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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

General Geology and Mineral Resources of the Coal Area of South-Central Utah

Compiled by

K. A. Sargent and Dan E. Hansen

With sections on Landslide Hazards by Roger B. Colton, Coal-Mine Subsidence by C. Richard Dunrud, and Landscape Geochemistry by J. J. Connor

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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GENERAL GEOLOGY AND MINERAL RESOURCES OF THE COAL AREA OF SOUTH-CENTRAL UTAH

INTRODUCTION

This report is a summary of the topography, physiography, geology, coal and other resources, and geologic hazards of the coal areas of south-central Utah. Although discussion pertains chiefly to the areas of three coal fields, Kaiparowits, Kanab (Alton), and Kolob, it also discusses mineral resources in nearby areas whose exploration or exploitation have had or may in the future have effects on south-central Utah. The report area lies generally between lat. 37° and 38° N. and long. 111° and 113° W. Cedar City, Utah and Zion National Park form the border on the west, Arizona and Lake Powell are near the border on the south and southeast, the Waterpocket fold and Henry Mountains border on the east, and three plateaus, Aquarius, Paunsaugunt, and Markagunt, form the border on the north.

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SOURCES OF INFORMATION

Numerous geological reports have been written on south-central Utah. Probably the best known published works are those by H. E. Gregory, who published on the areal geology in the U.S. Geological Survey Professional Paper series and in the Bulletin of the Geological Society of America in the 1930's, 40's, and 50's on the Navajo Country and the Kaiparowits Plateau, Markagunt Plateau, and Paunsaugunt Plateau. Much has also been published by the Utah Geological and Mineralogical Survey (UGMS) on the area: H. H. Doelling and R. L. Graham (1972) of that organization have published important works on the coal fields of southern Utah. Major regional geologic maps by L. F. Hintze and W. L. Stokes have been printed by the Utah State Land Board (Hintze, 1963; Hintze and Stokes, 1964).

More recent work includes efforts by the U.S. Geological Survey: 1:250,000-scale mapping of the Salina 2° quadrangle by Williams and Hackman (1971), and the Escalante 2° quadrangle by Hackman and Wyant (1973); coal studies and 1:24,000 scale maps of the Kaiparowits coal basin (W. E. Bowers, 1973a, b, c; Fred Peterson, 1973, 1975; Fred Peterson and B. E. Barnum 1973a, b, c, d; E. V. Stephens, 1973; H. D. Zeller, 1973a, b, c, d; H. D. Zeller and E. V. Stephens, 1973), the Alton coal field area (W. E. Bowers, unpub. mapping, 1976), the Cedar City area (Paul Averitt, 1962), and the Orderville coal area (W. B. Cashion, 1961). H. D. Zeller, W. E. Bowers and Fred Peterson currently are working in south-central Utah.

Also useful for this report were parts of the 1976 Bureau of Land Management Environmental Impact Statement on the proposed Kaiparowits power project.

Carl von Hake of the National Oceanic and Atmospheric Administration provided information from the earthquake data file which was particularly helpful for seismic information since 1965.

TOPOGRAPHY AND PHYSIOGRAPHY

South-central Utah lies within sections of the Colorado Plateau province known as Canyonlands and High Plateaus of Utah (Fenneman, 1931 and fig. 1), whose outstanding topographic features are terraced

Figure 1.--NEAR HERE

plateaus, monoclinal ridges, high mesas, and deep canyons. North of the area, the plateaus descend southward by a series of large rock terraces which are generally 20-60 miles (32-96 km) long and as much as 10 miles (16 km) wide. The cliffs separating each terrace range in height from a few hundred to as much as 1,500 feet (100-500 m). The terraces are indented by branching large and small canyons, the longer canyons cutting across successive terraces.

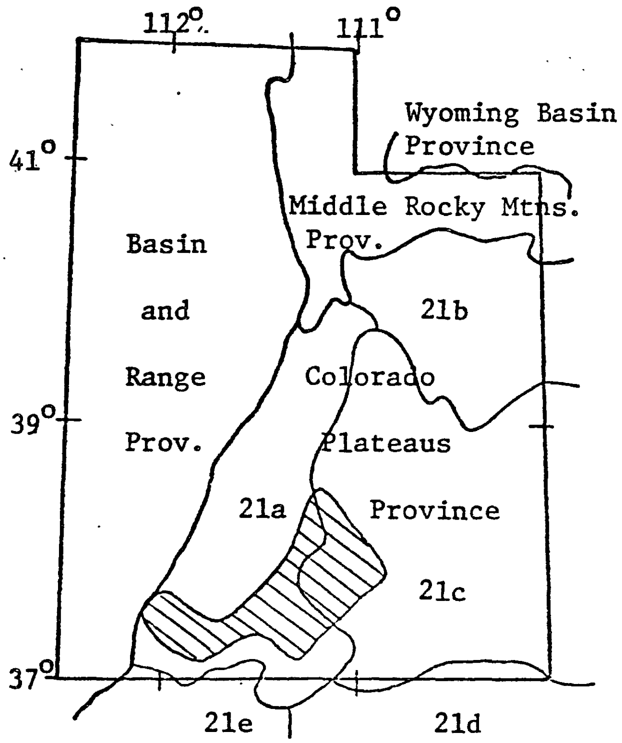

Fig. 1--Map of Utah showing physiographic divisions and area of this report (patterned). Divisions of the Colorado Plateaus Province are 21a, High Plateaus of Utah; 21b, Uinta Basin; 21c, Canyon Lands; 21d, Navajo section; 21e, Grand Canyon section (modified from Fenneman, 1931).

Except for the volcanic rocks that partly cover the Aquarius, Paunsaugunt, and Markagunt Plateaus, the topographic features of south-central Utah are developed on sedimentary strata. The rocks of the High Plateaus and Canyonlands are flat or only slightly tilted, locally interrupted by such monoclines as the Waterpocket fold on the east and the East Kaibab fold (The Cockscomb) near the center of the area. Areas of strong monoclinal folding weather to elongate ridges of steeply dipping beds. Areas of lesser folding erode to more gentle ridges.

The northwest part of the area is drained by the north-flowing Sevier River; all other streams flow southward to the Colorado River. Of the south-flowing rivers, the Virgin, Paria, and Escalante are perennial, whereas the rest are intermittent or flow only in times of floods.

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The altitude of the region varies between about 3,700 feet (1,230 m) at Lake Powell on the south and 11,000 feet (3,700 m) on the Aquarius Plateau to the north. Changes in altitude are generally abrupt although gentle rolling topography may be present on terraces and plateaus. Above the valley floors the terraces, or benches, rise by steps from south to north. Each bench is underlain by an erosion-resistant geologic unit. In the Kaiparowits Plateau area the benches are well developed. (Physical features are shown on Escalante 1:250,000-scale USGS sheet 1956-62.) The first bench is just above Lake Powell, at about 3,800 feet (1,270 m). Successively higher benches occur at 4,200-4,400 feet (1,400-1,470 m) (Grand Bench), 5,200-5,400 feet (1,730-1,800 m) (Nipple Bench), 6,000-6,200 feet (2,000-2,070 m) (Fourmile Bench), and 10,200-10,600 feet (3,400-3,530 m) (Aquarius Plateau). A similar series of benches, although fewer in number, occur to the west. (Physical features are shown on Cedar City 1:250,000-scale USGS sheet 1953-1961.) Northward from Kanab the bench levels are 5,000-5,200 feet (1,670-1,730 m) (Shinarump Cliffs), 5,600-5,800 feet (1,870-1,930 m) (Wygaret Terrace), 6,400-6,600 feet (2,130-2,200 m) (Skutumpah Terrace), and 8,800-9,200 feet (2,930-3,070 m) (Paunsaugunt Plateau).

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GENERAL GEOLOGIC SETTING AND STRATIGRAPHY

Most of the exposed section in south-central Utah is composed of Mesozoic sedimentary rocks (plate 1, in pocket). However, in areas of upwarp and deep erosion, such as at the Circle Cliffs, rocks as old as Permian are exposed. The highest plateaus are capped with Tertiary and some Quaternary volcanic rocks. Table 1, modified from Gregory and

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Table 1.--NEAR HERE

Moore (1931), is a generalized section of most of the common units in south-central Utah. A thin cover of Quaternary unconsolidated deposits is common throughout the area; however, these units are not shown in table 1.

Unconsolidated Deposits

Unconsolidated deposits are largely Quaternary alluvium, colluvium, and gravel. Windblown sand and silt are common but only locally are thick enough to be mapped. Glacial moraine and outwash deposits occur in small areas scattered around the Aquarius Plateau (plate 1). Landslide deposits are common on steep slopes, especially those underlain by thick shales.

Table 1. Generalized section of the rock formations in south-central Utah (modified from Gregory and Moore, 1931)

System	Series	Formation	Character	Thickness in feet (meters)
Quaternary	Holocene(?) and Pleistocene	Basalt	Dark-gray dense basaltic and andesitic lava and dark-red scoriaceous basalt; hard resistant unit, commonly is cap-rock unit	0-300 (0-100)
Tertiary	Pliocene to Oligocene	Volcanic lavas, ash-flow tuffs, and sediments	Gray to dark-gray basalt and andesitic basalt flows; medium-gray ash-flow tuff, and light-gray tuffaceous sandstone and conglomerate. Basalt and densely welded tuff are generally dense, resistant units and form high plateaus.	0-1,500 (0-500)
		Unconformity		
	Eocene and Paleocene	Wasatch Formation	Calcareous sandstone, shale, and limestone; pink, white, and varicolored, soft; underlies highest plateaus; crops out in cliffs and forms slopes	0-1,600 (0-530)
		Local Unconformity		
	Paleocene(?)	Pine Hollow Formation 1/	Red and gray calcareous mudstone and bentonitic claystone; generally poorly exposed, forms slopes	0-400 (0-130)
		Local Unconformity		
Tertiary(?) and Cretaceous	Paleocene(?) and Upper Cretaceous	Canaan Peak Formation 1/	Light-gray sandstone and conglomerate with clasts of quartzite, chert, porphyry, and limestone	0-1,000 (0-330)
		Unconformity		
		Kaiparowits Formation	Pale-olive fine- to moderately coarse grained arkosic sandstone and sandy shale, with a weak calcareous cement; forms slopes and badlands; a fresh- or brackish-water deposit	2,200 (730)

Table 1. Generalized section of the rock formations in south-central Utah--Continued

		Wahweap Sandstone	Yellowish-gray massive sandstone with some sandy shale, the upper 200 feet (67 m) very massive and hard; grades downward into alternating hard and soft beds; a prominent cliff-forming unit	1,100-1,300 (370-430)
Cretaceous	Upper Cretaceous	Straight Cliffs Formation	Yellowish to brown irregularly bedded medium to massive sandstone; contains coal beds; forms prominent escarpments	900-1,200 (300-400)
		Tropic Shale	Bluish-drab argillaceous to sandy shale; very uniform in color and texture; grades to fossiliferous sandstone at base; shale contains abundant Gryphaea newberryi and other fossils; forms slopes and badlands	550-1,450 (180-480)
		Dakota Sandstone	Yellow to nearly white sandstone; conglomeratic in part; irregularly bedded; contains thin beds of coal and large silicified trees in places	0-100 (0-30)
		Unconformity		
Jurassic	Upper Jurassic	Morrison Formation[1/]	Maroon to light-bluish-gray sandy banded shale, very massive, hard conglomerate, and coarse gritty maroon, yellow, and gray irregularly bedded sandstone; forms escarpments	0-565 (0-190)
		Unconformity		
		Summerville[1/] Formation	Thin-bedded red-brown to gray friable sandstone; shale-like beds, alternating red and white, form banded cliffs	100-500 (30-170)
		Unconformity		
Jurassic		Entrada Sandstone	Yellow, tan, light-red, brown and gray fine, even-grained sandstone; in places on massive crossbedded stratum; some poorly bedded sandstone and red shale	200-800 (70-270)

Table 1. Generalized section of the rock formations in south-central Utah--Continued

	Upper Jurassic			
	Middle Jurassic	Carmel Formation	Pink to red and bluish sandy shale; white and buff sandstone; gypsum in beds and as cement; dense siliceous and earthy dark-maroon and light-bluish-green limestone; weathers in badlands and forms bench on top of Navajo Sandstone	90-900 (30-300)
		Unconformity		
Triassic(?) and Jurassic	Upper Triassic(?) and Middle Jurassic	Navajo Sandstone	Light-creamy-yellow, white, pinkish, and buff, highly crossbedded sandstone; weathers in high cliffs and innumerable cones, towers, and domes; forms caves, alcoves, and natural bridges	1,200-1,800 (400-600)
		Local Unconformity		
Triassic(?)	Upper Triassic(?)	Kayenta Formation	Maroon coarse-grained crossbedded sandstone, conglomerate, blue-gray hard, dense limestone; and maroon and brown shale; all in thin irregular beds	125-249 (40-83)
	Upper Triassic	Wingate Sandstone	Reddish-brown, very massive sandstone; prominently jointed; crops out commonly in a single vertical cliff that resembles a palisade; crossbedded but not so prominently as Navajo Sandstone	250-400 (80-130)
		Unconformity		
Triassic	Upper Triassic	Chinle Formation	Thick variegated calcareous shale or "marl," fine-grained sandstone, cherty limestone, and conglomeratic limestone; sandstone most abundant in the middle part; contains large silicified trees. Basal 0-40 m is Shinarump Member; light-gray to yellow coarse-grained to conglomeratic sandstone, very irregularly bedded and variable in thickness; grades locally into bluish sandy shale; contains silicified wood; forms prominent bench	475-1,200 (160-400)

Table 1. Generalized section of the rock formations in south-central Utah--Continued

		Unconformity		
	Lower and Middle(?) Triassic	Moenkopi Formation	Chocolate-brown to yellowish shale and sandstone, containing locally in upper portion very thin hard limestones; shale very sandy and grades into shaly sandstone; the sandstone ranges from thin-bedded platy to thick massive beds; ripple marked	304-500 (100-170)
		Unconformity		
Permian		Kaibab Limestone	White to yellowish massive, more or less dolomitic limestone, in part cherty; lower part increasingly sandy and grades downward into sandstone without sharp change; fossiliferous in part	0-1,050 (0-350)
Permian		Coconino Sandstone	Light-creamy-white calcareous crossbedded medium-grained sandstone	10-93+ (3-31+)

1/ Stratigraphic names and lithologies apply mainly to the Kaiparowits region.

Sedimentary Rocks

The aggregate exposed sedimentary section exceeds 10,000 feet (3,300 meters) in the southern Utah study area. It consists mostly of nonmarine sandstone and siltstone, and marine shale, with some conglomerate, limestone, dolomite, gypsum, and coal. Many of the sandstone units are crossbedded or irregularly bedded, moderately friable, and light gray to tan, or pink. Most formations exhibit little lithologic variation across the area, although notable exceptions exist in marine to nonmarine transitions along an east-west line (Tropic-Dakota transitions, Mancos-Straight Cliffs transitions). Significant changes occur commonly in the percentage of limestone and gypsum in a given stratigraphic interval across the area. Complex facies changes and stratigraphic correlations occur in Upper Jurassic units as well as in some lower Tertiary sedimentary rock units.

Igneous Rocks

Deposits of Quaternary and Tertiary basaltic-to-andesitic lava flows and latitic ash-flow tuffs are 500-1,000 feet (170-330 m) thick. In the eastern part these rocks were deposited mainly in the high plateaus but locally have moved to lower elevations by faulting or gravity sliding. In the west, Quaternary basalts have been extruded at lower elevations as well. Quaternary volcanic cones and vents are common in the basalt fields. Their topographic forms do not appear to have altered much since the time of their formation.

STRUCTURE

The structural geology of south-central Utah is on the same grand scale as the physiography. Here are not only the large-scale deformational features such as the large monoclines of the Waterpocket fold and the Cockscomb (East Kaibab monocline), the large anticlines of the Circle Cliffs and Kaibab upwarps, the large downwarps of the Henry Mountain and Kaiparowits synclines, and the large strata displacements of the Paunsaugunt, Sevier and Hurricane faults, but also there are more numerous, smaller-scale versions of these deformational features. Mapped on a geologic datum, the portrayed deformational features give the impression of a large crenulated area of strata broken here and there by faults (plate 2).

The area of south-central Utah has been studied extensively by numerous geologists, including many famous pioneer geologists, and consequently, there are many references. Most background material used has been limited, however, to relatively recent publications. The chief source of data north of the 38th parallel are the geology and structural maps by Williams and Hackman (1971). South of the 38th parallel and east of the 112th meridian, the chief source of data are the geology and structural maps by Hackman and Wyant (1973). West of the 112th meridian, the chief source of data are maps by Cashion (1961, 1967), by Averitt (1962, plate 1), and by Gregory (1951, plate 1). Each publication mentioned contains a large list of reference material.

Beginning in the eastern side of the area, the large Waterpocket fold extends northwest-southeast for about 90 miles (145 km) as a one- to two-mile-wide band of tilted rocks that dip from 3° to 32° northeast. Immediately east of this large monocline is the Henry Mountain syncline; immediately west of the monocline is the Circle Cliffs upwarp, a large and elongate anticline about 65 miles (104 km) long (Davidson, 1967, p. 59), and two lesser anticlines, the Thousand Lake anticline and the Teasdale anticline. North of the Circle Cliffs anticline, the Boulder Mountain segment of the Aquarius Plateau also abuts the monocline. There is at least an 8,000 foot (2,400 m) amplitude of folding, measured from the crest of the Circle Cliffs anticline to the deep of the Henry Mountain syncline. Ages of the strata involved range from Permian to Late Cretaceous. Faults in this area of the Waterpocket monocline are usually small normal faults, except for the large normal fault that bounds the Teasdale anticline on the southwest side.

Between the Circle Cliffs upwarp and the basin under the Kaiparowits Plateau are a series of smaller anticlines and synclines. Largest of the fold features are the Harris Wash syncline, the Escalante anticline, and the Escalante monocline. Although relatively short in length, the Escalante anticline and monocline together are an impressive fold feature with an amplitude of about 4,500 feet (1,350 m) of folding. Most of the strata involved in the folding are of Triassic and Jurassic age (Navajo Sandstone and the overlying Carmel Formation).

Farther west are a series of crenulations within the Kaiparowits basin. Perhaps the most striking fold features are the Upper Valley anticline and the adjacent Dutton monocline (both of which extend for 25 miles (40 km) in a northwest-southeast direction). Other large folds are the Table Cliff, Wahweap, Last Chance Creek and Alvey Wash synclines. The ages of the surface strata involved in folding of these features is Late Cretaceous, but Eocene to Miocene age rocks are present in the Table Cliff syncline. Farther south, the Rees Canyon anticline, Last Chance Creek syncline, Smoky Mountain anticline, Glen Canyon syncline, and the north end of the Echo monocline involve rocks as old as the Triassic and Jurassic Navajo sandstone. Several small normal faults occur in the southernmost part of the Kaiparowits basin. North of the Kaiparowits, several normal faults have been mapped where the Kaiparowits basin goes under the Table Plateau and Griffin Top (the Escalante Mountains). There normal faults also transect the flat-lying volcanic rocks of Miocene age.

Between the Kaiparowits basin and Kaibab upwarp is the East Kaibab monocline (The Cockscomb). This large monoclinal fold has a vertical component of structural relief of about 5,500 feet (1,650 m) in a horizontal distance of less than 4 miles (6.4 km). Rocks involved in the monocline range in age from Late Cretaceous (Kaiparowits Formation) to Permian (Kaibab Formation). The fold plunges northeastward and the northeast side of the Kaibab upwarp is defined by the Butler Valley and Johns Valley anticlines, and the northward continuation of the Kiabab anticline. Another large flexure on the Kaibab upwarp is the Tropic syncline. Numerous small normal faults occur along the East Kaibab monocline and some occur up on the upwarp. The upwarp is bounded on the west by the Paunsaugunt fault zone, which probably has a maximum throw of at least 2,000 feet (600 m). Strata involved in the faulting range in age from the Jurassic Navajo Sandstone to the Paleocene-Eocene Wasatch and farther north, volcanic rocks of Miocene age.

West of the Paunsaugunt fault zone, the strata under the Paunsaugunt Plateau and Skutumpah terrace are folded into a large syncline. Rocks within this large fold are as young as the Paleocene-Eocene Wasatch Formation. The Pausaugunt Plateau is bounded on the west by the Sevier fault zone, which probably has a maximum throw of about 2,500 feet (750 m). Rocks involved in the faulting range in age from the Triassic-Jurassic Navajo Sandstone to the Paleocene-Eocene Wasatch Formation, but some upper Tertiary volcanic rocks (flows) are locally involved.

The rocks underlying the Kolob Terrace and the Markagunt Plateau are chiefly a series of Cretaceous and Paleocene-Eocene strata dipping rather uniformly northeastward (dips are less than 6°). Small normal faults are present throughout much of the area. The large-scale faulting in this western area occurs in the Hurricane fault zone, which bounds the area on the west. The structure along the Hurricane fault zone is complex, but essentially is an ancestral anticline, the Kanarra fold of Gregory and Williams (1947, p. 240), broken by later, large scale faulting. Beds in the fold generally dip 20° to 60° eastward but locally (near Kanarraville), according to Averitt (1962, p. 42), the beds are overturned westward. Averitt (1962, p. 41) estimated vertical displacement along the Hurricane fault in the Cedar Mountain quadrangle to be between 8,000 (2,440 m) and 10,000 feet (3,050 m).

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The time when this deformation took place can be ascertained by the relationships of certain strata within the masses of rock involved. The earliest evident deformation took place after deposition of the Late Cretaceous Kaiparowits Formation. Clues to earlier events of deformation lie buried and are more obscure. In the area of the Table Cliffs, Bowers' map (1973) shows that most of the folding in the area took place during very Late Cretaceous and Early Paleocene time (about 70,000,000 years ago). The folded rocks were above depositional level and were beveled to a relatively smooth surface during this time. Probably the rocks were not very high above the base level of erosion and shortly after the beveling, deposition of coarse river-borne materials began. It seems as though there was a relatively abrupt rise in the southwest source area of the sediments. The strata of south-central Utah were probably given most of their regional northward tilt at this time. Gradually an extremely large lake basin developed northward and the mixed fluvial and lacustrine strata of the Paleocene-Eocene and Oligocene(?) Wasatch Formation were deposited. After deposition of the Wasatch and related strata, uplift resumed throughout the entire area and the strata were probably planated again to a relatively smooth northward sloping surface. Volcanic pyroclastics and flat-lying flows were deposited in the Aquarius Plateau area and the plateaus further west. The volcanics probably are Oligocene-Miocene in age. A surface of moderate relief was formed--the tops of the high plateaus are rather flat. The entire area then was subject to stronger uplift and the strata along the Paunsaugunt, Sevier and

Hurricane fault zones were moved into much of their present attitudes. On the other hand, the entire Colorado Plateau had to be raised high enough and quickly enough relative to base level in order that the cycle of canyon erosion could take place.

