone (probably equivalent to unit I). In the Naval Oil Shale Reserve, the main zone is 20 to 45 feet (6-14 m) thick, and the upper zone is 5 to 15 feet (1.5-4.5 m) thick (Cashion, 1959).

Accessible resource information on oil shale in Carbon County is sparse. Information comes from two measured sections and several drill holes. The first measured section (section 32, T. 11 S., R. 18 E.) has a total of 15 feet (4.6 m) of oil shale averaging 15 gallons per ton (gal/ton) of kerogen of which 3 feet (0.9 m) averages 30 gal/ton (Pruitt, 1961). The second measured section (section 13, T. 12 S., R. 17 E.) has 14 feet (4.3 m) of oil shale averaging 15 gal/ton of which 5 feet (1.5 m) averages 30 gal/ton (Pruitt, 1961). Of the 98 well logs listed by Trudell and others (1982) only one is in Carbon County, but three others are just east of the Green River in adjacent Uintah County. Information for the four wells in summarized in table 59. Using different cut-off values, Cashion (1967) calculated that well 39 (NOSR#12) contained 53.8 feet (16.4 m) of oil shale averaging 15 gal/ton of which 13 feet (4.0 m) averaged 30 gal/ton.

Cashion (1967) calculated the resource for all of T. 12 S., R. 18 E. to be 570 million barrels in oil shale using a minimum thickness of 15 feet (4.6 m) thick and a minimum average grade of 15 or more gal/ton kerogen. Of the 570 million-barrel total, 303 million barrels occur in oil shale containing an average of 25 gal/ton kerogen and 93 million barrels occur

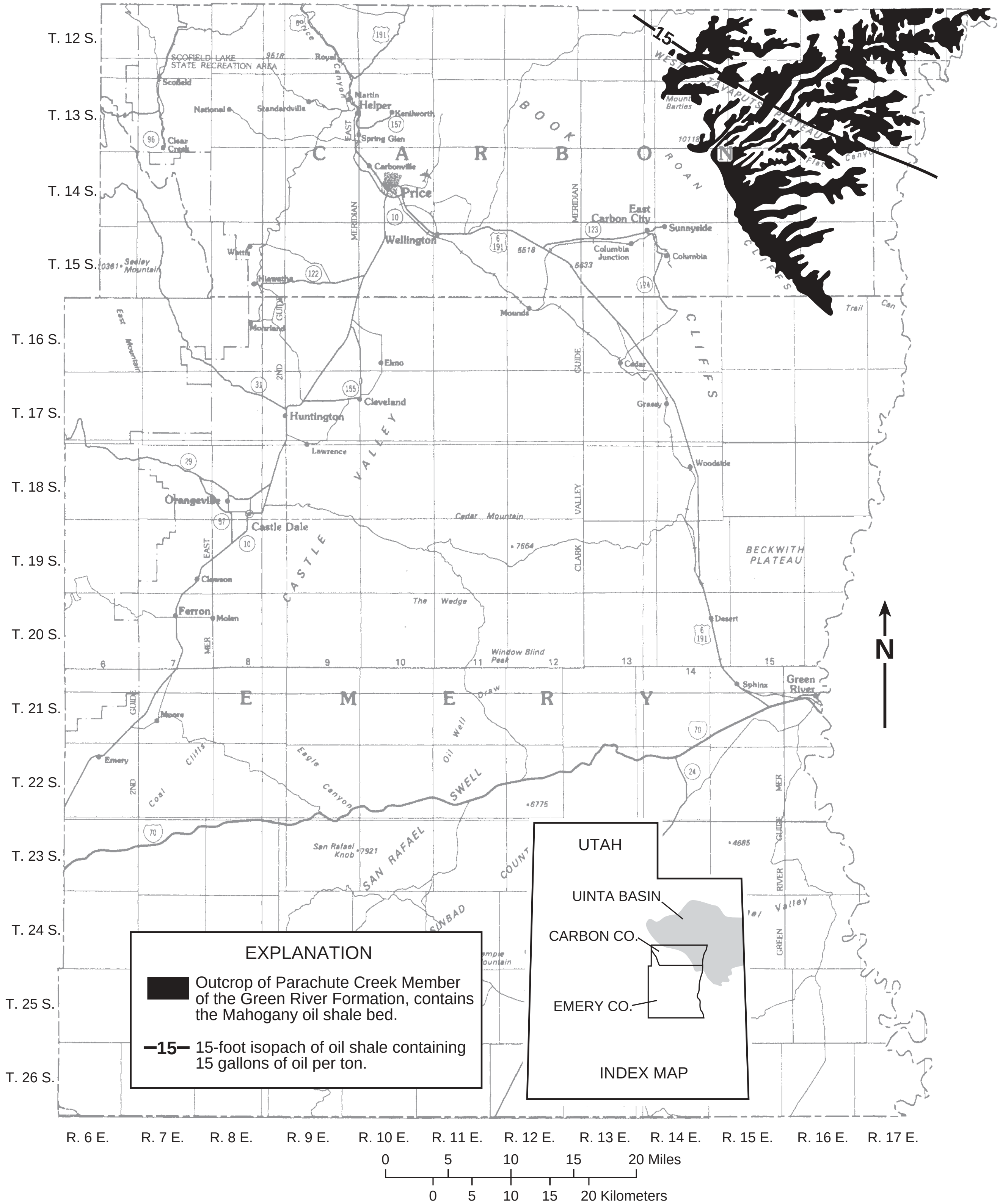


Figure 33. *Area underlain by oil-shale-bearing Upper Member (Parachute Creek) of Green River Formation, Carbon and Emery Counties, Utah. Outcrops from Cashion (1973), Weiss and others (1990), and Witkind (1995). Oil shale 15 gpt limit from Cashion (1967).*

Table 59. *Drill-hole oil-shale intercepts and average yield in T. 12 S., R. 18 E., Carbon and Uintah Counties, Utah (from Trudell and others, 1982). Includes data for both Mahogany (M) zone and richer central part (R) of Mahogany zone.*

Hole (no.)	Location (sec.)	Depth to Top (ft)	Depth to Bottom (ft)	Thickness (ft)	Avg. Yield (gal/ton)	In-place Resource per Acre (bbls)
38M	NENW sec 2	64.0	154.4[B]	90.4[P]	14.13	98,970
38R		107.9	147.9	40.0	21.82	63,940
39M	SWNW sec 4	54.8[T]	181.5[B]	126.7[PG]	10.35	104,700
39R		115.5	156.3	40.8	18.50	56,600
40M	NWNW sec 13	57.6	173.2[B]	115.6[P]	10.85	99,690
40R		106.3	150.2	43.9	17.02	56,660
41M	NWSE sec 26	30.9	166.6[B]	135.7[PG]	9.34	102,000
41R		68.2	143.6	75.4[G]	10.67	63,970

[T] = Top of assayed core samples
[P] = Unit only partially represented because core starts/ends within unit
[B] = Bottom of assayed core sample
[G] = Unit interrupted by gap of 25 feet or more yielding < 5 gal/ton

in oil shale averaging 30 gal/ton kerogen. Only about 30 percent of the resource in this township is in Carbon County. Additional oil shale resources are also present to the west in T. 12 to 13 S., R. 15 to 17 E. Total oil shale resources in Carbon County could be as high as 1.5 to 2.0 billion barrels based on extrapolating thickness trends of oil shale containing an average of 15 gal/ton kerogen. However, Cashion and others (1990) noted that the deposits do not fit minimum criteria even to be considered for development (average oil yield of 25 gal/ton or more in beds at least 25 feet [7.6 m] thick).

Additional oil shale information for Carbon County is contained in Gustavson Associates (1996) and Smith (1981). Additional information on oil shale could be calculated from sonic and density logs from oil and gas exploration wells such as those from nearby Jacks Canyon oil field and Peters Point gas field.

Past and Current Exploration Activity and Production

The only exploration activity that resulted in published data was the work done by the USGS and the USBM to evaluate the oil shale resource of Naval Oil Shale Reserve No. 2 in the early to mid-1950s. Work included mapping and sampling, measuring stratgraphic sections, determining oil yields from outcrop samples, and drilling and assaying samples from 18 core holes (Cashion, 1959). Most of the information collected was from Uintah County; only one hole was drilled in Carbon County. In view of the current energy market, it is unlikely that there will be any oil shale exploration in Carbon and Emery Counties in the foreseeable future.

Potential for Development

Oil shale in Carbon and Emery Counties is thinner and contains less kerogen than oil shale in the Piceance Basin (Colorado), the Green River Basin (Wyoming), and other parts of the Uinta Basin (Utah). Most of the local resource is also covered by too much overburden for open pit mining; more expensive underground or in-situ mining would be necessary. Even if an efficient and economic recovery process were developed and oil prices were significantly higher, the thicker and higher grade oil shale deposits in Colorado, Wyoming, and in Uintah County, Utah would be developed and mined before those in Carbon County.

Low-Temperature Geothermal Water Resources

Known Occurrences and Characteristics

Low-temperature geothermal resources are generally considered to be shallow (less than 3,000 feet [900 m]) sources (wells or springs) with temperatures of 212°F (100°C) or less. Geothermal resources in this temperature range are commonly used for space heating, aquaculture, recreation, and for therapeutic applications. In Carbon and Emery Counties, low-temperature geothermal water at temperatures ranging between 64 and 84°F (18 and 29°C) have been noted at eight springs, four wells, and one mine (figure 34, table 60). Fluids in this temperature range could be used in various aquacultural and recreational applications. There is no evidence, such as the presence of young volcanic rocks or high heat-flow zones, however, to suggest that moderate- to high-temperature geothermal systems (greater than 212°F) are present at economical drilling depths in either Carbon or Emery Counties. These counties are situated within the Colorado Plateau province which is characterized by low heat flow.

A brief listing of tabulated data, taken from Blackett (1994), on low-temperature wells and springs is shown in table 60. Temperatures range between 64 and 84°F (18 and 29°C), while total dissolved solids (TDS) content ranges from 365 to 13,531 milligrams per liter (essentially equivalent to parts per million for fresh and brackish water). Carroll (1962) classified waters with TDS values from 0 to 1,000 as fresh, from 1,000 to 10,000 as brackish, and from 10,000 to 100,000 as saline.

Exploration and Production History

The low-temperature wells and springs located in Carbon and Emery Counties have been developed by individuals, companies, and government agencies. These wells and springs were developed mainly as water sources for agricul-

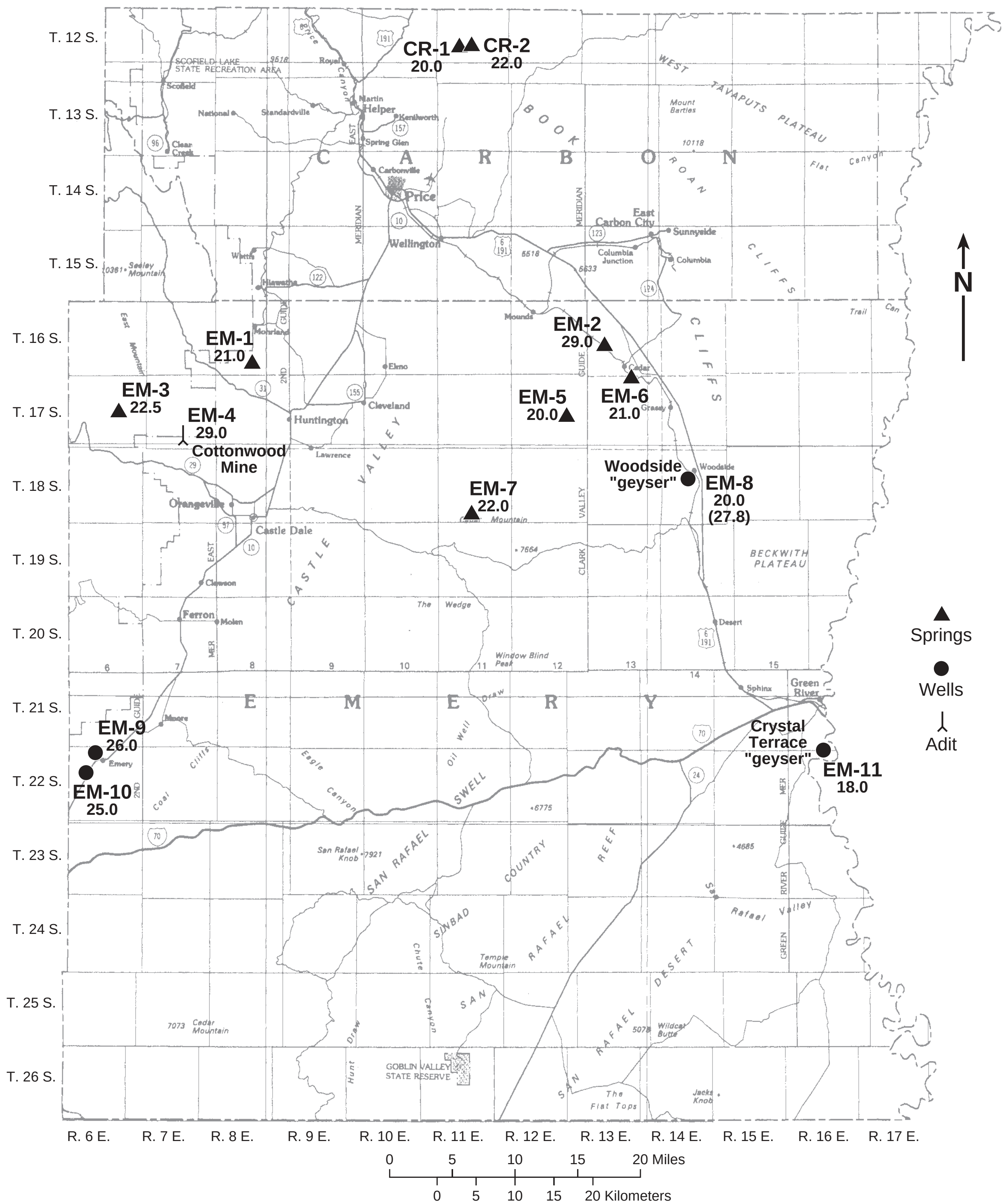


Figure 34. Low-temperature geothermal sources in Carbon and Emery Counties, Utah. Values are in degrees Celsius. Sources as shown on table 60 (from Blackett, 1994).

Table 60. *Summary of low-temperature geothermal sources in Carbon and Emery Counties, locations of geothermal sources shown on figure 34 (from Blackett, 1994).*

Number	Source	Type	UTM East	UTM North	Temp. (°C)	Depth (M)	Flow (L/min)	TDS (mg/L)	Reference
CR-1	unnamed	S	524984	4401784	20.0	—	11.36	—	Blackett, 1994
CR-2	unnamed	S	525670	4401786	22.0	—	3.52	365	Blackett, 1994
EM-1	unnamed	S	498089	4361324	21.0	—	—	—	Blackett, 1994
EM-2	Bureau of Land Management	S	545074	4362842	29.0	—	113.56	3,253	Blackett, 1994
EM-3	US Forest Service	S	481163	4354999	22.5	—	2.46	—	Blackett, 1994
EM-4	Cottonwood Mine (?)	M	489389	4352298	29.0	1231.1	—	542	Blackett, 1994
EM-5	Bureau of Land Management	S	539953	4354157	20.0	—	—	5,234	Blackett 1994
EM-6	Bureau of Land Management	S	548260	4358522	21.0	—	0.38	3,306	Blackett, 1994
EM-7	Bureau of Land Management	S	526927	4340507	22.0	—	—	2,700	Blackett, 1994
EM-8	Woodside “geyser”	W	556336	4345957	20.0	969.0	—	8,262	Mayo and others, 1991
EM-9	unnamed	W	477828	4309021	26.0	—	—	742	Blackett, 1994
EM-10	unnamed	W	476589	4306339	25.0	—	—	732	Blackett, 1994
EM-11	Crystal Terrace “geyser”	W	573524	4309881	18.0	800.7	—	13,531	Mayo and others, 1991

S = spring W = well M= mine

tural and domestic use. None were developed for thermal uses.

Two interesting wells are carbon dioxide-charged and erupt periodically in geyser-like fashion. Mayo and others (1991) reported that the Woodside “geyser” (SE1/4 section. 9, T. 18 S., R. 14 E.) violently erupts ground water and exsolved gas from an abandoned water-supply well drilled by the Denver and Rio Grande Railroad in 1910. Drilled to 3,180 feet (970 m), the well erupts water at about 68°F (20°C) on roughly 2- to 3-hour intervals. Bliss (1983) quoting Feltis (1966) reported that the water temperature for this well in 1947 was about 82°F (28°C) and that the well depth was 180 feet (55 m). Similarly, the Crystal Terrace “geyser” (SE1/4 section 34, T. 21 S., R. 16 E.) violently erupts ground water and exsolved gas at about 64°F (18°C). This well was drilled as a wildcat well in 1934 to a depth of 2,627 feet (800 m) (Mayo and others, 1991). The Woodside well was drilled on the north end of the Woodside anticline, which encloses a shut-in gas field described in the oil and gas resources section of this report. The Crystal Terrace well was drilled along the Little Grand Wash fault.

Other than regional assessments, no exploration is known to have taken place specifically for geothermal resources in either Carbon or Emery Counties. No direct-use application of low-temperature water is presently known.

Potential for Additional Discoveries and/or Development

The Colorado Plateau is an area of relatively undeformed Paleozoic and Mesozoic sedimentary rocks. The province is seismically inactive and has low heat flow (Mariner and others, 1983). Heat flow in this part of the Colorado Plateau ranges generally between 40 and 50 milliwatts per square meter, generally one-half to one-third that of the Basin and Range (Muffler, 1979, Map 1). Typically, this range of heat-flow values yields regional temperature gradients of about 1.4°F/100 feet (25°C/km). Assuming an annual average ambient temperature of 55°F (13°C) and this gradient, one would expect temperatures on the order of 212°F (100°C) at depths approaching 11,500 feet (3,500 m). These depths do not permit well drilling to tap geothermal resources economically. Low-temperature water found in Carbon and Emery Counties could, however, be used in conjunction with geothermal heat-pump technology for space heating and cooling.

URANIUM AND VANADIUM RESOURCES

Known Occurrences and Characteristics

Uranium and vanadium have been mined for over a century in Emery County. Deposits are in rocks ranging in age from Permian to Eocene with most of the production from the Triassic Chinle Formation and Jurassic Morrison Formation. Other occurrences are known in the Permian Black Box Dolomite; the Triassic Moenkopi Formation; the Jurassic Wingate, Navajo, and Entrada Sandstones and Carmel and Summerville Formations; and the Cretaceous Buckhorn Conglomerate and Cedar Mountain Formation. Most of the uranium and vanadium occurs in peneconcordant tabular or associated roll-type ore bodies in fluvial sandstone (Nash and others, 1981). Most of the roll-type bodies are in the Temple Mountain district. A few small occurrences in the Temple Mountain area of the San Rafael Swell are in collapse structures or breccia pipes.

The characteristics of deposits in the main uranium-vanadium mining areas are shown in table 61. Locations of uranium-vanadium mining areas and deposits are shown on plate 10. Major mines and deposits for the various mining areas are listed in tables 62, 63, 64, and 65 and shown in figures 36, 37, and 38. The production statistics in tables 62, 63, 64, and 65 for individual mines or deposits should be considered as approximations and indicate only the relative size of each deposit. The difficulty in assigning completely accurate numbers to individual mines is due to the following five factors:

1. Many individual mines reported production under as many as five or more different names.
2. Production from a number of mines was lumped together either by producing company, by mining area, or by claim group, and it is impossible to accurately divide the production amongst the various mines. For example, nearly 300,000 pounds (136,0000 kg) of U_3O_8 production from the Temple Mountain district was assigned to “various.”
3. For some mines with multiple entries, production was most likely assigned to the point of exit from the mine rather than from where it was actually mined. This problem is particularly evident for mines along the Calyx Bench in the Temple Mountain district and for several mines in the North Tidwell belt of the San Rafael River mining area.
4. Several different mines have the same name, and it is sometimes difficult to be sure production is assigned to the proper mine.
5. Reporting requirements became much less stringent after 1971, and production reports for individual mines are scarce.

Chinle-hosted Deposits

Chinle-hosted uranium-vanadium and uranium-copper deposits in Emery County are concentrated in four separate areas: three in the San Rafael Swell (San Rafael mining district) and one in the southeast corner of the county in the Mineral Canyon mining area of the Green River district (plate 10). The San Rafael Swell occurrences are separated into a northern belt (Calf Mesa mining area), a southern belt (Tomsich Butte, Delta, Wild Horse and Sinbad mining areas) and the Temple Mountain district. The distribution of mines and prospects defines two northwest-trending belts of favorable host rocks: a northern belt which includes the northern San Rafael area and extends southeast into the Mineral Canyon area of Grand County, and a southern belt which includes the southern area and the Temple Mountain district and extends southeast into the Orange Cliffs area of Garfield County (figure 35) (Johnson, 1959a; Mickle and others, 1977). The better deposits occur in the southern belt and the Temple Mountain district. Deposits in these two areas generally contain 1,000 to 10,000 short tons (900-9,000 metric tons) of ore but may be as large as 150,000 short tons (136,000 metric tons) (Delta mine). Deposits in the northern belt are generally small, containing less than 100 to 2,000 short tons (90-1,800 metric tons) of ore. Most deposits in the Mineral Canyon area are also small (less than 400 short tons [360 metric tons]), but several (Hey Joe, Cottonwood, A-group) produced from 2,000 to 20,000 short tons (180-18,000 metric tons) of ore. All of the better deposits in the Mineral Canyon area are in Grand County.

Most of the uranium deposits are in fine- to coarse-grained, massive sandstones or conglomerates of the Moss Back Sandstone Member of the Chinle Formation and are usually within 40 feet (12 m) of the basal contact. Other deposits are found in sandstones in the underlying Monitor Butte (Delta mine) or Temple Mountain Members (Sinbad mine) and in the overlying Church Rock Member (Mineral Canyon area). Although only a few deposits have been found in the Monitor Butte or Temple Mountain Members, several are very large with estimated production of 400,000 to 850,000 pounds (180,000-385,000 kg) of U_3O_8.

The ore-bearing sandstones are 1 to 50 feet (0.3-15 m) thick, 100 to 3,000 feet (30-900 m) wide, and traceable for several miles. Host sandstones are larger in the Temple Mountain district than in the other parts of the San Rafael Swell. Host sandstones are generally confined to recognizable north-, northwest-, and west-trending channels. Ore sandstones can be either deeply incised cut-and-fill channel sandstones or broader, aggradational channel sandstones. Most of the Moss Back Sandstone Member basal sandstones are deeply incised cut-and-fill channels, but those in the middle and upper Monitor Butte or Temple Mountain Members are aggradational.

The deposits in the Chinle Formation in the San Rafael Swell, exclusive of the Temple Mountain district, are similar in many respects to other Chinle-hosted deposits on the Colorado Plateau. The deposits are mostly irregular, tabular, ovoid to amoeboid-shaped, “peneconcordant” deposits. Individual ore pods are usually less than several hundred feet wide or long, but often cluster in groups. Deposits are generally confined to fine- to coarse-grained, occasionally conglomeratic, fluvial channel sandstones. Cut-and-fill scour channels are particularly favorable with the best mineralization concentrated in the basal portions or sides of the channel in association with carbonaceous debris, shale interbeds and fragments, and clay galls. The basal sandstone is usually the best mineralized and, in any area, only one horizon is usually mineralized. The units below and adjacent to the uranium mineralization are often altered and bleached to a purple-white “mottled zone.” The uranium occurs as uraninite and uraniferous asphaltite and is usually associated with organic carbon. Vanadium content is generally low. Copper minerals (sulfides, carbonates, and oxides) are commonly and zinc sulfides occasionally associated with the uranium and sometimes approach co-product ore grade.

The typical Chinle-hosted deposits are generally thought to be of late Triassic age or younger (Shawe and others, 1991). The deposits were probably formed by slightly acidic (pH 4 to 7), slightly oxidizing, CO_2-rich fluids. These fluids would be acidic enough to form kaolinite and mobilize silica, acidic and reducing enough to mobilize ferric iron, and oxidizing and basic enough to carry sufficient uranium as uranyl bicarbonate complexes. The solutions moved through

Table 61. Characteristics of uranium deposits in major mining areas, Emery County, Utah.

	San Rafael Mining Area Green River District	Temple Mountain District	Southern Belt San Rafael District
Host Unit and Nature	In thicker, medium- to coarse-grained, channel sandstones in upper part of Salt Wash Member of Morrison Formation. Minor mineralization in silty carbonaceous mudstone/sandstone of overlying Brushy Basin Member.	In fine- to medium-grained, massive sandstones of Moss Back Sandstone Member of Chinle Formation 10 to 40 feet above base. Commonly multiple mineralized horizons. Minor mineralization in Coconino Sandstone, Moenkopi Formation, Church Rock Member of Chinle Formation, and Wingate Sandstone, usually near collapse structures.	In fine- to coarse-grained, lensoid channel sandstones in basal 10 to 15 feet of Moss Back Sandstone Member of Chinle Formation and in well sorted, fine- to medium-grained sandstone lenses in underlying Monitor Butte Member of Chinle Formation. At any location usually only one mineralized horizon in Moss Back-hosted deposits and up to two in Monitor Butte-hosted deposits.
Thickness and Texture	In aggrading, lensoid channels 10 to 15 feet thick that may aggregate to form sandstone bodies up to 30 to 80 feet thick. Medium- to coarse-grained sandstone with lenses and partings of pebble conglomerate. Ore often in poorly sorted, heterogeneous, basal part of channels.	In aggrading, broad lensoid channel sandstones (not confined to scours). Ore-bearing sandstones 30 to 50 feet thick. Channels trend northwest, subparallel, 1,600 to 3,500 feet wide.	In basal scour-and-fill channels of Moss Back Sandstone Member particularly where cut into underlying Monitor Butte Member and in lensoid, aggrading channel sand stones in Monitor Butte Member. Ore-bearing sandstone 1 to 40 feet thick (usually less than 10 feet), 30 to 600 feet wide and traceable for several miles. Channels trend north, northwest, and west.
Size and Shape of Ore Bodies	Peneconcordant tabular and elongate parallel to channel trends. Range from several square feet to bodies up to 200 feet long and 10 feet thick. Typically consist of central high-grade zone up to 1.5 to 2.0 feet thick with lower grade zones on top and bottom 1 to 4 feet thick. Deposits often cluster in zones up to 500 feet long. Deposits range from 2,000 to 20,000 tons with clusters up to 100,000 tons.	Mostly elongate C-shaped rolls but some associated peneconcordant tabular bodies. Rolls 100 to 700 feet long, 2 to 15 feet thick, and average 40 feet wide. Peneconcordant tabular up to 120 feet long, 70 feet wide, and 12 feet thick. Roll-types irregular but generally elongate along channel trends and often in thicker part of channel. Deposits range from 1,000 to 20,000 tons; often in 6,000 to 10,000 ton range.	Mostly peneconcordant tabular deposits, oval to slightly elongate, parallel to channel trends. Often irregular and discontinuous but may cluster in zones up to 2,000 to 3,000 feet long. Individual ore pods range from several square feet to 400 by 500 feet. Deposits range from 100 to 20,000 tons with most in 1,000 to 5,000 ton range.
Mineralogy	Primary - mostly coffinite with subordinate uraninite, and montroseite. Associated sulfides mostly pyrite and marcasite but only minor base metal sulfides (sphalerite). Oxidized - mostly tyuyamunite and corvusite.	Primary - uraniferous asphaltite with subordinate uraninite and montroseite. Associated sulfides mostly pyrite, ferroselite, and sphalerite. Subordinate galena and chalcopyrite and native arsenic. Base metal values, particularly Cu, lower and V_2O_5 values higher than in southern belt San Rafael district. Base metal values: <.03% Cu; <.02% Pb; 0.01 to 0.12% Zn. Oxidized - mostly carnotite, tyuyamunite, and corvusite. Wide variety of other high-valence U and V minerals.	Primary - mostly uraninite and uraniferous asphaltite with associated pyrite and base-metal (Cu, Pb, Zn) sulfides. Only minor V minerals but up to 0.27 % V_2O_5 for some mines. Base metal values: 0.01-0.70% Cu, 0.02-0.18% Zn, and 0.03-0.07% Pb. Oxidized- torbernite, zeunerite, zippeite, copper carbonates, and sulfates. Few U-V secondary minerals since low-V ore.
Grade	Minable ore ranges from 0.10 to 0.30% U_3O_8 with average of 0.24% U_3O_8 and 0. 19% V_2O_5.	Minable ore ranges from 0.10 to over 0.70% U_3O_8 with average value of 0.25% U_3O_8 and 0.73% V_2O_5 (1948-1956). V_2O_5:U_3O_8 ratio varies from 2.2 to 4.8 with highest values near collapse structures.	Minable ore ranges from 0.10% U_3O_8 to 1.00% U_3O_8 with estimated average of 0.25% U_3O_8 and 0.06% V_2O_5.
Alteration Color	Generally white to dark gray, moderately reduced sandstone and gray to greenish gray mudstone; limonite occasionally found in sandstone adjacent to ore indicative of slightly oxidizing solutions. (Proximity of ore to red brown oxidized units not found here - all host units relatively reduced).	Deposits occur in regionally altered areas characterized by removal of carbonate cement, and partial remobilization of petroleum ("bleached zone"). Overlying units bleached (white to buff vs. normal red to pale orange). Interbedded mudstone dark gray near ore vs. normal light green color away from ore. Local development of green Cr- and V-rich clay near ore.	Deposits in and adjacent to stratiform 'purple-white mottled' alteration zones in originally red to brown mudstone of Monitor Butte/ Temple Mountain Members. Sandstone only minable where intersects purple-white mottled horizon. Purple-white mottled zone contains minor U and Cu minerals and thought to reflect low-angle shear zones.
Relation of Ore to Host Rock	Ore minerals fill pore spaces and replace interstitial clay, cementing material and organic debris and fossil logs. Ore deposits along base and margins of sandstone lenses, but may occasionally occur along bedding planes in upper or middle part of sandstone lenses.	Ore associated with uraniferous asphaltite that fills pore spaces, fractures and voids and replaces detrital grains and cement. Little associated with wood fragments Asphaltite occurs at contact between petroliferous sandstone and white 'bleached' organic carbon-poor sandstone.	Uranium minerals (uraninite and uraniferous asphaltite) fill pore spaces and locally replace detrital grains and impregnate logs and organic debris and coat interbedded shale lenses and clay galls. Ore deposits commonly at base and margins of cut-and-fill scours.

(Compiled and summarized from information in Hawley and others, 1965, 1968; Trimble and Doelling, 1978.)

Table 62. Mines and prospects in the San Rafael district (northern belt).

Mine Name	Location		Type Entry [1]	Extent of Workings[1]	Production	
	UTM. N	UTM. E			Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
1. Buckhorn	4326330 N	528830 E	Adit	50'	2	minor
2. Plymouth Rock (Mayflower)	4324000 N	525460 E	Two adits	80'	525	525
3. Re-entrant	4321550 N	523300 E	unknown	unknown	-	unknown
4. Douglas	4320990 N	523030 E	Two adits	70'	-	minor
5. Clifford Smith	4320900 N	523860 E	Adit	10-20'	-	none
6. Dalton Group (Bluebird)	4320560 N	525650 E	Three adits	120-130'	58	minor
7. Lone Tree	4321400 N	526300 E	Three adits	250'	249	250-300
8. Dexter 7	4319860 N	524860 E	Five adits	700-800'	5,594	5,820
9. Dexter 5	4319785 N	523470 E	Two adits	120'	-	minor
10. Jasmine 1	4323180 N	535800 E	Adit	110'	-	minor
11. Red Canyon East	4322260 N	535950 E	unknown	unknown	-	unknown
12. Deep Snow-Joy Ride	4315000 N	521300 E	unknown	unknown	-	unknown
13. Jubilee	4313500 N	520900 E	unknown	unknown	-	unknown
14. Macobar-Delle Butte	4313200 N	522650 E	Adit	125'	-	minor
15. Bob Claims	4320320 N	542400 E	Adit and dozer cuts	10'	none	-
16. High Boy	4308800 N	547750 E	Incline	50'	-	minor
17. Unknown	4304000 N	546700 E	Adit	225'	-	minor
18. Uneva	4303700 N	546550 E	Two shafts and adit	> 300'	-	2,000 est.
19. Silver Reef	4302600 N	546200 E	Decline	50'	-	minor
20. Flaming Star	4301600 N	546800 E	Prospect pit	-	-	minor
21. Cliff Dweller	4300950 N	546080 E	Four adits and open cuts	231'	-	268
22. Folly	4297930 N	545600 E	Prospect pits	-	-	none

Sources:
[1] Utah Geological Survey, 1999
[2] Unpublished AEC/DOE records, 1999

Table 63. *Mines and prospects in the San Rafael district (southern belt).*

Mine Name	Location		Type Entry[1]	Extent of Workings[1]	Production	
	UTM. N	UTM. E			Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
1. Wickiup No. 1	4304360 N	527120 E	Three adits	150'	207	207
2. Wickiup No. 2	4304240 N	527390 E	Adit	20'	-	minor
3. Wickiup No. 3	4303700 N	528050 E	Three adits	230'	-	500-600 est.
4. Cancer Cure No. 1	4303410 N	523510 E	Adit	75' est.	-	minor
5. Cancer Cure No. 10	4303000 N	522450 E	unknown	unknown	-	unknown
6. Virginia Low	4302760 N	524050 E	Two adits	210'	-	< 300
7. Donna B	4301840 N	522700 E	unknown	unknown	-	unknown
8. School Section 36 (Pilling Brothers)	4300340 N	522030E	Two adits	60' est.	-	minor
9. Sinbad	4299940 N	519950 E	Decline	substantial	-	250,000 est. (to 1985)
10. Moroni Hunt	4295700 N	516020 E	Adit	41'	-	minor
11. Red Valley (Nelson)	4295410 N	515780 E	Adit	155'	-	< 200
12. Green Vein No. 5 (Strike)	4294130 N	514990 E	Adit	250'	11,828	11,828
13. Pay Day	4293850 N	514470 E	Two adits	150'	2,998	2,998
14. Green Vein No. 2 and No. 3	4293740 N	514200 E	Dozer cuts and adits	200'	963	963
15. Hertz	4292280 N	514460 E	Two adits	1362'	11,058	11,927
16. Little Joe	4292320 N	508050 E	unknown	unknown	200	200
17. Consolidated	4291680 N	514210 E	Three-four adits	550'	5,185	5,185
18. Family Butte NE	4291340 N	514630 E	Adit	40'	-	none
19. Snow Claim	4290800 N	514830 E	Adit	35'	-	minor
20. Dolly	4290735 N	513000 E	Two adits	105'	243	243
21. Apex	4290700 N	506350 E	Small	unknown	38	minor
22. Lucky	4290270 N	506420 E	Small	unknown	-	minor
23. Lucky Strike	4289950 N	504560 E	Seven adits	1,350'	53,533	50,775

Table 63. *(continued)*

Mine Name	Location UTM. N	UTM. E	Type Entry[1]	Extent of Workings[1]	Production Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
24. South Fork Group	4289910 N	513500 E	Adit	45'	-	minor
25. Commonwealth	4289700 N	505210 E	Two adits	250'	-	< 2,000 est.
26. Commonwealth South	4289310 N	505000 E	Adit	268' est.	-	3,500-5,000
27. Mildred V	4288590 N	504000 E	Two adits	50'	-	minor
28. Paleface	4288160 N	503350 E	Adit	300'	-	unknown
29. Mildred	4288100 N	504150 E	Adit	15'	-	none
30. Conrad	4287780 N	502720 E	Six adits	825' +	51,528	51,528
31. Crossbow	4287520 N	502650 E	Adit	550'	4,876	7,500
32. Red Butte (Hilltop ?)	4287100 N	502750 E	Adit	1,186'	603	minor
33. Standard Ore and Alloy	4286570 N	502760 E	Adit	340'	-	<500
34. Joshua	4285550 N	502850 E	Adit	80'	29	29
35. Blue Bird 1-3 (Green Dragon)	4288590 N	504000 E	Three adits	460'	4,584	3,904
36. Green Dragon No. 3	4283450 N	500190 E	Adit	465'	200	included with Bluebird 1-3
37. Rio Colorado	4282600 N	501570 E	Five adits	116'	-	minor
38. Dirty Devil 6	4282200 N	501 1 00 E	Two adits	700-800'	1,026	>15,410 12,000 est.
39. Dirty Devil 3 & 4	4281550 N	500820 E	Three adits	2,500'	10,187	> 16,380 37,000 est.
40. Dirty Devil 1 & 2	4281530 N	500380 E	Four adits	600'	34,770	> 4,200 9,000 est.
(Note: AEC/DOE production from Dirty Devil 1 & 2 probably includes some Dirty Devil 3 & 4 production)					Total Dirty Devil Production 58,113	58,111
41. Tea for Two	4280760 N	499550 E	Adit	unknown	-	minor
42. Spanish Trail	4280660 N	499590 E	Adit	310'	-	< 500
43. Eagle (Battleship)	4280300 N	500000 E	Two adits	250'	771	771
44. Rainbow	4280120 N	499730 E	Three adits	700' est.	-	1,000-2,000 est.
45. Lost Sunday	4279970 N	499700 E	Two adits	30'	-	minor
46. Big Chief	4279825 N	500075 E	Adit	100'	43	43

Table 63. *(continued)*

	Location				Production	
Mine Name	**UTM. N**	**UTM. E**	**Type Entry[1]**	**Extent of Workings[1]**	**Pounds U_3O_8 to 1971[2]**	**Pounds U_3O_8 to 1973 (unless noted)[1]**
47. Little Emma 2	4275950 N	520500 E	Adit	145'	771	771
48. Brown Dog	4275300 N	521650 E	Two adits	47'	-	none
49. Little Emma (Wild Horse)	4275100 N	521100 E	Seven adits	975'	1,524	34,171 (suspect number)
50. Ryan 101	4274370 N		Two adits	345'	14	< 200
51. Magor	4273500 N	514500 E	Six adits	> 600'	-	7,000 est.
52. Cistern	4272850 N	515750 E	Incline	600'	53,505	55,503
53. Great Basin	4271300 N	511200 E	Pit	40' x 12'	139	1,525
54. Little Susan	4270700 N	500500 E	Two adits	800'	724	724
55. Fremont	4270640 N	500950 E	Adit	80'	-	minor
56. Ryan	4269900 N	501250 E	Adit	750'	15	15
57. Black Jack	4268400 N	502300 E	Adit	130'	-	none
58. Delta (Hidden Splendor)	4268320 N	504450 E	Three adits	> 5,000'	826,092	827,248
59. Bluebird (Hunts)	4267850 N	503880 E	Adit	800'	821	1,353
60. Queen Ethel	4267850 N	504500 E	unknown	unknown	-	unknown
61. Alpha	4268750 N	504600 E	unknown	unknown	-	unknown
62. Bullberry Spring	4271500 N	509850 E	unknown	unknown	-	unknown
63. West Great Basin	4272400 N	511400 E	unknown	unknown	-	unknown
64. Virginia Valley	4276620 N	522620 E	Open cut	75' x 5'	323	450
65. Desolation	4277130 N	522790 E	Three adits and open cut	50-60'	80	80
66. Golden Cinch	4283850 N	530540 E	Dozer cuts	300'	-	none
67. Golden Pipe	4284370 N	529880 E	Dozer cuts	15' x 300'	-	none
68. Big Cat	4282300 N	532050 E	Adit	20'	-	none
69. Twilight	4281430 N	530350 E	Adit	30'	-	60-80
70. Mellenoid	4285300 N	535770 E	Dozer cuts	1,500' long	-	none
72. Ferrous	4293120 N	542380 E	Decline and caved adit	70-100'	-	100

Table 63. *(continued)*

Mine Name	Location		Type Entry[1]	Extent of Workings[1]	Production	
	UTM. N	UTM. E			Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
Morrison-hosted deposits						
73. Good Luck	4266600 N	510800 E	unknown	unknown	-	unknown
74. Pandora	4266100 N	511400 E	unknown	unknown	-	unknown
75. Yellow Canary (Canary)	4268500 N	515000 E	Open cut		1,556	1,556
76. GG and S	4269200 N	515000 E	unknown	unknown	-	unknown
77. San Rafael Desert	4274500 N	532300 E	unknown	unknown	-	unknown

Sources:
[1] Utah Geological Survey, 1999
[2] Unpublished AEC/DOE, 1981
est. is estimate from size of workings for individual mine and total production from grouped deposits if records available

Table 64. *Mines and prospects in the Temple Mountain district.*

Mine Name	Location		Type Entry[1]	Extent of Workings[1]	Production	
	UTM. N	UTM. E			Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
1. Camp Bird No. 7	4282120 N	527500 E	Three adits	800-900'	89,587	88,951
2. Unknown	4282250 N	527650 E	Adit	20'	-	none
3. Eagles Nest	4282070 N	527750 E	Four adits	150-200'	33	1,000 est.
4. Vanadium King 7	4282240 N	528070 E	Five adits	200'	354	7,576 est.
5. Vanadium King 4	4282175 N	528210 E	Adit	120'	15,800	4,545 est.
6. Flat Top Mines	4281250 N	523620 E	Numerous adits Three open pits	1,500'	43,300	43,308
7. Fumerole	4281710 N	527350 E	Adit & shafts	110'	-	minor
8. Migliaccio	4281940 N	527700 E	Two adits	60'	-	minor
9. Young	4281610 N	527730 E	Pit & adit	100'	-	minor
10. Vanadium King 5	4281815 N	528050 E	Three adits	900'	39,861	34,092 est.
11. Vanadium King 6	4281815 N	528185 E	Adit	465'	159	17,614 est.
12. Vagabond (Denny)	4281440 N	528050 E	Two adits	80-100'	2,368	2,368 est.

Table 64. *(continued)*

Mine Name	Location: UTM. N	Location: UTM. E	Type Entry[1]	Extent of Workings[1]	Production: Pounds U_3O_8 to 1971[2]	Production: Pounds U_3O_8 to 1973 (unless noted)[1]
13. Baker Incline	4281100 N	528050 E	Incline	350'	7,963	10,331
14. Unknown	4281580 N	528185 E	Adit	60'	-	minor
15. Unknown	4281560 N	528350 E	Adit	280'	-	2,000 est.
16. Vanadium King 3	4281530 N	528600 E	Three adits	1,000'	Included in Vanadium King1	67,900 est.
17. Vanadium King 1 (Rex)	4281530 N	528800 E	Two adits	2,500'	230,200 (Assumes 1/2 LeDuc prod. is Vanadium King 1)	154,800 est.
18. Calyx 6 (AEC 6)	4281250 N	528400 E	Shaft	250-300'	55,920	30,800 est.
19. Calyx 8 (AEC 8) Connects with Calyx 11 & Vanadium King 1	4281230 N	528640 E	Shaft	>3,600'	647,074 (Assumes 1/2 LeDuc production is Calyx 8)	500,900 est. (Actual 1952-56 225,800)
20. Calyx 5 & 5 1/4 (AEC5) Connects with Calyx 4	4281110 N	528470 E	Two shafts	1,250-1,300'	22,805	133,560 est.
21. Calyx 4 (AEC 4)	4281020 N	528430 E	Shaft	600'	32,748	61,600 est.
22. Calyx 11 (AEC 11) Connects with Calyx 8	4281080 N	528630 E	Shaft	>900'	68,783	123,300 est.
23. Marchback Incline (Flewelling) Rept. connects to Flewelling incline to north	4280910 N	528125 E	Incline	>300'	8,295	8,295
24. North Mesa 9	4280640 N	528025 E	Three adits	1,800'	129,717	91,800 est.
25. North Mesa 10	4280740 N	528010 E	Adit	300'	-	15,300 est
26. North Mesa 7	4280500 N	527930 E	Adit	180-200'	350	10,200 est.
27. North Mesa 2-5	4280400 N	528020 E	Two adits	1,200'	577	61,200 est.
28. North Mesa 1	4280320 N	528080 E	Two adits	600'	61,382	31,800 est.
29. Lopez Incline	4280270 N	528000 E	Incline	300'	5,194	15,300 est.
30. Calyx 9 (AEC 9) Connects to Calyx 10	4280940 N	528470 E	Shaft	400'	29,656	41,000 est.
31. Calyx 10 (AEC 10) Connects to Calyx 9 & Calyx 12	4280910 N	528410 E	Shaft	1,000'	46,028	102,700 est.
32. Calyx 3 (AEC 3) Connects to Calyx 12 & Calyx 10	4280790 N	528340 E	Shaft	1,200'	123,092	123,250 est.

Table 64. (continued)

	Location				Production	
Mine Name	**UTM. N**	**UTM. E**	**Type Entry[1]**	**Extent of Workings[1]**	**Pounds U_3O_8 to 1971[2]**	**Pounds U_3O_8 to 1973 (unless noted)[1]**
33. Calyx 2 & 2.5	4280810 N	528220 E	Two shafts	400'	4,640	41,100 est.
34. Calyx 1	4280230 N	528120 E	Shaft	250'	2,280	25,675 est.
35. Calyx 12 Connects to Calyx 3 & Calyx 10	4280730 N	528600 E	Shaft	2,000'	55,488	205,400 est.
36. Camp Bird 12 (Mountain King)	4279700 N	527670 E	Numerous short adits	1,000'	11,118	> 7,580
37. Black Beauty	4279595 N	527500 E	Two adits	>170'	1,010	1,013

Sources:
[1]Utah Geological Survey, 1999
[2]Unpublished A.E.C. records, 1981
Note: Production of 298,990 pounds U_3O_8, assigned to "various" not included in production to 1971 listings, but included in production to 1973 listing and assigned to total Calyx production
est. is estimate from size of workings for individual mine and total production from grouped deposits if available

permeable zones (probably low-angle shear zones) in the shale and siltstone of the Moenkopi Formation and Monitor Butte Member of the Chinle Formation until they encountered local reducing conditions near organic material in the permeable sandstones of the Monitor Butte, Church Rock, or Moss Back Sandstone Members of the Chinle Formation which precipitated the uranium and possibly some of the ferrous iron as uraninite, asphaltite, and pyrite. This hypothesis accounts for most of the observed features of the deposits (see table 61) and only requires a single, relatively simple mineralizing event. The source of the uranium could be the bentonitic clays in the Moenkopi and Monitor Butte shale and siltstone (Hawley and others, 1968).

The deposits in the Temple Mountain district are significantly different than the more normal deposits in the other parts of the San Rafael Swell (table 61). These deposits are: (1) mostly roll-type, (2) associated with asphaltite usually at the contact between petroliferous sandstone and barren sandstone, (3) spatially associated with collapse or breccia structures, (4) exhibit a consistent regional alteration and mineral zoning pattern, (5) richer in selenium, vanadium, and chromium, and poorer in copper and zinc than the other Chinle-hosted deposits, and (6) possibly younger than the other Chinle-hosted deposits. The deposits occur along irregular C- to S-shaped rolls suggesting deposition at a contact between two chemically different ground-water regimes. They are associated with asphaltite (pyrobitumen) which represents migrated, degraded petroleum. The association requires an initial introduction of petroleum and later introduction of uranium ore fluids which may have, in part, remobilized the asphaltite. The deposits cluster around several collapse or breccia structures that developed during or after the Laramide (Paleocene) deformation that formed the San Rafael Swell. The deposits show consistent, gradational, regional alteration and mineral zoning patterns. There is less carbonate cement, more abundant and coarser-grained kaolinite, more chromium-rich mica clays, more introduced dolomite, higher V:U ratios, higher arsenic, and generally higher copper, lead, and zinc closer to the collapse structures suggesting that the ore fluids were introduced near the collapse structures and migrated away from these structures in the permeable sandstones of the Moss Back Sandstone Member. The deposits and alteration also exhibit features that were apparently controlled by the anticlinal structure of the San Rafael Swell. The current, relatively horizontal alteration contact and confinement of better deposits to a specific elevation interval (bath-tub ring) suggest a post-folding age for the Temple Mountain deposits. The locations of deposits (depicted by mines) in the Temple Mountain district are shown in figure 36.

The deposits are probably Paleocene or younger. Hawley and others (1965) proposed a relatively complicated process with a single mineralizing episode, but involving significant changes with time in the chemical nature of ore solutions. They envisioned a slightly acidic CO_2-rich fluid migrating up the collapse structures and subsequently away from the structures within permeable sandstones of the Moss Back Sandstone Member. The slightly acidic (pH 5-7) fluids caused removal of carbonate cement, formation of kaolinite, and displacement and degradation of the petroleum. The solutions later became more alkaline by reaction with the host rocks. The uranium is thought to have been precipitated at this later time followed by precipitation of dolomite and siderite when the solutions became even more alkaline. In addition to the proposed change from slightly acidic to slightly alkaline, the solution also probably changed from slightly oxidizing to slightly reducing.

