MINERAL AND ENERGY RESOURCES IN KANE COUNTY, UTAH AND THEIR OCCURRENCE WITH RESPECT TO WILDERNESS STUDY AREAS

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SUMMARY

In late 1990 the Bureau of Land Management (BLM) released its "Utah BLM Statewide Wilderness Final Environmental Impact Statement" (Final EIS; Bureau of Land Management, 1990). The BLM prepared this seven-volume document following many years of studying lands in Utah for possible inclusion into the "National Wilderness Preservation System." The BLM's work focused on 83 Wilderness Study Areas (WSAs) throughout Utah encompassing roughly 3.24 million acres (1.3 million ha). The BLM considered 18 alternative combinations in the Final EIS. Six of these alternatives were analyzed in detail and ranged from a "No Action" (no wilderness) alternative to an "All Wilderness" (83 WSAs) alternative. The "Proposed Action" alternative would designate nearly 1.98 million acres (802,000 ha) in all or part of 66 WSAs. In late 1991 the BLM recommended the Proposed Action alternative to the Secretary of Interior for inclusion into the wilderness system.

As part of the study and recommendation process, the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM), at the request of the BLM, performed mineral and energy resource evaluations on selected WSAs included in the BLM's Proposed Action. Evaluations performed by the USGS and the USBM describe mineral resources in terms of known mineral resources and resource potential. In order to present regional perspectives and to expand on the USGS and the USBM work, the Utah Geological Survey (UGS) studied available mineral and energy resource information associated with 15 WSAs in Kane County included in the BLM's All Wilderness alternative. The UGS study involved: (1) compilation of mineral occurrence data for metals and industrial mineral commodities, (2) compilation of coal resource data, primarily for the Kaiparowits Plateau coal field, and (3) presentation of regional perspectives for petroleum and CO_2.

Identified coal resources within Kane County represent nearly 30 percent of the state's total coal resources. The majority of coal resources in Kane County are contained within the Kaiparowits Plateau coal field. The WSAs considered in the BLM's All Wilderness alternative would be in direct conflict with most of the coal resources in the Kaiparowits Plateau coal field. However, the BLM has reduced the potential coal-resource conflicts significantly as WSAs considered in the BLM's Proposed Action do not generally conflict with major coal resource areas in the Kaiparowits Plateau, Alton, or Kolob coal fields.

Oil and gas resource potential in Kane County is undetermined. To date, no commercial discoveries of petroleum have been made from any of the 29 exploratory wells drilled although favorable geologic conditions are present, and 23 of the exploratory wells penetrated hydrocarbon-bearing strata. Two exploration concepts appear to warrant future testing. One hypothesis, based upon the petroleum reservoir at Upper Valley field in Garfield County, suggests that hydrocarbons may be displaced toward the largely untested flanks of major structures in Kane County. The second hypothesis suggests that

potential hydrocarbon source-rocks may be present within Precambrian strata beneath much of Kane County and that older, untested formations may be potential hydrocarbon reservoirs.

Large portions of Kane County are underlain by sedimentary rock formations containing gypsum, high-calcium limestone, and possibly manganese. Potential conflicts with WSAs, however, would probably be minor because higher-quality deposits of these commodities are found elsewhere. Similarly, resource potential for most base and precious metals would be affected little by proposed wilderness designation. The Fifty Mile Mountain WSA might conflict with areas containing potential uranium and titanium-zirconium deposits.

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INTRODUCTION

Background

The Federal Land Policy Management Act (FLPMA) (PL 94-579, October 21, 1976) requires the Bureau of Land Management (BLM) to identify lands meeting criteria for inclusion into the National Wilderness Preservation System. The Utah BLM Statewide Draft Environmental Impact Statement or Draft EIS (Bureau of Land Management, 1985) presented seven alternative configurations of lands in Utah designated as Wilderness Study Areas or WSAs (i.e lands meeting a set of criteria under FLPMA). After completing a scoping process and receiving public comments on the Draft EIS, the BLM prepared a Final EIS (Bureau of Land Management, 1990). The alternative WSA configurations described in the Final EIS range from a "No Action" (no acreage designated) alternative to an "All Wilderness" alternative (3.24 million acres designated -- 1.3 million ha). The BLM recommended their Proposed Action for Utah as suitable for "Wilderness" designation to the Secretary of Interior in the fall of 1991. The Proposed Action consists of some 1.98 million acres (802,000 ha) of public land contained in 66 WSAs.

At the request of the BLM, the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS) evaluated identified mineral resources and mineral resource potential respectively for "selected" WSAs. The selected WSAs were those generally included as part of the BLM's Proposed Action alternative outlined in the Draft EIS. The USBM reviewed in-house reports, BLM files, and published information and collected new data on individual mines and prospects to identify known mineral resources. The USBM documented their results in a series of open-file reports. The USGS followed on the work of the USBM and prepared analyses of resource potential using USBM findings, regional geology, geophysics, and new geochemical data. The USGS describes levels of resource potential and levels of certainty for mineral resources based on the adequacy of available information. Their results are presented as a series of USGS bulletins for individual WSAs (Bartsch-Winkler and others, 1988a, 1988b, 1989; Van Loenen and others, 1988a, 1988b, 1989; Bell and others, 1990).

Purpose and Scope

The Utah Department of Community and Economic Development enlisted the help of the UGS to review and report on the objectives and procedures for mineral resource evaluations performed by federal agencies as part of the wilderness study process. Because a review of work completed on all 66 WSAs in Utah was not feasible, we decided to focus on evaluations performed on a few WSAs in southern or southeastern Utah. WSAs in Kane County (figure 1, table 1) were chosen for the study due to (1) the relatively large acreage of WSAs in the county, (2) the large amount of mineral resource information for Kane County available at the UGS, and (3) the recently published UGS comprehensive geologic report on Kane County by Doelling and Davis (1989).

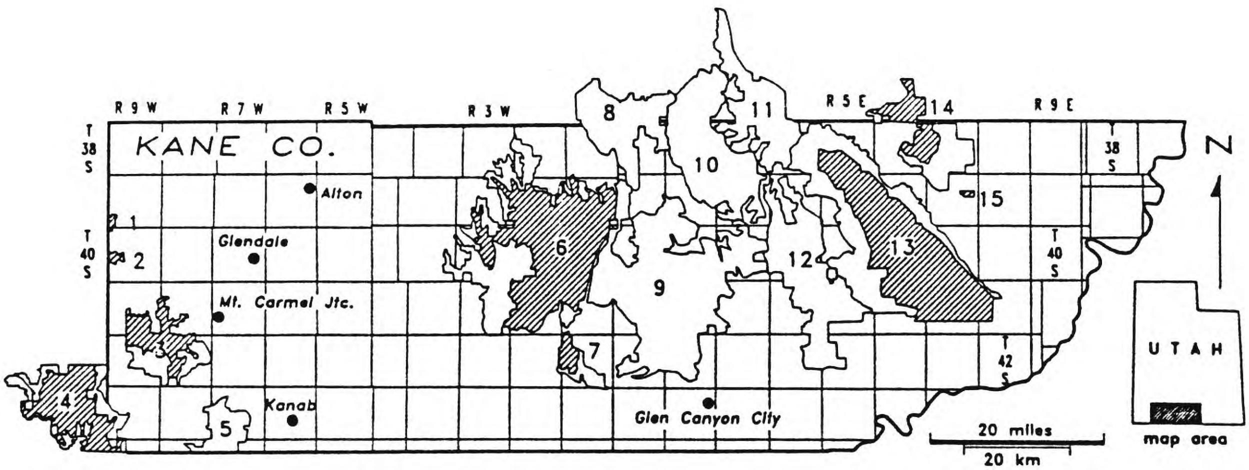

Figure 1: Wilderness Study Areas in Kane County. 1-North Fork Virgin River, 2-Orderville Canyon, 3-Parunuweap Canyon, 4-Canaan Mountain, 5-Moquith Mountain, 6-Paria-Hackberry, 7-The Cockscomb, 8-Mud Spring Canyon, 9-Wahweap, 10-Death Ridge, 11-Carcass Canyon, 12-Burning Hills, 13-Fifty Mile Mountain, 14-Scorpion, 15-Escalante Canyons Tract 5 ISA Complex (after Bureau of Land Management, 1985; 1990). Cross-hatched pattern indicates the BLM's "Proposed Action" alternative.

Table 1: Comparison of acreage between the BLM's Proposed Action and the All Wilderness alternatives as reported in the Final EIS. Last column indicates the change in acreage for the Proposed Action alternative from the Draft EIS to the Final EIS (Bureau of Land Management, 1990, p. 40).

No.	WSA Name	ALTERNATIVE		
		Proposed Action	All Wilderness	Change from Draft EIS
1	N. Fork Virgin River	1,040	1,040	
2	Orderville Canyon	1,750	1,750	
3	Parunuweap Canyon	17,888	30,800	+3,788
4	Canaan Mountain	33,800	47,170	+1,000
5	Moquith Mountain	0	14,830	
6	Paria-Hackberry	95,042	136,222	+35,772
7	The Cockscomb	5,100	10,080	
8	Mud Spring Canyon	0	38,075	
9	Wahweap	0	134,400	-70,380
10	Death Ridge	0	62,870	
11	Carcass Canyon	0	46,711	
12	Burning Hills	0	61,550	
13	Fifty Mile Mountain	91,361	146,143	
14	Scorpion	14,978	35,884	+5,358
15	Escalante Can. Tr. 5	760	760	
	TOTAL	261,719	768,285	

Previous studies done on Kane County WSAs by the USGS and USBM were limited only to those WSAs in the BLM's Proposed Action alternative. Mineral resources in most of the remaining WSAs (Mud Spring Canyon, Death Ridge, Carcass Canyon, and Burning Hills) comprising the All Wilderness alternative were not covered by formal reports. This report describes aspects of mineral and energy resources in all WSAs in Kane County including those not reported on by the USGS and the USBM.

Although several mineral commodities are described in this study, more emphasis was placed on characterizing coal resources of the Kaiparowits Plateau coal field, and on describing the regional potential for oil, gas, and CO_2 resources within the WSAs. These commodities were selected since coal resources represent, by far, the County's most important mineral resource (Kane County contains nearly 30 percent of the state's coal reserves), and undiscovered petroleum resources could, conceivably, make a large impact on local economies.

This report of investigations provides the reader with some additional perspectives concerning the regional distribution of mineral and energy resources in Kane County. The information and interpretations presented here should be used as a supplement to the more detailed work performed by the federal agencies.

Methodology

Unlike the work done by the USGS and the USBM where WSAs as part of the BLM's Proposed Action alternative were analyzed on an individual basis, we studied the distribution of resources with respect to the distribution of WSAs in the BLM's All Wilderness alternative. We describe identified mineral and energy resources in some detail, and we discuss resource potential in a qualitative manner.

Information on coal resources was compiled from UGS publications and from UGS confidential data files. Oil, gas, and CO_2 information was compiled from UGS publications and from data available through Petroleum Information Corporation. Drill hole information and regional structural data taken from various published sources were used to describe the potential for the discovery of oil, gas, and CO_2 resources on a regional scale. Reports of the U. S. Department of Energy's National Uranium Resource Evaluation program (U.S. Department of Energy, 1979) were used, among other sources, to describe uranium resource potential.

Due to large potential conflicts between WSAs and coal resources in the Kaiparowits Plateau coal field, we describe coal resource potential of the Kaiparowits field in more detail. Coal resource information was compiled from published sources and from confidential UGS files. The confidential coal resource data were taken from 170 exploratory drill holes and were used in conjunction with more than 500 measured sections from Doelling and Graham (1972). Methods and data summaries are documented in a supplemental report (Blackett, in preparation).

Location and Physiography

The WSAs are located near the western edge of the Colorado Plateau physiographic province (figures 1 and 2). The region is divided by Stokes (1977) into two physiographic subdivisions called the Grand Staircase and the Kaiparowits Plateau -- Escalante Benches. The East Kaibab monocline (The Cockscomb) roughly divides Kane County in half along a north-south line separating the two subdivisions. Broad highlands, part of the Southern High Plateaus, extend southward into northwestern Kane County. Upwarping associated with the Circle Cliffs and Teasdale anticlines extend southeastward into northeastern Kane County.

Topography is characterized by wide benches of resistant strata alternating with slopes of less resistant rock cut by steep walled canyons. Altitudes range generally between 5,000 and 7,000 feet (1,524 and 2,134 m). High desert vegetation grows in the region and includes a variety of desert shrubs and grasses. Pinyon-juniper and ponderosa pine forests generally cover the higher elevations.

GEOLOGY

Regional Structure

Topographic features in Kane County reflect the underlying geologic structure. Sedimentary strata generally dip gently northward and form high plateaus, buttes, and mesas. Superimposed on these features are generally north-south oriented faults, monoclines, and broad anticlines and synclines. Significant features include the Sevier fault, Paunsagunt fault, Kaibab uplift, and the East Kaibab monocline which is also known as The Cockscomb (figure 3).

The Sevier fault, a high-angle fault system, extends along a 300-mile (480 km) zone of rupture in a north-northeast trend beginning near the Grand Canyon to the south, through western Kane County, and ending within the volcanic rocks of the Sevier Plateau to the north. Strata on the west side of the Sevier fault are displaced down with offset varying from 1,000 to 2,000 feet (305 to 610 m). Along the fault, escarpments with as much as 800 feet (244 m) of vertical relief can be seen. Minor faults have splayed off from the main fault zone and have created small, tilted blocks where strata dip as much as 60 degrees (Doelling and Davis, 1989, p. 93).