Despite the magnitude of structure and of canyon erosion, large areas of Late Cretaceous coal-bearing rocks have been preserved within synclinal and basin structures. On a regional basis, the coal-bearing rocks are preserved within the Kaiparowits basin and the extension under the Aquarius plateau, within the synclinal fold that underlies the Paunsaugunt Plateau and Skutumpah terrace, and within the rocks dipping uniformly northeastward under the Kolob terrace and the Markagunt Plateau.

ECONOMIC GEOLOGY

Coal is the single most significant economic product of south-central Utah. Three fields, the Kaiparowits, Alton (Kanab), and Kolob, contain enormous reserves in the Cretaceous succession and have been studied by workers for many years.

Oil has been produced in commercial quantity since 1964 from Permian rocks in the Upper Valley field west of Escalante. Elsewhere only shows or minor production have been reported.

The rocks of south-central Utah are only slightly mineralized. Some sandstones and shales contain small deposits of uranium, minor gold, titanium, selenium, arsenic, antimony, thorium and rare earths, manganese, and small amounts of low-grade copper.

Aggregate, "clinker" (rock baked by burning coal), silica, and semiprecious gem materials are locally abundant. Sandstone for building is abundant, and some clay deposits are known. Gypsum is widely distributed and may locally be of commercial grade. Limestones suitable for industrial use and chemical applications are present but not common.

Mineral Fuels

Coal

The coal deposits of south-central Utah are very large potential sources of energy. They are separated east to west by geography and geology into three major coal fields. These are the Kaiparowits Plateau, Alton (Kanab), and Kolob fields (plate 3). The coal deposits occur in a plateau-and-canyonland physiography, which is in an area of rugged relief at elevations from 5,000 to 9,200 feet (1,500 to 2,760 m) above sea level. The coal was first mined in 1852 in the Kolob field (Doelling and Graham, 1972, p. 267), but except for some sustained and briefly intensive mining in the Coal Creek-Cedar Mountain areas of the Kolob field, most production has been of an intermittent nature and the mines have been of small areal extent. This is generally an isolated area that is far from large markets and from accessible bulk transportation facilities.

Stratigraphic relationships

The coal deposits occur as several coal zones in strata of Late Cretaceous age. The strata are described in the generalized rock formation sections (figures 2-4) for each field. The coal zones, as

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Figure 2.--NEAR HERE

3.--NEAR HERE

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mapped (Doelling and Graham, 1972), have an east-west extent of about 150 miles (240 km) and south-north of about 40 to 60 miles (64 to 96 km) (Plate 3). Individual zones generally are composed of several coal beds that are usually of limited areal extent (lenticular). Lateral continuity of the zone is generally maintained by overlap of the coal beds. Locally a coal bed may be thick, up to 25 feet (7.5 m) or more in the Kaiparowits Plateau field; and where thick beds overlap, the total thickness of beds in a zone may be quite large.

Figure 2. Generalized section of Cretaceous strata, Kolob Field

POST-CRETACEOUS (TERTIARY AND QUATERNARY)

System	Series	Stratagraphic Unit	Thickness in feet (meters)	Description
CRETACEOUS	Campanian	Kaiparowits Formation	0-1,200 (0–360)	Gray, brown, white, coarse-grained, arkosic sandstones, sandy shales and thick conglomerates; freshwater deposits, in places friable, elsewhere resistant; forms badlands, slopes and strong cliffs.
	? Santonian ? Coniacian ?	Wahweap Formation and Straight Cliffs Formation undivided *Minor Coal*	0-1,590 (0–477)	Buff, gray, yellow, massive sandstone in thick and thin, subordinate and soft, irregular beds; subordinate calcareous, carbonaceous and argillaceous shale and some *coal*, marine and brackish water fossils, forms a series of escarpments.
	Turonian Cenomanian	Tropic Shale and Dakota Sandstone undivided *MAJOR COAL*	0-1,350 (0–405)	Drab, sandy, argillaceous, calcareous beds of shale, many beds of yellow–gray sandstone, more abundant in lower part, marine, brackish and fresh-water fossils, occasional conglomeratic beds and *coal*.

PRE-CRETACEOUS (JURASSIC)

(Modified from Doelling and Graham, 1972, p.259)

Figure 3. Generalized section of Cretaceous strata, Alton Field

POST-CRETACEOUS (TERTIARY AND QUATERNARY)

System	Series	Stratigraphic Unit	Thickness in feet (meters)	Description
Cretaceous	Campanian	Kaiparowits Formation	265-700 (80–210)	Dark gray to gray-green, arkosic sandstone, friable with weak calcareous cementation.
				Unconformity
		Wahweap Formation *Minor Coal*	500-1300 (150–390)	Alternating sandy shale and thin- to thick-bedded resistant sandstone, ledge and slope topography.
	Santonian ? Coniacian ? Turonian	Straight Cliffs Formation *Minor Coal*	80-500 (24–150)	Yellow-gray to brown, thick-bedded to massive cliff-forming sandstone with subordinate intervening gray shale, shaley sandstone, *coal* and carbonaceous shale.
		Tropic Shale	700-1000 (210–300)	Drab gray shale with subordinate thin brown fine-grained sandstone, slope former.
	Cenomanian	Dakota Formation *Major Coal Seams*	150-450 (45–135)	Yellow-gray to brown fine- to medium-grained sandstone alternating with gray shale, sandy shale, carbonaceous shale and *coal*, ledge and slope former creating Gray Cliffs; best *coal* near bottom and top of unit.

PRE-CRETACEOUS (JURASSIC)

(Modified from Doelling and Graham, 1972, p.8)

Figure 4. Generalized section of Cretaceous strata, Kaiparowits Plateau

POST-CRETACEOUS (TERTIARY AND QUATERNARY)

System	Series	Stratigraphic Unit	Thickness in feet (meters)	Description
CRETACEOUS	Campanian	Conglomeratic member	0- 500 (0-150)	Red and gray mudstone and bentonitic claystone overlying interbedded light brown, gray, pink and red sandstone, conglomeratic sandstone and conglomerate.
				— Unconformity —
		Kaiparowits Formation	2,000-2,500 (600-750)	Gray to dark gray, fine- to moderately coarse-grained, friable 'salt and pepper' arkosic sandstone with subordinate light gray mudstone; weak calcareous cement, forms badlands and slopes.
		Wahweap Formation	760-1,350 (228-405)	Yellow-gray resistant sandstone, gritstone and conglomerate alternating with yellow-orange nonresistant sandstone and gray mudstone; lower half dominantly nonresistant, upper half massive and hard.
		Straight Cliffs Formation, Upper: Drip Tank Member	100- 350 (30-105)	Yellow-brown to gray-orange, fine- to medium-grained sandstone with some gritstone and conglomerate interbedded, with subordinate gray shale; resistant cliff former.
	Santonian / Coniacian	Straight Cliffs Formation, Upper: John Henry Member, *MAJOR COAL SEAMS*	500- 900 (150-270)	Interbedded yellow-gray, white and orange medium-grained sandstone, gray shale, carbonaceous mudstone and *coal*; forms ledgy outcrops; often exhibits reddish to black outcrops from clinker and burned sandstone due to natural burning of coal.
				— Unconformity —
	Turonian	Straight Cliffs Formation, Lower: Smoky Hollow Member, *MINOR COAL*	24- 500? (7-150?)	Interbedded white or yellow-gray sandstone, light gray to dark gray mudstone and sometimes thin *coal* seams; lower part ledge to slope forming, upper part cliff forming.
		Straight Cliffs Formation, Lower: Tibbet Canyon Member	70- 185 (21-56)	Yellow-gray and gray-orange, medium-grained sandstone interbedded with subordinate gray mudstone; cliff former.
		Tropic Shale, *MINOR COAL*	550-1,000 (165-300)	Medium- to dark-gray argillaceous to sandy shale, contains thin yellow-gray sandstone beds at top and base, otherwise uniform; forms badlands and slopes.
	Cenomanian	Dakota Formation, *MINOR COAL*	0- 250 (0-75)	Yellow-gray sandstone alternating with gray shale, carbonaceous shale and *coal*; forms semiresistant ledge.

PRE-CRETACEOUS (JURASSIC)

(Modified from Doelling and Graham, 1972, p. 74)

The coal zones extend stratigraphically upward from the basal strata of the Dakota-Tropic interval in the eastern part of the Kolob field to the highest strata of the John Henry Member, Straight Cliffs Formation, in the Kaiparowits field. This vertical stratigraphic range is about 1,800 to 2,000 feet (240 to 600 m) over the miles of outcrop. The spatial relationships of the coal zones are the result of transgressive and regressive phases of nonmarine and marine deposition at or near the southwest edge of a Late Cretaceous seaway. The relationships of the coal zones and related strata are illustrated by figure 5.

Figure 5.--NEAR HERE

In the Cedar Mountain area of the Kolob field, the coal beds occur in several zones (after Averitt, 1962, p. 26). The Straight Cliffs coal zone is about 75 feet (23 m) above the strata assigned to the Straight Cliffs Sandstone ("Tropic Sandstone"). This coal zone appears to be of limited extent and is poorly exposed. The Upper Culver coal zone occurs at the top of the Tropic-Dakota interval and the Lower Culver coal zone is 11 to 34 feet (3.3 to 10.2 m) below the Upper zone. The Willow Creek coal zone is about 145 feet (44 m) below the top of the Tropic-Dakota interval. The coal beds in the Willow Creek zone are thin and discontinuous.

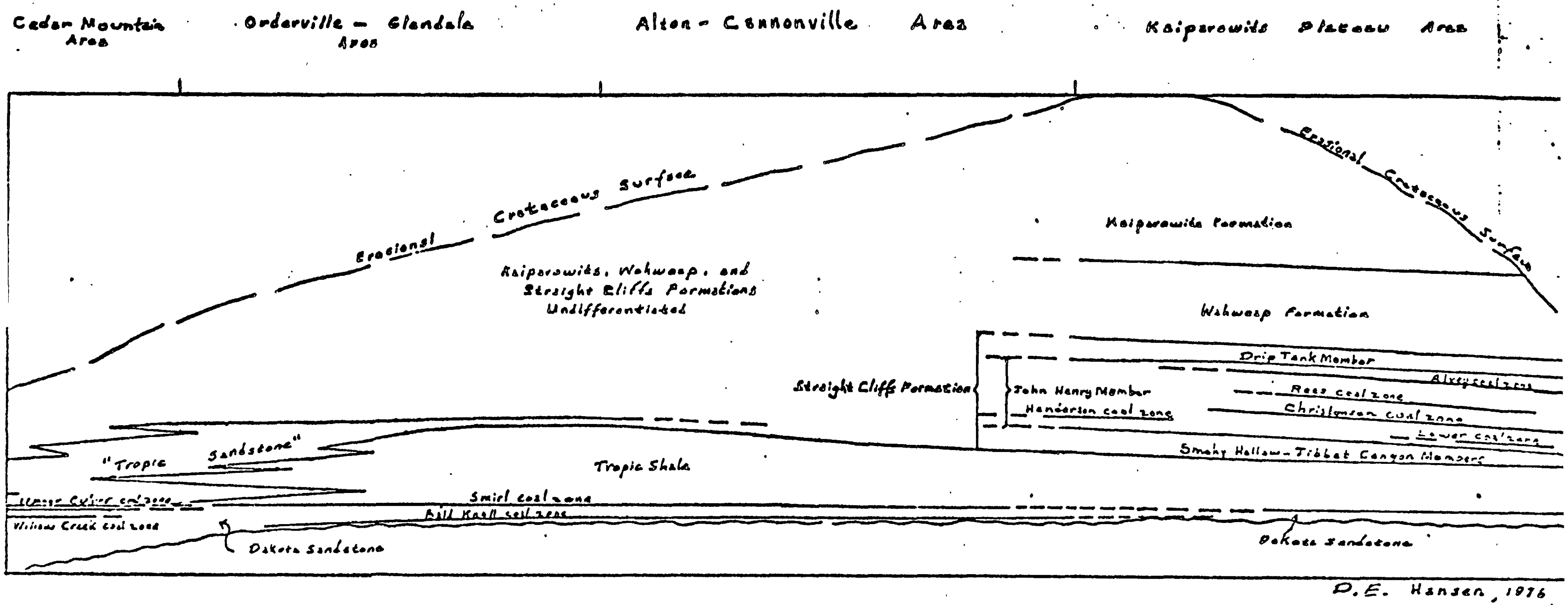


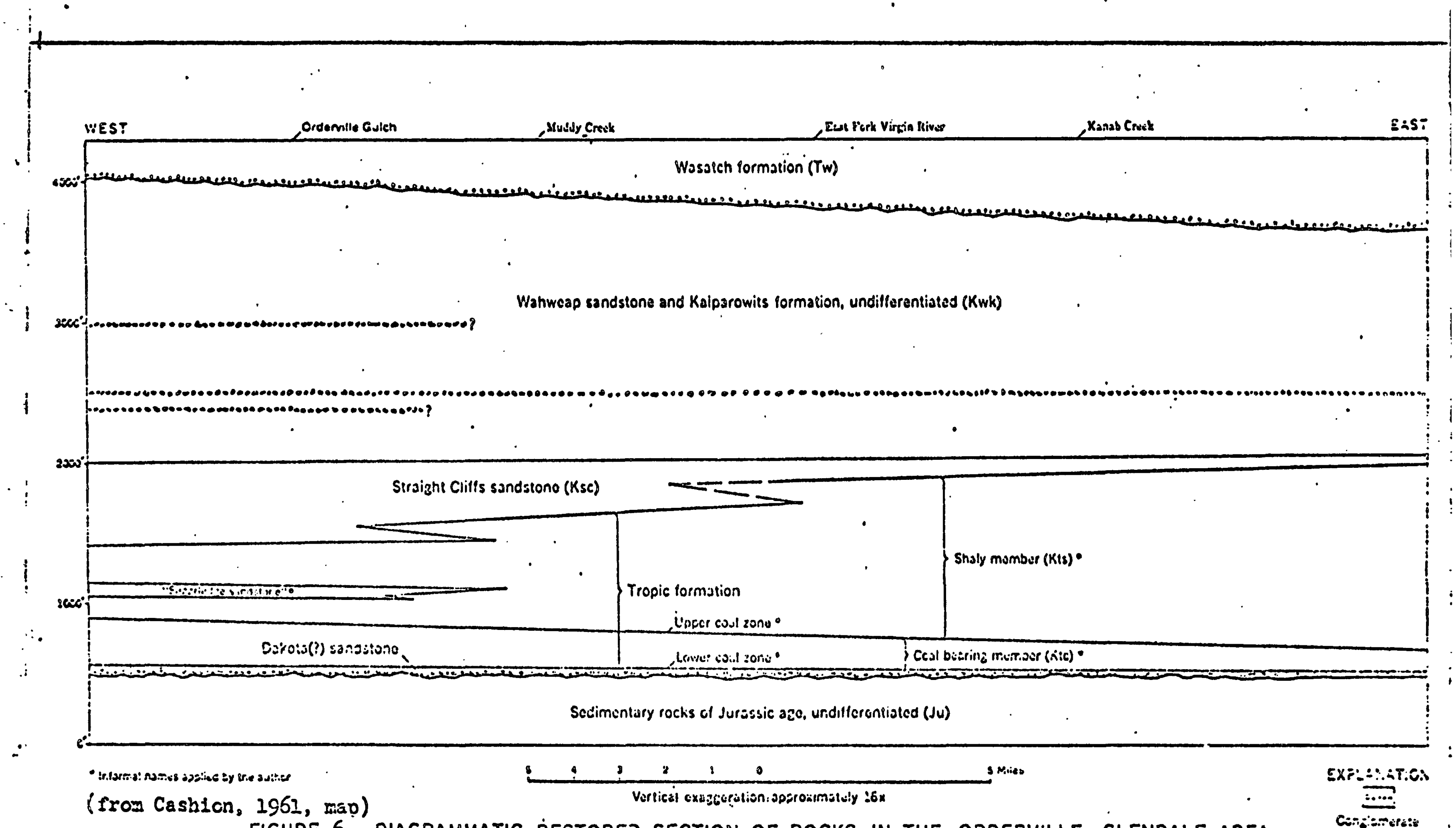
FIGURE 5. DIAGRAMMATIC SECTION OF CRETACEOUS ROCK UNITS AND COAL ZONES OF SOUTH-CENTRAL UTAH

Near Orderville and Glendale in the Kolob field, the major coal zones occur within 50 feet (15 m) of both the top and bottom of the Tropic-Dakota interval. Doelling and Graham (1972, p. 6) named the upper zone the Smirl coal zone and the lower zone the Bald Knoll coal zone. These are the Upper and Lower coal zones as mapped by Cashion (1961 and 1967, maps). The diagrammatic section of stratigraphic relationships of the coal zones and enveloping Cretaceous strata, shown by figure 6, illustrates the stratigraphic changes of the Dakota-

Figure 6.--NEAR HERE

Tropic interval and the Straight Cliffs Sandstone in this area. The coal-bearing member (Ktc) is now called the Dakota Sandstone and the Straight Cliffs Sandstone is recognized as chiefly a lateral equivalent of the Tropic Shale. The Wahweap Sandstone and Kaiparowits Formation, undifferentiated, as shown are incorrectly mapped relative to the Kaiparowits area further east, unless, of course, there are either large intra-Cretaceous erosional surfaces overlapping this area or facies changes of large magnitude exist.

These same stratigraphic conditions continue from the eastern part of the Kolob coal field into the Alton coal field. Both the Smirl and Bald Knoll coal zones occur in the Dakota Sandstone. Above the Dakota-Tropic interval, there is no known data on other coal zones (if they exist) and most of the stratigraphic relationships need to be studied and mapped.



(from Cashion, 1961, map)

FIGURE 6.--DIAGRAMMATIC RESTORED SECTION OF ROCKS IN THE ORDERVILLE—GLENDALE AREA

The coal zones in the Kaiparowits Plateau field are chiefly in the John Henry Member of the Straight Cliffs Formation. Some lenses of coal occur in the Smoky Hollow Member of the Straight Cliffs, and in the Dakota Sandstone, but none of these currently are considered economic. The stratigraphic relationships within the Kaiparowits Plateau have been worked out chiefly by Peterson (1969) and fellow USGS geologists. The relationships of the members of the Straight Cliffs Formation and the coal zones are shown by figure 7. This is an area where coals were

Figure 7.--NEAR HERE

deposited in swamps very close to the shoreline of the Cretaceous sea. There are many transitions from marine to nonmarine strata in this area and consequently thick and numerous beds of coal were deposited in elongate lenses parallel to the shoreline (northwest-southeast). There are four main coal zones within the John Henry Member. In ascending order, they are: Lower coal zone, Christensen coal zone, Rees coal zone, and Alvey coal zone. The zones extend north to south across most of the basin under the Kaiparowits Plateau. They do not, however, apparently crop out on the northwest flank of the basin where only one coal zone is recognized. This is the Henderson coal zone, which appears to be roughly at a stratigraphic position between the Lower coal zone and the Christensen coal zone.

Because of the stratigraphic relationships discussed above, and the general depth of the coal throughout the southern Utah area, few of the coals are considered strippable with present technology.

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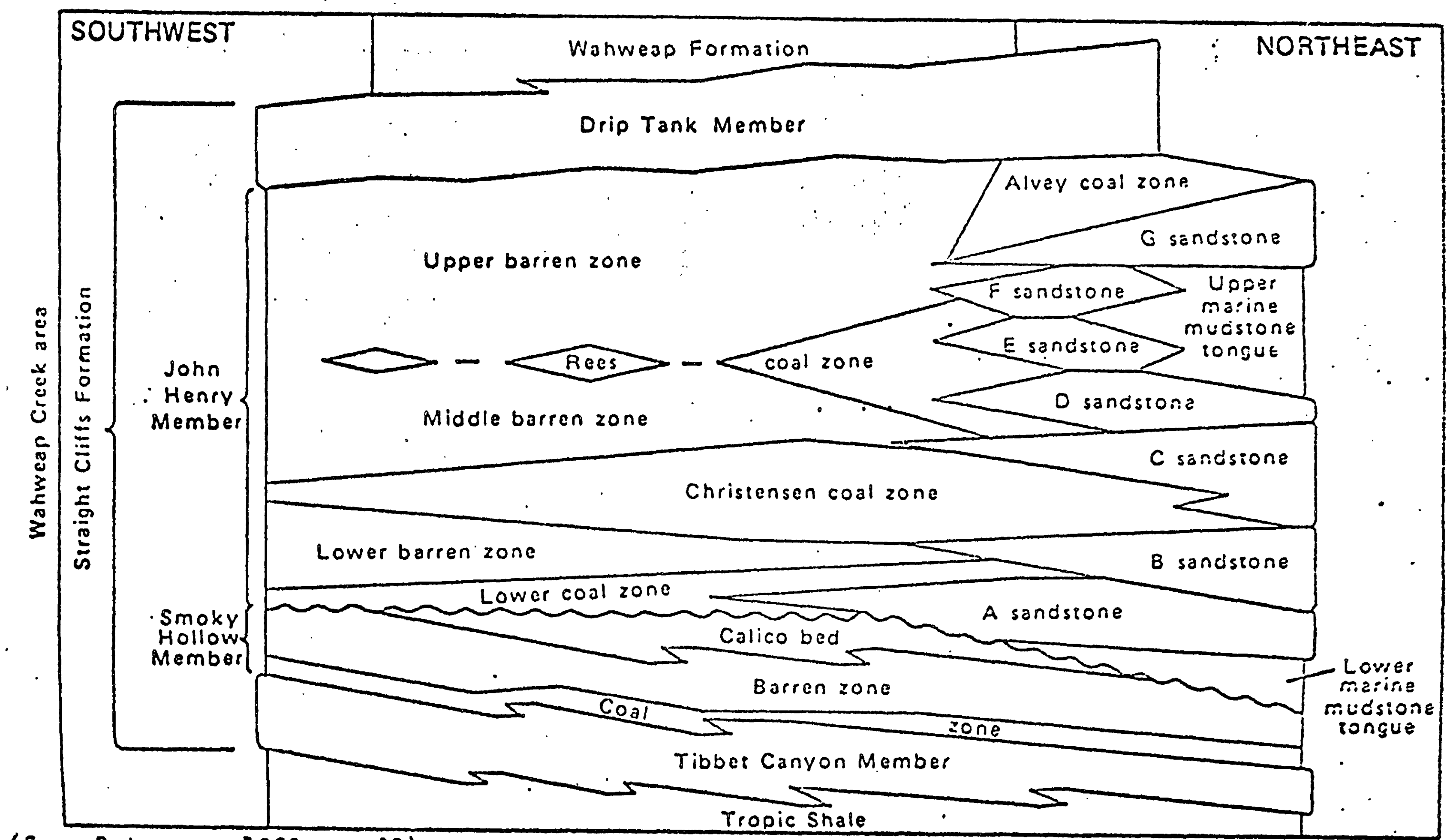

(from Peterson, 1969, p. J8)

Figure 7. Relations of members and informal units in the Straight Cliffs Formation–southeast Kaiparowits Plateau coal field

Quality

The coals of all the zones are generally classified as medium- to high-volatile bituminous. Ash content, sulfur content, and moisture content varies widely. The BTU values also vary widely. Knowledge of these aspects similarly varies greatly from field to field and area to area. None of the coals have coking qualities and most would require mechanical cleaning.

