Geology and Uranium Deposits at Crooks Gap, Fremont County Wyoming

GEOLOGICAL SURVEY BULLETIN 1147-F

Prepared on behalf of the
U.S. Atomic Energy Commission

Geology and Uranium Deposits at Crooks Gap, Fremont County Wyoming

By JAMES G. STEPHENS

With a section on

GRAVITY AND SEISMIC STUDIES IN THE CROOKS GAP AREA

By DON L. HEALEY

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1147-F

Prepared on behalf of the U.S. Atomic Energy Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in separate volume]

TABLES

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGY AND URANIUM DEPOSITS AT CROOKS GAP, FREMONT COUNTY, WYOMING

By James G. Stephens

ABSTRACT

The Crooks Gap area includes about 200 square miles in Fremont County, south-central Wyoming. In 1954, commercial uranium deposits were found in the central part of the area; by 1955, three mines were producing uranium ore and several uranium occurrences had been discovered by surface prospecting and drilling.

Near-surface uranium deposits are of erratic distribution, generally less than 20 feet across, only a few feet thick, and generally concordant with bedding. The deposits occur throughout a stratigraphic interval of about 1,500 feet.

Production from the area totaled about 4,200 tons to September 1957. However, drilling indicates the existence at depth of larger and more continuous deposits, and ore reserves of more than a million tons have been reported in sec. 16, T. 28 N., R. 92 W. These deep deposits are not considered in this report.

Exposed rock containing uranium in commercial quantities is confined to the lower folded member of the Battle Spring Formation of Eocene age and consists either (1) of sandstone impregnated with uranophane and autunite having minor amounts of uraninite, coffinite, and metatyuyamunite, or (2) of sandstone having no visible uranium minerals. Uraninite has been identified from a few deep samples.

Uranium also occurs in gouge along thrust faults at the northeast side of Crooks Gap. Preliminary development of these deposits below the weakly mineralized surface rock has failed to indicate an increase of uranium content with depth.

Rocks exposed in the area range in age from Precambrian to Recent. The Precambrian rocks, consisting predominantly of granite, crop out in a discontinuous band trending eastward across the central part of the area. Paleozoic rocks, which are about 2,065 feet thick, consist of limestone and sandstone containing some shale and are exposed only adjacent to faults in the central and east-central parts of the area. Rocks of Mesozoic age are also exposed in the central and east-central parts of the area; they consist largely of shale and beds of sandstone and are about 8,900 feet thick.

Rocks of Cenozoic age are present over most of the Crooks Gap area. The Fort Union Formation of Paleocene age is 0 to 960 feet thick and consists mostly of mudstone and some lenticular beds of conglomerate and sandstone in the lower part. The formation unconformably overlies the Cody Shale of Late Cretaceous

age and is unconformably overlain by the Battle Spring Formation of Eocene age. The Battle Spring Formation is as much as 4,700 feet thick and is exposed in most of the southern half of the area. It is made up of arkosic sandstone and conglomerate and lenticular beds of sandy carbonaceous siltstone. At Crooks Gap, an angular unconformity is believed to separate the formation into a lower folded member (member A) and an upper unfolded member (member B). The lower member is estimated to be 2,200 feet thick. Cobbles and pebbles of Paleozoic rocks are mixed with Precambrian granite detritus locally at the base of the member, but higher in the stratigraphic section cobbles and pebbles of granite predominate. The upper member (member B) is at least 500 feet thick in the gap but thickens southward to perhaps 2,500 feet within a few miles. The member contains large boulders of granite, some as much as 40 feet across, in the central part of Crooks Gap, but in the southern part of Crooks Gap both members A and B are finer grained and are difficult to distinguish.

Deposits of tuffaceous clayey siltstone of Oligocene age (White River Formation) are exposed in an area of about half a square mile near the north end of Crooks Gap. Although only 60 feet of these rocks are exposed, drilling north of North Happy Springs oil field indicates a subsurface thickness of about 900 feet.