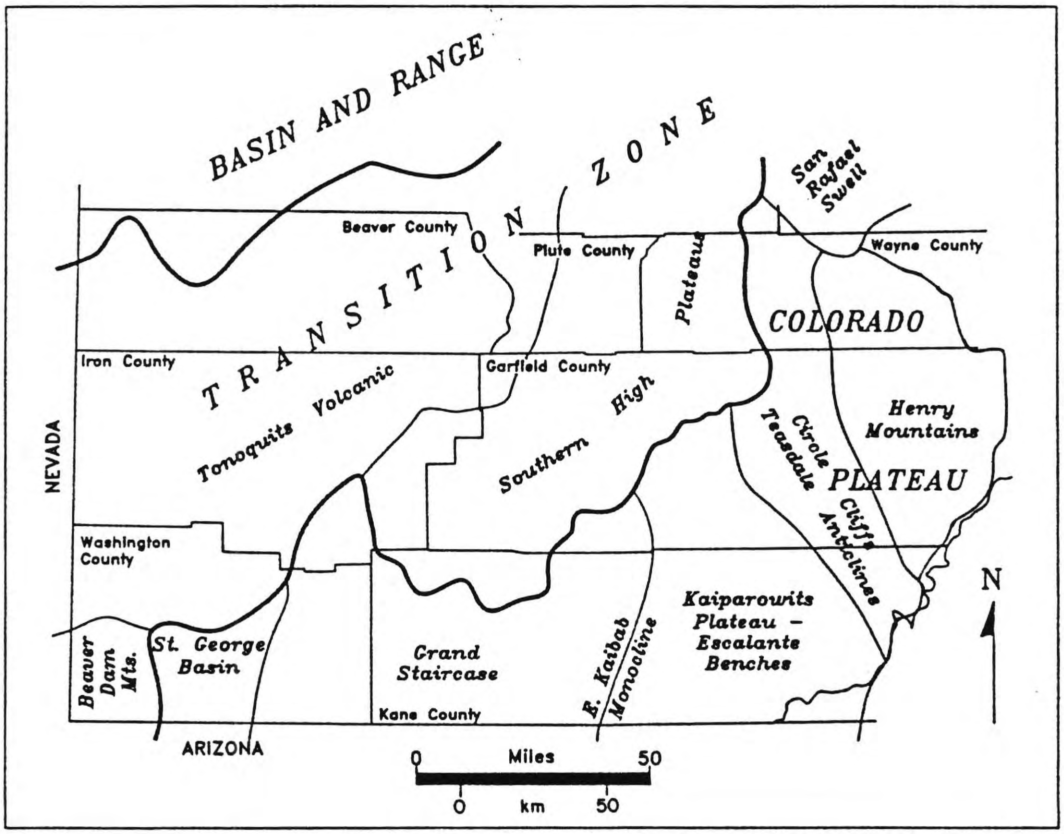

Figure 2: Physiographic provinces in southwestern Utah (modified from Stokes, 1977).

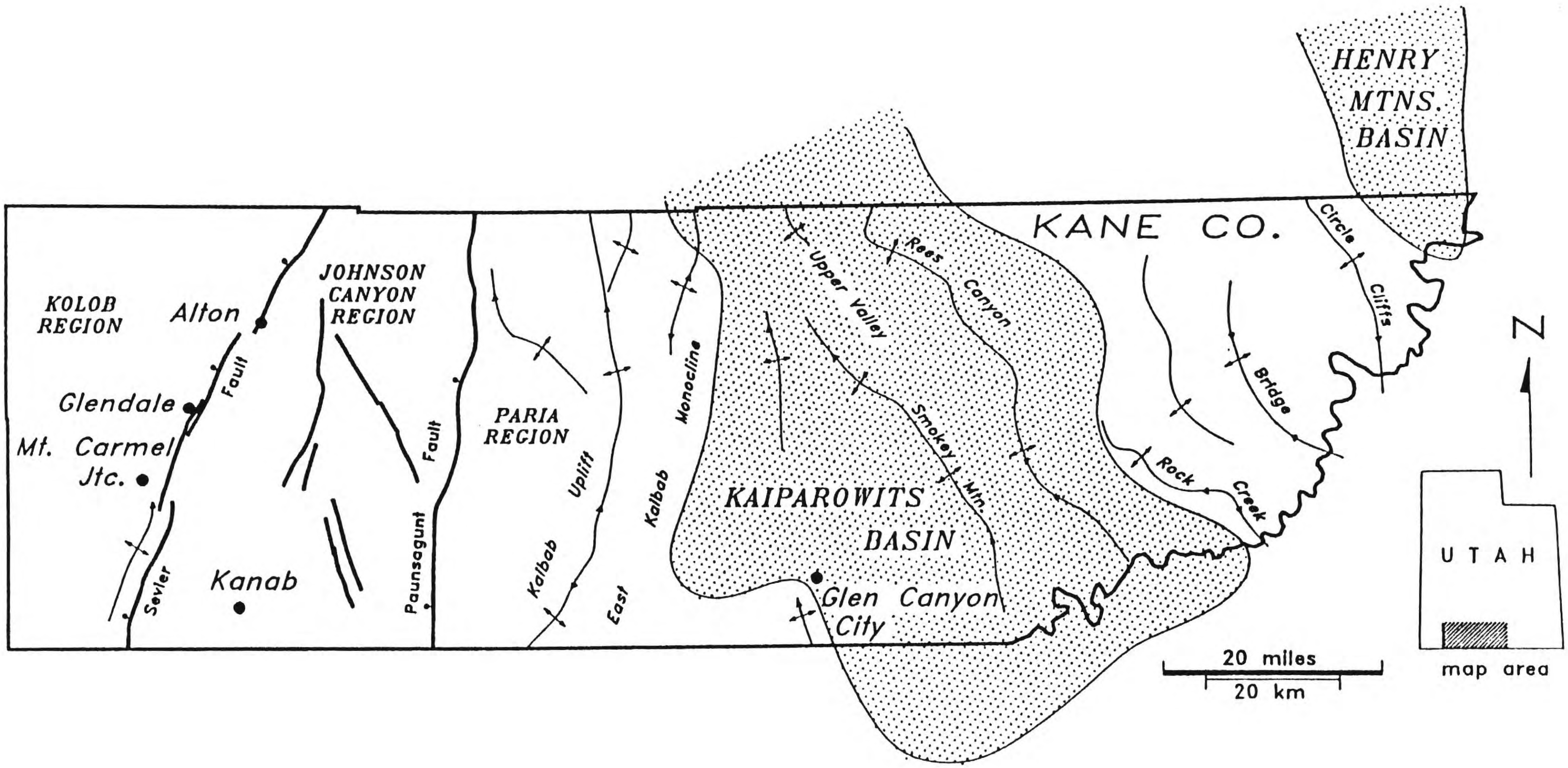

Figure 3: Generalized structure of the study region, showing major faults and anticlines. The outlines of the present-day Kaiparowits and Henry Mountains structural basins are based on the 5,500 feet (1,676 m), structural contour drawn on the base of the Dakota Sandstone. Sources of information include Peterson (1988, p. 135), and Doelling and Davis (1989).

The Paunsagunt fault, like the Sevier fault, is a high-angle zone of rupture extending from northern Arizona into central Utah, that roughly parallels the Sevier fault. Displacement along the Paunsagunt fault is also down to the west and varies between 100 and 800 feet (30 and 244 m) of offset. In areas of minimum displacements, strata within the upthrown block are folded and dip sharply toward the fault (Doelling and Davis, 1989, p. 93).

Probably the single most outstanding geologic feature in the study region is the East Kaibab monocline. The East Kaibab monocline is a north-northeast-trending structure along which rocks dip abruptly to the east. Dips along the monocline vary from about 15 degrees east to slightly overturned, and most often range from 40 to 60 degrees east along steeper segments. Maximum vertical structural relief estimated at 5,000 feet (1,524 m) occurs in southern Kane County. Displacement decreases northward and the structure dies in the north-central part of the county.

Kane County can be subdivided into four regions separated by these prominent geologic features. The Kolob region, the region lying west of the Sevier fault, is characterized by gently northward-dipping strata along which erosion has created a series of southward-facing plateaus.

The Johnson Canyon region, located between the Sevier and Paunsagunt faults, is comprised of another series of southward-facing terraces. Sedimentary beds in this region generally dip gently northward, rarely exceeding 3 or 4 degrees. This broad homocline is cut by a number of high-angle, normal faults of small displacements (up to 200 feet [61 m] of offset) that trend north-northeast to north-northwest (Doelling and Davis, 1989, plate 1).

The Paria region, lying between the Paunsagunt fault and the East Kaibab monocline, is structurally higher than adjacent regions. The Kaibab Uplift, the main feature of the Paria region and situated adjacent to the East Kaibab monocline, is a broad northeast-oriented anticline. The Paria region is otherwise characterized by gently warped strata that generally dip to the north (Doelling and Davis, 1989, p. 95).

The Kaiparowits region, a present-day structural basin, lies to the east of the East Kaibab monocline and contains gentle anticlines and synclines. This feature roughly coincides with a Mesozoic depositional basin where thick sedimentary deposits accumulated during the Jurassic and Cretaceous Periods. Faulting does occur, but is rare (Gregory and Moore, 1931; Bissell, 1954).

Stratigraphy

Exposed sedimentary geologic units range in age from Permian to Holocene and represent marine, continental, and marginal marine deposition. Hintze (1988, p.194) presents generalized stratigraphic columns for surface and subsurface rock units from Precambrian to Holocene. Doelling and Davis (1989, p. 18-91) provide detailed descriptions of stratigraphic units and present interpretations of stratigraphic relationships for surface and subsurface rock units across Kane County (figures 4 and 5).

The oldest rocks penetrated in Kane County by the deep Tidewater No. 1 Kaibab Gulch well (figure 5) include the Precambrian Chuar Group and the upper part of the Unkar Group. The Tidewater well reportedly penetrated the upper 20 feet (6 m) of the Shinumo Sandstone (Proterozoic) of the Unkar Group at the bottom of the well. Chuar Group rocks (Proterozoic), primarily of carbonaceous shale, were reportedly 1,040 feet (317 m) thick (Chidsey and others, 1990).

Paleozoic rocks in Kane County, penetrated by deep drill holes, are illustrated on figure 5. Many of these units are well exposed in the Grand Canyon of Arizona to the south. Total thickness of all Paleozoic units penetrated by the Tidewater well is about 5,200 feet (1,585 m). Cambrian rock units consist of the Tapeats Sandstone, Bright Angel Shale, and Muav Formation -- the Cambrian on-lap series. Total thickness of Cambrian units in Kane County ranges from 1,200 to 2,000 feet (366 to 610 m) (Doelling and Davis, 1989, p. 21).

The Ouray Limestone and the Elbert Formation represent Devonian-age rocks throughout most of the county. These units unconformably overlie the Cambrian Muav Limestone, and they are unconformably overlain by the Mississippian Redwall Limestone. Toward the southwest, the Mississippian unconformity truncates the Ouray, and the remaining Devonian section is called the Temple Butte Formation. Total thickness of the Devonian section in Kane County ranges from 100 feet (30 m) in the southwest to over 400 feet (122 m) in the northeast (Doelling and Davis, 1989, p. 22).

The Redwall Limestone comprises the Mississippian system in Kane County. The Redwall is a marine unit consisting of predominantly crystalline dolomite and limestone and has a karst-type upper contact with overlying Pennsylvanian strata. Thickness of the Redwall ranges generally between 700 and 900 feet (213 and 274 m) (Doelling and Davis, 1989, p. 24).

The Pennsylvanian Hermosa and Molas Formations are present in eastern Kane County and the equivalent Callville Formation is present in extreme western Kane County. There is however a difference of opinion on the presence of Pennsylvanian strata in central Kane County. Heylman (1963) suggested that early Pennsylvanian uplift (Kaibab uplift) in western Kane County caused Pennsylvanian strata to become thin or absent. Heylman's view is supported by others (Mallory, 1972; Hintze, 1973), and is illustrated in figure 5. Doelling and Davis (1989, p. 25), however, provide arguments suggesting that Pennsylvanian-age units, although locally thin, may underlie all of Kane County.

Permian-age rock units consisting of alternating marine carbonates and marginal marine sandstone and shale units underlie all of the county. In western Kane County Permian units consist

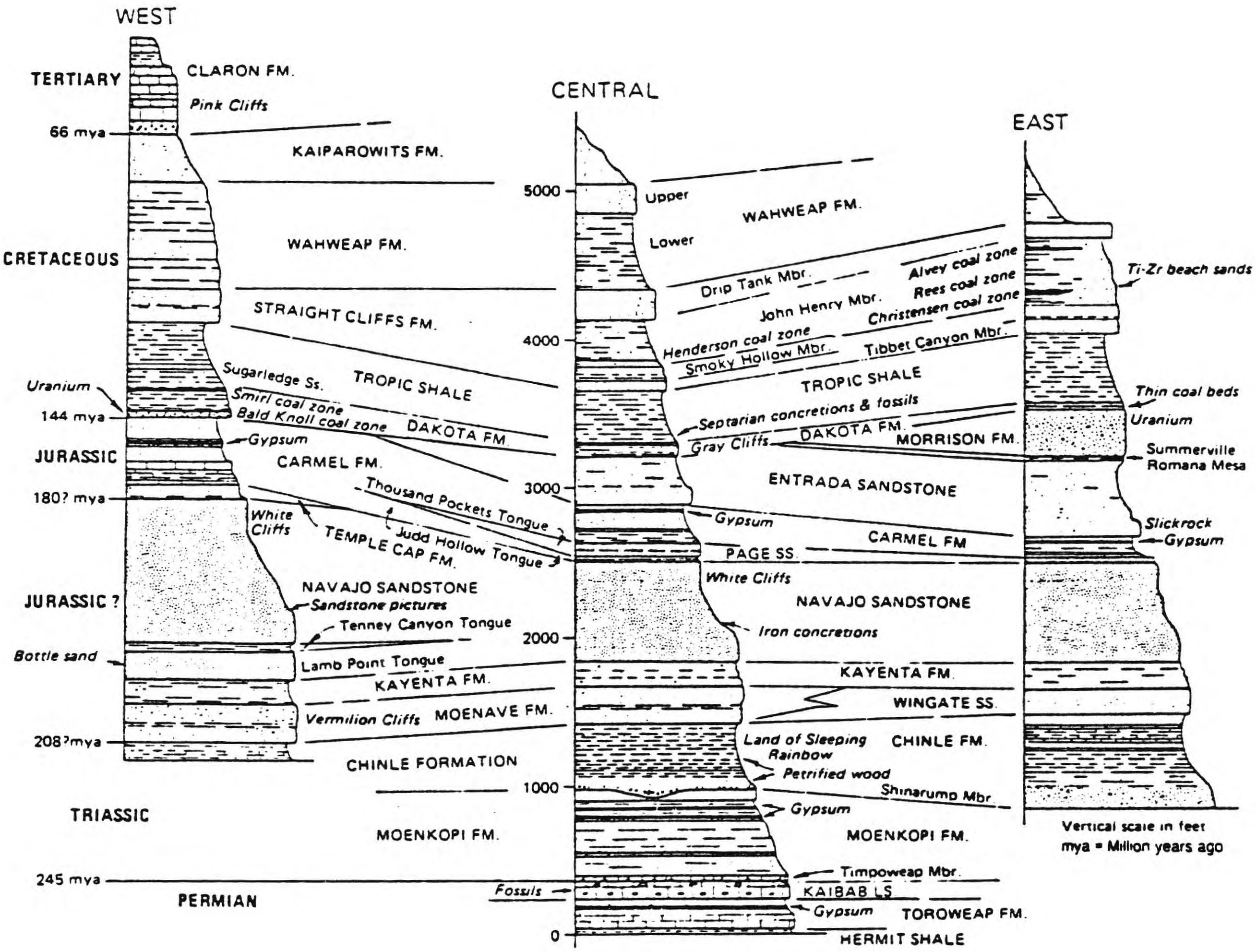

Figure 4: Stratigraphic relationships, from west to east, of exposed rock units in Kane County (from Doelling and Davis, 1989, p.18).