Coals of the Kolob field range in rank from high-volatile bituminous C to subbituminous A. They have generally moderate to high sulfur content, and generally high ash content. A summary of quality is given in table 2. Because of bias in sampling and the limited number of

Table 2.--NEAR HERE

samples, Doelling and Graham (1972, p. 271) believe the sulfur content in the Orderville area is slightly less than that shown. Cannel coal also is present in the Orderville area, but it is of limited extent and is not included in the analyses.

The coals of the Alton field are of subbituminous C to bituminous high-volatile C rank. They have low to moderate sulfur content, but have very high ash content, especially in the lower zone (Bald Knoll) in the eastern part of the field. According to Doelling and Graham (1972, p. 15) most of the samples analyzed were from outcrops and the quality of coal should be better in the subsurface. Most of the samples were from the upper coal zone (Smirl). A summary of quality is given in table 3.

Table 3.--NEAR HERE

Table 2. Quality analyses of coal, Cedar City and Orderville areas, Kolob coal field

	No. of Samples	Percent Average	Percent Range
CEDAR CITY AREA			
Moisture	86	8.2	2.8 -17.3
Volatile matter	86	39.8	33.4 -46.1
Fixed carbon	86	42.3	26.7 -50.3
Ash	87	10.8	3.2 -27.1
Sulfur	67	5.76	1.11- 7.30
Btu/lb	64	10,492	8,480-11,430
ORDERVILLE AREA			
Moisture	9	12.1	4.8 -17.6
Volatile matter	9	40.1	37.0 -46.9
Fixed carbon	9	36.0	27.3 -46.0
Ash	9	11.5	3.9 -23.2
Sulfur	9	2.21	1.10- 4.03
Btu/lb	9	10,344	9,508-11,297

(modified from Doelling and Graham, 1972, p. 271)

Table 3. Quality data for the Alton coal field

	Percent		No. of samples
	Range	Average	
ALTON AREA			
Moisture	13.7-20.6	17.0	13 as-received
Volatile matter	37.5-44.6	40.1	12 dry
Fixed carbon	40.5-54.0	50.3	12 dry
Ash	6.3-14.9	9.4	13 dry
Sulfur	0.5- 2.3	1.3	13 dry
Btu/lb.	10,782-12,329	12,069	12 dry
SKUTUMPAH AREA			
Moisture	12.5-28.3	19.3	11 as-received
Volatile matter	39.2-47.4	43.6	11 dry
Fixed carbon	40.7-53.8	46.7	11 dry
Ash	4.7-14.6	9.8	11 dry
Sulfur	0.46-2.3	1.07	11 dry
Btu/lb.	8,580-11,758	10,166	11 dry
CANNONVILLE AREA			
Moisture	8.8-21.7	15.8	4 as-received
Volatile matter	35.5-40.7	37.9	4 dry
Fixed carbon	37.8-43.5	41.6	4 dry
Ash	15.8-25.7	20.5	4 dry
Sulfur	0.7- 1.2	0.87	4 dry
Btu/lb.	8,080-9,723	8,530	4 dry
ENTIRE COAL FIELD			
Moisture	8.4-28.3	17.4	29 as received
Volatile matter	35.5-47.4	41.2	27 dry
Fixed carbon	37.8-54.0	47.5	27 dry
Ash	4.7-25.7	11.1	28 dry
Sulfur	0.46-2.57	1.15	28 dry
Btu/lb.	8,080-12,329	10,371	27 dry

(modified from Doelling and Graham, 1972, p. 18)

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The coals in the Kaiparowits Plateau field are extremely variable in quality, ranging from subbituminous C to high-volatile bituminous A. Generally, however, these coals are of better quality than the coals in the Kolob and Alton fields. The sulfur content is generally lower and the BTU values tend to be higher. Further, on this comparative basis, the Kaiparowits Plateau coals will require less mechanical cleaning for large-scale usage. In addition, there are several zones and several beds within the zones and extreme variation could be normal in the Kaiparowits Plateau field. The coals in the Christensen zone tend to be of higher quality than the coals of the Alvey zone (the two major coal zones). Analyses of the coals in the Kaiparowits Plateau field given in table 4 are for samples about one-half of which came from

Table 4.--NEAR HERE

surface outcrops or old mine samples (Doelling and Graham, 1972, p. 93).

Resources

The coal beds of south-central Utah presently are relatively undisturbed by mining. Most of the now abandoned mines produced coal for local uses and where the mines were larger, in the Cedar Mountain area of the Kolob field, production was only some tens of thousands of tons. Faults, steep dips, and great depths are limiting geologic factors, but the area is large and many places suitable for mining exist.

Table 4. Quality data for the Kaiparowits Plateau coal field

	Percent		
	Range	Average	No. of analyses
KAIPAROWITS PLATEAU COAL FIELD (all areas)			
Moisture	3.60-28.70	11.33	137 as-received
Volatile matter	21.92-57.38	43.63	164 dry
Fixed carbon	22.81-71.51	47.25	164 dry
Ash	3.38-33.03	8.96	165 dry
Sulfur	0.26- 3.40	0.87	129 dry
Btu/lb	8,499-14,236	11,999	161 dry
SMOKY MOUNTAIN AREA COAL			
Moisture	3.70-24.20	9.63	77 as-received
Volatile matter	21.92-57.38	42.44	91 dry
Fixed carbon	22.81-71.51	48.70	91 dry
Ash	3.60-19.80	8.59	91 dry
Sulfur	0.26- 1.50	0.75	91 dry
Btu/lb	10,736-13,746	12,401	91 dry
ESCALANTE AREA COAL			
Moisture	3.60-24.80	10.51	40 as-received
Volatile matter	37.47-57.49	45.39	53 dry
Fixed carbon	38.49-53.59	46.81	53 dry
Ash	3.38-24.89	7.80	54 dry
Sulfur	0.42- 3.40	1.26	24 dry
Btu/lb	8,499-14,236	11,563	53 dry
TROPIC AREA COAL			
Moisture	9.36-28.70	19.50	20 as-received
Volatile matter	35.73-48.03	44.42	20 dry
Fixed carbon	31.23-47.07	41.81	20 dry
Ash	7.71-33.03	13.77	20 dry
Sulfur	0.60-1.73	0.98	14 dry
Btu/lb	8,826-12,699	11,207	17 dry

(from Doelling and Graham, 1972, p. 93)

The coal resource data for south-central Utah (taken from Doelling and Graham, 1972) can be considered for practical purposes estimates of coal in place (nonmined). The resource data, in addition, generally fits into the more comprehensive classification of Averitt (figure 8)

Figure 8.--NEAR HERE

as data of unidentified and undiscovered-hypothetical economic coal resources. Subeconomic coal resources were not considered and undiscovered-speculative coal resources could not be considered. The terms and definitions used here are from Doelling and Graham but Averitt's definitions are added in parentheses. Averitt's definitions are as follows:

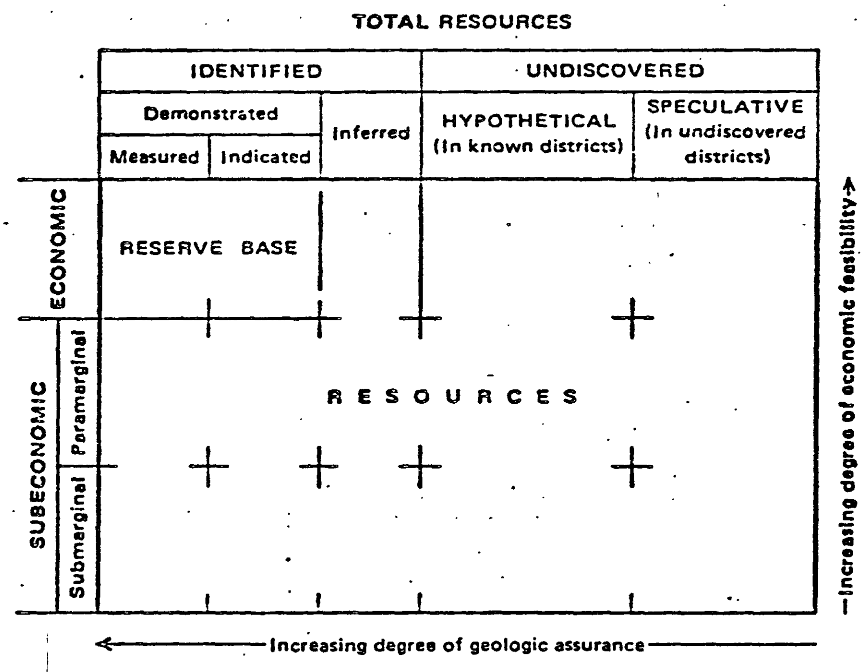

Figure 8. Diagram showing classification of total coal resources based on geologic knowledge and economic factors (from Averitt, 1974, p. 3).

(1) Demonstrated resources--combined measured and indicated categories.

(2) Measured resources--tonnage of coal in ground based on assured coal-bed correlations and on closely spaced observations about one-half mile apart.

(3) Indicated resources--tonnage of coal in ground based partly on specific observations and partly on reasonable geologic projection. The points of observation and measurement are about 1 mile apart but may be 1 1/2 miles apart for beds of known continuity.

(4) Inferred resources--tonnage of coal in ground based on an assumed continuity of coal beds downdip from adjoining areas containing measured and indicated resources. In general, inferred coal lies 2 miles or more from outcrops or from points of precise observation.

(5) Hypothetical resources--estimated tonnage of coal in the ground in unmapped and unexplored parts of known coal basins to an overburden depth of 6,000 feet; determined by extrapolation from nearest areas of identified resources.

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Doelling and Graham (1972, p. 251) estimate the Kolob field to extend along outcrop for about 32 miles (59 km) at an average width of 12 miles (22 km). This comprises about 384 square miles (995 sq km) of coal less than 3,000 feet (915 m) below surface. The resource figures given in table 5 are in beds with mostly less than 2,000 feet

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Table 5.--NEAR HERE

(610 m) of overburden (Doelling and Graham, 1972, p. 278). These resources are in the two coal zones of the Tropic-Dakota interval, Upper coal zone of Cashion (1961) (Culver of Averitt, 1962) and the Lower coal zone of Cashion. Resource estimates are limited to beds more than 4 feet (1.2 m) thick. The coal bed in the upper zone averages 5 to 6 feet (1.5-1.8 m) thick in the Orderville area and averages 5.5-6.5 feet (1.7-2.0 m) in the Cedar City area. The larger resources are in this zone. Most of the resource data are based on outcrop measurement and the surface mapping by Averitt (1962) and Cashion (1961), and lacks the greater precision of drill-hole data.

Table 5. Coal resources in the Kolob coal field (in short tons)

Identified	Class I (Demon-strated)	Measured reserves	Based on adequate exploration and development data, properly correlated.
Identified	Class II (Demon-strated)	Indicated reserves 708,710,000[1]	Based on geologic measurement supplemented by limited drill-hole information and limited to 1½ miles from a control point.
Identified	Class III	Inferred reserves 1,305,590,000	Based on geologic inference and projection of the habit of the coal beyond 1½ miles from control points.
Undiscovered	Class IV	Potential (hypothetical) reserves 1,305,000,000	Based on geographic and geologic position with little supporting data and includes coal up to 3,000 feet of cover.
	Total	2,014,300,000	

[1]Includes a small amount of Class I reserve.

(modified from Doelling and Graham, 1972, p. 278)

9.1267

Coal resources in the Alton field extend along U-shaped outcrop for about 35 miles (63 km) and are 4-6 miles (7.2-10.8 km) wide. The coal resources lie in the two coal zones of the Dakota Sandstone. The upper zone, the Smirl, contains the larger resource. The coal beds of the lower zone, the Bald Knoll, are badly split and the beds are very lenticular. Average coal thickness of the upper zone is more than 12 feet (3.7 m) in the Alton area and thins eastward to less than one foot in the Cannonville area. Thickness of coal beds in the lower zone is 5-6 feet (1.5-1.8 m) in the Alton and Skutumpah areas, though sometimes badly split, but it may be 8-10 feet (2.4-3.1 m) in localities of the Cannonville area. Doelling and Graham (1972, p. 15) believe about 20.8 percent of the resource of the Alton field might be suitable for strip-mining. The suitable sites are in the Alton and Skutumpah areas. About one-half of the resources are under less than 1,000 feet (305 m) of cover. Most of the resource data in table 6 are based on

Table 6.--NEAR HERE

geologic work done by Cashion (1961, 1967) and unpublished data of the Utah Geological and Mineralogical Survey.

Table 6. Coal resources in the Alton coal field (in short tons)

Identified	Class I (Demonstrated)	Measured reserves	–based on adequate exploration and development data, properly correlated.
Identified	Class II (Demonstrated)	Indicated reserves 643,800,000 tons[1]	–based on geologic measurement supplemented by limited drill-hole data and limited to 1½ miles from a control point.
Identified	Class III	Inferred reserves 865,600,000 tons	–based on geologic inferrence and projection of the habit of the coal beyond 1½ miles from control points.
Undiscovered	Class IV	Potential (hypothetical) reserves 639,500,000 tons	–based on geographic and geologic position with little supporting data and includes coal up to 3,000 feet of cover.
	Total	2,148,900,000 tons	

[1]Includes a small amount of Class I reserves.

(modified from Doelling and Graham, 1972, p. 18)

The coal resources in the Kaiparowits Plateau field occur chiefly in the Alvey and Christensen coal zones but significant resources also occur in the Rees zone. Most of the known coal resources are in the Smoky Mountain and Escalante areas, but recent detailed investigations by U.S. Geological Survey geologists and private companies in these and other areas should increase the estimate of resources, perhaps substantially. Great depths and steep structures limit the northward extent of resources. The coal has been extensively burned along the outcrop, especially in the southeastern part of the field, thereby reducing the resources. The coals occur in a northwest-trending belt 18-25 miles (29-40 km) wide. Within this belt, beds up to 25 feet (7.5 m) thick have been measured and total thickness of beds at several locations exceed this. However, total thickness may locally have been measured in coal beds over a 300-400-foot (90-120 m) vertical span and the total thickness may not mean the addition of significantly recoverable coal. The resources given in table 7 are of beds over 4 feet (1.2 m) thick. Most of the data pertains

Table 7.--NEAR HERE

to the coal beds in the Christensen zone. Much of the data are based on published work by several U.S. Geological Survey geologists--Bowers (1968a, 1968b), Peterson (1967), Peterson and Horton (1966), Peterson and Waldrop (1966), Waldrop and Peterson (1967), Waldrop and Sutton (1966, 1967a, 1967b), and Zeller (1967a, 1967b, 1967c, and 1969). Other published work was done by Doelling (1967, 1968). Most of the data in the Tropic area are based on work by Robison (1966), who mapped the Henderson coal zone in the area of Tropic.

Table 7. Coal resources in Kaiparowits Plateau coal field (in short tons)

Identified	Class I (Demon-strated)	Measured reserves	Based on adequate exploration and development data, properly correlated.
Identified	Class II (Demon-strated)	Indicated reserves 3,984,800,000[1]	Based on geologic measurement supplemented by limited drill-hole information and limited to 1½ miles from a control point.
Identified	Class III	Inferred reserves 3,893,200,000	Based on geologic inference and projection of the habit of the coal beyond 1½ miles from control points.
Undiscovered	Class IV	Potential (hypothetical) reserves 7,320,000,000	Based on geographic and geologic position with little supporting data and includes coal up to 3,000 feet of cover.
	Total	15,198,000,000	

[1]Includes a small amount of Class I reserve.

(modified from Doelling and Graham, 1972, p. 102)

9.1267

Oil

Central and eastern parts (Kaiparowits region)

The first oil well to be drilled in the central and eastern parts of the report area was a dry hole by the Ohio Oil Company in 1921 in the Circle Cliffs anticline. No shows of oil or gas were encountered. In 1930, Midwest Exploration Company drilled a dry hole on a closed anticline at Butler Valley. Between 1949 and 1965, 30 wildcat wells were drilled in the region at the rate of several each year (except in 1950, 1953, and 1959 when none were drilled). Shows of oil were first discovered in the area in 1948 on the Upper Valley anticline by the California Company (now Chevron). No production resulted from the rocks of these shows (Mississippian), even though testing continued until 1951. It was not until 1964, when Tenneco Oil Company found oil in the Kaibab Formation, that the Upper Valley field became commercial. Up to that time 27 dry holes had been completed by various companies in the Kaiparowits region (Kunkel, 1965, and fig. 9). Oil is now being

Figure 9.--NEAR HERE

produced from porous zones in the Kaibab and Timpoweap (lowest member of the Moenkopi Formation) limestones of Permian age at depths between 6,700 and 7,700 feet (2,233 and 2,566 m). The oil is brownish black, asphaltic-base crude, 27° (API) with 1.75 percent sulphur content (Ritzma, 1970). Production at the Upper Valley field in October 1965 was 142,263 barrels from 16 wells, an average of 4,590 barrels per day for the field and 287 barrels per day per well. By 1972 the volume

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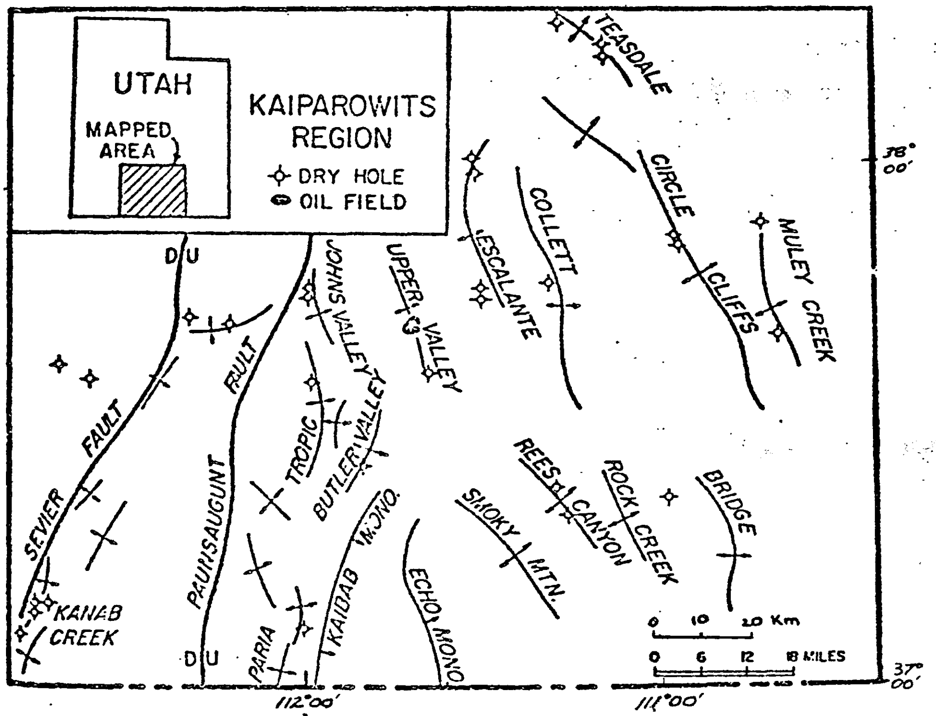

Fig. 9. —Generalized anticline and fault map of the Kaiparowits region showing distribution of dry holes (from Kunkel, 1965)

amounted to 7,900 barrels of oil per day, and wells averaged about 320 barrels of oil per day. Twenty-two producing wells had yielded 1.95 million barrels and the field had cumulatively produced 6.86 million barrels of oil. As of June 1974, 12.47 million barrels had been produced from this field.

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Exploration in other areas of the plateau region has not been productive thus far, nor have commercial quantities of natural gas been found (U.S. Bur. of Land Management, 1976).

Western part

Although no oil has been found to date in the western part of the study area, oil was discovered in 1907 at the nearby Virgin field on North Creek about 10 miles (16 km) northwest of Zion National Park (fig. 10). Production was from the Triassic Moenkopi Formation at about

Figure 10.—NEAR HERE

500 feet (170 m) depth. By 1938, 125 exploratory wells had been sunk along North Creek and in neighboring areas. Although 199,569 barrels of oil were produced at the Virgin field through 1962 an examination of cost versus production as early as 1935 showed the area to be commercially unprofitable (E. W. Henderson, U.S.G.S., Oil and Gas Leasing Division records, 1935).

Asphalt

In the Circle Cliffs area the lowermost beds of the Shinarump Member of the Chinle Formation locally contain asphalt, which generally occurs as disseminated brown specks but locally is so abundant that brownish-black liquid asphalt seeps out along the contact with the Moenkopi. Locally where asphalt occurs in the Shinarump Member some has penetrated into the upper few feet of the Moenkopi (Davidson, 1967, p. 69). Wood and Ritzma (1972, p. 10) report asphalt from vugs in the Kaibab Limestone, also in the Circle Cliffs area. There has been no commercial production of asphalt at Circle Cliffs or elsewhere in south-central Utah.