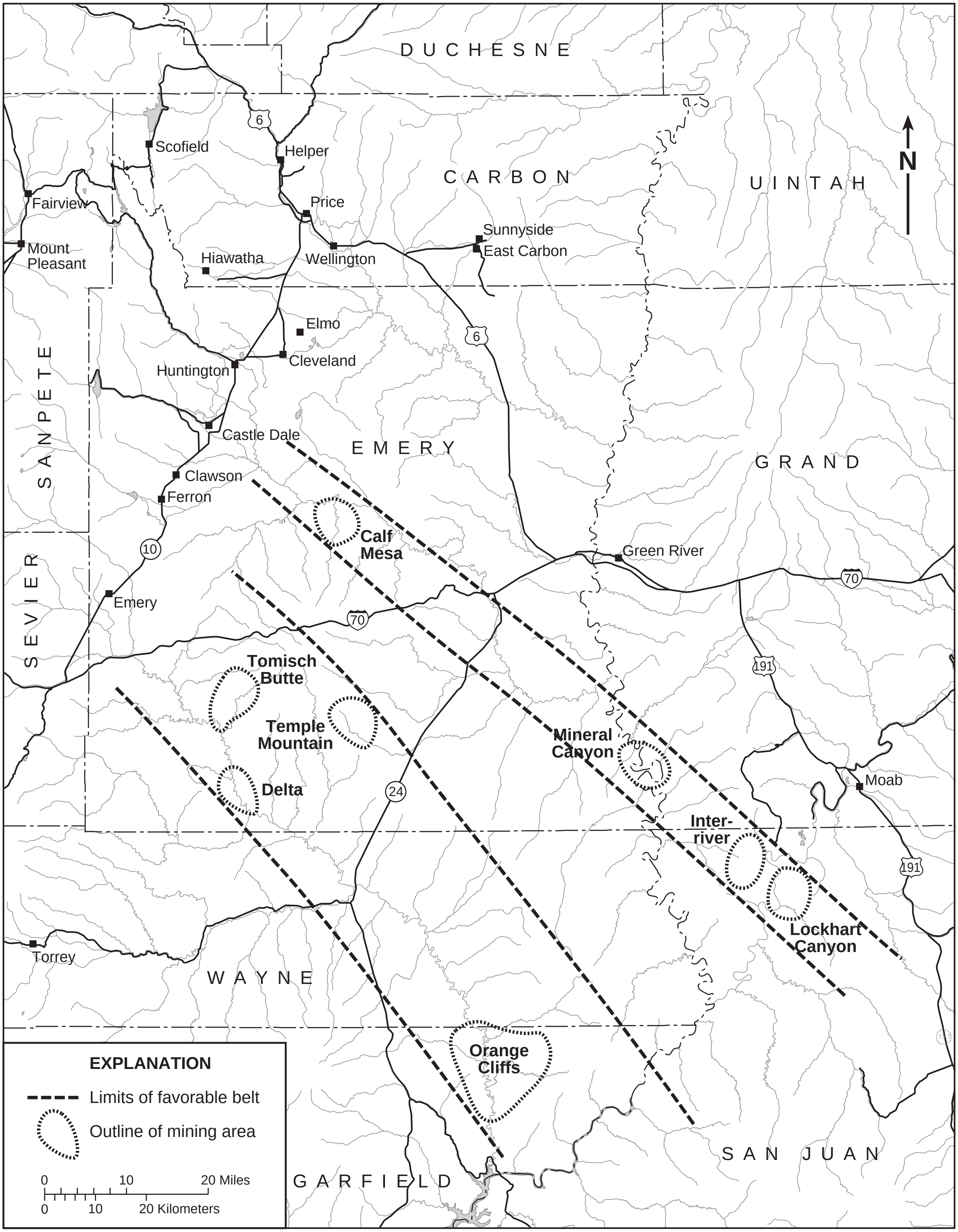


Figure 35. *Favorable mineral belts for Chinle-hosted uranium deposits, southeastern Utah.*

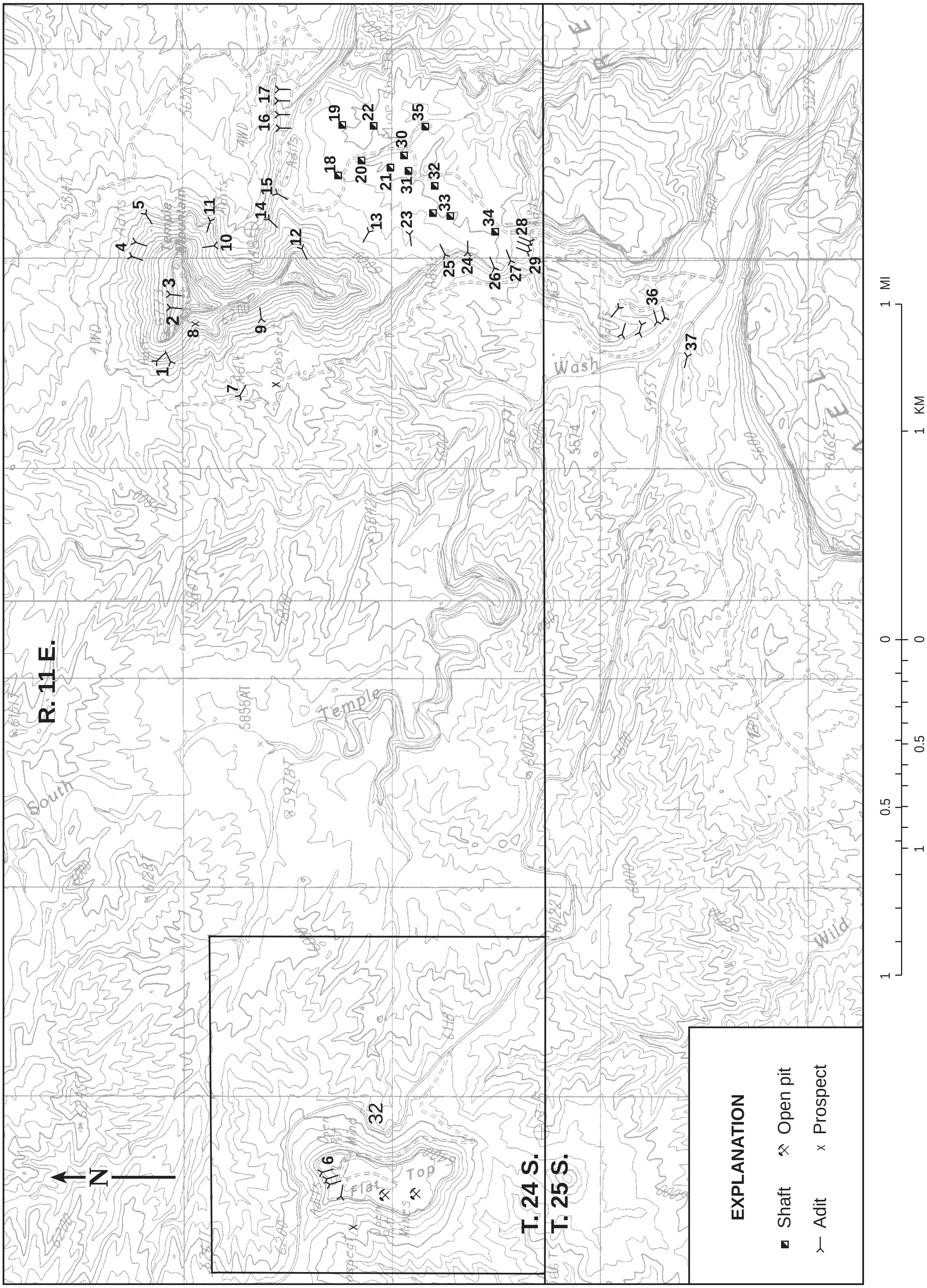


***Figure 36.** Mine locations in the Temple Mountain mining district, Emery County, Utah. Numbers correspond to names and locations in table 64. Base from USGS Temple Mountain 7.5-minute quadrangle.*

Morrison-hosted Deposits

Morrison-hosted uranium-vanadium deposits in Emery County are concentrated in three separate areas: the West San Rafael mining area of the San Rafael district on the northwest flank of the San Rafael Swell, the Cedar Mountain mining area on the north end of the San Rafael Swell, and the San Rafael River (Desert) mining area of the Green River district on the east flank of the San Rafael Swell (plate 10). The mines and prospects in the San Rafael River mining area are listed in table 65 and the locations are shown in figures 37 and 38. In addition, there are a few occurrences in the southern part of the county at the north end of the Henry Mountains. Deposits in the West San Rafael and Cedar Mountain mining areas are small (less than 1,000 short tons [900 metric tons] of ore), but those in the San Rafael River mining area are much larger and may form clusters containing 25,000 short tons (25,000 metric tons) or more of ore (Utah Geological and Mineral Survey, 1974).

Most Morrison-hosted uranium deposits are in medium- to coarse-grained fluvial sandstones of the Salt Wash Member of the Morrison Formation, but a few small deposits are in siltstone and fine-grained sandstone of the overlying Brushy Basin Member, particularly near its lower contact. Some thick but very low-grade deposits also occur in shale and siltstone of the middle to upper portions of the Brushy Basin Member in the Cedar Mountain and West San Rafael mining areas.

Salt Wash-hosted deposits in the San Rafael River mining area are confined to thick, massive to cross-bedded, channel sandstones in the upper third of the member. Individual channel sandstones are from 5 to 35 feet (1.5-10 m) thick and may coalesce to form thick aggregate sand units 80 to 90 feet (24-27 m) thick (Trimble and Doelling, 1978). In the West San Rafael mining area, the sands are thinner and rarely aggregate more than 40 feet (12 m). Channel sandstones are mostly aggradational and trend northeasterly in the San Rafael River mining area (from west to east: Tidwell drainage system, Sahara drainage system, and Acerson drainage system) (Trimble and Doelling, 1978) and north to northwest in the Cedar Mountain and West San Rafael Swell mining areas (from southwest to northeast: White Star drainage system, Price drainage system, and Woodside drainage system) (Mickle and others, 1977). Plate 11 shows the location of these sandstone channel trends as favorable areas and figure 41 shows the channel trends in the San Rafael River mining area.

Brushy Basin-hosted uranium mineralization is in thin (3 to 6 feet [1-2 m] thick), fine-grained, commonly iron-stained, sandstones in the basal part of the member and in fractured light gray mudstones in the middle and upper parts of the member. Mineralization in sandstone and siltstone is spotty and low-grade. Mineralization in the mudstone consists of secondary uranium minerals (meta-autunite, meta-tyuyamunite, uranopilite) coating fractures and along bedding planes. Grades range from 0.01 to 0.06 percent U_3O_8 (up to 0.25 percent U_3O_8 in subsurface) over thicknesses of 0.5 to 65 feet (0.2-20 m) (Mickle and others, 1977). Mineralized mudstone commonly weathers to a dark yellowish-orange ("buckskin" of uranium miners) in contrast to the normal gray color for unmineralized mudstone.

Most of the ore mined has been from tabular, amoeboid to elongate bodies ranging in size from several square feet to bodies up to 10 feet (3 m) thick and 200 feet (60 m) long. Individual ore bodies often are concentrated in clusters that are as much as 1,200 feet (370 m) long and 200 to 300 feet (60-90 m) wide. The clusters are commonly aligned parallel to the channel trends. The ore is generally concentrated at the edges and base of individual channels, particularly in heterogeneous zones containing abundant carbonaceous material, clay galls, pebble beds, and shale partings or in highly carbonaceous sandstone (Trimble and Doelling, 1978).

Unoxidized ore consists of coffinite, uraninite, and the vanadium minerals montroseite and para-montroseite. Associated sulfide minerals include pyrite and marcasite with minor chalcopyrite, sphalerite, and clausthalite (PbSe). Oxidized ore consists mostly of tyuyamunite, meta-tyuyamunite, and corvusite. Ore grades range from less than 0.05 to over 2.5 percent U_3O_8 and average 0.15 to 0.20 percent U_3O_8 (Trimble and Doelling, 1978). Uranium:vanadium ratios range from 1:1 to 1:2, significantly less than for Morrison-hosted deposits farther to the east in Grand and San Juan Counties, Utah, and in Colorado. Some ore bodies show a zonal arrangement with a high-grade core surrounded by lower grade material. For example, in the San Rafael River mining area, Trimble and Doelling (1978) reported that the ore zone typically consists of an upper low-grade zone 2 to 4 feet thick containing 0.01 to 0.20 percent U_3O_8, a central high-grade zone up to 1.5 feet thick containing 0.25 to 2.5 percent U_3O_8, and a lower low grade zone 1 to 4 feet thick containing 0.01 to 0.20 percent U_3O_8.

Although the Salt Wash Member-hosted uranium-vanadium deposits occur in a variety of fluvial environments, the better, larger, and more closely spaced deposits occur in several "belts" that are roughly perpendicular to the depositional channel trends. Examples include the Uravan mineral belt in western Colorado and eastern Utah and the Tidwell belt in the San Rafael River mining area in Emery County. These favorable belts correspond to: (1) an increased percentage of interbedded siltstone and shale, (2) a more braided, less well defined channel system, and (3) finer grained, more dispersed carbonaceous material. In the San Rafael River mining area, Trimble and Doelling (1978) believe these changes reflect a transition from higher velocity, well-defined trunk streams to lower velocity, more braided streams in a flood-plain environment.

The Salt Wash-hosted deposits are thought to be early Tertiary in age based on geologic relationships and alteration, but uranium-lead dating of the ores suggests a Cretaceous age ranging from about 70 to 115 Ma (Shawe and others, 1991). Most investigators believe that the ores were deposited at or near an interface between two chemically different ground-water regimes. One of the solutions was stagnant, reduced, connate water and the other was introduced, uranium-bearing, probably alkaline bicarbonate-type ground water (Thamm and others, 1981). The introduced solution was probably somewhat oxidizing and close to the ferric-ferrous transition. Shawe and others (1991) proposed a more complicated origin involving additional oxidizing and reducing alteration episodes to explain the Salt Wash-hosted deposits in the Uravan mineral belt, but these additional alteration episodes are not necessary to explain the less complicated Morrison-hosted deposits in Emery County. The source of the uranium was probably tuffaceous shales in the Brushy Basin Member of the Morrison Formation and the

Table 65. Mines and prospects in the San Rafael River (Desert) mining area.

Mine Name	Location				Production	
	UTM. N	UTM. E	Type Entry[1]	Extent of Workings[1]	Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
NORTH TIDWELL BELT						
1. Calyx No. 1	4315500 N	554800 E	Shaft	100'	232	321
2. Calyx No. 2	4315225 N	554775 E	Shaft	1,000'	1,405	2,213
3. Lucky Strike No. 2	4315030 N	554675 E	Incline	850'	9,917	850 est.
4. Lucky Strike No. 3	4314975 N	554500 E	Incline	290'	Included with Lucky Strike 2	2,000 est.
5. Lucky Strike No. 1	4314900 N	554300 E	Incline	160'	Included with Lucky Strike 2	1,100 est.
6. Thunderbird	4314750 N	554500 E	Incline	100' +	Included with Lucky Strike 2	1,000 est.
7. Waterson	4314675 N	554325 E	Incline	380'	Included with Lucky Strike and Wedding Bell	unknown (probably 3,000-5,000)
8. San Rafael No. 2	4314400 N	554300 E Shaft	Incline &	90'	Included with San Rafael 1	1,500 est.
9. San Rafael No. 3	4314425 N	554360 E	Shaft	150'	Included with San Rafael 1	2,500 est.
10. San Rafael No. 1	4314000 N	554365 E	Incline	175'	6,956	2,900 est.
11. Incline No. 12	4314410 N	554390 E	Adit Open Pit	250 150' x 25'	16,014	16,014
12. Wedding Bell	4314405 N	554410 E	Incline	>250'	9,980	5,000 est.
13. Newell Shaft (Shaftuck,Dean, Lit Lill, Simon J, Red 2)	4314600 N	555100 E	Shaft	Include with No. 7 workings	291,837	295,044
14. Welsh Shaft (Red Bone 9)	4314600 N	554800 E	Shaft	Include with No. 7 workings	60,535	68,776
15. No. 7 Incline Group (#7 incline, #1 shaft, #2 shaft)	4314200 N	554600 E	Incline & two shafts	19,605'	479,096	631,566
(Note: AEC reports additional 12,694 pounds from inclines 13, 18, 19, 20, 21 & 22. May be part of No. 7 incline group.)						
16. Incline No. 7 - West	4314200 N	554480 E	Incline	350'	Included with No. 7 incline	2,275
17. Incline No. 3 (Smith Lucas, Betty Ann)	4314050 N	554500 E	Incline	1,730'	50,303	50,303
18. Porter Shaft	4314150 N	554350 E	Shaft	310'	-	unknown
19. Incline No. 10	4314000 N	554400 E	Incline	1,100'	3,123	3,243
20. Incline No. 14	4313875 N	554300 E	Incline	960'	10,027	16,290 (to 1976)
21. No. 15 Shaft	4313800 N	554300 E	Shaft	250'	3,654	Included with No.14
22. Incline No. 17	4313650 N	554300 E	Incline	1,000'	21,202	21,202
23. Incline 4, 5, 6, and 4C-6	4313650 N	554550 E	Four inclines & shaft	14,190'	557,908	556,101
24. Snow	4313625 N	555575 E	Shaft	2,460'	-	81,854 (to 1974)
25. United Prospectors (Jack Rabbit)	4313370 N	554970 E	Shaft	1,550'	55,589	55,589

Table 65 (continued)

Mine Name	Location UTM. N	UTM. E	Type Entry[1]	Extent of Workings[1]	Production Pounds U_3O_8 to 1971[2]	Pounds U_3O_8 to 1973 (unless noted)[1]
26. Incline No. 9	4313025 N	554375 E	Incline	7,150'	137,565	145,518
27. Desert Moon	4312925 N	553850 E	Incline	325'	3,172	1,302
28. Incline No. 8	4312550 N	554400 E	Incline & shaft	3,400'	131,574	135,426
29. Incline No. 8 West (Dinosaur)	4312125 N	553250 E	Incline	Included with No.8	Included with No.8	Included with No.8
SOUTH TIDWELL BELT						
30. Incline No. 16	4311975 N	553800 E	Incline	220'	5,000	2,392
31. Incline No. I 1	4311450 N	553900 E	Incline	500'	1,934	2,706
32. North Slope No. 2	431041 0 N	552860 E	Three adits	225'	1,753	1,965
33. Aud	4310250 N	552700 E	Open pit	150' x 150'	-	1,680 (to 1977)
34. Blue Goose #1	4309400 N	552500 E	Incline	80'	1,167	1,167
35. Black Panther	4308300 N (Hilltop)	552300 E	Open pit	400' x 200'	11,594 includes production incorrectly assigned to Yellow Queen	13,120 (to 1977)
36. Costanzi	4308070 N	552800 E	Adit	50'	-	minor
37. Yellow Queen	4307650 N	552150 E	Adit	25'	-	minor
ACERSON BELT						
38. Rabbit No. 1	4304390 N	553650 E	Numerous small pits	-	797	797
39. Fantastic (Birthday)	4303725 N	552400 E	Numerous pits & dozer cuts	-	2,072	5,758
40. Windy (Black Dragon)	4303500 N	553200 E	Three adits	265'	19	minor
41. Sahara	4306290 N	556200 E	Incline	700'	4,031	6,731 (to 1977)
42. Ceciliaite No. 1	4302925 N	556780 E	Adit	100'	8	minor
43. School Section H2	4299600 N	556900 E	Small open pits	-	3,148	3,148
44. Cometoite No. 2	4300270 N	556725 E	Adit	210'	-	unknown
45. Big Ben	4300500 N	557150 E	Open pit	140' x 170'	2,023	2,325
46. Aceite No. 2 (Aceite)	4300300 N	557350 E	Open pit	50' x 100'	Included with Big Ben	Included with Big Ben
47. Cometoite No. 1 East	4300420 N	557290 E	Adit	270	Included with Cometoite No. 1	2,250 est.
48. Cometoite No. 1	4300350 N	557300 E	Adit	325	2,139	2,250 est.

Source:

[1] Trimble and Doelling, 1978
[2] Unpublished AEC/DOE records, 1981
est. is estimate from size of workings for individual mine and total production from grouped deposits if records available

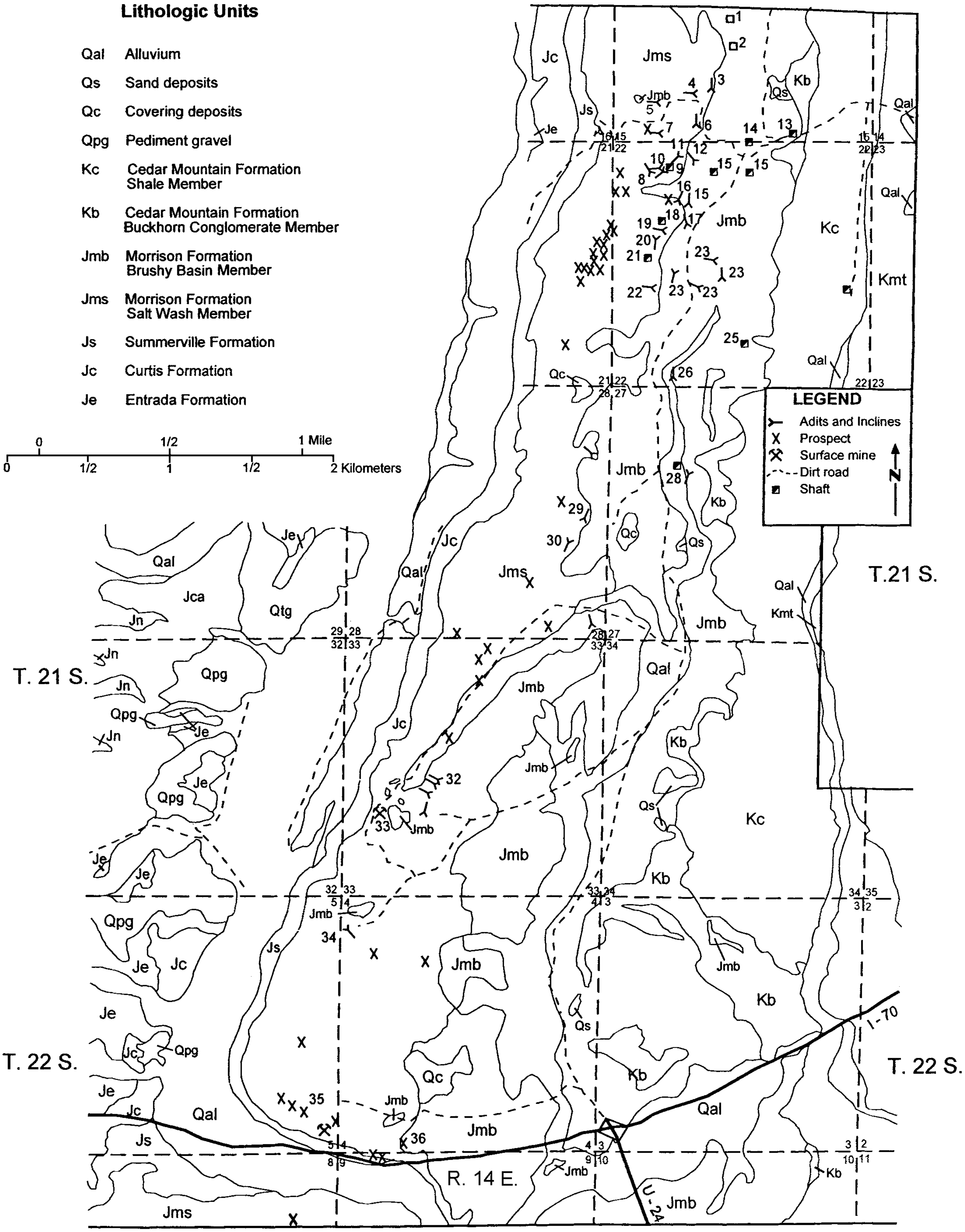


Figure 37. Mine locations in the Tidwell mineral belt, San Rafael River mining area, Emery County, Utah. Numbers correspond to names and locations in table 65 (after Trimble and Doelling, 1978).

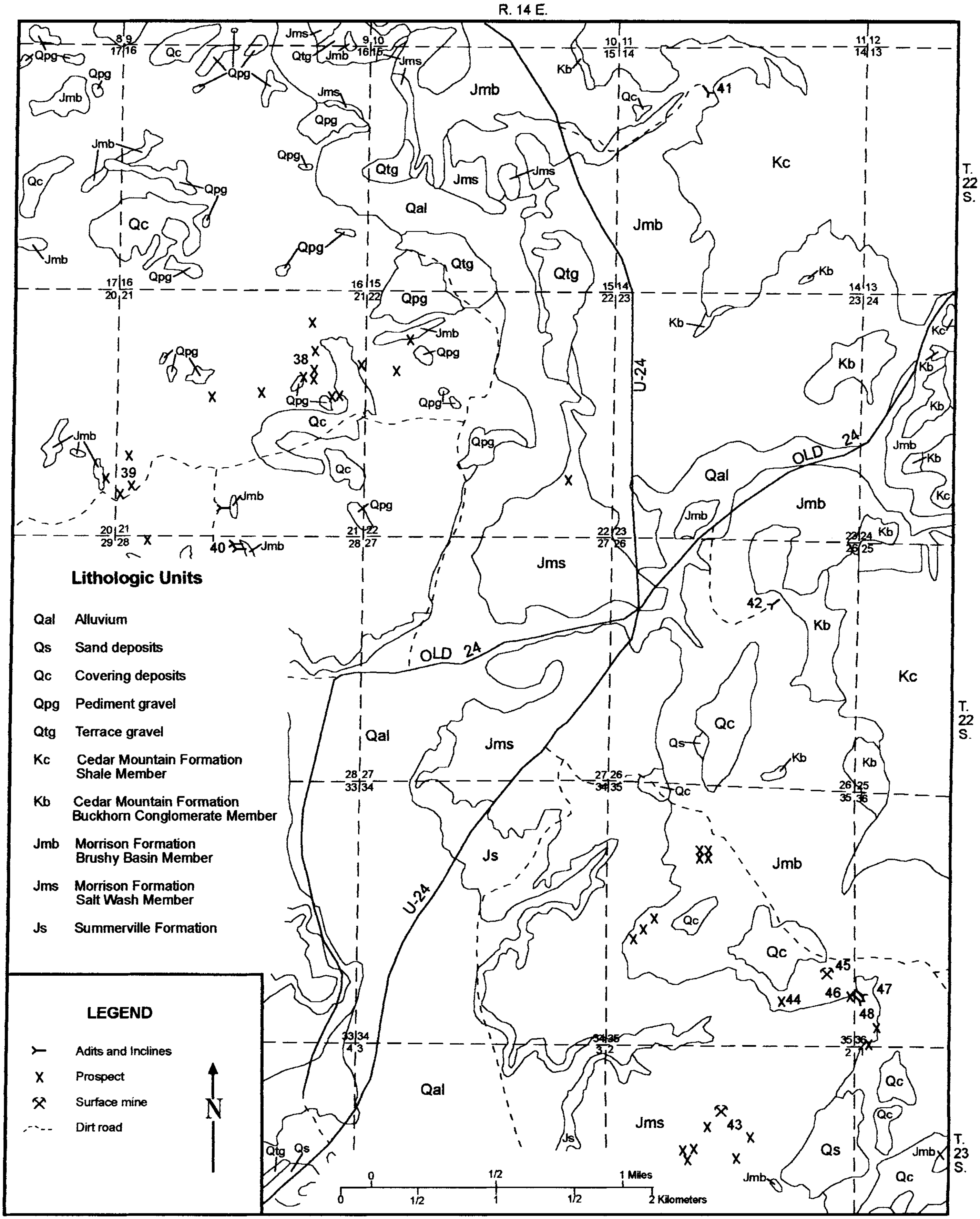


Figure 38. *Mine locations in the Acerson mineral belt, San Rafael River mining area, Emery County, Utah. Numbers correspond to names and locations in table 65 (after Trimble and Doelling, 1978).*

source of the vanadium was either from altered iron-titanium oxide minerals in sandstones in the Salt Wash Member or vanadiferous black shales in the Cretaceous Mancos Shale.

Collapse Structure-Related Deposits

Several small uranium occurrences are found near collapse structures in the San Rafael Swell. Sixteen collapse structures were recognized by Hawley and others (1968). Six of the collapse structures are somewhat uraniferous, but only the Temple Mountain collapse structure contains appreciable uranium. The collapse structures consist of a central core of brecciated, contorted, and down-dropped sedimentary rocks surrounded by a “sag area” of inward-dipping sedimentary rocks. The collapse structures are 100 to 2,500 feet (30-760 m) across and have a vertical extent of as much as 800 feet (250 m) (Hawley and others, 1965). Sedimentary units are down-dropped as much as 400 feet (125 m) from their original position. The collapse structures bottom out in the Permian White Rim Sandstone. They most likely formed by dissolution of subsurface carbonate units, such as the Permian Black Box Dolomite and the Triassic Sinbad Limestone Member of the Moenkopi Formation. These carbonate units are greatly thinned or missing altogether in the vicinity of the collapse structures. The collapse structures are thought to have formed in the early Tertiary.

Uranium deposits in and immediately adjacent to the collapse structures are all small with most prospects producing less than 100 short tons (90 metric tons) of ore. Deposits occur in the Wingate Sandstone, the Church Rock and Moss Back Sandstone Members of the Chinle Formation, and near the Moenkopi-White Rim Sandstone contact. Ore occurs as near-vertical pipes, veins, irregular roll-like masses, and breccia void fillings.

Although the collapse structures are similar in shape and form to the uranium-bearing breccia pipes in northern Arizona, there are some notable differences. The Arizona pipes extend over a greater stratigraphic interval and bottom in a lower stratigraphic horizon (Redwall Limestone), are older (Triassic-Jurassic), contain significantly higher percentages of sulfides with a massive sulfide “pyrite cap” above the uranium ore, and the hydrocarbons were introduced after rather than prior to brecciation (Krewedl and Carisey, 1986; Wenrich and others, 1989). The older age and the higher sulfide content, possibly reflecting a larger, more long-lived, metal-bearing brine circulation episode, may partially explain the larger and higher grade nature of the northern Arizona pipes.

Past Production and Exploration Activity

Uranium was discovered in Emery County in the 1880s and was mined intermittently until 1988. Most of the production was between 1948 and 1972. The uranium-vanadium mining activity can be divided into five main periods of production: (1) pre-1940, (2) war years (1940-1947), (3) Atomic Energy Commission (AEC) unlimited buying at guaranteed price (1948-1961), (4) AEC limited buying at variable price and private sector buying (1962-1970), and (5) private sector buying only at market price (1971-1988) (Chenoweth, 1990). Uranium and vanadium production is shown in table 66 by period of production, and in table 67 by major mining area. Annual uranium and vanadium production is shown in figures 39 and 40. Relatively complete production statistics are available for the period 1947 to 1982 (collected by AEC and its successors), but production records for the other periods are incomplete and must be estimated from scattered published and company records.

Earliest production in Emery County was probably from the San Rafael River mining area and the Temple Mountain district. Between 1880 and 1913, an estimated 30,000 pounds (13,500 kg) of uranium was mined from the San Rafael River mining area (Trimble and Doelling, 1978) and between 1914 and 1920, a considerable but unknown tonnage of ore, which averaged about 1.75 percent U_3O_8 and 4.0 percent V_2O_5, was shipped from the Temple Mountain district (Hawley and others, 1965). Most of the production during the early part of this period was for radium, but with the entry of the United States into World War I emphasis shifted from the production of radium to the production of vanadium for steel alloying

Table 66. *Uranium and vanadium production in Emery County, Utah, by period of production.*

	Pounds U_3O_8	**Grade in percent U_3O_8**	**Pounds V_2O_5**	**Grade in percent V_2O_5**
1900-1941[1]	162,735	1.0-1.2	77,000	0.9-4.0
1942-1946[2]	9,000	0.78	5,000	0.32
1948-1953[3]	865,902	0.26	1,553,639	0.61
1954-1979[3]	5,250,116	0.21	4,398,291	0.18
1980-1982[4]	776,738	0.19	600,000	unknown
1983-1988[5]	770,500	unknown	555,000	unknown
Total	**7,834,991**		**7,188,930**	

Sources:
[1] Estimates from data of Hawley and others, 1965; Cohenour, 1967; Trimble and Doelling, 1978; and Munts, 1989.
[2] Production numbers withheld (Manhattan Project). Estimates based on Webber, 1947.
[3] Unpublished ore production records: Atomic Energy Commission, Energy Research and Development Administration, and Department of Energy; Grand Junction, Colorado.
[4] Uranium from DOE unpublished records. Vanadium estimated from uranium production.
[5] Rough estimate based on data from Union Carbide, and Utah Geological Survey UMOS (mineral occurrence) files. (UGS, 1999)

Table 67. *Uranium and vanadium production in Emery County, Utah, by mining area or district.*

Period	Ore (st)	U_3O_8 in pounds (grade)	V_2O_5 in pounds (grade)	Source
San Rafael River (Desert) Mining Area--Green River District				
1948-1977		2,154,176		Utah Geological Survey, 1999[1]
1948-1967 (includes Interriver area)	542,116	2,565,365 (0.24%)		Cohenour, 1967
1948-1974	600,000	2,880,000 (0.24%)		UGMS, 1974
1948-1975	710,571	2,802,514 (0.19%)		Trimble and Doelling, 1978
1948-1979	670,000	2,632,000 (0.20%)	2,540,000 (0.19%)	Shawe and others, 1991
1948-1988*	950,000	3,800,000 (0.20%)	3,610,000 (0.19%) est.	Union Carbide[2]
San Rafael Swell Mining District (does not include Temple Mountain)				
1948-1973		1,182,995		Utah Geological Survey, 1999[1]
1948-1974	300,000	1,380,000 est.		UGMS, 1974
1948-1988		2,140,000		Munts, 1989
1948-1988*	400,000	2,000,000 (0.25%) est.	480,000 (0.06 %) est.	R.W. Gloyn[3]
Temple Mountain Mining District				
1914-1956	265,000	1,448,560 (0.27%)	3,875,800 (0.73%)	R.W. Gloyn,[3] Hawley and others, 1965
1948-1973		2,066,258	5,031,814	Utah Geological Survey,[1] Hawley and others, 1965
1948-1974	>300,000	>1,500,00 (0.25%)		UGMS, 1974, Chenoweth, 1996[4]
1918-1986		1,533,083		Hawley and others, 1965
1914-1988*	400,000 est.	2,075,000 (0.26%)est.	5,056,000 (0.63%) est.	R.W. Gloyn[3]
Temple Mountain and San Rafael Swell Mining Districts				
1948-1967 (0.26%)	593,809	3,033,566		Cohenour, 1967
1948-1970	687,100	3,460,000 (0.25%)	2,900,000 (0.28%)	Shawe and others, 1991
1904-1973	600,000	3,060,000 (0.255%)	1,008,000 (0-084%)	UGMS, 1974
1948-1984	705,000	3,525,000 (0.25%)		Chenoweth, 1996[4]
1948-1988*	800,000	4,075,000	5,536,000	R.W. Gloyn[3]
Total of Best Estimates Major Mining Districts	1,750,000	7,875,000	9,146,000	

* Best estimate starred
[1] Mineral occurrence database (UMOS) and files - Individual mine production reports and estimates
[2] Estimate as reported by W.L. Chenoweth - written communication
[3] Estimate based on earlier estimates and UMOS mineral occurrence database and files reserve data
[4] Written communication

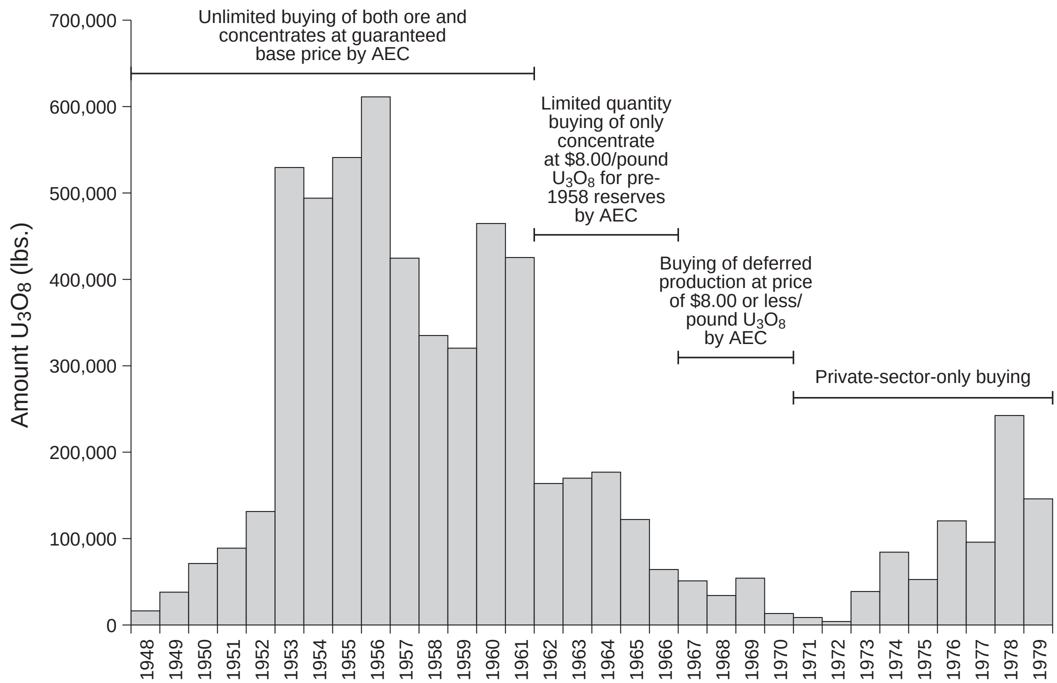


Figure 39. *Annual uranium production in Emery County, 1948 to 1979. Source: Unpublished AEC, ERDA, and DOE production records.*

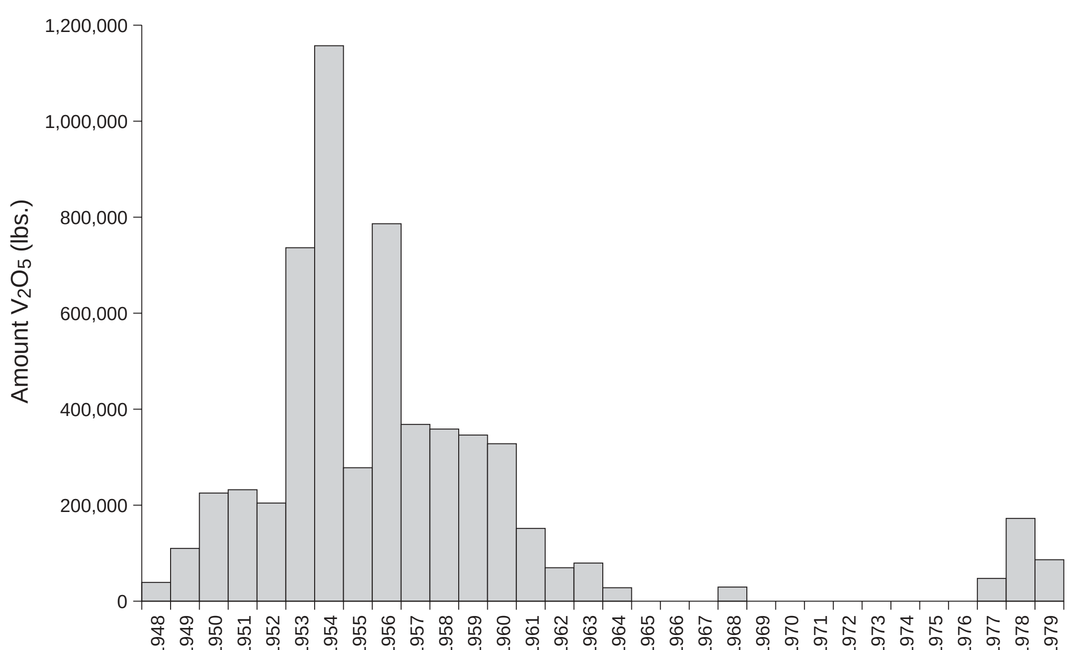


Figure 40. *Annual vanadium production in Emery County, 1948 to 1979. Source: Unpublished AEC, ERDA, and DOE production records.*

(Chenoweth, 1990). Between 1920 and 1942, only a small amount of ore was produced in Emery County, even though substantial vanadium was produced in Utah during this period, mostly from Grand and San Juan Counties (Chenoweth, 1990).

Between 1943 and 1945, uranium mined in Utah was for the Manhattan Bomb Project and the development of atomic weapons. Production statistics are withheld, but Chenoweth (1990) estimates that over 265,000 pounds (120,000 kg) of U_3O_8 were produced in Utah. Most of the processed ore was from mines in San Juan and Grand Counties; very little ore was from Emery County (Webber, 1947).

The "uranium boom" lasted from 1948 to 1961 and corresponds to the AEC procurement program. Under this program the AEC established a number of buying stations and purchased unlimited amounts of uranium ore at a guaranteed minimum price. The AEC program stimulated exploration, and a number of new discoveries were made in Emery County, particularly between 1952 and 1954. Major deposits discovered during this period include the Delta mine in the San Rafael Swell district, the deposits on the Calyx Bench in the Temple Mountain district, and deeper deposits in the North Tidwell trend of the San Rafael River mining area. Initial mining in most of the areas was divided among a number of small operators, but with time properties were consolidated until only one or two major operators remained. Consolidated Uranium Corporation, who subsequently sold their interest to Union Carbide Nuclear Company, became the main operator in the Temple Mountain district, and Four Corners Oil and Minerals, who subsequently sold their interest to Atlas Corporation in 1965, became the major operator in the San Rafael River mining area. Between 1948 and 1961, mines in Emery County produced 881,435 tons (799,638 metric tons) of uranium ore containing 4,474,534 pounds (2,029,648 kg) of U_3O_8 and 5,330,208 pounds (2,417,782 kg) of V_2O_5.

By 1958 it was apparent that the AEC procurement program was too successful; more uranium was being produced than the government could use. In late 1958, the AEC redefined its procurement program for the period 1962 to 1966 and would only purchase concentrate derived from ore reserves developed prior to November 24, 1958. The new government policy had a drastic effect and annual uranium production in Emery County from 1962 to 1966 dropped to 25 percent of earlier levels (figure 35). The effect was quite pronounced in Emery County because there were no mills close to the operating mines. However, by 1962 it was apparent that the private market would not sustain the uranium industry at the end of 1966, and the government announced a "stretch-out" program whereby deferred production could be sold until 1970. However, the “stretch-out” program did not help Emery County, and annual production decreased even more during this period.

"Beginning in 1971, all uranium concentrate produced was destined for use in nuclear power plants for generation of electricity” (Chenoweth, 1990, p.122). Prices for uranium were low (less than $8.00/ pound) in the early 1970s and the annual production from Emery County was less than 10,000 pounds (4,500 kg) per year. Between 1976 and 1980, the price of uranium in concentrate increased to over $40.00 per pound. A number of mines reopened, and several new discoveries were made including the Sinbad mine and deeper deposits in the San Rafael River mining area. From 1980 to 1983 the uranium price dropped to $20.25 per pound (Chenoweth, 1990), and many operations ceased or were cut back. In 1984 Atlas closed its Moab mill, and in 1988 Rio Algom closed its Lisbon Valley mill. Since 1988 no significant uranium production has come from Carbon or Emery County.

Current Production and Exploration Activity

Although a number of claims are still held for uranium in Emery and Carbon Counties (Benjamin, 1989; Close, 1989; Lipton, 1989; Munts, 1989; Neumann, 1989), there has been very little recent activity. No “Notices of Intent to explore” (NOIs) for uranium in these two counties have been recorded by DOGM since 1992 and by 1999 all of the older NOIs had been retired. In 1996, Carbon and Emery Counties had no uranium/vanadium mines with active mining permits and only three uranium/vanadium mines with permits under suspension. 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 mines with permits under suspension included two regular mines (greater than five acres disturbance) and one small mine (less than five acres disturbance). By 1999 there were no active or suspended mining permits for uranium or vanadium for either small or regular mines.

Potential for Additional Discoveries and/or Development

Some uranium-vanadium reserves remain in existing mines in Emery County. In 1975, the Utah Geological Survey estimated that 505,500 tons (458,600 metric tons) of measured, indicated, and inferred uranium ore containing 1,600,000 pounds (725,000 kg) of U_3O_8 and 1,755,000 pounds (800,000 kg) of V_2O_5 remained in the existing mines in Emery County (Utah Geological and Mineral Survey, 1974). The reserves are listed by district in table 68.

Reserves for individual mines in the San Rafael district as of 1975 are shown in table 69. Many of these reserves were probably mined during the period of high uranium prices between 1976 and 1980, but some reserves may remain at the Delta, Sinbad, Dirty Devil, and Lucky Strike mines. Most of the remaining reserves in the Temple Mountain district were also depleted between 1976 and 1980. Known reserves were mined in the San Rafael River area, but additional discoveries were made, and reserves still remain at the Snow, Four Corners, and Probe mines in the area. Estimated remaining ore reserves in Emery County are between 200,000 and 300,000 tons (90,000-136,000 kg) at a grade of 0.15 to 0.20 percent U_3O_8.

The potential is good for additional discoveries of uranium-vanadium deposits in Emery County. Most of the new discoveries would be similar to the known deposits and at depths of 300 to over 2,000 feet (100-600 m). Potential areas for new discoveries are shown on plate 13. Plate 13 is a compilation of “favorable areas” proposed by Johnson (1957, 1959a, and 1959b), Lupe (1977), Mickle and others (1977), Lupe and others (1982), and Campbell and others (1982). Uranium favorability was determined using thickness of host units, sandstone/shale ratios of host units, distribution of known deposits, and extrapolation of known channel trends.

Table 68. Uranium-vanadium reserves in Emery County by district or area, 1975 (from Utah Geological and Mineral Survey, 1974).

District or Area	Ore (st)	U_3O_8 grade	V_2O_5 grade
Temple Mountain	28,900	0.17 %	unknown
San Rafael	405,000	0.22 %	unknown
San Rafael River	73,000	0.20 %	0.80%

Table 69. Deposits with major uranium reserves in 1975 - San Rafael district.

Deposit Name	Tons ore	Percent U3O8	Pounds V2O5	Remarks
Dexter 7	7,200 30,000 17,000	0.20 0.15 0.10	28,800 90,000 34,000	Tons and contained pounds for different grade categories
Sinbad	25,000 100-150,000	0.25 0.20	125,000 400,000	Early estimate Updated estimate (still low)
Consolidated	750	0.15	2,250	
Lucky Strike	25,000	0.22	110,000	
Conrad	35,000	0.20	140,000	
Crossbow	> 25,000	0.20	> 100,000	
Dirty Devil 6	1,200	0.20	4,800	
Dirty Devil 3 & 4	1,200	0.15	3,600	
Dirty Devil	5,500	0.20	22,000	
Little Emma	17,000	0.20	68,000	
Cistern	30,500	0.20	122,000	
Delta	35,000 70,000	0.20 0.10	140,000 140,000	Tons and contained pounds for different grade categories
Bluebird	10,000	0.20	40,000	
Yellow Canary	58,000	0.05	58,000	Morrison-hosted

Sources: Utah Geological and Mineral Survey, 1974; Utah Geological Survey, 1999

Chinle-hosted Deposits

Potential is good for discovery of Moss Back- and sub-Moss Back-hosted, peneconcordant deposits around the flanks of the San Rafael Swell. The better potential is on the west side because possible new discoveries would be at shallower depths. Two favorable belts are characterized by greater sub-Moss Back thicknesses and thinner or more variable Moss Back thicknesses (figure 35). Nearly all of the better deposits are confined to the southern belt. Between the two belts is a zone of thick, massive Moss Back sandstone containing few deposits. Within the favorable belts, more favorable areas can be delineated by projecting major channel trends into the subsurface (cross-hatched areas on plate 11). Examples include the Temple Mountain and Flat Top channels south of Temple Mountain and the Tomich and Temple Mountain channels north and west of San Rafael Knob. The discovery of the Sinbad mine within the "barren interbelt" suggests that this belt may be more favorable than previously thought for sub-Moss Back-hosted deposits. Mickle and others (1977) believe a favorable Moss Back and sub-Moss Back area exists on the east side of the San Rafael Swell within the “ barren interbelt” based on radiometric anomalies in oil wells. The best potential area for peneconcordant deposits is to the west and north of San Rafael Knob (plate 11).

Only limited potential exists for "Temple Mountain-type" uranium deposits in the Temple Mountain district. The better deposits all occur 1/2 to 1 mile from the collapse structures and are probably related to the collapse structure. Only a small area to the south and east of the Vanadium King 1 appears to be favorable (see figure 36).

Morrison-hosted Deposits

The San Rafael River mining area has excellent potential for discovery of Salt Wash-hosted uranium-vanadium deposits, but only low potential exists elsewhere around the San Rafael Swell. Favorable areas exist where major trunk paleochannels "break up into a complex of splays and meanders that provide lithologic heterogeneity and an abundance of preserved organic trash" (Mickle and others, 1977). Three to four major trunk channels are recognized in the San Rafael River mining area (figure 41) and four are known around the margins of the San Rafael Swell (plate 11). Significant uranium has been mined from the San Rafael River area channels in the North Tidwell belt (western channel zone in figure 41). Each of the unmined San Rafael River area channels could contain as much uranium as was mined in the North Tidwell belt for an aggregate potential of 7 to 10 million pounds (320,000-450,000 kg) each of U_3O_8 and V_2O_5. Potential for Salt Wash-hosted deposits on the west and north ends of the San Rafael Swell is probably low because only minor uranium has been found in this area.

Potential also exists for relatively large, but low-grade deposits in the Brushy Basin Member of the Morrison Formation. Mickle and others (1977) believe that the entire Brushy Basin outcrop belt has potential for this type of deposit. They describe several unmined deposits that fit this category.

Even though potential exists for new uranium-vanadium deposits, there is little incentive to explore for such deposits. Because of the small lateral extent and spotty, discontinuous nature of the mineralization, an extensive and close-spaced drilling program would be required. New discoveries would be at greater depths and probably would not be significantly larger or higher grade than previously mined deposits.

Although known uranium reserves remain at some of the mines, and good potential exists for discovery of additional deposits, the future of uranium mining in Emery and Carbon Counties is still doubtful. Recent studies by Neumann (1989) and Close (1989) calculated costs for a hypothetical deposit containing 100,000 short tons (90,000 metric tons) of 0.20 percent U_3O_8 ore. Total operating and capital costs for mining were $41.00 to $65.00 per ton and milling costs were $29.00 per ton for a total of $70.00 to $94.00 per ton. At recent (September-December 2001) uranium prices of $7.10 to $9.60 per pound U_3O_8 in concentrate a typical Emery County deposit would contain only $30.00 to $40.00 worth of uranium per ton even with 100 percent recovery.

The effect of co-production of vanadium would increase the value per ton for several deposits. Many of the deposits contain one to three times as much vanadium as uranium. At current prices (2001) of $1.20 to $1.40 per pound V_2O_5 the co-product vanadium could be worth from $2.50 to $22.50 per ton. Although co-product vanadium does not significantly improve the economics at current vanadium prices, some occurrences may become marginally economic with substantial increases in the price of V_2O_5 to $5.00 or more per pound as occurred in 1989 and 1998.

A serious obstacle to developing any uranium-vanadium deposit in Emery or Carbon County is the absence of any nearby milling facility. Existing mills in southeastern Utah are more than 100 miles away from existing reserves or probable new discoveries requiring transport costs of up to or greater than $25.00 per ton to be added to the above-mentioned mining and milling costs. In addition, the existing mills might not accept ore from the San Rafael Swell and Temple Mountain districts because of their high asphaltite content (Neumann, 1989). The deposits in the San Rafael River mining area probably have the best chance for development; they are closer to the existing mill, do not contain significant asphaltite, and have high vanadium contents.

Use of in-situ uranium-leaching techniques could reduce both capital and operating costs, but these techniques have not been successfully applied to any Emery County occurrences. The lack of any attempt to use these techniques in Emery County suggests a fundamental problem in applying these methods to Morrison- and particularly Chinle-hosted ores. The high vanadium content and asphaltic nature of much of the ore severely limit the ability of uranium to go into solution. In addition, deposits amenable to in-situ leaching must be below the water table which would limit in-situ mining to the deeper deposits.

METALLIC MINERAL RESOURCES

Carbon and Emery Counties are poorly endowed with metallic mineral resources. Minor occurrences of manganese, silver, copper, titanium, and zirconium-bearing minerals are known from Jurassic and Cretaceous sedimentary units in Emery County (Doelling and Bon, 1991). In addition, minor or anomalous amounts of copper, lead, zinc, molybdenum, selenium, cobalt, arsenic, chromium, nickel, and silver are associated with the uranium-vanadium deposits in the Triassic Chinle and Jurassic Morrison Formations. Only very minor production of metallic minerals, mostly copper and manganese, has occurred in Carbon and Emery Counties, and only vanadium and very minor amounts of copper (Close, 1989) and lead have been recovered as a by-product of uranium production. None of the known occurrences has much potential for significant development, and there is very limited potential for discovery of significant new metallic mineral deposits.

Copper and Silver Resources

Known Occurrences and Characteristics

Several small copper occurrences not associated with uranium or vanadium are known in Emery County (plate 12, table 70). They consist of azurite, malachite, and occasionally chalcocite along bedding planes, fractures, and fault zones in fine- to coarse-grained Jurassic sandstone (Navajo Sandstone, Kayenta Formation, Wingate Sandstone, and Entrada Sandstone).

Most of the occurrences are along steeply dipping fault or fracture zones, and the mineralization rarely extends much beyond the faults or fractures. The mineralized fault and fracture zones generally trend from N. 60° W. to N. 70° E.