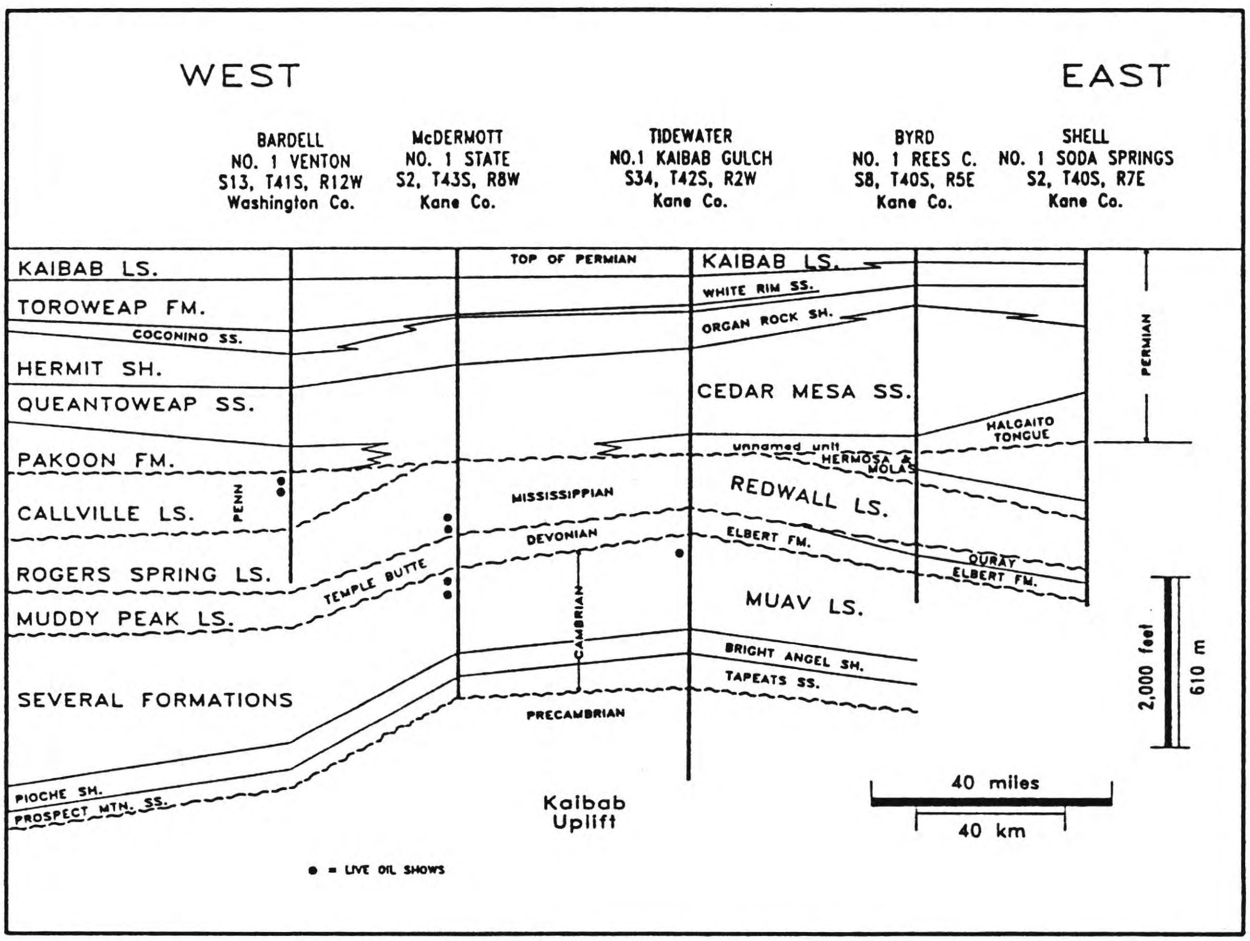

Figure 5: Correlation of Paleozoic units, west to east, across Washington and Kane Counties (from Doelling and Davis, 1989, p. 25).

of, in ascending order, the Pakoon Formation, Queantoweap Sandstone, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone. In central and eastern Kane County facies changes, principally from west to east, in some of the units have resulted in name changes. The Queantoweap Sandstone becomes the Cedar Mesa Sandstone, the Hermit Shale becomes the Organ Rock Shale, and the Toroweap Formation and Coconino Sandstone are equivalent to the White Rim Sandstone. Total thickness of these units varies widely from place to place but averages roughly 2,000 feet (610 m). Upper Permian units including the Hermit Shale, Coconino Sandstone, Toroweap Formation, White Rim Sandstone, and Kaibab Limestone crop out in a small area south of The Cockscomb along Kaibab Gulch (Doelling and Davis, 1989. p. 26).

Triassic-age rocks (figure 4) are exposed in southern Kane County and include six members of the Moenkopi Formation with an aggregate thickness of up to 1,400 feet (427 m) near Kanab and two members of the Chinle Formation, with a total thickness of about 500 feet (152 m) (Hintze, 1988, p. 194). The Moenkopi Formation is comprised of (from oldest to youngest) the Timpoweap, Lower Red, Virgin Limestone, Middle Red, Shnabkaib, and Upper Red Members; all deposited in inter-tidal or shallow marine environments. The Shinarump Member of the Chinle Formation is a fluvial conglomeratic sandstone unit resting unconformably on the Moenkopi Formation. The Shinarump Member is overlain by a series of mudstones and thin sandstones usually assigned to the Petrified Forest Member but may also include the Monitor Butte, Owl Rock and Church Rock (?) Members. All of the members, however, are related to fluvial channel and overbank deposition. The upper units contain colorful, variegated mudstone and sandstone.

Peterson (1988) places Jurassic and younger sedimentary units into divisions bounded by unconformities or depositional surfaces where little inter-tonguing occurs. The Glen Canyon Group (1,770 to 2,170 feet -- 539 to 661 m) is the oldest of the Jurassic divisions. It consists of the Wingate Sandstone, Moenave and Kayenta Formations, and the Navajo Sandstone. The Wingate and Navajo Sandstones are massive, wind-deposited (eolian) units separated by the fluvio-lacustrine Moenave and Kayenta Formations which were shed from highland source regions located to the east and southeast. Glen Canyon Group strata thicken to the west and northwest (Peterson, 1988, p. 135).

The San Rafael Group (700 to 1,600 feet -- 213 to 488 m) overlies the Glen Canyon Group and is comprised of the Page Sandstone, the Carmel Formation, the Entrada Sandstone, the Curtis Formation, and the Summerville Formation (Romana Sandstone). The lower division of the San Rafael Group (Page Sandstone and Carmel Formation, 200 to 800 feet -- 61 to 244 m) is primarily limestone and mudstone deposited in shallow marine environments. These deposits are flanked to the east and southeast by time-equivalent deposits of mudstone and lenticular gypsum beds deposited in a coastal sabkha environment (Peterson, 1988, p. 136).

The Entrada Sandstone (500 to 1,100 feet -- 152 to 335 m) comprises the middle division of the San Rafael Group. It is separated into three members consisting primarily of flat-bedded siltstone and cross-bedded sandstone deposited in sabkha and eolian environments, respectively.

In the Henry Mountains region, the upper division of the San Rafael Group consists of the Curtis and the overlying Summerville Formations (100 to 300 feet -- 30 to 91 m). In the Kaiparowits region, the Curtis is absent and the Summerville is replaced by the Romana Sandstone (100 feet -- 30 m), which is the landward facies of the Summerville. The Curtis Formation is largely a marine sandstone with minor limestone, and the Summerville Formation consists of distinct, thin-bedded, red mudstone and siltstone probably deposited in shallow, restricted marine conditions. The Romana Sandstone was deposited in marginal marine and eolian environments.

The Salt Wash and Tidwell Members of the Morrison Formation together form the lower division of the upper Jurassic series (300 to 700 feet -- 91 to 213 m). The Salt Wash Member consists of fluvial sandstone or conglomerate and very minor mudstone of lacustrine and overbank flood-plain origin. The Tidwell Member consists of mudstone, sandstone, and thin limestone lenses deposited distally to the Salt Wash alluvial complex in large lakes, mudflats, small eolian dune fields, and in evaporative environments (Peterson, 1988, p. 141).

The upper division of the Morrison Formation consists of the Brushy Basin Member in the Henry Mountains and northern Kaiparowits regions, and the Fiftymile Member (120 to 350 feet -- 37 to 107 m), a facies equivalent of the Brushy Basin Member, in the southern Kaiparowits region. These units were deposited in a broad lowland containing mud flats, lakes, and dune fields with few streams. The Fiftymile Member represents an alluvial complex that gradually moved from southwest to northeast across the Kaiparowits region toward mud flat and lacustrine environments represented by the Brushy Basin Member (Hintze, 1988, p. 199; Peterson, 1988, p. 141).

Lower Cretaceous rocks are absent over much of Kane County, but Hintze (1988, p. 199) indicates some remnants are present of the Cedar Mountain Formation in southeastern Kane County. The Cedar Mountain Formation (0 to 50 feet -- 15 m), is a unit consisting of interbedded fluvial sandstone and overbank mudstone derived from western highlands of the Sevier orogenic belt.

The upper Cretaceous is separated into three divisions based on transgressive-regressive cycles (figures 4 and 6). The lower division consists of the Dakota Formation (20 to 170 feet -- 6 to 52 m), Tropic Shale (610 to 730 feet -- 186 to 223 m), and the Tibbet Canyon (70 to 150 feet -- 21 to 46 m) and Smoky Hollow (30 to 90 feet -- 9 to 27 m) Members of the Straight Cliffs Formation. The Tibbet Canyon Member consists primarily of marine sandstone, and the Smoky Hollow Member consists of sandstone, siltstone, and coal. The Smoky Hollow Member is capped by the Calico Bed (0 to 60 feet -- 18 m), a fluvial unit related to a major regression of the Cretaceous shoreline. The

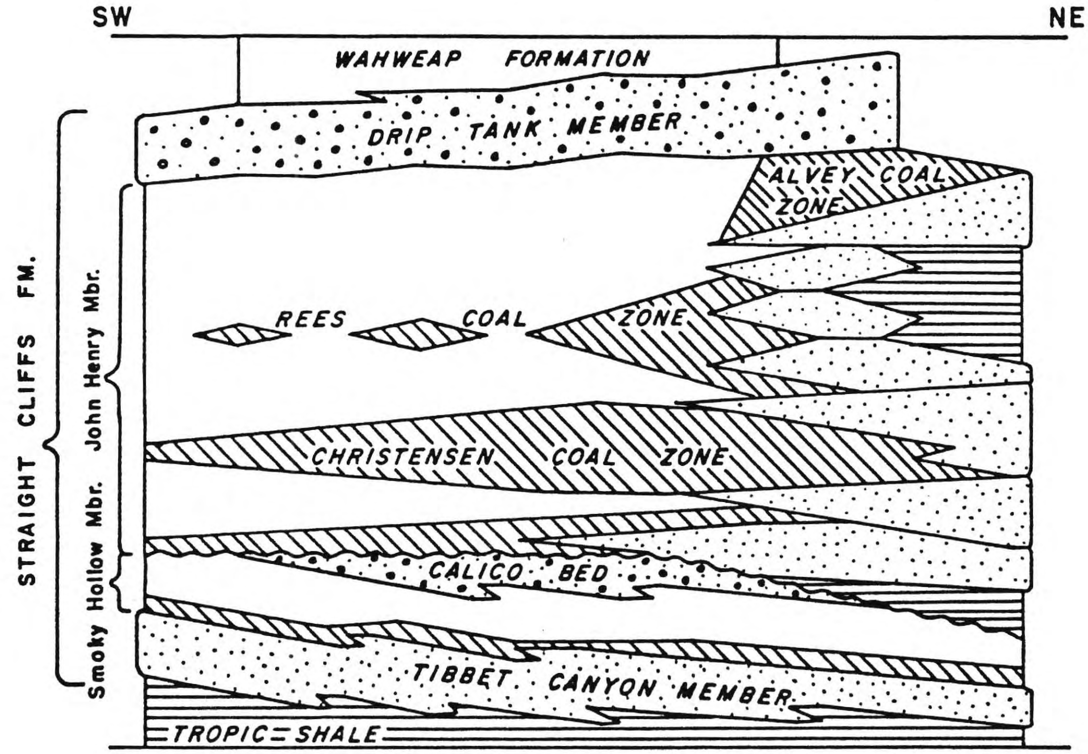

Figure 6: Stratigraphic relationships within the Straight Cliffs Formation. Slanted line pattern denotes coal zones; stipple pattern denotes marine sandstone; coarse stipple pattern denotes fluvial deposits; horizontal line pattern denotes marine mudstone; and blank areas denote alluvial-plain facies (after Peterson, 1969 and 1988).

Calico Bed is thought to represent a brief pulse of uplift in the source region to the southwest and resulting outpouring of detritus (Hintze, 1988, p. 199; Peterson, 1988, p. 142).

Coal deposition in the lower division was apparently influenced by geologic structure. Coal beds in the Dakota Formation, the lower part of the lower division, occur in small synclines (related to restrictive conditions in structural troughs) in the deepest parts of the Kaiparowits basin. Coal beds in the upper part of the lower division, the Smoky Hollow Member of the Straight Cliffs Formation, become thin or are absent over paleo-anticlines and up-thrown fault blocks, indicating that repeated movement on folds and faults influenced coal deposition (Peterson, 1988, p. 142).

The middle division consists of the John Henry and Drip Tank members of the Straight Cliffs Formation and was deposited during two significant transgressive-regressive cycles (Peterson and Kirk, 1977, p. 172-173). The John Henry Member, which consists of marine sandstone and shale and non-marine fluvial deposits, contains the major coal zones of the Kaiparowits basin. The coal zones represent a narrow belt of coastal swamps and lagoons confined between upper Cretaceous shoreline (barrier islands) facies to the northeast and alluvial-plain facies to the southwest. The Drip Tank Member, a fluvial sandstone unit, represents a major regression of the Cretaceous shoreline (from west to east) across the Kaiparowits basin (Peterson, 1988, p. 142).