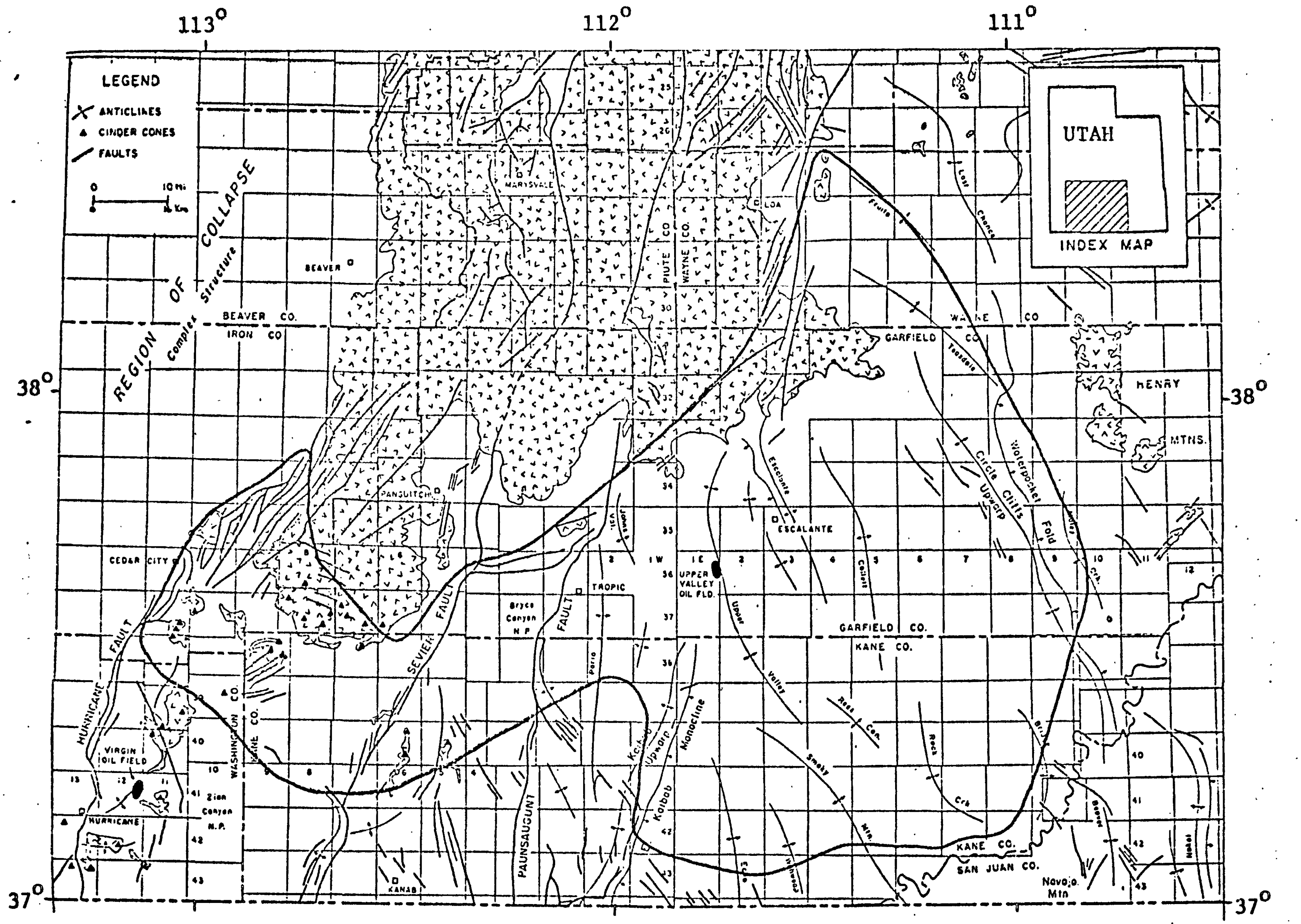

Figure 10. Tectonic map of south-central Utah showing location of the Virgin and Upper Valley oil fields. Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop. Modified from Stokes and Heylmun (1965).

Metallic Mineral Deposits

Copper

Copper deposits in south-central Utah generally are associated with uranium and vanadium. They occur mostly in fluvial Triassic sandstone and conglomerate, especially the Shinarump Member of the Chinle Formation. The ore minerals fill pores in the host rock and locally replace fossil wood fragments and detrital grains. Copper deposits are mostly in channels cut into the underlying rock and are lenticular or tabular. Minor copper deposits are reported in Wayne County at Miners Mountain (Capitol Reef area) where oxidized copper minerals (malachite, azurite) occur in channels in Chinle sandstone (Finch, 1959, p. 152; U.S. Geol. Survey, 1969, p. 70, 83; Butler and others, 1920, p. 632) (fig. 11).

Figure 11.--NEAR HERE

Elsewhere prospecting for copper in the Moenkopi, Chinle, and Navajo Formations has been carried out at a number of places in the Paria Valley and in Tertiary beds around the Aquarius Plateau (Gregory and Moore, 1931, p. 148); however, no deposits of commercial value were found in any of the rocks.

Iron

Although no iron deposits are known within the study area they are briefly discussed here because they do occur nearby and constitute a significant part of the mineral resources of south-central Utah. Additional buried reserves could exist within the study area.

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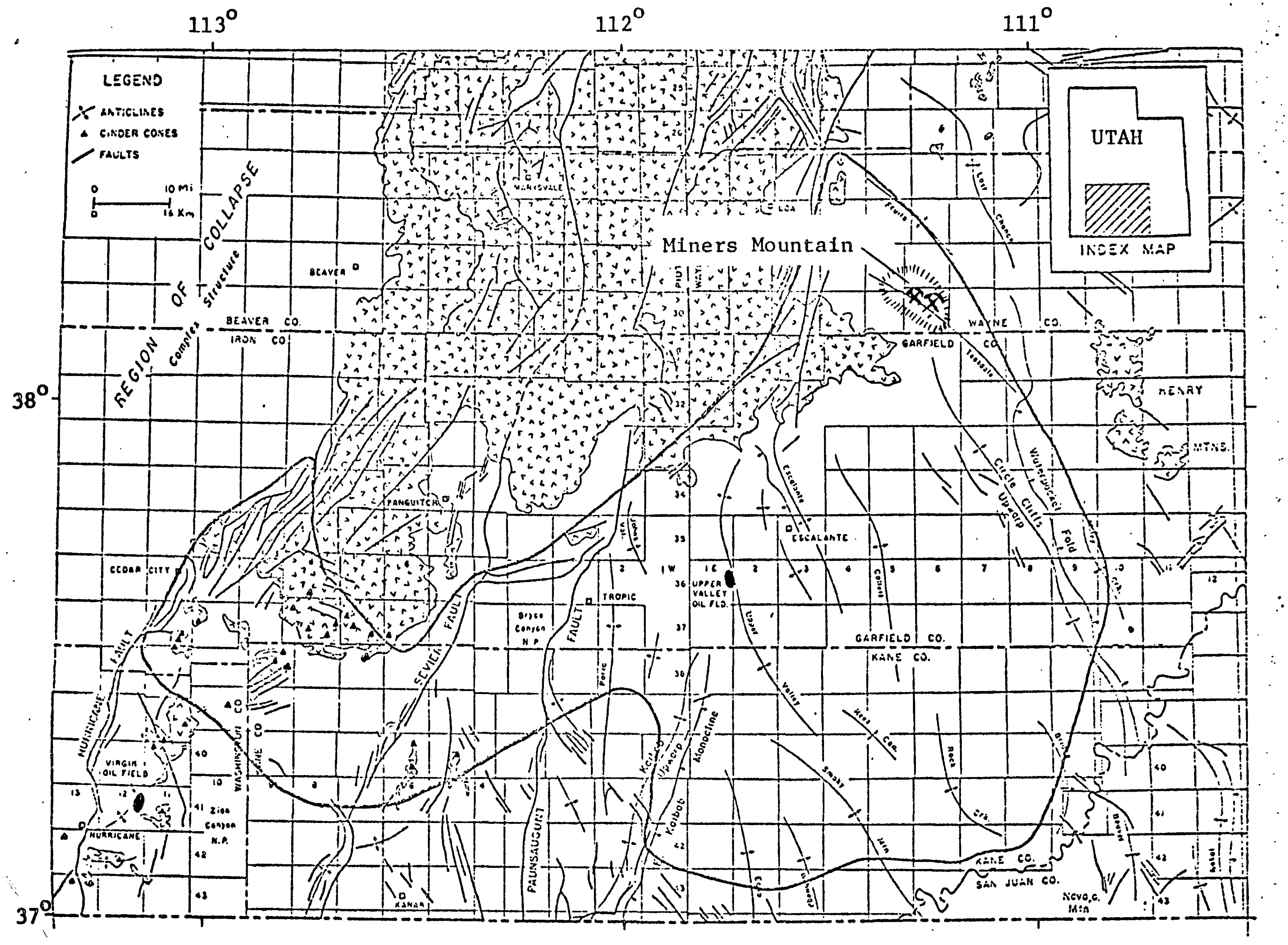

Figure 11. Tectonic map of south-central Utah showing location of Miners Mountain and two copper prospects (base and tectonic map from Stokes and Heylmun, 1965). Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop.

Most of the iron ore produced in Utah comes from the Iron Springs district, about 10 miles (16 km) west of Cedar City (fig. 12). Here

Figure 12.--NEAR HERE

hematite and magnetite occur as replacement bodies and veins in the Jurassic Homestake Limestone Member of the Carmel Formation. Ore bodies are clustered around three quartz monzonite intrusives.

Iron ore was discovered at Iron Springs in 1849. It has been intermittently exploited since 1852, and continuously exploited since 1924 on a large scale for blast furnaces at Ironton and later at Geneva near Provo, Utah. By 1962, 67 million long tons of iron ore had been produced with a value of $313 million. Large reserves are still present.

Additional reserves are known east of Paragonah where massive magnetite occurs as replacement bodies in intrusive volcanic rock (U.S. Geol. Survey, 1969, p. 89-96).

Gold

Between 1910 and 1913 an attempt was made to recover very fine grained, widely distributed gold flakes from the Chinle and Moenkopi Formations on the Paria River at Lees Ferry (south of area shown in Plate 1) and Paria by hydraulic mining. The planning for such a venture was considerable and much money was invested in assays and equipment. Eventually work began but because the area was so remote and the difficulty and expense in recovery so great, work was discontinued in 1913 (Gregory and Moore, 1931, p. 148).

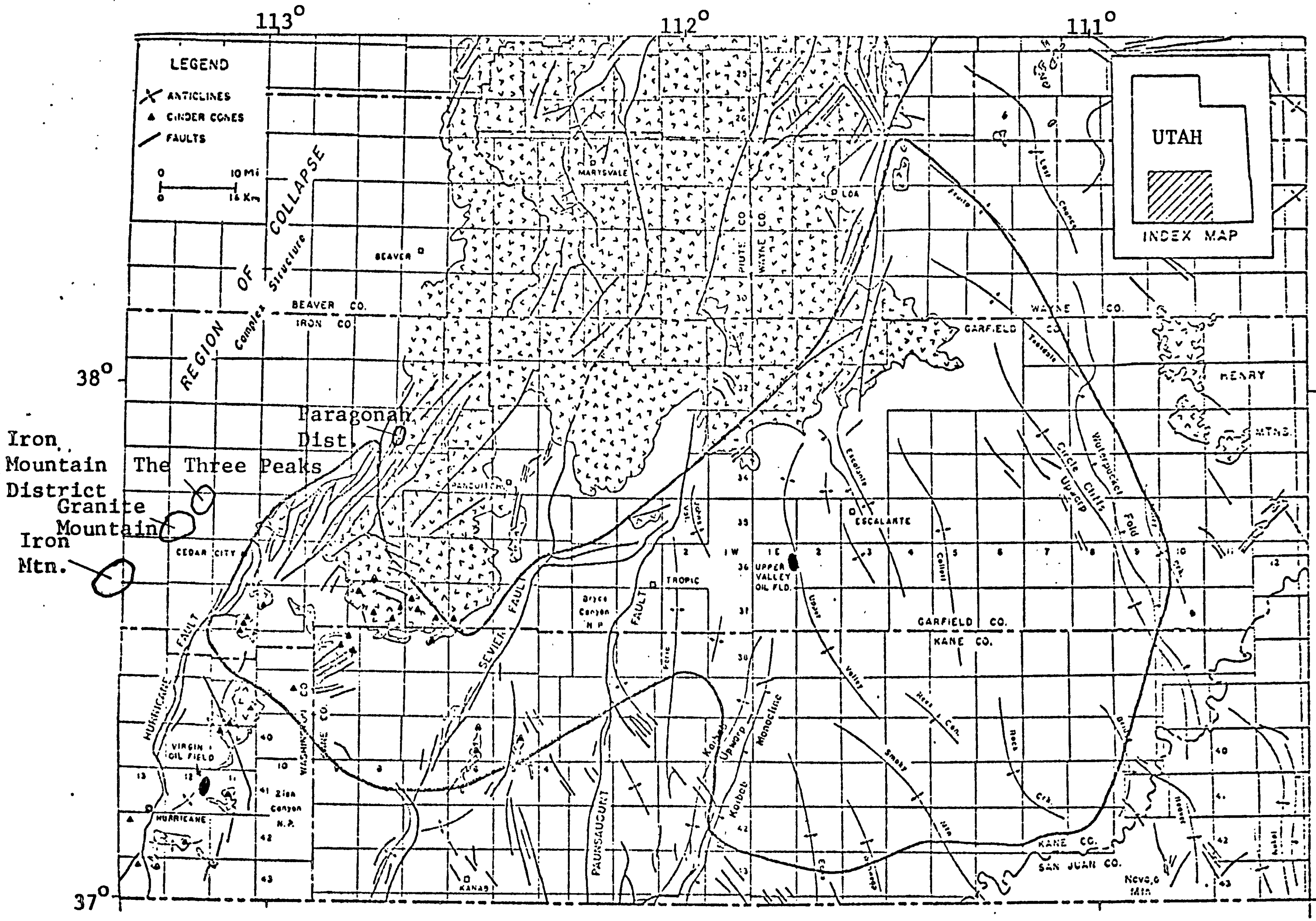

Figure 12. Tectonic map of south-central Utah showing location of Iron Springs and Paragonah iron districts. Iron Springs district is comprised of three stocks; Iron Mountain, Granite Mountain, and The Three Peaks (base and tectonic map from Stokes and Heylmun, 1965). Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop.

9.1267

Manganese

Although manganese deposits occurring as thin veins, nodules, and impregnations of oxides are known in sedimentary rocks at several localities in south-central Utah the low concentration and cost of milling make it unlikely that they will ever be productive, except during periods of artificial price supports (U.S. Geological Survey, 1969, p. 103-108; Davidson, 1967, p. 91-92).

Titanium, zirconium, thorium and rare earths

Minerals containing titanium, zirconium, thorium, and rare earths are found in paleo-placer deposits in which monazite, ilmenite, leucoxene, zircon, and other heavy minerals have been concentrated. The paleo-placers are in Late Cretaceous sandstones and they probably formed from the weathering of igneous and metamorphic rocks. Such placers are known in the Straight Cliffs Sandstone and Ferron Sandstone Member of the Mancos Shale, but none appear to have commercial significance at the present time because of the extremely fine grain size and the varying degrees of alteration of the minerals (U.S. Geological Survey, 1969, p. 115-120).

Uranium

The uranium deposits of south-central Utah are small and of low grade. Of the numerous scattered occurrences in south-central Utah only those in the Circle Cliffs and Capital Reef areas constitute deposits which might be of future interest. The interested reader should consult Map 36 of the Utah Geological and Mineralogical Survey (1975) for additional localities of minor occurrences.

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In the Circle Cliffs area most of the larger deposits are in the uppermost Moenkopi Formation on the edges of channels filled with sandstone of the Shinarump Member of the Chinle Formation. Uranium also occurs in the Salt Wash Sandstone Member of the Morrison Formation where the rock changes from massive thick-bedded to a thinner bedded lenticular sandstone. The primary uranium mineral in the Shinarump and Moenkopi probably is uraninite (Davidson, 1967).

The Moenkopi is always slightly radioactive in a zone a few inches to one foot thick adjacent to the Shinarump channel contact, but mineable concentrations of uranium occur only in irregular elongate ridges, probably former streambanks, that extend as much as a few feet above the channel. This type of deposit is shoestring-shaped in plan view and represents a very small drilling target. The mined bodies are exposed at the surface and were small enough to be mined profitably by 2 or 3 men. The Rainy Day, Stud Horse, Yellow Jacket, and Sneaky-Silver Falls prospects are typical of this type (Davidson, 1967).

Deposits near the base of the Morrison Formation are confined to the lowermost sandstone unit of the Salt Wash Member. Uranium is evenly disseminated in a 3-4-foot (1-1.3 m)-thick sandstone bed that contains abundant small pieces and flakes of charcoaly wood.

Locally uranium has been redeposited along fault surface; however, these are not large deposits and the grade is far below mining quality.

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In places large charcoaly and silicified logs in beds near the base of the Petrified Forest Member of the Chinle Formation are heavily impregnated with carnotite. Most of the mineralized logs have been found on the west side of the Circle Cliffs area. This type of occurrence, however, is not mineable (Davidson, 1967; Finch, 1959).

Minor occurrences of uranium are also found in the Wingate sandstone. Deposits appear to be the result of ground-water redeposition along fractures (Finch, 1959).

Lead

Minor amounts of lead occurring as cerussite and plumbojarosite are associated with the small copper deposits found at Miners Mountain. (See discussion on copper, this report; Butler and others, 1920, p. 632.) No lead has been produced from south-central Utah.

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Antimony and arsenic

Antimony minerals (stibnite, mainly) occur as veinlets, irregular masses, and disseminations in and near faults and fractures in argillaceous sandstone and conglomerate of the Paleocene Flagstaff Limestone at Antimony Creek (also known as Coyote Creek) in northwestern Garfield County (a few miles west of the study area) (fig. 13). Although

Figure 13.--NEAR HERE

production between 1880 and 1917 was sporadic, 1,200 tons of hand sorted ore containing 600 tons of stibnite was mined. Commonly deposits occur as layerlike irregular bodies a few inches (several centimeters) thick. The larger lenslike deposits have been mined out and no sizeable bodies of stibnite are known to remain. Large quantities of low-grade ore are still present at Antimony Creek and at several small deposits about 5 miles (8 km) to the north. An excellent discussion of the antimony deposit is presented by Callaghan (1973).

Small quantities of arsenic minerals (realgar, orpiment) have been found contiguous to the antimony deposits but not immediately associated with them. They are not commercially mineable (Butler and others, 1920, p. 561-563; U.S. Geol. Survey, 1969, p. 138-140).

Selenium and other metalliferous occurrences

Selenium is reported associated with carnotite from the Salt Wash Member of the Morrison Formation in the Circle Cliffs area (Davidson, 1967, p. 92). Various other metals occurring in minor (but detectable) amounts and associated with uranium include cobalt, vanadium, and arsenic (Finch, 1959).

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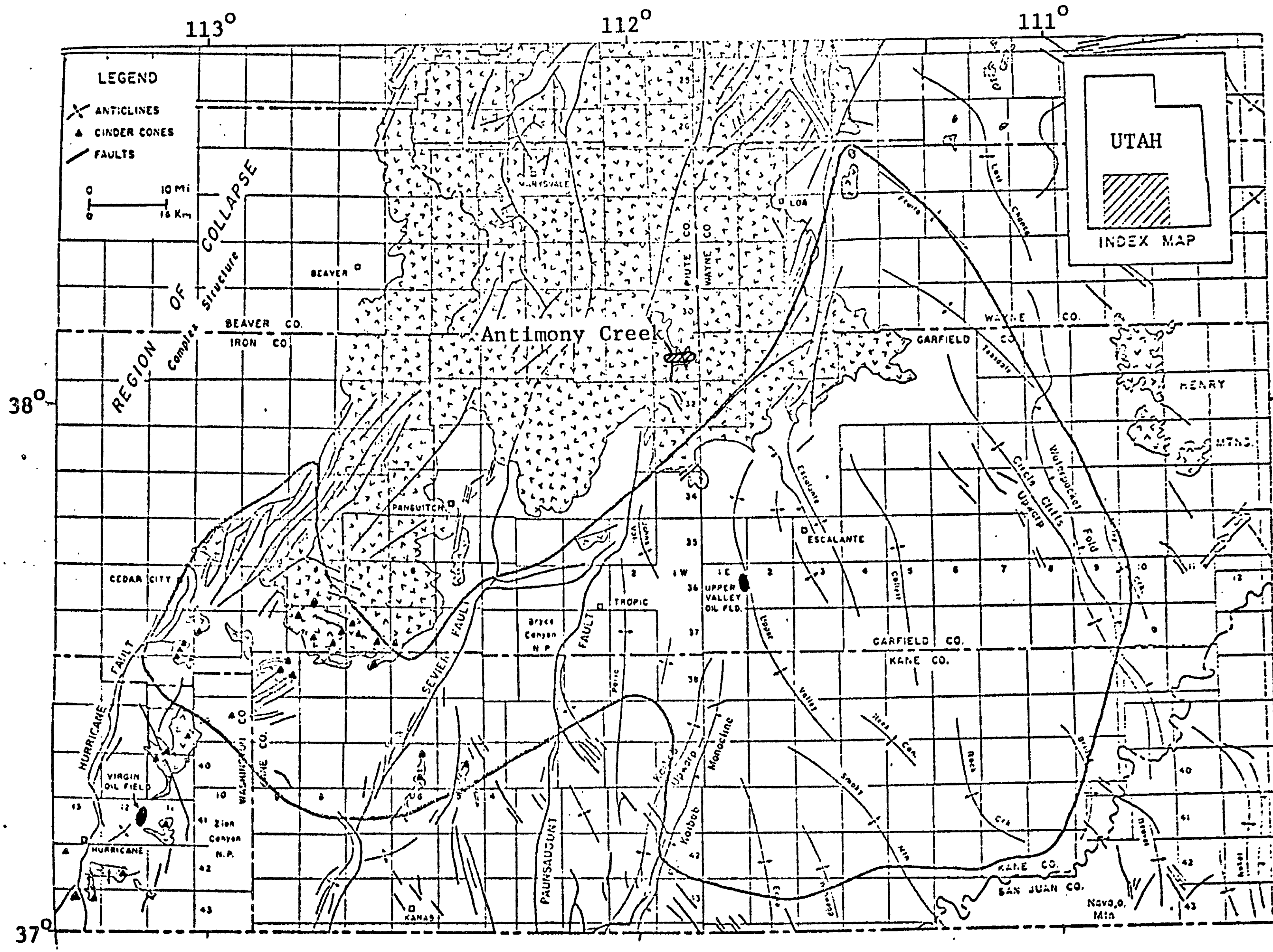

Figure 13. Tectonic map of south-central Utah showing location of antimony deposits (hachured) at Antimony Creek (base and tectonic map from Stokes and Heylmun, 1965). Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop.

Nonmetallic and industrial minerals and material resources

Clay

Clays suitable for use in low-heat refractory products are present in the Straight Cliffs (fig. 14, loc. 1) and Dakota (Cretaceous) sandstones

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Figure 14.--NEAR HERE

(fig. 14, loc. 2) west of Escalante and the Dakota at the Barney deposits (fig. 14, loc. 3) in northern Garfield County (near the Waterpocket fold). The latter are the highest grade refractories of sedimentary origin in Utah and are considered to be of significant economic importance (Van Sant, 1964).

Common clays and bentonitic mudstones suitable for drilling mud, canal sealing, and the bonding of molding sand have been found in the Tropic-Dakota formation near Tropic and Henrieville and have been mined and processed north of Cannonville (fig. 14, loc. 4) in Garfield County (U.S. Geol. Survey, 1969, p. 160; U.S. Bur. of Land Management, 1976, p. 11-99).

Gem materials

The most common gem minerals occurring south-central Utah are agate, jasper, petrified dinosaur bone, petrified wood, and green onyx marble. Excellent red and yellow moss agate are reported present in the area surrounding Cedar Breaks National Monument (fig. 15, loc. 30).