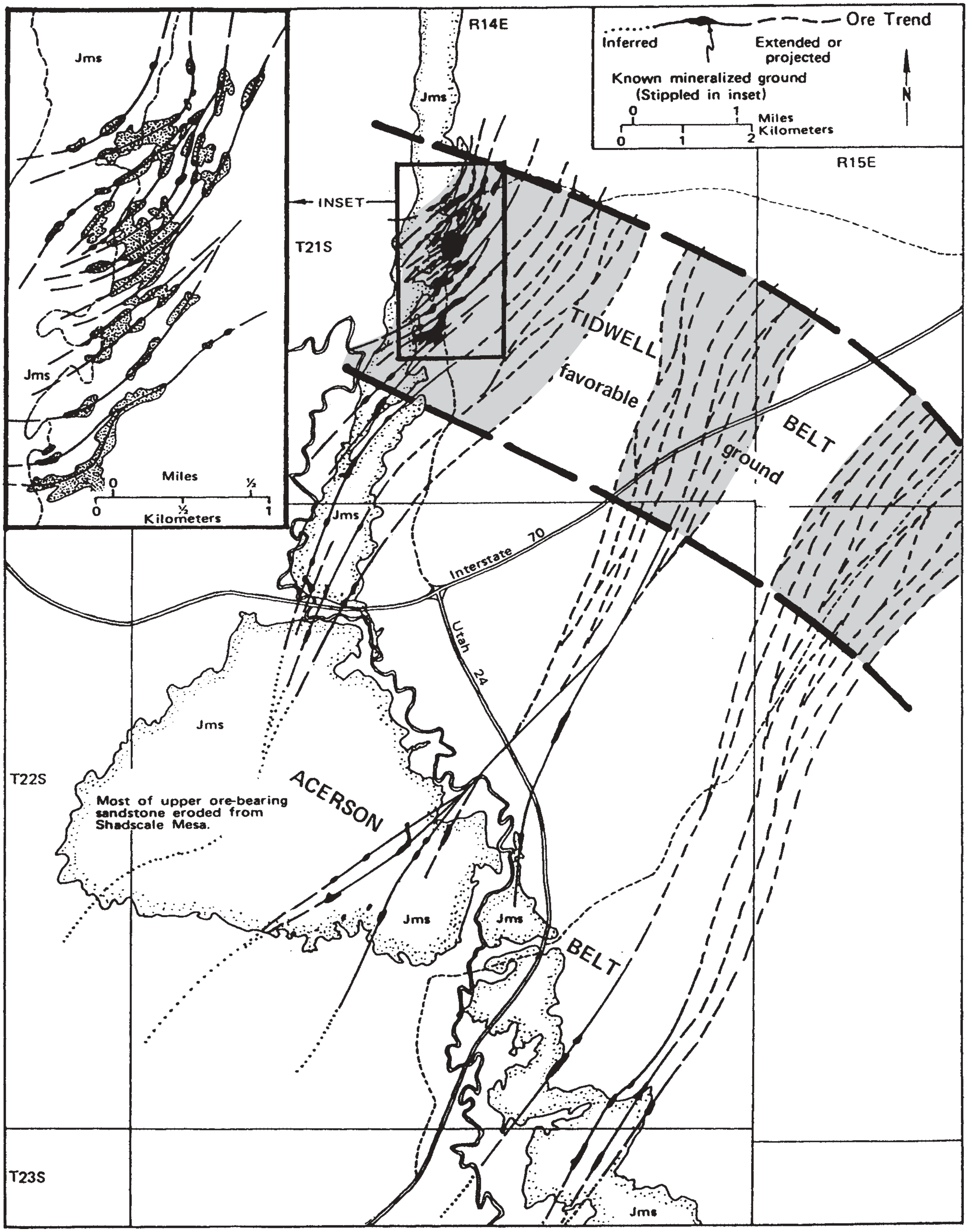


Figure 41. *Favorable exploration areas, San Rafael River mining area, Emery County, Utah (from Trimble and Doelling, 1978).*

Table 70. *Copper and silver occurrences in Carbon and Emery Counties, arranged by decreasing age of host rock and from north to south.*

Name	**Location**		**Extent of Workings**	**Host Formation**	**Description**
	UTM N	**UTM E**			
Red Canyon	4323000 N	535840 E	No workings	Chinle Formation	Anomalous silver (28 ppm) and copper (800 ppm) in coarse-grained conglomeratic sandstone
Chimney Rock 3	4343425 N	542825 E	Shaft 25' deep with 55' of drifts, 5' adit	Navajo Sandstone	Minor malachite and azurite disseminated in fractures along N 80° E fault
Chimney Rock 2	4343375 N	542450 E	Two adits each with drifts 75' and 100' long	Navajo Sandstone	Minor malachite and azurite disseminated in sandstone along N 80° E fault and along fractures
Chimney Rock 1	4343300 N	541215 E	Shaft 200' deep and several prospect pits	Navajo Sandstone	Minor malachite and azurite disseminated in sandstone along N 80° E fault and along fractures
Chimney Rock 4	4341950 N	541720 E	Four adits with 150' (total) of workings and small prospect pits	Navajo Sandstone	Malachite and azurite along N 70° E fault; traceable for 2,000'
Bob Hill Knoll	4334150 N	524500 E	Adit 780' long and dozed area, shaft to east	Navajo Sandstone	Iron- and manganese-stained sandstone. May contain silver values. No secondary copper carbonates observed
Sorrel Mule	4327460 N	515120 E	Adit 1,060' long	Navajo Sandstone	Iron and manganese staining along northwest-trending, vertical fractures in sandstone. Chalcopyrite reported, but USBM sampling showed no anomalous metal values
Copper Globe	4294660 N	507680 E	Several short adits/inclines, 2 shafts up to 50-60' deep, 2 prospect pits	Navajo Sandstone	Minor malachite/azurite along bedding planes and fractures in sandstone
ZCMI	4311540 N	513550 E	Two adits (117' and 227') two shafts (12' and caved), and three pits	Kayenta Formation and Wingate Sandstone	Malachite, azurite, and chalcocite as blebs along fractures and as staining in 4-5'-wide fault zone trending N 71° W. Some mineralization along N 60° E fault. Fault zone contains anomalous copper (600-7,500 ppm), molybdenum (40-880 ppm), zinc (220-2,200 ppm), and lead (180-1,200 ppm)
Alice East	4318290 N	552600 E	Shaft probably 25' deep, now backfilled	Entrada Sandstone	Malachite and azurite as coatings on fractures
Alice	4318100 N	552370 E	Two pits	Entrada Sandstone	Malachite and azurite as coatings along vertical fractures and bedding planes, minor disseminated. Anomalous copper (500-24,000 ppm), silver (4-32 ppm), and lead (1,022-3,351 ppm)
Primrose North	4317700 N	552450 E	Small pit and short adit	Entrada Sandstone	Malachite and azurite as coatings along 2-3' wide, N 60° W-trending, 60° NE-dipping, bleached fracture zone. Trace copper (200 ppm) and silver (3.6 ppm)
Primrose South	4316800 N	552840 E	Two pits	Entrada Sandstone	Malachite, azurite, and chalcocite as coatings along 2-3' thick, bedding parallel, bleached fault zone (N 60° E; 50° SE). Anomalous copper (14,000-16,000 ppm), molybdenum (30-40 ppm), and silver (230-370 ppm)
Flaming Star	4301600 N	546800 E	Prospect pit	Entrada Sandstone	Minor malachite staining along bedding in thin sandstone bed

Source: Benjamin, 1989; Lipton, 1989; Utah Geological Survey, 1999.

The fault and fracture zones are generally narrow, 3 to as much as 10 feet (1-3 m) wide, and mineralization can be traced sporadically along the faults for several hundred to as much as 2,000 feet (60-600 m). Grades are highly variable. Samples collected by the USBM contained from 0.05 to 2.4 percent copper for the better mineralized zones (Benjamin, 1989; Lipton, 1989; Munts, 1989). Some of the samples also contained silver (10 to 300 ppm), molybdenum (40 to 800 ppm), lead (200 to 3,400 ppm), and zinc (200 to 2,200 ppm) (Benjamin, 1989; Lipton, 1989).

Copper and silver are also associated with some uranium-vanadium deposits, most notably those in the Triassic Chinle Formation on the western side of the San Rafael Swell. Select samples from individual prospects contained 0.3 to 2.3 percent copper (Close, 1989; Neumann, 1989; Lipton, 1989). Silver values were usually less than 0.3 ounces/ton (10 g/mt) but one sample from the Dexter mine assayed 232 ounces silver/ton (7.95 kg/mt) (Lipton, 1989). The Chinle uranium-vanadium deposits are described in the uranium-vanadium section.

Past and Current Exploration and Production Activity

Most of the past exploration and production activity for copper and silver was surface prospecting and very minor development by shallow shafts, short adits, and surface pits. Total recorded production of copper and silver for Emery County is 8,350 pounds (3,800 kg) of copper and 368 ounces (11.4 kg) of silver (U.S. Geological Survey and U.S. Bureau of Mines, 1913 -1931; U.S. Bureau of Mines, 1932-1952). Roughly 2,100 pounds (950 kg) of the copper production was from mines in the Cedar Mountain area (Chimney Rock prospects [?]) and 6,000 pounds (2,700 kg) was from mines in the “Lost Springs (Summerville) district.” The Chimney Rock area had recorded production in 1947, and the Lost Springs area had recorded production in 1915 and 1917. The precise location of the Summerville district is unclear, but it is within 3 to 4 miles (5-6.5 km) of the Chimney Rock mines and the production assigned to the “Summerville district” may actually be from the Chimney Rock prospects (table 70). The grade of the shipped ore (11 to 18 percent copper) indicates it was hand-sorted before shipping. Several test lots of ore were shipped from mines west of Green River (Alice or Primrose South) in 1906-07, but the amount is not recorded (U.S. Geological Survey, 1882-1912). Close (1989) reported that some copper was produced as a by-product of uranium-vanadium mining but gave no numbers. The USBM reported that 9 troy ounces (280 g) of gold, 4,935 troy ounces (153.5 kg) of silver, 880,000 pounds (400,000 kg) of copper, and 2,000 pounds (900 kg) of lead were recovered from uranium ore shipments from three mines in San Juan and Emery Counties in 1958, but does not separate the production by county. The Emery County production was probably from the Delta mine and probably accounted for most of the lead produced.

There is no current exploration or production activity for copper or silver in Carbon or Emery Counties.

Potential for Additional Discoveries and/or Development

Additional occurrences of malachite and azurite are likely present in Emery County along narrow faults and fractures in sandstone, similar to the known deposits. However, even if additional discoveries were made, it is unlikely that any would be developed. The deposits would be small, and the ore-grade mineralization would be discontinuous and sporadic.

Permissive geologic conditions are present for two “geologic target types” that would have better potential for development: Lisbon Valley-type copper and Dzhezkazgan-type copper (plate 12). The target areas were identified based on identifying favorable conditions that matched the ore deposit conceptual models. In most cases, there are no known copper occurrences to support the model, and the likelihood that such deposits are present is low.

Lisbon Valley-type copper: “Lisbon Valley-type” sedimentary copper deposits could be present along the eastern side of the San Rafael Swell (plate 12). In “Lisbon Valley- type deposits,” copper mineralization is disseminated in favorable beds adjacent to feeder faults (Kirkham, 1989). The better deposits occur in beds with sufficient indigenous reductants (carbon trash, plant fragments) or introduced reductants (dead oil, hydrocarbons) to precipitate the copper. Numerous northwest-trending faults are present on the east side of the San Rafael Swell and could have acted as feeders for saline, copper-bearing fluids from the underlying Paradox Formation and Cutler Group. Unfortunately, most of the potential Cretaceous host units (host for the Lisbon Valley deposit) are either missing or lithologically unfavorable. Only the thin Ferron Sandstone Member of the Mancos Shale is sufficiently permeable and reducing enough to be considered as a potential host. The southern areas have more potential since they are closer to the presumed source of the copper. Even if deposits were found, they would probably be small and of modest grade.

Dzhezkazgan-type copper: Southeastern Emery County has some potential for “leaky-reservoir-type” sedimentary copper deposits (Dzhezkazgan model). In this model, hydrocarbon or hydrogen sulfide leakage from below would cause reduction of Permian to Jurassic red beds, and precipitation of copper would occur where metal-bearing, oxidized solutions inherent in the red beds encounter this reduced front (Kirkham, 1989). Potential for this type of deposit is much greater in Grand and San Juan Counties where the “host-source” red beds are thicker, and there are known oil and gas fields to supply the necessary reductant. Geologic constraints limit the potential, particularly in Emery County, where depths to the target red beds would be between 2,500 and 3,500 feet (750-1,000 m).

Kupferschiefer-type copper: No potential exists for Kupferschiefer-type deposits in Carbon and Emery Counties. Although thick Permian to Jurassic red-bed sequences are present, they are not overlain by favorable pyritic shales or sandstones (Kirkham, 1989).

In summary, the potential for discovery of economic copper with or without subordinate by-product silver deposits in Carbon and Emery Counties is low.

Manganese Resources

Known Occurrences and Characteristics

Eighteen small, sedimentary-hosted manganese deposits are known in Emery County (plate 12, table 71) (Pardee, 1922; Baker and others, 1952). The deposits are found in (1) limey sandstone and sandy shale of the Jurassic Summerville Formation, (2) sandy shales, sandstones, and conglomerates of the Brushy Basin Member of the Jurassic Morrison Formation, (3) limestone and conglomerate of the Cretaceous Cedar Mountain Formation, and (4) Recent gravels.

Summerville-hosted deposits: The Summerville-hosted deposits are in the Little Grand district, mostly in Grand County but partially in the eastern part of Emery County. The deposits consist of pyrolusite, manganite, and psilomelane as (1) replacements in limestone, (2) small nodules, veinlets, and impregnations in limey sandstone and sandy shale, and (3) small nodules and irregular masses of sooty manganese oxides in shale and cherty shale (Baker and others, 1952). The limestone replacement deposits are generally thin (0.3 to 1.5 feet [0.1-0.5 m] thick), traceable for several hundred feet, and usually are high grade (30-50 percent manganese). The nodule, veinlet, and impregnation deposits in sandstone are 1 to 6 feet (0.3-2 m) thick, traceable for 50 to 400 feet (15-120 m), and generally average 5 to 15 percent manganese. The nodules and irregular masses in shale are usually several feet thick, traceable for many hundreds of feet, and may contain as much as 10 percent manganese although grades are usually lower (Baker and others, 1952). Detrital deposits, consisting of nodules and hard manganese-oxide replacements weathered from in-situ deposits and remaining as lag gravel, are common near many of the occurrences. The four reported Summerville-hosted manganese occurrences in Emery County are mostly nodules and im-pregnations in sandstone and shale (table 71).

Morrison-hosted deposits: The Morrison-hosted deposits occur on the southwest side of the San Rafael Swell in two areas: east of the town of Emery and along Muddy Creek (plate 12). They consist of pyrolusite, psilomelane, and manganite as nodules and sooty impregnations in shale and sandy shale of the Brushy Basin Member of the Morrison Formation. Some manganese also occurs as replacement of cement in sandstones and conglomerates, or as thin, black, manganiferous chert horizons. The manganese occurs in stratiform zones from 2 to 5 feet (0.6-1.5 m) thick, occasionally up to 25 feet (8 m) thick and traceable for 100 to over 1,500 feet (30-460 m). Grades average between 5 and 15 percent manganese (Baker and others, 1952). Some deposits have multiple zones distributed as irregular lenses within a 50- to 60-foot-thick (15-18 m) stratigraphic interval (table 71). In the thicker manganiferous zones, the higher grade manganese is usually in the basal part of the zone.

Cedar Mountain-hosted deposits: Cedar Mountain-hosted deposits occur on the northwest side of the San Rafael Swell in the Cedar Mountain area. The deposits consist of small pyrolusite nodules and rare veinlets in shale and limestone or as thin, discontinuous replacements of limestone. The manganese-bearing zones are from less than l to nearly 8 feet (0.3 to 2.5 m) thick, traceable for up to 500 feet (150 m), with estimated grades of 4 to 25 percent manganese. The higher grades are associated with the thin limestone replacement deposits. Several of the deposits in the Cedar Mountain area occur along faults and fractures that may have acted as feeders, and some residual nodules may have come from veins (Baker and others, 1952).

Recent gravel-hosted deposits: A small manganese deposit in caliche-cemented gravel is located in Saucer Basin in southeastern Emery County. The deposit is 4 to 5 feet (1.2-1.5 m) thick, of unknown grade, and covers an area of 10 to 15 acres (4.05 -6.10 ha) (Baker and others, 1952). The gravel rests on the Entrada Sandstone.

Past and Current Exploration and Production Activity

Approximately 23,000 short tons (21,000 metric tons) of manganese ore averaging 10-15 percent manganese has been produced from the Little Grand district in Grand and Emery Counties (Crittenden, 1964). Over 95 percent of this production came from Grand County, mainly from the Colorado Fuel and Iron Company (C.F.& I.) deposits at Duma Point and Needles. Only minor amounts, estimated at less than 500 short tons (450 metric tons), were from Emery County. Production from the other areas in Emery County was also probably less than 200-300 short tons (180-270 metric tons) of ore. Most of the manganese was produced during World Wars I and II and during the Korean conflict, when government price supports were in effect (Crittenden, 1964). Much of the early production was from “residual deposits” of hard manganese-oxide nodules that weathered out of the in-situ deposits. There has been no production of manganese from the Little Grand district since 1959. No current exploration or development activity for manganese is known in Carbon or Emery Counties, and there are no active or suspended mine permits nor any Notices of Intent to Explore (NOIs) for manganese in either county.

Potential for Additional Discoveries and/or Development

Baker and others (1952) estimated the manganese resource for some of the prospects in Emery County (table 71). Although modest resources of manganese are present, they are unlikely to be developed in the near future. Most manganese ore currently mined elsewhere contains from 35 to 54 percent manganese while the grade of Emery County ore is less than 25 percent, making the deposits uneconomic. In addition, the Emery County deposits are small, thin, and discontinuous and could only support a very small operation. Additional similar, undiscovered deposits probably exist in Emery County, but little incentive exists to explore because the deposits would not even approach an economic size or grade.

Other, more significant types of manganese deposits (Groote Eylandt-type) are unlikely to occur in the Upper Cretaceous rocks of Carbon and Emery Counties. Too much clastic material was supplied to the depositional area, and the sheltered environments necessary to prevent detritus from diluting the deposited manganese apparently were absent. Also, the western margin of the Cretaceous seaway was not steep enough to allow focused upwelling of anoxic manganese-bearing waters (Mayes, 1992).

Lead-Zinc Resources

Known Occurrences and Past Production

No confirmed lead-zinc deposits occur in Emery County although anomalous lead and zinc are associated with both uranium-vanadium and copper deposits (see sections on copper-silver and uranium-vanadium). *Mineral Resources of the United States* for 1915 (U.S. Geological Survey and U.S.

Table 71. Manganese occurrences in Carbon and Emery Counties, arranged by decreasing age of host rock and from north to south.

Name	UTM N	UTM E	Extent of Workings	Description	Resources Measured, indicated, and inferred
Summerville-hosted deposits					
Dry Lake Wash A	4295340 N	568660 E	Shallow pit	Nodules and impregnations in sandy shale in zone 13' thick, 300' + long	None– too low grade
Dry Lake Wash B	4294930 N	568010 E	unknown	Nodules and impregnations in sandy shale in zone 1.5' thick, 60' long, and 30' wide	300 tons @ 7-10% Mn
Dry Lake Wash C	4294880 N	567750 E	Trench 35' long	Nodules and lenses in limey sandstone and sandy shale 3' thick, 50' + long. Probably averages 15-20% Mn	300 tons @ <20% Mn
Red Cloud (Dry Lake Wash D)	4294970 N	567520 E	Shallow pit	Nodules and impregnations in sandstone 6' thick, 200' + long. Some sorted high grade ore	Minor– <100 tons @ 35% + Mn (detrital deposit)
Morrison-hosted deposits					
Rochester Manganese	4311210 N	495730 E	Several small pits	Nodules and impregnations in shale, often as irregular lenses at various stratigraphic horizons, and as replacement of cement in sandstone. Mineralized zone up to 12' thick and 900' long.	3,000-5,000 tons @ 5-10% Mn
South Rochester Manganese A	4309100 N	494450 E	None	Nodules and irregular impregnations in shale 5' thick, 100' long	<300 tons @ 10-15% Mn
South Rochester Manganese B	4308800 N	494420 E	None	Nodules in black chert 2.5' thick, 100' long @ 5% Mn (est.)	None– too low grade
Snow A	4294960 N	484380 E	Trench and short adit	Gray shale–no manganese	None
Snow B	4294960 N	484420 E	Trench and short adit	Nodules in sandy shale, often along fractures, 5' thick by 40' long.	3,000-6,000 tons 15% Mn
Snow C	4294850 N	484460 E	Prospect pit	Minor nodules in sandy shale 3' thick	None– too low grade
Snow D	4294820 N	484460 E	Prospect pit	Nodules in sandy shale 5' thick by 25-50' long @ 8% Mn	300-500 tons @ 8% Mn
Snow E	4294780 N	484470 E	Trench and 50' pit	Nodules and disseminations in shale and shaley sandstone and as replacement of cement in conglomerate; 6' thick by 100-200' long (est.)	10,000-20,000 + tons @ 12.7% Mn
Snow F	4294770 N	484560 E	Prospect trench	Nodules in shale 2' thick by 50-60' long, low grade	None
Cedar Mountain-hosted deposits					
Bob Hill Spring (Cedar Mountain B)	4340460 N	527250 E	Several small prospect pits	Mn oxides along N 22° E-trending fault with some replacement of limestone and conglomerate cement adjacent to fractures, zone 150' long.	Minor occurrence and of low grade
Cedar Mountain C	4339550 N	524700 E	Three prospect pits	As nodules and veins/veinlets in conglomerate, limestone, and shale	< 1,000 tons of unknown grade
Cedar Mountain D	4342300 N	523725 E	Several shallow pits	Thin (< 1' thick) replaced limestone bed. Mineralized zone 500' long and up to 120' wide.	2,000-4,000 tons @ < 25% Mn
Cow Flats (Cedar Mountain A)	4347650 N	521650 E	Two prospect pits	Small nodules in limestone and sandy shale 5-7' thick by 280' long	5,000-15,000 tons @ 4% Mn
Recent-gravel-hosted deposits					
Saucer Basin	4275500 N	571500 E	None	Disseminated Mn oxide in caliche-cemented gravel 4-5' thick	100,000-150,000 tons but probably very low (uneconomic) grade

Source: Baker and others, 1952; Utah Geological Survey, 1999

Bureau of Mines, 1913-1931) lists small production of oxidized zinc ore from the Good Hope claim in eastern Emery County (139 short tons [126 metric tons] containing 59,075 pounds [26,000 kg] of zinc). The deposit was described as a 5-foot-thick (1.5 m) mineralized shale between limestone and sandstone with assays of 27 percent zinc, 4 percent lead, and 13.5 ounces silver/short ton (463 g/mt). No known occurrence fits this description, and the recorded production was most likely mis-applied to Emery County by the Bureau of Mines.

Potential for Additional Discoveries and/or Development

Little obvious potential exists for discovery of lead-zinc deposits in Emery County. Conceptually, the area could be favorable for "Mississippi Valley-type" deposits in the Permian Pakoon Dolomite, Elephant Canyon Formation, or Black Box Dolomite. In this model, lead-zinc-rich brines from the Mancos Shale would migrate to favorable host beds on the flanks and crest of the San Rafael Swell. Studies by the USGS (Bartsch-Winkler and others, 1990) detected five areas around the San Rafael Swell containing anomalous lead in stream-sediment, heavy-mineral concentrates. Assay values of heavy-mineral concentrates ranged from 700 to 50,000 ppm lead. Several of the anomalous areas are probably related to lead associated with uranium-vanadium deposits in the Chinle Formation, but two of the anomalous areas are associated with outcrops of the Black Box Dolomite and White Rim Sandstone. Both the White Rim Sandstone and Black Box Dolomite contain asphaltite. Hydrocarbons are associated with many "Mississippi Valley-type" deposits, and the White Rim Sandstone could have acted as a channelway for potential ore fluids. According to the USGS, the anomalies are "isolated and low level," and the corresponding stream sediment silt samples contained no anomalous values (Bartsch-Winkler and others, 1990).

Titanium and Zirconium Resources

Known Deposits and Characteristics

Seven exposures of titanium- and zirconium-bearing, fossil, black-sand beach placer deposits are found in sections 30 and 32, T. 22 S., R. 7 E., about 6 miles (10 km) southeast of Emery (plate 12). The placer deposits occur in strata-bound lenses of fine-grained, purplish sandstone which is strongly cemented by hematite and carbonate. They have an average thickness of 5 feet (1.5 m) and outcrop lengths from 90 to 280 feet (30-85 m). They contain magnetite, titanium-bearing minerals (probably ilmenite), zircon, and minor monazite (Dow and Batty, 1961). Assays of three samples averaged 12.6 percent TiO_2, 1.8 percent ZrO_2, 33.4 percent Fe, and 0.10 percent ThO_2 (Dow and Batty, 1961). Dow and Batty (1961) described the deposits as lying below a prominent sandstone, which I interpret to lie within "delta front unit number 4" of Ryer (1981). Five of the exposures are part of a single belt, but the remaining two exposures are on a parallel belt to the east. It is not known if the two belts are at the same stratigraphic horizon. The belts trend N. 40° W. parallel to the ancient shoreline (Houston and Murphy, 1977). For the seven exposures Dow (1957) estimated a measured, indicated, and inferred resource of 236,000 tons (214,000 mt) averaging 14 percent titanium minerals and 5 percent zircon. Houston and Murphy (1977) studied a number of similar deposits in Upper Cretaceous rocks of Montana, Wyoming, Utah, Colorado, Arizona, and New Mexico. They concluded that the deposits:

(1) are beach placers deposited in the upper foreshore or back beach environment,
(2) occur exclusively in regressive sequences usually close to the point of maximum transgression,
(3) often occur in en-echelon patterns with subparallel lenses more seaward and slightly higher stratigraphically, and
(4) probably formed during major storms.

Past and Current Exploration and Production Activity

Past work has been limited to surface prospecting and sampling; no production is recorded. There is no current exploration activity for titanium-zirconium minerals in Carbon and Emery Counties.

Potential for Additional Discoveries and/or Development

As documented by Dow and Batty (1961) and Houston and Murphy (1977), titanium-zirconium-bearing fossil placers are common within Upper Cretaceous sandstones of the western interior of the United States. Other, similar occurrences are found in the Ferron Sandstone in Garfield County 80 miles (130 km) southeast of the Emery County exposures. In addition, the deposits often cluster in groups of en-echelon parallel zones. Additional titanium-zirconium-bearing, black-sand deposits are possible in the Upper Cretaceous rocks of Carbon and Emery Counties. Deposits could be present not only in the Ferron Sandstone Member but also in other sandstone members of the Mancos Shale (Garley Canyon and Emery Sandstone Members) and in beach sandstones of the Blackhawk Formation. Favorable sites would be in regressive sequences above areas of maximum transgression. Unfortunately most of these favorable areas are at overburden depths of over 500 feet (150 m) and would not be economic. Only in the area around Emery, in several northwest-trending zones in the eastern part of the Wasatch Plateau, and along the Book Cliffs would the favorable zones be exposed at the surface (plate 12). Ground or air radiometric surveys could help pinpoint the placer deposits because many are slightly radioactive.

It is unlikely that the known or potential titanium-zirconium-bearing, black-sand deposits in Carbon and Emery Counties will be developed. Thicker, higher grade, and topographically more favorable deposits are known, particularly in Wyoming and Montana (Houston and Murphy, 1977), but none are being developed. The deposits are well cemented, fine grained, and difficult to process and beneficiate. The USBM (Dow and Batty, 1961) tested similar samples from several locations in Utah using a relatively complicated process. They produced a finished titanium concentrate containing 55-60 percent TiO_2 with a 60 percent recovery, and a zirconium concentrate containing 50-65 percent ZrO_2 with a 75 percent recovery. The titanium concentrate would meet minimum specifications for sale, but the zirconium concentrate would not. Additional recent studies failed to develop an economic recovery process that will produce clean, salable concentrates (Carpco, 1987). Recent work by 3-R Minerals (R. Reeves, verbal communication, 1998) on similar deposits in Garfield County has developed a revised beneficiation process that reportedly produces concentrates at a reasonable cost from test samples. Additional work is being done to refine the process to produce higher grade, cleaner products. However, even if a better beneficiation process were developed, the deposits in Carbon and Emery Counties would not be developed; the known deposits are probably too small and too low grade to justify the investment at current prices.

Gold Resources

Known Occurrences and Characteristics

No well-documented occurrences of gold are known in Carbon or Emery County. Early glowing reports in the Salt Lake Mining Review (Warren, 1971), a generally promotional publication, noted production of gold, silver, copper, and lead from high-grade veins in the Emery (Lost Spring, Summerville) district, but only very minor production was reported by the USGS or USBM. The location of the mines was conveniently vague, and the UGS's Utah Mineral Occurrence System (UMOS) shows no mines fitting the descriptions anywhere within the area (Sprinkel, 1999). The existence of these mines, at least as described, and their reported production is questionable.

Some placer gold was recovered from the Emery County side of the Green River and possibly from some other drainages in Emery County. The source of the gold is unknown.

Past and Current Exploration and Production Activity

Recorded production from Emery County is only five ounces of placer gold recovered in 1916 (Johnson, 1973). Production probably was from gravels along the Green River. Very little recent gold-exploration activity is known in Carbon and Emery Counties. Between 1975 and 1999, only two NOIs (Notice of Intent to Explore) have been filed for precious metals with DOGM and none is currently active. In 1996 only two Small Mine Permits (suspended) were issued for precious metals; one apparently for placer gold along the Green River about 8 miles south of the town of Green River, and one apparently for gold in the Cretaceous Mancos Shale just south of I-70 near Fivemile Wash. Both were subsequently dropped. In 1999, three small mine permits for precious metals were active (plate 13). All the permits were issued to individuals or small companies; no medium to large companies are involved.

Potential for Additional Discoveries and/or Development

Potential is low for discovery of economic gold deposits in Carbon or Emery County. Fossil placer gold deposits might be found in Mesozoic sandstone but would most likely be too low grade to even consider mining. Widespread anomalous gold values are reported for Permian to Jurassic rocks in southeastern Utah, 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/ short ton (0.3-0.7 g/mt) or higher have been reported, but are most likely exaggerations. Values of 0.001 to 0.004 ounces gold/short ton (0.03-0.14 g/mt) are more realistic estimates, even for the better occurrences (Lawson, 1913). Some placer gold could also be associated with known or potential titanium-zirconium black-sand deposits in Cretaceous sandstones. Small amounts of gold (up to 0.04 ounces/short ton) have been detected in some of the better deposits in Kane County (Doelling and Davis, 1989). Gold has also been reported for basal sandstones in the Ferron Sandstone sequence, but no values were given (J. Prudden, independent consultant, verbal communication, 1996).

Some small, Holocene, placer-gold deposits probably are also present along the Green River in Emery and particularly Carbon County. Gold was mined from a number of placer operations at Horseshoe Bend, 25 miles north of the Carbon-Uintah County line (Johnson, 1973). The gold was fine grained and difficult to recover. Most of the Horseshoe Bend operations were on the inner side of a large oxbow meander. A number of somewhat similar meanders, with relatively wide flood plains, are present in Carbon County particularly north of T. 18 S. and could contain placer gold similar to that found farther north. If present, however, the deposits would probably not be economic. Most of the grades for the Green River placers were low, and the total amount of gold produced was small. All of the past operations, even those using large dredges, were unsuccessful (Johnson, 1973).

Rumors persist about fine-grained, disseminated gold in the Mancos Shale. Several small operations have been established near Crescent Junction in Grand County, and the three current small mine permits for precious metals (plate 13) are for bulk testing of the Mancos Shale. Recent work in the Crescent Junction area failed to confirm the rumored gold grades; gold was not detected in most samples, even those rumored to be high grade (Marlatt, 1991). No published information or assays are known for the areas to the north near the current NOIs. However, until confirmed, rumors of high-grade gold in the Mancos Shale should be viewed with skepticism.

INDUSTRIAL ROCK AND MINERAL RESOURCES: PRODUCED COMMODITIES

Sand and Gravel

Known Occurrences and Characteristics

Good-quality sand and gravel is scarce in Carbon and Emery Counties. Most of the usable sand and gravel is found in a series of pediments related to erosion of the Book Cliffs and Wasatch Plateau (Utah State Department of Highways, 1966). A small amount of sand and gravel deposited by active streams is present but is only found on the floors of steep-sided canyons and is commonly inaccessible.

Spieker (1931) noted three pediment surfaces of different ages in Carbon and Emery Counties adjacent to the Book Cliffs and Wasatch Plateau. The oldest pediment is at the highest elevation and has the most limited areal extent. The second surface is at an intermediate elevation and occurs as narrow, isolated benches sloping away from the cliffs. The youngest surface is at the lowest elevation and covers an extensive area relatively undissected by streams. The three surfaces merge on the valley floor away from the cliffs. The pediment gravels range in thickness from 5 to 75 feet (1.5-23 m) and locally exceed 100 feet (30 m). The sand and gravel is cemented locally with calcium carbonate (Spieker, 1931). Pediment and alluvial gravel outcrops and sand and gravel pits are shown in plate 14.

Sand and gravel in Carbon and Emery Counties is derived mostly from Mesozoic and Tertiary shale and friable sandstone. These source rocks are too weak to produce clasts suitable for making good bituminous or concrete aggregate (Utah State Department of Highways, 1966). This material is most suitable for borrow and fill.

Past and Current Production and Exploration Activity

Past exploration was driven largely by the need to find suitable material for public works projects in the area. The only known systematic exploration for sand and gravel was done in support of Interstate Highway 70 construction during the 1960s (Utah State Department of Highways, 1966).

Annual and cumulative production statistics are generally not available for Carbon and Emery Counties to protect producer confidentiality; however, it is known that in 1994 the Emery County Highway Department and two commercial operators produced roughly 180,000 tons (165,000 mt) of sand and gravel.

Potential for Additional Discoveries and/or Development

New sand and gravel deposits will be developed as demand grows in Carbon and Emery Counties. However, it is uncertain how much of the demand can be satisfied by deposits within these counties, particularly when higher quality material is needed. It may be more economic to import some sand and gravel from surrounding counties. In addition, increasingly stringent specifications for concrete and bituminous aggregate may restrict the amount of natural aggregate that is suitable and force a shift toward use of crushed stone.

Crushed Stone and Clinker

Known Occurrences and Characteristics

Because Carbon and Emery Counties have poor-quality sand and gravel resources, locating bedrock suitable for crushing to make aggregate is more important here than in most other Utah counties. Formations quarried for crushed stone in Utah that are present in Carbon and Emery Counites include the following: Permian White Rim Sandstone, Permian Black Box Dolomite, Triassic Sinbad Limestone Member of the Moenkopi Formation, Triassic Moss Back Sandstone Member of the Chinle Formation, Jurassic Carmel Formation, Cretaceous Buckhorn Conglomerate Member of the Cedar Mountain Formation, and Cretaceous Castlegate Sandstone (Utah State Department of Highways, 1966).

Clinker (baked rock overlying coal burn zones) has potential for use as crushed stone in Carbon and Emery Counties but has not been evaluated. Spieker (1931) provides the only known information on clinker in this area. He noted that clinker is very common in the Wasatch Plateau coalfield except for the Pleasant Valley area. Burned zones tend to be more common on projecting spurs of the plateau and are less common at the heads of gulches. Based on tours through coal mines, Spieker concluded that coal burn zones generally extend only about 200 to 300 feet (60 - 90 m) in from the outcrop; rarely to 500 feet (150 m).

Hoffman (1996) described the clinker deposits and uses for clinker in the southwestern United States; much of this information is applicable to Utah. Clinker is variable in texture and other physical properties. Hoffman (1996) stated:

> Fine-grained rocks immediately above the burning coal bed or along the sides of the chimneys may melt completely, forming highly vesicular, glass-like material that Cosca and others (1989) called paralava. Above the paralava, the rocks are partially melted to a dense, brick-like rock called buchite or more appropriately porcellanite .... Porcellanite is fused shale or clay that exhibits conchoidal fracture and ranges in color from gray to yellow-beige to deep red, depending on the iron geochemistry. Above the porcellanite ... some claystones and shales are more friable than in their original state .... Sandstones in the sequence above the coal burn commonly become better indurated and can be of reddish color.

Most clinker mined in New Mexico and Arizona has been used for road base, road metal, and rock mulch. Attempts to use clinker as concrete and bituminous aggregate have been unsuccessful; clinker is generally too weak and porous (Hoffman, 1996). However, careful sampling and testing and selective mining might yield material more suitable for concrete and bituminous aggregate than the friable sandstone and low-quality sand and gravel of Carbon and Emery Counties.

Past and Current Production and Exploration Activity

Crushed stone production was reported by the Utah Department of Highways (1966) for Carbon and Emery Counties, but no specifics were given about the quantity produced or the locations of the crushed stone quarries. The lack of information in subsequent geological studies implies that these “quarries” were very small or consisted of portable crushing plants processing talus or float.

There has been no production of clinker, nor has there been any specific exploration for clinker besides the mapping of “burn zones” done for coal studies. Clinker deposits are easy to explore for; they are associated with well-mapped coal zones (see plate in coal section); they are commonly brightly colored (which shows up on color aerial photography); and burning often reduces iron in adjacent sediments, producing magnetite which can be detected in outcrop with a magnetometer.

Potential for Additional Discoveries and/or Development

In Carbon County several geologic formations have high potential for crushed stone. The Tertiary Green River Formation and Flagstaff Limestone, the Tertiary/Cretaceous North Horn Formation, and the Cretaceous Price River Formation have potential in the Book Cliffs and Wasatch Plateau.

The Green River contains an upper lacustrine limestone unit that is thin- to thick-bedded, even-bedded, dense, and occasionally oolitic. The Flagstaff consists of dense, thin-bedded, locally cherty, lacustrine limestone. The North Horn contains some interbedded limestone and limestone conglomerate. The Price River contains conglomerate and conglomeratic sandstone with clasts of quartzite, chert, and limestone.

The Flagstaff, North Horn, and Price River Formations also have potential for crushed stone production in Emery County. In addition, the Cretaceous Dakota Sandstone and Buckhorn Conglomerate Member of the Cedar Mountain Formation, the Jurassic Salt Wash Member of the Morrison Formation, the Triassic Sinbad Limestone Member of the Moenkopi Formation, the Permian Kaibab Limestone, and Pennsylvanian Honaker Trail Formation of the Hermosa Group are other formations in Emery County worth investigating for crushed stone. The Dakota contains conglomeratic sandstone and conglomerate and is exposed on the flanks of the San Rafael Swell. The Buckhorn Conglomerate contains conglomerate and conglomeratic sandstone with clasts of chert, quartzite, limestone, and sandstone in outcrops along the flanks of the San Rafael Swell. The Salt Wash is exposed extensively on the flanks of the San Rafael Swell and has lenticular beds of conglomeratic sandstone and conglomerate. The Sinbad Limestone consists of thin- to medium-bedded, crystalline, locally oolitic, marine limestone and dolomite. Its outcrops form the flat-lying central portion of the San Rafael Swell. The Permian Black Box Dolomite (Kaibab Limestone of some reports) is a thin- to medium-bedded, even-bedded, marine dolomite and limestone. The Black Box Dolomite is widely exposed in the center of the San Rafael Swell. The Honaker Trail Member of the Hermosa Group is a thin- to thick-bedded, finely to coarsely crystalline, cherty, fossiliferous, marine limestone. It has limited exposures in the center of the San Rafael Swell.

Bedrock suitable for crushed stone production is common in Carbon and Emery Counties and will be developed further as economic development occurs in the area. However, crushed stone is more expensive to process than sand and gravel and has higher transportation costs because it tends to be in more remote locations.

Gypsum

Known Occurrences and Characteristics

The Jurassic Summerville and Carmel Formations contain commercial quantities of gypsum in Carbon and Emery Counties (figure 42). The Pennsylvanian Paradox Formation of the Hermosa Group also contains subsurface gypsum of unknown purity and thickness in the southeast corner of Emery County, but this gypsum has no current economic value due to its extreme depth of burial.

The upper part of the Carmel and the top of the Summerville contain gypsum along the entire western flank of the San Rafael Swell, but the Summerville beds are not as continuous or as pure as the Carmel beds (Stokes and Cohenour, 1956). The Summerville gypsum has a reddish tint whereas the Carmel gypsum is very white (Lupton, 1913). Parts of both the Summerville and Carmel gypsum are strongly folded, compact, and fine grained; these characteristics decrease the value of gypsum for plaster and wallboard manufacture. Gilluly (1929) described the regional variability in Summerville gypsum as follows: "In the northern part of the area [San Rafael Swell] the bedding is very even and continuous, but farther down the west flank of the Swell it is irregular, and the beds are lenticular and show much channeling and numerous intraformational unconformities." The Summerville also contains numerous small chert nodules of various colors which distinguished it from the Carmel which contains very little chert. Lupton (1913) estimated the quantity of gypsum on the west flank of the San Rafael Swell: "To be conservative the upper bed (Summerville?) is assumed to average 10 feet in thickness and the lower beds (Carmel?) to contain an average of 30 feet of gypsum. These assumed thicknesses probably represent 25 to 50 percent less than the true average. On this basis the beds of gypsum on the west flank of the San Rafael Swell are estimated to contain 2,425,400,000 tons to 9,701,600,000 tons in the upper bed (Summerville?) and 7,276,200,000 tons in the lower bed (Carmel?)." Observations of gypsum outcrops in the San Rafael Swell by Lupton and other geologists are tabulated below (table 72) and the locations of analytical and thickness data are plotted on figure 42.

Specifications for gypsum purity depend on the manufactured end product. Most of the gypsum produced in Utah is captive production for wallboard and plaster manufacture; smaller amounts are sold to cement plants as a cement setting retarder. Jorgensen (1994) gave general information on gypsum specifications for use in wallboard. Most gypsum mined in the U.S. for wallboard is 80-95 percent pure. As much as 15 percent insoluble, unreactive contaminants such as limestone, dolomite, anhydrite, and silicates can be present in the gypsum. Only 0.02 to 0.03 percent by weight, soluble evaporite minerals (halite, sylvite, mirabilite, epsomite, and others) can be tolerated whereas 1 to 2 percent hydrous clays (montmorillonite and others) are allowed.

Since gypsum is a low unit-value commodity, transportation costs must be low for a deposit to produce economically. Jorgensen (1994) stated that most gypsum operations mine and deliver gypsum to their mills for $3 to $11/ton. The few gypsum analyses that have been published for Emery County are listed in table 73.

Past and Current Production and Exploration Activity

Most development of gypsum in the San Rafael Swell has occurred in the last decade: only a few small prospects existed before then. Lupton (1913) describes an 8-foot-diameter (2.4 m) prospect that was 8 feet (2.4 m) deep in NW1/4 SW1/4 section 6, T. 19 S., R. 11 E., directly south of Cedar Mountain. Stokes and Cohenour (1956) mention a number of small alabaster prospects on the east face of Cedar Mountain. In the last decade the center of gypsum mining in Utah has begun to shift from the area around Sigurd, Utah to the San Rafael Swell. The four active and two inactive gypsum mines in the Swell are described in table 74 and their locations are shown in figure 42 and plate 14. In September 1999 a permit was granted to open a new mine (Wm. B. Wray mine) on state land in NE1/4 NE1/4 NE1/4 section 2, T. 23 S., R. 8 E., but by December 2000 no mining had been done on the property.

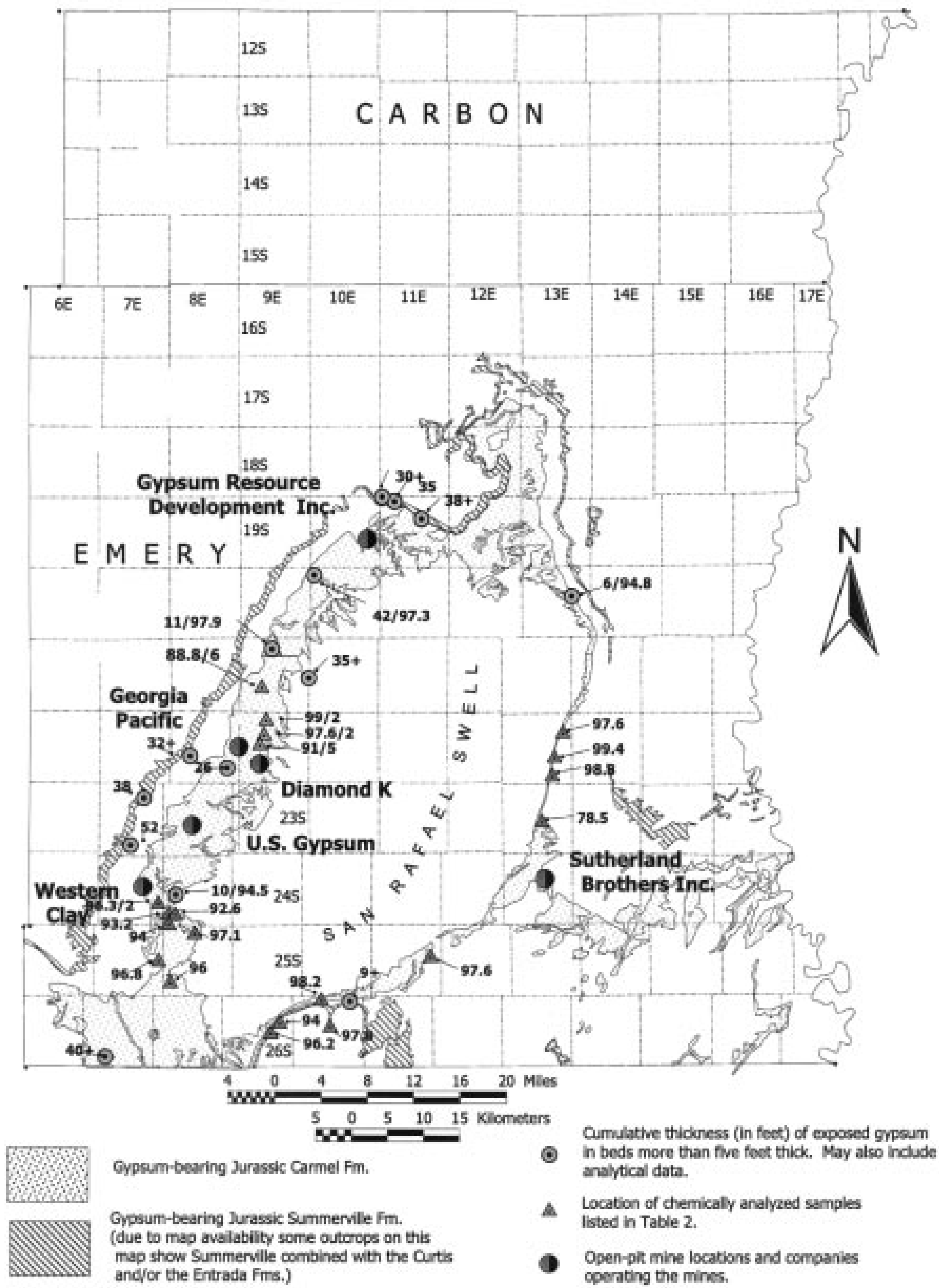


Figure 42. *Gypsum resources of Emery County, Utah. Outcrop data from Williams and Hackman (1971), and Witkind (1995). Gypsum thickness and assay data from: Lupton (1913), Gillully (1929), Stanton (1976), Benjamin (1989), Close (1989), Lipton (1989), Munts (1989), and Neuman (1989).*

Table 72. *Descriptions from the literature of gypsum outcrops in the San Rafael Swell, Emery County, Utah (sorted in ascending order by cadastral township, then range, and then section).*

Outcrop	Description
Summerville Point section 27, T. 18 S., R. 13 E.	Only 0.25 feet (0.1 m) of gypsum noted in the Summerville at this location (Gilluly, 1929).
Cedar Mountain A NW1/4SW1/4 section 06, T. 19 S., R. 11 E.	One 8-foot-diameter (2.4 m) pit 8 feet (2.4 m) deep in the Carmel Formation. Gypsum bed is at least 30 feet (9 m) thick. Lupton (1913) location 1.
Cedar Mountain B section 10, T. 19 S., R. 11 E. although	Seven gypsum beds are present in the Carmel Formation. Gypsum bed thicknesses are (from top to bottom): 4 ft (1.2 m), 5 ft (1.5 m), 5 ft 3 in (1.6 m), 3 ft (1 m), 5 ft (1.5 m), 16 ft 9 in (5.1 m), and 6 ft 3 in (2.0 m). Most of the gypsum is high quality some is of selenite or alabaster texture (Gilluly, 1929).
Fullers Bottom section 06?, T. 20 S., R. 10 E.	Two beds are present in the Carmel Formation (?). Upper bed is fairly pure (assaying 97.3 percent gypsum in one hand sample), is 30 to 35 feet (9.1-10.7 m) thick, and becomes less pure at the top and the base. Lower bed is 7 feet thick (2.1 m) and is very pure. Lupton (1913) location 2.
Calf Mesa SW1/4SE1/4 section 14, T. 20 S., R. 13 E.	The upper part of the Carmel contains an extensive outcrop of commercial gypsum in a 6-foot-thick (2 m) bed (Benjamin, 1989). See analyses in table 73.
Horn Silver Gulch section 08?, T. 21 S., R. 9 E.	Summerville (?) contains an 11-foot-thick (3.4 m), slightly reddish-tinted gypsum bed with nodules of variegated chert. A sample taken near the middle of the bed assayed 97.9 percent gypsum. Lupton (1913) location 3.
Cold Wash section 26?, T. 21 S., R. 9 E.	Carmel (?) gypsum crops out from here to the Green River Desert and is more than 35 feet (10.7 m) thick. Lupton (1913) location 4.
Colt Gulch section 30?, T. 22 S., R. 8 E.	The Summerville (?) contains four gypsum beds at this location; the thickest is 22 feet (6.7 m) thick but is impure. A 10-foot-thick (3 m), almost pure-white bed is probably the best material here. A total of 32+ feet (9.7+ m) of gypsum is exposed. Lupton (1913) location 5.
B and J Gypsum sections 24,25,30,31, T. 22 S., R. 8 E. sections 19,29,30,31,33, T. 22 S., R. 9 E. sections 01,02, T. 23 S., R. 8 E.	Carmel gypsum beds explored by 21 drill holes. The gypsum averages 26 feet (7.9 m) thick (in beds more than 5 feet thick, containing more than 80 percent gypsum) (John T. Welsh, unpublished drilling summary). Samples are stored at the Utah Core Research Center at the Utah Geological Survey.
San Rafael Reef SW1/4SW1/4SW1/4 section 13, T. 22 S., R. 13 E.	A 4-foot-thick (3.3 m) Carmel gypsum bed outcrops for 4.5 miles (7.2 km) immediately east of the San Rafael Reef. Five samples show the material to be of good quality (Munts, 1989). See analyses in table 73.
Interstate 15 sections 09, 10, T. 23 S., R. 7 E.	Two gypsum beds are exposed in the upper 164 feet (50 m) of the Summerville. Upper bed contains 38 feet (11.6 m) of gypsum with siltstone and sandstone interbeds. Lower bed contains 3.6 feet (1.1 m) of gypsum (Stanton, 1976).
Muddy Creek section 27?, T. 23 S., R. 7 E.	One 52-foot-thick (15.8 m) bed of Summerville (?) gypsum is exposed at this location. Lupton (1913) location 6.
Willow Springs Wash S1/4 section 19, T. 24 S., R. 8 E	Carmel Formation gypsum, with an average thickness of 10 feet (3 m), is exposed intermittently for about 1.5 miles (2.5 km) on a mesa above Willow Springs Wash. The gypsum averages 94.48 percent pure. The gypsum is interlayered with carbonates (Neumann, 1989). See analyses in table 73.
Last Chance Creek section 31?, T. 26 S., R. 7 E. (1913)	Gypsum at this location is too poorly exposed to be measured, but Lupton inferred that it was comparable to the Fullers Bottom occurrence (40+ ft [12 m] thick). Lupton location 7.
Little Wild Horse Mesa section 02, T. 26 S., R. 10 E. im- the See	An average of more than 9 feet (2.7 m) of Summerville gypsum is exposed for approximately 6 miles (10 km) in the cliffs along the north rim of Little Wild Horse Mesa between Wild Horse and Muddy Creek. The gypsum is white, of alabaster texture, and contains interbedded anhydrite, mudstone, and sandstone with occasional limonite as an purity. The Carmel gypsum is also exposed in this area but is less continuous than Summerville; only small scattered lenses of gypsum are exposed (Close, 1989). analyses in table 73.
Caineville section 17 ? T. 28 S., R. 8 E.	The Summerville (?) is exposed at this location (center of township) in Wayne County. An 8-foot-thick (2.4 m), very pure bed crops out over a 2 square mile (5.2 km^2) area. Lupton (1913) location 8.