The upper division consists of the upper Cretaceous to Paleocene Wahweap (900 to 1,500 feet -- 274 to 457 m), Kaiparowits (1,000 to 3,000 feet -- 305 to 914 m), Canaan Peak (0 to 900 feet; 0 to 274 m), and Pine Hollow (0 to 450 feet; 0 to 137 m) Formations. These stratigraphic units, which consist of primarily lacustrine and fluvial clastic sediments, were deposited during the Laramide orogeny from source regions primarily to the west and southwest. They are locally truncated by the Eocene Claron Formation, a lacustrine limestone unit thought to be the equivalent of the Flagstaff Limestone in north-central Utah.

Holocene unconsolidated deposits include alluvial sediments, colluvium, talus, and eolian sand and silt. Stream channel sediments are found at the mouths of canyons and along the course of stream beds. Colluvium and talus accumulate along slopes, at the base of steep slopes, and at the base of cliffs. Eolian deposits are found throughout the study area.

METALLIC AND INDUSTRIAL MINERALS

Metallic Mineral Occurrences

Metallic mineral deposits in Kane County are small and widely scattered. Locations of metallic mineral occurrences are illustrated on figure 7 and listed in table 2. Deposit types include:

- precious metal (gold, silver, and platinum) placers along the Colorado River
- base and precious metal vein-replacement deposits along fractures in carbonate and calcareous sandstone units
- bedded manganese in the Chinle Formation
- heavy mineral concentrates within marine sandstone of the Straight Cliffs Formation.

Gold

Placer gold was first discovered along gravel bars of the Colorado River in the late 1800s. Fine-grained gold particles occur within "black sand" associated with heavy minerals such as magnetite, hematite, ilmenite, garnet, chromite, zircon, and rutile. Present-day Lake Powell has inundated all bars along the course of the Colorado River in Kane County. There is, however, the possibility for the occurrence of fossil placers in older gravel bars above the present level of Lake Powell or in tributaries of the Colorado River. Three known placer gold occurrences are shown on figure 7 and tabulated on table 2 as numbers 13, 14, and 15. Other small, unreported occurrences may be present.

Gold was also found within the Chinle Formation during the 1900s. Lawson (1913) sampled the Chinle Formation near the townsite of Paria and reported anomalous gold values. Following the discovery, several unsuccessful attempts were made in the early 1900s to mine gold from the Chinle using hydraulic mining techniques.

Titanium-Zirconium

In Kane County titanium (Ti) and zirconium (Zr) minerals, along with other heavy minerals, are found in sandstone lenses in the Straight Cliffs Formation. Typical mineral assemblages for these deposits include zircon, magnetite, ilmenite, rutile, quartz, calcite, monazite, garnet, sphene, hematite, and anatase. Ilmenite is the dominant titanium mineral (Doelling and Davis, 1989, p. 134).

Up to 14 individual Ti/Zr deposits have been reported within a 40- to 50-mile (64 to 80-km) long belt from near the town of Escalante in Garfield County to the middle of Kane County. The Kane County deposits are shown on figure 7 and tabulated on table 2. Deposits to the north in Garfield County at Dave Canyon lie stratigraphically between the Alvey and Christensen coal zones, but the deposits in Kane County (Nos. 1 through 6, figure 7) lie stratigraphically below the Christensen coal zone. Individual deposits vary in length up to 1,500 feet (457 m) and in width up to 400 feet (122 m). Thicknesses vary usually between 4 and 12 feet (1.2 and 4 m). Analyses of several samples taken by

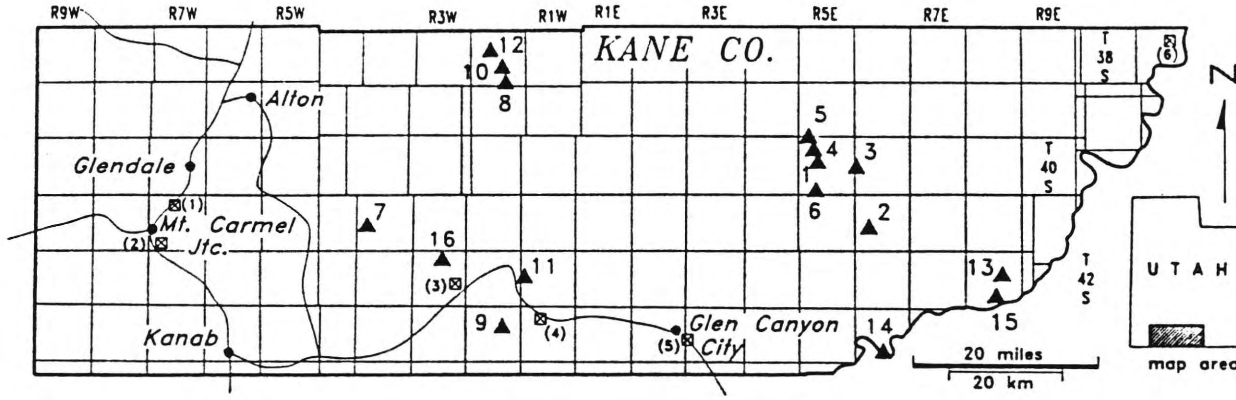

Figure 7: Metallic mineral occurrences (triangles) and sand and gravel pits (squares with crosses) in Kane County. Numbered triangles refer to mineral deposits listed in table 2. Numbers in parentheses refer to sand and gravel localities discussed in the text.

Table 2: Listing of metallic mineral occurrences in Kane County.

No.	Name	Commodities	Deposit Type	Host Rock
1	Mann Deposits	Ti, Zr	fossil placer	Str. Cliffs Fm.
2	Croten Canyon	Ti, Zr	fossil placer	Str. Cliffs Fm.
3	Sunday Canyon	Ti, Zr	fossil placer	Str. Cliffs Fm.
4	Sargent (1)	Ti, Zr	fossil placer	Str. Cliffs Fm.
5	Sargent (2)	Ti, Zr	fossil placer	Str. Cliffs Fm.
6	U-429 Claim	Ti, Zr	fossil placer	Str. Cliffs Fm.
7	Jodies Knoll	Cu, Ag	vein/replacement	Carmel Fm.
8	Bullet Shafts	Cu	vein/replacement	Page Ss.
9	Copper Cliffs	Cu	vein/replacement	Moenave Fm.
10	Ridge Copper	Cu	vein/replacement	Page Ss.
11	Hattie Green	Cu	vein/replacement	Navajo Ss.
12	Rock Springs	Pb, Cu	vein/replacement	Page Ss.
13	Kaiparowits	Pt, Au	placer	sediments
14	Meskin Bar	Au	placer	sediments
15	Klondike Bar	Au, Pt	placer	sediments
16	Manganese King	Mn	chemical precip.	Chinle Fm.

Dow and Batty (1961) indicated TiO_2 values ranging from 9.5 percent to 23.9 percent and ZrO_2 values ranging from 2.9 percent to 7.3 percent. The relative abundance and widespread distribution of Ti/Zr deposits in the region suggests the favorability for the discovery of new deposits in other locations at or near the known stratigraphic positions.

Copper

Copper mineralization is present along the southern end of the East Kaibab monocline (The Cockscomb) and 3 miles (5 km) west of the Paunsagunt fault in west-central Kane County (numbers 7 through 11 on figures 3 and 7, and table 2). The mineralization is associated with fractures that sub-parallel regional folds. Copper oxide minerals with some associated sulfide minerals occur in fractures within the Navajo Sandstone, the Moenave Formation, and the Shinarump Member of the Chinle Formation. Along The Cockscomb, the fractures generally sub-parallel the strike of the monocline to the north-northeast and dip steeply eastward. Mineralization usually consists of coatings of malachite and copper pitch (a mixture of copper oxides, malachite and chrysocolla) with abundant iron staining. Most mineralized fractures are small, extending only a few feet along strike, with the largest extending for several hundred feet. Width of mineralization is usually narrow, less than 5 feet (1.5 m), but may be as much as 30 feet (9 m). Some fissures also contain uranium or uranium-copper minerals (Doelling and Davis, 1989, p. 131).

The Hattie Green copper mine is located along The Cockscomb in section 18, T. 42 S., R. 1 W. The mine is in the Navajo Sandstone near a normal fault which strikes slightly east of north, and dips to the east.

The Rock Springs, Ridge Copper, and Bullet Shaft deposits are located northwest of The Cockscomb on the Kaibab Plateau in sections 22, 26, and 35, T. 38 S., R. 2 W. respectively. These deposits lie on the east side of the north plunging Kaibab anticline (Kaibab Uplift) and occur in the Jurassic Thousand Pockets Tongue of the Page Sandstone. The Rock Springs deposit was mined for lead, although there is abundant copper staining. Mineralization occurs in irregularly shaped pods a few feet in length. Ore minerals include anglesite (lead sulfate) and galena. Malachite is present as a secondary mineral.

Mineralization at the Ridge Copper and Bullet Shafts prospects consists of copper carbonates (primarily malachite) and iron oxide staining on fractures within the Thousand Pockets Tongue of the Page Sandstone. Iron concretions are present and anglesite is present in small amounts. The Ridge Copper prospect, also known as the "Surprise deposit," consists of several shallow pits within a mineralized area of about 50 feet (15 m) by 1,500 feet (457 m). The Bullet Shafts prospect, located about 3/4 mile south of the Ridge Copper prospect, consist of two vertical shafts about 100 feet (30 m) deep.

Copper-silver mineralization is found at Jodies Knoll near the south edge of Skutumpah Terrace in section 17, T. 41 S., R. 4 W. Mineralization is present as weak malachite and iron oxide staining within the Thousand Pockets Tongue of the Page Sandstone. Analysis of one high-quality "grab" sample yielded 12.55 percent Cu, 10.95 oz per ton Ag, 25 ppm Pb, and 875 ppm Zn (Utah Geological Survey, mineral occurrence files).

At the Copper Cliffs prospect, along The Cockscomb in southern Kane County, copper mineralization has been noted (Utah Geological Survey, mineral occurrence files). Malachite and chrysocolla reportedly fill fractures within the Moenave or Kayenta Formations. Unidentified manganese minerals are also reported at this prospect.

Manganese

Manganese was mined from the Manganese King mine located along Kitchen Corral Wash in section 2, T. 42 S., R. 3 W. The deposit is contained within dark manganese-bearing mudstone of the Petrified Forest Member of the Chinle Formation (Triassic), and consists of irregular bodies of manganese oxide comprised of psilomelane, pyrolusite, and wad. Shipments made from the property in the 1940s reportedly averaged about 40 percent manganese (Havens and Agey, 1949).

Industrial Rock and Minerals

Gypsum

Gypsum, a hydrous calcium sulfate, is used in wallboard manufacturing and for a variety of other industrial purposes. Nearly all commercial gypsum deposits occur as sedimentary beds ranging in thickness from about 3 feet to 100 feet (0.9 m to 30 m) or more. Most gypsum deposits contain from 5 to 15 percent impurities such as clay, salt, and other mineral matter (Stone and Lupton, 1920). Gypsum is widespread throughout southwestern and south-central Utah and is sometimes quarried in Kane County as a decorative stone.

Sedimentary gypsum beds greater than 3 feet (1 m) thick are found within the upper part of the Toroweap Formation (Permian), the Shnabkaib Member of the Moenkopi Formation (Triassic), and the Paria River and Wiggler Wash Members of the Jurassic Carmel Formation (Doelling and Davis, 1989). The Paria River gypsum, considered to have the best potential for commercial development, is usually a massive, white gypsum bed that is consistently thick in the western parts of Kane County. Gypsum beds in the Toroweap Formation and in the Shnabkaib Member of the Moenkopi Formation are lower in quality, more discontinuous, and therefore of less commercial value than beds in the Paria River Member. The Wiggler Wash Member usually has high quality gypsum, but the beds are usually very thin and discontinuous. The Carmel Formation underlies a large part of eastern Kane County and possibly includes the Paria River Member, however, depths to the potential gypsum-bearing strata may exceed 2,000 feet (610 m) beneath the WSAs. West of The Cockscomb in north-central Kane County, the outcrop pattern for the Carmel Formation lies generally northward from the Paria-Hackberry WSA. In extreme western Kane County, the Carmel Formation outcrops in the North Fork Virgin River and Orderville Canyon WSAs. The inaccessible nature of these two WSAs along with other factors reduce the development potential for gypsum there.

Limestone

Limestone is composed mainly of calcium carbonate and is used in the production of cement, lime, flux for steel making, filtration material, poultry grit, coal-mine rock dust, fillers and extenders, and calcium carbide. High-quality limestone bearing rock units in western Kane County include the Toroweap and Kaibab Formations (Permian), the Timpoweap Member of the Moenkopi Formation (Triassic), the Co-op Creek Member of the Carmel Formation (Jurassic), and the Claron Formation (Tertiary). Thin, discontinuous limestone beds are also found in the Virgin Limestone Member of the Moenkopi Formation, the Chinle Formation (Triassic), the Kayenta Formation and Navajo Sandstone (Jurassic), and the Paria River Member of the Carmel Formation. In general the limestone units are thin in eastern Kane County and thicker to the west.

The suitability of limestone-bearing rock units in Kane County for industrial purposes is unknown due to the absence of adequate analytical data. Because of their thickness and wide distribution, the Co-op Creek Member of the Carmel Formation and the Claron Formation are considered to have the greatest prospective value. Outcrop samples analyzed from the Co-op Creek Member indicate that the limestone is relatively high in SiO_2 (Doelling and Davis, 1989, p. 140) and therefore probably not suitable for cement. The Co-op Creek Member of the Carmel and the Claron Formation might be suitable for use as agricultural limestone, road materials, and for coal mine dust control.

Sand and Gravel

Sand and gravel for use in construction is widespread in Kane County. The best sand and gravel sites reported by the Utah Department of Transportation (1968) occur as old, partly cemented stream-terrace deposits in six areas listed below and located on figure 7.

	AREA	SECTION	TOWNSHIP	RANGE
-	southern Long Valley;	09	41 S.	07 W.
-	south of Mount Carmel Junction;	31	41 S.	07 W.
-	Kitchen Corral Wash;	14	42 S.	03 W.
-	adjacent to the Paria River;	03	43 S.	01 W.
-	adjacent to Wahweap Creek;	02	43 S.	02 E.
-	near Bullfrog on Lake Powell;	09	38 S.	11 E.

The deposits occur in (Pleistocene ?) stream channels with source areas on the Markagunt Plateau, Canaan Mountain, and the Henry Mountains (Doelling and Davis, 1989, p. 135). These old stream deposits contain an abundance of indurated, well-rounded quartzite, quartz, limestone, and varieties of dense igneous rocks.