Figure 15.--NEAR HERE

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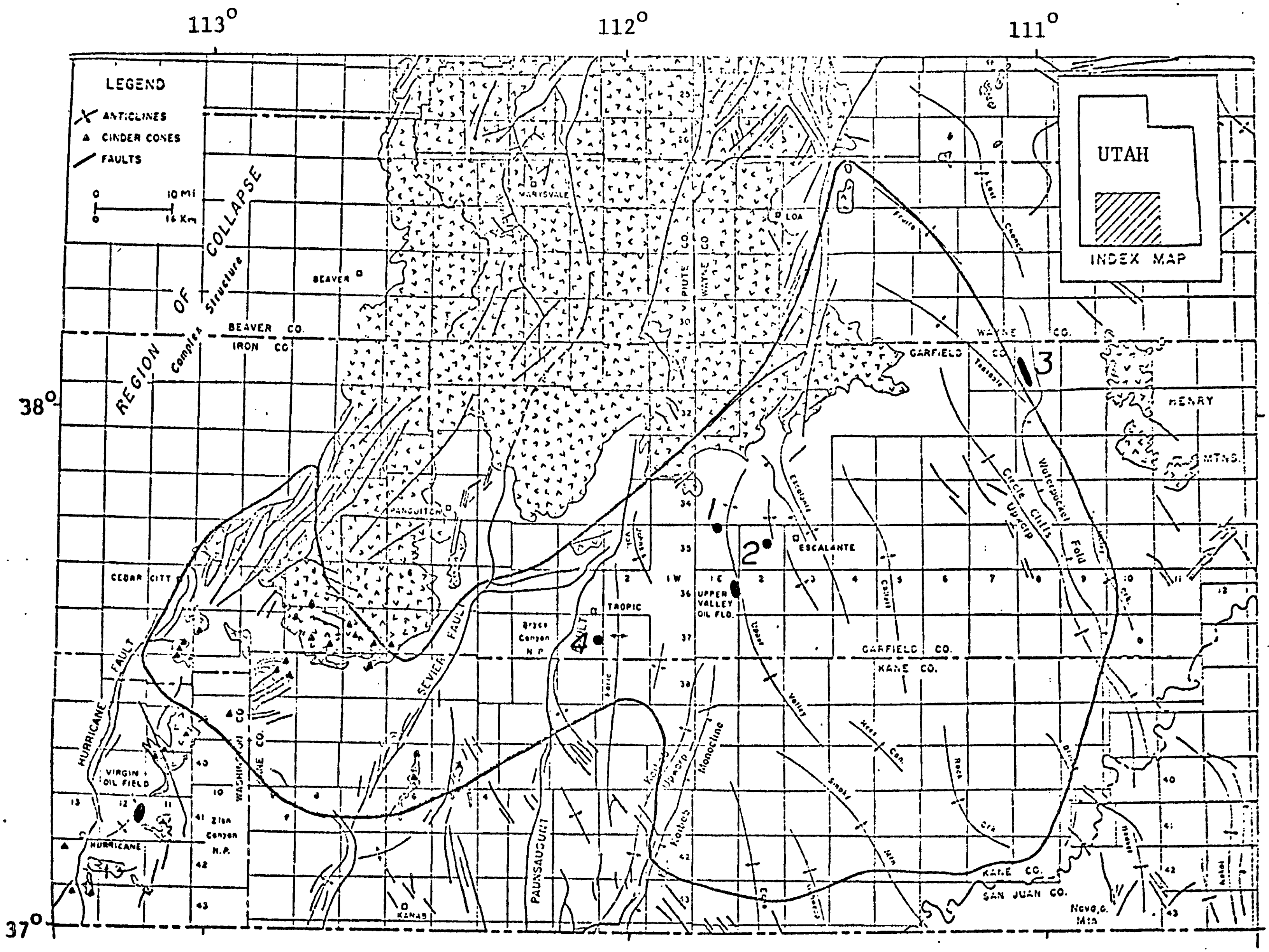
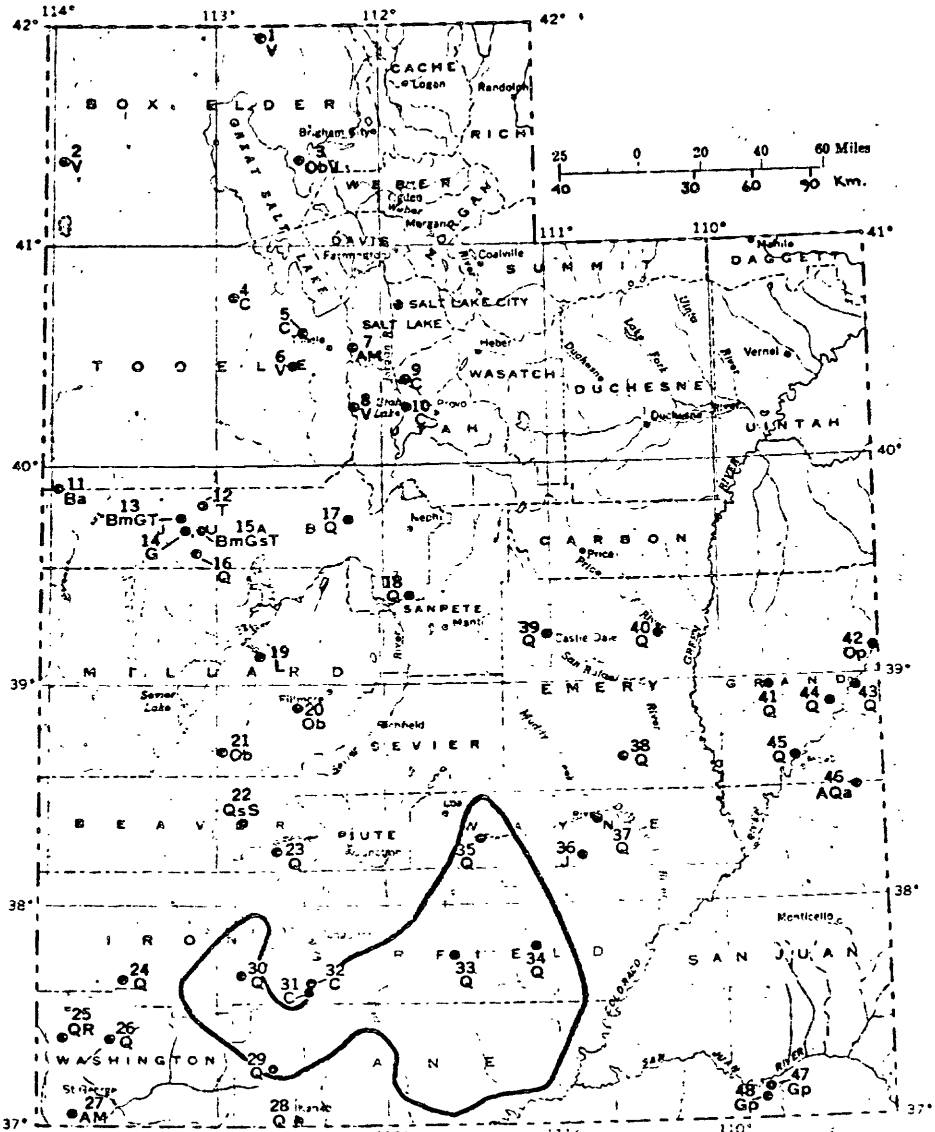


Figure 14. Tectonic map of south-central Utah showing locations of clay deposits (numbered). Localities are described in text. Base and tectonic map from Stokes and Heylmun (1965). Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop.



EXPLANATION

● Deposit of gem material (Numbers refer to localities mentioned in text)

A	Azurite	Q	Cryptocrystalline quartz (One or more varieties: agate, chalcedony, jasper petrified wood, dinosaur bone)
Ba	Aquamarine	Qa	Amethyst
Bm	Morganite	Qs	Smoky quartz
C	Calcite, referred to as "onyx"	R	Banded rhyolite
G	Garnet, unspecified	S	Scheelite
Gp	Pyrope	T	Topaz
Gs	Spessartite	V	Variscite
J	Jet		
L	Labradorite		
M	Malachite		
Ob	Obsidian		
Op	Opal		

Fig. 15--Gem materials in Utah. Heavy line is boundary of area of this report. Numbered localities in study area are described in text (from U. S. Geol. Survey, 1969, p. 171).

Petrified wood has been reported in the vicinity of Kanab (fig. 15, loc. 28) and agate and petrified wood are present near Orderville (fig. 15, loc. 29). Agate, agatized wood, and dinosaur bone are reported from the vicinity of Escalante (fig. 15, loc. 33). Petrified logs, some measuring from 10-12 feet (3.5-4 m) in diameter are abundant in the Circle Cliffs area (fig. 15, loc. 34).

Most of the petrified wood occurs in the Triassic Petrified Forest and Shinarump Members of the Chinle Formation. Dinosaur bones, replaced by varieties of quartz, occur in the Jurassic Brushy Basin Member of the Morrison Formation.

Translucent green onyx marble has been quarried at Hatch (fig. 15, loc. 32) and on Mammoth Creek (fig. 15, loc. 31) in southwestern Garfield County (U.S. Geol. Survey, 1969, p. 173-175).

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Gypsum

Utah has an abundant supply of gypsum; its resources are among the largest in the United States. In the study area large deposits are known, although none have ever been commercially mined. By far the most extensive gypsum deposits are in the Curtis Formation of Jurassic age. According to Cashion (1967) this unit is the gypsiferous member of the Carmel Formation of Middle and Upper Jurassic age. The formation crops out discontinuously from Cedar City southward into Washington County and eastward into Kane County. A basal gypsum bed in the Curtis ranges in thickness from less than 6 feet (2 m) to as much as 101 feet (34 m) in the crest of anticlines. An exposure in Cedar Canyon (fig. 16, loc. 33) showed 101 feet (34 m) of massive resistant white alabaster

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Figure 16.—NEAR HERE

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apparently in one bed. About 4 miles (6 km) east of Kanarraville (fig. 16, loc. 34), Gregory (1950b, p. 126) reported about 92 feet (31 m) of gypsum mixed with clay (U.S. Geol. Survey, 1969, p. 184).

In the northeast corner of Washington County (fig. 16, loc. 35), the gypsum in the Curtis has thinned to about 6 feet (2 m), is white to gray and contains lenses of red silt (Gregory, 1950b, p. 89). Southward in Washington County, the gypsum thickens to 15 feet (5 m). In an exposure 11 miles (18 km) west of Orderville and also further eastward in Kane County (fig. 16, loc. 36), the gypsum is in a 30-foot (10-m)-thick bed (Gregory, 1950a, p. 125). About 3 miles (5 km) southwest of Orderville, Kane County (fig. 16, loc. 37), Gregory (1950a, p. 126) reported three beds of gypsum, ranging from 3-16 feet (1-5 m) in thickness and separated by sandstone and shale (U.S. Geol. Survey, 1969, p. 184).

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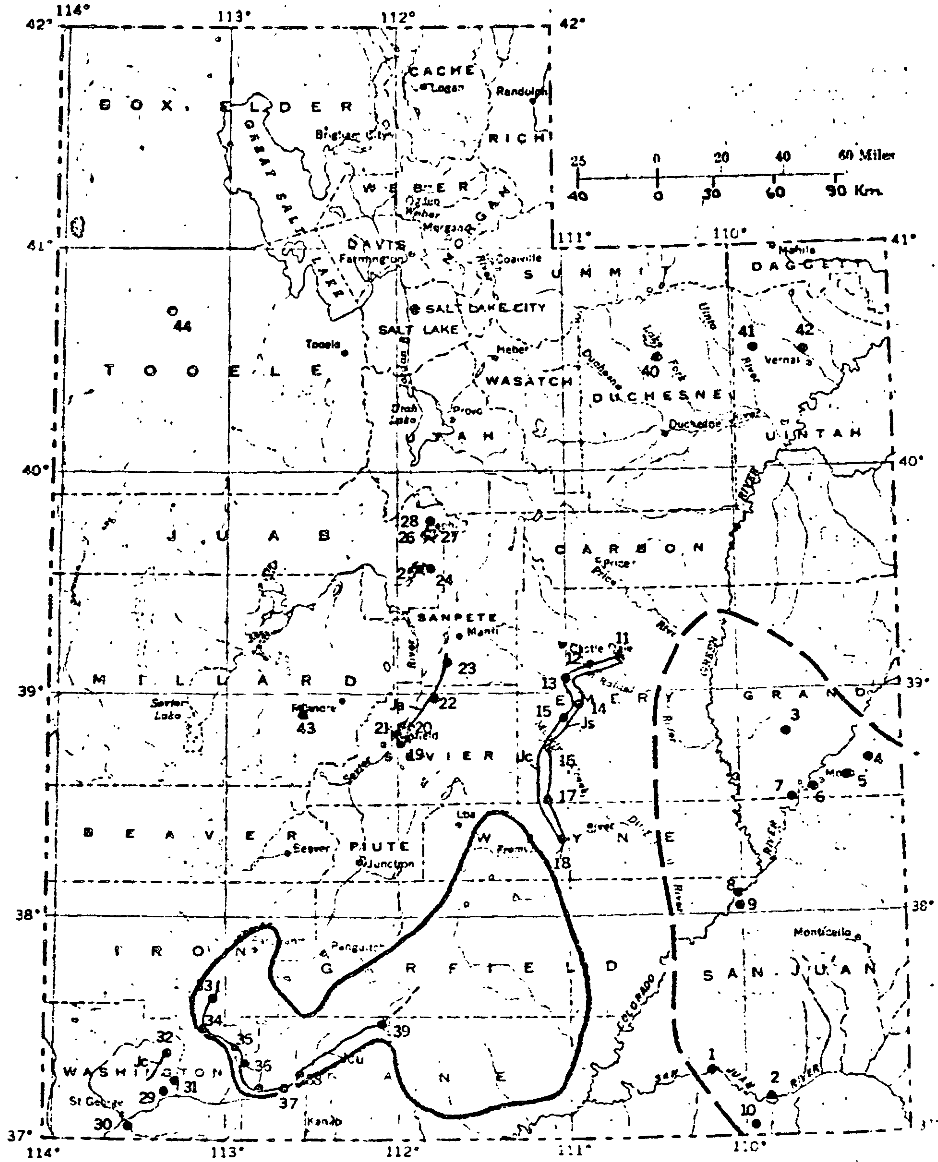

EXPLANATION

Approximate trace of gypsum- and anhydrite-bearing stratigraphic units; formations identified by initials: Upper Jurassic Summerville (Js), and Arapien (Ja); Upper and Middle Jurassic Carmel (Jc) and Curtis (Jcu).

Approximate outline of basin of sedimentation containing extensive gypsiferous and associated saline units of the Paradox Member of the Pennsylvanian Hermosa Formation.

6 Gypsum locality described in text

Gypsum mine or quarry

Fig. 16—Gypsum and anhydrite in Utah. Heavy solid line is boundary of area of this report. Numbered localities in study area are described in text (from U. S. Geol. Survey, 1969, p. 180).

The gypsum in the Curtis thickens eastward, and 3 miles (5 km) east of Glendale (fig. 16, loc. 38), Gregory (1950a, p. 126) reported a 28-foot (9-m)-thick bed of white, massive gypsum--part of it a waxlike alabaster (U.S. Geol. Survey, 1969, p. 184).

Eastward from Glendale, the area of the outcrop of the Curtis is relatively inaccessible. According to Gregory (1951, p. 29) the gypsum is a persistent stratigraphic marker that ranges in thickness from 3-16 feet (1-5 m). Near Cannonville (fig. 16, loc. 39), two thin beds of gypsum, both impure, are present (Gregory, 1951, p. 57-58). Eastward the Curtis becomes less gypsiferous, and in the eastern parts of Kane and Garfield Counties gypsum is absent (Gregory and Moore, 1931, p. 22).

Lightweight aggregate

Two potential sources of lightweight aggregate exist in south-central Utah--basaltic cinder deposits and diatomaceous earth deposits.

Numerous Quaternary volcanic cinder cones are present south of Parowan (fig. 17). Some have been quarried, probably for road metal.

Figure 17.--NEAR HERE

Although the quality of these deposits for lightweight aggregate is mostly unknown, they constitute a large potential source area (U.S. Geol. Survey, 1969, p. 187).

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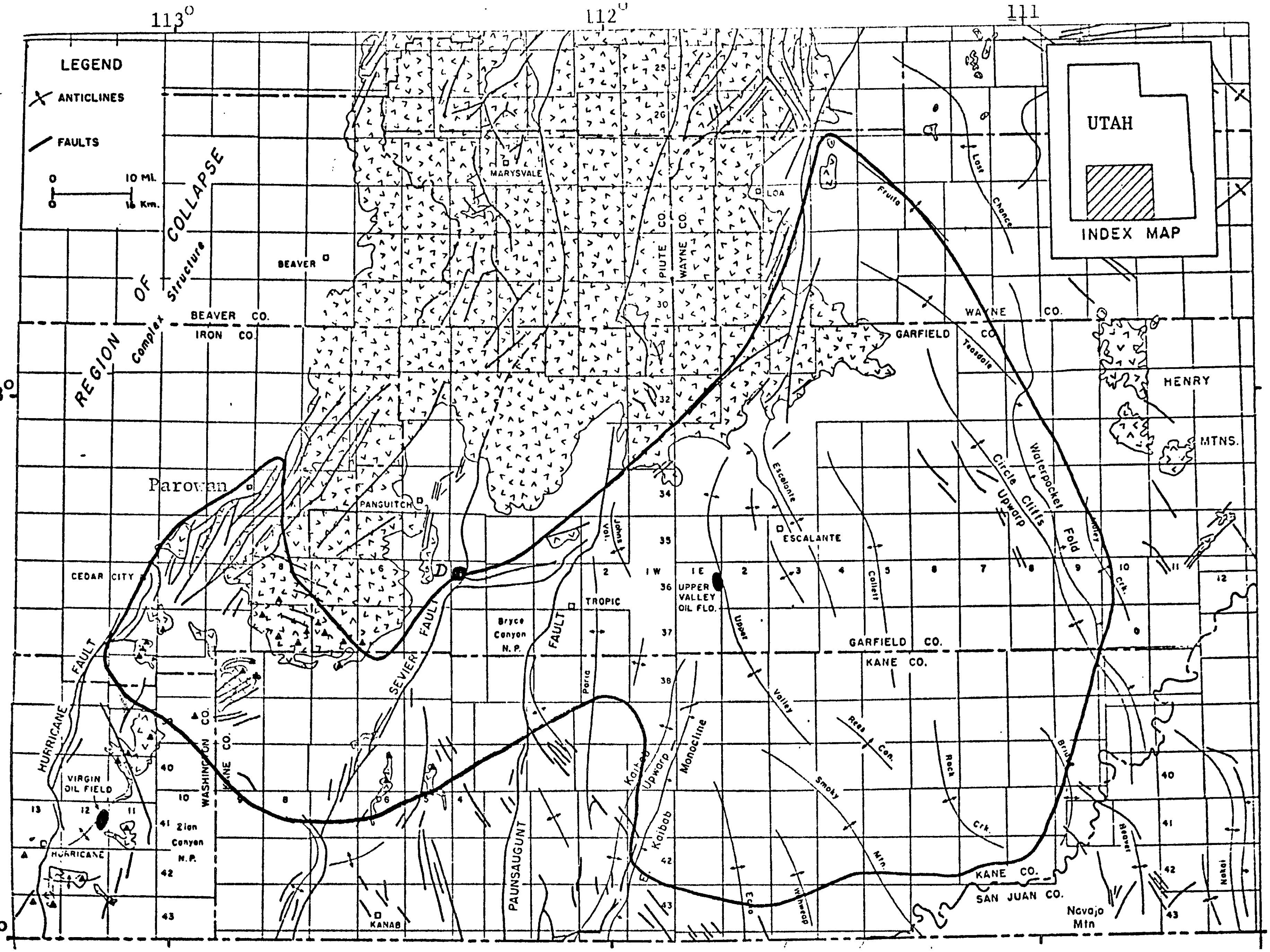

Figure 17. Tectonic map of south-central Utah showing location of lightweight aggregate deposits; ▲, cinder cones, D, diatomite deposit. Base and tectonic map from Stokes and Heylmun (1965). Heavy line is boundary of study area. Patterned areas are igneous (largely volcanic) rock outcrop.

Deposits of diatomaceous earth have been reported in southwestern Garfield County (locality D, fig. 17) near the entrance to Bryce Canyon (about 2 miles (3 km) east of Hillsdale). The extent and thickness of the deposits are not known. Claims have been developed and pits dug, one of which indicates the deposits to be at least 20 feet (7 m) thick. The diatomite is believed to be of Pliocene age and is reported to be interbedded with tuffaceous material. The suitability of these deposits for lightweight aggregate has not been evaluated (Crawford, 1951; U.S. Geological Survey, 1969, p. 187).

Limestone

Limestone is common in southern Utah. Many deposits known to be high-carbonate varieties are suitable for chemical applications such as stack scrubbing of SO_2 in coal-fired electric generating plants or as rock dust for protection against fire and explosion propagation in mines. One deposit of limestone that has the desired qualities for industrial use occurs in the Wasatch Formation on the west side of Johns Valley (north of Bryce Canyon National Park); it was planned for use with the Kaiparowits power plant. Equally good deposits probably occur in the Wasatch Formation throughout the area and in the Carmel Formation near Orderville (Bur. of Land Management, 1976, p. II-99-100).

Sand and gravel

Sand and gravel are generally abundant throughout south-central Utah. Most canyon bottoms and terraces in the area contain gravel in amounts ample for local use. Important deposits are contained on Wahweap Creek drainage near Glen Canyon City, where sand and gravel are mined, on Horse Mountain and along the Paria River drainage (Bur. of Land Management, 1976, p. II-99). Additional resources have been indicated in Johns Valley and on the south flank of the Aquarius Plateau, although the latter appears to be largely colluvium with much clay--suggesting that good sand and gravel deposits may be difficult to find (U.S. Geol. Survey, 1969, p. 217).

Dune sands are most abundant in the southern part of the area at East Clark Bench (southwest of Nipple Bench), but smaller scattered deposits are common locally.

Silica

Utah's principal reserves of pure silica are in sandstones and quartzites. In south-central Utah the principal siliceous rocks are Triassic and Jurassic aeolian formations such as the Wingate, Navajo, Entrada, and Bluff Sandstones. The only known active quarry in south-central Utah, located just north of Kanab, mines silica from the Navajo Sandstone (U.S. Geol. Survey, 1969, p. 220).

Stone

Resources in this category are of three types: (1) crushed and broken stone, or aggregate, (2) dimension stone, and (3) field stone.

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Crushed and broken stone

Large quantities of clinker, a term used here for rock baked and fused by the burning of adjacent coal beds, are present in many of the canyons where coal-bearing strata are exposed. Clinker is commonly used as a road-surface material and as railroad ballast (Bur. of Land Management, 1976, p. II-99). Common rock types that are suitable for aggregate include most quartzites, basalt, and limestone; and resources in this area are abundant. Stone suitable for rip-rap consists of well-indurated irregular cobble- to boulder-size fragments common in many canyon bottoms and along most terraces throughout the region (U.S. Geol. Survey, 1969, p. 222-225; Bur. of Land Management, 1976, p. II-99).

Dimension stone

Sandstone is the most widely used dimension stone in Utah. Most of it comes from the Nugget (Lower Jurassic) in central-northern Utah, but other sandstones of good quality are quarried from the Moenkopi, Chinle, and Wingate Formations in southern and eastern Utah. Quarries southeast of Cedar City, near Parowan, and near Kanab are in sandstone (U.S. Geol. Survey, 1969, p. 224-227).