Miocene rocks (Split Rock Formation) consisting of at least 950 feet of poorly consolidated tuffaceous sandstone and lenses of arkose in the lower part cover most of the northern half of the area.

A history of complex geologic activity that produced a structural relief on the Precambrian rocks of as much as 10,000 to 15,000 feet is recorded at Crooks Gap. The several episodes of folding and faulting in the area may be summarized as follows:

In Late Cretaceous time, folding of Mesozoic and Paleozoic rocks was followed by erosion of the folds at least to the Cloverly Formation of Early Cretaceous age. In Paleocene time, the Fort Union Formation was deposited on an irregular surface carved on folded Mesozoic rocks.

In Eocene time, imbricate sheets were thrust south and southwestward. Arkosic sediments derived from exposed granite areas were deposited as member A of the Battle Spring Formation, and continued compression may have folded the arkosic sediments. When compression relaxed, sediments of the upper part of the Battle Spring Formation (member B) were deposited on the complex structure. The Granite Mountains block was eroded, pediments were formed, and a gently sloping alluvial apron was extended southward to the Green River Lakes. Northwest-trending oil-producing structures, the south Happy Springs, Crooks Gap, and Sheep Creek anticlines, may have formed contemporaneously with this thrusting or may have formed earlier in Late Cretaceous time.

In Oligocene, Miocene, and Pliocene time, the area was covered by 3,000 feet or more of sediments rich in volcanic debris. Probably some of the higher peaks of the Granite Mountains remained above this sedimentary blanket.

In post-middle Miocene to post-Pliocene time, subsidence of the Granite Mountains block to the north of the Crooks Gap area produced large-scale normal faulting.

Since Pliocene time, erosion has removed the upper Tertiary rocks from the southern part of the area. Recent structural adjustment in the Crooks Gap area is indicated by an offset pediment surface.

Two factors are suggested as controls that influenced uranium deposition: (1) carbonaceous siltstone beds provided a local reducing environment where uranium might be precipitated from uranium-bearing ground water; (2) abrupt changes in permeability (caused by impermeable gouge along fault zones or by

facies changes from coarse-grained to finer grained material) effectively controlled the pattern of circulation of uranium-bearing ground water.

Preliminary exploration of deep deposits suggests that buried uranium deposits are concentrated in synclinal troughs of the lower folded member of the Battle Spring Formation.

Analysis of ground-water samples for uranium is an inexpensive technique of delimiting areas for intensive uranium prospecting. Analyses of four bulk water samples from Tertiary rocks suggest that the geochemistry of the source rock is related to the amounts of uranium, sodium, aluminum, phosphorus, manganese, strontium, and lead contained in the water.

Gravity and seismic measurements were obtained at Crooks Gap to define buried structure in this highly complex area. The gravity data are presented as three maps—a complete Bouguer anomaly map and two grid-residual maps. The gravity data exhibit numerous anomalies, most of which closely correlate with known geologic structure. One significant anomaly in Crooks Mountain quadrangle is a northwest-trending gravity low that delimits the southwest boundary of the Emigrant Trail thrust sheet penetrated by the Carter Oil Co. Immigrant Trail 1 test. A tie is thus provided between the Laramide thrust faults, which extend into the area from the northwest, and the faults exposed at the north entrance to Crooks Gap.

Both the gravity data and the seismic data indicate that a thrust sheet of Precambrian granite underlies the area between Crooks Gap and the Granite Mountains.

The combined reflection-refraction data define a rather smooth bedrock surface that dips southward from the Granite Mountains and extends to the Kirk normal fault. South of the Kirk normal fault, usable seismic data were not obtained.

INTRODUCTION

Uranium was discovered in Crooks Gap in December 1953. The discovery was made in the area of exposed reverse faults at the northeast side of Crooks Gap where uranium minerals were found coating fracture planes in faulted shale of Cambrian age. Radioactivity anomalies were detected in the southern part of the gap in February 1954 by prospectors using privately owned airborne scintillation equipment. Ground checking of these anomalies led to the filing of mineral claims and to the subsequent development of open-pit uranium prospects and mines. Prospecting in Crooks Gap as well as along the adjacent east-west mountainous belt has continued to the present time (April 1963).