Table 73. *Chemical analytical data for gypsum in the San Rafael Swell, Emery County, Utah. Data are sorted in ascending order by cadastral township (south), then range (east), and then section. Assay values in weight percent.*

Location ¼, Sec., T., R.	**Fm.**	**$CaSO_4$**	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**K_2O**	**MgO**	**MnO**	**Na_2O**	**P_2O_5**	**TiO_2**	**Ms**	**LOI**	**Sample Type / Data Source**
SW,SE,14, 20, 13	Carmel	94.77	0.09	0.05	1.49	-	-	-	-	-	-	19.6	-	Benjamin (1989) sample 190.
SE,SW,SE 21, 21, 9	Carmel	97.3	0.06	0.12	0.94	-	-	-	-	-	-	19.6	-	Lipton (1989) sample 136.
SE,SW,SE 21, 21, 9	Carmel	99.27	0.02	0.04	0.23	-	-	-	-	-	-	20.1	-	Lipton (1989) sample 137.
SE,SW,SE 21, 21, 9	Carmel	97.08	0.06	0.06	0.82	-	-	-	-	-	-	19.6	-	Lipton (1989) sample 138.
SE,SW,SE 21, 21, 9	Carmel	88.36	0.57	0.31	5.12	-	-	-	-	-	-	18.0	-	Lipton (1989) sample 139.
SE,SW,SE 21, 21, 9	Carmel	86.95	0.35	0.17	2.49	-	-	-	-	-	-	17.5	-	Lipton (1989) sample 140.
SE,SW,SE 21, 21, 9	Carmel	63.91	1.05	0.42	6.21	-	-	-	-	-	-	13.4	-	Lipton (1989) sample 141.
NW,SE,NW,08, 22, 9	Carmel	99.3	0.03	0.06	0.77	-	-	-	-	-	-	20.2	-	Lipton (1989) sample 171.
NW,SE,NW,08, 22, 9	Carmel	98.66	0.05	0.05	1.17	-	-	-	-	-	-	19.3	-	Lipton (1989) sample 172.
N2,SE,NE,17, 22, 9	Carmel	99.66	0.01	0.01	0.5	-	-	-	-	-	-	19.4	-	Lipton (1989) sample 174.
N2,SE,NE,17, 22, 9	Carmel	95.46	0.16	0.10	1.8	-	-	-	-	-	-	20.0	-	Lipton (1989) sample 175.
NE,NW,NW,20, 22, 9	Carmel	98.78	0.07	0.04	1.38	-	-	-	-	-	-	20.5	-	Lipton (1989) sample 176.
NE,NW,NW,20, 22, 9	Carmel	99.03	0.04	0.03	1.08	-	-	-	-	-	-	16.6	-	Lipton (1989) sample 177.
NE,NW,NW,20, 22, 9	Carmel	79.86	1.00	0.45	8.37	-	-	-	-	-	-	17.2	-	Lipton (1989) sample 178.
NE,NW,NW,20, 22, 9	Carmel	84.88	0.42	0.24	2.73	-	-	-	-	-	-	18.6	-	Lipton (1989) sample 179.
NE,NW,NW,20, 22, 9	Carmel	92.39	0.15	0.15	2.56	-	-	-	-	-	-	20.6	-	Lipton (1989) sample 180.
SW,NE,NE,12, 22, 13	Carmel	97.63	0.07	0.04	1.91	-	-	-	-	-	-	20.4	-	Munts (1989) sample 12.
SW,NE,SE,23, 22, 13	Carmel	99.44	<.01	0.02	0.42	-	-	-	-	-	-	20.2	-	Munts (1989) sample 48.
SW,SE,NW,35, 22, 13	Carmel	98.82	0.05	0.06	0.91	-	-	-	-	-	-	16.2	-	Munts (1989) sample 71.
SW,NE,NW,22, 23, 13	Carmel	78.53	1.44	0.45	12.13	-	-	-	-	-	-	19.2	-	Munts (1989) sample 103.
NW,SW,NE,24, 24, 7	Carmel	94.47	0.39	0.24	2.11	-	-	-	-	-	-	19.1	-	Neumann (1989) sample 32.
S2,SE,SE,24, 24, 7	Carmel	98.19	0.15	<0.01	<0.01	0.07	<.01	<0.01	0.12	<0.01	<0.01	-	21.01	Neumann (1989) sample 35.
SE,NE,SE,19, 24, 8	Carmel	93.18	0.45	0.28	1.84	0.24	0.59	0.05	0.02	<0.01	0.03	-	21.25	Neumann (1989) sample 34.
SW,SW,SW,20, 24, 8	Carmel	92.59	0.42	0.28	4.19	0.22	0.35	0.04	0.03	0.03	0.03	-	20.64	Neumann (1989) sample 36.
SE,NE,NE,30, 24, 8	Carmel	93.96	0.37	0.2	1.47	0.21	0.52	<.01	0.04	0.04	0.01	-	21.21	Neumann (1989) sample 37.
SW,SE,SE,24, 25, 7	Carmel	96.82	0.14	0.2	2.15	-	-	-	-	-	-	19.7	-	Neumann (1989) sample 114.
SW,NE,SW,05, 25, 8	Carmel	97.07	0.17	0.16	1.12	0.07	0.07	0.03	0.02	0.05	0.02	-	20.6	Neumann (1989) sample 105.
SW,SE,SW,30, 25, 8	Carmel	95.98	0.2	<0.01	1.08	0.09	0.04	<.01	0.02	<0.01	<0.01	-	21.43	Neumann (1989) sample 130.
SE,NE,SW,14, 25, 11	Carmel	97.60	0.16	0.07	1.07	0.08	0.12	0.01	0.01	0.05	0.02	-	19.76	Chip sample across 2-ft. lens. Close (1989) sample 148.
NE,NE,SE,11, 26, 9	Summer.	93.98	0.21	0.03	0.48	0.07	0.09	-	0.03	.01	0.02	-	20.12	Chip sample across 3-ft. lens. Close (1989) sample 167.
SW,SW,NE,22, 26, 9	Summer.	96.18	0.34	0.08	2.31	0.13	0.12	-	0.30	.01	0.03	-	18.70	Chip sample across 18-ft. lens. Close (1989) sample 168.
SE,SE,NE,04, 26, 10	Carmel	98.23	0.13	0.05	0.22	0.05	0.06	-	-	-	0.02	-	19.35	Chip sample across .8-ft. lens. Close (1989) sample 149.
NE,NE,SE,16, 26, 10	Summer.	97.84	0.18	0.04	0.73	0.07	0.09	-	0.02	-	0.02	-	18.97	Chip sample across 7.2-ft. lens. Close (1989) sample 158.

Abbreviations: Fm. - geologic formation, Ms - moisture, LOI - loss on ignition (water and CO_2), and Summer. - Summerville.

Table 74. *Gypsum mines, San Rafael Swell, Emery County, Utah (Utah Division of Oil, Gas and Mining mine permit files).*

Mine Name	Operator	Location (Sec.,Twn.,Rng.)	Notes
Kimbal Draw	U.S. Gypsum Co.	NW1/4 21, 23S, 8E	The Carmel Formation was being drilled at this property in the fall of 1996. In 1997 the company submitted a Plan of Operations for a 12,000 to 50,000 ton per year (tpy) that would ship gypsum to the U.S. Gypsum wallboard plant at Sigurd. Because of delays in permitting, the company resubmitted its application as a small mine and mined a test shipment of 241 tons in 1999.
Eagle Canyon mine	Georgia Pacific	SE1/4SE1/4 24, 22S, 8E SW1/4SW1/4 19, 22S, 9E	The Carmel (?) Formation has been mined at this property since 1992. The 25-acre open-pit mine produced 43,221 tons in 1994, 68,056 tons in 1995, 0 tons in 1996, 92,825 tons in 1997, and 95,171 tons in 1998.
Hebe mine	Western Clay Co.	14, 15, 24S, 7E 23, 24S, 7E	The property contains a 12-foot-deep pit in the Carmel Formation and covers 41.5 acres. The material is shipped to Western Clay's Redmond plant for processing.
DKG mine	Diamond K	NE1/4SW1/4 29, 22S, 9E NW1/4SW1/4 29, 22S, 9E	The property contains a 12-acre pit in the Carmel Formation which produced 26,182 tons of gypsum in 1994, 17,480 tons in 1995, 16,914 tons in 1996, 17,209 tons in 1997, and 16,440 tons in 1998.
White Cap #8	Gypsum Resource Development Inc.	SW1/4 23, 19S, 10E	This mine produced small quantities of Carmel Formation gypsum for agricultural purposes; it produced 4,502 tons in 1990, 26,600 tons in 1991, 0 tons in 1993, and 300 tons in 1994. The mine has been inactive since 1994.
Whitecloud mine	Sutherland Brothers	15, 24S, 13E	This mine is the site of exploration and small production. The only recorded production is 149 tons in 1989. In 1993, 52 exploration holes were drilled. It is currently inactive.

Potential for Additional Discovery and/or Development

The San Rafael Swell contains a huge amount of high-quality gypsum, therefore, future discovery and development is likely. Demand, transportation costs, and land-use restrictions will control development in Emery County. Because almost all gypsum is used in wall board and Portland cement manufacture, demand for gypsum directly correlates with the strength of building construction in the region. In spite of a national recession, the construction industry in Utah is currently (December 2001) still very active due in large part to low interest rates. Even though existing mines could easily increase production to meet increased demand, new mines are being developed.

Development of technology to use scrubber-waste-product gypsum and fly ash from power plants for wallboard manufacture could adversely affect production of gypsum from Emery County. Use of waste-product gypsum may require a substantial capital investment for retrofitting existing wallboard plants or building new plants.

Transportation costs have been a long-standing problem for San Rafael Swell gypsum deposits. They are distant from the two wallboard plants near Sigurd in Sevier County and the cement plants in Juab and Morgan Counties. Also there is no rail line near the San Rafael Swell.

Bentonite

Known Occurrences and Characteristics

Carbon and Emery Counties contain large amounts of bentonite of uncertain quality in Cretaceous, Jurassic, and probably Triassic rocks. Little data are available to judge the size or potential of the resource; most detailed studies of bentonite of the area use the bentonite units as stratigraphic markers or discuss the geochemistry and alteration patterns of lacustrine bentonite.

Cretaceous units: Four bentonite beds are present in the lower part of the Cretaceous Mancos Shale (Elder, 1988). These beds can be traced over a large part of the western United States; most of these beds should be present in the study area. The four beds are each less than 3 feet (1 m) thick, but it is possible that marine currents locally reworked the air-fall tuff precursor of the bentonite into thicker, localized deposits. In the Henry Mountains to the south of Emery County, Hunt and others (1953) mentioned thin bentonite beds in the Cretaceous Dakota Sandstone and the Mancos Shale. To the southwest of Emery County, Olsen and Williams (1960) mentioned bentonite beds in the Dakota and in the upper part of the Tropic Shale (an equivalent formation to the Mancos Shale). Olsen and Williams (1960) and Van

Sant (1964) described bentonite production in this area from a mine near the town of Cannonville where an 11-foot-thick (3.4 m) unit of bentonite occurs between lignite units at the base of the Dakota Sandstone. A thick section of bentonitic mudstone is present in the Mussentuchit Member of the Cedar Mountain Formation (Kirkland and others, 1997). The Mussentuchit Member is absent to nearly 100 feet (30m) thick, thickens to the west, and consists almost entirely of bentonite. In Carbon and Emery Counties the Mussentuchit Member is thickest in the northern (Cedar Mountain) and western (Mussentuchit Flat-Muddy Creek) parts of the San Rafael Swell.

Jurassic units: Everett and others (1990) describe bentonite beds of the time-equivalent Jurassic Carmel and Twin Creek Formations of central Utah. They took three samples from the east flank of the San Rafael Swell in the NW1/4NE1/4 section 12, T. 22 S., R. 13 E. Their sample ESRS-3 was from a 1/2 inch-thick (1 cm) bentonite layer located 1.5 feet (0.5 m) above the base of the Carmel. Sample ESRS-2 was collected from a 3-foot-thick (1 m) bentonite bed located 2 feet (0.6 m) above the base of the Carmel. Sample ESRS-1 came from a 6-inch-thick (16 cm) bentonite layer which is 140 feet (42 m) above the base of the Carmel.

The Jurassic Salt Wash Member of the Morrison Formation contains a large quantity of bentonite (montmorillonite) and is exposed over a large part of Carbon and Emery Counties (Craig, 1955). Keller (1962) sampled and analyzed sections of the Salt Wash at two sites in Emery County. At the San Rafael River Bridge site (section 27, T. 22 S., R. 14 E.), Keller (1962) concluded that most of the Salt Wash clay was illite, but that at least three beds of mixed-layer montmorillonite were present at 20 (6 m), 54 (16 m), and 157 feet (48 m) above the base of the formation. He also observed that “this is the easternmost locality in which montmorillonite was observed in the Salt Wash Member, and is probably near the thin edge of a montmorillonite-bearing lens that thickens toward the west.” At the Little Cedar Mountain site (section 34 and 35, T. 18 S., R. 9 E., and in sections 2 and 3, T. 19 S., R. 9 E.), Keller (1962) noted a zone of montmorillonite-rich beds alternating with illite-rich beds in the interval from 35 to 90 feet (10-28 m) above the base of the Salt Wash Member.

Keller (1962) observed a considerable amount of montmorillonitic clay in the Jurassic Brushy Basin Member of the Morrison Formation at the Little Cedar Mountain site. The lower 65 feet (20 m) and upper 245 feet (75 m) of the Brushy Basin Member contain predominantly montmorillonite, some of which is mixed layered. At the San Rafael River Bridge section, the bulk of the clay in the Brushy Basin is montmorillonite. Additional quantitative data are available for Morrison outcrops located southeast of the study area; Owens and others (1989) carefully analyzed the mineralogy of the Brushy Basin Member at two sites: Courthouse Draw in Grand County and Lisbon Valley in northern San Juan County. At Courthouse Draw three samples taken 138 (42 m), 160 (49 m), and 298 feet (91 m) above the base of the Brushy Basin, approached 100 percent smectite (the clay group including bentonite) content. At Lisbon Valley 23 samples contained at least 60 percent smectite, and 20 of these samples approached 100 percent smectite. The interval from 220 to 313 feet (67 - 95 m) above the base of the Brushy Basin was essentially pure smectite. Craig and others (1955) showed the thickness and distribution of the members of the Morrison Formation.

Triassic units: The Triassic Chinle Formation in Emery County may have potential for bentonite production, but there is no specific information available. Doelling (1975) mentioned clay potential in the Monitor Butte and Petrified Forest Members of the Chinle in Garfield County, but both of these members pinch out northward toward Emery County.

Past and Current Production and Exploration Activity

Western Clay Company sporadically produces clay from southwestern Emery County (NW1/4 section 8, T. 25 S., R. 6 E.). Western Clay’s Last Chance mine produced sodium bentonite from the Cretaceous Mussentuchit Member of the Cedar Mountain Formation (Tripp, 1997). Production amounted to 6,382 tons (5,790 mt) in 1998, 10,705 tons (9,710 mt) in 1997, 7,885 tons (7,153 mt) in 1996, and 9,356 tons (8,488 mt) in 1995 (DOGM unpublished file data).

ECDC Environmental LC periodically produces clay from northern Emery County (NE1/4 section 1, T. 16 S., R. 11 E. and SE1/4 section 36, T. 15 S., R. 11 E.). The ECDC mine produces clay from the Cretaceous Tununk Shale Member of the Mancos Shale for use as liner material at the East Carbon landfill site (Tripp, 1997). Production was 220,000 tons (200,000 mt) in 1994, 0 tons in 1995, 100,000 tons (90,000 mt) in 1996, 0 tons in 1997, and 0 tons in 1998 (DOGM unpublished file data).

Potential for Additional Discoveries and/or Development

Carbon and Emery Counties contain large quantities of bentonite although much of it may not meet specifications for demanding uses such as clay for oil well drilling. Access to the clay outcrops is often poor; much of the area is only accessible over unpaved roads. Also, the possible designation of much of the San Rafael Swell as federal wilderness will inhibit exploration and mining.

Humate

Known Occurrences and Characteristics

Valuable deposits of humate are associated with the Cretaceous Ferron Sandstone Member of the Mancos Shale and may also be present in the Cretaceous Blackhawk Formation and Cretaceous-Tertiary North Horn Formation. Humate is a weathered coal or carbonaceous mudstone or shale that contains large amounts of humic acids. Humic acids are mixtures of colloidal organic molecules, with molecular weights between 5,000 and 50,000 grams, that result from decay of organic matter (Siemers and Waddell, 1977). The quality of the humate or weathered coal increases with increasing humic acid content. The humic acid content of weathered coal typically increases with degree of weathering (Hoffman and others, 1994). Humate and weathered coal have been used primarily as a soil amendment and as a drilling mud additive. Full discussion of the terminology of humate and its industrial uses is beyond the scope of this article; good reviews of these subjects are contained in Siemers and Waddell (1977), Hoffman and Austin (1994), and Hoffman and others (1994). Emery County humate has also been used to make an “elixir”which is marketed as a nutritional supplement. Pontolillo (1997) described marketing extracts of this humate and gives chemical analyses of the extracts.

Past and Current Production and Exploration Activity

Despite the large areas with potential humate and weathered organic shale existing in Carbon and Emery Counties, scant information exists on the nature and extent of these resources. The only information readily available is that eight mines have permits from DOGM to extract humic shale or trace minerals; six are active small mine permits and two are inactive small mine permits. Four of these mines have combined cumulative production of more than 25,000 short tons (22,600 metric tons) of humate, much of which has been processed into a nutritional trace-element supplement for human consumption and as a soil amendment. Information on the eight permitted mines from DOGM files is listed below in table 75 and their locations are plotted on plates 13 and 14. The list includes two operations with inactive permits and one active permitted operation that has not yet produced. The four producing mines apparently produce from the upper coal zone of the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale in the Emery coalfield (Doelling, 1972).

Potential for Additional Discoveries and/or Development

Abundant humate occurs in coal of the Ferron Sandstone, but access and marketing problems may inhibit future production. The outcrops near Emery are far from a rail line making production of humate for a low-unit-value use, such as soil amendment, less likely to be an economic success. This humate also would require skillful marketing because there are abundant humate resources in the U.S. A new humate operation would have to develop a niche market, perhaps as a soil amendment for West Coast agriculture.

Other Commodities

The following four commodities have been produced in Carbon and Emery Counties, but because their development potential is limited they are discussed only briefly.

Barite

Non-commercial quantities of barite are associated with uranium deposits in Triassic rocks of Emery County and in Upper Cretaceous rocks of both Carbon and Emery Counties. Small amounts of barite are contained in low-temperature altered rocks in the San Rafael Swell of Emery County. The barite was deposited, along with uranium, copper, and other minerals, during strata-bound alteration of the Monitor Butte and Temple Mountain Members of the Triassic Chinle Formation. The purple-white to pale-green altered rocks contain local concentrations of jasperoid, kaolinite, barite, uraniferous asphaltite, and sulfides (Hawley and others, 1968). Barite was specifically mentioned by Hawley and others (1968) as occurring in: (1) uranium deposits at Green Vein Mesa (T. 23 S., R. 10 E.), (2) the Wickiup uranium claims (sections 21

Table 75. *Humate mining operations in Emery County, Utah.*

Mine Name	Other name	1/4 1/4 1/4	Location: Section	Twn.	Rng.	Production (short tons	- years)
Rockland mine	Boddy Toddy	N1/2 NW NE	02	23S	06E	6,328 4,507 3,135	1997 1996 1988-1995
No. 1 Clark mine	Cowboy mine	S1/2 SW NW	02	23S	06E	Inactive - no production	
Miller Rock mine	Bret Clark	NE SW NW	26	22S	06E	1,000 1,834	02/98-02/99 01/90-02/95
Daddy Dearest 1-9	Blackhawk	SW NE NW	26	22S	06E	100 3,000 2,500 1,400	1998 1997 1996 1992-1996
Clark Mine	Emeryide	SW NE NW	26	22S	06E	1,000 0 325	1998 1997 1994-1995
T.J. Clark		NE NE NW	02	23S	06E	Inactive-awaiting agreement with other leaseholders	
Co-op Placer		NW SE	03	23S	06E	<20	1990-1998
Walker Flat		SW SW	07	23S	06E	Active - no production	

and 22, T. 22 S., R. 11 E.), (3) interstices of the sandstones and in concretionary masses in most deposits of the Triassic Temple Mountain Member of the Chinle Formation, and (4) hematitized sandstone peripheral to uranium ore at the Delta mine (section 9, T. 26 S., R. 9 E.) (plate 14).

The Barium, Inc. Company mine produced small amounts of barite during 1959 to 1961 (Brobst, 1964) from a location somewhere in the north-central San Rafael Swell. The exact location of this mine and details on the deposit are not known, but the deposit is probably the same type as that described by Hawley and others (1968).

Cashion and others (1990) described anomalous amounts of barite (containing some strontium) as authigenic cement in Upper Cretaceous rocks of much of the Turtle Canyon Wilderness Study Area and the southern part of the Desolation Canyon Wilderness Study Area in eastern Carbon and Emery Counties (plate 2). They also reported anomalous barite (2,000 to more than 5,000 ppm) in red-stained conglomeratic sandstone samples from the Floy Canyon Wilderness Study Area in nearby Grand County.

Gemstones, Fossils, and Mineral Specimens

Stokes and Cohenour (1956) and Wilson (1995) reported an array of semi-precious gemstones, fossils, and mineral specimens in Carbon and Emery Counties. A brief description of collecting sites is contained in table 76. For detailed information on these collecting localities refer to the original publications.

Small amounts of specimen-grade blue celestite ($SrSO_4$) have been produced over a long period of time from the Strontium King #2 property in the SE1/2 section 22, T. 23 S., R. 07 E. (plate 16) (data from DOGM unpublished mine permit files). Crawford and Buranek (1952) mention specimens from this property being seen in collections as early as 1929. Crawford and Buranek described the main geologic occurrence as pale-blue euhedral crystals in veins and veinlets along orthogonal fracture sets cutting the sandstones of the Jurassic Entrada Formation. Individual veins are up to 2 feet (0.6 m) across and are exposed in an area 100 feet by 100 feet (30 m by 30 m). The other celestite occurrence is 700 feet (210 m) north and consists of veinlets up to 4 inches (10 cm) thick in fracture sets in the Entrada Formation. Crawford and Buranek (1952) believed that these deposits originated through low-temperature ground-water transport of sulfate-rich water.

Some portions of the Jurassic Summerville gypsum beds contain alabaster which may be suitable for carving. A number of small workings have been opened for alabaster on the east face of Cedar Mountain (Stokes and Cohenour, 1956).

Other ornamental siliceous rocks suitable for cutting and polishing include agate, jasper, and silicified bone and wood derived chiefly from the

Table 76. *Fossil and mineral collecting localities in Carbon and Emery Counties, Utah (arranged in ascending order by township, then range, then section).*

Site Name/Location/Data Source	Description
Ford Creek sec. 8, T. 12 S., R. 9 E. Wilson (1995)	Fossil plants are associated with coal seams of the Cretaceous North Horn Formation.
Mounds Reef Sec. 05, T. 16 S., R. 12 E. Wilson (1995)	Pelecypods and cephalopods.
Grassy Wash T. 17 S., R. 14 E. Wilson (1995)	"Fragments of the pelecypods *Ostrea* and *Inoceramus* are common in the Mancos Shale throughout the area."
Straight Canyon T. 18 S., R. 6 E. Wilson (1995)	"Plant material is abundant in the Cretaceous Blackhawk Formation of Emery and Sevier Counties."
Cedar Mtn. T. 18 S., R. 12 E. Stokes and Cohenour (1956)	Red petrified wood occurs on the northwest flank of Cedar Mountain.
South of Castle Dale sec. 34, T. 19 S., R. 8 E. Wilson (1995)	The cephalopod *Scaphites* occurs in a broad area at the north end of the San Rafael Swell. Jasper and agate fragments are also found in this area in the gravel veneers on higher hills.
Castle Dale sec. 20, T. 19 S., R. 9 E. Stokes and Cohenour (1956)	Stems of the fossil fern *Tempska* are found in the Cedar Mountain Formation.
Buckhorn Wash T. 19 S., R. 11 E. Wilson (1995)	"The pelecypod *Inoceramus* occurs in outcrops of the Cretaceous rocks alongside the road into Buckhorn Wash."
Summerville Wash sec. 06?, T. 19 S., R. 14 E. Wilson (1995)	Red agate and petrified wood are found south of Summerville Wash.
Tidwell Draw T. 21 S., R. 14 E. Wilson (1995)	"Jasper is abundant in the Curtis Formation in this vicinity."
San Rafael River T. 22 S., R. 13-14 E. Stokes and Cohenour (1956)	Orange to yellow botryoidal chalcedony is found in the Summerville Formation and has been mined in significant quantities.
The Squeeze T. 22 S., R. 13-14 E. Wilson (1995)	Some horizons of the Curtis Formation contain nodules of jasper often partially or completely filled with quartz, calcite, or celestite.
Greasewood Draw sec. 5, T. 23 S., R. 14 E. Wilson (1995)	"Jasper is abundant in the Curtis and Summerville Formations...Some of the nodules are geodes containing pink, white, or blue celestite. A few of the geodes contain quartz crystals."

Cedar Mountain, Morrison, and Chinle Formations (Stokes and Cohenour, 1956).

Fossil leaves and dinosaur tracks are associated with the Cretaceous Blackhawk Formation coal (Stokes and Cohenour, 1956).

INDUSTRIAL ROCKS AND MINERAL RESOURCES: POTENTIAL COMMODITIES

The following section describes industrial mineral commodities that are known or are likely to be present in Carbon and Emery Counties but have not been produced. Consequently, the format differs somewhat from the previous sections. Sections are not separated into formal subdivisions, but the discussion for individual commodities follows roughly the same order: description and location of the resource or potential resource followed by a discussion of the potential for production or development and possible problems.

Zeolites

Two subeconomic occurrences of zeolites are known in Emery County (Mayes and Tripp, 1991), but potential exists for discovery of additional, more significant, zeolite resources. The known occurrences include analcime ($NaAlSi_2O_6 \bullet H_2O$) in coal beds of the Wasatch Plateau coalfield, and analcime, thomsonite ($NaCa_2Al_5Si_5O_{20} \bullet 6H_2O$), and natrolite ($NaAl_2Si_3O_{10} \bullet 2H_2O$) in igneous dikes at the south end of the San Rafael Swell.

Finkelman (1991) described the widespread occurrence of analcime in Cretaceous coal of the Wasatch Plateau coalfield. Only a small amount of analcime is present, predominantly as fracture-fillings. Because analcime has no industrial mineral uses, and the amount of analcime present is small, the occurrences are economically unimportant. The only economic "significance" of the analcime is that it accounts for much of the sodium detected in the coal. Some sodium minerals can be harmful to electric power plant boilers, but analcime is not known to be detrimental.

Gilluly (1927) reported thomsonite, analcime, and natrolite mineralization in altered Tertiary diabase and syenite dikes and sills of the southern San Rafael Swell. The dikes are as much as 10 feet (3 m) wide, and the sills are as much as 100 feet (30 m) thick. Most of the zeolites were deposited in vesicles and on fracture surfaces of the host rock. The zeolites formed during hydrothermal alteration of plagioclase in the host rock (Gartner, 1986). The total amount of contained zeolite is small, and the three zeolites are noncommercial varieties so these occurrences are only valuable as mineral collecting sites.

The best speculative economic potential for zeolite production in Carbon and Emery Counties is for clinoptilolite ($[NaKCa]_{2\text{-}3}Al_3[AlSi]_3Si_{13}O_{36} \cdot 12H_2O$) which is found in altered tuffaceous units in Cretaceous or Jurassic rocks. Clinoptilolite has hundreds of industrial uses including absorbing ammonia in fish hatcheries and municipal wastewater treatment plants, use as a time-release fertilizer, inclusion in poultry and other animal food, and use as a feedlot deodorant (Mayes and Tripp, 1991). Turner-Peterson (1987) and Turner and Fishman (1991) described laterally zoned analcime and clinoptilolite in tuffaceous sediments in the Jurassic Brushy Basin Member of the Morrison Formation in Grand County roughly 12 miles east of the Emery County line. The zeolites formed by alteration of volcanic ash during early diagenesis in a saline-alkaline lake that existed in Brushy Basin time. Turner-Peterson's zeolite alteration zones do not extend westward into Carbon and Emery Counties, but similar lakes with similar alteration might have existed in the two counties. Zeolitization often produces only subtle changes to the rock which can be easily overlooked without detailed geologic analysis, therefore, a substantial deposit may exist in an area that had previously been explored. Other units that should be examined for zeolites include: the Tertiary Green River Formation and the Colton Formation; and Flagstaff Member of the Green River Formation; the Cretaceous Mancos Shale; and the Triassic Monitor Butte Member of the Chinle Formation.

Dimension Stone/Building Stone

Carbon and Emery Counties have good potential for production of flagstone, ashlar, and dimension stone from sandstone. Lesser potential exists for production of building stone from limestone and igneous intrusive rock.

The two-county area contains abundant Mesozoic sandstones that might be suitable for use as building stone. The best potential is for production of flagstone for paving and building veneer. To date (December 2001) there has been no significant production of flagstone in the two counties, but the Jurassic Kayenta Formation may have potential because it is thinly bedded in part. It is exposed around the San Rafael Swell in central Emery County, and some outcrops are close to existing roads. Although the Kayenta has not been commercially quarried in Utah, the age-equivalent Nugget Sandstone produces large quantities of flagstone and ashlar from quarries near Park City and Heber City in Summit County. Flagstone operations require little capital expense, but are very labor intensive so lack of available labor in the area could inhibit production.

There is less potential for quarrying blocks of massive sandstone for production of dimension stone. Desirable characteristics of sandstone for dimension stone include structural strength, resistance to weathering, attractive color and texture, and ease of cutting. Several formations in Carbon and Emery Counties may have potential because they have been quarried in neighboring counties. The Triassic Moenkopi Formation is exposed around the San Rafael Swell in central Emery County. Tan and red, massive sandstone from this unit is quarried in large blocks 45 miles to the southwest of Emery County near Torrey in Wayne County. The Tertiary Colton Formation in northern Carbon County contains the gray "Kyune" sandstone which was quarried near Colton in Utah County immediately north of the Carbon County line. This sandstone was used to construct the Salt Lake City and County Building, among others.

Limestone has even less potential for building stone. Several Paleozoic and younger limestones present in Carbon and Emery Counties could be quarried, but limestone dimension stone is in low demand except for tan to white limestone. Numerous quarries in the Tertiary Green River Formation of Sanpete County have produced large amounts of white, oolitic limestone, the "Sanpete White Stone," since the late 1800s. This stone was used extensively for construction locally and in California (Dixon, 1938). Only one quarry (near Manti) was producing this stone in 1999. Similar white stone may occur in the Green River Formation of Carbon and Emery Counties. The Green River and other formations containing limestone also should be examined for the presence of cream- to tan-colored limestone similar to French limestone or German Solenhofen Limestone, both of which have large international markets.

Carbon and Emery Counties have small potential for production of "granite." Only high-quality black granite (actually a diabase), red granite, or granite with unusual colors and textures commanding a premium price, would be economic so distant from inexpensive transportation and markets. The diabase sills and dikes on the south end of the San Rafael Swell (Gilluly, 1927; Gartner, 1986) are the only intrusive rocks in the study area that might meet these criteria. Commercial stone production from the San Rafael dikes and sills may be hindered by two factors: (1) the dikes are often heavily altered, and (2) they occur in one of the most remote areas of Utah, making transportation difficult and expensive. An on-site investigation would be required to determine if a thick, unaltered, unfractured outcrop of this diabase is present, and if the stone can be cut and polished to yield attractive building stone.

Hansen (1964) showed the location of a building stone quarry or deposit southeast of Price but provides no specific information and none is available from other sources.

Lightweight Aggregate

Carbon and Emery Counties probably contain large quantities of shale suitable for thermal expansion into lightweight aggregate (bloated shale). Lightweight aggregate is any naturally occurring or processed mineral material that can be mixed with a binder (usually Portland cement) to produce a lightweight building material (Mason, 1994). Pumice, perlite, scoria, vermiculite, diatomaceous earth, and bloated shale are lightweight aggregates, and all occur in Utah (Van Horn, 1964); however, only shale and clay with bloated shale potential are present in Carbon and Emery Counties. Bloated shale is a clay or shale that when heated softens to a plastic state but also evolves gas through decomposition of organic or mineral matter. The evolved gas causes the plastic shale to expand into a somewhat glassy, vesicular material. Bloating characteristics of shales cannot be determined by visual examination; they are best determined through controlled heating tests.

Hyatt (1956) sampled shales of the Green River, Colton, and North Horn Formations along U.S. Highway 6/50 between the Utah County line and Price. He sampled eight locations and found that all eight samples bloated. He gives no further specifics about the quality of the bloated shale produced.

Van Sant (1964) sampled shales across the north end of the San Rafael Swell (table 77). Shales from seven of his nine locations (58 to 60, 62, and 64 to 66) bloated when heated. These samples were from the Cretaceous Blue Gate Shale and Tununk Shale Members of the Mancos Shale, the Cretaceous Dakota and Cedar Mountain Formations, and the Jurassic Brushy Basin Member of the Morrison Formation.

Market and infrastructure factors affect the potential production of bloated shale in Carbon and Emery Counties. On the negative side, lightweight aggregate is used most extensively in large population centers, and Carbon and Emery Counties are far from large cities. Also, the two closest large cities connected by rail transport to the two counties are Salt Lake City and Denver, and both have local bloated shale plants. Bloated shale plants also are expensive to build. On the positive side, bloated shale production is energy intensive, and the two counties have abundant natural gas and coal resources. These counties also contain at least six widespread formations that have potential for bloated shale production, and have trained miners and mining infrastructure.

Limestone/Dolomite

Carbon and Emery Counties are poorly endowed with high-calcium limestone or high-magnesium dolomite. Typical uses for high-calcium limestone and dolomite include crushed stone, cement, quick and hydrated lime, steel and iron smelting, flue gas desulfurization, paper processing and construction (Miller, 2000; Tepordei, 2000; van Oss, 2000). There has been no production of either of these commodities in the two-county area.

Table 77. *Selected clay sample locations for Emery County, Utah.*

Van Sant Location No.	Sec[1].	Twn.	Rng.	Formation[2]
*58	30	18S	9E	Cret. Blue Gate Shale Mbr. of the Mancos Sh.
*59	29	18S	9E	Cret. Blue Gate Shale Mbr. of the Mancos Sh.
*60	33	18S	9E	Cret. Tununk Shale Mbr. of the Mancos Sh.
61	33	18S	9E	Cret. Tununk Shale Mbr. of the Mancos Sh.
*62	35	18S	9E	Cret. Dakota/Cedar Mtn. Fms.
63	14?	19S	13E	Cret. Dakota/Cedar Mtn. Fms.
*64	5?	19S	14E	Cret. Blue Gate Shale Mbr. of the Mancos Sh.
*65	5	19S	14E	Cret. Tununk Shale Mbr. of the Mancos Sh.
*66	6	19S	14E	Jur. Brushy Basin Mbr. of the Morrison Fm.

[1] Section locations were estimated; there may be as much as a 0.5 mile error.
[2] Geologic unit determined by comparing Van Sant's 1964 small-scale index map with geologic mapping by Witkind (1988), so uncertainty occurs in some cases.
[*] Sample bloated when heated.

The Tertiary Flagstaff Limestone has the best potential to produce high-purity limestone based on a few assays of the Flagstaff in these counties and based on analyses and mine production in the surrounding area. Six grab samples taken from the Flagstaff at a butte called the Cap (section 27, T. 18 S., R. 6 E.) in western Emery County averaged 92.1 percent $CaCO_3$. The best sample of the group had the following assay (in percents): $CaCO_3$ = 93.2, $MgCO_3$ = 3.6, SiO_2 = 2.7, Al_2O_3 = 0.45, Fe_2O_3 = 0.21, P_2O_5 = 0.05, S < 0.05, and moisture < 0.1 (Smith, 1981). Limestone is not mined from the Flagstaff within Carbon and Emery Counties but is mined in several adjacent counties. Emery Industrial Resources began producing limestone for coal-mine rock dusting in 1993. They mine about 30,000 short tons (27,000 metric tons) per year of limestone from the Flagstaff in eastern Utah County (section 36, T. 11 S., R. 08 E.). Western Clay Company mines limestone from the Flagstaff in Sevier County (sections 5, 7, 8, T. 21 S., R. 1 E.) for coal-mine rock dust, crushed stone, and, in the past, for steel smelter flux. During the period 1988 to 1997 this quarry produced at least 87,425 short tons (79,300 metric tons) of limestone (mine permit files, available for inspection at Utah Division of Oil, Gas and Mining).

The following units may have potential for high-purity limestone, but only limited analytical information is available: the Tertiary Green River Formation, the Cretaceous North Horn Formation, the Jurassic Carmel Formation and Arapien Shale, and the Triassic Sinbad Limestone and Shnabkaib Members of the Moenkopi Formation. These units are probably mostly impure, but selected beds might be pure enough to supply limestone for local uses such as coal-mine rock dusting or flue-gas desulfurization at coal-fired power plants. The only known analyses done on these units were published as part of U.S. Geological Survey and U.S. Bureau of Mines wilderness investigations. For example, a limestone sample of the Carmel Formation from section 19, T. 24 S., R. 08 E., contained 89.29 percent $CaCO_3$ (Neumann, 1989). Additional sampling is necessary to evaluate the potential of the prospective units.

No data are available to indicate the presence of high-purity dolomite in the two-county area. However, in the Fiddler Butte Wilderness Study Area of Garfield County (about 70 miles [110 km] south of the Emery County line), Gese (1988) sampled a 20-foot-thick (6 m), high-magnesium dolomite (>43 percent $MgCO_3$) in the Navajo Sandstone. Similar Navajo strata could be present in Carbon or Emery County, but no detailed studies have been done. Careful sampling and analysis of the Permian Black Box Dolomite also may reveal high-purity dolomite in selected beds. No dolomite has been produced in these or adjacent counties. The only current (2001) dolomite production in Utah is from the Ordovician Fish Haven Dolomite west of Salt Lake City, in Tooele County, and from the Cambrian Limestone of the Cricket Mountains south of Delta, in Millard County.

Moderate potential exists for future production of limestone for coal-mine rock dusting or for flue gas desulfurization use at coal-fired power plants, but there is low potential for future production of dolomite. Carbon and Emery County coal mines currently use ground limestone, with less than 5 percent silica content, to coat walls of coal mines to decrease risk of coal-dust explosions and fires, and Carbon County power plants may soon be required to use ground limestone to absorb sulfur from smokestack emissions. Most of this limestone is or will be imported from quarries outside of Carbon and Emery Counties. The market is well served by current suppliers, and it would be difficult to break into the market even if increased coal mining resulted in an increased limestone demand. Existing limestone and dolomite plants outside of Carbon and Emery Counties are well established, and transportation costs are not nearly as critical in determining the economic feasibility because of trucking and railroad backhauls. Empty coal trains returning to the coal mines to load more coal can very economically deliver limestone to the coal mines.

Silica

Carbon and Emery Counties contain large amounts of Paleozoic and Mesozoic sandstone and Quaternary eolian sand that could be potential sources of silica (figure 43). Sandstone units mentioned in geologic literature with potential include: Cretaceous Dakota Sandstone; Jurassic Wingate Sandstone, Kayenta Formation, Navajo Sandstone, and Entrada Formation; and Permian White Rim Sandstone (Ketner, 1964; Munts, 1989). Chemical analyses for samples within Carbon and Emery Counties are shown in table 78 along with chemical specifications for various silica applications. Most sources of silica need some processing to remove impurities to meet specifications for various uses, so known Carbon and Emery County resources cannot be excluded on the basis of their in-situ chemical purity.

Two geologic units having the highest potential for silica production within these counties are the Permian White Rim Sandstone and Quaternary eolian sands (figure 43). The White Rim Sandstone is exposed in the interior of the San Rafael Swell and covers an extensive area. It is roughly 700 feet (210 m) thick so it represents a very large resource. The White Rim Sandstone has been prospected as a source of glass sand (U.S. Bureau of Land Management, 1989), a very demanding use with stringent specifications, but little data are available. Extensive sampling and assaying would be required to determine how much of this formation meets the stringent specifications needed for glass or foundry sand. A premium-quality sand might be economically shipped the long distance to market. The White Rim Sandstone would be inexpensive to process because it is only lightly cemented and is easy to crush.

Quaternary eolian sand occurs in dunes in the San Rafael Swell and in large dune fields in the southeast corner of Emery County. A very large quantity of sand is present here. Purity should be high since the sand is derived from multicycle sandstones. The unconsolidated Quaternary sand would be less expensive to mine and process than lithified units.

Salt, Potash, and Magnesium

Sodium, potassium, and magnesium salts are contained in halite (NaCl), sylvite (KCl), and carnallite ($KMgCl_3.6H_2O$) beds (figure 44) and associated brines (figure 45) in the subsurface of southeastern Emery County.

Bedded Deposits

The bedded saline resources occur in some of the 29

Table 78. *Sandstone analyses (>88 percent SiO_2) of samples from Carbon and Emery Counties and product specifications. Analyses in weight percent unless otherwise noted (P= parts per million). In location field, T. = cadastral township and is always south, R. = cadastral range and is always east. Analyses are sorted by township, then by range, and then by section.*

Formation	Location 1/4 Sec.T.R.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO_2	LOI	Ag (oz/t)	Au (ppb)	Source
Navajo	SE NW NW 32 20 10	94.03	4.57	0..38	0.2	0 .07	0.25	1.1	0.12	0.08	<0.01	0.75	<0.01	<5	Lipton (1989) sample 102.
Navajo	NE SE SW 14 20 12	95.68	1.81	0.25	0.04	0.11	0.10	0.2	0.04	0.03	<0.01	0.34	0.15	<5	Benjamin (1989) sample 186.
Wingate	NE NE NW 09 21 10	90.6	4.07	0.21	0.24	0.29	0.15	1.1	0.1	0.05	<0.01	1.31	<0.01	<5	Lipton (1989) sample 117.
Wingate	NW SE SW 13 22 09	93.87	2.51	0.32	0.07	0.19	0.15	0.5	0.06	0.04	0.01	0.74	<0.01	<5	Lipton (1989 sample 181.
Navajo	NE SE NW 24 22 09	88.04	4.22	0.45	0.64	1.16	0.15	0.8	0.2	0.05	<0.01	2.58	<0.01	<5	Lipton (1989) sample 182.
Entrada	NW SW NW 24 22 13	89.44	1.5	0.33	0.15	4.39	0.13	<0.1	0.04	0.03	0.02	2.91	<0.01	<5	Munts (1989) sample 35.
Navajo	SE NW NW 25 24 12	88.98	3.48	0.42	0.22	1.76	0.14	0.9	0.11	0.03	0.01	1.98	<0.01	<5	Munts (1989) sample 141.
Navajo	SW SE SE 26 24 12	93.64	2.38	0.36	0.06	0.19	0.14	0.4	0.08	0.03	0.05	0.82	<0.01	<5	Munts (1989) sample 167.
Wingate	SW NW NE 32 24 12	89.01	4.39	0.4	0.46	0.65	0.14	1.1	0.21	0.06	0.05	1.85	0.03	<5	Munts (1989) sample 189.
Navajo	SW SE SE 34 25 08	92.75	3	0.26	0.12	0.1	0.15	0.7	0.14	0.03	0.01	0.77	<0.01	<5	Neumann (1989) sample 132.
Navajo	NE NW SE 01 25 11	92.43	3.4	0.22	0.1	0.07	0.15	0.8	0.1	0.04	0.01	0.83	<0.01	<5	Munts (1989) sample 177.

LOI = Loss on ignition

SPECIFICATIONS

Specification	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO_2	LOI	Ag (oz/t)	Au (ppb)	Source
FOUNDRY SAND	>98	-	-	-	-	-	-	-	-	-	-	-	-	Zdunczyk and Linkous (1994).
FLAT GLASS (1)	>99.5	<0.30	<0.04	-	-	-	-	<0.1	-	<0.002	-	-	-	Zdunczyk and Linkous (1994).
FLINT CONTAINER GLASS (2)	>98.5	<0.5	<0.035	(3)	(3)	-	-	<0.03	-	-	-	-	-	Zdunczyk and Linkous (1994).
FIBERGLASS	>99	<0.30	<0.50	-	-	<0.10	<0.10	-	-	-	(4)	-	-	Zdunczyk and Linkous (1994).
GROUND SILICA	-	<0.38	<0.10	-	-	<0.10	<0.10	-	-	-	-	-	-	Zdunczyk and Linkous (1994).

Notes: (1) Flat glass, other specifications: Cr_2O_3 < 2 ppm, Co_3O_4 < 2 ppm, H_2O <0.05 percent
(2) Flint container glass, other specifications (in percents): Cr_2O_3 < 0.001, ZrO_2 < 0 .01, H_2O < 0.1
(3) MgO + CaO < 0.2 percent
(4) LOI + H_2O < 0.50 percent

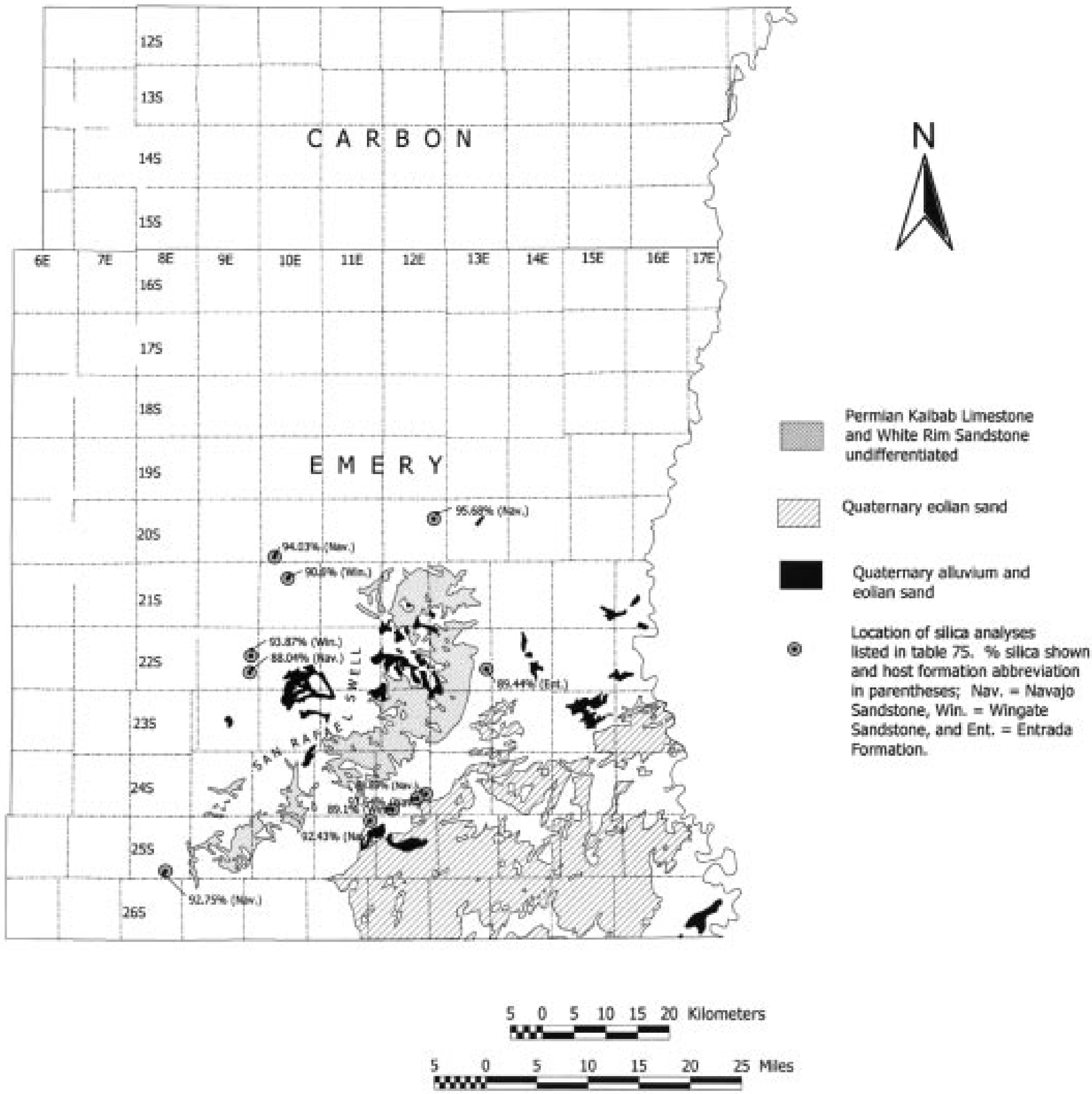


Figure 43. *Silica resources of Carbon and Emery Counties, Utah. Outcrop data from Williams and Hackman (1971), Witkind and others (1987), and Witkind (1988).*

evaporite cycles in the saline facies of the Pennsylvanian Paradox Formation of the Hermosa Group. The Hermosa Group is not exposed in southeast Emery County; it is at depths of several thousand feet. Most of the published, detailed information available for Paradox basin bedded salt is from the central part of the basin in Grand and San Juan Counties (Gloyn and others, 1995), but Woodward - Clyde Consultants (1983) presented an isopach (thickness contour) map of the saline facies in eastern Emery County (figure 44). Hite and others (1972) showed the limits of halite and potash deposition in Emery County (figure 44) and gave a detailed stratigraphic column of the bedded salt interval from a well

(Superior Oil Company, Unit No. 22-34, section 34, T. 22 S., R. 17 E.) drilled a few miles east of the Emery County line. The saline facies thins rapidly to the west of this well so the salt beds in Emery County are probably thinner with more clastic interbeds than at the Superior Oil well.

The Superior well penetrated 26 salt beds that total approximately 3,400 feet (1,030 m) of halite and potash in the saline facies, which is approximately 4,185 feet (1,275 m) thick. The beds are numbered in descending order from the surface (number 1 is the shallowest). The top of the salt in the Superior Oil Company well is 5,590 feet (1,704 m) below surface. The thickest salt bed is bed number 2 which is 620 feet (190 m) thick. Salt bed 2 is anomalously thick at this well, much thicker than most salt beds anywhere in the Paradox basin. Six potash units were intersected by this well. The potash units have a total thickness of 260 feet (80 m) and are interbedded with the halite. The thickest potash unit is in halite unit 6; the potash is 120 feet (36 m) thick. Other potash zones occur in halite units 5, 13, 16, 18, and 19 (Hite and Carter, 1972). Reported thicknesses of halite and potash often include interbedded impurities and may also reflect local diapiric thickening of the salt. The potential is low for development of the Emery County resource due to great depth of burial and competition from established potash producers with large reserves such as the Canadian potash mines in Saskatchewan.

Magnesium chloride may occur in the Paradox Formation salt in Emery County. Bedded magnesium chloride in the Paradox basin occurs as high-purity carnallite which is thick enough in some parts of the basin to have been seriously considered for solution mining. Detailed information is available on carnallite in the Paradox basin from the Reeder No. 1 well drilled in Grand County 17 miles east of the Emery County line (SE1/4 SW1/4 SE1/4 section 4, T. 22 S., R. 19 E.) (Severy and others, 1949). The Reeder well penetrated a 220-foot-thick (67 m) section of the saline facies having a high percentage of carnallite in beds up to 12.5 feet (3.8 m) thick, although most were only a foot or two thick. The potential is low for production of this bedded carnallite because of the depth of burial and the probable small size of the resource compared to the main part of the saline facies in Grand and San Juan Counties. Magnesium chloride also occurs at Buckhorn Draw in Emery County (section 3, T. 20 S., R. 11 E.). Crawford and Buranek (1942) investigated this occurrence and concluded that the deposit was minor salt efflorescence associated with ground-water movement.

Brines

A zone of deep saline ground water containing potassium, sodium, magnesium, and trace elements underlies the southeastern part of Emery County in the Paradox basin. The most detailed published data on the chemistry of the brine resources is contained in Mayhew and Heylmun (1966) and Gwynn (1996), who described lateral variations in brine concentration and chemistry for brine in Mississippian and Pennsylvanian rocks. Mayhew and Heylmun (1966) showed an area of southeastern Emery County containing brine with total dissolved solids (TDS) concentrations as high as 400,000 parts per million (ppm) (figure 45a), magnesium concentrations of up to 5,000 ppm (figure 45b) in Pennsylvanian strata, and TDS as high as 300,000 ppm in Mississippian strata (figure 45c). The Mississippian brine concentration values generally agree with the 285,586 ppm TDS (285,586 mg/L) values reported by Gwynn, 1996 for Mississippian strata at the Salt Wash oil field in Grand County just east of the Emery County line (T. 23 S., R. 17 E.) (figure 44).