Field stone

Field stone has been used as a building material since pioneer days. Cobbles and boulders are split and trimmed for veneers and walls in both exterior and interiors of residences and commercial buildings. Numerous localities in south-central Utah have abundant sandstone suitable for this usage.

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Geothermal Resources

Two principal origins of the heat necessary for a geothermal resource are: 1) heat directly related to volcanic sources localized as "hotspots" in the shallow crust of the Earth, and 2) heat related to geothermal gradient, or the general increase in temperature with depth as a consequence of conductive heat flow. Basalts and andesites, common in much of Utah, have probably risen rapidly from the Earth's mantle to the surface in volcanic eruption and their heat is dispersed rather than stored and generally does not provide useful geothermal concentrations. However, the high silica varieties of volcanic rocks (rhyolites, rhyodacites), perhaps because of their high viscosities, commonly are associated with magma chambers at shallow levels in the crust (perhaps 2 to 10 km but most commonly about 4 km) and can sustain high-temperature convection systems for many thousands of years. Many large geothermal systems appear to be associated with young silicic volcanic rocks. Some hot-spring systems that have no direct association with young silicic volcanic systems may derive their heat from older volcanic systems or from very young igneous systems with no surface expression. Other hot-spring systems are probably not related to silicic volcanic rocks. The heat of their systems is related to the regional geothermal gradient, which is higher in some regions such as the Basin and Range province than in others. Many hot springs of the Basin and Range emerge from steeply dipping faults that may extend to depths of at least a few kilometers. The water may be entirely of surface origin, circulating downward, being heated by thermal conduction and then rising and discharging from surface springs (Renner, White, and Williams, 1975).

In southern Utah, geothermal prospects of high-temperature (above 150°C) hot-water convection systems are found at Roosevelt Hot Springs, Cove Fort-Sulphurdale, and Thermo Hot Springs, and systems of intermediate temperature (90° to 150°C) are found at Monroe Hot Springs and Joseph Hot Springs (Renner, White, and Williams, 1975). All these prospects, however, are north and northwest of the study area. Other areas having geothermal interest are the LaVerkin (Dixie) Hot Springs located to the southwest, near Hurricane (Mundorff, 1970) and the Newcastle KGRA (known geothermal resource area), located 50 km west of Cedar City. The latter probably represents a typical basin-range hot spring system derived by deep circulation of cold meteoric waters along high-angle faults. The heat is related to the higher than normal geothermal gradient characteristic of the Basin and Range province (U.S. Geological Survey, Utah Geothermal Resource Leasing Minutes No. 11, 1976; Sass and others, 1971).

Heylmun (1966, fig. 1) shows the Panguitch area (western Garfield and parts of adjacent Piute and Kane Counties) to be a thermal area but says (p. 13) that "Only a few warm springs are recorded for the Panguitch area. Prospects are not encouraging for steam development in spite of Late Tertiary or Quaternary volcanism." No specific reports of hot springs occurring within the boundary of the study area were found.

Young basic volcanoes are indicators of magma source regions in the mantle and under some conditions are potential indicators of buried high-level silicic bodies with no obvious surface manifestations. The common association of silicic domes and lavas with basaltic lava fields shows that basaltic systems should not be automatically rejected for geothermal exploration (Smith and Shaw, 1975). The Markagunt Plateau contains basic lava fields and cinder cones, some of which are inferred to be less than about 10,000 years old (Smith and Shaw, 1975). The Navajo Lake area, about 20 miles (32 km) southeast of Cedar City is a KGRA (Utah Geological and Mineralogical Survey, 1975) containing about 20 volcanic cones. Many of the cones retain their summit craters, indicating a relatively young age, and outpouring of lava from many of their vents has interrupted drainage systems in the area. Some of the flows were early enough to have been faulted; some are covered with a thin mantle of soil and vegetation; others appear to be very recent (Holocene?) (Wilson and Thomas, 1964). Eruptions probably began in the Pleistocene and continued into the Holocene. The youngest dated basalt in the area is a flow dated at 0.44 ± 0.04 m.y. (Pleistocene), located about 3 miles (5 km) northeast of Parowan (Fleck and others, 1975).

Silicic and intermediate composition volcanic lavas and tuffs are common in and adjacent to the Markagunt Plateau, but all are middle to late Miocene in age and are believed too old to provide a heat source of sufficient magnitude for geothermal development.

At present it is difficult to evaluate the geothermal resource value of the south-central Utah study area, but it is probably very low.

NATURAL EARTH HAZARDS

Seismicity

Seismic activity in the area is slight except for two zones parallel and related to well-known faults. Earthquake zones occur locally along the Hurricane fault which trends NNE-SSW and passes near Cedar City and Parowan, and along the Sevier fault trending NNE-SSW near Orderville and Alton. Data on the seismicity of Utah, tabulated by Cook and Smith (1967) for the period between 1850 and June 1965, indicate that magnitudes along these faults have not exceeded 4.9 and the majority are less than 4.0. Earthquake data since June 1965 (Carl von Hake, written commun., 1976) indicate a continuation of mild activity in the western part of the area along the Hurricane and Sevier faults and some additional mild earthquakes on the east side of the Sevier Plateau east of Mt. Dutton and Casto Bluff.

Smith and Sbar (1974, p. 1210) report that "The most recent swarm of activity of the ISB (Intermountain seismic belt, a north-trending zone of seismicity in the western United States) was located north of Cedar City near the Hurricane fault zone. This sequence began on November 11, 1971, and culminated after four hours with an earthquake of magnitude 4.5. As many as 300 events per day occurred following the main event. The activity was located along a north-trending zone that bounds Tertiary and Quaternary basalt flows and outlines a prominent line of springs. Field investigations revealed three north-trending fractures in alluvium. The longest fracture was 0.8 km and showed several centimeters of east-west horizontal extension. Focal depths were shallow, from near surface to 2 km, which probably accounts for the surface deformation." For the same area Smith and Sbar (1974, p. 1212) report: "A composite fault plane solution, from the main event and aftershocks, indicates normal faulting along a north-northwest-trending fault plane. On the basis of a comparison with the Hurricane fault, the most likely fault plane dips 62° northeast."

Only a few shocks of intensity VII to VIII on the Modified Mercalli scale (table 8) have been recorded in northern Arizona and

Table 8.--NEAR HERE

southern Utah. The nearest moderate-sized recorded earthquakes were magnitude 5.5 and 5.7 near Kanab, Utah in 1887 and 1959 respectively. Seismologists have classified the entire area as a region of lesser seismicity, indicating that earthquakes of a Modified Mercalli intensity of VII or greater, or a Richter magnitude of 5 or greater, will occur with a frequency of one or fewer per square degree of surface per decade (Rocky Mountain Association of Geologists, 1972).

Relevant data indicate that the region is still active and that earthquakes of low intensity will occur (fig. 18); however, the effects

Figure 18.--NEAR HERE

of such activity can be predicted as slight (Bur. of Land Management, 1976, p. II-88-90).

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Table 8.—Modified Mercalli Intensity Scale of 1931 (abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like a passing truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.

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Table 8.—Continued

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

U.S. GOVERNMENT PRINTING OFFICE : 1970 O - 397-064

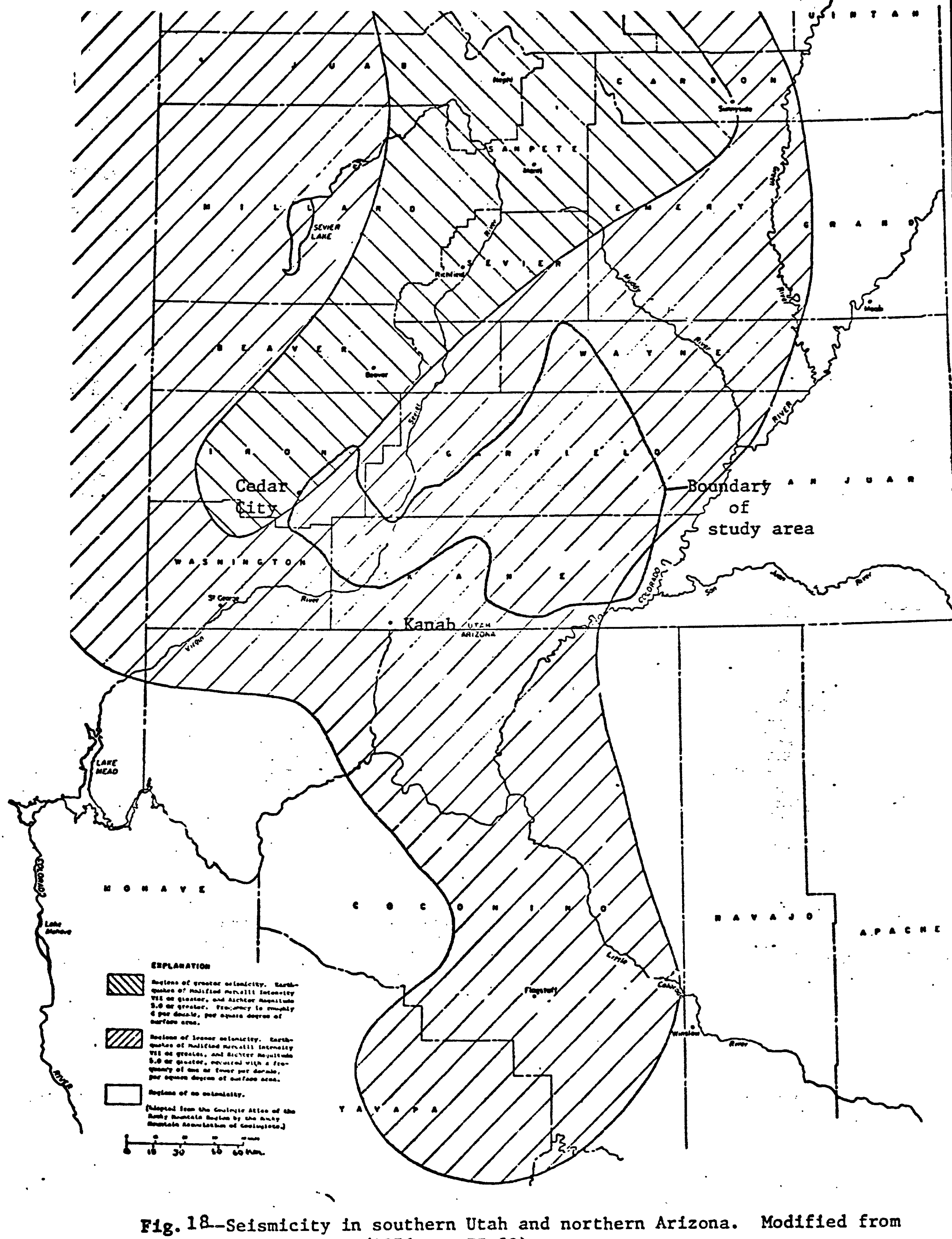


Fig. 18—Seismicity in southern Utah and northern Arizona. Modified from Bur. Land Management (1976, p. II-89).

Landslide Hazards

By Roger B. Colton

In the general area of the Kaiparowits Plateau Coal Field, the Alton Coal Field, and the Kolob Coal Field, several formations are susceptible to landsliding--especially those containing bentonite. They are named, their lithology described, and their thickness presented in table 9, which is derived from the explanations on the geologic maps

Table 9.--NEAR HERE

of the Escalante and Salina $1^{\circ} \times 2^{\circ}$ quadrangles (Hackman and Wyant, 1973; Williams and Hackman, 1971) and from stratigraphic charts in Hintze (1973) for the Cedar City $1^{\circ} \times 2^{\circ}$ quadrangles. The incidence of landsliding is shown in a generalized way on plate 4, which was compiled from the published 1:250,000-scale geologic maps and by an inspection of large-scale (1:24,000 and 1:63,360) topographic maps. Many areas of landslide and rockfall deposits probably were missed during the compilation of the 1:250,000-scale maps and should be mapped on aerial photographs and shown on maps at a scale of 1:125,000.

Rockfall areas lie along the outcrop of such cliff-forming stratigraphic units as the Navajo Sandstone, various lava flows, and various sandstone members of the Straight Cliffs, Moenkopi, Chinle, and Moenave Formations. These areas are shown in a generalized way on plate 4.

Table 9. Formations susceptible to landsliding or slumping during excavation in the coal area of south-central Utah

UNIT NAME OR TYPE	LITHOLOGY	THICKNESS IN FEET (METERS)
Alluvium	Silt, sand, and gravel	0-50 (0-15.3)
Colluvium (talus, slope wash)	Coarse to fine rock fragments, sand, and gravel	0-200 (0-61)
Till	Unsorted and unstratified mixture of all sizes	0-100 (0-30.5)
Lake deposit	Fine- to coarse-grained stratified sediments	0-50 (0-15.3)
Windblown sand and silt	Sand and silt	0-100 (0-30.5)
Andesite mudflow breccias and tuff	Clay- to boulder-sized mixture	0-2,500 (0-763)
Wasatch Formation	Limestone, mudstone, sandstone, conglomerate	1,600 (480)
Pine Hollow Formation	Mudstone, bentonitic claystone, sandstone	0-400 (0-122)
Mancos Shale	Shale, mudstone, sandstone, coal, bentonite, limestone	3,000-4,900 (315-1,495)
Tropic Shale	Shale, sandstone, siltstone, bentonite	600-900 (183-275)
Morrison Formation	Bentonitic mudstone, sandstone, conglomerate, siltstone	0-800 (0-244)
Chinle Formation	Siltstone, conglomerate, sandstone, bentonitic mudstone, limestone	215-1,200 (66-365)
Moenkopi Formation	Siltstone, sandstone, gypsum, anhydrite, conglomerate, limestone, dolomite, mudstone	100-1,700 (30.5-513) 100-1,000 (30.5-305)

COAL-MINE SUBSIDENCE

By C. Richard Dunrud

General Aspects of Subsidence

Mining activities in south-central Utah will be controlled by geologic and topographic conditions in at least two ways. First, the plateau cliff-and-canyon topography probably will require that nearly all the coal be mined by underground methods. The overburden is thick, or it varies in thickness over short distances. Also, most of the rocks comprising the overburden are competent, strong Upper Cretaceous sandstones, alternating with mudstones. The cost of mining a given quantity of coal by surface methods here would be higher than the cost, for example, of mining in the weaker lower Tertiary rocks of the Powder River Basin of Wyoming and Montana. Second, the rugged topography and the presence of numerous joints and local faults near cliffs and steep slopes may increase or alter the effects of subsidence as compared to mining conditions beneath more uniform overburden of similar thickness, even though the amount of ground settlement may be comparable in the two situations. In this section, only the more important effects of underground coal mining will be discussed because only a very small area is amenable to current surface-mining methods.

Coal-mine subsidence can be defined as all the deformation within the overburden and at the surface that is caused by underground mining. It includes the local upward movement of strata that sometimes occurs above solid-coal mine boundaries or large barrier pillars, which may be caused by downwarping of overburden into mine cavities. It also includes the downwarping itself; the associated horizontal tensile, compressive, and shear strains produced by flexure of strata; and the compressive strain induced by compression arches (Dunrud, 1976).

Subsidence is the most serious problem of underground mining from an environmental viewpoint, although earth tremors as strong as 3.5 to 4.0 on the Richter scale were measured in the Sunnyside district in east-central Utah when accumulated mine-induced stresses were suddenly released in the rock or coal. These so-called rock bursts, or "coal-mine bumps," commonly are a hazard to life and property in the immediate mine area but also can damage brick chimneys and other susceptible structures many miles from the tremor source.

The most damaging aspect of coal-mine subsidence is differential settlement, which is caused by settling of overburden into the mine cavities while the strata above the unmined coal do not settle, rise slightly, or settle only a little (fig. 19). This differential settlement commonly produces a trough above the mine workings. The maximum depth of the subsidence trough commonly is 50 to 90 percent of the thickness of the coal mined, depending on geologic, topographic, and mining conditions (fig. 20). The area covered by the subsidence

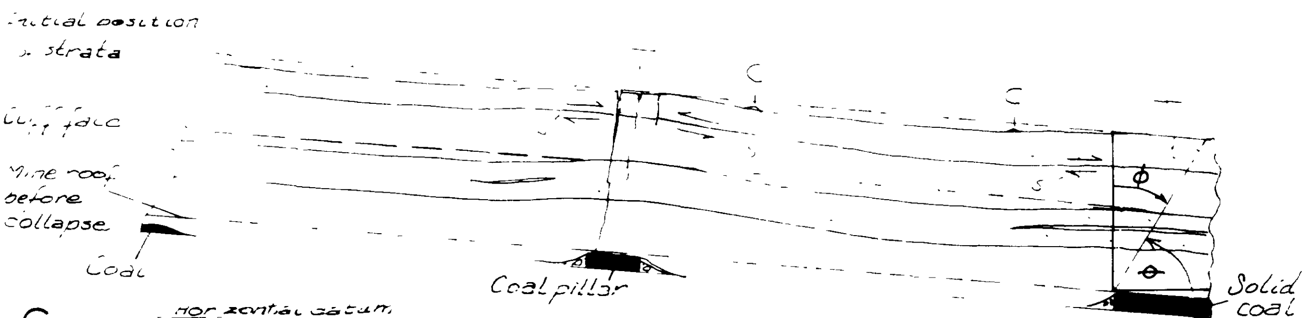
Figure 19.--NEAR HERE

20.--NEAR HERE

trough commonly is somewhat larger than the actual mine area. The angle made by a straight line drawn between the limit of surface settling and the limit of mine cavities producing the subsidence, referenced to the vertical or the horizontal, is called the angle of draw, or limit angle (fig. 19) (National Coal Board, 1966, fig. 1.1). This angle varies with geology, topography, and mining procedures but commonly ranges between 25° and 45° from vertical in foreign countries (Zwartendyk, 1971, p. 142-143), and between 10° and 25° from vertical in room-and-pillar mining in the Somerset, Colo. area (Dunrud, 1976), where very rugged terrain is underlain by moderately strong Mesaverde lenticular sandstones and mudstones of Late Cretaceous age. In the Raton, N. Mex. area, the limit angle ranges between 15° and 26° from vertical above a longwall mining panel in rugged terrain underlain by Paleocene mudstones and lenticular sandstones (Gentry and Abel, 1977).

A

B



C

Figure 1 . Subsidence effects caused by coal mining in the Book Cliffs area near Sunnyside, Utah (modified from Dunrud, 1976). A, Example of tensile failure; B, Example of compressive failure; C, Diagrammatic cross section. Tensile (T), compressive (C), and shear (S) stresses are produced by differential settlement of the overburden into the mine cavities. Thickness of coal bed and subsidence are exaggerated for clarity. The overburden above the mine void to the right of the coal pillar behaves as a plate composed of different materials in contact that is supported on two sides. Flexure of strata into the mine voids produces shear stress along the lithologic boundaries. The overburden above the mine near the cliff behaves as a cantilever--a plate supported on one side by a coal pillar and by a restraining tensile stress in the overburden. Failure occurred because the coal was mined too close to the outcrop. Failure of the cantilevered part of the overburden produces wide extension cracks above the barrier pillar that commonly are many hundreds of feet deep. Tensile stress produced by settlement into the mine cavity on the right adds to the extension produced by the cantilever failure.

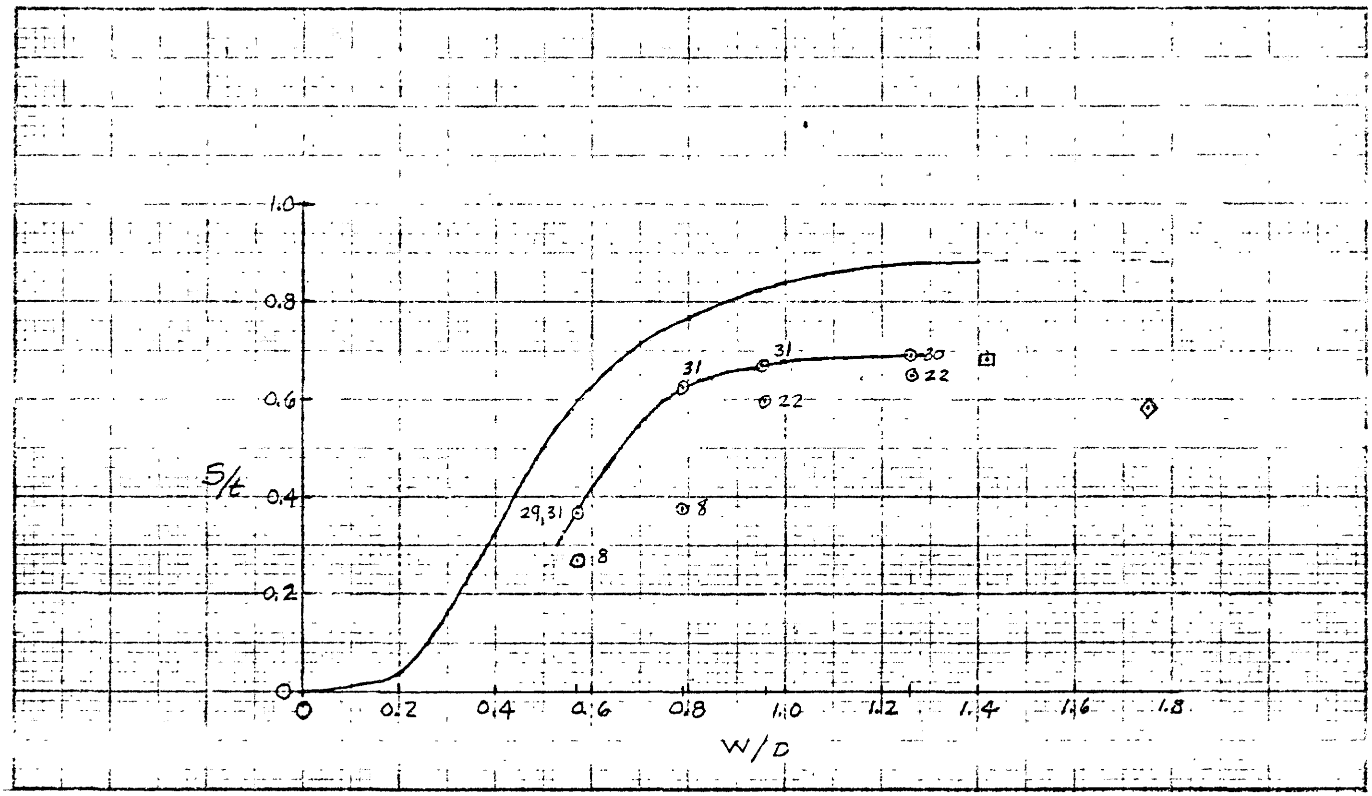


Figure 20. Graph showing the ratio of maximum subsidence (S) to thickness of coal mined (t) (subsidence ratio) versus the ratio of mining panel width (W) to overburden depth (D) for selected mining areas in the United Kingdom, Somerset, Colo., and Raton, N. Mex. The left-hand curve is from Wardell (1971, p. 206), derived from surface measurements in the United Kingdom above caved longwall panels greater than 1.40 D in length, in strata dipping less than 15°. The circled data points are from USGS measurements in very rugged terrain near Somerset, Colo., above two caved room-and-pillar mining panels; extraction progressed toward deeper overburden beneath a high ridge underlain by moderately strong Mesaverde sandstones and mudstones of Cretaceous age; the subsidence values are corrected to 1.40 D by use of the National Coal Board (1966, fig. 2.2) correction graph. Circled points beneath the curve from Somerset show the subsidence value when mining ended in each panel. The points in squares and diamonds are from measurements made by the Colorado School of Mines (Gentry and Abel, 1977) in rugged topography above caved longwall workings; the square shows the subsidence ratio when mining progressed toward shallower overburden, and the diamond shows the subsidence ratio when mining progressed toward deeper overburden. Note that surface subsidence was about 10 percent greater when mining progressed from deeper to shallower overburden than when mining was from shallower to deeper overburden.