ENERGY RESOURCES

Uranium

Uranium mineralization in Kane County is found in the Chinle, the Moenave (or Kayenta), the Morrison, and the Dakota Formations (Hackman and Wyant, 1973; Dubyk and Young, 1978; Doelling and Davis, 1989). Uranium mineralization with associated copper, vanadium, and silver is found in mines and prospects in eastern Kane County along Fiftymile Bench, in central Kane County around The Cockscomb and Buckskin Mountain, and in western Kane County along Orderville Canyon.

Near Orderville Canyon, in western Kane County, uranium occurs in a basal member of the Dakota Formation and was mined on a small scale until 1973 (Doelling and Davis, 1989). Uranium occurrences here are on the Bullock and Lynn groups of lode claims located on both sides of Orderville Canyon (figure 8). Uranium mineralization is contained in carbonized wood fragments and clay lenses and is associated with relatively high percentages of vanadium plus anomalous concentrations of copper, molybdenum, lead, cobalt, nickel, yttrium, and germanium.

Uranium exploration was done in and around The Cockscomb and Buckskin Mountain in central Kane County. Four occurrences are reported and include the Kitchen Coral Wash, Movie Town, Radiance group, and Fleabag prospects (figure 8). Uranium mineralization is associated with copper, silver, and other metals, and occurs in a variety of settings. Uranium is found as coatings along fractures in the Moenave (Kayenta) Formation, in channel sandstones associated with carbonaceous material within the Shinarump Member of the Chinle Formation, and as isolated occurrences along faults.

East of the Kaiparowits Plateau along Fiftymile Bench, a zone of anomalous radioactivity is present in conglomeratic sandstone lenses of the Morrison Formation. The Steele prospect is located within this zone (figure 8). Low concentrations of uranium and vanadium occur in three sandstone lenses of the Morrison Formation (Doelling and Davis, 1989). The stipple pattern on figure 8 shows the extent of areas of uranium potential within the Morrison Formation, identified by Peterson and others (1982).

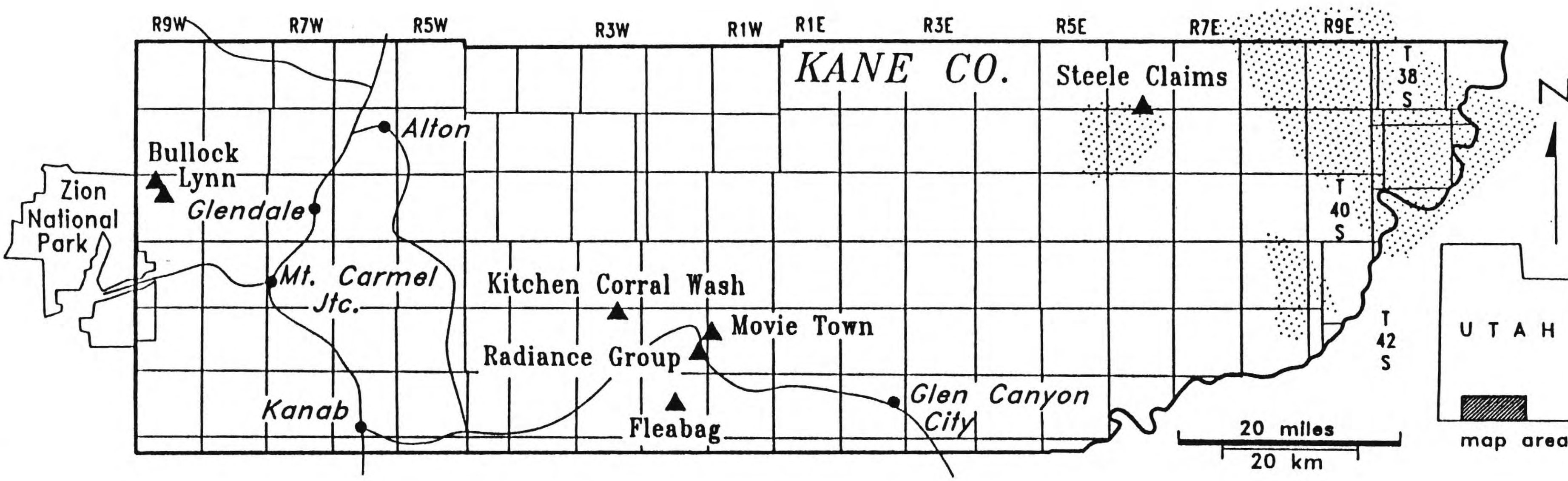

Figure 8: Areas of uranium resource potential in the Morrison Formation (stipple pattern) and locations of uranium occurrences in the Morrison and other formations (triangles -- described in the text) in Kane County (after Peterson and others, 1982 and Utah Geological Survey, mineral occurrence files).

Petroleum Resources

Background

Kane County lies within a region which is favorable for the discovery of oil and gas. The region has thick sequences of Paleozoic and Mesozoic marine carbonate and terrigenous sedimentary rocks deposited on stable shelfs or platforms. The greatest thickness of Paleozoic sedimentary rocks were deposited during Permian-age subsidence. During the Laramide orogeny (late Cretaceous through Eocene), uplift and regional tectonism transformed flat-lying shelf sedimentary strata into broad uplifts, anticlines, and synclines which could act as potential hydrocarbon traps. Gregory and Moore (1931, p.154) first recognized the oil and gas potential of the region. Subsequently, Tapp (1963) described oil and gas exploration of the region between the Sevier and Paunsagunt faults, and Kunkel (1965) later reviewed the exploration history of the Kaiparowits Plateau. The oil and gas potential of the region, including Kane County, was more recently assessed by Petroleum Information (1984a) and by Brandt (in Doelling and Davis, 1989, p. 115-126).

Despite favorable structures, reservoir strata, and source rocks, the Kaiparowits basin region remains one of the least explored of the major Rocky Mountain geologic provinces. Kane County is considered to have moderate potential for discovery of petroleum. Wells drilled in Kane County have indicated the presence of hydrocarbons, but no commercial discoveries have been made.

Oil Seeps and Tar Sands

Oil seeps and asphaltic deposits (figure 9) have been known in the region since the late 1800s. In southwestern Utah, geologists first noted oil seeps at Timpoweap Canyon and oil-impregnated rocks at North Creek and Gould Ranch. The North Creek and Gould Ranch deposits occur on the upthrown, eastward dipping block of the Hurricane fault (Blakey, 1979) and may indicate upward migration of oil along the fault and entrapment in porous carbonates of the Moenkopi Formation. Other oil-impregnated rock deposits occur at the Tar Baby Mine and at Black Rock Canyon in Mohave County, Arizona.

Oil was discovered in 1921 at Bennett's seep (now submerged beneath Lake Powell) along the eastern border of Kane County in the Shinarump Conglomerate Member of the Chinle Formation. The first exploratory drilling at Bennett's seep was done that same year although no production was recorded (Gregory and Moore, 1931). Riggs (1978) reported that a well drilled in 1965, along the Waterpocket monocline (also near Bennett's seep), produced some 26 barrels of 22.1 degree API gravity oil from the Shinarump Conglomerate Member. Production from this well, however, dropped significantly after six hours of bailing.

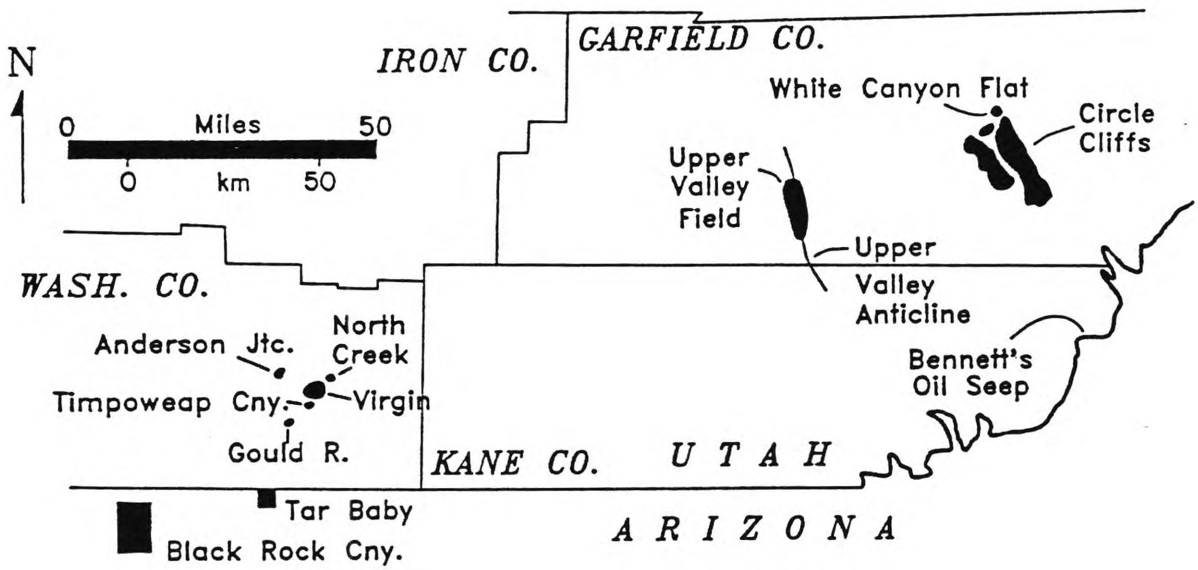

Figure 9: Locations of oil fields and oil-impregnated rock deposits near Kane County (after Doelling and Davis, 1989).

The Circle Cliffs contain one of the largest oil-impregnated rock deposits in the United States (Ritzma, 1980). Oil occurs within the middle sandstone unit of the Moenkopi Formation, and to a much lesser degree, within the Kaibab Limestone and the Shinarump Conglomerate Member of the Chinle Formation. Ritzma (1980) estimated that nearly 1.3 billion barrels of oil are contained within sandstones of the Moenkopi Formation in the Circle Cliffs area.

Upper Valley Field

The Upper Valley field, located about 4 miles (6.4 km) north of the Kane County line in Garfield County, is the only commercial field in the Kaiparowits region. The field has produced almost 23 million barrels of oil from 25 wells (Petroleum Information, 1986). Production comes from the Kaibab Limestone and Timpoweap Member of the Moenkopi Formation. A minor amount of oil was reportedly produced from the Redwall Limestone (Petroleum Information, 1984a).

The Upper Valley field is located on the west flank of the Upper Valley anticline. Oil has been hydrodynamically displaced off the anticlinal crest onto the western and southwestern flanks. In plan view the field is elongate, trends north-northwest, and measures about 7 miles (11 km) long by 1 mile (1.6 km) wide (Sharp, 1976). Wells drilled near the crest or on the east flank of the Upper Valley anticline found fresh water, oil staining and pyrite in porosity zones indicating the reservoir had been flushed of hydrocarbons (Allin, 1990).

Virgin Field

The Virgin field is located in Washington County roughly 15 miles (24 km) from the Kane County line. Discovered in 1907, the Virgin field has been the site of intermittent activity through the early 1980s. At least 182 wells were drilled within the field. Many more wells were likely drilled but never recorded. The field is subcommercial due to poor success rates and low daily production rates from wells penetrating small, isolated pools. Two types of oil are produced -- a paraffinic oil from the Timpoweap Member of the Moenkopi Formation, and an asphaltic oil from the Kaibab Limestone. Since discovery the Virgin field has produced more than 200,000 barrels of oil, nearly 4 million cubic feet (113,000 m^3) of gas, and over 30,000 barrels of water (Petroleum Information, 1984a).

Petroleum Exploration

Although the geologic setting of the region suggests the potential for the accumulation of oil and gas, only 29 exploratory wells have been drilled in Kane County (figure 10 and table 3). All of the wells are classified as dry holes. This sparse well density and apparent lack of exploration success may be due, in part, to the region's relative remoteness and inaccessible nature.

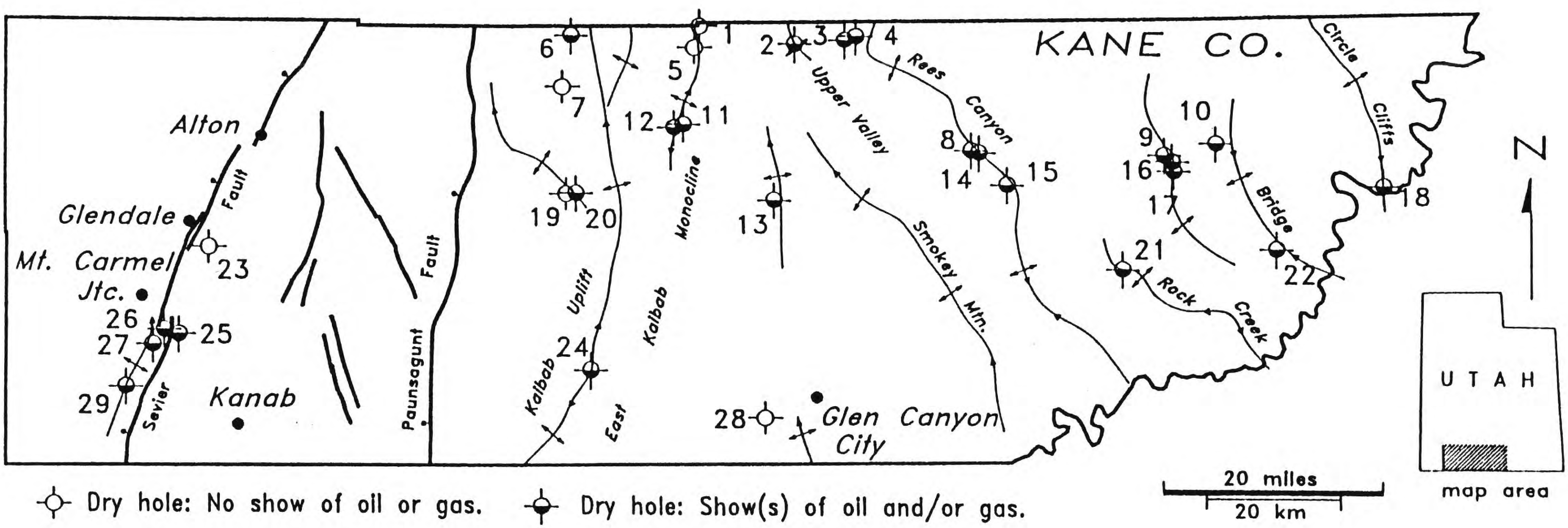

Figure 10: Locations of oil and gas test wells and structural features in Kane County. Numbers for oil and gas wells are keyed to table 3 (from Doelling and Davis, 1989, p. 115).