Brine resources are also present in Carbon and Emery Counties outside the Paradox basin; Gwynn (1995) lists cation and anion concentrations for 18 samples in the Salt Wash oil field and data for two brine samples from the Grassy Trail oil field (figure 44). The Grassy Trail samples, from Mississippian rocks, assayed only 56,409 ppm TDS.

The only brine produced in Carbon and Emery Counties was from oil and gas wells as a waste product. All this brine has been reinjected or otherwise disposed of; no salt has yet been recovered.

Brine in Emery County has some long-term potential for production but faces serious competition from the more extensive saline resource in Grand and San Juan Counties and other deposits. By-product brine production from oil and gas wells is more likely and could be used to supply drilling fluid for drilling holes through salt horizons; production facilities for this use do not require large capital investments.

Common and Fire Clay

Carbon and Emery Counties contain unknown quantities of common clay and smaller quantities of refractory fire clay in Cretaceous and Jurassic shales There is little available information on this resource; the only specific resource information on these clays is from Van Sant (1964) and Hyatt and Cutler (1953).

Van Sant (1964) collected and analyzed nine shale samples along a dirt road through the north end of the San Rafael Swell during his inventory of refractory clays in Utah. The locations and geologic units he sampled are shown in table 77. Some of the units sampled could be used for manufacturing brick or other common-clay products, especially if mixed with other clays, but none of the samples were particularly desirable even for brick. Only one sample, No. 66, was somewhat higher grade, possibly acceptable as sub-low-duty refractory clay (pyrometric cone equivalent = 15). Van Sant (1964) gave extensive additional data on raw and fired characteristics of these samples.

Hyatt and Cutler (1953) fired eight Mancos Shale samples to 1,920 to 2,150°F (1,050-1,180°C) and then determined resulting color, shrinkage, and porosities. They concluded that despite a high concentration of deleterious carbonate and sulfate, the Mancos Shale is suitable for manufacture of common clay products such as brick and tile.

Minobras (1974) reported a white, refractory clay occurrence on the northeast flank of the San Rafael Swell (section 5,6, T. 19 S., R. 14 E.) but provided no additional information.

Sulfur

There are four small, undeveloped sulfur occurrences in Emery County. They are poorly described in the literature, and some of the deposit locations are uncertain. The deposit locations are plotted on plate 14 and other known information is listed in table 79.

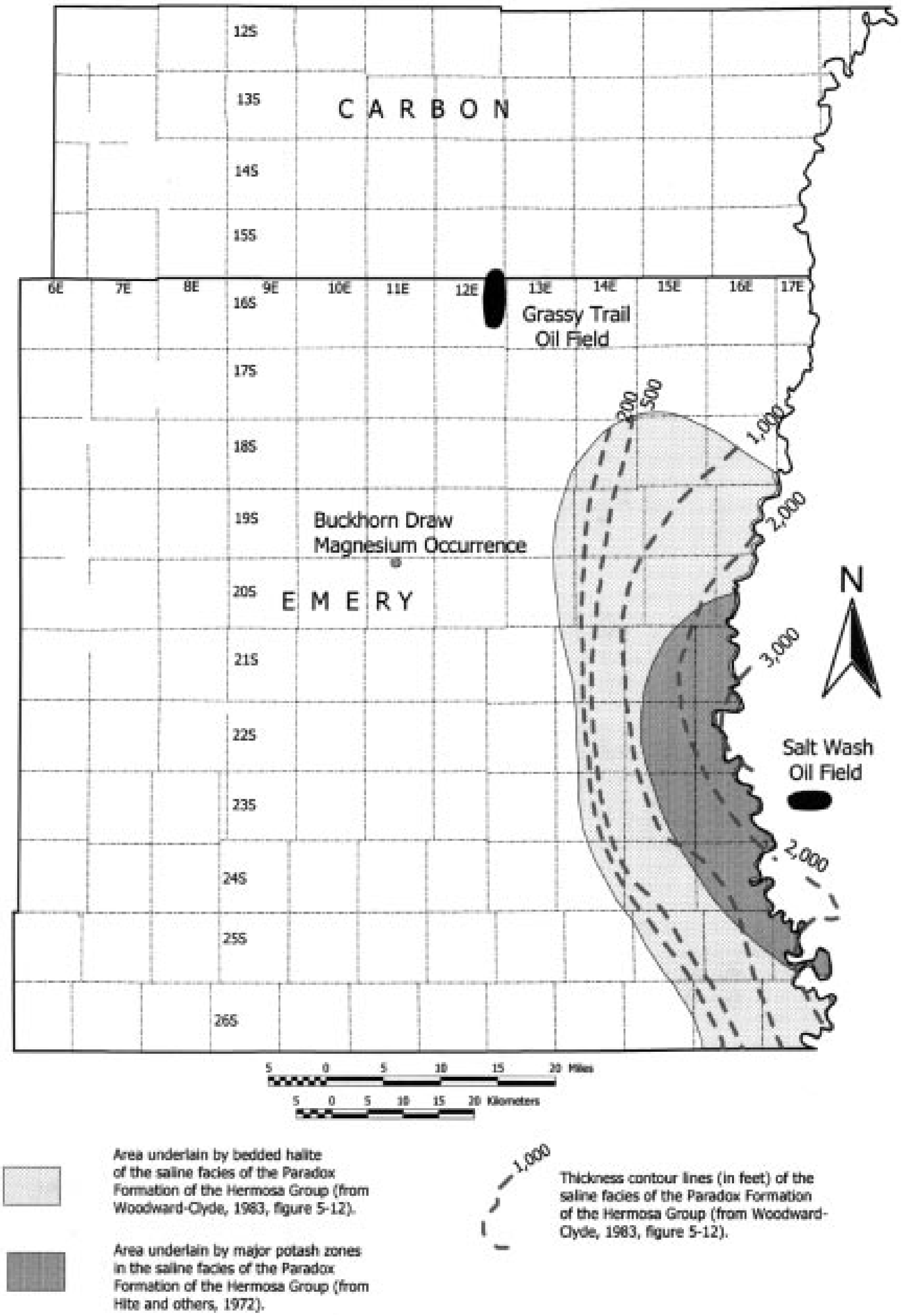
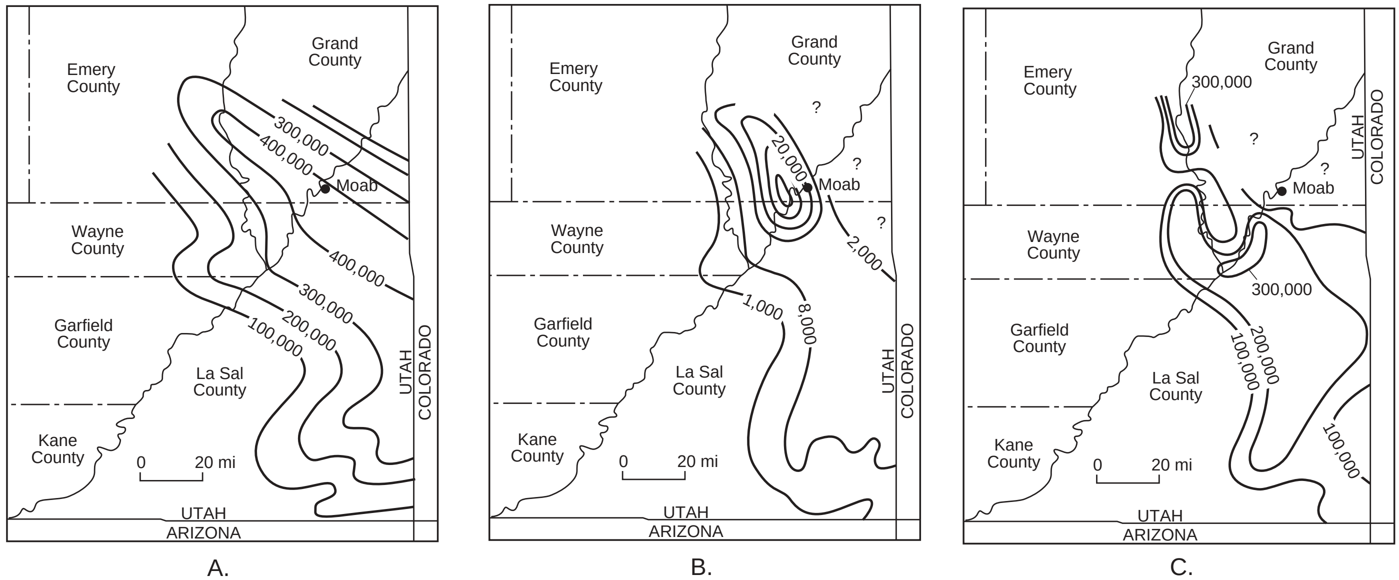


Figure 44. *Halite and potash resources of Emery County, Utah.*



Concentration contour lines

A. Concentration of brine from Pennsylvanian rocks (TDS in ppm)
B. Concentration of magnesium in brine from Pennsylvanian rocks (in ppm)
C. Concentration of brine from Mississippian rocks (TDS in ppm)
TDS Total dissolved solids

Figure 45. *Variation in subsurface brine chemistry in Emery County and adjacent areas, Utah (modified from Mayhew and Heylman, 1966).*

Table 79. *Sulfur occurrences of Emery County, Utah.*

Deposit	**Location/Data Source**	**Description**
Cedar Mountain	Approx. section 7, T. 19 S., R. 12 E., Chimney Rock 7.5' quad. (Minobras, 1974).	"Native sulfur is associated with cool springs, and is largely sulfur cementing the soil. The mineralized material is pale yellow to gray in color. Because the deposit is small and low grade, it has not been mined" (Mount, 1964).
Mexican Bend	Approx. section 2, T. 21 S., R. 13 E., Mexican Mtn. 7.5' quad. (Minobras, 1974)	"Native sulfur occurs in small crystals and as earthy material cementing soil and rock fragments. It is pale yellow to grey. The deposits appear to have been formed around vents and do not cover any appreciable area" (Wideman, 1957). This is probably the San Rafael River site mentioned by Hess (1913).
San Rafael Canyon (Sulphur Spring)	Approx. section 23, T. 21 S., R. 13 E., Spotted Wolf Cyn. 7.5' quad. (Minobras, 1974).	Several small warm springs have deposited native sulfur and travertine along the contact between the Moenkopi and Kaibab Formations (Benjamin, 1989). Also, small sulfur crystals and amorphous sulfur impregnate soil around the springs. The deposit is about 150 feet wide and 750 feet long and has been explored with shallow prospect trenches; no sulfur has been produced (Mount, 1964). Benjamin (1989) collected samples from the deposit; the best sulfur assay was 1.79 percent sulfur. Claims covering the deposit (the Sulfur Gas claims) were active in 1986 (Benjamin, 1989).
Black Dragon Canyon	Section 36 (unsurv.), T. 21 S., R. 13 E., Spotted Wolf Cyn. 7.5' quad. (Minobras, 1974)	The sulfur occurs over an area of 50 feet by 25 feet and is less than 10 feet in thickness. "Some of the sulfur occurs as small, yellow crystals, but a large part of it is a dirty, yellowish color and some of the higher grade material is almost black, probably stained by hydrocarbons" (Wideman, 1957).

GROUND-WATER RESOURCES

Ground water is an important but limited resource in Carbon and Emery Counties. It is only partially utilized in the counties, and most ground water used is from springs and seeps. Few studies have been done on the ground-water resources of the counties, and there has been little incentive, or attempt, to more fully develop these resources. With increased population growth, ground-water resources will become more important. Unfortunately, only a few areas in Carbon and Emery Counties have potential to supply substantial amounts of high-quality ground water from shallow depths. Other areas have potential to supply substantial amounts of water, but most would be poor quality and would require deep drilling.

Streams provide most of the water used for irrigation and reservoirs provide domestic, municipal, and industrial water for the larger communities. Only a few towns or areas use ground water from wells, although ground water from deep wells is used by coal-fired electric power plants for cooling. Springs supply most of the water used for stock watering and are the principal source of domestic and municipal culinary water for many small communities in western Emery and western and northern Carbon Counties. In the Wasatch Plateau many large springs flow from fractured rocks, and in the Book Cliffs many springs flow from bedding contacts (figure 46). Figure 47 shows the location and extent of rock units that have many springs.

Ground-Water Flow Systems

Ground-water flow systems consist of ground water entering recharge areas, usually at topographically higher sections of the aquifer, flowing through bedrock aquifers to lower sections of the aquifer where the water is discharged. Areas of natural discharge include springs, gaining reaches of streams, and areas of phreatophyte plant growth.

Topography, related precipitation patterns, and the hydrologic properties of rocks control the quantity and availability of ground water in Carbon and Emery Counties. The topography establishes the driving force to move water from recharge areas in the higher elevations to discharge areas at lower elevations. The precipitation patterns provide the water to areas where it can infiltrate the ground surface. The hydrologic properties of the rocks establish the rate of ground-water movement and volume of ground water that moves through an area. Geologic considerations controlling the hydrologic properties of rocks include the lithology, bedding, fractures (faults and joints), and permeability contrasts of the rocks and structures of an area. Topography and elevation differences between highlands and lowlands drive the movement of ground water in three types of flow systems (figure 48): regional, intermediate, and local.

A regional flow system is a large ground-water flow system having deep, slow circulation. Local topographic variations do not affect regional flow systems. Regional flow systems react slowly to changes in recharge because of long ground-water flow paths to discharge areas. They generally contain vast volumes of water in storage. The regional flow system in Carbon and Emery Counties is from west to east. Recharge areas are near drainage-basin divides in the Wasatch Plateau and Book Cliffs and discharge occurs in the lowest areas as base flow to the Green River (figure 48).

Intermediate flow systems, characterized by one or more topographic highs, develop in areas with pronounced relief between the highlands and lower areas. Intermediate flow

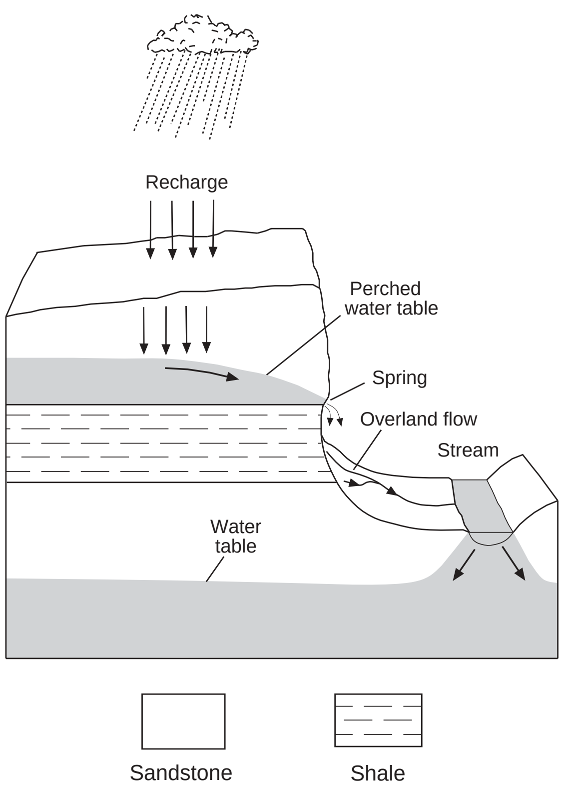


__Figure 46.__ Diagram showing spring discharge along the contact of a permeable sandstone and a relatively impermeable shale.

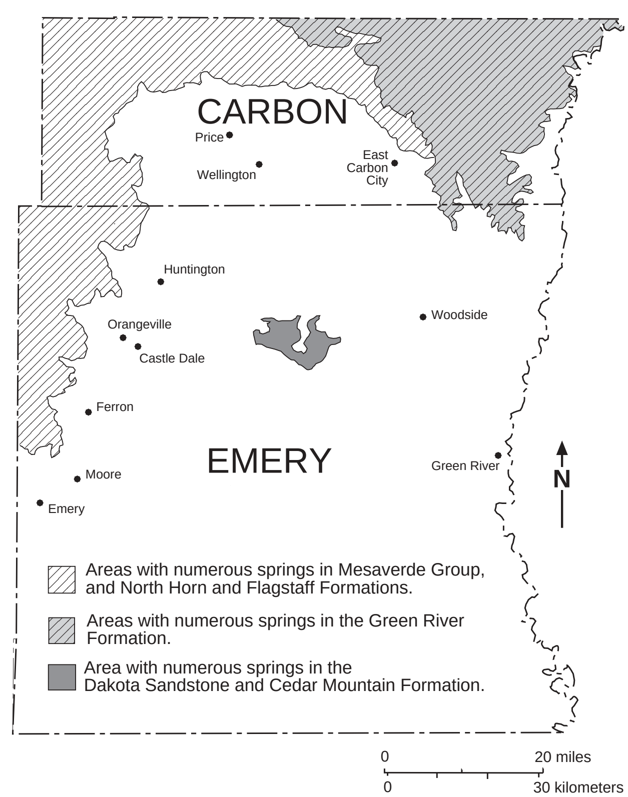


__Figure 47.__ Location of areas with numerous springs and seeps.

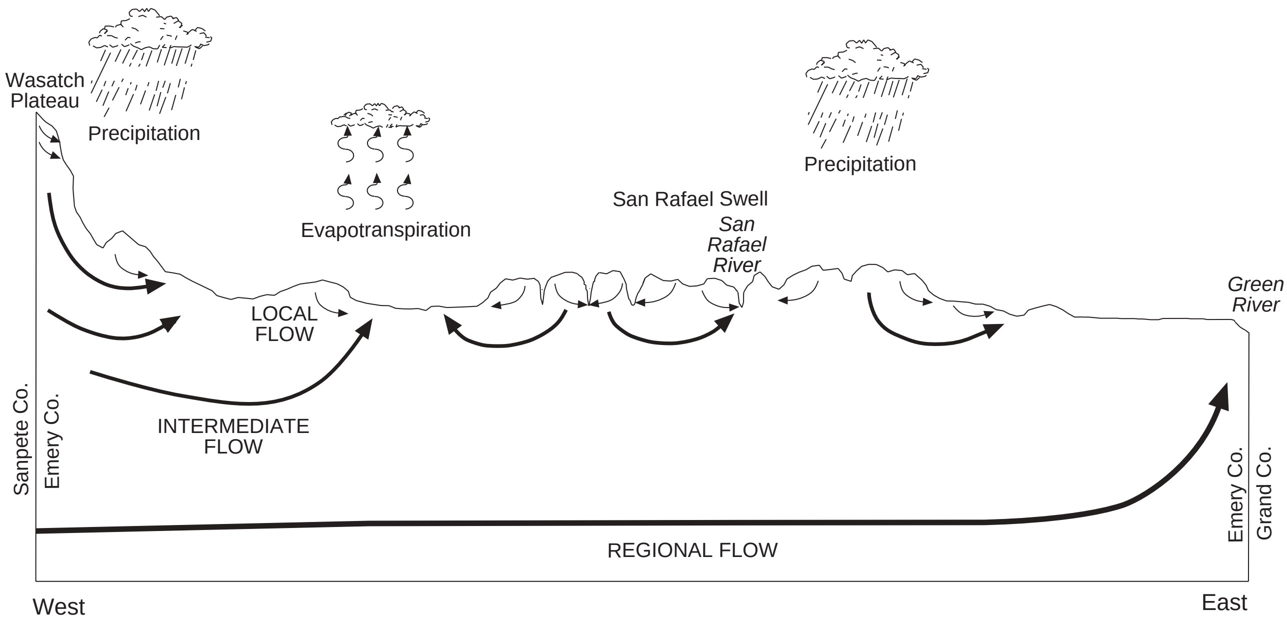


***Figure 48.** Flow systems developed in Emery County. Diagram shows relationship between surface topography and scale of ground-water flow system.*

systems have relatively slow rates of flow. Intermediate flow systems react more quickly to changes in amounts of recharge than regional flow systems and may sometimes reflect annual, but generally not seasonal, changes in recharge. The recharge areas of intermediate flow systems in Carbon and Emery Counties are in higher elevation areas, such as the Wasatch Plateau, Book Cliffs, Cedar Mountain, and San Rafael Swell. Discharge from intermediate flow systems occurs along medium and large drainages, and at springs discharging at the base of the highlands.

Local flow systems develop at shallow depths in areas having local relief. These flow systems are characterized by relatively fast rates of ground-water flow and rapid, sometimes seasonal, responses to changes in amounts of recharge. Local flow systems have relatively short ground-water flow paths and travel times, and transport a large part of the ground water within an area. Recharge occurs at local topographic highs, and discharge takes place at adjacent topographic lows, commonly providing base flow to small streams and rivers. Local flow systems supply many of the springs found in the Wasatch Plateau and Book Cliffs. Local flow systems also provide water to canyon bottoms in areas like the San Rafael Swell.

Ground-water recharge is mostly from infiltration of snow and rain with some contribution from seepage from streams and irrigation. Most of the precipitation falls in the higher elevations with a higher percentage falling during the winter months (figure 49). The precipitation varies widely across the area, generally reflecting variations in elevation. The average annual precipitation in Carbon and Emery Counties ranges from less than 6 inches (15 cm) in southeastern Emery County near Green River to more than 30 inches (75 cm) in the higher plateaus in northwestern Carbon County. Maximum average annual precipitation can exceed 40 inches (100 cm) in the Wasatch Plateau and 20 inches (50 cm) in the Book Cliffs. However, precipitation is less than 8 inches (20 cm) over much of the area (Lines and others, 1984).

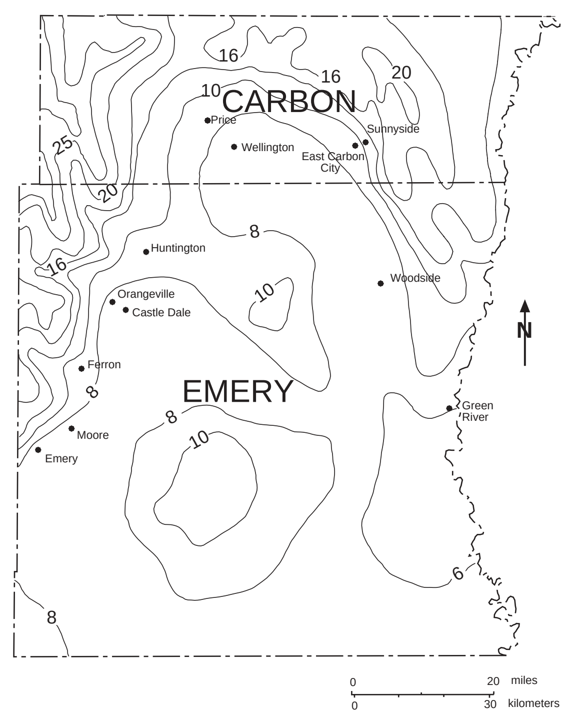


***Figure 49.** Average annual precipitation in inches in Carbon and Emery Counties for the years 1931 to 1960 (modified from Lines and others, 1984).*

Aquifer Characteristics

In Carbon and Emery Counties, ground water occurs in more than 16,000 feet (4,800 m) of sedimentary rocks that extend under the area. Nearly all rocks in Carbon and Emery County contain some water at various depths, but many rocks yield water very slowly to wells. Rock units that yield water easily are aquifers, and those that do not are aquitards or confining units. Several physical characteristics of rocks useful in evaluating ground water potential include: porosity (the aquifer's capability to hold water), permeability (the aquifer's capacity to transmit water), hydraulic conductivity (rate at which the aquifer yields water), and transmissivity (amount of water an aquifer can yield in a set time period). Typical ranges of porosity, permeability, and hydraulic conductivity for several rock types are listed in table 80.

Introduced water (precipitation, snowmelt, irrigation, etc.) moves downward through the rock until it reaches the water table or the top of the zone of saturation where water fills all of the interstitial openings. The water table is an irregular surface that usually mimics the surface topography but is generally more subdued. Below the water table, ground water moves laterally through the rocks until it intercepts either the land surface where the water is discharged as a spring or along the gaining reaches of streams, or at a well or other conduit (either natural or constructed) that intersects the water table. In areas where the ground water is present beneath impermeable rocks, the water may be confined (under pressure) and will rise up a conduit or wellbore some distance above the level of water in the permeable aquifer. This level represents the static head of the ground water in the confined aquifer and is used to determine the potentiometric surface for the confined aquifer. This potentiometric surface is often used to determine the general ground-water flow direction for a confined aquifer.

Ground-Water Quality

The quality of ground water in Carbon and Emery Counties is extremely variable, with total-dissolved-solids (TDS) concentrations ranging from less than 500 to more than 30,000 mg/L. Fresh water is generally available from shallow aquifers in rocks above an elevation of 7,000 feet, and in rocks with a good hydrologic connection (short residence time) to principal recharge areas. At lower elevations fresh water can sometimes be found in relatively permeable sandstone aquifers, such as the Navajo and Ferron aquifers. Descriptive terms (Hem, 1970, p. 219) for the quality of water are:

Class	Dissolved solids (mg/L)
Fresh	less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Briny	more than 35,000

Many factors affect the quality of ground water including: (1) the quality of water recharging the ground-water flow systems, (2) the nature of water-rock interaction, and (3) the length of time the water is in the ground-water flow system, called residence time (Freethey and Cordy, 1991). Lithologic characteristics of the aquifer and adjacent rocks exert a major control on the dissolved solids content and chemical constituents of ground water. Water quality generally deteriorates with increasing residence time, increasing depth, and association with shales and siltstones. The soluble minerals in shaly units, above or below an aquifer, may

Table 80. *Ranges of porosity, permeability, and hydraulic conductivity for various rock types (after Davis and De Wiest, 1966; Davis, 1969; Freeze and Cherry, 1979; Marsily, 1986; Domenico and Schwartz, 1990; and Walton, 1991).*

Material	Aquifer Quality	Porosity %	General Permeability	Hydraulic Conductivity ft/day
Fractured rock (all types)	Good to poor	2 - 10	Permeable to impermeable	10^{-6} - 10^{4}
Massive limestone and dolomite	Good to poor	1 - 10	Permeable to impermeable	10^{-6} - 10^{-1}
Cavernous limestone	Good to moderate	5 - 15	Permeable to semi-permeable	10^{-1} - 10^{4}
Coal	Good to moderate	4 - 23	Permeable to semi-permeable	10^{-1} - 10^{2}
Sandstone	Good to moderate	10 - 35	Permeable to semi-permeable	10^{-4} - 1
Fine-grained sandstone	Moderate to poor	5 - 20	Semi-permeable to impermeable	10^{-5} - 10^{-3}
Siltstone	Moderate to poor	10 - 25	Semi-permeable to impermeable	10^{-7} - 10^{-2}
Shale	Moderate to poor	1 - 10	Semi-permeable to impermeable	10^{-8} - 10^{-3}
Mudstone	Poor	5 - 15	Impermeable	10^{-6} - 10^{-2}
Claystone	Poor	2 - 7	Impermeable	10^{-9} - 10^{-5}
Salt and gypsum	Poor	0.5 - 3	Impermeable	10^{-10} - 10^{-4}

also affect the chemical quality of its ground water. Well- to moderately sorted sandstones, like those found in the Navajo, upper part of the upper Paleozoic, and Dakota aquifers, generally contain less soluble material. Much soluble material is present in the shale and siltstone that underlie large parts of the lower elevation areas in Carbon and Emery Counties. Saline water is common in these lower elevation areas, but even in these areas aquifers may locally contain fresh water. The following formations in Carbon and Emery Counties cause significant deterioration in the quality of water flowing through them:

(1) the Blue Gate Shale and Tununk Shale Members of the Cretaceous Mancos Shale, widely exposed along the base of the Wasatch Plateau and the Book Cliffs;

(2) the Salt Wash and Brushy Basin Members of the Morrison Formation;

(3) the Carmel-Curtis and Summerville Formations and, in the western part of the area, the subsurface Arapien Shale;

(4) the Moenkopi and Chinle Formations; and

(5) the Paradox Formation of the Hermosa Group.

Characteristics of Major Hydrostratigraphic Units

In Carbon and Emery Counties ground water has been withdrawn over the past century from two types of aquifers: (1) fractured, porous-bedrock aquifers and (2) unconsolidated deposits. Most “production” has come from fractured porous-bedrock reservoirs (mainly springs). To simplify the description of ground-water resources, we have divided the stratigraphic section into 17 hydrostratigraphic units, stratigraphic intervals with similar hydrogeologic characteristics. We have characterized each hydrostratigraphic unit as either an aquifer that transmits significant quantities of water to wells and springs, or a confining unit (aquitard) that does not readily transmit water. The characteristics of these hydrostratigraphic units, along with their hydrologic properties, are discussed below and summarized in table 81. All township and range locations are referenced to the Salt Lake Base Line and Meridian.

All of the rocks in Carbon and Emery Counties can be water-bearing to some degree, depending on their permeability, thickness, and location with respect to recharge areas. From oldest to youngest, the bedrock hydrostratigraphic units in Carbon and Emery Counties are the: lower Paleozoic aquifer, middle Paleozoic confining unit, upper Paleozoic aquifer, Triassic confining unit, Navajo aquifer, Carmel confining unit, Entrada aquifer, Curtis confining unit, Morrison aquifer, Morrison confining unit, Dakota aquifer, Tununk Shale confining unit, Ferron aquifer, upper Mancos confining unit, Mesaverde aquifer, Green River aquifer, and Quaternary aquifer.

Lower Paleozoic Aquifer

Cambrian- to Mississippian-age rocks with a total thickness of more than 2,000 feet (5,500 m) comprise the lower Paleozoic aquifer (table 81). The lower Paleozoic aquifer does not crop out and is penetrated by very few wells in Carbon and Emery Counties. Based on the limited data available, the most widespread and transmissive water-bearing formations within the lower Paleozoic aquifer are the Mississippian Redwall Limestone and its equivalent, the Leadville Limestone, and permeable intervals in the overlying Molas and Pinkerton Trail Formations. Rocks are mainly limestone; dolomite; fine-crystalline limestone and dolomite; sandy coarse-crystalline limestone; and interbedded fine-grained sandstone, shale, and siltstone. Ground water occurs in these formations throughout Carbon and Emery Counties. These rock units are hydraulically integrated into one system by joints, bedding plane partings, faults and subsidiary fractures, and cavernous features that enhance certain permeability zones within the rocks. The ability of the unit to transmit water is dependent on these enhanced permeability zones.

Water flowing through the lower Paleozoic aquifer within Carbon and Emery Counties is part of a regional ground-water flow system. Recharge to the lower Paleozoic aquifer is restricted by overlying relatively impermeable rocks, and it is doubtful that there is much recharge over most of the area. Where fracturing and faulting extend through overlying rocks, however, some water probably moves downward. Hydrogeologic data for the lower Paleozoic aquifer in Carbon and Emery Counties are very scarce. It is an important aquifer in southern Utah, particularly in central San Juan County where many of the oil and gas test wells drilled into these rocks have yielded relatively large amounts of water. Formations penetrated by these oil and gas wells range from impermeable to permeable. Undisturbed carbonates have very low permeabilities, but when fractured or cavernous the permeability is very high. Teller and Chafin (1984) reported hydraulic conductivities ranging from 0.00003 to 100 feet/day (ft/d) in sandstones and from 0.01 to 0.04 ft/d for carbonates in the Redwall Limestone. Fractures play an important role in increasing permeability of these rocks, and local structural setting probably plays an important role in controlling the frequency and orientation of fractures.

Water from wells penetrating the lower Paleozoic aquifer in Emery County is very saline to briny with TDS values ranging from 11,445 to 201,512 mg/L (Gwynn, 1995). The higher values are in the eastern part of the county near the Paradox basin (T. 23 S., R. 16 E.) and were collected at depths of 8,200 to 8,700 feet (2,500-2,650 m). The high values suggest some influence from the Hermosa Group evaporites as found in San Juan County where TDS values increase toward the evaporites. The lower values (11,000 to 16,000 mg/L TDS) are in extreme northern Emery County (T. 16 S., R.11 E.) and extreme southern Emery County (T. 26 S., R. 13 E.) at depths of 5,600 to 8,500 feet (1,700-2,600 m). Few data are available from the San Rafael Swell where the aquifer is at its shallowest depth. However, a well in central Emery County (section 28, T. 23 S., R. 10 E.), where these rocks are at relatively shallow depth, contained slightly to moderately saline water (Hood and Patterson, 1984). Fracturing and faulting that extends through the overlying rocks probably allows local recharge from downward leakage in the area. In Utah, ground water from this aquifer south of Carbon and Emery Counties ranges from very saline to briny (Feltis, 1966), although some samples in San Juan County contained only 6,500 mg/L TDS.

Table 81. *Characteristics of hydrostratigraphic units in Carbon and Emery Counties (modified from Cordova, 1964; Feltis, 1966; Price and Miller, 1975; Waddell and others, 1981; Hood and Patterson, 1984; Lines, 1985; Holmes and Kimball, 1987; and Frethey and Cordy, 1991).*

Hydrostratigraphic Unit	Principal Formations	Thickness (Feet)	Principal Lithologies	Hydrologic Characteristics	Water Quality
Quaternary Aquifer	Alluvium, colluvium, and terrace deposits	0-100	Surficial deposits of clay, silt, sand, gravel, and boulders.	In some areas wells yield substantial amount of water, and in other areas deposits are thin and not saturated. Low to high permeability.	Water from these deposits may be fresh. These deposits generally yield saline water because they receive recharge from shaley bedrock and poor quality stream flow.
Green River Aquifer	Douglas Creek, Garden Gulch, and Parachute Creek Mbrs. of the Green River Fm.	100-2,300+	Claystone, shale, and fine-grained sandstone.	Yields water to numerous, small fresh-water springs. Low permeability and generally low yields.	Fresh to saline with quality generally depending on depth.
Mesaverde Aquifer	Colton Fm.; Flagstaff Limestone; North Horn Fm.; Mesaverde Group consisting of the Price River Fm. Castlegate Sandstone, Blackhawk Fm., and Star Point Sandstone	1,100-4,000+	Interbedded sandstone, shale, siltstone, mudstone, claystone, conglomerate, carbonaceous shale, and coal.	Yields water to numerous springs with higher yields where fractured. Transmissivities range from 0.003 to 100 ft^2/d. Individual rock units range from good to poor aquifers, but overall a good aquifer	Fresh to saline with quality generally depending on depth. Some small fresh-water springs.
Upper Mancos Confining Unit	Blue Gate Shale Mbr. of the Mancos Shale	2,800-3,400	Fissile marine shale, silty shale and interbedded siltstone, limestone, and thin sandstone.	Generally not water bearing.	Generally saline water, locally better quality water near surface.
Ferron Aquifer	Ferron Sandstone Mbr. of the Mancos Shale	80-850	Interbedded sandstone, sandy shale, and shale. Important coal beds.	Low to high permeability, with moderate to high permeabilities in the western parts of the counties.	Fresh to saline water, with quality highly dependent on depth.
Tununk Shale Confining Unit	Tununk Shale Mbr. of the Mancos Shale	300-1,000	Thick marine shale, siltstone, limestone, and thin sandstone.	Low permeability except where faulted or fractured.	Water is generally saline, samples from wells contain 11,117 to 12,093 mg/L.
Dakota Aquifer	Dakota Sandstone and Cedar Mountain Fm. including Buckhorn Conglomerate	150-800	Interbedded sandstone, mudstone, siltstone, and conglomerate. Abundance of associated fine-grained rocks, carbonaceous shale, and coal.	Yields water to numerous small springs. Low to moderate permeability. Reported hydraulic conductivity ranges from 0.00003 to as much as 1 ft/d. Overall probably a moderate aquifer.	Fresh to slightly saline water. Where deeply buried, aquifer probably yields water of greater salinity.
Morrison Confining Unit	Brushy Basin Mbr. of the Morrison Fm.	150-500+	Variegated siltstone, mudstone, and claystone. Minor conglomeratic sandstone.	Generally not water bearing. Permeability generally very low. Can yield small quantities of water near outcrop areas.	Generally saline, but small amounts of fresh water from some springs.
Morrison Aquifer	Salt Wash and Tidwell Mbrs. of the Morrison Fm.	50-600	Fine- to coarse-grained sandstone and conglomeratic sandstone interbedded with shale, mudstone, and siltstone. Some limestone and gypsum at the base.	Sandstone yields small supplies of water locally. Moderate to low permeability. Where fully saturated has good potential for supplying water.	Supplies small amounts of slightly saline water to wells and springs. Fresh water from some springs. Deeper ground water likely to be slightly to moderately saline.
Curtis Confining Unit	Summerville Fm., Curtis Fm., and upper Entrada Fm.	250-700+	Thin, but continuous siltstone, mudstone, and sandstone. Some glauconitic marine sandstone, limestone, shaley sandstone, sandy shale, and gypsum.	Generally not water bearing. Generally low to very low permeability.	Generally saline water.
Entrada Aquifer	Middle and lower Entrada Fm.	150-800	Fine-grained, cross-bedded sandstone with some siltstone and shale.	Yields small supplies of water where fractured. Low to moderate permeability. Hydraulic conductivity can range from 0.00001 to 1 ft/d.	Provides fresh ground water south of Emery County. In Emery County produces small amounts of slightly to moderately saline water.
Carmel Confining Unit	Carmel Fm.	50-500+	Limestone, siltstone, gypsum, anhydrite, shale, shaley sandstone, and sandy shale.	Yields small, localized supplies of water.	Fresh to moderately saline.
Navajo Aquifer	Page Sandstone, Navajo Sandstone, Kayenta Fm., and Wingate Sandstone	600-1,600	Cross-bedded, fine- to medium-grained sandstone with minor, thin limestone, claystone, and conglomerate.	Yields moderate to good supplies of water where fractured.	Fresh water is produced in some areas. TDS ranges from 239 to 8,839 mg/L in the subsurface.
Triassic Confining Unit	Chinle Fm. and Moenkopi Fm.	700-1,500	Interbedded siltstone, mudstone, claystone, shale, and fine- to medium-grained sandstone. Minor amounts of limestone and conglomeratic sandstone.	Not water bearing.	Slightly saline to moderately saline water.
Upper Paleozoic Aquifer	Black Box Dolomite (Kaibab of past). White Rim Sandstone, Elephant Canyon Fm., upper Honaker Trail Fm., and Pakoon Dolomite.	1200+	Fine- to medium-grained, cross-bedded sandstone, siltstone, sandy siltstone, limestone, and dolomite.	Yields small to moderate supplies of water. Permeability can be as high as 1,148 millidarcies, but averages 403 millidarcies in the sandstones.	Fresh to very saline water. TDS ranges from 3,531 to 40,916 mg/L in the subsurface, but shallow areas can have fresh water.
Middle Paleozoic Confining Unit	Lower Honaker Trail Fm. and Paradox Fm.	0-1,500+	Halite with interbeds of gypsum, anhydrite, dolomite, siltstone, shale, limestone, and cherty limestone.	Generally not water bearing, but does contain some thin, interbedded clastic-carbonate units that can yield low to moderate amounts of water if fractured.	Brine.
Lower Paleozoic Aquifer	Pinkerton Trail Fm., Molas Fm., Doughnut Fm., Humbug Fm., Redwall Limestone, Ouray Limestone, Elbert Fm., Lynch Dolomite, Maxfield Limestone, Ophir Fm., and TinticQuartzite.	2,000+	Thick, massive limestone with some siltstone, sandstone, and shale.	Can yield moderate amounts of water, especially where fractured. Hydraulic conductivities for sandstones range from 0.00003 ft/day to 100 ft/d and carbonates range from 0.00006 ft/day to 600 ft/d.	TDS ranges from 21,062 to 201,512 mg/L. Poor quality water is chemically unsuitable for most uses.

The depth of rocks belonging to the lower Paleozoic aquifer ranges from 3,500 feet (1,050 m) in the southern part of the San Rafael Swell in central Emery County to over 10,000 feet (3,000 m) in Carbon County. Although the lower Paleozoic aquifer contains considerable water in storage, it is probably not feasible to develop the resource because of its great depth and generally poor water quality.

Middle Paleozoic Confining Unit

The middle Paleozoic confining unit consists of rocks ranging in age from Middle to Late Pennsylvanian (table 81). This unit is not exposed in Carbon and Emery Counties but is penetrated by a number of oil and gas exploration wells in the counties. It consists of black shales and thin salt beds that interfinger with undifferentiated marine rocks and forms an almost uninterrupted confining unit in some areas (Hite, 1970). Stratigraphic thinning to the north and west away from the depositional center of this unit indicates that it could be missing from northern and western Carbon and western Emery Counties. The middle Paleozoic confining unit has low permeabilities and contains little water in Carbon and Emery Counties. Farther south in Utah, the middle Paleozoic confining unit generally consists of aquitards with some isolated high-permeability reservoirs in the Honaker Trail Formation and, to a lesser extent, the Paradox Formation.

Upper Paleozoic Aquifer

The upper Paleozoic aquifer consists of Late Pennsylvanian to Permian-age rocks, with a total thickness of more than 1,200 feet (370 m) in Carbon and Emery Counties (table 81). It includes, from top to bottom: the Black Box Dolomite, which consists of limestone, dolomite, and thin shale with sandstone near its base; the White Rim Sandstone, which consists of mainly large-scale cross-bedded, fine-grained sandstone with subordinate flat-bedded sandstone and minor limestone; the Organ Rock Shale, which consists of fine-grained sandstone, mudstone, and siltstone; the Cedar Mesa Sandstone, which consists of massive, cross-bedded sandstone; the Elephant Canyon Formation and equivalent Pakoon Dolomite which consist of limestone, cherty limestone, sandstone, siltstone, and shale; and the upper Honaker Trail Formation, which consists of limestone, arkosic sandstone, siltstone, and shale. The upper part of the aquifer is predominantly sandstone and dolomite and the lower part limestone. The Permian-age Black Box Dolomite and underlying White Rim Sandstone (upper part of the aquifer) crop out in the center of the San Rafael Swell and are the oldest rocks exposed in Emery County. The thickness of the Black Box Dolomite ranges from 0 to 100 feet (0-30 m) in the San Rafael Swell in Emery County. The White Rim Sandstone has an exposed thickness of about 650 feet (200 m) in the San Rafael Swell area, but appears to be about 880 feet (270 m) thick to the southwest in a well in section 28, T. 24 S., R. 10 E. (Hawley and others, 1968).

The upper Paleozoic aquifer is part of the regional ground-water flow system over most of Carbon and Emery Counties and part of the intermediate and local ground-water flow systems in central Emery County in the San Rafael Swell area. Figure 50 shows the outcrop area and the calculated potentiometric surface of the upper Paleozoic aquifer. In all of Carbon and part of Emery County recharge to the upper Paleozoic aquifer is restricted by overlying relatively impermeable rocks, and it is doubtful there is much recharge in most of the area. However, where fracturing and faulting extend through overlying rocks some recharge is possible. The San Rafael Swell contains outcrops of the upper Paleozoic aquifer and is part of a potentially significant recharge area that extends along its east flank (figure 51). Precipitation directly on the Black Box Dolomite, White Rim Sandstone, and fractured sedimentary rocks that overlie the upper Paleozoic hydrostratigraphic unit provide local recharge to the aquifer. Local and intermittent ground-water flow systems develop in these areas of local relief near the outcrop of the aquifer. Natural discharge from the upper Paleozoic aquifer is limited to small, scattered springs emanating from the Permian formations in the San Rafael Swell. These springs represent perched zones overlying the more regional water table of the upper Paleozoic aquifer. The aquifer itself consists of discontinuous zones of porosity extending throughout Carbon and Emery Counties, with ground-water flow strongly controlled by porosity distributions related to depositional facies trends. The aquifer is characterized by a sequence of permeable, water-bearing zones and leaky, less permeable zones integrated into one aquifer by fractures in its upper part and cavernous zones and fractures in its lower part. Because of recrystallization, the primary permeability of the Black Box Dolomite is almost zero, but significant secondary permeability is present due to solution features, fracturing, and bedding-plane partings. Laboratory permeabilities of the White Rim Sandstone in the San Rafael Swell average 1,148 millidarcies, and the permeability of other Permian sandstones are about 403 millidarcies (Jobin, 1962). Permeability in much of the aquifer is predominantly secondary, the results of fracturing and bedding-plane separation in clastic rocks and fracturing and dissolution in carbonate rocks.

Ground-water quality for the upper Paleozoic aquifer is generally poor, ranging from fresh to very saline although only a few areas have been sampled. TDS concentrations in oil and gas wells range from 3,531 mg/L near Wellington (T. 15 S., R. 11 E.) to more than 40,916 mg/L near Woodside (T. 18 S., R. 14 E.) (Gwynn, 1995). Samples from wells in southeastern Emery County contain 18,000 to 20,000 mg/L TDS. Water from springs in the White Rim Sandstone south of Carbon and Emery Counties contain from 2,470 to 4,060 mg/L TDS (Feltis, 1966). Warm springs at the top of the Black Box Dolomite (T. 21 S., R. 12-13 E.) along the San Rafael River also contain moderately high TDS and apparently also contain dissolved hydrogen sulfide and possibly carbon dioxide. The springs form sulfur and travertine deposits (Hawley and others, 1968). Ground-water quality is highly variable in the permeable zones comprising the upper Paleozoic aquifer. In areas with enhanced permeability and near outcrops there is some potential to obtain some good-quality ground water from the upper sandstones in the upper Paleozoic aquifer.

Development of the upper Paleozoic aquifer is possible in areas where it is at shallow depths, but well yields are typically low. In most of Carbon County the aquifer is at depths greater than 6,000 feet (1,800 m), and in Emery County the aquifer is at depths between 0 and 8,000 feet (0-2,400 m). The aquifer is generally too deep to be an economically feasible target, and water quality is generally poor.

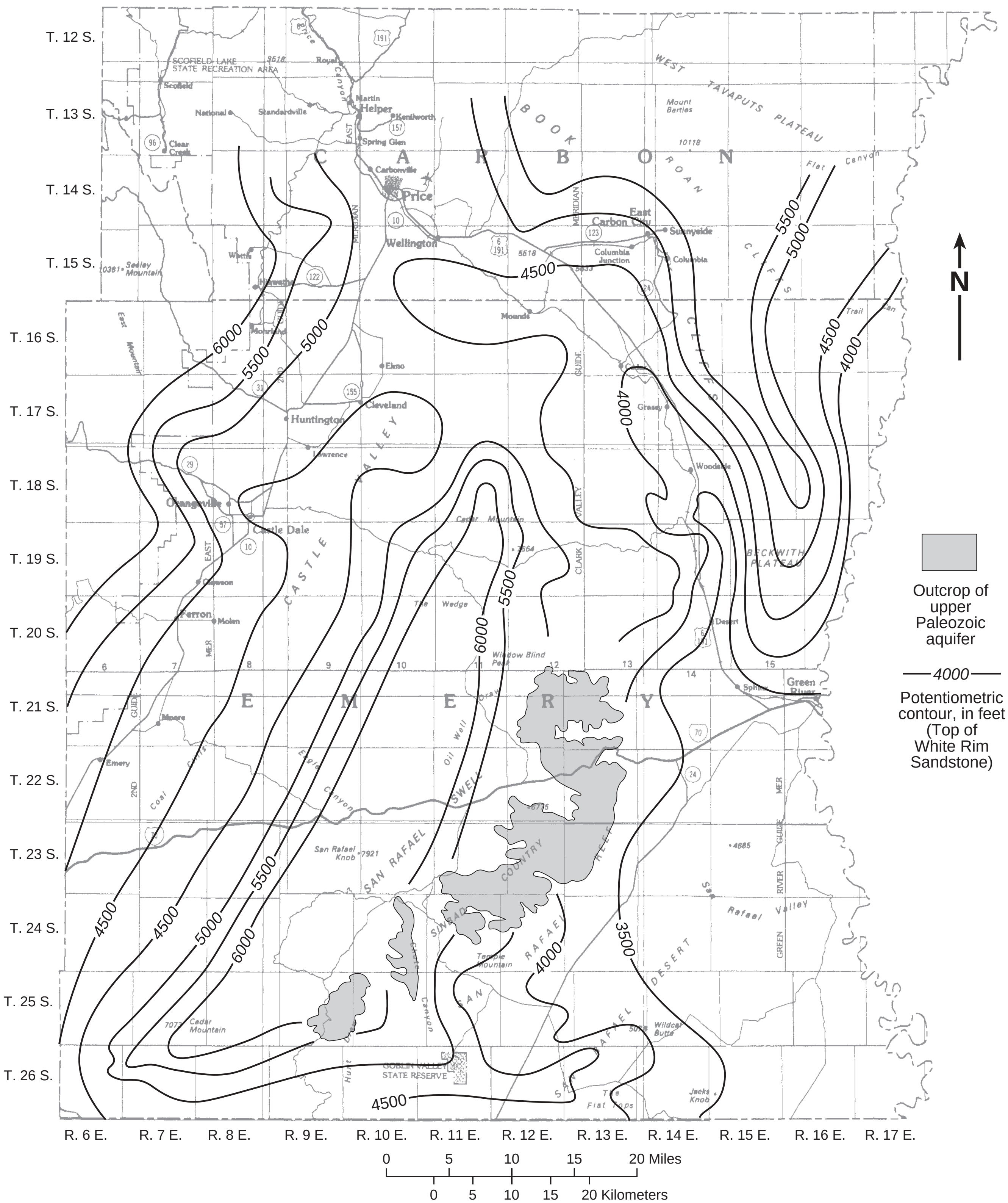


Figure 50. *Outcrop of upper Paleozoic aquifer and potentiometric surface. Outcrop from Hintze (1980) and calculated potentiometric contours from Tripp (1993).*

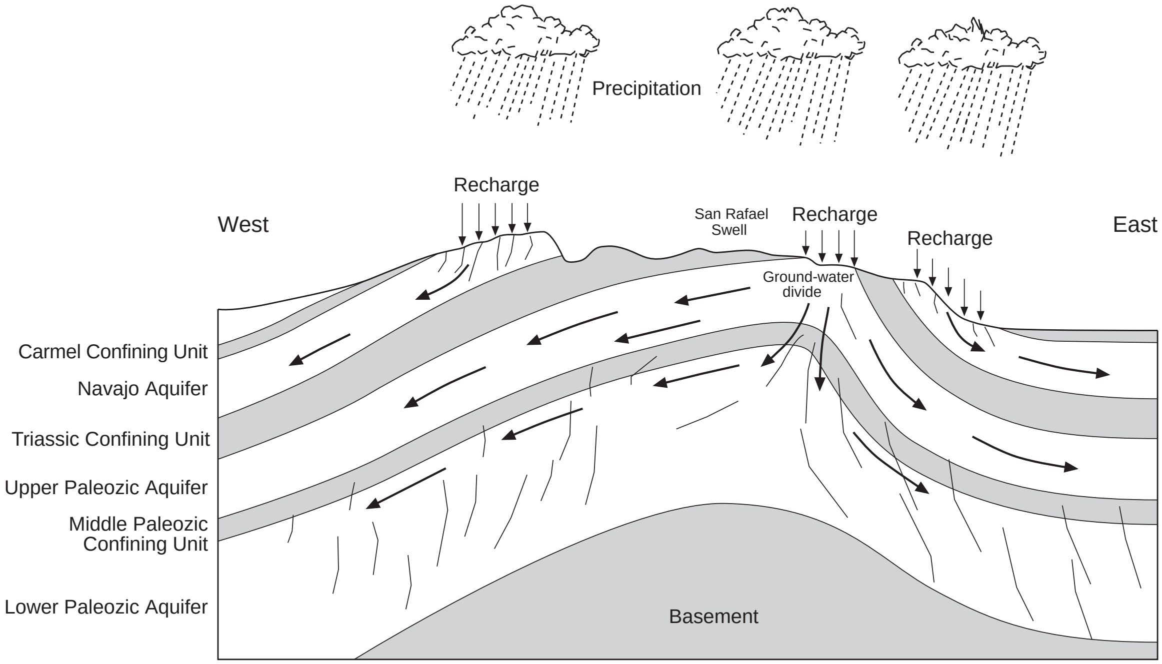


Figure 51. *Diagrammatic section showing recharge and ground-water flow patterns of Lower and Upper Paleozoic aquifers and Navajo aquifer across San Rafael Swell, Emery County.*

Triassic Confining Unit

The Triassic confining unit consists of the Moenkopi and Chinle Formations (table 81). It underlies most of Carbon and Emery Counties and is exposed around the San Rafael Swell and as isolated buttes and mesas in west-central Emery County. This confining unit is perhaps one of the most effective barriers to water migration in Carbon and Emery Counties (Freethey and Cordy, 1991). As a whole the Triassic confining unit acts as an aquitard, with permeable units confined to thin sandstone beds. Some low-yield wells and small springs could be developed in these sandstone beds, particular close to the outcrops. Water quality would be highly variable depending on depth and host-rock lithology.