Differential settlement that produces the trough geometry tends to cause horizontal strain and deformation. At the margins of the trough, the surface commonly is subjected to tensile stresses because the ground is bowed upward (positive curvature) (fig. 19A). These tensile stresses commonly produce tensile strains and open cracks, particularly where bedrock joints or faults parallel the direction of mining. Tensile stresses and associated extension and cracking commonly are increased or even doubled above coal barrier pillars that separate two mining panels. Inward from the margins of the trough, the ground surface tends to bow downward (negative curvature). This produces high compressive stresses and strains that can bulge and buckle strong massive sandstones (fig. 19B).

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Effects of Topography and Geology

Gentry and Abel (1977) noted topographic effects on subsidence in the Raton, N. Mex., area. When a longwall face that was parallel to canyon-and-ridge topography retreated from beneath a canyon toward a ridge, vertical settlement was as much as 10 percent less than it was when the longwall face progressed from a ridge toward a canyon (figs. 20, 21). Topographic effects on horizontal movement were even more

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Figure 21.--NEAR HERE

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striking. The horizontal component of movement commonly was as much as or more than the vertical component of movement when the longwall face moved from beneath a ridge toward a canyon, whereas the horizontal component commonly either was nearly zero or was in a direction opposite to the direction of movement of the face when the face moved from beneath a canyon toward a ridge.

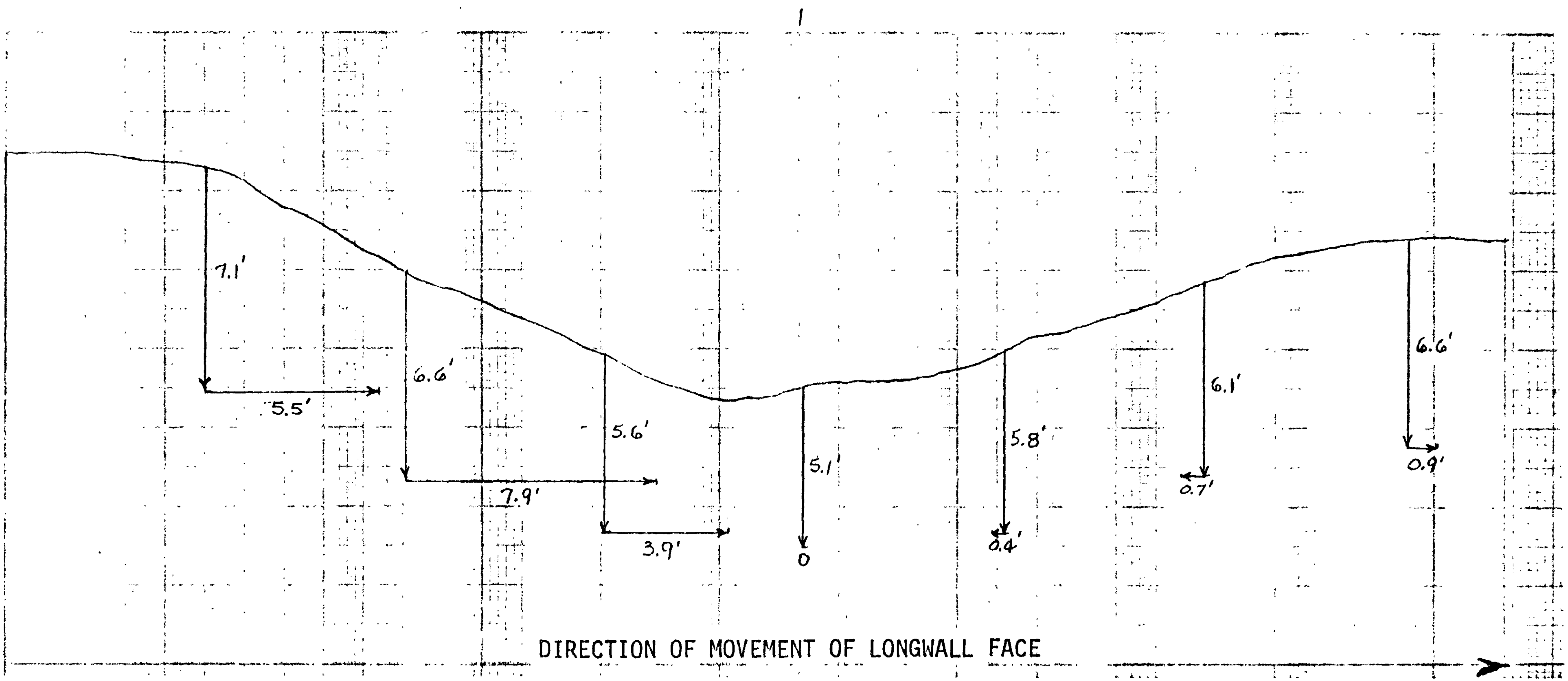

Figure 21. Profile along a centerline of a longwall panel in the Raton, N. Mex., area showing surface relief and the vertical and horizontal components of surface movement (modified from Gentry and Abel, 1977). Note that when the direction of movement of the longwall face is in the downslope direction of the ground surface the horizontal component of surface movement is much greater and the vertical component is as much as 10 percent more than they are when face movement is in the upslope direction with respect to the ground surface. Longwall face is oriented perpendicular to profile; direction of movement is parallel to profile.

In other words, with a longwall face oriented parallel to a slope contour and the direction of movement of the face parallel to the downslope direction, both the vertical and horizontal components of subsidence are increased, whereas when the direction of face movement is in the upslope direction, both the vertical and horizontal components of subsidence are decreased. The mining direction of room-and-pillar mining at Somerset, Colo. has been only in a direction toward deeper overburden in the subsidence study area, so that comparative information is not available. Gentry and Abel (1977) also found that the vertical component of subsidence beneath draws was much less than that measured beneath ridges (fig. 21); the horizontal component also was small as compared to that measured beneath ridges. This might be attributed to the subjection of canyons to greater lateral confinement than uniform overburden because of adjacent ridges, which could cause stable compression arches to form above mine workings and thereby reduce subsidence.

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The effects of cliff-and-canyon topography on subsidence in the Sunnyside area of Utah are striking, especially where coal is mined near cliffs (fig. 19). The overburden has no lateral support near the cliffs; consequently, any mining activity near the cliffs that produces settlement of the overburden at the cliff face tends to cause the overburden to behave as a cantilever--a rock mass supported by coal on one side, inward from the cliff, and a restraining force. Rocks, particularly jointed rocks, are weak in tension. Failure of the overburden as a cantilever tends to produce large open cracks that follow joints. Cracks such as these have been observed to extend as much as 950 ft (290 m) below the surface (Dunrud, 1976; fig. 19A). Surface drainage is, of course, diverted underground by open cracks (as in fig. 19A), and any underground waterflow also is interrupted and often diverted to the mine workings. In more uniform overburden with lateral support, cracks and bulges produced in subsidence troughs commonly are much shallower and less extensive than those produced by cantilever failure.

Rockfalls and small landslides are common when coal is mined beneath cliff outcrops or in steep canyons. Large-scale landslides could occur, however, where bedrock dips toward the cliff outcrop instead of away from it, as shown in figure 19. If the dip is sufficient to overcome frictional resistance along the coal bed, the overburden can fail as a cantilever, become detached, and slide as a block along the coal; the effects could have serious mining and environmental consequences.

Effects of Mining

Mining methods, together with topography and geology, also control the time at which initial subsidence occurs, as well as the rate and amount of surface subsidence. Subsidence development curves for selected caved longwall mining panels in the United Kingdom and near Raton, N. Mex., and caved room-and-pillar mining near Somerset, Colo., are shown in figure 22. They show that (1) the surface commonly begins

Figure 22.--NEAR HERE

to subside farther ahead of a retreating longwall face in the United Kingdom than in the rugged terrain in the Raton, N. Mex. area; (2) in the United Kingdom, the surface commonly has subsided nearly 20 percent of the total amount when the face is directly beneath the measuring station, whereas in the Raton, N. Mex. area the corresponding surface has subsided only about 5 percent; and (3) the overburden subsides more quickly, completely, and apparently more predictably above longwall mining panels than occurs above the room-and-pillar mining panels. In addition, subsidence measuring stations near the initial positions of pillar retreat lines (the curves defined by the circled points in fig. 22A, B) were not subsiding when the pillar retreat lines were beneath the stations (positions X/D = 0 in fig. 22A, B), whereas the stations near the final positions of the pillar retreat lines had settled 10 to 15 percent of the total amount when the pillar retreat lines were directly beneath these stations.

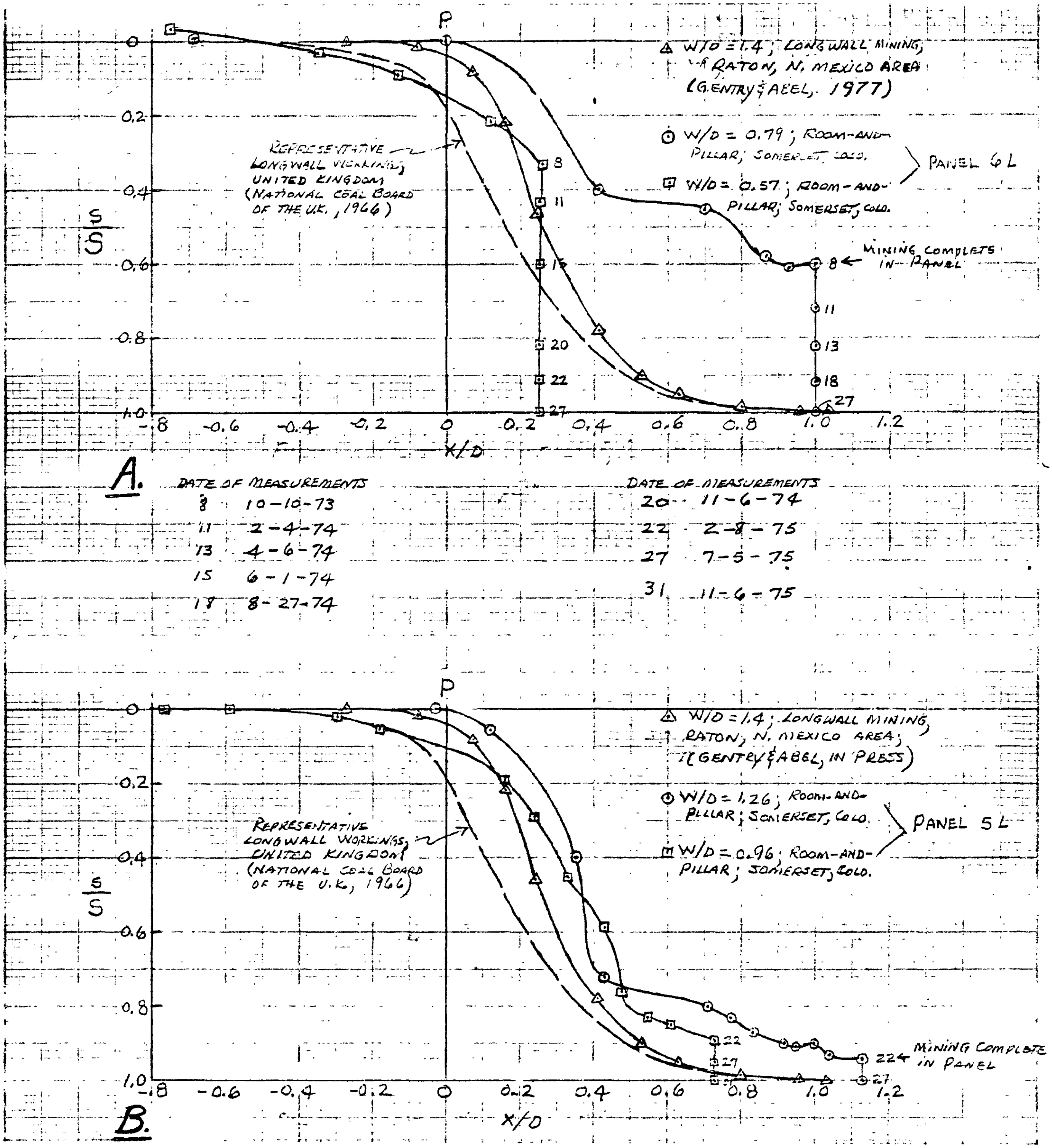

Figure 22. Subsidence development curves for caved longwall workings in the United Kingdom and in the Raton, N. Mex. area, and for caved room-and-pillar workings near Somerset, Colo. The curves are a plot of the ratio of surface subsidence measured (s) to the maximum subsurface subsidence (S) versus the ratio of the position of face or pillar line distance (X) to the overburden depth (D) at the point where the subsidence was measured (P). The circled points in A and B are USGS measurements from surface bench marks near the initial position of the pillar retreat lines; the points enclosed by squares are USGS measurements from bench marks near the final position of the pillar retreat lines, and the points enclosed by triangles are subsidence measurements made by the Colorado School of Mines in the Raton, N. Mex. area (Gentry and Abel, 1977).

Subsidence above the 5L room-and-pillar mining panel in the Somerset area, where the panel width-to-depth ratio was about 1:1.25, tended to follow the amount and rate of subsidence measured above longwall mining panels much more closely than that above panel 6L, where the ratio of W/D was about 0.6:0.8 (fig. 22). Also, the residual subsidence, after mining was completed, was much less in panel 5L than that in panel 6L, probably because a compression arch is present above panel 6L (Dunrud, 1976). Subsidence appears to have been complete about 9 months after mining was finished in panel 5L, whereas subsidence may not have been complete in panel 6L for about 21 months after mining was completed. Measurements are continuing to determine whether or not subsidence is complete above these and other room-and-pillar mining panels in the Somerset area.

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The rate of subsidence with respect to position of the longwall face is greater in the rugged terrain near Raton, N. Mex. than in the gently rolling to hilly terrain common in Great Britain (fig. 22). The slope, curvature, and surface strain also are inferred to be greater near Raton than in typical areas in the United Kingdom. Indeed, surface compressive and tensile strains of as much as 22,000 and 21,000 microinches/inch were measured near a canyon where longwall mining was retreating in a direction parallel to the downslope direction of the surface (Gentry and Abel, 1977). These strains are nearly twice the amount predicted by the National Coal Board (1966) of the United Kingdom (about 13,000 μin/in) for subsidence amount and overburden depth. The rate of subsidence was even greater above the 5L room-and-pillar mining panel near Somerset, Colo. (fig. 22B), when coal was mined beneath progressively thicker overburden. The surface strain, therefore, should be greater; however, surface strains tend to be erratic and undefinable in jointed bedrock because of the presence of surface cracks.

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Summary

Subsidence can severely alter the ground surface as well as other coal or mineral deposits or fluid-bearing rocks. The effects of topography, geology, and mining procedure on subsidence type, rate, and amount are significant. The obvious remedy to subsidence seems to be either (1) to mine the coal completely in a uniform manner over a large enough area so that the overburden settles uniformly and the tensile, compressive, and shear stress effects of differential settlement are minimized, or (2) to leave enough coal in the ground to support the overburden uniformly until mining is completed, and later on perhaps to extract the remaining coal by another means, assuming that the coal pillars left behind will remain competent and not lose strength through exposure to air or water.

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Both these options entail problems that in turn vary with specific geologic and topographic conditions in the area to be mined. The overburden may be too thick or too variable in thickness to implement a mining plan that would extract the coal completely over an area extensive enough to minimize the effects of differential settlement, or the coal deposit may comprise more than one vertically superposed bed, thus complicating complete extraction. It also may be difficult to implement a uniform mining plan involving partial extraction and secondary recovery in the rugged terrain of south-central Utah because (1) variable overburden load would dictate variable pillar dimensions, and (2) secondary recovery procedures, such as in-place gasification, might burn out of control if air were available via subsidence cracks caused by voids created during the burning.

The best and most efficient mining activity is one that incorporates geologic and topographic information as well as mining experience into the mining plan. This means that site-specific geological and geotechnical investigations should be conducted early in the mine-planning stage.

LANDSCAPE GEOCHEMISTRY

By J. J. Connor

Coal-based energy development in south-central Utah is expected to affect the geochemical landscape primarily by changing the chemistry of vegetation. Examples of such effects observed to date in the Northern Great Plains Coal Region include altered copper/molybdenum ratios in sweetclover growing on spoil banks, slightly increased concentrations of cadmium, cobalt, fluorine, uranium, and zinc in crested wheatgrass growing on reclaimed spoils, and elevated concentrations of selenium and uranium in native vegetation growing within 5-10 km of coal-fired electric-generating plants. Lowered copper/molybdenum ratios might induce molybdenosis in ruminants; cadmium, selenium, and fluorine are known poisons. In general, while natural scientists can define an "excessive" trace-element level in natural materials, medical scientists are the only ones capable of assessing a "health hazard" based on such levels.

The two greatest geochemical impacts on the western landscape resulting from large-scale coal development are likely to be geochemical alteration at coal mine sites by overturn, and geochemical alteration adjacent to electric-generating sites through coal combustion. The first impact tends to be rather localized, but the second may have regional significance.

The environmentalist interest in the chemical composition of the natural landscape arises solely from fears that disturbed (or restored) landscapes may exhibit visibly changed compositions. For all practical purposes, this interest focuses on the chemical potential of disturbed or restored materials in supporting a desirable vegetative cover, which in turn can support animal life of interest (including animals exploited directly by humans).

If the area to be disturbed by mining or related activity presently supports vegetation, the chemical composition of the substrate (soil or rock) obviously meets at least the minimum requirements of this vegetation. Therefore, a primary geochemical need in impact assessment is a knowledge of the chemistry of these substrates in terms of geochemical backgrounds or "baselines." Such baselines in essence define the minimum levels of total nutrient elements and the maximum levels of "toxic" elements to which this vegetation is exposed, although not necessarily defining the extremes that this vegetation can endure. They also provide a basis for estimating the chemical potential of abandoned or reclaimed land to support the same vegetation.

Considerable research suggests that bulk soil chemistry is only weakly reflected by element levels in plant tissue. Therefore, work in plant geochemistry should focus on levels in the plant that may be toxic to wildlife or domestic animals. Because the plants that are there demonstrate by their very presence that current element-concentration levels in the supporting soil can be tolerated by the vegetation, the major botanical problem becomes whether or not such plants can be expected to grow on some new kind of substrate (resulting from man's activities) and whether or not such growth will result in changed tissue concentrations of elements.

The first part of this question can only be answered by a study of the geochemistry of the new substrate. The chemical composition of these materials may indicate levels of nutrient elements below, or levels of toxic elements above, the concentrations found in the original ("native") substrate. It is true that chemical requirements or chemical tolerances of vegetation are determined by the "available" amounts, not total amounts, of certain elements in the substrate, but the experimental difficulties of determining or stating in a general way the criterion of element availability without reference to species-selective membrane response make the concept very difficult or impossible to apply to native ecosystems.

While nutrient deficiencies are not uncommon in the plant and animal world, public concern over trace-element impact of coal development tends to focus on element excesses or "toxicities." Examples of such impact on vegetative cover is suggested in an examination of the copper/molybdenum ratio in sweetclover (Melilotus officinalis or M. alba) growing on spoil banks in the Northern Great Plains (table 10).

Table 10.--NEAR HERE

This ratio ranges from 0.43-6.5 and averages about 2; this compares with an "optimal" ratio in forage of about 5-7 (U.S. Geological Survey, 1976). A browse diet formed largely of such a plant might induce symptoms of a copper/molybdenum imbalance in grazers. Grass (Bouteloua gracilis) in the Powder River Basin, Wyoming has an average ratio of 4.7 (U.S. Geological Survey, 1975, p. 17), and sagebrush (Artemisia tridentata) in the Green River Basin exhibits an average ratio of about 11 (U.S. Geological Survey, 1976). Presumably such plants growing in south-central Utah would have similar ratios.

Additional effects have been observed in crested wheatgrass (Agropyron desertorum and A. cristatum) at the southern edge of the Powder River Basin (table 11). Expected concentrations (geometric

Table 11.--NEAR HERE

means) of cadmium, cobalt, fluorine, uranium, and zinc are elevated in wheatgrass growing on reclaimed spoil materials when compared to controls. Uranium in particular is increased four-fold.

Table 10.--Copper and molybdenum in sweetclover (*Melilotus* sp.), and pH in spoil materials from eight coal mines in the Northern Great Plains

[Geometric mean (GM) concentrations and observed ranges expressed as parts per million in dry material; GD, geometric deviation; mines listed in order of increasing Cu:Mo ratios]

Mines, or baseline data	Sweetclover, above-ground parts: Copper			Molybdenum			Cu:Mo ratio			Mine spoils: pH		
	GM	GD	Observed range[1/]	GM	GD	Observed range[1/]	GM	GD	Observed range[1/]	AM	SD	Observed range[1/]
Big Sky------	8.2	1.16	6.5 - 9.8	13	1.23	10 -20	0.61	1.21	0.44 - 0.75	7.6	0.53	6.5 - 8.5
Utility------	6.9	1.14	5.3 - 9.0	11	1.33	6.4 -18	.62	1.29	.43 - 1.0	7.8	1.30	4.4 - 9.0
Velva--------	7.2	1.18	5.9 - 9.5	7.9	1.25	5.3 -12	.92	1.27	.63 - 1.4	7.8	.40	7.0 - 8.5
Savage-------	5.9	1.27	4.1 - 9.3	6.4	1.30	4.8 -10	.92	1.47	.50 - 1.9	8.2	.49	7.0 - 8.5
Kincaid------	9.0	1.20	6.7 -13	6.5	1.84	2.8 -18	1.4	1.70	.65 - 2.8	7.8	.71	7.1 - 9.4
Beulah-------	5.5	1.14	4.4 - 6.7	2.6	1.60	1.2 - 8.3	2.1	1.60	.63 - 3.8	7.0	.69	6.2 - 8.7
Dave Johnston	7.0	1.19	5.2 - 9.5	3.1	2.18	1.5 -14	2.3	2.34	.47 - 6.5	6.2	1.59	4.0 - 8.5
Welch--------	8.1	1.27	5.6 -11	3.4	1.68	1.9 - 9.5	2.4	1.77	1.2 - 5.0	6.6	.96	5.4 - 7.8
Baseline data[2/]	7.6	1.66	2.8 -21	2.1	2.57	.32-14	3.6	2.35	.65 -20	7.2	.46	6.3 - 8.1

[1/] Ranges given for baseline data are not the "observed" ranges, but the expected central 95-percent ranges as described in the text.