Table 3. Oil and gas wells drilled in Kane County (after Doelling and Davis, 1989, p. 116-117).

No.	Well Name	TD (ft)	Deepest Fm.	Remarks
1.	Amerada Hess #1, Fed. Skyline	7,094	Kaibab Ls.	No shows reported
2.	Tenneco Oil Co. #1	8,900	Cedar Mesa Ss.	DST[1] gas shows in Timpoweap. Oil and gas shows in Kaibab.
3.	Sun Oil Co. #1	8,920	Cedar Mesa Ss.	Oil shows in Cedar Mesa; DST tested mud. DST in Kaibab tested water with oil odor.
4.	Houston Oil and Min. #11-9	10,285	Redwall Ls.	1 BOPD[2], 44 BWPD[3] from Shinarump. Timpoweap and Kaibab cores had oil shows.
5.	Amerada-Hess #1, Fed. Midwest	6,496	White Rim Ss.	No shows reported. Fresh water in Navajo and Kaibab.
6.	Texaco #1, Govt.-Schneider	5,954	Cedar Mesa Ss.	Dead oil and stains in Upper Cedar Mesa cores.
7.	MFS Co. #1, Henrieville	5,239		No shows reported.
8.	Great Western #2, Rees Canyon	9,017	Pennsylvanian	DST shows in Coconino.
9.	G.C. Bingham #1, Fed.-Richter	3,232	Kaibab Ls.	Shows in Kaibab core. DST tested sulphurous water.
10.	Webb Resources #28-13 Fed.	3,092	White Rim Ss.	Oil shows in Shinarump and Kaibab.
11.	Midwest #31, Parry	6,403	Supai Gp.	Oil shows in Kaibab and Toroweap.
12.	Marathon #1, Govt.-Butler Val.	6,614	Ouray Ls.	Timpoweap cores bled oil. Dead oil and stains in Mississippian.
13.	Tenneco #1, Tibbet Canyon	9,336	Cedar Mesa Ss.	Oil in Kaibab core. Trace of heavy oil in Toroweap.
14.	Byrd #1, Rees Canyon-Govt.	10,045	Br. Angel Sh.	Oil show from DST in Upper Hermosa.

[1]DST = drill stem test
[2]BOPD = barrels of oil/day
[3]BWPD = barrels of water/day

Table 3 (cont.). Oil and gas wells drilled in Kane County (after Doelling and Davis, 1989, p. 116-117).

No.	Well Name	TD (ft)	Deepest Fm.	Remarks
15.	Cleary Funds, Inc. #1-16 State	6,425	Cedar Mesa Ss.	Residual oil in Kaibab core. Oil show in Shinarump.
16.	Shell Oil #1, Soda Unit	7,155	Elbert Fm.	Oil shows in Kaibab.
17.	W.W. West #1, Letts Federal	3,163	Kaibab Ls.	Dead oil stains in Kaibab core.
18.	Kissinger #1, Rincon Dome	4,466	Redwall Ls.	Bailed 26 bbl of 22°API oil in 6 hrs from Shinarump.
19.	Pan-Am Pet. #1, Paria Oper. Unit	2,085	Chinle Fm.	No shows recorded.
20.	Pan-Am Pet. #1A, Paria Oper. Unit	6,000	Devonian	Gas shows and dead oil stains in Toroweap. Asphalt in Hermit (?).
21.	Romex #1, Federal-Rock Creek	3,939	Cedar Mesa Ss.	Kaibab cores show stains and oil in vugs.
22.	Sojourner Exploration #1	3,351	Cedar Mesa Ss.	Oil show in Kaibab.
23.	Houston Oil & Min. #41-11, Fed.	9,954	Br. Angel Sh.	No oil shows.
24.	Tidewater #1, Kaibab Gulch	6,253	Chuar Gp.	Oil and gas shows in Cambrian units.
25.	Superior Oil Co. #1, Kanab Cr.	9,119	Tapeats Ss.	Free oil observed in Moenkopi. Oil shows in the Kaibab, Toroweap, and Queantoweap.
26.	McDermott & Co., Inc. #2, Govt.	3,712	Kaibab Ls.	Asphalt residues and oil stains in the Kaibab.
27.	McDermott & Co., Inc. #1, Govt.	3,652	Kaibab Ls.	Oil show in Moenkopi.
28.	Union Oil of Cal. #1, Judd Hollow	7,341	Cambrian	No shows reported.
29.	McDermott & Co., Inc. #1, State	10,503	Precambrian	Oil shows in Chinle, Moenkopi, Kaibab, Redwall, and Cambrian

Most wells drilled in the region were positioned either on or near the crests of surface anticlines or monoclines. Hydrocarbon "shows" within Paleozoic and lower Mesozoic rocks were encountered in 23 Kane County wells. The most significant shows of oil and gas were found in two wells: (1) the Houston Oil and Minerals No. 11-9 Federal (section 9, T. 38 S., R. 3 E.) which produced a very minor amount of oil from the Permian Cedar Mesa Sandstone before the well was plugged and (2) the Kissinger No. 1 Rincon Dome (section 3, T. 40 S., R. 10 E.) which produced 26 barrels of oil from the Shinarump Conglomerate Member of the Chinle Formation during a 6-hour test (Riggs, 1978).

Recently, researchers have reported that rocks within the Kwagunt Formation of the Precambrian (Late Proterozoic) Chuar Group, which are exposed in the Grand Canyon of Arizona, may be a potential source for the generation of petroleum in the Colorado Plateau (Reynolds and others, 1988; Chidsey and others, 1990; and Rauzi, 1990). Geochemical analysis indicates that black shales of the Chuar Group may contain as much as 10 percent organic carbon, and are within the "oil-generating window." The Tidewater No. 1 Kaibab Gulch well, located in southern Kane County (section 34, T. 42 S., R. 2 W.), penetrated possibly as much as 1,100 feet (335 m) of Chuar Group rocks containing carbonaceous shales. A few wells in east-central Utah may have penetrated the Chuar Group or equivalent rocks, suggesting the Precambrian source rock potential extends to other portions of the western Colorado Plateau. Relatively untested, Paleozoic formations, such as the Cambrian Tapeats Sandstone (overlain and sealed by the Bright Angel Shale) as well as fractured Precambrian rocks, may be potential hydrocarbon reservoirs. Potential drilling targets, defined by active seismic methods, include deep anticlines, pre-Phanerozoic tilted fault blocks, and possible stratigraphic pinchouts.

Hydrodynamically displaced oil and gas trapped on the flanks of major structures represent additional exploration targets in Kane County. Allin (1990) and other explorationists believe that this type of trapping mechanism is not limited to the Upper Valley field in Garfield County, but that similar conditions may exist throughout much of Kane County and warrant future exploration.

Carbon Dioxide Resources

To date, no significant carbon dioxide (CO_2) reservoirs are known in Kane County. A major CO_2 accumulation occurs in Garfield County on the Escalante anticline, a feature designated as a Known Geologic Structure or KGS by the USGS, and is estimated to contain between 1 and 3 trillion cubic feet (30 and 80 billion m^3) of CO_2 (Petroleum Information, 1984b). Tests performed in two wells during 1986 along the Escalante anticline indicated that the CO_2 resource might be smaller than previous estimates. The Upper Valley anticline, situated a few miles to the west and parallel to the Escalante KGS, contains some accumulations of CO_2 as a trapped gas cap above the oil reservoir (Doelling and Davis, 1989, p. 123).

The northwest corner of Kane County (figure 11) has potential for the discovery of CO_2 resources (Petroleum Information, 1984b). The presence of high heat flow, a thick section of Paleozoic carbonates, and the proximity to Tertiary intrusive and volcanic rocks represent favorable conditions for the generation of CO_2. Even in the absence of additional drilling information, however, CO_2 resource potential in Kane County is still considered to be low.

Coal Resources

Background

It is estimated that coal resources contained within the Kaiparowits Plateau, Kolob, and Alton coal fields located mainly in Kane and Garfield Counties may total more than 11 billion short tons (10 billion mt), and represent roughly 47 percent of Utah's total coal resources (figure 12). Doelling and Davis (1989, p. 105) estimate that Kane County alone contains nearly 30 percent of Utah's coal resources. Within the Kaiparowits Plateau field in Kane County, Doelling and Davis (1989, p. 113) estimated the principal coal resources at about 4.4 billion short tons (4.0 billion mt). They also estimated the principal coal resources of the Kolob and Alton coal fields at roughly 1.1 and 1.5 billion short tons (1.0 and 1.4 billion mt), respectively. The "principal coal resource" includes measured, indicated, and inferred coal occurring in reasonably continuous beds that are at least 4 feet (1.2 m) thick and have less than 3,000 feet (914 m) of overburden lying above the beds. The maximum area of influence for each control point used in the reserve calculations was a circle with a radius of 4.5 miles (7.2 km) (Doelling and Davis, 1989, p. 113). Coal resource estimates represent tons of coal in-place. The recoverable portion of the principal coal resource through underground mining would be much less.

Although large coal deposits are present within Kane County, very little mining of coal has taken place. County-wide production of coal through 1986 was only about 90,000 short tons (81,650 mt) (Doelling and Davis, 1989, p. 105). A number of small mines were operating around the turn of the century providing coal for local domestic use. By the 1930s, most of the mines had closed. The Alton mine, near Alton, the last producing coal mine in the region, closed in 1970.

In 1971 the Warm Creek test mine, located on the southeast side of the Kaiparowits Plateau (section 19, T. 41 S., R. 4 E.), was opened for a short time to gather production cost data and to examine underground mining conditions. Most recently, Andalex Resources, Inc. has proposed opening a 2 million ton-per-year (1.8 million mt/yr) coal mine near the site of the Warm Creek test mine. The property is situated between the Wahweap and Burning Hills WSAs and contains about 40,000 acres (16,200 ha) of federal coal leases and some 7,500 acres (3,000 ha) of state mineral leases. Production is proposed initially for an estimated mine life of 30 years at a rate of 2 million

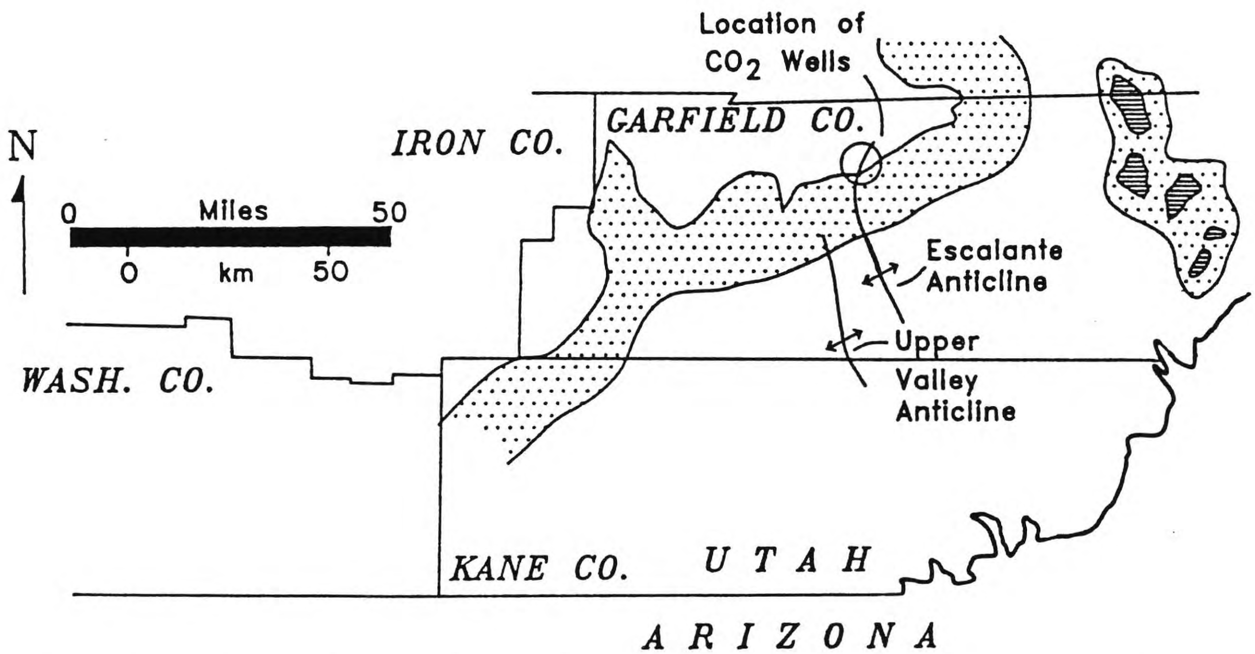

Figure 11: Region of CO_2 potential (stipple pattern) in southwest Utah showing the location of the Upper Valley and Escalante anticlines, and CO_2 wells (after Petroleum Information, 1984b).

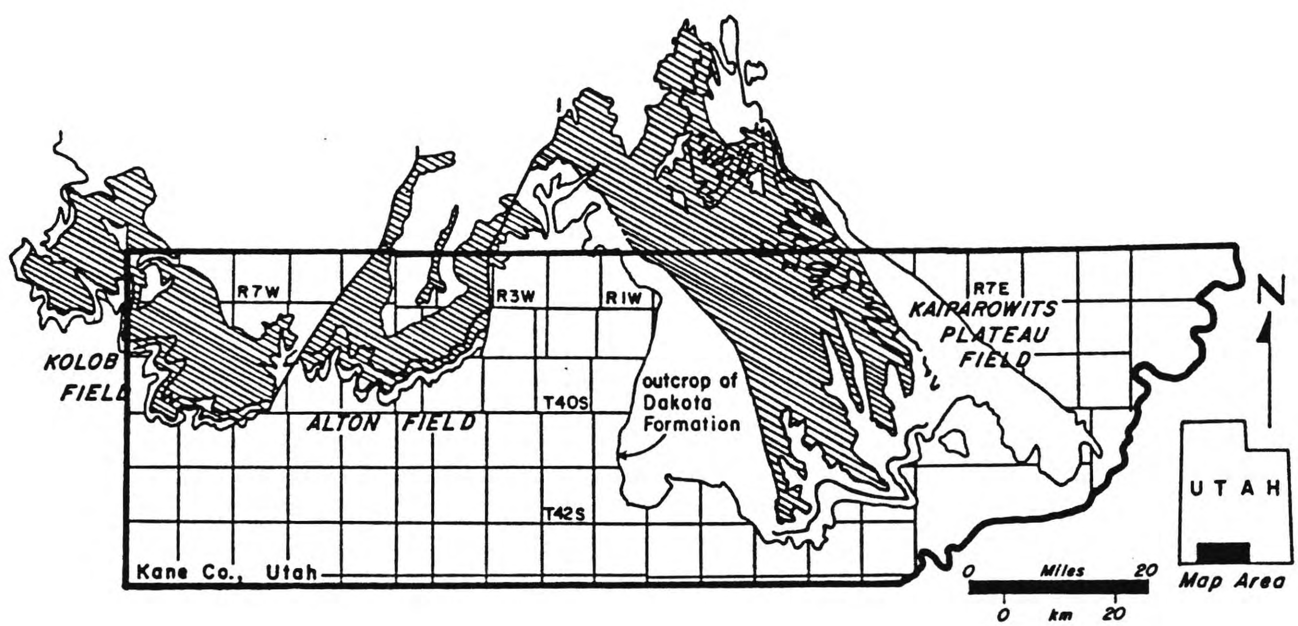

Figure 12: Extent of Cretaceous coal-bearing rocks of the study region, showing the locations of the Kaiparowits Plateau, Alton, and Kolob coal fields. Cross-hatch pattern denotes areas underlain by coal zones with seams generally thicker than four feet (1.2 m). Heavy lines denote outcrops of important coal zones (from Doelling and Graham, 1972).

tons-per-year (1.8 million mt/yr). Andalex estimates that 1.7 billion tons (1.55 billion mt) of coal reserves in-place underlie the property, and that about 440 million tons (400 million mt) of the in-place reserves are recoverable. Transport of coal from the area would be by truck haulage over upgraded access roads to railheads at Moapa, Nevada; Williams, Arizona; or Cedar City, Utah (Andalex Resources, Inc., 1991).