Navajo Aquifer

Early to Middle Jurassic rocks, with a total thickness averaging about 1,200 feet (370 m) in the San Rafael Swell, comprise the Navajo aquifer (table 81). These rocks are relatively resistant to erosion and produce a distinctive escarpment around the San Rafael Swell. Figure 52 shows the circular outcrop pattern of the Navajo aquifer and, where data are available, its calculated potentiometric surface. The potentiometric contours are based on a small data set and regional computer modeling (Hood and Patterson, 1984). Built into these potentiometric contours is the assumption that no water enters the area from the north and northwest because of the depth and lack of outcrops. This assumption basically controls the direction of the contours in the northern part of the area. Rocks comprising the Navajo aquifer include, from oldest to youngest: the Wingate Sandstone, 200 to more than 400 feet (60-120 m) thick; the Kayenta Formation, 100 to more than 250 feet (30-75 m) thick; the Navajo Sandstone, 300 to more than 500 feet (100-150 m) thick; and the Page Sandstone, 0 to 80 feet (0-25 m) thick. The Page Sandstone is included in the Navajo aquifer because of its lithologic similarity and proximity to the underlying Navajo Sandstone. The aquifer is predominantly sandstone with some claystone and minor limestone. This widespread sequence of predominantly non-marine sandstone is one of the most important aquifers in southern Utah and underlies all of Carbon County and part of Emery County.

The Navajo aquifer is part of the regional ground-water flow system in most of Utah where it is present, and forms intermediate and local flow systems in Emery and Carbon Counties near the San Rafael Swell. The dominant ground-water flow direction follows the dip of the rocks in the area and is away from the San Rafael Swell, where the more closely spaced potentiometric-surface contours indicate higher hydraulic gradients. Where the Navajo aquifer is exposed in Emery County, recharge is by direct precipitation on the outcrop. Intermediate and local flow systems develop in the Navajo aquifer near outcrop areas, enhanced by increased permeability due to regional fracture systems. The aquifer is generally a well-cemented, fine-grained sandstone with substantial secondary permeability as a result of fractures and bedding-plane separations. The Navajo aquifer is probably saturated a short distance downdip from outcrops in Emery County and everywhere in Carbon County. Relatively impermeable overlying rocks restrict recharge to the Navajo aquifer in all of Carbon County and much of Emery County. Where fracturing and faults extend through overlying rocks, however, water can move downward into the Navajo aquifer.

The Navajo aquifer consists of discontinuous zones of porosity extending throughout Carbon and Emery Counties, with ground-water flow strongly controlled by porosity dis-

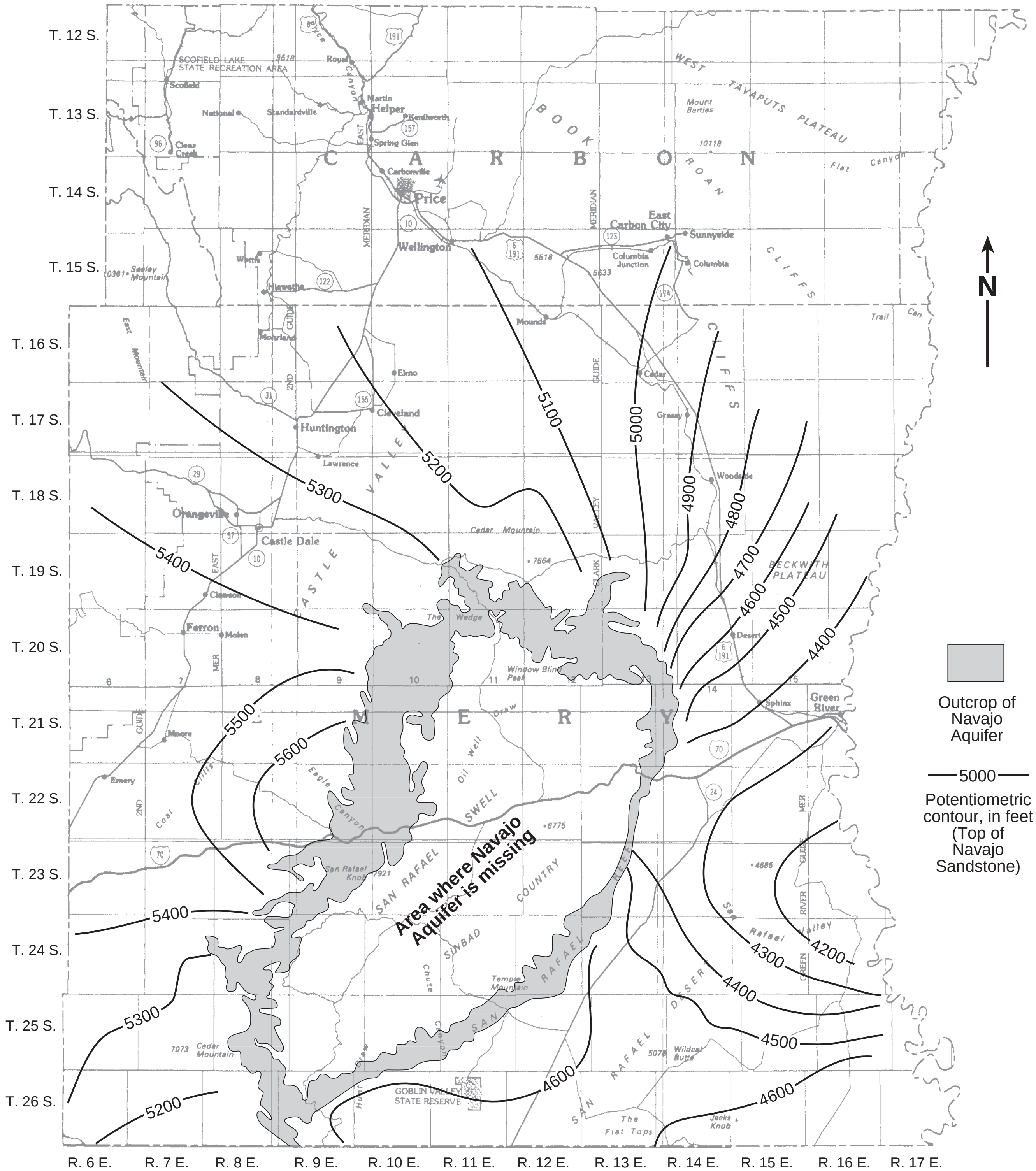


***Figure 52.** Outcrop of Navajo aquifer and potentiometric surface. Outcrop from Hintze (1980) and calculated potentiometric contours from Hood and Danielson (1981).*

tributions related to depositional facies trends. Laboratory measurements show relatively high permeability in the Navajo Sandstone, moderate permeability in the Kayenta Formation, and good permeability in the Wingate Sandstone (Jobin, 1962). In-situ permeabilities are probably low to moderate throughout the aquifer because of the fine-grained nature of the rocks. Erratically distributed fracturing can locally enhance or decrease permeability. Hydraulic conductivity values for the Navajo aquifer in southern Emery County range from 0.1 to 10 ft/d (Freethey and Cordy, 1991). The Navajo aquifer's hydraulic conductivity is probably high in the moderately deformed rocks east of the San Rafael Swell, somewhat lower in less deformed rocks to the west, and decreases even more where the rocks are at greater depth to the north.

Water samples from the Navajo aquifer in southern Carbon and northern Emery Counties are moderately saline with TDS concentrations ranging from 8,839 mg/L (3,000-foot deep [910 m] well in T. 15 S., R. 13 E.) to 5,180 mg/L (3,200-foot-deep [975 m] well in T. 18 S., R. 14 E.) (Gwynn, 1995). Water quality is better to the south, and the Navajo aquifer contains relatively fresh water in the northern part of the San Rafael Swell (Hood and Patterson, 1984). Water from wells in the areas where the Navajo aquifer crops out in San Juan County is relatively fresh (239 to 403 mg/L TDS in T. 40 S., R. 21-22 E.) (Feltis, 1966) and similar conditions should be present in the San Rafael Swell. The water quality should be moderate to good around the southern and western San Rafael Swell (even though there are few samples available for confirmation). Samples taken downdip in easternmost Emery County are only slightly saline (2,084 mg/L TDS) even 15 to 20 miles (24-32 km) from the outcrop.

The Navajo aquifer is at depths of 0 to 5,000 feet (0-1,500 m) in Emery County. In Carbon County, it is at depths of 4,000 to more than 12,000 feet (1,200-3,700 m). Development of the aquifer in Carbon County would probably not be economical due to the depth of the aquifer and the generally poor water quality at these depths. Some development of the aquifer in Emery County is possible where there is a thick saturated zone at shallow depths. The aquifer is at depths of 2,000 feet (600 m) or less in western Emery County and should contain moderate to good-quality water. Unfortunately, few towns or communities are located in the favorable areas. The Navajo aquifer yields water to many wells and springs in Emery County and is used extensively as an aquifer in other areas of Utah.

Carmel Confining Unit

The Carmel confining unit consists of the Middle Jurassic-age Carmel Formation (table 81). It is relatively thin in southwestern Emery County, 50 to 100 feet (15-30 m) thick, but thickens to the north where it is 500 feet (150 m) or more thick in northwestern Carbon County. The unit is entirely marine strata, in contrast to the continental strata in the underlying rocks. It was deposited along the eastern margin of a northeast-trending marine trough and consists of deep-water limestone, and gray, orange-red, and greenish shale (Hintze, 1980). The hydrologic character of this unit is variable, but permeability is generally low. In most areas, the Carmel forms a confining unit above the Navajo aquifer. The Carmel Formation has yielded minuscule amounts of water ranging from fresh to moderately saline (Feltis, 1966).

Entrada Aquifer

The Entrada aquifer consists of Middle to Late Jurassic sandstone and siltstone (table 81) of the Entrada Sandstone. In much of Carbon and Emery Counties the Entrada aquifer is a fine-grained, marginal-marine sandstone. The Entrada aquifer has been eroded away in some of Emery County, but underlies all of Carbon County. The aquifer varies from 150 to 800 feet (45-240 m) in thickness and crops out as steep slopes and cliffs in Emery County. The Entrada aquifer generally increases in thickness and becomes finer grained to the west. Figure 53 shows the outcrop pattern of the Entrada aquifer and a calculated potentiometric surface, where data are available.

The Entrada aquifer is part of both the intermediate and local ground-water flow system in the area. Recharge occurs from infiltration of precipitation on outcrops, and through Quaternary deposits where the Entrada aquifer is at shallow depths. Aquifer rocks dip away from the outcrop areas around the San Rafael Swell, and ground water subsequently flows away from the swell. Leakage from overlying rocks, most likely associated with fractures, also recharges the aquifer. The aquifer is saturated in most of Carbon and Emery Counties, but in some areas of southeastern Emery County, where it is under shallow cover, unsaturated zones are present (Freethey and Cordy, 1991). The primary permeability of the Entrada aquifer is low to moderate and varies with the proportions of sand and silt and degree of sorting. Jobin (1962) postulated a low-permeability region over the San Rafael Swell area, where the Entrada aquifer is eroded, based on laboratory permeability measurements from surrounding areas. However, the permeability of these clastic rocks is predominantly secondary, the result of fracturing and bedding-plane separations. Hydraulic conductivity values for the Entrada aquifer are scarce in Carbon and Emery Counties, but a few values derived from laboratory tests on drill cores and outcrop samples in widely scattered parts of Emery County are available. Tests indicate that in Emery County north of the San Rafael Swell the Entrada aquifer is a moderate to poor aquifer with hydraulic conductivity ranges of less than 0.00001 to 0.001 ft/day. In southern Emery County it is a good to moderate aquifer with hydraulic conductivity ranges of 0.001 to 1 ft/day (Freethey and Cordy, 1991).

Water quality in the Entrada aquifer is variable, with the aquifer yielding fresh water in some areas and saline water in others (Feltis, 1966). A well in northeastern Emery County (T. 16 S., R. 14 E.), at a depth of 6,000 feet (1,800 m), produced moderately saline water with a TDS concentration of 8,305 mg/L (Gwynn, 1995). The Entrada aquifer yields fresh to moderately saline water to wells in Emery, Kane, and Wayne Counties, with TDS concentrations varying from approximately 380 to 3,500 mg/L. Wells in southern and eastern Emery County produce slightly to moderately saline water, and wells in Wayne County produce fresh water (Feltis, 1966). Springs that issue from the Entrada aquifer in Grand and Wayne Counties generally have fresh water with TDS concentrations ranging from about 190 to 740 mg/L (Feltis, 1966).

The extensive thickness of the Entrada aquifer suggests that it contains a large volume of stored water. However, the overall poor hydraulic properties of the aquifer may prevent the development of high-yield wells, and in some areas water

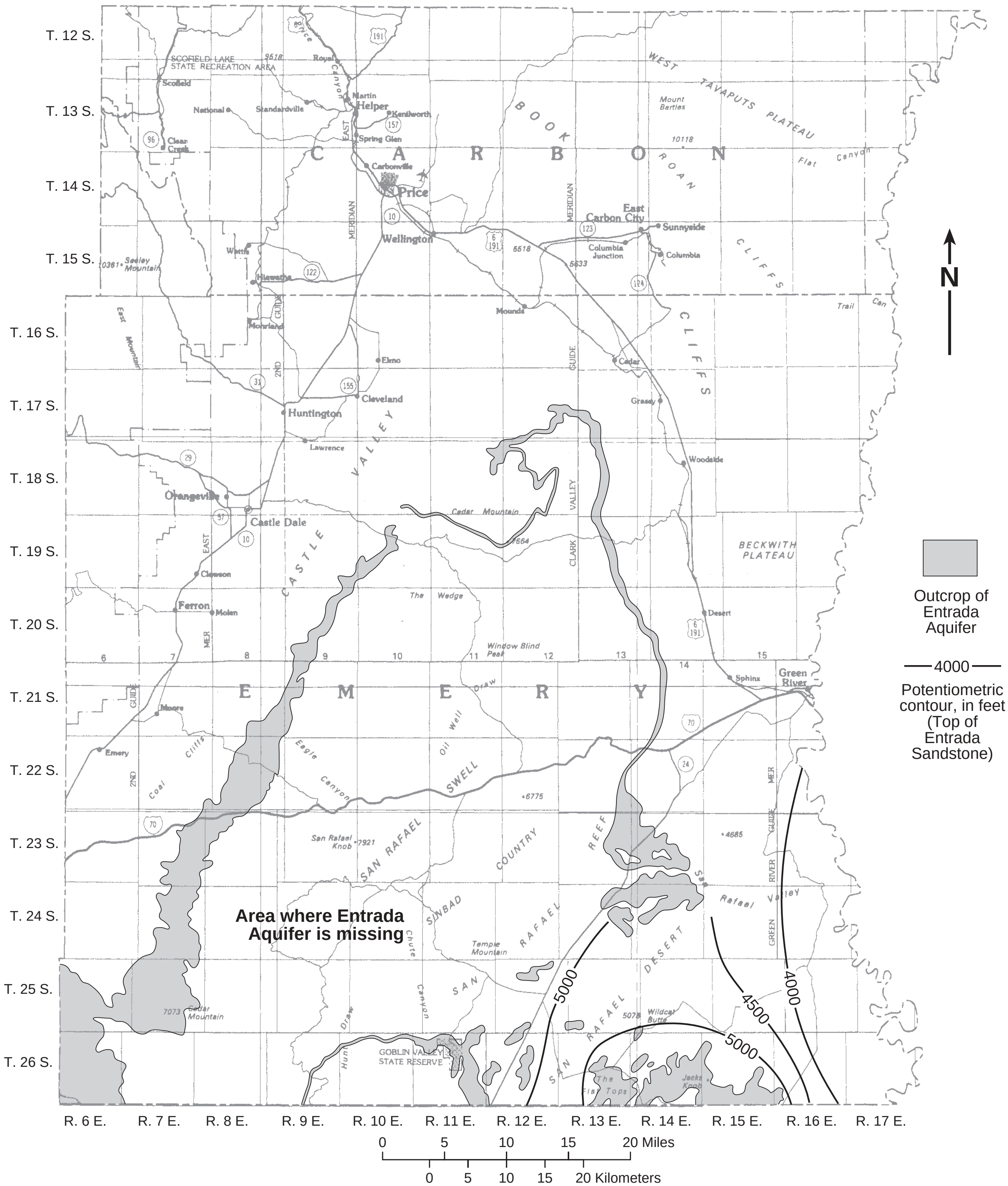


***Figure 53.** Outcrop of Entrada aquifer and potentiometric surface. Outcrop from Stokes (1963) and measured potentiometric contours from Freethey and Cordy (1991).*

quality may be too poor for some uses. In Emery County the Entrada aquifer has some potential for development, particularly where rocks overlying the Entrada aquifer are less than 2,000 feet (600 m) thick, and water quality is good. In southern Emery County the Entrada water quality is better. In Carbon County the potential is lower because the Entrada aquifer is deeper than 2,000 feet. Obtaining water from these depths may be economically unfeasible due to high drilling costs, and water from these depths is commonly unsuitable for most uses because of high TDS concentrations.

Curtis Confining Unit

The Curtis confining unit consists of Late Jurassic rocks (table 81) belonging to the upper Entrada, Curtis, and Summerville Formations. The confining unit is comprised exclusively of marine rocks in contrast to the marginal marine nature of the underlying rocks. The confining unit thickness ranges from 250 feet (75 m) in the east to more than 700 feet (210 m) in the west and from 400 feet (120 m) in the north to about 200 feet (60 m) in the south. The Curtis confining unit is composed of thin, continuous horizons of interbedded, locally gypsiferous siltstone, mudstone, sandstone, and marine limestone deposited during repeated transgressions and regressions of the Jurassic sea. These rocks weather to form gentle to steep debris-covered slopes with projecting sandstone ledges. The hydrologic character of this unit is variable, but permeability is generally low (Jobin, 1962). The Curtis confining unit has little potential to yield water because of a high percentage of siltstone and mudstone and generally acts as a confining unit above the Entrada aquifer.

Morrison Aquifer

The Morrison aquifer of Late Jurassic age consists of sandstone and conglomerate with minor shale (table 81). It contains thick, lenticular, fine- to coarse-grained sandstone and conglomerate of fluvial origin. The contact with the overlying confining unit is not well defined but is arbitrarily placed at the top of the uppermost relatively continuous sandstone of the Salt Wash Member of the Morrison Formation (Freethey and Cordy, 1991). The aquifer thickness ranges from more than 600 feet (180 m) in the north to less than 50 feet (15 m) in the extreme southwest part of Emery County. Over most of Carbon and Emery Counties the Morrison aquifer is 200 or more feet (60 m) thick. The Morrison aquifer underlies all of Carbon County but is missing from the central part and most of the southern part of Emery County. It forms distinctive, craggy, blocky to ledgy outcrops with wide benches. Figure 54 shows the outcrop pattern of the Morrison aquifer.

Intermediate and local flow systems develop in the Morrison aquifer within the area. The Morrison aquifer is largely undeveloped but yields water in many outcrop areas where springs are quite common. Recharge to the Morrison aquifer is by direct precipitation on its outcrops and by downward movement of water through overlying rocks if significantly fractured. Generally, the Morrison aquifer is fully saturated except in southwestern Emery County where it is only partially saturated as a result of both thinning and an increased percentage of fine-grained rocks in the aquifer (Freethey and Cordy, 1991). No water-level data are available to construct a potentiometric surface, and the overall direction of ground-water movement is unknown. In Emery County the hydraulic properties of the aquifer, determined mostly from laboratory tests on outcrop samples, indicate it is a good to moderate aquifer in the northern and eastern parts of the county and a moderate aquifer in the southeastern part of the county. Morrison permeability and hydraulic conductivities decrease to the north-northeast because of decreasing grain size (Jobin, 1962). The permeability of the rocks is highly variable but usually is low. Laboratory hydraulic conductivities for the Morrison aquifer range from 0.75 to 2.4 ft/d (Freethey and Cordy, 1991). Transmissivities are probably higher to the north because of increasing saturated thickness.

The Morrison aquifer supplies small amounts of slightly saline and occasionally fresh water to springs (Hood and Danielson, 1981; Hood and Patterson, 1984). In the Cedar Mountain area of central Emery County springs yield some fresh water from the aquifer. A spring in central Emery County (T. 19 S., R. 10 E.) yields fresh water with a TDS concentration of 768 mg/L (Feltis, 1966). Wells in Grand County yield water from the Morrison aquifer that is fresh to very saline. A water well (T. 19 S., R. 25 E.) at a depth of about 600 feet (180 m) yielded moderately saline water (7,350 mg/L TDS). Water from an oil and gas well (T. 20 S., R. 22 E.) at a depth of about 2,400 feet (730 m) yielded very saline water (22,584 mg/L TDS). Mines in the Morrison aquifer in Grand County (T. 22 S., R. 22 E. and T. 23 S., R. 22 E.) yield slightly saline (1,430 mg/L TDS) to fresh (759 mg/L TDS) water. Because the Morrison aquifer is largely undeveloped in Carbon and Emery Counties, water quality is relatively unknown. Fresh ground water will generally be found near outcrop areas, and ground water will become more saline with increasing depth.

The Morrison aquifer stores a large volume of water in Carbon and Emery Counties, but much is at depths greater than 2,000 feet (600 m) (Freethey and Cordy, 1991). Water from these depths is likely to be unsuitable for most uses because of high TDS concentrations, and uneconomical to develop because of high drilling costs. However, in areas where the Morrison aquifer is less than 2,000 feet (600 m) deep, development of moderate to good-quality ground water is possible, but the highly variable hydrologic properties of the rocks make well yields difficult to predict. Higher yield wells are more likely on the east side of the San Rafael Swell based on limited transmissivity data.

Morrison Confining Unit

The Morrison confining unit consists of the Late Jurassic Brushy Basin Member of the Morrison Formation (table 81). The confining unit consists of mostly varicolored, poorly sorted, horizontally laminated mudstone, siltstone, and claystone with some channel sandstone. The abundant clays in the confining unit impede seepage and block downward movement of ground water (Freethey and Cordy, 1991). The thickness of the Morrison confining unit is variable but ranges from 150 to more than 500 feet (45-150 m). The lower contact is gradational with the underlying Morrrison aquifer, and the upper contact is a major regional unconformity. It is a highly effective confining unit because of its continuity, impermeability, thickness, and high percentage of swelling clays (Freethey and Cordy, 1991).

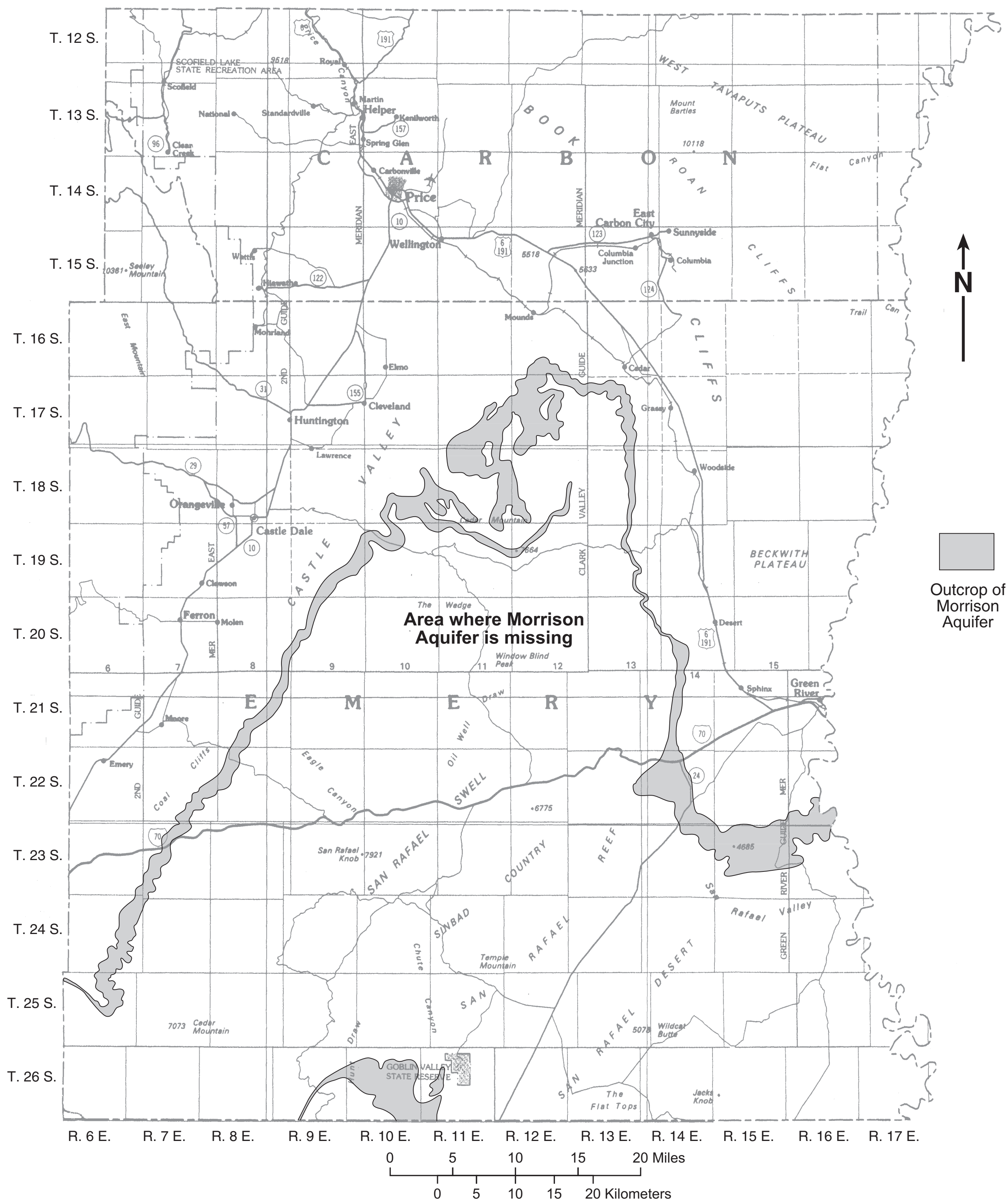


Figure 54. *Outcrop of Morrison aquifer (from Stokes, 1963).*

Dakota Aquifer

The Dakota aquifer consists of Early to Late Cretaceous sandstone, conglomeratic sandstone, conglomerate, mudstone, shale, siltstone, and interbedded thin beds of shale and coal (table 81). These strata were deposited along the margins of an interior sea in nearshore, marine, deltaic, and fluvial depositional environments. In this aquifer, sandstone and mudstone are the dominant rock types, with conglomerate horizons usually associated with sandstone units both near the base and within the aquifer. Impure coaly and carbonaceous rocks, deposited along the margins of the marine sea, are common throughout the aquifer sequence, but relatively good coal beds occur only in a few places. The aquifer includes the Buckhorn Conglomerate, Cedar Mountain Formation, and Dakota Sandstone. The aquifer is present in Carbon County and northwestern and northeastern Emery County, but is absent in central and southern Emery County. The aquifer has a broadly curving outcrop pattern stretching across much of Emery County and generally forms low, inconspicuous cuesta ridges above the rough hills and badlands of the Morrison Formation. Figure 55 shows the outcrop pattern of the Dakota aquifer and its calculated potentiometric surface where data are available. The thickness of the aquifer generally increases from less than 150 feet (45 m) in southwestern Emery County to more the 800 feet (240 m) in Carbon County to the north; however, the thickness is quite irregular even over short distances. An unconformity marks the base of the aquifer, and several unconformities are present within the aquifer. The upper contact with the overlying confining unit is conformable. Locally, the Dakota aquifer can be a confining unit due to interbedded shale and siltstone, but the lower part is usually an aquifer due to the abundance of conglomerates at the base of the aquifer (Freethey and Cordy, 1991).

Intermediate and local flow systems develop in the Dakota aquifer within Carbon and Emery Counties. Recharge to the Dakota aquifer is from leakage from fractured rocks overlying the aquifer and direct precipitation on outcrops. The limited potentiometric surface data suggest that the Wasatch Plateau acts as a major recharge area for the aquifer. In Emery County the saturated thickness of the Dakota aquifer west of the San Rafael Swell ranges from 100 to more than 500 feet (30-150 m) where the overlying rock thickness is less than 2,000 feet (600 m) (Freethey and Cordy, 1991). Outcrops are partly saturated to unsaturated, but the aquifer becomes saturated at depths of 1,000 feet (300 m) or more. The primary permeability of the Dakota aquifer varies from high to low depending on the ratio of sand to fine-grained rocks. The hydraulic conductivity of the Dakota aquifer in Carbon and Emery Counties is largely unknown. Hydraulic conductivity values from oil and gas well tests in western Emery County, where the aquifer is coarser grained, indicate a relatively high hydraulic conductivity (Freethey and Cordy, 1991). Laboratory analyses of hydraulic conductivities of the Dakota aquifer in Emery County range from 0.0001 to 1 ft/d, and oil and gas well tests in western Emery County indicate 1 ft/d (Freethey and Cordy, 1991). Weigel (1987) reported hydraulic conductivities varying from 0.00003 to 0.028 ft/d, a transmissivity of 0.97 square feet/day (ft^2/d), effective porosities ranging from 1.5 to 9.5 percent, and horizontal permeabilities ranging from 0.01 to 1.5 millidarcies from a well in western Emery County (T. 21 S., R. 6 E.) where the Dakota aquifer is over 4,000 feet (1,200 m) deep. Laboratory analyses showed a hydraulic conductivity of 0.012 ft/d, a horizontal permeability of 18 millidarcies, and an effective porosity of 11.8 percent for a Dakota aquifer sandstone in west-central Emery County (T. 18 S., R. 9 E.) (Weigel, 1987). Transmissivities of the aquifer are generally low because of the abundance of fine-grained rocks.

Water quality in the Dakota aquifer is variable. South of Emery County the aquifer yields fresh to slightly saline water to springs and wells with TDS concentrations ranging from approximately 186 to 1,760 mg/L. In Carbon and Emery Counties, the aquifer has not been sampled extensively. However, the aquifer probably contains poor-quality water in most areas because of leakage from the overlying confining unit. Feltis (1966) reported that the Dakota aquifer contains salty to brackish water. Near outcrops or areas with a good connection to recharge areas the aquifer should contain fresher water.

The Dakota aquifer is an economically feasible water-well target for ground-water development in many areas of Carbon County and possibly also some areas of Emery County (Freethey and Cordy, 1991). In Carbon County, south and west of the Book Cliffs, the Dakota aquifer is saturated, and the overlying rock is not too thick. However, because of the varying hydrologic properties and the abundance of fine-grained rocks, ground-water movement may be locally hampered. However, the unconformities within the Dakota aquifer could be major conduits for ground-water movement and provide good targets for development.

Tununk Shale Confining Unit

The Tununk Shale confining unit consists of the Late Cretaceous Tununk Shale Member of the Mancos Shale (table 81). The Tununk Shale confining unit underlies most of Carbon County and the northern and north-central parts of Emery County. It crops out as a narrow arcuate band in central to northern Emery County. The unit has very low permeability and forms an aquitard that inhibits infiltration of precipitation and recharge to underlying units. It is 300 to 1,000 feet (90-300 m) thick and forms a massive barrier to ground-water movement. Water from wells in this unit in T. 14 S., R. 9 E. tested very saline with TDS concentrations of approximately 11,117 and 12,093 mg/L (Feltis, 1966).

Ferron Aquifer

Within Carbon and Emery Counties the Ferron aquifer (table 81) varies in thickness from 80 feet in the north to 850 feet in the south. It includes the entire thickness of the Late Cretaceous Ferron Sandstone Member of the Mancos Shale. The aquifer forms distinct massive cliffs in southwestern Emery County that become more subdued toward the north. In western Carbon and Emery Counties, the Ferron Sandstone dips westward and is at shallow depths under much of the area. Figure 56 shows the outcrop pattern of the Ferron aquifer and a measured and calculated potentiometric surface where data are available. In western Emery County the Ferron aquifer consists of massive beds of very fine- to fine-grained sandstone, carbonaceous shale, coal, mudstone, and siltstone. In northern and eastern Carbon County and eastern Emery County the Ferron aquifer is a very fine-grained, silty

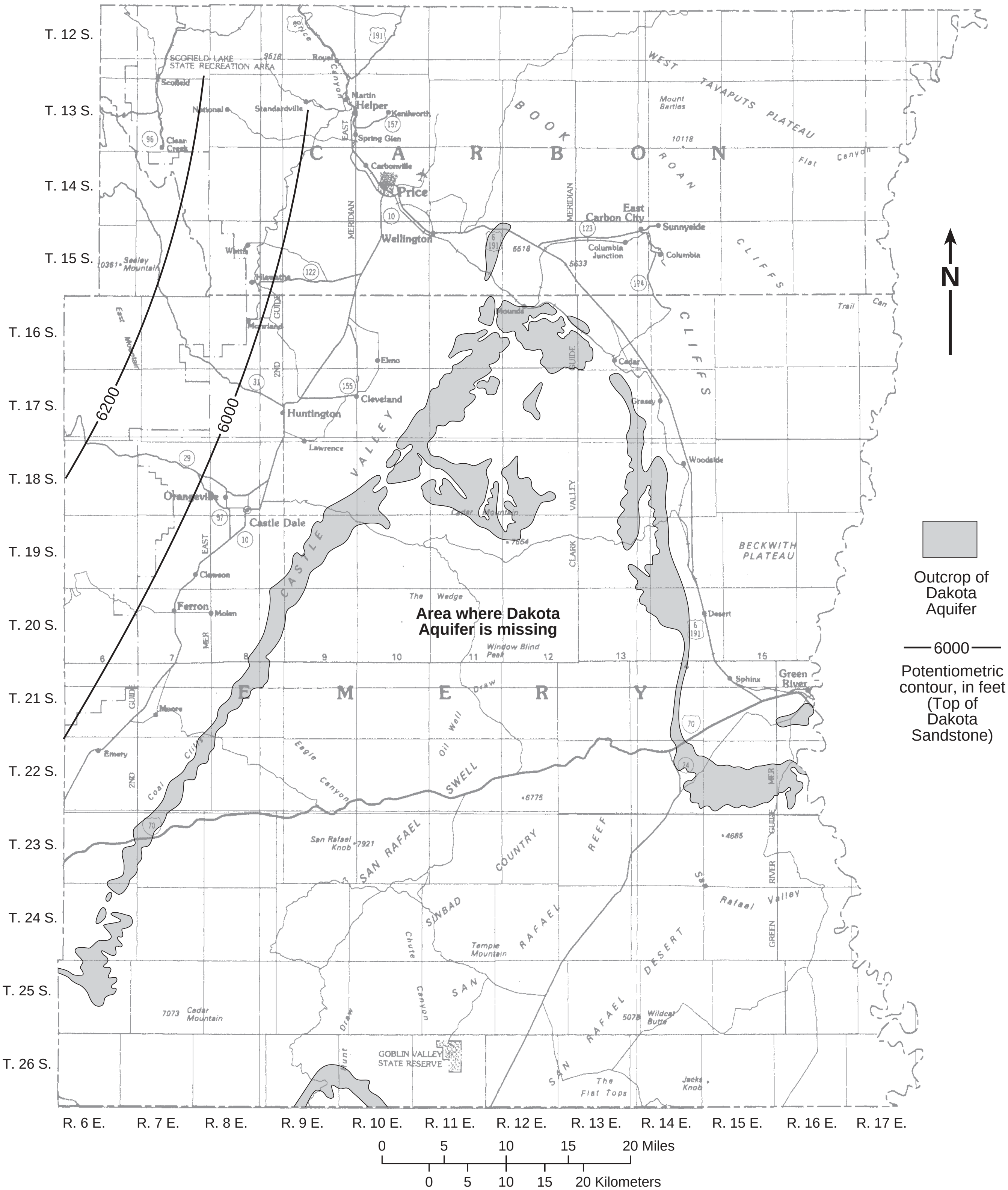


Figure 55. Outcrop of Dakota aquifer and potentiometric surface. Outcrop from Hintze (1980) and calculated potentiometric contours from Freethey and Cordy (1991).

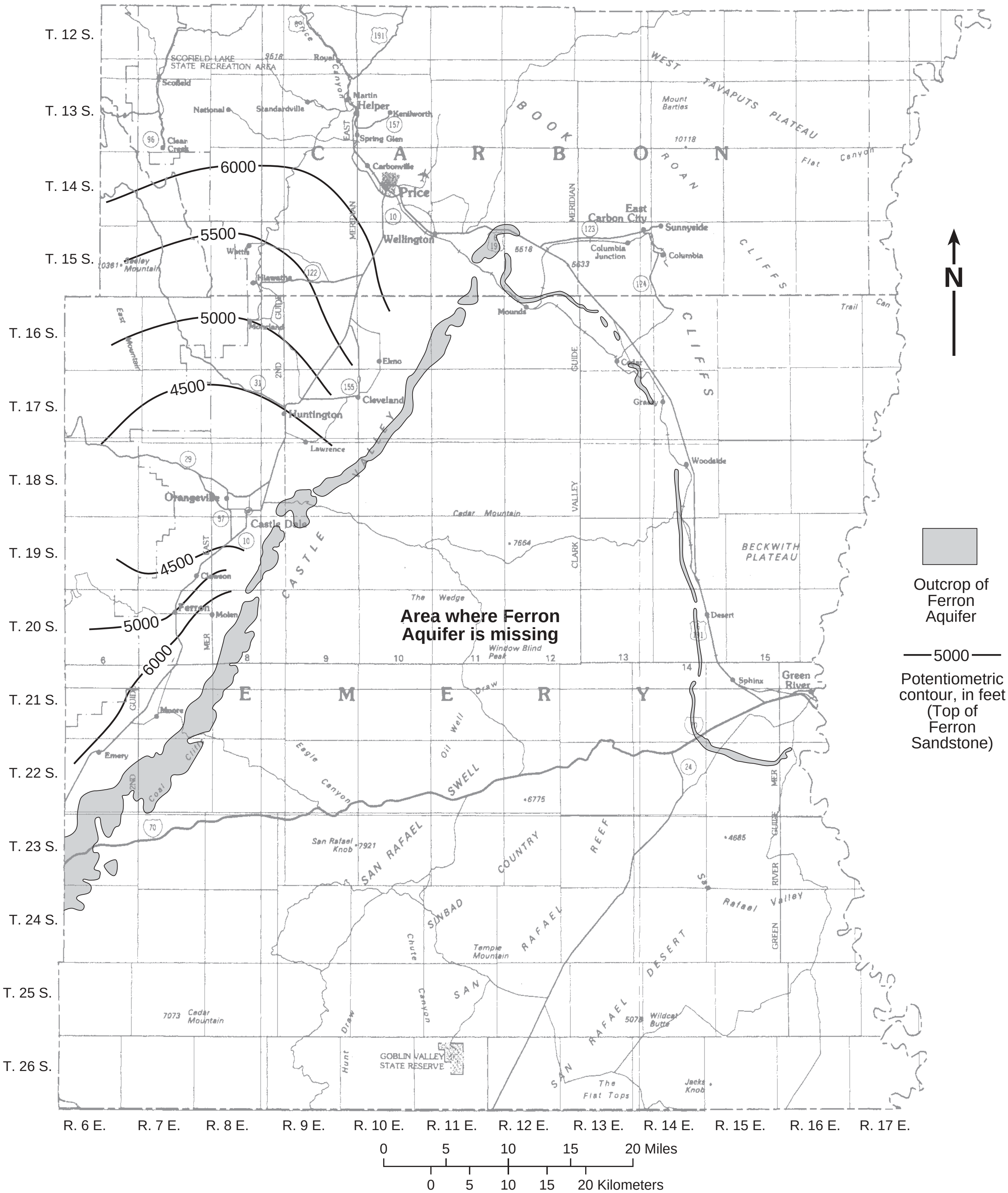


***Figure 56.** Outcrop of Ferron aquifer and potentiometric surface. Outcrop from Hintze (1980) and calculated and measured potentiometric contours from Tabet (1998) and Lines and Morrissey (1983).*

sandstone with abundant, interbedded carbonaceous shale (Lines and Morrissey, 1983).

Intermediate and local flow systems develop in the Ferron aquifer within Carbon and Emery Counties. Ground water in the Ferron aquifer generally belongs to the intermediate flow system, but local flow systems develop in some areas. The potentiometric surface of the aquifer indicates that recharge to the Ferron aquifer is from the west. Rocks overlying the Ferron aquifer in the Wasatch Plateau are generally impermeable; however, near the Paradise-Joes Valley fault system, vertical fractures cause increased permeability (figure 57). Direct precipitation on outcrops and infiltration from streams are additional sources of recharge to the aquifer, particularly for the sizable outcrop area of the aquifer in the Castle Valley area in southwestern Emery County (figure 57). The Ferron aquifer is commonly saturated where buried in western Carbon and Emery Counties (Lines and Morrissey, 1983).

Differences in grain size, degree of cementation, and compaction cause the aquifer to vary greatly in porosity and hydraulic conductivity. In western Emery and Carbon Counties the average hydraulic conductivity for sandstone in the Ferron aquifer is 0.1 ft/d and porosity averages 16 percent (Lines and Morrissey, 1983). Hodder and Jewell (1979) reported an estimated average hydraulic conductivity for the Ferron coals and upper sandstone in the Emery coalfield of 1.743 ft/d and a transmissivity of 174 ft^2/d for a saturated water-producing zone with a thickness of 100 feet (30 m). Lines and Morrissey (1983) reported hydraulic conductivities from laboratory tests ranging from 0.000055 to 0.77 ft/d for the Ferron Sandstone aquifer, but included data from shales within the Ferron Sandstone. In northern and eastern Carbon County and eastern Emery County the permeability and hydraulic conductivity are probably much lower because of the finer grained and siltier nature of the sandstone.

Water quality is quite variable in the Ferron aquifer ranging from fresh to briny. Lines and Morrissey (1983) reported TDS values ranging from less than 500 mg/L to greater than 50,000 mg/L for springs and wells up to 6,000 feet (1,800 m) deep in western Emery County. The Emery City water well (section 4, T. 22 S., R. 6 E.) is developed in the lower part of the Ferron aquifer, and contains about 790 mg/L TDS. Water produced from a coal-bed methane well in Carbon County (T. 14 S., R. 10 E.) contained roughly 6,500 to 9,000 mg/L TDS (Woodward-Clyde Consultants and U.S. Bureau of Land Management, 1995). Water samples collected from deeper wells in central Carbon County (T. 14 S., R. 9 E.) had TDS concentrations of about 37,000 and 51,000 mg/L (Feltis, 1966). In west-central Emery County, TDS values ranged from 3,454 mg/L in a coal mine (T. 22 S., R. 6 E.) to 21,534 mg/L for a well (T. 20 S., R. 7 E.) (Feltis, 1966). Samples from shallow wells in southern Emery County (section 17 and 31, T. 22 S., R. 6 E.) had TDS concentrations ranging from 652 to 2,230 mg/L.

The Ferron aquifer supplies water to private and public-supply wells in west-central Emery County. The Ferron aquifer is an economically feasible water-well target and has suitable characteristics for ground-water development in other areas of Emery County and possibly also in some areas of Carbon County. Although of marginal water quality, the Ferron Sandstone aquifer is probably one of the most attractive targets for additional ground-water development. The Ferron aquifer might be a feasible source of ground water in areas of Carbon County south of the Book Cliffs, where the Ferron aquifer is saturated and relatively close to recharge areas. However, the water quality would most likely be marginal and yields low.

Upper Mancos Confining Unit

The upper Mancos confining unit consists of marine shales of the Late Cretaceous Bluegate Shale Member of the Mancos Shale (table 81). The unit is about 2,800 to 3,500 feet (850-1,050 m) thick in Carbon and Emery Counties. Erosion has removed the upper Mancos confining unit in much of central and southern Emery County. It is exposed in a broad arcuate band in southern Carbon County and northeastern and northwestern Emery County, forming extensive areas of low relief. The confining unit consists of a thick sequence of marine shale and siltstone with some interbed-

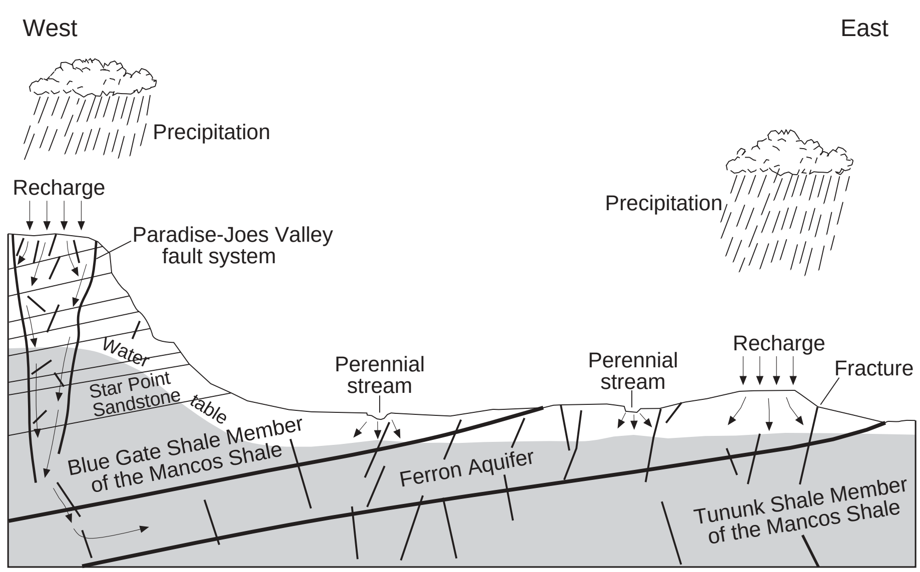


Figure 57. Diagrammatic section showing various recharge sources to Ferron aquifer.

ded sandstone. The sandstones are potential sources of water, but they are fine grained and of limited extent, especially in Emery County. The upper Mancos is an extremely effective confining unit because of its great thickness and continuity of impermeable shale and siltstone units.

Mesaverde Aquifer

The Mesaverde aquifer consists of Late Cretaceous and Paleocene to Eocene rocks (table 81). The Mesaverde aquifer is composed of the Mesaverde Group, consisting of the Star Point Sandstone, Blackhawk Formation, Castlegate Sandstone, and Price River Formation; the North Horn Formation; the Flagstaff Limestone; and the Colton (Wasatch) Formation. The aquifer consists of interbedded sandstone, mudstone, siltstone, shale, coal, and limestone. The thickness of the aquifer is highly variable but is generally greater than 4,000 feet (1,200 m). Rocks of the Mesaverde aquifer represent marine, continental, and lacustrine depositional environments associated with transgressions and regressions of a Late Cretaceous sea, and a large, fresh-water, Tertiary lake. Sediment deposition occurred in fluvial, deltaic, lagoonal, shallow marine, and lacustrine environments. Because of the diverse and fluctuating environments of deposition, the lithologic units exhibit complex lateral and vertical gradational and intertonguing relationships particularly near the delta-marginal marine transition. In spite of these fluctuating environments of deposition, many of the individual sandstones are continuous and traceable for tens of miles. Erosion has removed rocks of the Mesaverde aquifer from much of the region. The aquifer crops out in the Wasatch Plateau and Book Cliffs. Figure 58 shows the outcrop pattern of the Mesaverde aquifer.

The Mesaverde aquifer contains both intermediate and local ground-water flow systems. An intermediate flow system is found within the lower Blackhawk Formation and Star Point Sandstone. These are generally saturated where present in Carbon and Emery Counties and form a more regional ground-water table (Danielson and others, 1981; Danielson and Sylla, 1983; Lines and others, 1984). Local flow systems occur as perched aquifers with shallow water tables (figure 46) in the Flagstaff Limestone, Colton Formation, North Horn Formation, Price River Formation, Castlegate Sandstone, and upper Blackhawk Formation. The sequences of rocks are not necessarily hydrologically interconnected and unsaturated zones separate saturated zones, but they do have similar hydrogeological characteristics (Lines and others, 1984).

Danielson and others (1981) determined recharge to the Mesaverde aquifer to be predominantly from snowmelt on outcrops in the Wasatch Plateau and Book Cliffs with local topography controlling the flow of ground water. Much of the ground-water discharge in high elevations is the result of small, localized, sometimes intermittent, ground-water flow systems (perched) above the more regional ground-water table. Perched aquifer systems yield ground water from outcrops where local hydraulic conductivity is significantly greater than in underlying rocks, and ground water flows laterally, discharging as springs or seeps on the mountainside. Ground water discharges as springs from formation contacts at or near the base of sandstones, between zones of differing permeability within a formation, near faults and fracture systems, and into mines. Perched aquifers probably maintain a small volume of water in storage and receive recharge only from local precipitation, whereas the deeper, more regional aquifer receives recharge from the entire area. The more regional aquifer, in the lower Blackhawk Formation and Star Point Sandstone, also yields water in areas where the hydraulic conductivity is enhanced, generally by fracturing and bedding-plane separations. These features are shown diagrammatically in figure 59. In general, most ground-water flow is probably taking place only at a moderate depth, and there is little deep ground-water flow.

The main water-producing zones in the Mesaverde aquifer generally consist of sandstones with low primary porosities and permeabilities. The grain size is generally in the fine to medium size range, which causes ground-water to move slowly through the rocks. The porosity and permeability of the Mesaverde aquifer are predominantly secondary, the result of fracturing and bedding-plane separations. Thus, variations in porosity, permeability, and hydraulic conductivity generally reflect the fracturing and bedding-plane separations in an area. Lines (1985) reported porosities ranging from 11 to 17 percent and hydraulic conductivities ranging from 0.0037 to 0.01 ft/d for sandstones in contrast to porosities as low as 2 percent and hydraulic conductivities ranging from 10^{-6} to 10^{-8} ft/d for shales and siltstones in the Blackhawk Formation and Star Point Sandstone of the Mesaverde aquifer. Transmissivities for rock units in the Mesaverde aquifer of the Wasatch Plateau are as follows: the Blackhawk Formation and Star Point Sandstone range from 2.0 to 100 ft^2/d, the Price River Formation averages 0.8 ft^2/d; and the North Horn Formation averages 10 ft^2/d (Lines, 1985). Waddell and others (1986) estimated the transmissivity of the Castlegate Sandstone in the Wasatch Plateau and Book Cliffs to range from 0.003 to 0.02 ft^2/d. However, these transmissivity values only represent that part of the aquifer supplying water to a well and not the full saturated thickness of the aquifer. Sandstones in the Star Point Sandstone, Blackhawk Formation, and Castlegate Sandstone can be good aquifers, particularly where fractured.

The Mesaverde aquifer generally yields fresh to slightly saline water to springs and shallow wells in Carbon and Emery Counties. The residence time of ground water is the principal control on chemical quality of ground water in the Mesaverde aquifer. Total-dissolved-solids concentrations are generally low for ground water from springs and shallow wells indicating a short travel distance from the recharge area, but some local areas may be slightly more saline. Seiler and Baskin (1988) reported TDS concentrations of ground water as follows: the North Horn Formation, Castlegate Sandstone, and Price River Formations contained 208 to 1,350 mg/L; the Blackhawk Formation contained 277 to 5,210 mg/L, with most samples containing fresh water (277 and 371 mg/L with the higher concentrations from springs in the lower strata); the Star Point Sandstone contained 383 to 579 mg/L; and the Flagstaff Limestone contained 273 to 386 mg/L. Dissolved solids in lower formations may increase in part because of restricted circulation.