[2/] Sweetclover baseline based on eight samples collected throughout the United States; pH baseline based on 64 A-horizon soil samples collected across the Powder River Basin (U.S. Geological Survey, 1976).

Table 11.--Statistical analysis of element concentrations in the ash of crested wheatgrass from topsoil borrow areas and from reclaimed spoil areas at the Dave Johnston mine, southern Powder River Basin, Wyoming

[Concentrations expressed as parts per million, except for Ca, Na, K, P, S, Si, and ash, which are in percent; *, component of variance tested to be significant at the 0.05 probability level; Ratio, number of samples in which element was detected to total number of samples analyzed.]

Element, or ash	Analysis of variance				Summary statistics							
	Total $\log_{10}$ variance	Natural variance[1/]		Variance due to analytical error[1/]	Topsoil borrow areas				Reclaimed spoil areas			
		Between areas	Among samples within areas		Ratio	Geometric mean	Geometric deviation	Observed range	Ratio	Geometric mean	Geometric deviation	Observed range
Ca------	0.0046	<1	95*	5	20:20	4.1	1.11	3.6-5.2	20:20	3.9	1.21	2.6-5.3
Cd------	.0702	27*	<1	73	20:20	.86	1.90	.2-2	20:20	1.4	1.40	.6-2
Co------	.0991	35*	13	52	10:20	.72	1.76	<1-2	15:20	1.5	2.59	<1-8
F[2/]-----	.0240	30*	61*	9	20:20	4.5	1.17	3-6	20:20	6.2	1.46	3-10
Hg[2/]----	.0138	<1	18	82	20:20	.011	1.33	.01-.02	20:20	.011	1.29	.01-.02
K-------	.0148	<1	96*	4	20:20	18	1.23	13-24	20:20	20	1.38	9.8-30
Li------	.1081	15	83*	2	20:20	13	2.02	4-30	20:20	22	1.93	8-65
P-------	.0267	55*	29*	16	20:20	2.1	1.16	1.8-2.4	20:20	1.4	1.38	.6-2.4
S, total[2/]	.0203	<1	97*	3	20:20	.17	1.29	.10-.27	20:20	.18	1.45	.09-.33
Se[2/]----	.0710	<1	91*	9	20:20	.23	1.91	.10-.60	20:20	.27	1.73	.10-.70
Si------	.0138	15	65*	20	20:20	20	1.22	14-26	20:20	16	1.33	9.4-26
U-------	.2165	39*	54*	7	9:20	.25	2.41	<.4-1.2	19:20	1.0	3.02	<.4-10
Zn------	.0199	59*	39*	2	20:20	310	1.20	220-460	20:20	440	1.25	300-580
Ash-----	.0035	<1	94*	6	20:20	6.3	1.15	5.3-8.0	20:20	6.0	1.14	2.6-5.3

[1/] Expressed as percent of the total variance

[2/] Analyses determined on dry material, not ash; therefore expressed on dry weight basis

Regional geochemical impacts are likely to result largely from windborne transport of extraneous materials. Two sources of such materials are unreclaimed or abandoned disturbed areas and stack emissions from coal-fired generating plants. Again, the focus of such impact is on potential changes in the vegetative cover. It is reasonable to suppose that powerplant emissions contain at least small amounts of every naturally occurring element, but any practical assessment of their impact can only be based on elemental effects observed in the landscape adjacent to or downwind from the stack. Such effects were looked for in both sagebrush and soil lichen downwind of the Dave Johnston powerplant at the southern edge of the Powder River Basin (fig. 23 and 24). The strongest effect, as measured by regression techniques, was

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Figures 23, 24.--NEAR HERE

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that due to selenium, a particularly important element because of its known toxic effects to browsers. In both vegetation species, selenium appears to be elevated out to distances of 5-10 km. Other suspect elements include strontium, vanadium, uranium, fluorine, and perhaps titanium, zinc, lithium, and cobalt.

The fears aroused by such accumulations reflect concern not so much for absolute amounts introduced as concern for the availability to plants of such emissions. Because the lichen samples were cleaned prior to analysis, the selenium accumulation noted there probably reflects biological accumulation, not simple physical entrapment.

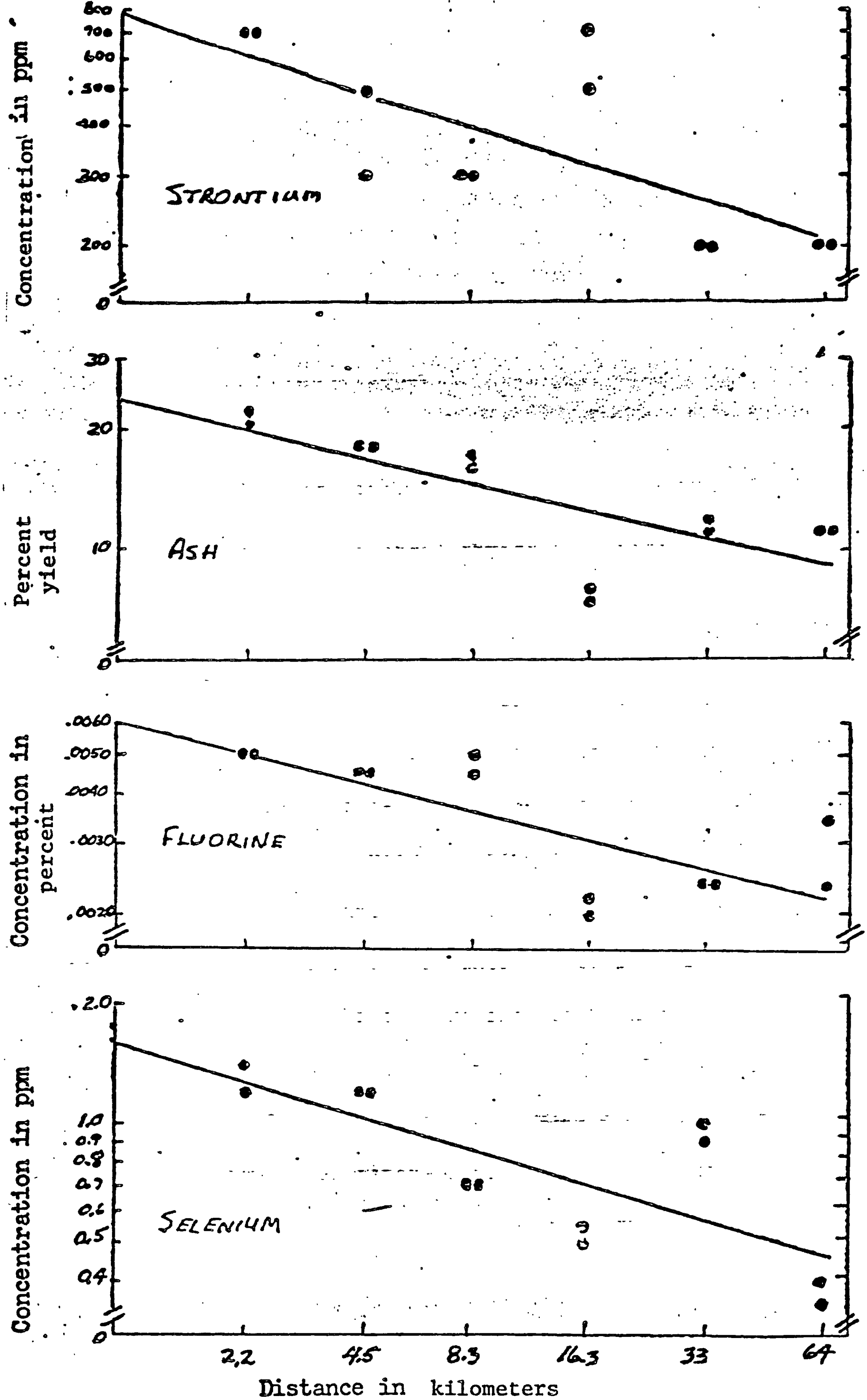

Figure 23.--Regression trends in Parmelia chlorochroa for concentrations of fluorine, selenium, strontium, and ash progressing east from the Dave Johnston powerplant. Sbpes are significantly different from zero at the 0.01 probability level or less.

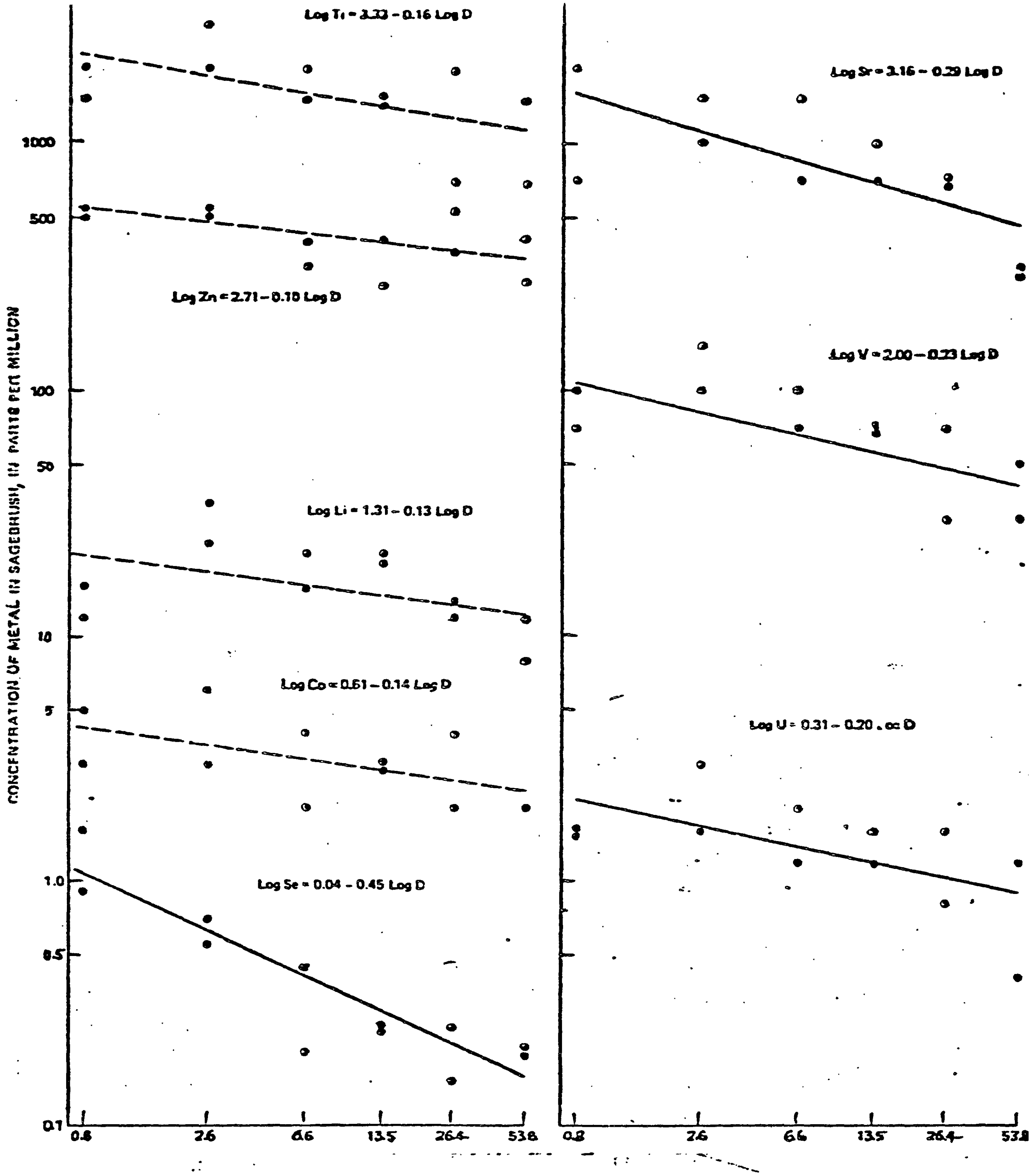

Figure 24.—Metal trends in sagebrush away from powerplant. Slopes of solid regression lines are statistically significant at the 0.05 or lower probability level of dashed regression lines at the 0.05- to 0.10-probability levels; both define trends in concentration. Concentrations of selenium measured in dry weight; all other concentrations measured in ash weight. (From Connor and others, 1976.)

The most abundant emissions from power plants probably would be the oxides of sulfur, carbon, nitrogen, and hydrogen (water); but as essential constituents of vegetative tissue, it is unlikely that such effects on plant material could be measured as simple distance-related accumulation (although it might be measured in general terms of plant "health").

The hydrologic impact of energy development is expected to be substantial, although the greatest changes will likely be on the quantity or flow direction of water supplies, rather than on chemical quality (at least in a regional sense). Table 12 lists interim EPA standards for nine constituents in primary drinking water.

Table 12.--NEAR HERE

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Table 12. --Environmental Protection Agency primary drinking water, proposed interim standards for inorganic chemicals

[*, varies with annual average of the maximum daily air temperature for the locality]

Constituents	Maximum allowable values	Constituents	Maximum allowable values
As ----------	0.05 mg/l	NO_3 (as N) ----	10.0 mg/l
Ba ----------	1.0 mg/l	Se -------------	.01 mg/l
Cd ----------	.01 mg/l	Ag -------------	.05 mg/l
Cr ----------	.05 mg/l	F* --------------	1.4-2.4 mg/l
CN ----------	.2 mg/l	Gross alpha ---	15 pCi/l
Pb ----------	.05 mg/l	Gross beta ----	50 pCi/l
Hg ----------	.002 mg/l	Ra_{226} ----------	3 pCi/l

U.S. Environmental Protection Agency, 1975, Interim primary drinking water regulations: 40 Code of Federal Regulations, Pt. 141, Federal Register, v. 40, no. 51, March 14, 1975, p. 11,990-11,998.

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The most difficult aspect of impact assessment on the trace-element character of the landscape, however, is that of assessing the broad-scaled regional effects. This is so because while changes in trace-element concentrations far from mines or powerplants will almost certainly be very small, the fear exists that such changes may still pose a potential hazard to plant, animal, or human health. This fear arises largely from the fact that the exact roles played by many trace elements in living tissue remain unclear or unknown and the relation of the local geochemical environment to biological health or disease is even more obscure. (See Hopps and Cannon, 1972; Cannon and Hopps, 1971.) Moreover, such assessment must be an interdisciplinary one. While it is the role of the natural scientist to determine the magnitude of man's contributions to the geochemical environment, it is the role of the medical scientist to determine what, if any, health hazard may ensue from that contribution.

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DESCRIPTION OF MAP UNITS SHOWN ON PLATE 1

(Modified from Hackman and Wyant, 1973)

Qay YOUNGER ALLUVIUM (QUATERNARY)--Relatively younger unconsolidated stream deposits

Qa ALLUVIUM (QUATERNARY)--Unconsolidated bouldery to sandy stream channel deposits

Qds DUNE DEPOSITS (QUATERNARY)--Deposits are chiefly quartz sand; includes active and inactive accumulations

Qls LANDSLIDE DEPOSITS (QUATERNARY)--Unsorted, commonly in large slumped blocks

Qac ALLUVIUM AND COLLUVIUM (QUATERNARY)--Unconsolidated stream, fan, talus, and slope wash deposits

Qgm GLACIAL MORAINE (PLEISTOCENE)--Till and other poorly sorted unstratified glacial deposits, located below rim of Aquarius Plateau

Qgo GLACIAL OUTWASH (PLEISTOCENE)--Stratified deposits of sand and gravel laid down by streams beyond margins of glacier

Qb BASALT (QUATERNARY)--0 to 100 m thick

QTb BASALT (QUATERNARY AND/OR TERTIARY)--Dark-gray thin basaltic lava flows, generally less than 70 m thick

QTu SURFICIAL DEPOSITS OF UNCERTAIN AGE (QUATERNARY AND/OR TERTIARY)

Tvu VOLCANIC ROCKS UNDIVIDED (TERTIARY)

Tvll LAVA FLOWS (MIDDLE TO LATE TERTIARY)--Basalt and basaltic andesite flows

Tvtl LATITIC ASH-FLOW TUFFS (MIDDLE TO LATE TERTIARY)

Tvbh RHYOLITIC ASH-FLOW TUFFS (MIDDLE TO EARLY TERTIARY)--Largely rhyolitic but contains some rhyodacitic ash-flow tuff, air-fall tuff, and reworked tuff; called Brian Head Formation by Gregory (1949, 1950b, and 1951)

Tw WASATCH FORMATION (TERTIARY)--Light-gray to pink, thick-bedded, fine grained, fluvial or lacustrine limestone, mudstone, and calcareous sandstone. Locally conglomeratic in upper part. Weathers to basland topography. Maximum thickness about 530 m

TKcp CANAAN PEAK FORMATION (UPPER CRETACEOUS AND PALEOCENE(?))--Light gray, pink or brown sandstone and conglomerate, clasts of quartzite, chert, porphyry, and limestone; forms slopes. Around Aquarius Plateau includes the overlying Pine Hollow Formation of Paleocene(?) age, a red and gray calcareous mudstone and bentonitic claystone, forms slopes. 0-460 m thick

Kk KAIPAROWITS FORMATION (UPPER CRETACEOUS)--Pale olive, friable, arkosic and biotitic continental sandstone. 700 to 1000 m thick

Kmv MESAVERDE FORMATION (UPPER CRETACEOUS)--Yellowish-gray, fine-grained to conglomeratic sandstone and thin interbeds of gray shale; located in easternmost part of area only. 100 m thick

Kws WAHWEAP AND STRAIGHT CLIFFS FORMATIONS UNDIVIDED (UPPER CRETACEOUS)

Kw WAHWEAP FORMATION (UPPER CRETACEOUS)--Yellowish-gray mudstone and well-cemented sandstone; forms ledgy cliffs and slopes. 300 to 500 m thick

Ks STRAIGHT CLIFFS FORMATION (UPPER CRETACEOUS)--Light-yellow, gray to white, fine- to coarse-grained locally conglomeratic crossbedded cliff forming sandstone; contains thin slope forming beds of shale, mudstone, and thin to thick beds of bituminous coal. Maximum thickness about 500 m

Km MANCOS SHALE (UPPER CRETACEOUS)--Nearshore continental and marine beds aggregating about 1000 m thick; consists of five members: an upper dark gray silty mudstone, carbonaceous shale and light-gray sandstone, 200-300 m thick (Masuk Member); a crossbedded pale-gray sandstone, mudstone, carbonaceous shale, and coal, 40-120 m thick (Emery Sandstone Member); a bluish-gray marine shale 400-500 m thick (Blue Gate Shale Member); a yellowish-brown lenticular sandstone and marine mudstone, coal in upper part, 50-120 m thick (Ferron Sandstone Member); and a lower dark-gray marine mudstone and shale, partly bentonitic, 170-220 m thick (Tununk Shale Member)

Kdt TROPIC SHALE AND DAKOTA SANDSTONE UNDIVIDED (UPPER CRETACEOUS)

Kt TROPIC SHALE (UPPER CRETACEOUS)--Dark bluish-gray calcareous marine shale. Weathers to slopes. 200 to 500 m thick

Kd DAKOTA SANDSTONE (UPPER CRETACEOUS)--Yellow to nearly white, and pale reddish-brown, cross bedded, coarse-grained sandstone and quartzite. Contains thin interbedded mudstone, carbonaceous shale and coal. 0-50 m thick

Ju JURASSIC UNDIFFERENTIATED--Near Escalante includes Morrison and Summerville Formations; near south end of Kaiparowits Plateau includes Summerville Formation and Entrada Sandstone; in southwestern part of map area includes some Entrada Sandstone but probably is largely the Winsor Member of the Carmel Formation

Jm MORRISON FORMATION (UPPER JURASSIC)--Maroon to light-bluish-gray continental sandstone, conglomeratic sandstone and bentonitic mudstone; thins west of Kaiparowits Plateau to a wedge edge. Includes Summerville Formation, a reddish to pale-brown sandstone and shaly siltstone in Straight Cliffs area. May include some Curtis Formation in northern part of area. 0-200 m thick

Je ENTRADA SANDSTONE (UPPER JURASSIC)--Upper pale-gray to brown eolian sandstone, a middle pale-reddish-brown marine siltstone and silty sandstone, and a lower reddish-brown to pale-gray fine-grained eolian sandstone. Total thickness about 300 m

Jc CARMEL FORMATION (MIDDLE JURASSIC)--Thin-bedded limy siltstone, friable sandstone, limestone and gypsum, all of marine origin. 50-300 m thick

JTrn NAVAJO SANDSTONE (TRIASSIC(?) AND JURASSIC)--Gray and yellowish-gray thickly crossbedded medium- to fine-grained eolian sandstone. Erodes to massive cliffs and domes. 150 to 600 m thick

Trk KAYENTA FORMATION (UPPER TRIASSIC(?))--Reddish-brown to pale-gray fluvial sandstone, siltstone, shale, and minor shale-pellet conglomerate and fresh-water limestone. Interfingers with overlying and underlying formations. About 80 m thick

Trmo MOENAVE FORMATION (UPPER TRIASSIC(?))--Composed of two fluvial members: an upper pale-reddish-brown, medium-grained, micaceous, cliff-forming sandstone and minor siltstone; and an underlying reddish-orange, coarse- to fine-grained, slope-forming friable sandstone, siltstone, and mudstone. Unit indicated on map only south of Cedar City. 0-130 m thick

Trw WINGATE SANDSTONE (UPPER TRIASSIC)--Reddish-brown, light-brown, grayish-orange, fine-grained, thickly crossbedded, calcareous eolian sandstone. Erodes to vertical cliffs. 0 to 130 m thick

Trc CHINLE FORMATION (UPPER TRIASSIC)--Varicolored beds of fluvial and lacustrine origin, generally sandy at top; limy, muddy, and bentonitic in middle; sandy and conglomeratic near base. 130 to 400 m thick

Trm MOENKOPI FORMATION (LOWER AND MIDDLE(?) TRIASSIC)--Reddish-brown, fine-grained shale and sandstone beds and thin gray marine limestone and evaporite tongues. 30 to 330 m thick

IPk KAIBAB LIMESTONE (PERMIAN)--Grayish-yellow, fossiliferous, cherty, thin- to thick-bedded dolomitic limestone and interbedded light-gray to brown siltstone and sandstone. 0-350 m thick. In Circle Cliffs area contains White Rim Sandstone Member of the Cutler Formation (called Coconino(?) Sandstone by some workers), a yellowish-orange, crossbedded, very fine grained, silty sandstone

SYMBOLS

CONTACT

FAULT--Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side

VOLCANIC CONE

CORRELATION OF MAP UNITS