Doelling and Davis (1989, p. 114) present representative coal analyses for samples taken throughout Kane County (table 4). The analyses show wide variability in coal quality across the county probably due to a number of physical, structural, and depositional factors.

Kolob Coal Field

The Kolob coal field lies within the Kolob Plateau in western Kane County extending geographically from the Sevier fault north-westward to the Cedar City area (figure 12). The portion of the field lying within Kane County is known as the "Orderville" area. Important coal beds occur within the Dakota Formation in two zones. Coal zones in the Kolob field are named the upper and lower Culver zones, which correlate to the Smirl and Bald Knoll zones, respectively, of the Alton field to the east. The upper Culver zone is continuous consisting of a single bed averaging 7.5 feet (2.3 m) thick. The lower Culver zone is often separated into multiple beds with thicknesses typically less than 4 feet (1.2 m). Lower Culver seams do, however, achieve thicknesses of up to 10 feet (3.0 m). Several small mines, opened in the Orderville area since the early 1900s, are now all either inactive or abandoned. Total production from the area was less than 2,000 short tons (1,814 mt) (Doelling and Davis, 1989, p. 112).

Alton Coal Field

The Alton coal field lies in western Kane County between the Sevier and Paunsagunt fault zones, and extends northward and eastward into Garfield County (figure 12). Coal occurs within the Dakota Formation at two horizons known locally as the Bald Knoll (lower) and Smirl (upper) coal zones. The Dakota Formation in this area varies in thickness from 140 to 240 feet (43 and 73 m), becoming thicker toward the west. Generally, coal-bearing strata dip 1 to 3 degrees northward beneath increasing cover. The 3,000-feet (914 m) overburden contour is roughly coincident with the basal contact of the Claron Formation and is located about 5 to 6 miles (8.0 to 9.7 km) north of the coal zone outcrop (Doelling and Davis, 1989, p. 110).

The Bald Knoll coal zone consists of one coal seam often split by thin mudstone and siltstone beds. The average thickness of the zone is about 5.5 feet (1.7 m), although only portions of the seam are considered commercial in quality. The thickest exposure of the Bald Knoll zone is at the Bald Knoll mine where the seam is 18 feet (5 m) thick but contains a 1-foot (0.3 m) shale parting. The Smirl

Table 4: Averages of proximate analyses for the various coal resource areas in Kane County (after Doelling and Davis, 1989, p.114).

coal area	1	2	3	4	5	6	7
			PROXIMATE	ANALYSIS			
moisture (%)	10.5	9.6	19.5	15.8	19.3	17.0	12.1
volatile (%)	40.6	38.4	35.7	31.9	35.2	33.4	40.1
fixed carbon (%)	41.9	44.1	33.7	35.0	37.7	41.8	36.0
ash (%)	7.0	7.9	11.1	17.3	7.8	7.8	11.5
sulfur (%)	0.88	0.68	0.79	0.73	0.86	1.1	2.2
Btu/lb	10,349	11,211	9,022	7,182	8,204	10,018	10,492

1: Escalante area, Kaiparowits coal field, Straight Cliffs Fm., 40 samples.
2: Smoky Mtn. area, Kaiparowits coal field, Straight Cliffs Fm., 77 samples.
3: Tropic area, Alton coal field, Straight Cliffs Fm., 20 samples.
4: Cannonville area, Alton coal field, Dakota Fm., 4 samples.
5: Skutumpah area, Alton coal field, Dakota Fm., 11 samples.
6: Alton area, Alton coal field, Dakota Fm., 13 samples.
7: Orderville area, Kolob coal field, Dakota Fm., 9 samples.

zone is generally a single seam which averages about 12 feet (4 m) thick. The thickest exposure is about 18 feet (5 m) (Doelling and Davis, 1989, p. 110).

Nearly all production from the Alton field has come from the currently inactive Alton and Smirl mines, two of nine mines that have produced from the Alton field at various times.

Kaiparowits Plateau Coal Field

The Kaiparowits Plateau coal field is located in eastern Kane County and south-central Garfield County and coincides roughly with the area of the Kaiparowits Plateau (figure 12). The lateral extent of the coal field is defined by the erosional limits of Cretaceous coal-bearing strata (Dakota Formation, Tropic Shale, and Straight Cliffs Formation). Within the Kaiparowits Plateau coal field, coal seams of commercial interest occur within the middle member of the Dakota Formation, and within the Smokey Hollow and the John Henry Members of the Straight Cliffs Formation. The most important coal seams are contained within the John Henry Member. At least three of the four John Henry Member coal zones contain coal seams of commercial thickness and quality. Coal zones, in ascending order, are named the (1) Lower, (2) Christensen, (3) Rees, and (4) Alvey. Thicker coal beds generally occur in the Christensen and Alvey coal zones (Doelling and Davis, 1989, p. 107).

Hansen (1978a) compiled coal seam outcrop data from a number of 7.5 minute geologic quadrangle maps and from a small number of drill holes to show the general distribution of coal thickness within the John Henry Member of the Straight Cliffs Formation. Using the same geologic information, Hansen (1978b) also projected the thickness of overburden above the Christensen coal zone. Lidke and Sargent (1983) compiled geologic data from available oil and gas exploratory wells and prepared a series of cross-sections within the Kaiparowits basin.

Thickness of coal seams varies throughout the Kaiparowits Plateau field. To the east, coal zones in the Straight Cliffs Formation tend to thin and pinch out against marine sandstone tongues in the vicinity of Fiftymile Mountain. To the southwest, the coal seams of the Straight Cliffs Formation become thinner and eventually pinch out in the vicinity of The Cockscomb. The main coal region of the Kaiparowits Plateau coal field lies in a 15 to 18 mile (24 to 29 km) wide band trending roughly N. 30° W. through the center of the plateau, reflecting the dominant position of coal-bearing swamps during Straight Cliffs time. The coal seams within this band are thicker in and adjacent to synclinal troughs and often pinch out near the crests of anticlines (Peterson, 1988, p. 142).

At least three mines and a small number of prospects have produced coal from the Straight Cliffs Formation of the Kaiparowits Plateau field in the past. These include the Warm Creek experimental mine (section 19, T. 41 S., R. 4 E.), the Spencer No. 1 and No. 2 mines (section 3, T. 42 S., R. 3 E.), and the John Henry prospect (section 12, T. 42 S., R. 3 E.). These mines are located in the Smoky Mountain area on the southern end of the field and are now abandoned. Total production from all mines was probably less than 14,000 short tons (12,700 mt), with the majority (12,000 short tons or 10,900 mt) of coal production coming from the Warm Creek experimental mine (Doelling and Davis, 1989, p. 108).

Since proposed WSAs cover a large portion of the Kaiparowits Plateau, a more detailed evaluation of the distribution of coal resources was required. Coal thickness data were compiled from published coal measurements and from unpublished confidential drilling data contained in UGS controlled access files. Information included data from 560 coal outcrop measurements (Doelling and Graham, 1972), coal-bed intercepts from 170 confidential drill-hole files, and published reports by Hansen (1978a, 1978b) and Lidke and Sargent (1983). The results and methodology of the analysis are described in detail in Blackett (in preparation). The overall findings are summarized on figure 13. Coal intercepts from measured sections and drill holes were used to categorize coal resource areas into four principal divisions based on the apparent continuity, thickness, and number of seams present within the John Henry Member of the Straight Cliffs Formation. The John Henry Member was chosen for the analysis because its coal seams are of greater economic importance throughout the Kaiparowits Plateau field than coal seams in the Cretaceous Dakota Formation or the Smoky Hollow Member.

The patterns on figure 13 show a general northwest to southeast trend reflecting the depositional trends of coal swamps described by Peterson (1988, p. 142). The central portion, determined on coal intercepts in drill holes, depicts a region of relatively thick (greater than 8 feet -- 2.4 m), multiple seams. Surrounding this central portion are areas where coal zones are thinner and more variable, but still generally considered of minable thickness (greater than 4 feet -- 1.2 m). Beyond these areas, coal seams are generally less than 4 feet (1.2 m) thick, or they are of undetermined thickness, and/or buried beneath thick overburden.

From outcrop measured sections and drill-hole data, the principal coal resource areas overlap with the Death Ridge, Carcass Canyon, Burning Hills, and parts of the Wahweap and Fifty Mile Mountain WSAs. Although very little coal information is available within the Wahweap and Mud Spring Canyon WSAs, a potential coal resource may exist within their boundaries. Due to thick overburden and possible thinning of coal zones in the Wahweap and Mud Spring Canyon WSAs, however, resource development potential in these WSAs may be much less. All WSAs would be included in the BLM's All Wilderness alternative. The BLM does not include Death Ridge, Carcass Canyon, Burning Hills, Wahweap, or Mud Spring Canyon WSAs and only includes part of the Fifty Mile Mountain WSA in its Proposed Action alternative. The BLM's Proposed Action alternative, therefore, eliminates conflicts with the major coal resource areas of the Kaiparowits Plateau field.

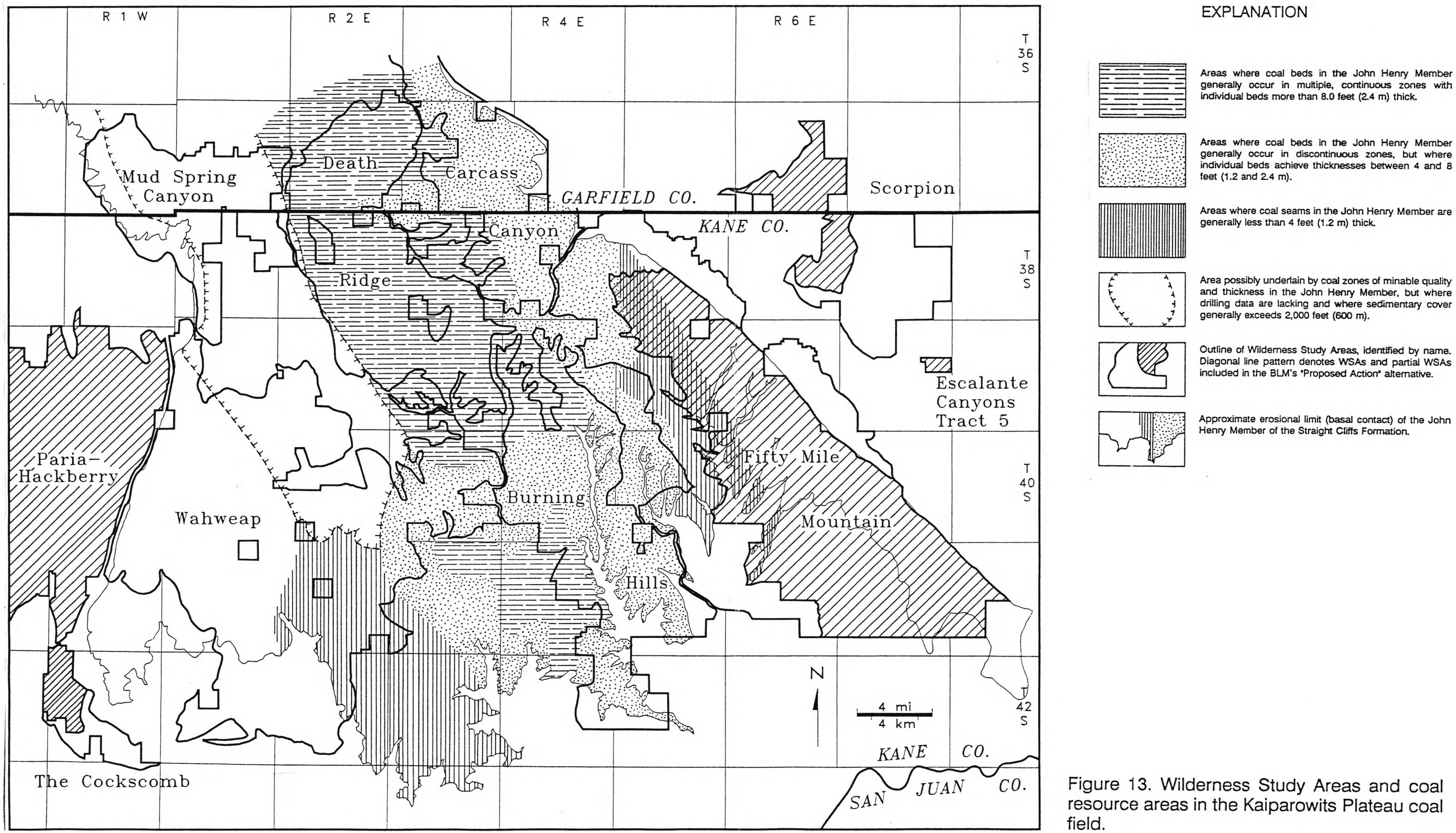

Figure 13. Wilderness Study Areas and coal resource areas in the Kaiparowits Plateau coal field.