Ground water is available in the Mesaverde aquifer in varying amounts depending on the lithology and the development of secondary permeability. Domestic supply and livestock watering are the most common uses of ground water from the Mesaverde aquifer. Because of the lenticular

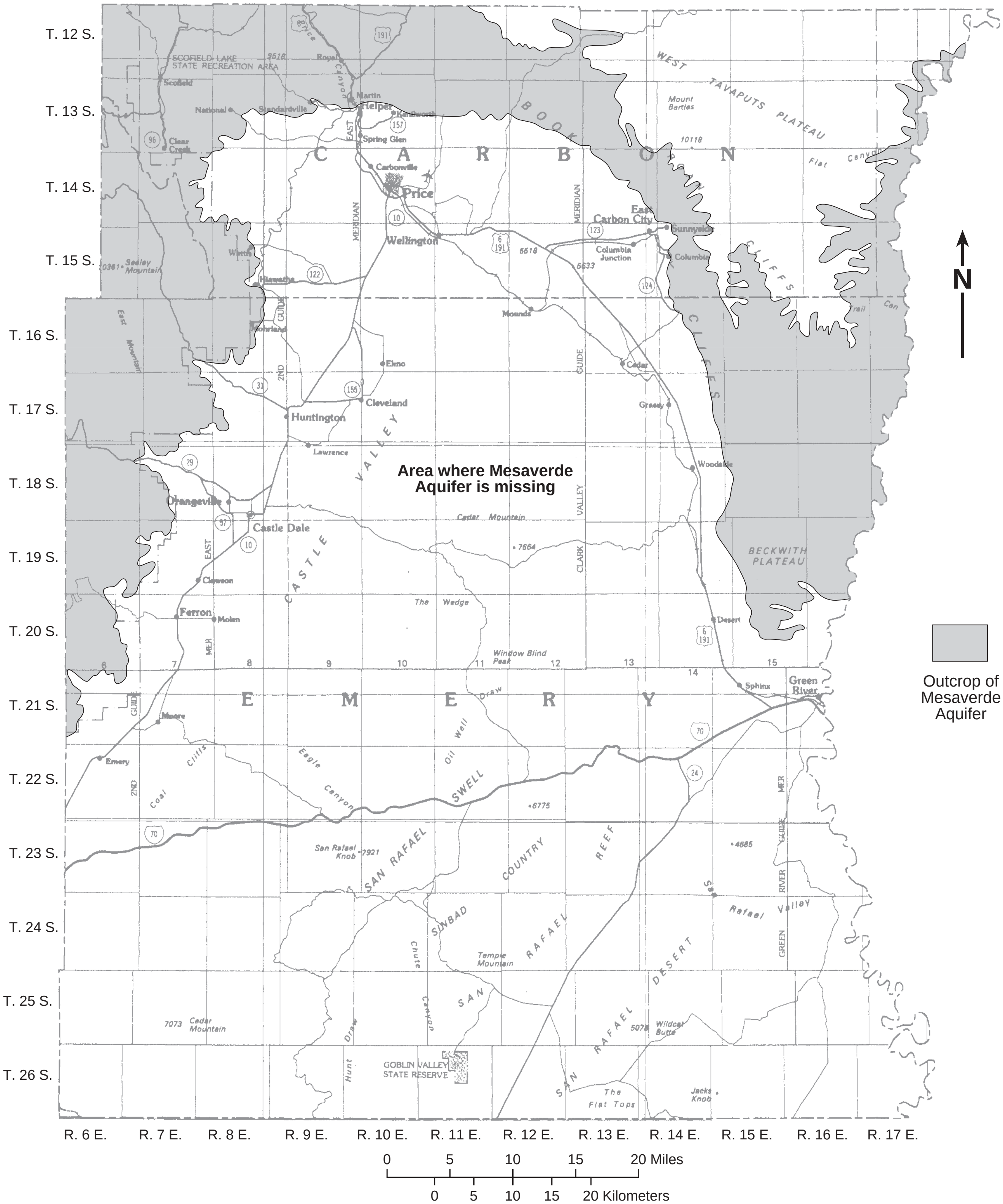


Figure 58. Outcrop of Mesaverde aquifer (from Hintze, 1980).

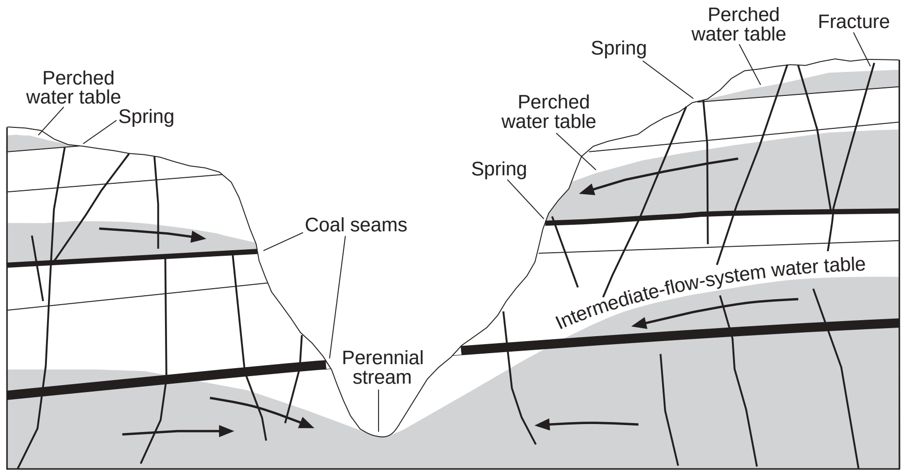


Figure 59. *Diagrammatic section showing hydrology in the highlands of the Wasatch Plateau and Book Cliffs (modified from Lines and others, 1984.*

nature of the bedding and high topographic relief of outcrops, many springs and seeps are present, but these probably would not sustain large withdrawals for long periods and may dry up during droughts. Many of these springs and seeps in the higher elevations discharge potable water, but are too small and remote to be used. The Blackhawk Formation and Star Point Sandstone are the most probable sources of large quantities of ground water and seem to have a good source of ground-water recharge. Water in these aquifer systems may be of suitable quality for most uses. Springs in the Blackhawk Formation and Star Point Sandstone have some potential for moderate development of ground water. Wells could be drilled to intercept aquifers in the Blackhawk Formation and Star Point Sandstone, which generally discharge ground water to springs or gaining reaches of streams. Drilling sites that offer the best chances for success should be sited sufficiently close to faults or fracture systems so that the well intercepts the fault plane or fractures in the water-bearing zones. However, any ground-water development in a given area might affect existing water rights, which could be a major constraint to ground-water development. Underground coal mines in the Wasatch Plateau and Book Cliffs naturally divert and intercept ground water and then discharge the water. This is probably the largest human-caused source of discharge from the Mesaverde aquifer. Mine-discharge water quality generally varies from fresh to moderately saline, and this water has some potential for use. Additionally, after mining stops, the mined out areas still intercept ground water and provide large underground water storage areas that have some potential for use, but existing water rights would need to be considered.

Green River Aquifer

The Green River aquifer consists of a complex system of shallow, unconfined, perched aquifers, and a deeper, confined aquifer in Eocene rocks in eastern Carbon County and a small part of northeastern Emery County (table 81). It includes the Parachute Creek, Garden Gulch, and Douglas Creek Members of the Green River Formation. The rocks crop out as dip slopes on the southern edge of the Uinta Basin and consist of thinly bedded claystone, siltstone, fine-grained sandstone, and limestone. Figure 60 shows the outcrop pattern of the Green River aquifer.

The shallow, unconfined parts of the aquifer are in the upper part of the formation, often within the Parachute Creek Member. They usually are within several miles of the outcrop along the Book Cliffs and the southern rim of the Uinta Basin and are usually within recharge areas. The Parachute Creek Member contains what is locally referred to as the "bird's-nest aquifer" which supplies many springs and seeps in the southern Uinta Basin.

The confined aquifer is in the lower part of the formation in northeastern Carbon County beneath the West Tavaputs Plateau and underlies most of the southern Uinta Basin (Price and Miller, 1975). This aquifer consists of beds of sandstone and limestone of the Douglas Creek Member and may also include some limestone and sandstone horizons in the underlying Garden Gulch Member.

The thickness of the Green River aquifer is highly variable and thickens to the north and northeast. It is over 3,200 feet (975 m) thick in northeastern Carbon County. The lower parts of the Green River aquifer are a major source of fresh water in the southeastern Uinta Basin (Holmes and Kimball, 1987).

The Green River aquifer is part of both the local and intermediate ground-water flow system. Local flow systems are developed in the upper parts of the aquifer, mostly in perched aquifers, but both intermediate and local flow systems probably are developed in the lower confined parts of the aquifer. The principal areas of ground-water recharge are the topographically higher parts of the Book Cliffs, and movement is generally down dip toward the northeast. Discharge by springs and seeps is common at high elevation, above 7,000 feet (2,100 m), where streams have cut below the principal unconfined and perched water-bearing zones. Overall aquifer permeability is low. Most springs generally yield less than 5 gallons per minute, but can yield as much as 60 gallons per minute from sandstone (Price and Miller, 1975). Wells in the southeastern Uinta Basin associated with fractures may yield as much as 5,000 gallons per minute from the deeper confined aquifer (Holmes, 1980; Holmes and Kimball, 1987).

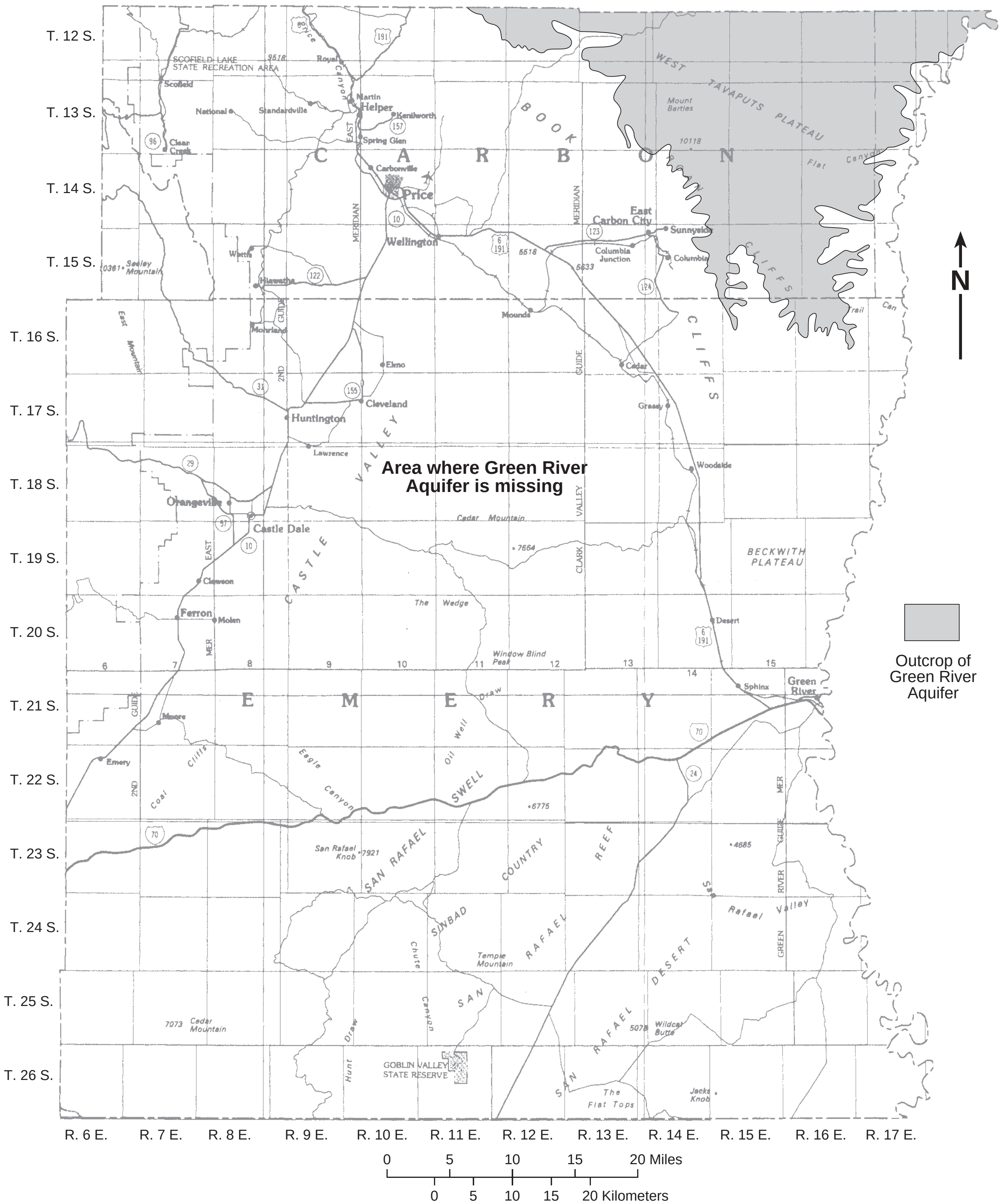


Figure 60. Outcrop of Green River aquifer (from Hintze, 1980).

The TDS concentrations of ground water change drastically from one rock unit to another, and reportedly range from fresh to briny (Price and Miller, 1975). Water from springs generally is fresh; water from oil and gas wells is slightly saline to briny. Near outcrops, the water is commonly fresh, and water quality is also generally better in the lower water-yielding parts of the aquifer near outcrops. Concentrations of TDS in the aquifer usually increase with depth. Even in areas at high elevation where fresh water is obtained from springs, the deep parts of the aquifer are likely to contain higher dissolved solids concentrations (Price and Miller, 1975). In northern Carbon County, ground water at depths of 635 to 650 feet in an oil well (T. 11 S., R. 12 E.) contained 619 mg/L TDS.

The Green River aquifer is not developed to any extent in Carbon County; only a few springs have been developed for stock watering. The limited recharge area available to the aquifer in Carbon County probably prevents any large-scale development of the aquifer. In addition, the remoteness of the aquifer from most of the towns in Carbon County probably precludes its use as a water supply.

Quaternary Aquifer

The Quaternary aquifer includes unconsolidated gravel, sand, silt, and clay deposits of Quaternary age occurring mostly in lowland areas of Carbon and Emery Counties (Williams, 1972; Witkind, 1995). Unconsolidated deposits in Carbon and Emery Counties include numerous deposits of alluvium along streams, as well as terrace, eolian, talus, pediment-mantle, colluvial, and deeply weathered sandstone deposits. Many of these aquifers occur in alluvium near major drainages (Price River, Ferron Creek, San Rafael River, Huntington Creek, Cottonwood Creek, Muddy Creek, and the Green River) and in lowland areas at the base of the Wasatch Plateau and Book Cliffs. Alluvial aquifers in Carbon and Emery Counties are generally areally small and relatively thin.

The Quaternary aquifer consists of many small, shallow, and disconnected unconfined aquifers that are usually part of local ground-water flow systems. They have a wide range of hydrologic characteristics mostly because of the high variability of grain size, sorting, bedding, and degree of consolidation. Recharge to the Quaternary aquifer comes from local snowmelt and precipitation and infiltration from losing reaches of streams, irrigation, and ground-water discharge from bedrock. Discharge usually occurs at springs at the contact of Quaternary deposits with the underlying bedrock and at places where more permeable beds overlie finer grained, less permeable beds within the deposits; or as infiltration into gaining reaches of streams and rivers (figure 61). Most springs are associated with small, local flow systems and do not sustain large flows. Sand and gravel typically form the water-yielding part of the alluvium and generally have a higher permeability and storativity than bedrock aquifers. Alluvial aquifers, however, are small in area and relatively thin. The thickness of the Quaternary aquifer varies with the relief of the underlying rock surface and the depositional thickness of the deposits; thickness varies from a few feet to as much as 100 feet (30 m).

Ground water in the Quaternary aquifer commonly contains high TDS, up to several thousand mg/L, presumably due to recharge from surrounding bedrock, irrigation, and nearby streams. Much of the contained minerals are probably derived from the Blue Gate Shale Member of the Mancos Shale, which underlies most of the lowlands and crops out along many of the rivers and streams. Shales in the Mancos typically have large quantities of soluble salts and ground water of low quality; ground-water seepage from these shales into streams and unconsolidated Quaternary deposits contributes large quantities of dissolved salts to the ground water. However, some water is of good quality with low TDS, apparently derived from rain water that collected in small depressions or in pockets of sand and gravel.

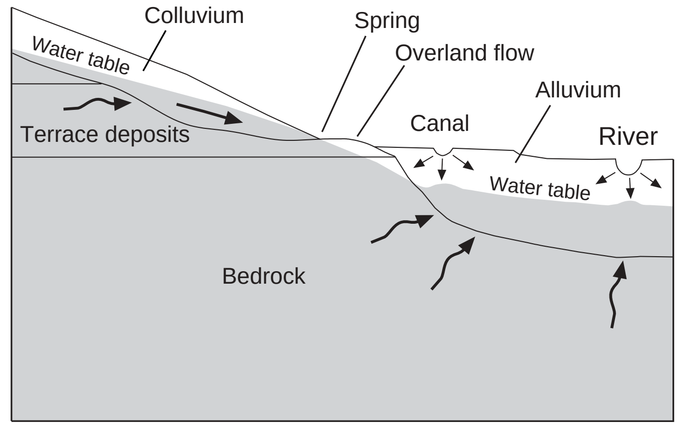


Figure 61. *Diagrammatic section showing the ground-water system in the Quaternary aquifer.*

The Quaternary aquifer is little developed because of its relatively high salinity. Where it is developed, it is mainly used for stock watering.

Summary of Potential Ground-water Resources

Only a few aquifer units in Carbon and Emery Counties have potential to supply moderate quantities of good quality water. In most cases, the favorable units are restricted to a small, commonly remote, portion of the counties. The Jurassic Navajo aquifer has the best potential to supply large amounts of high-quality ground water, but most of the better areas for development are not near towns or farming areas. The Cretaceous Ferron probably has the second highest potential for development particularly within the Castle Valley area of western Emery County and southwestern Carbon County. The lower part of the Cretaceous Mesaverde aquifer has the third best potential for development particularly near fault or fracture zones in the Book Cliffs and northern Wasatch Plateau areas of Carbon and Emery Counties.

All of the aquifer units except the Lower Paleozoic aquifer have some potential to provide usable ground water at least in parts of Carbon and Emery Counties. The potential of each of these aquifers is summarized below:

1. The Upper Paleozoic aquifer could produce moderate amounts of the fresh to slightly saline water from the Pemian White Rim Sandstone at shallow depths downdip from outcrops around the San Rafael Swell, particularly along the southeastern

side of the Swell. Elsewhere in the counties, the aquifer is at greater depths and the water is moderately saline to briny and generally unsuitable.

2. The Jurassic Navajo aquifer has good potential to supply moderate to large quantities of moderate- to good-quality ground-water in southern Emery County on both sides of the San Rafael Swell. In this area the aquifer is at reasonable drill depths (< 2,000 feet [610 m]) and contains good quality water. The aquifer is much deeper and the water quality much lower in Carbon and northern Emery Counties.

3. The Jurassic Entrada aquifer has some potential for development in southern Emery County particularly on the west side of the San Rafael Swell; ground water is fresh to slightly saline and the aquifer has moderate hydraulic conductivity. To the north, the aquifer is deeper, has low hydraulic conductivity, and contains much lower quality ground water (moderately saline to saline).

4. The Jurassic Morrison aquifer could be developed in northern Emery County where the aquifer is less than 2,000 feet (610 m) deep, but the highly variable hydrologic properties of the aquifer make well yields difficult to predict. The aquifer is eroded in most of southern Emery County. In eastern Emery and Carbon Counties the aquifer is too deep and contains poor quality water.

5. The Cretaceous Dakota aquifer could be developed in Carbon County south of the Book Cliffs at shallow depths (<1,500 feet), but well yields likely would be highly variable and difficult to predict. Elsewhere in Carbon and Emery Counties, the aquifer is absent or too deep for economic development and probably contains poor-quality water.

6. The Cretaceous Ferron aquifer could be developed in western Emery County and southwestern Carbon County in areas where it is less than 2,000 feet (610 m) deep. Elsewhere the aquifer is missing, too deep (northwestern Carbon County), or would have low well yields because of low hydraulic conductivity (northern and eastern Carbon County, eastern Emery County).

7. The Cretaceous Mesaverde aquifer could be developed in the Book Cliffs and Wasatch Plaeau areas. The aquifer is at moderate to shallow depths and water quality is generally good. However, overall the aquifer has low ground-water yields unless enhanced by fracturing or bedding-plane separation, and many of the permeable unit are perched aquifers with only a small volume of stored ground water. The Blackhawk Sandstone and Star Point Sandstone close to fault and fracture zones have the best potential; the permeable units are more continuous, contain a large amount of ground water, and seem to have a good source of ground-water recharge. The Mesaverde aquifer could be a ground-water source for Price, Helper, and other towns in northern Carbon County.

8. The Tertiary Green River aquifer could be developed for very local, limited use in northeastern Carbon County. Overall the aquifer has low hydraulic conductivity and most of the ground water in the aquifer is perched resulting in limited yields for springs or wells.

9. The Quaternary aquifer also has potential for limited, local development. The aquifer is shallow with moderate to good permeability in the sandier units and contains good-quality ground water where not contaminated by runoff from the Mancos Shale. Unfortunately, most ground water is poor quality and the water-bearing units with good-quality ground water are thin, have limited recharge, and would yield only limited amounts of water.

SUMMARY

Carbon and Emery Counties have potential for discovery and development of additional mineral, energy, and ground-water resources. The most prospective areas for development of additional energy resources are in western Carbon and Emery Counties and in north-central and eastern Carbon County. The most prospective areas for development of additional mineral resources are in eastern and central Emery County. The most prospective areas for development of ground-water resources are in southern and western Emery County and western Carbon County. Areas with lower potential for ground-water development include central and south-central Carbon County and southeastern Emery County. A good infrastructure with a transportation network (rail and truck roads), oil and gas pipelines, and available support services is present in western and northern Carbon and northwestern Emery Counties, and this portion of the counties has a relatively low percentage of lands considered by the BLM to have wilderness characteristics. Infrastructure is not as well developed in other parts of Carbon and Emery Counties, particularly central Emery County, and there is considerable uncertainty about availability of land for mineral, energy, or ground-water development in much of this area.

Oil and Gas

There is good potential in Carbon and Emery Counties for significant new gas discoveries and additional development, but the potential for significant new oil discoveries or development is much lower. Oil production should continue to decline, but gas production, particularly from coal-bed gas wells, should continue to increase as more wells are drilled and then level off as the reservoirs become depleted. Although there are numerous hydrocarbon plays that are productive or have the potential to be productive, the Ferron, Mesaverde, and Tertiary plays are the most likely to have new discoveries or additional developments.

The Ferron Sandstone play covers more than 1,800 square miles (4,600 km^2) in western Emery County and western and northeastern Carbon County. Most of the near-term exploration and development will be in western Carbon and Emery Counties and will be directed towards expanding the Helper, Drunkards Wash, Marsing Wash, and Buzzard Bench coal-bed gas fields and testing the area between these fields. Much less exploration for coal-bed gas will be done in northeastern Carbon County because of the greater drill depth and eastern pinch-out of many of the coal beds.

The Mesaverde and Tertiary plays are the next most likely to have significant discoveries or additional developments. The Tertiary play includes the Wasatch (Colton) and Green River Formations and covers an area of nearly 800 square miles (2,100 km^2) mostly in eastern Carbon County. Any future drilling will most likely initially be along northwest-trending anticlinal trends and later off trend. Access to this prospective area is difficult, and much of the prospective area is considered by the BLM to have wilderness characteristics. The Mesaverde play covers over 800 square miles (2,100 km^2) in eastern Carbon and northeastern Emery Counties and includes both coal-bed and sandstone reservoirs. Coal-bed gas discoveries are most likely, but exploration may be limited for this type of target because of depth and the excessive amounts of associated water encountered by previous drilling.

A number of other plays are prospective in isolated areas in Carbon and Emery Counties including: (1) Moenkopi, (2) Kaibab, (3) Dakota-Cedar Mountain-Morrison, (4) Paradox, (5) Leadville, and (6) Entrada. It is unlikely that near-future exploration programs will be directed towards these targets in Carbon and Emery Counties.

Coal and Coal Resin

Coal will continue to be a major economic resource for Carbon and Emery Counties for at least the next 40 to 50 years. In the Book Cliffs coalfield several new mines are in development and production should increase from the 1999 level of 3 million short tons (2.7 million metric tons) to 6 million short tons (5.4 million metric tons) of coal per year (MM tpy). The new mines include Dugout Canyon (2 MM tpy) and Westridge (3 MM tpy). Remaining recoverable reserves in the Book Cliffs coalfield are estimated at 752 million short tons (688 million metric tons) of coal, sufficient for 125 years of production at the planned production rate of 6 MM tpy. However, much of the remaining recoverable reserves are in beds less than 6 feet (2 m) thick and at depths greater than 2,500 feet (760 m) and may not be economic to mine. Mining in the near term will continue to be concentrated in the Castlegate and Soldier Canyon areas and north of Sunnyside. Later production will be from the southern Sunnyside and Woodside areas.

Coal production from the Wasatch Plateau coalfield should continue at the 20 to 22 million short tons (18-20 million metric tons) per year rate for the next 10 to 30 years. Many of the larger producers have mineable reserves of 15 to 20 or more years at their existing operations. Most of the production will be from Carbon and Emery Counties, but approximately 6 million short tons (5.4 million metric tons) per year will come from the Sevier County portion of the coalfield. Remaining recoverable reserves in the Wasatch Plateau coalfield are estimated at 1.36 billion short tons (1.23 billion metric tons) of coal, sufficient for about 60 years of production at current rates. As with the Book Cliffs, much of the remaining recoverable reserves will probably not be mined because they are too thin or too deep, and the expected life of the Wasatch Plateau field is considerably less than the 60-year estimate. Near-term production will continue to be concentrated in the Scofield-Clear Creek, Cottonwood Creek, East Mountain, and Quitchupah (Sevier County) areas. Later production will be from areas farther to the south in Emery County.

Coal production from the southern end of the Emery coalfield is not expected to resume in the near future. Although remaining recoverable reserves are estimated at 417 million short tons (378 million metric tons), the field is nearly 50 miles (80 km) from the nearest rail loadout, and the coal is often oxidized and of lower quality than coal in the Wasatch Plateau or Book Cliffs coalfields. No production is expected from the central or northern Emery coalfields. Although some thick coal zones are present, most are at depths of 1,000 to 4,000 feet (300-1,200 m) and would not be economic to mine at the present time.

The future of coal resin production from the Book Cliffs and Wasatch Plateau coalfields is problematic. The coalfields contain a substantial resource of resin that could be easily produced as a by-product of coal mining and washing. The recoverable resin resource for the Wasatch Plateau and western Book Cliffs coalfields is large, estimated at 19.4 million short tons (17.5 million metric tons) or 38.8 billion pounds. In addition, the worldwide resin market is expanding, and resin is being used in a number of other applications in addition to the ink industry. The coal resin requirement for just the United States ink industry could be as high as 110 million pounds (50 million kg) per year, and low-cost Utah resin could provide a substantial amount of this need. At present, however, a shortage of resin refining capacity poses a significant bottleneck in getting Utah resinite to the end users in the ink, plastics, and varnish industries. A cooperative effort is required between several resin-supplying coal companies and resin refiners so that the miners are assured an outlet for their resin concentrate and the refiner is assured a large, steady supply of feedstock material.

Coal-bed Gas

Coal-bed gas production should continue to be of major importance in Carbon and Emery Counties for the next 30 or more years. Most of the production will continue to be from coals in the Ferron Sandstone in the Castle Valley portion of the Emery coalfield. As of December, 2000 there were 482 producing coal-bed gas wells with an aggregate monthly production of over 6.2 billion cubic feet. The three major operators ultimately plan to drill as many as 900 coal-bed gas wells in the area. If all the potential wells were drilled and achieved a daily production equal to River Gas' current wells at 525 cubic feet per well per day, then the area's wells could produce 470,000 Mcf per day of coal-bed gas. The average well life has been estimated at 20 years, but there is no historical production data to confirm this estimate. Well life could be either longer or shorter depending on when maximum production is achieved, the rate at which production declines, well work-over success, and well-head gas price. Some of the earliest wells have been producing for about seven years and hopefully should have 13 or more years of remaining production. The production rate is still increasing in several of these older wells, and for others that appear to have reached maximum production the decline curves are too short and varied to make long-range predictions. Full development of all proposed wells in the field may take another 10 or more years, so coal-bed gas production in Carbon and Emery Counties should continue at least until 2025 or 2030.

Potential for additional coal-bed methane development in Carbon and Emery Counties exists in: (1) the Blackhawk Formation in western Carbon County, (2) the deeper Ferron Sandstone in western Carbon and Emery Counties, and (3) the Emery Sandstone Member of the Mancos Shale in western Carbon and Emery Counties. There is little or no potential for coal-bed gas development in the Blackhawk Formation in the Wasatch Plateau coalfield or in the Ferron Sandstone in the southern Emery coalfield because the coals are either too shallow, too dissected, or too faulted to have retained any coal-bed gas that might have been generated. The most likely development would be in the Blackhawk Formation in the Castlegate and western Soldier Canyon areas where the coals are thicker and at sufficient depths to retain coal-bed gas.

Oil-Impregnated Rock, Oil Shale, and Geothermal Energy

Fifteen oil-impregnated rock deposits are known in Carbon and Emery Counties. The deposits can be divided into a southern group mostly around the San Rafael Swell and a northern group on the south flank of the Uinta Basin. The southern group is mostly hosted by Permian to Jurassic sandstones and limestones and the northern group is hosted mostly by Eocene sandstones. The known deposits contain an estimated 3,500 to 75,000 million barrels of oil (in-place resource), but most deposits are low grade and unlikely to be developed in the future. The best deposit in the two counties is the Sunnyside-Jacks Canyon deposit in northeastern Carbon County. It contains an estimated 3,500 to over 6,000 million barrels of oil at an average estimated grade of 13 (Campbell and Ritzma, 1979) to 20.5 (Oblad and others, 1987) gallons per ton in 3 to 12 principal pay zones over a net pay thickness of 15 to 550 feet (4.5-170 m). About 335,000 tons (300,000 mt) of material was mined for asphalt and paving material between 1892 and 1948. Since 1955 the area has been evaluated for liquid oil production using both surface mining and in-situ extraction; results have been generally poor. In-situ mining methods had only limited success and very low recoveries. Underground mining would not be feasible as estimated underground mining costs, even using low-cost, longwall methods, are greater than the value of the contained oil even at $25.00 per barrel. Only the near-surface, richest portion of the deposit would be amenable to large-scale surface mining and would require improvement in recovery technology and/or a significant increase in the price of oil to be feasible. Even with improvement in technology or price increases, other better deposits, most notably in Uintah County, will probably be developed long before the Sunnyside deposit.

Oil shale is present in the middle member of the Eocene Green River Formation in northeastern Carbon County. Total oil shale resources in Carbon County could be as high as 1.5 to 2.0 billion barrels of oil, but the oil shale beds are thin (15 to 40 feet [4.5-12 m]) and low grade, generally less than 25 gallons per ton. It is unlikely that Carbon County oil shale resources will be developed in the near future. Even if an efficient and economic recovery process were developed and oil prices were significantly higher, the thicker and higher grade oil shale deposits in Colorado, Wyoming, and in Uintah County, Utah would be developed and mined long before any in Carbon County.

Only a few wells and springs in Carbon and Emery Counties are known to contain even low-temperature geothermal water. Most low-temperature geothermal water is from springs. Water temperatures range between 18 and 29°C (64-84°F). Such waters could be used in various aquacultural and recreational applications. Unfortunately, most of the low-temperature springs and wells are not near established population centers and are unlikely to be developed. There is no evidence, such as high heat flow or young volcanic rocks, to suggest that moderate- to high-temperature geothermal systems (greater than 100°C) are present at economical drilling depths in either Carbon or Emery Counties.

Uranium and Vanadium

Over 8 million pounds (3.6 million kg) of U_3O_8 and over 7 million pounds (3.2 million kg) of V_2O_5 have been mined in Emery County since 1900. Most of the production was from peneconcordant sandstone deposits in the Moss Back Sandstone Member of the Triassic Chinle Formation or in the Salt Wash Member of the Jurassic Morrison Formation. The major period of production was between 1953 and 1965 with a small revival between 1976 and 1979 in response to an increased uranium price. Since 1988 there has been no uranium or vanadium mining in Carbon or Emery County. Uranium reserves are present at several mines in Emery County, and there is good potential for additional discoveries. Remaining reserves in Emery County are estimated at 200,000 to 300,000 short tons (180,000-270,000 metric tons) at an average grade of 0.15 to 0.20 percent U_3O_8. The majority of the remaining reserves are in the San Rafael River mining area, the Sinbad mine, and in the southwestern part of the San Rafael district. There is good potential for discovery of additional Mossback-hosted uranium deposits downdip along channel trends from known deposits, with the best potential area west and north of San Rafael Knob. There is also good potential for discovery of additional Salt Wash-hosted uranium-vanadium deposits, with the best potential area in the San Rafael River mining area east of the north Tidwell belt of mined deposits. Even though potential exists for new uranium-vanadium deposits there is little incentive to explore. Because of the small lateral extent and discontinuous nature of the mineralization, an extensive, close-spaced drilling program would be required, and any new discoveries would be at greater depth and probably would not be significantly larger or higher grade than previously mined deposits. In spite of known reserves and good potential for additional discoveries, it is unlikely that uranium or vanadium mining will resume in Emery County in the near future. The current low price for both uranium and vanadium, and the lack of nearby uranium mills are major obstacles. The current price of uranium or vanadium would need to nearly double before the deposits became even marginally economically viable.

Metallic Minerals

There is little potential in Carbon and Emery Counties for production of base or precious metals. Several small copper occurrences are known that are not associated with uranium-vanadium deposits. Most occurrences consist of copper carbonates, rarely chalcocite, along bedding planes, fractures, and fault planes in fine- to coarse-grained Triassic to Jurassic sandstone. All are small and generally low grade. Undiscovered similar deposits are probably present in Emery County but would be uneconomic. The total amount of copper mined in Carbon and Emery Counties was probably less than 300,000 pounds (140,000 kg), and most was as a by-product of uranium mining and was not recovered. There is limited, highly speculative potential for "geologic target types" of copper that, if discovered, would have a better chance for development. The target types were identified based on conceptual models and permissive geology and generally do not have any copper occurrences to support the models. The most prospective, but still highly speculative, target is "Lisbon-Valley type" sedimentary copper deposits along and adjacent to faults and fractures on the east side of the San Rafael Swell. There is no obvious potential for lead-zinc deposits in Carbon or Emery Counties.

Twelve small manganese deposits and occurrences are known in Emery County. These deposits are hosted by sandstones and shales of the Jurassic Summerville Formation, the Jurassic-Cretaceous Brushy Basin Member of the Morrison Formation, and the Cretaceous Cedar Mountain Formation. All are small and low grade with grades that are generally 50 percent or less than manganese deposits currently in production internationally. It is unlikely that the deposits in Emery County will be developed.

Titanium-zirconium-bearing, fossil black sand deposits are present in the Ferron Sandstone southeast of the town of Emery. The black sand deposits have an average thickness of 5 feet (1.6 m) and occur in several northwest-trending lenses with outcrop lengths of 90 to nearly 300 feet (30-90 m). Assays of three samples averaged 12.6 percent TiO_2 and 1.8 percent ZrO_2 (Dow and Battey, 1961). Additional black sand deposits could be present in regressive sandstones deposited in a beach environment in other parts of the Ferron Sandstone and in Upper Cretaceous formations. However, it is unlikely that the known or potential black sand deposits in Carbon or Emery Counties will be developed in the near future. Other thicker, higher grade and more accessible deposits in Wyoming, Montana, and New Mexico are not currently being developed. If titanium or zirconium prices increase and if beneficiation techniques improve, these deposits will be developed much sooner than those in Carbon or Emery Counties.

There are few, if any, well-documented occurrences of gold in Carbon and Emery Counties, and total recorded production of gold for both counties is only 5 ounces (156 g). There is some potential for very fine-grained placer gold in the Green River and possibly other drainages, but it would likely be flour gold and difficult, if not impossible, to economically recover. There is also some potential for fossil placer gold in Triassic to Cretaceous continental to marginal-marine sandstone, but grades would most likely be far too low to be economic. Rumors persist about fine-grained disseminated gold in the Mancos Shale, and most of the recent, admittedly minor, precious metal activity has been directed toward this target type. However, recent (1991) work failed to confirm the rumored gold grades even for reportedly high-grade samples. Until independently confirmed, rumors of high- to moderate-grade gold in the Mancos Shale should be viewed with caution.

Industrial Rocks and Minerals

The industrial rock and mineral potential of Carbon and Emery Counties has not been studied in detail, and only a few commodities have been produced, mostly for local use and generally in small quantities. Produced commodities include sand and gravel, crushed stone, gypsum, bentonite and common clay, and humate.

Good-quality sand and gravel is scarce in Carbon and Emery Counties, and most of the sand and gravel mined in the two counties is composed of clasts that have inadequate compressive strength and abrasion resistance to make good aggregate for concrete or asphalt. New sand and gravel deposits will be developed as demand grows, but it is uncertain how much of the demand can be satisfied by deposits within the counties; it may be more economical to import the sand and gravel from the surrounding counties. There has been very little production of crushed stone in Carbon and Emery Counties. With increased building and development and the lack of good sand and gravel, crushed-stone production is expected to increase particularly for use as aggregate. In Carbon and Emery Counties, the Green River, Flagstaff, and North Horn Formations contain limestone and limestone conglomerate that would be suitable for crushed stone. Other units in Emery County that could be suitable include sandstone and conglomerate in the Dakota Sandstone, the Buckhorn Conglomerate of the Cedar Mountain Formation, and the Salt Wash Member of the Morrison Formation; and limestone in the Sinbad Limestone Member of the Moenkopi Formation, the Kaibab Formation, and the Honaker Trail Formation of the Hermosa Group.

The Summerville and Carmel Formations contain commercial quantities of gypsum in Carbon and Emery Counties, particularly on the western side of the San Rafael Swell. The gypsum occurs in multiple beds with individual beds ranging from 4 to over 50 feet (1.2-15 m) thick. There are four active operating gypsum mines in Emery County which together produce more than 100,000 tons (90,000 mt) per year of gypsum. These mines were developed between 1990 and 1994 primarily to supply gypsum for wall board manufacturing plants near Sigurd in Sevier County as the Sigurd deposits became depleted. The San Rafael Swell contains a huge amount of high-quality gypsum (estimated at nearly 10,000 million short tons [9,000 million metric tons]), so lack of resource will not limit future development. Demand, transportation costs, and land-use restrictions (particularly possible wilderness designation) will control development of gypsum resources in Emery County.

There are large amounts of bentonite of uncertain quality in Cretaceous, Jurassic, and probably Triassic rocks in Carbon and Emery Counties, particularly in the Cretaceous Mancos Shale and Cedar Mountain Formation and Jurassic Morrison Formation. There has been some development of the resource, but mostly for use as a waterproof liner for engineering projects such as landfills. Additional development is expected to be limited as most of the bentonite (1) probably will not meet specifications for higher unit value uses such as oil well drilling without polymer treatment, (2) is distant from most markets, and (3) generally cannot compete with the high-quality Wyoming sodium bentonite.

Valuable deposits of humate are associated with the Ferron Sandstone Member of the Mancos Shale. Other humate deposits may also be present in the Cretaceous Blackhawk

Formation and Cretaceous-Tertiary North Horn Formation. Several operations in Emery County currently mine Ferron Sandstone humate for use both as a nutritional trace element supplement and as a soil amendment and fertilizer. Nearly 10,000 short tons (9,000 metric tons) per year of humate is being mined by these operations. These small operations will probably continue and may be joined by similar new operations producing mineral supplements. Additional development of the humate resource for use as a soil amendment is less certain and will likely depend on markets and price.

In addition to the above commodities, Carbon and Emery Counties contain a number of other industrial rocks and minerals that could conceivably be developed. Quality and quantity data for these are limited, and much additional work would be required to adequately characterize these resources. Potential resources in rough order of probable export potential are listed below. Only the top four are considered to have even moderate potential; resources 6 to10 have much better potential in other areas of Utah outside of Carbon and Emery Counties.

1. Silica sand in Permian White Rim Sandstone and Quaternary eolian sand
2. Dimension stone in Moenkopi (sandstone), Colton (sandstone), and Green River (limestone) Formations
3. Flagstone in Kayenta Formation
4. Limestone for rock dusting and power plants in Flagstaff Limestone and possibly also in North Horn and Carmel Formations and Sinbad Limestone Member of the Moenkopi Formation
5. Lightweight aggregate (bloating shale) in Mancos, Green River, and Colton Formations
6. Bedded potash in Pennsylvanian Paradox Formation
7. Zeolites in tuffaceous rocks in Brushy Basin Member of Morrison Formation
8. Saline brines in Mississippian and Pennsylvanian-age units
9. Refractory clay
10. Sulfur

Ground Water

Ground water is an important but limited resource in Carbon and Emery Counties. The resource is only partially developed, and most of the ground water used is from springs; only a few towns use water from wells. Most of the water used in Carbon and Emery Counties is surface water; streams provide most of the water used for irrigation and reservoirs provide domestic, municipal, and industrial water for the larger communities. With increased population and anticipated industrial growth, water will become an increasingly more valuable commodity. Unfortunately, few areas in Carbon or Emery County have potential to supply substantial amounts of high-quality ground water, and most of these are in the less populated portions of the counties. Other areas have potential to supply large amounts of ground water, but most will be of poor to marginal quality. In the immediate future, most water used in Carbon and Emery Counties probably will be from surface sources, and ground water will only be developed in special situations, mostly for specific local uses.

The Navajo aquifer has the best potential of all aquifers in the two counties to supply large amounts of high-quality ground water. The aquifer is thick with some highly permeable units and contains good-quality water at shallow depths. The aquifer is probably too deep to be developed in Carbon County, but could be developed in southeastern and southern Emery County and in western Emery County east of the towns of Moore and Emery. Unfortunately, most of the better areas for development are not near towns or farming areas. The aquifer is probably at reasonable depths near Ferron and Emery, but the water quality might not be suitable at these locales.

The Ferron aquifer probably has the second-highest potential for development, particularly within the Castle Valley area of southwestern Emery County. In this area, the Ferron aquifer is relatively thick and permeable, has a sufficient recharge area, is at shallow depths, and contains good-quality water. It may also be a feasible source in southwestern Carbon County east of the Wasatch Plateau and south of the Book Cliffs. However, the water quality in this area might be marginal, and the well yields would be lower than in the Castle Valley area. Elsewhere in Carbon and Emery Counties, the aquifer is most likely too deep or has poor hydraulic properties that make it unsuitable as a source of ground water.

Several less favorable aquifers could yield moderate to large amounts of good- to moderate-quality water in several areas in Carbon and Emery Counties. Most of these aquifers have potential only in selected areas within the counties, and most of the favorable areas are remote from the population and farming and industrial areas. Wells could be developed for local use, but in most cases the amount of water needed would not justify the drilling and completion costs of the well. The potential aquifers are discussed below from oldest to youngest.

1. The Upper Paleozoic aquifer, particularly the White Rim Sandstone, has potential to supply moderate to large amounts of high-quality ground water within the central, mostly uninhabited, part of the San Rafael Swell. Elsewhere in Carbon and Emery Counties, the aquifer would be too deep, and the water quality poor.
2. The Entrada aquifer has potential for good- to moderate-quality ground water mainly in western Emery County on the gentler dipping, west side of the San Rafael Swell if at depths of 2,000 feet (600 m) or less. Below those depths, the water quality is expected to be poor. In Carbon County and eastern Emery County, the Entrada aquifer would be too deep, and water quality would be poor.
3. The Morrison Formation has potential for good- to moderate-quality ground water in eastern Emery County, mostly west of U.S. Highway 6, but the highly variable hydraulic properties of the aquifer would make well yields difficult to predict. In Carbon County and east of U.S. Highway 6 the water quality is expected to be poor.

4. The Dakota aquifer is an economically feasible water well target in south-central Carbon County south of the Book Cliffs. The aquifer is saturated, at reasonable depths and, if close to outcrop, recharge areas should contain good-quality water. However, away from these recharge areas the water will probably be salty to brackish.

5. The lower part of the Mesaverde aquifer (Star Point Sandstone and lower part of Blackhawk Formation) has good potential as a ground-water source in the Wasatch Plateau and Book Cliffs areas of Carbon and Emery Counties. The better potential would be near fault and fracture zones because the primary permeability of most of the units in the aquifer is low. Water-bearing units stratigraphically higher than the lower part of the Blackhawk Formation should have good water quality, but most would not sustain large withdrawals for long periods. Favorable areas for development of the Mesaverde aquifer are close to water users, and development of the aquifer will depend on the ability of the current water sources to supply the users' needs. However, development of the Mesaverde aquifer will need to consider existing water rights as development could drastically affect many of the springs and small streams within the area.

6. Sandstones within the Green River aquifer have potential as sources of ground water for local use in the West Tavaputs Plateau area of eastern Carbon County. The water quality would be good, but the aquifer would be unable to supply large amounts of water because of the limited recharge area of most of the water-bearing units. The Green River aquifer is not expected to be developed to any extent because of its remoteness.

7. Certain units within the Quaternary aquifer could supply modest amounts of ground water for local use. However, the units have a wide range of hydrologic characteristics so favorability must be determined for each local area. Most ground water in the aquifer is of poor quality, but good-quality ground water is locally present particularly if recharged by precipitation and snow melt. However, most of the units containing good-quality ground water would have only limited capacity and would be unable to supply large amounts of water.

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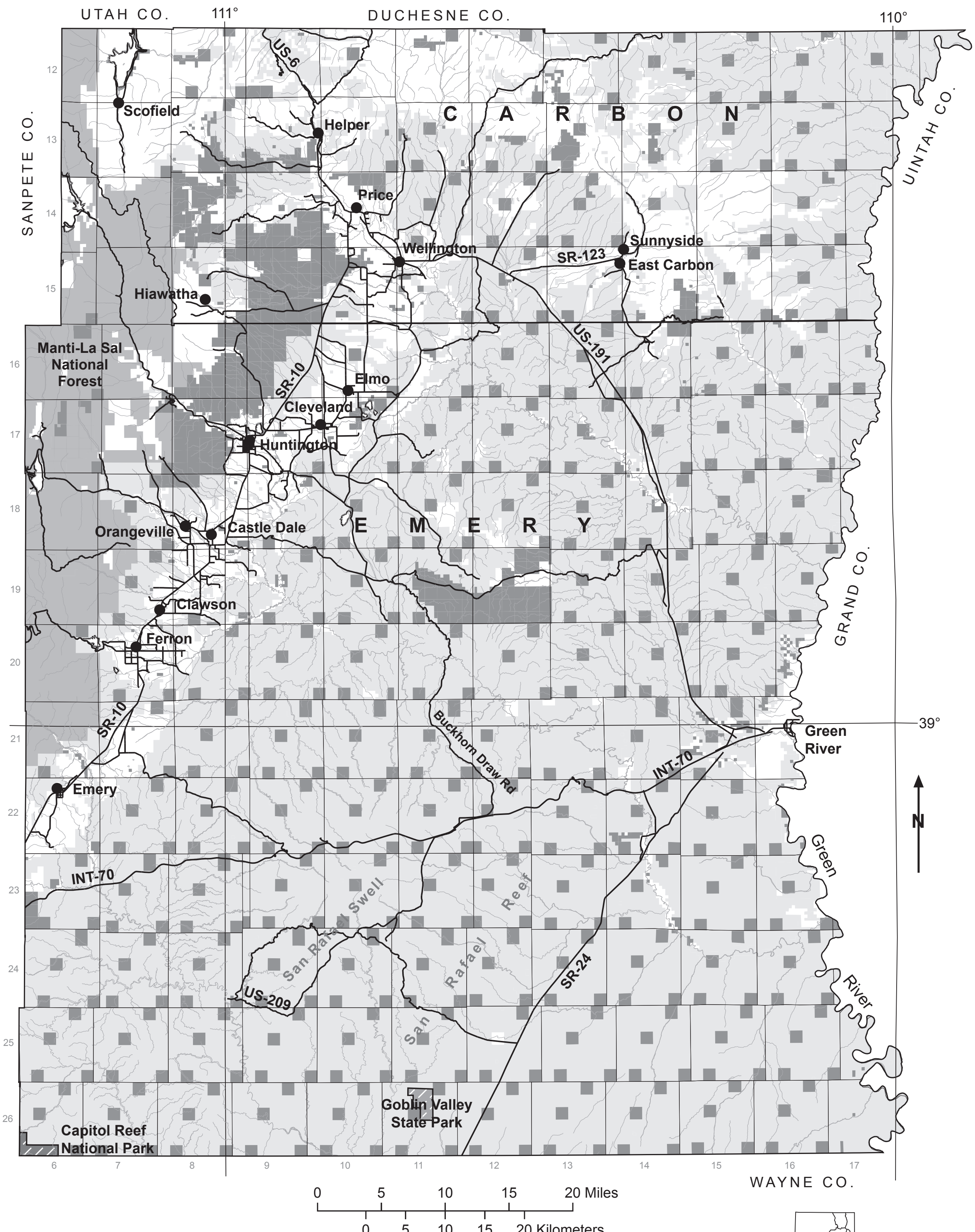
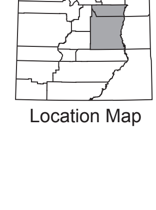


Plate 1. Land Ownership Status

- State Parks
- National Parks and Monuments
- Public Land - Bureau of Land Management
- Public Land - Forest Service
- State Land
- Private Land



Location Map

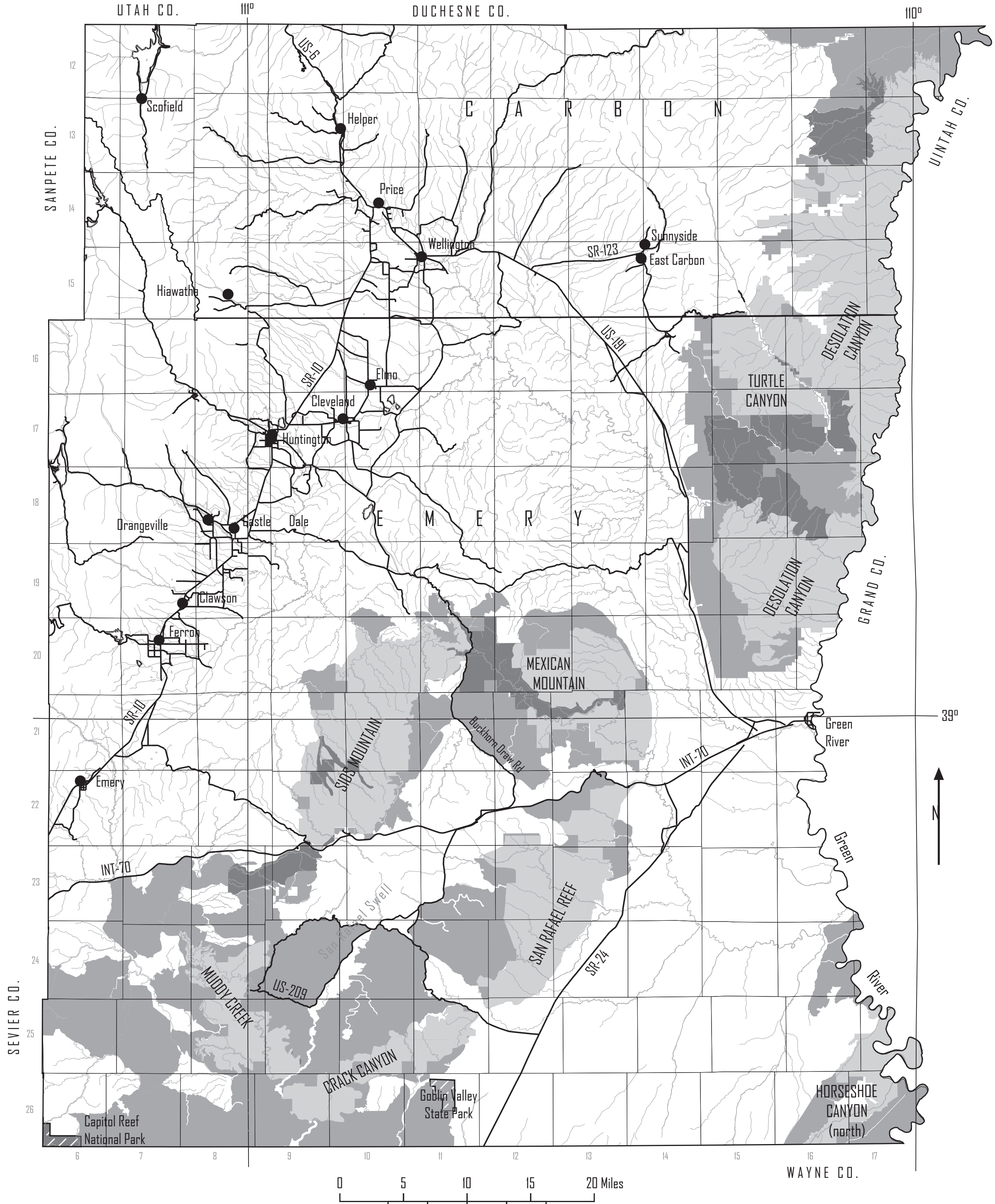
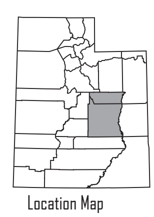


Plate 2. Wilderness Status

- Wilderness Study Area - Recommended for wilderness status by BLM
- Wilderness Study Area - Not recommended for wilderness status by BLM
- Additional areas with wilderness characteristics (1999 BLM inventory)



Location Map

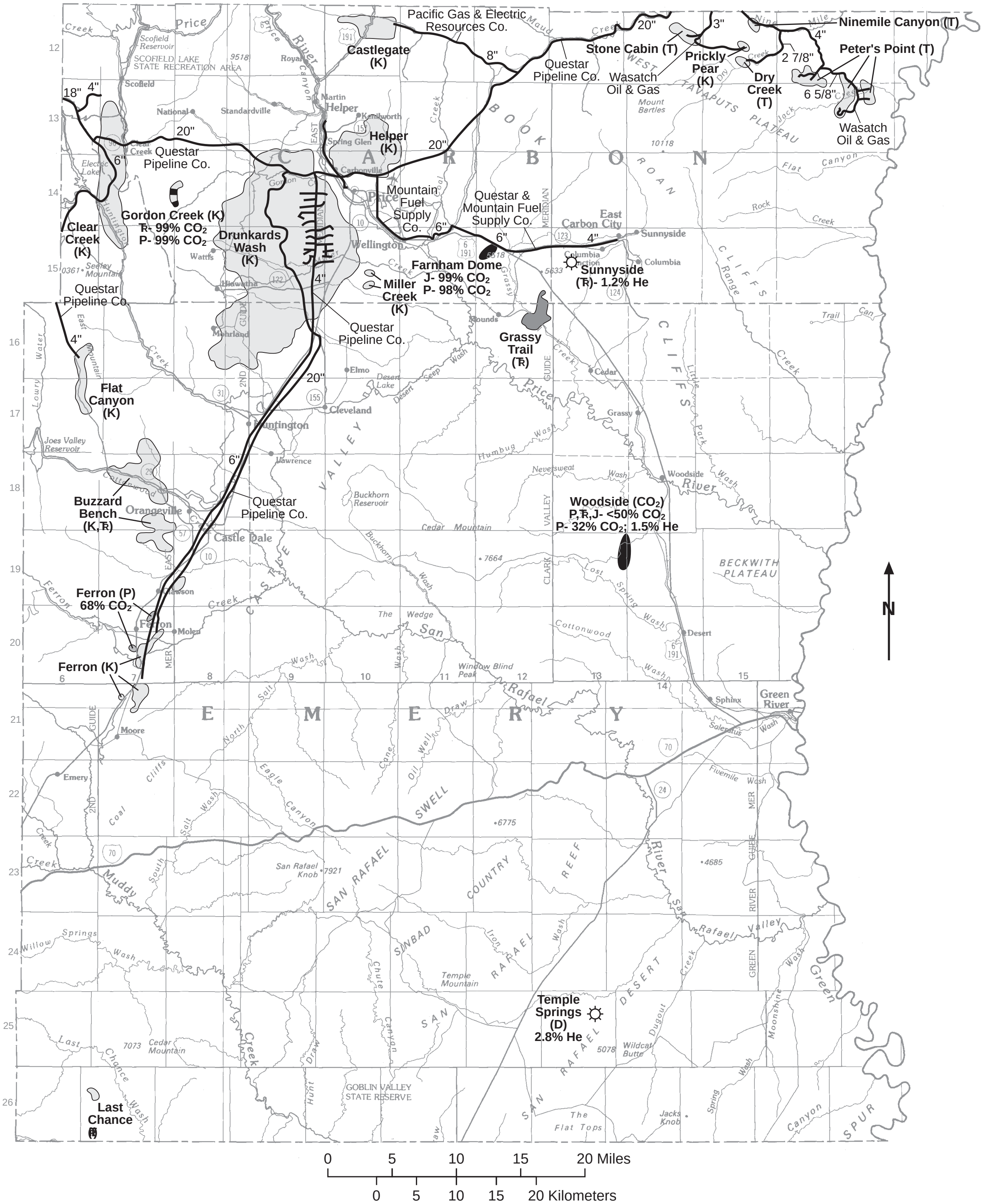


Plate 3. Oil and Gas Fields and Pipelines

- Gas field
- Oil field
- CO_2 field
- ☼ Drill hole with helium

Carbon dioxide (CO_2) and helium-rich (He) gas occurrences shown in mole percentage

Age of producing formation

T	Tertiary	J	Jurassic
K	Cretaceous	P	Permian
Ŧ	Triassic	D	Devonian

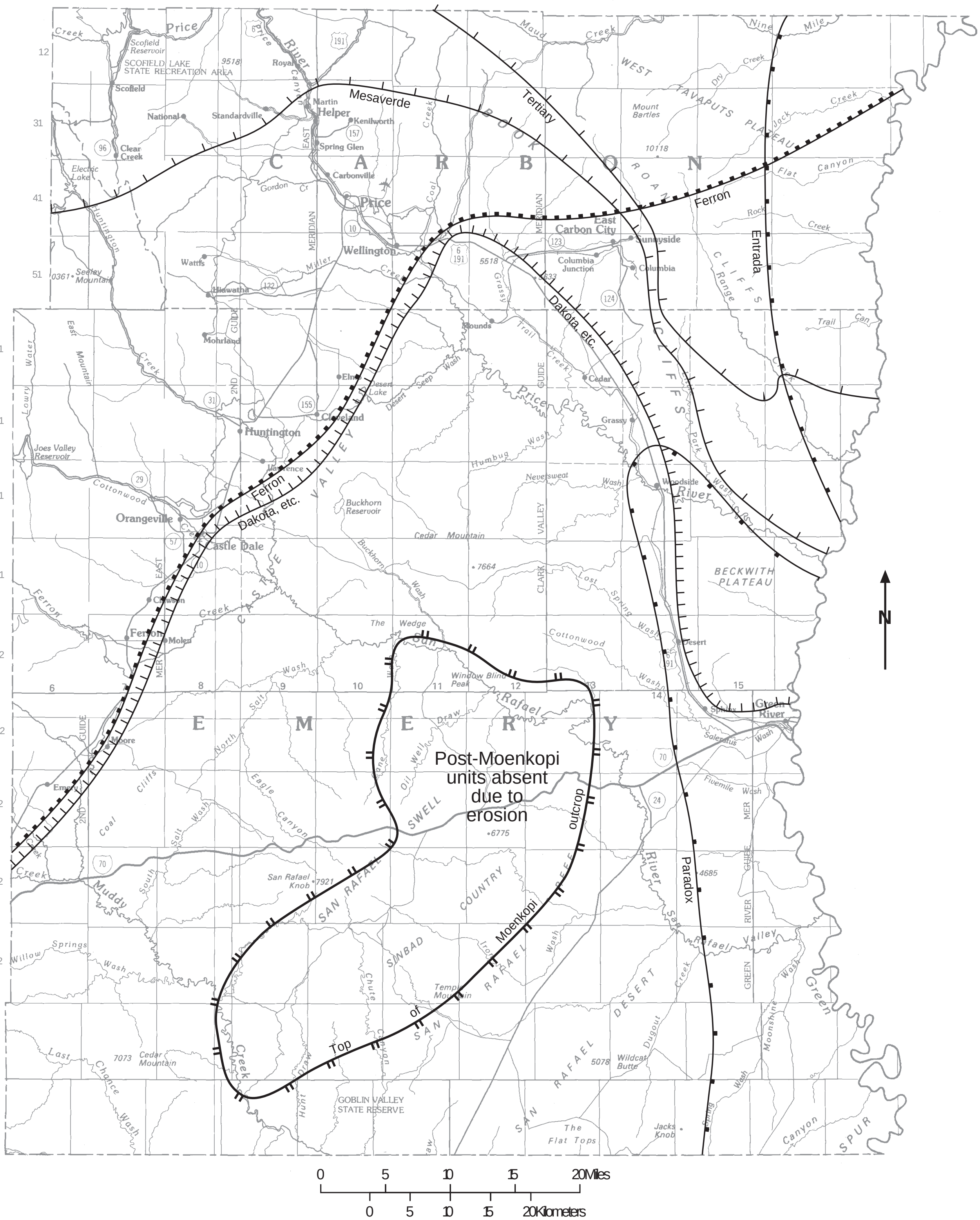


Plate 4. Oil and Gas Exploration Areas

Limits of Tertiary play

Limits of Mesaverde play

Limits of Dakota, Cedar Mountain, and Morrison play

Limits of Paradox play

Limits of Entrada play

Limits of Ferron play

Top of Moenkopi (Moenkopi play covers both counties except central part of San Rafael Swell)

Hachures on play side

Top of Moenkopi outcrop from Weiss and others, 1990

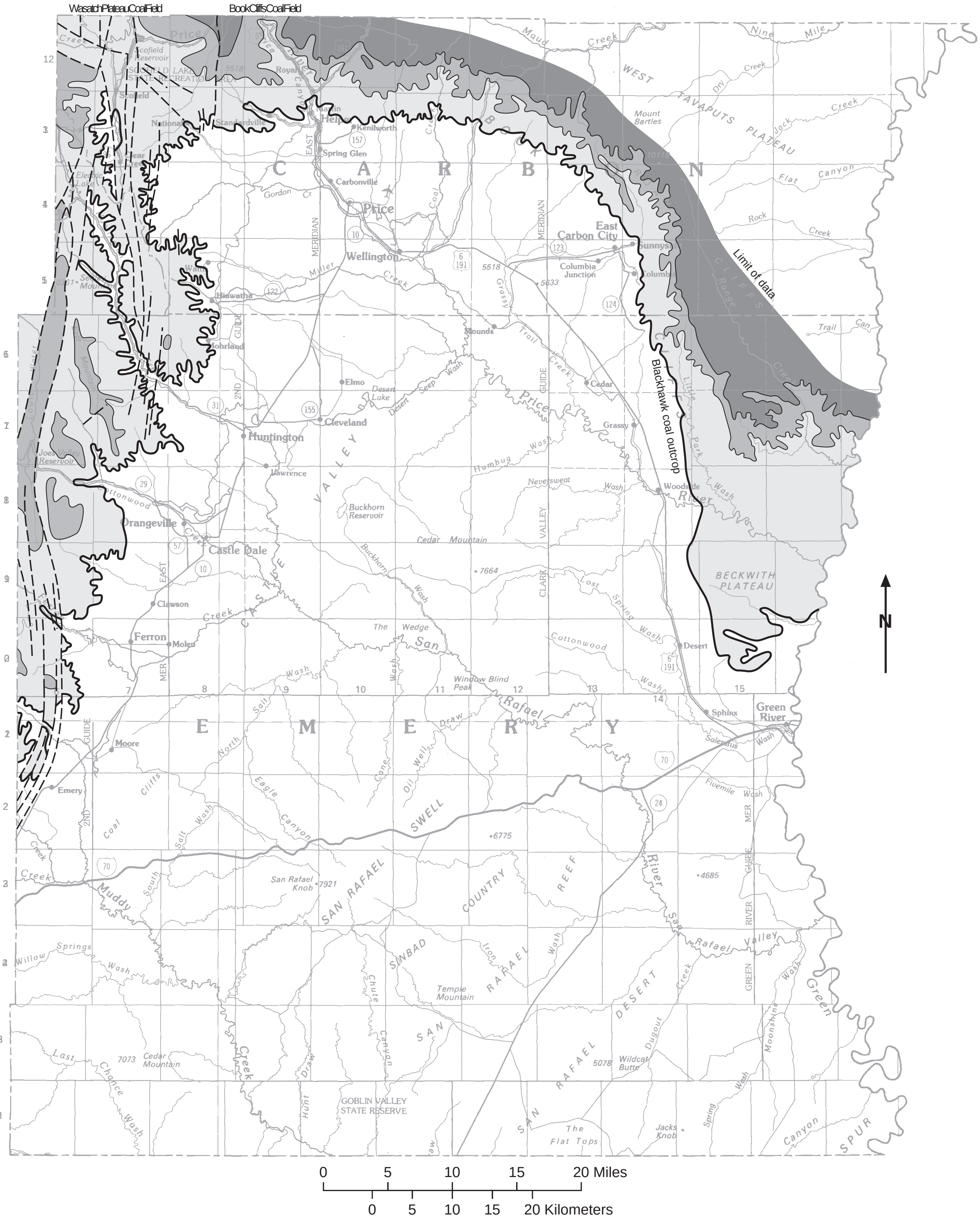


Plate 5. Depth to the Uppermost Coal of the Blackhawk Formation

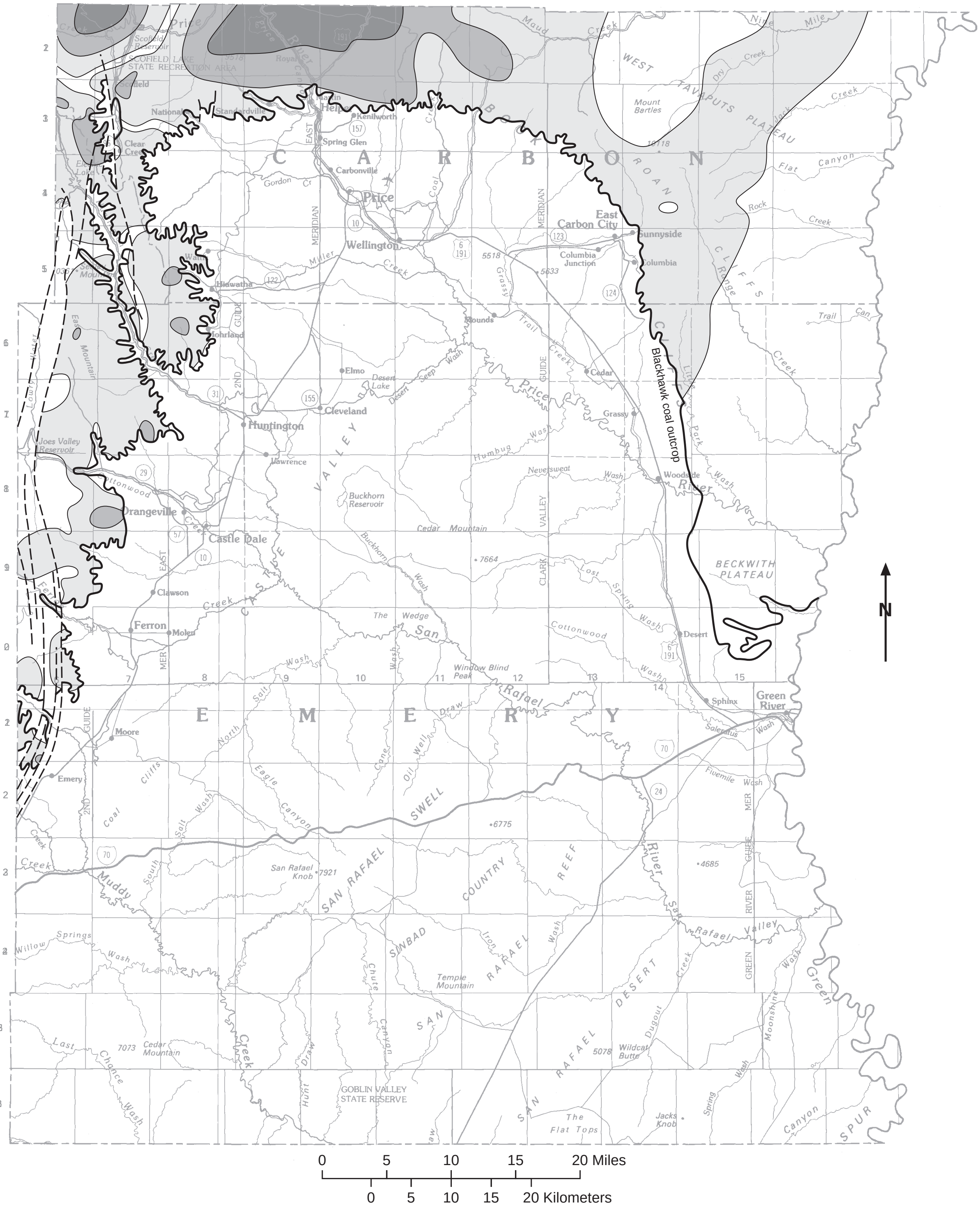


Plate 6. Total Net Coal in the Blackhawk Formation
(beds greater than or equal to 1 foot)

0'-10'
10'-30'
30'-50'
50'-70'
Blackhawk coal outcrop
Fault

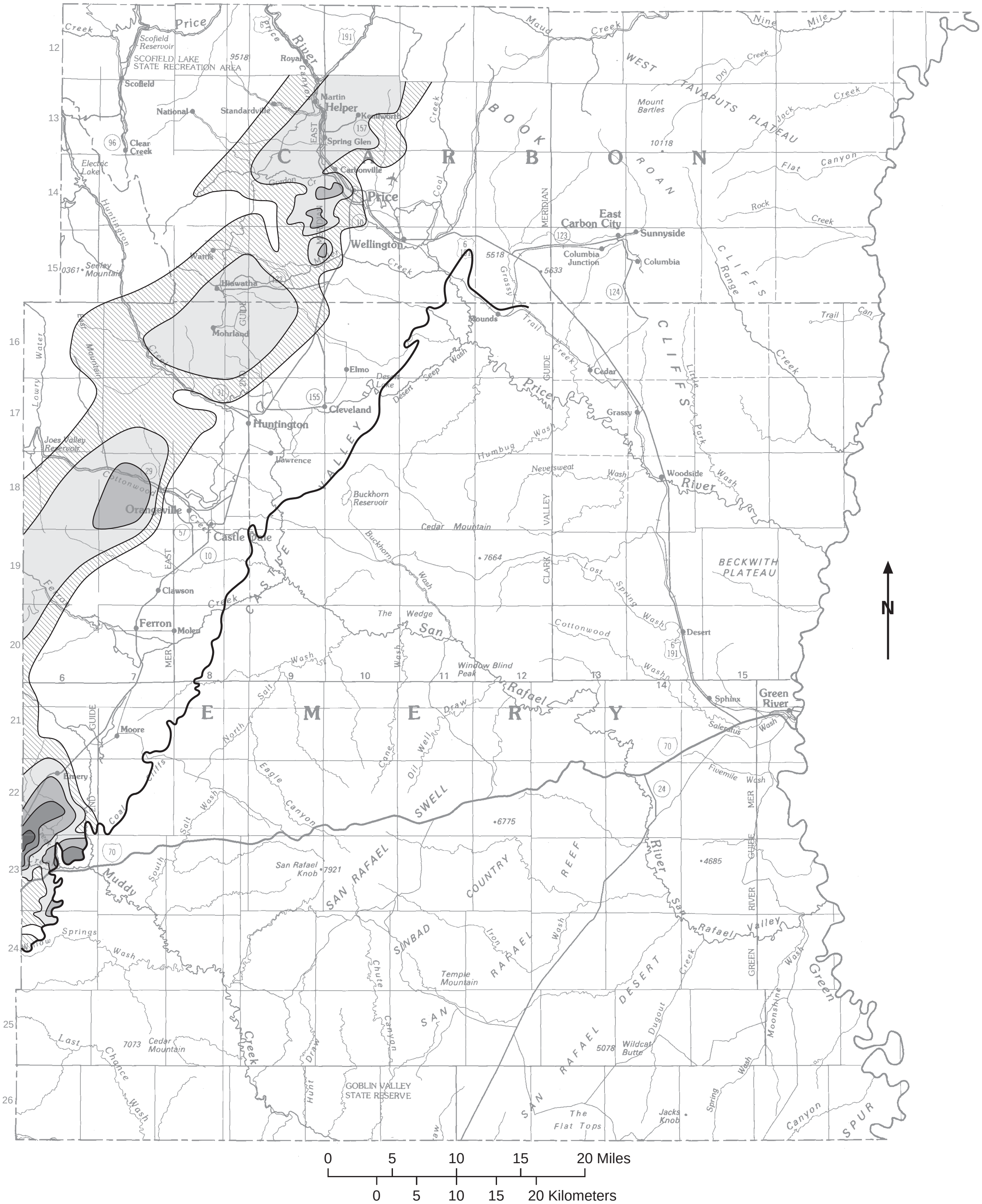


Plate 7. Total Net Coal in Ferron Sandstone Member of Mancos Shale
(all beds greater than or equal to 1 ft.)

10' - 20' | 20' - 30' | 30' - 40' | 40' - 50' | >50' | Ferron Sandstone outcrop

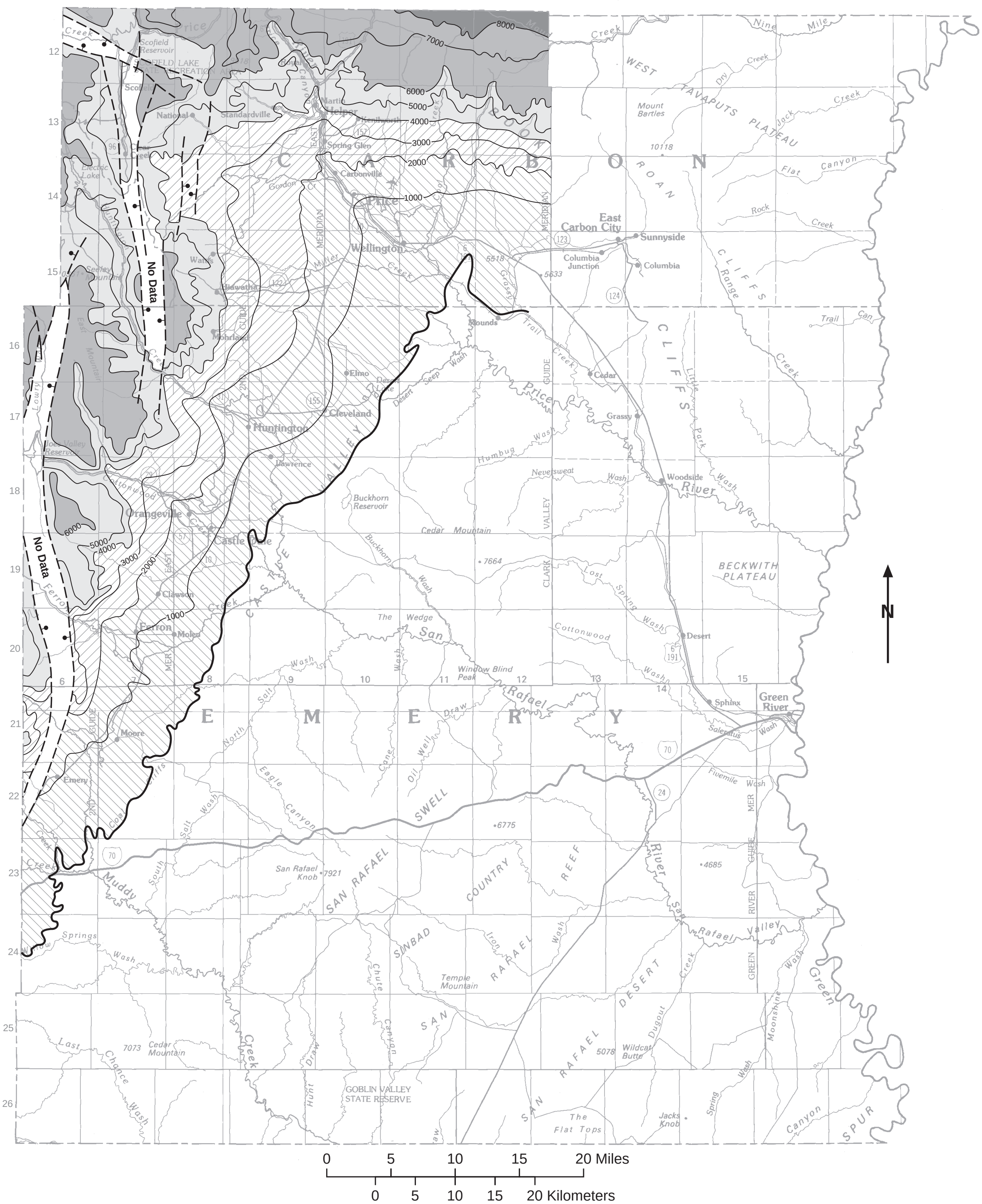
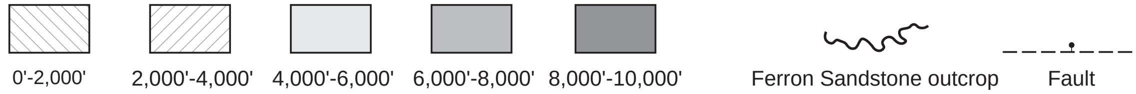


Plate 8. Depth to Top of Ferron Sandstone Member of Mancos Shale



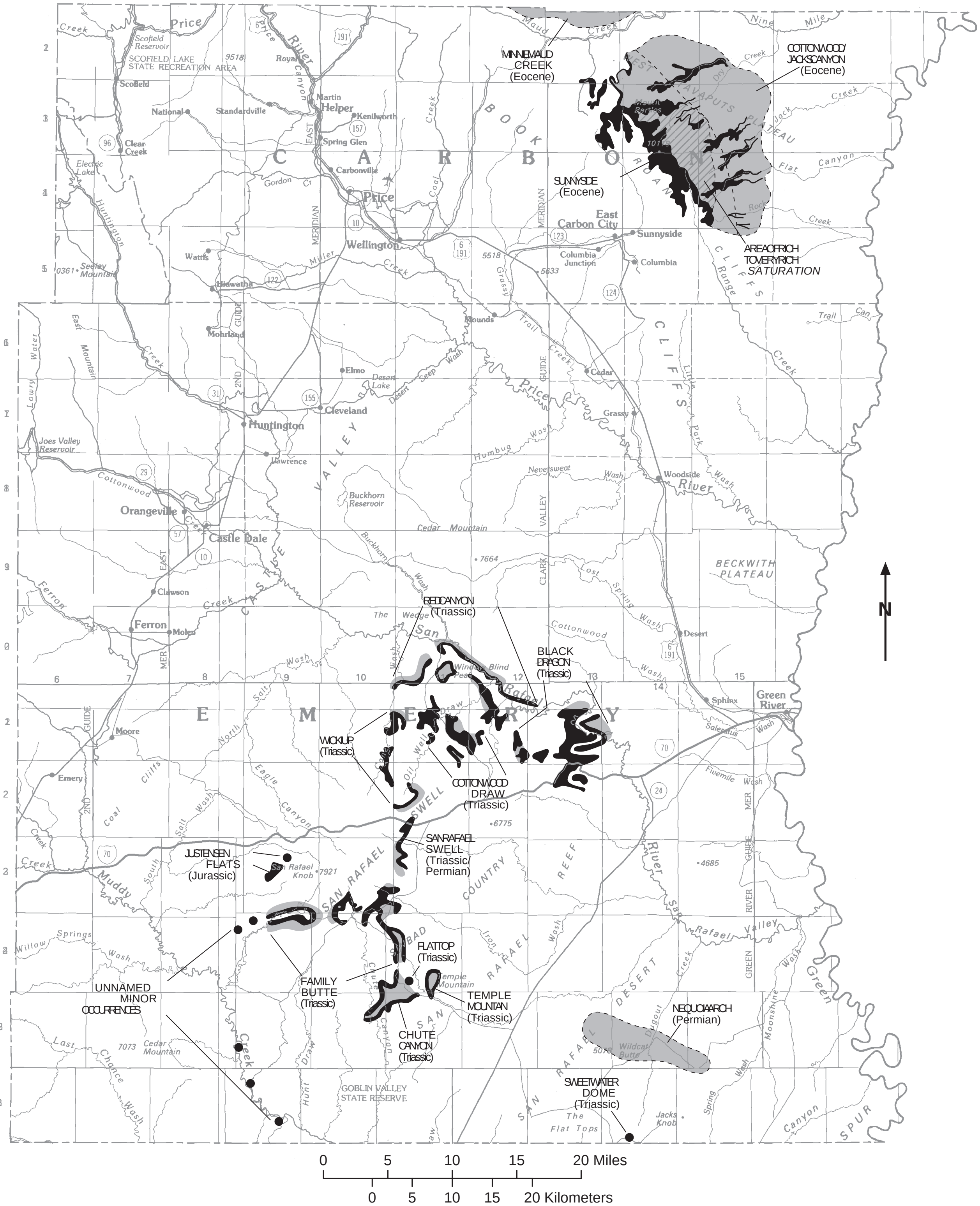


Plate 9. Oil-Impregnated Rock Deposits

Areal extent of deposit is known.

Extent beneath cover is inferred from outcrop or drilling information. Area of rich to very rich saturation indicated by diagonal lines. Limit of extent beneath cover shown by dashed line where limit can be inferred from outcrop or drilling information. Lower limit is about 500 feet of cover.

Deposit is concentrated or of small areal extent.

WICKIUP (Triassic)

Generally similar and grouped together (lines indicate grouping).

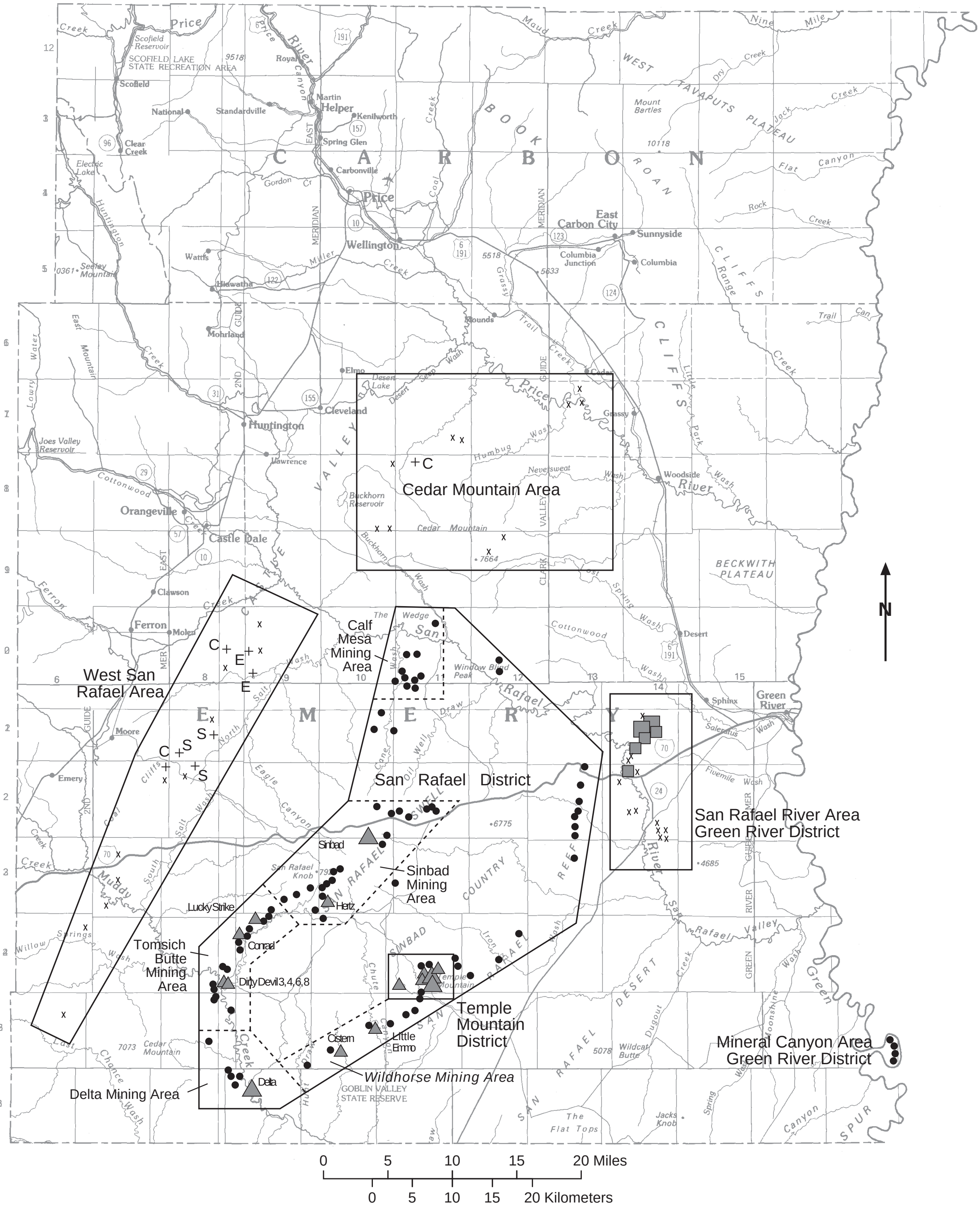


Plate 10. Uranium and Vanadium Mines and Prospects

Chinle-Hosted Deposits	Morrison-Hosted Deposits	Other Formations
● Prospect or small mine	x Prospect or small mine	+ C Cedar Mountain
▲ >10,000 lb U_3O_8 production	■ >10,000 lb U_3O_8 production	+ S Summerville
▲ >200,000 lb U_3O_8 production	■ >200,000 lb U_3O_8 production	+ E Entrada

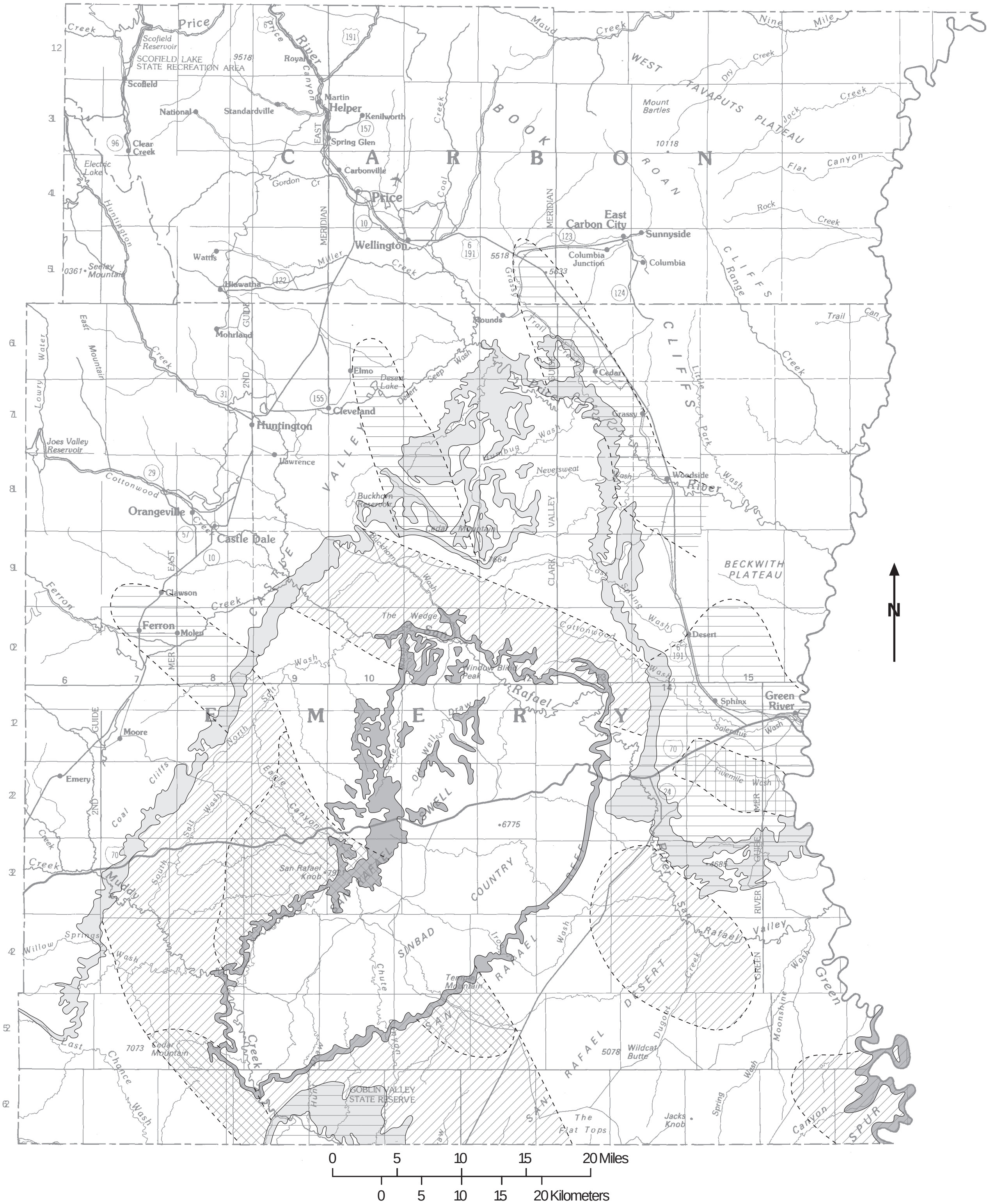


Plate 11. Uranium and Vanadium Exploration Areas

- Outcrop of Chinle Formation
- Outcrop of Morrison Formation
- Favorable areas for Chinle-hosted uranium-vanadium deposits
- Favorable areas for Morrison-hosted uranium-vanadium deposits
- Most favorable areas for Chinle-hosted uranium-vanadium deposits
- Most favorable areas for Morrison-hosted uranium-vanadium deposits

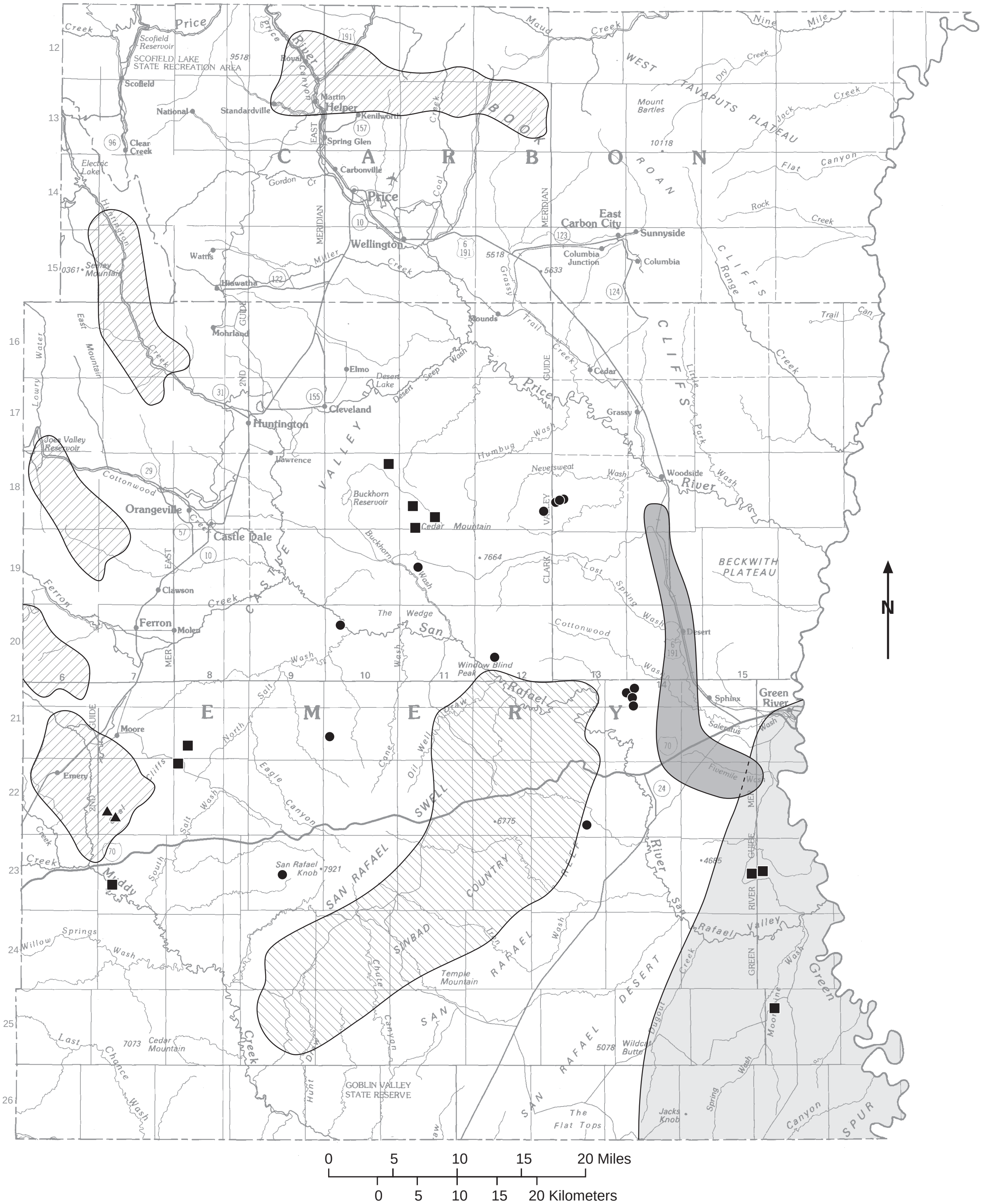


Plate 12. Metallic Mineral Resources and Exploration Areas

Known Occurrences

- ● Copper ± silver
- ■ Manganese
- ▲ Titanium-zirconium

Areas with Potential

- Lisbon Valley-type copper
- Dzhezkazgan-type copper
- Mississippi Valley-type lead-zinc
- Titanium-zirconium fossil placers

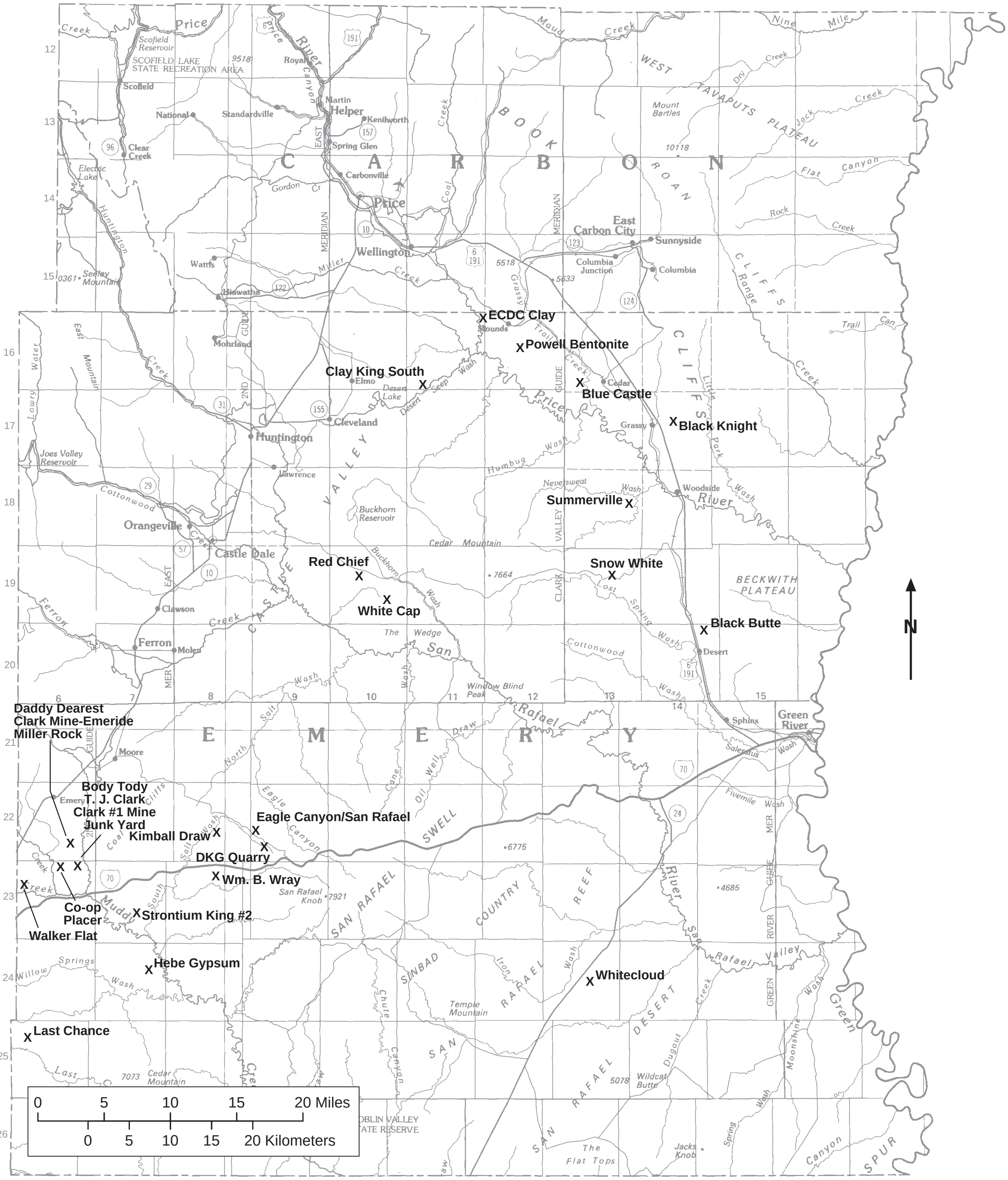


Plate 13. Active and Permitted Mines as of December 31, 2001

Active Small Mine Permits

Name	Operator	Commodity
Body Tody/Rockland	Miracle Rock Mining and Research	Humic shale
Miller Rock/Bret Clark	Hub Research and Development	Humic shale
Co-op Placer	Co-op Mining Company	Humic shale
Walker Flat	Miracle Rock Mining and Research	Humic shale
Strontium King #2	H. Steven Hatch	Celestite, barite
Black Butte	Goldterra, Inc.	Gold
Clay King South	Emery Industrial Development	Clay

Active Large Mine Permits

Name	Operator	Commodity
DKG Quarry	Diamond K	Gypsum
Eagle Canyon Quarry	Georgia Pacific Corp.	Gypsum
Hebe Gypsum	Georgia Pacific Corp.	Gypsum
San Rafael/Kimball Draw	U.S. Gypsum Co.	Gypsum
Last Chance #25 and #26	Western Clay Co.	Bentonite/zeolite
Blue Castle	Goldterra, Inc.	Gold

Inactive Small Mine Permits

Name	Operator	Commodity
Whitecloud Mine	Sutherland Brothers	Gypsum
White Cap #8	Gypsum Resource Devel.	Gypsum
Wm. B. Wray Mine	Wm. B. Wray	Gypsum
ECDC Clay	ECDC Environmental, LC	Clay
Powell Bentonite	Clark R. Powell	Bentonite
Summerville	Brenda Kalatzes	Gallium, gold
Red Chief	Quality Building Stone, Inc.	Building stone
Snow White	Quality Building Stone, Inc.	Building stone
Daddy Dearest/Blackhawk	Thomas J. Clark and Co.	Humic shale
Clark Mine/Emeride	Robert L. Clark	Trace minerals (humic shale)
Junk Yard	The Rockland Corp.	Humic shale
No. 1 Clark Mine	Robert L. Clark	Trace minerals (humic shale)
TJ Clark Mine	Freemont Corp.	Trace minerals (humic shale)
Black Knight	Goldterra, Inc.	Gold

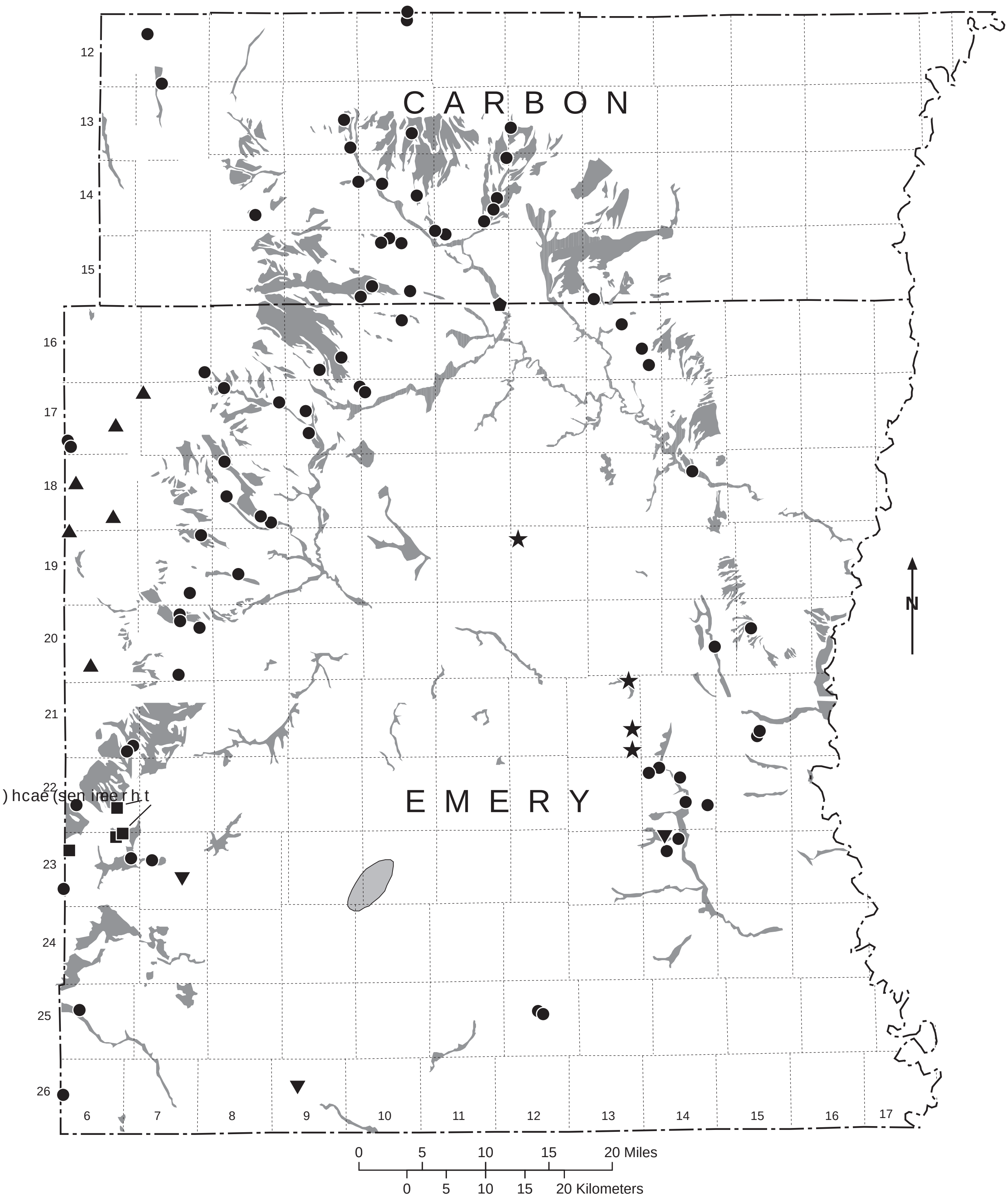


Plate 14. Selected Industrial Rock and Mineral Resources

- Barite occurrence area
- Outcrop of pediment and alluvial gravels from Williams (1972) and Witkind (1995)
- Sand and gravel pit
- Bentonite pit