DISCUSSION

In late 1990 the BLM released their Statewide Wilderness Final Environmental Impact Statement, or Final EIS (Bureau of Land Management, 1990). The Final EIS comprises seven volumes including a statewide overview and individual analyses of each of the 83 WSAs and ISA complexes in Utah. The Final EIS forms the basis for the BLM's recommendation to the Secretary of Interior. A comparison between the BLM's Proposed Action and All Wilderness alternatives for Kane County, their acreage, and changes in acreage from the BLM's Draft EIS is presented in table 1.

The USGS and the USBM prepared mineral appraisals and classifications of resource potential for the WSAs contained within the BLM's Proposed Action alternative. In this study, the UGS examined the regional aspects of mineral and energy resources with respect to those WSAs contained within the BLM's All Wilderness alternative. The work completed by the USGS and the USBM represents the most thorough compilation of known mineral resources, and the most complete evaluation of future resource potential for the BLM's Proposed Action available to date. The work completed by the UGS presents regional perspectives to mineral resources and the possible distribution of those resources with respect to all WSAs in Kane County.

Results of the work by the federal agencies and the UGS for each of the WSAs in Kane County are briefly summarized below.

North Fork Virgin River and the Orderville Canyon WSAs: Moderate potential for undiscovered petroleum resources, the presence of sub-economic gypsum resources is noted, and low resource potential for metals and coal (Van Loenen and others, 1989).

Parunuweap Canyon WSA: Moderate potential for petroleum resources, and identified sub-economic gypsum resources (Van Loenen and others, 1988a).

Canaan Mountain WSA: Moderate potential for petroleum resources (Van Loenen and others, 1988b).

Paria-Hackberry WSA: Moderate mineral potential for uranium resources in the Chinle Formation. There is a low mineral potential for resources of oil and gas, coal, and metals.

The Cockscomb WSA: Moderate potential for undiscovered petroleum resources (Bell and others, 1990).

Mud Spring Canyon WSA: Not included within the BLM's Proposed Action alternative. Potential exists for the discovery of petroleum and CO_2 resources. Coal resources may exist although depths to the resource likely exceed 2,000 feet (610 m) throughout much of the WSA (Blackett, in preparation).

Wahweap WSA: Not included within the BLM's Proposed Action alternative. High potential for sand and gravel deposits, moderate potential for undiscovered coal within the Straight Cliffs

Formation, and moderate potential for petroleum. The All Wilderness alternative would encompass a significant portion of the Kaiparowits Plateau coal field (Bell and others, 1990).

Death Ridge WSA: Not included within the BLM's Proposed Action alternative. The All Wilderness alternative would include identified coal resources of the Kaiparowits Plateau coal field (Blackett, in preparation). Potential also exists for petroleum and CO_2 resources.

Carcass Canyon WSA: Not included within the BLM's Proposed Action alternative. The All Wilderness alternative would include identified coal resources of the Kaiparowits Plateau coal field. Potential also exists for petroleum and CO_2 resources (Blackett, in preparation).

Burning Hills WSA: Not included within the BLM's Proposed Action alternative. The All Wilderness alternative would include identified coal resources of the Kaiparowits Plateau coal field (Blackett, in preparation).

Fifty Mile Mountain WSA: High potential for undiscovered, thin coal beds, high potential for titanium-zirconium deposits (except within the southwest corner of the WSA), high potential (with low certainty) for undiscovered uranium in the north-central and southeast portions of the WSA, and a moderate potential for petroleum, CO_2, and gypsum. The All Wilderness alternative would include part of the eastern margin of the Kaiparowits coal field (Bartsch-Winkler and others, 1988a).

Scorpion WSA: Moderate potential for petroleum and CO_2 (Bartsch-Winkler and others, 1989).

Escalante Canyons Tract V: Moderate potential for petroleum and CO_2 (Bartsch-Winkler and others, 1988b).

The wilderness study process is comprised of three phases that include (1) inventory, (2) study, and (3) reporting. The inventory and study phases are completed with the publication of the Final EIS. The final reporting phase, which included finalizing independent reports of the USGS and the USBM, and preparation of Wilderness Study Reports, is also complete. The Secretary of the Interior makes formal recommendations to the President regarding whether or not individual WSAs should be designated as wilderness. Within two years of receiving the recommendations from the Secretary, the President must make final recommendations to Congress. Only Congress can authorize wilderness designation or release WSAs from their current status.

The development potential of mineral and energy resources in Kane County may or may not be affected by the designation of lands into the wilderness system. The result of the BLM's study process has been to exclude certain WSAs from the Proposed Action that overlap with the identified coal resources of the Kaiparowits Plateau coal field. The BLM has also reduce the size of other WSAs in the Proposed Action that are marginal to the coal resource areas.

We encourage congressional decision-makers to consider and utilize the mineral resource information compiled by federal and state agencies, and others as a result of the BLM wilderness study process. With this detailed information, we feel that a sound decision regarding the designation of wilderness areas on public land can eventually be made.

CONCLUSIONS

Based upon our review of available mineral resource information for Kane County, we believe the BLM's Proposed Action alternative minimizes conflict with future development of identified mineral and energy resources, particularly with respect to the huge coal resource areas in the Kaiparowits Plateau field. Significant conflict with identified coal resource areas would occur, however, if all or portions of the All Wilderness alternative were adopted. We also believe that oil and gas resource potential of the region is largely undetermined, due to lack of adequate drilling information, and that new theories concerning potential petroleum source-rocks and reservoirs will need long-term future testing.

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REFERENCES

Allin, D.L., 1990, Colorado Plateau subsurface water flow key: Oil and Gas Journal, July, p. 52-54.

Andalex Resources, Inc., 1991, Warm Springs Project overview: Unpublished briefing, Price, Utah, 13 p.

Bartsch-Winkler, Susan, Barton, H.N., Cady, J.W., and Cook, K.L., 1988a, Mineral resources of the Fifty Mile Mountain Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1747-A, 20 p.

Bartsch-Winkler, Susan, Goldfarb, R.J., Cady, J.W., Duval, J.S., Kness, R.F., Corbetta, P.A., and Cook, K.L., 1988b, Mineral Resources of the Steep Creek Wilderness Study Area, Garfield County, Utah, and the Escalante Canyons Tract V, Kane County, Utah: U.S. Geological Survey Bulletin 1747-B, 20 p.

Bartsch-Winkler, Susan, Jones, J.L., Kilburn, J.E., Cady, J.W., Duval, J.S., and Cook, K.L., 1989, Mineral resources of the Scorpion Wilderness Study Area, Garfield and Kane Counties, Utah: U.S. Geological Survey Bulletin 1747-C, 15 p.

Bell, Henry, III, Kilburn, J.E., Cady, J.W., and Lane, M.E., 1990, Mineral resources of The Cockscomb and Wahweap Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1748-A, 18 p.

Bissell, H.J., 1954, The Kaiparowits region, in Geology of the High Plateau, central and south central Utah: Intermountain Association of Petroleum Geologists Guidebook, 5th Annual Field Conference, p. 63-70.

Blackett, R.E., in preparation, Wilderness Study Areas and coal resource areas in the Kaiparowits Plateau coal field: Utah Geological Survey.

Blakey, R.C., 1979, Oil-impregnated carbonate rocks of the Timpoweap Member Moenkopi Formation, Hurricane Cliffs area, Utah and Arizona: Utah Geology, v.6, no. 1, p. 45-54.

Bureau of Land Management, 1985, Utah statewide wilderness draft environmental impact statement: Salt Lake City, Utah State Office, Bureau of Land Management, v. I, 401 p.

Bureau of Land Management, 1990, Utah statewide wilderness final environmental impact statement: Salt Lake City, Utah State Office, Bureau of Land Management, v. I, 413 p.

Chidsey, T.C., Allison, M.L., and Palacas, J.G., 1990, Potential for Precambrian source rock in Utah: American Association of Petroleum Geologists Bulletin, v. 74, no. 8, p. 1319.

Doelling, H.H. and Davis F.D., 1989, The geology of Kane County -- geology, mineral resources, geologic hazards, with sections on petroleum and carbon dioxide by C.J. Brandt: Utah Geological and Mineral Survey Bulletin 124, 192 p., 10 pls.

Doelling, H.H., and Graham, R.L., 1972, Southwestern Utah coal fields: Alton, Kaiparowits Plateau, and Kolob-Harmony: Utah Geological and Mineralogical Survey, Monograph Series No. 1, 333 p.

Dow, V.T. and Batty, J.V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico and Colorado: U.S. Bureau of Mines Report of Investigation 5860, 51 p.

Dubyk, W.S. and Young, Patti, 1978, Preliminary study of uranium favorability in the Kaiparowits Plateau region, Garfield and Kane Counties, Utah: U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado, no. GJBX 64(78), 26 p.

Gregory, H.E., and Moore, R.C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U.S. Geological Survey Professional Paper 164, 161 p.

Hackman, R.J., and Wyant, D.G. 1973, Geology, structure, and uranium deposits of the Escalante quadrangle, Utah and Arizona: U.S. Geological Survey Miscellaneous Investigations, Map I-744, scale 1:250,000.

Hansen, D.E., 1978a, Map showing extent and total thickness of coal beds in the Kaiparowits coal basin: U.S. Geological Survey Miscellaneous Investigations Series Map I-1033-C, scale 1:125,000.

Hansen, D.E., 1978b, Maps showing amount of overburden on major coal zones in the Kaiparowits coal basin, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1033-D, scale 1:125,000.

Havens, Richard, and Agey, W. W., 1949, Concentration of manganese ores from Piute and Kane Counties, Utah: U. S. Bureau Mines Report of Investigation 4551, 9 p.

Heylman, E.B., Jr., 1963, Oil and gas possibilities of Utah, west of the Wasatch and north of Washington County: Utah Geological and Mineral Survey Bulletin 54, p. 287-301.

Hintze, L.F., 1973, Geologic history of Utah: Brigham Young University Geology Studies, v. 20, pt. 3, 181 p.

Hintze, L.F., 1988, Geologic history of Utah: Brigham Young University Geology Studies, Special Publication 7, Provo, Utah, 202 p.

Kunkel, R.P., 1965, History of exploration for oil and natural gas in the Kaiparowits region, Utah, in Geology and resources of south-central Utah: Utah Geological Society Guidebook 19, p. 93-111.

Lawson, A.C., 1913, The gold of the Shinarump at Paria: Economic Geology, v. 8, p. 434-448.

Lidke, D.J., and Sargent, K.A., 1983, Geologic cross-sections of the Kaiparowits coal-basin area, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1033-J, 2 sheets, sections.

Mallory, W.W., 1972, Regional synthesis of the Pennsylvanian System: Rocky Mountain Association of Geologists, Atlas of the Rocky Mountain Region, p. 111-127.

Peterson, Fred, 1969, Four new members of the Upper Cretaceous Straight Cliffs Formation in the southeastern Kaiparowits region, Kane County, Utah: U.S. Geological Survey Bulletin, 1274-J. p. J1-J28.

Peterson, Fred, 1988, Sedimentologic and paleotectonic analysis of the Henry, Kaiparowits, and Black Mesa Basins, Utah and Arizona, in Sloss, L.L., editor, Sedimentary cover -- North American craton: Geological Society of America, Geology of North America, v. D2, p. 134-144.

Peterson, Fred, Campbell, J. A., Franczyk, K. J., and Lupe, R. D., 1982, National uranium resource evaluation -- Escalante quadrangle Utah: United States Department of Energy Report PGJ/F-049(82), 65 p., 13 pls.

Peterson, Fred and Kirk, A.R., 1977, Correlation of the Cretaceous rocks in the San Juan, Black Mesa, Kaiparowits and Henry Basins, southern Colorado Plateau, in Fassett, J.E., editor, San Juan Basin III, northwestern New Mexico: New Mexico Geological Society, Guidebook, 28th Field Conference, p. 167-178.

Petroleum Information, 1984a, Kaiparowits basin -- an old frontier with new potential: Petroleum Frontiers, v. 1, no. 1, p. 4-25.

Petroleum Information, 1984b, Carbon Dioxide and its applications to enhanced oil recovery: Petroleum Frontiers, v. 2, no.1, 63 p.

Petroleum Information, 1986, Oil and gas production report for Nevada and Utah, June, 1986, 232 p.

Rauzi, S.L., 1990, Distribution of Proterozoic hydrocarbon source rock in northern Arizona and southern Utah: Arizona Oil and Gas Conservation Commission Special Publication 5, 38 p.

Riggs, E.A., 1978, Bennett's oil field, in Oil and gas fields of the Four Corners area: Four Corners Geological Society, p. 594-595.

Ritzma, H.R., 1980, Oil-impregnated sandstone deposits, Circle Cliffs uplift, Utah, in Henry Mountains Symposium: Utah Geological Association 1980 Field Trip Guidebook, Utah Geological Association Publication 8, p. 343-351.

Reynolds, M.W., Palacas, J.G., and Elston, D.P., 1988, Potential petroleum source rocks in the late Proterozoic Chuar Group, Grand Canyon, Arizona, in Carter, L.M.H., editor, V.E. McKelvey forum on mineral and energy resources: U.S. Geological Survey Circular 1025, p. 49-50

Sharp, G.C., 1976, Reservoir variations at Upper Valley field, Garfield County, Utah, in Symposium on Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists, p. 325-345.

Stokes, W.L., 1977, Subdivisions of the major physiographic provinces of Utah: Utah Geology, v. 4, no. 1, p. 1-17.

Stone, R.W. and Lupton, C.T., 1920, Gypsum in Utah, in Stone, R. W., editor, Gypsum deposits of the United States: U.S. Geological Survey Bulletin 697, p. 261-282.

Tapp, S.T., 1963, Kanab Creek unit area, Kane County, Utah, in Guidebook to the geology of southwestern Utah, transition between Basin-Range and Colorado Plateau provinces: Intermountain Association of Petroleum Geologists, 12th Field Conference Guidebook, p. 193-198.

U.S. Department of Energy, 1979, National uranium resource evaluation, interim report: U.S. Department of Energy, Grand Junction Operations Report GJO-111(79), Grand Junction, Colorado, 137 p.

Utah Department of Transportation, 1968, Materials inventory of Piute, Wayne, Garfield, and Kane Counties, Utah Department of Transportation report, 33 p.

Utah Geological Survey, mineral occurrence files, Salt Lake City, Utah.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., and Briggs, P.H., 1989, Mineral resources of eight wilderness study areas bordering Zion National Park, Washington and Kane Counties, Utah: U.S. Geological Survey Bulletin 1746-E, 22 p.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., Cook, K.L., 1988a, Mineral resources of the Parunuweap Canyon Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1746-B, 18 p.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., and Turner, R.L., 1988b, Mineral resources of the Canaan Mountain and The Watchman Wilderness Study Areas: U.S. Geological Survey Bulletin 1746-A, 21 p.