The Geological Survey's work in the area, done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission, had the following objectives: (1) to prepare a geologic map, (2) to study the uranium occurrences, and (3) to determine, insofar as possible, the controls of uranium mineralization.

Fieldwork was conducted August through October 1954 and July through October 1955. M. J. Bergin, in 1954, and James Knox, in 1955, gave valuable assistance in the field.

713-808 O—64——2

Mapping was done on aerial photographs at a scale of approximately 1:27,700 for the northern two-thirds of the area and at a scale of approximately 1:38,400 for the southern third. Mapping outside the gap area was by reconnaissance methods.

The base map of the northern two-thirds of the report area was compiled from the Crooks Mountain, Crooks Creek NE (renamed Jeffrey City quadrangle in 1957), and Split Rock NW 7½-minute topographic quadrangle maps of the U.S. Geological Survey. The base map for the southern third of the area was compiled from the Bureau of Land Management's township plats surveyed in 1882. The geology of the report area is shown on plate 1 and a detailed map of the uranium deposits is included as plate 2.

Don L. Healey of the U.S. Geological Survey made a gravimetric survey in the area during September and October 1955. Additional gravimetric work and limited seismic studies during May 1956 completed the geophysical field investigations. A report of Healey's work is presented as the last section of this paper, pages F65–F78.

Published geologic reports on the region include studies by Bauer (1934), Blackstone (1951), Hares and others (1946), and Thomas (1949; 1951). Detailed studies of nearby areas by Bell (1950; 1954), Masursky (1962), Pipiringos (1955; 1961), Van Houten (1950; 1954; 1955), Van Houten and Weitz (1956), and Zeller, Soister, and Hyden (1956) aid in understanding the regional geologic setting.

During the field investigation, claim owners and prospectors were most helpful in making available mine maps and drill-hole information. Robert Adams, Hepburn Armstrong, Kenneth Baker, Norman Harrower, Raymond Thompson, and Jerry Whalen supplied useful mining information. The writer expresses particular thanks for stimulating field discussions to Eugene Grutt, Charles Bromley, Spencer Shannon, and Leo Stone of the U.S. Atomic Energy Commission. The Sinclair Oil and Gas Co. loaned well cuttings of Tertiary rocks. Wayne Chisholm identified the heavy-mineral suites of the Oligocene and Miocene rocks. F. B. Van Houten studied the cuttings of Tertiary rocks from Sinclair Oil Co. well 37 in the North Happy Springs oil field and proposed a subdivision of these rock units. N. M. Denson helped guide the fieldwork and contributed much to the preparation of the report.

GEOGRAPHY

The Crooks Gap area includes 200 square miles in southeastern Fremont County, south-central Wyoming (fig. 1). The area is about halfway between Rawlins, 56 miles to the southeast, and Lander, 58 miles to the northwest.

Access is gained from U.S. Highway 287, which crosses the northern part of the area. A graded road extends southward from the highway at Jeffrey City and leads to the uranium-producing area in Crooks Gap. Dirt roads extend from Crooks Gap southward across the Great Divide Basin (Red Desert) to Wamsutter, and southeastward to Bairoil.

The northern half of the area is a youthfully dissected surface that slopes from an elevation of about 7,000 feet northward for 7 miles to the Sweetwater River at about 6,300 feet. This surface is bounded on the south by the high north-facing escarpment of flat-topped erosional mountains (collectively called the Green Mountains) that extends eastward across the south-central part of the area. From west to east the mountains are Crooks Mountain (alt 8,310 ft), Crooks Peak (alt 7,750 ft), Sheep Mountain (alt 7,900 ft), and Green Mountain (alt 9,025 ft). Crooks Gap, at an altitude of approximately 6,600 feet, is a water gap about 2½ miles wide that separates Crooks Peak on the west from Sheep Mountain on the east. These geomorphic features are erosional remnants separated by low saddles

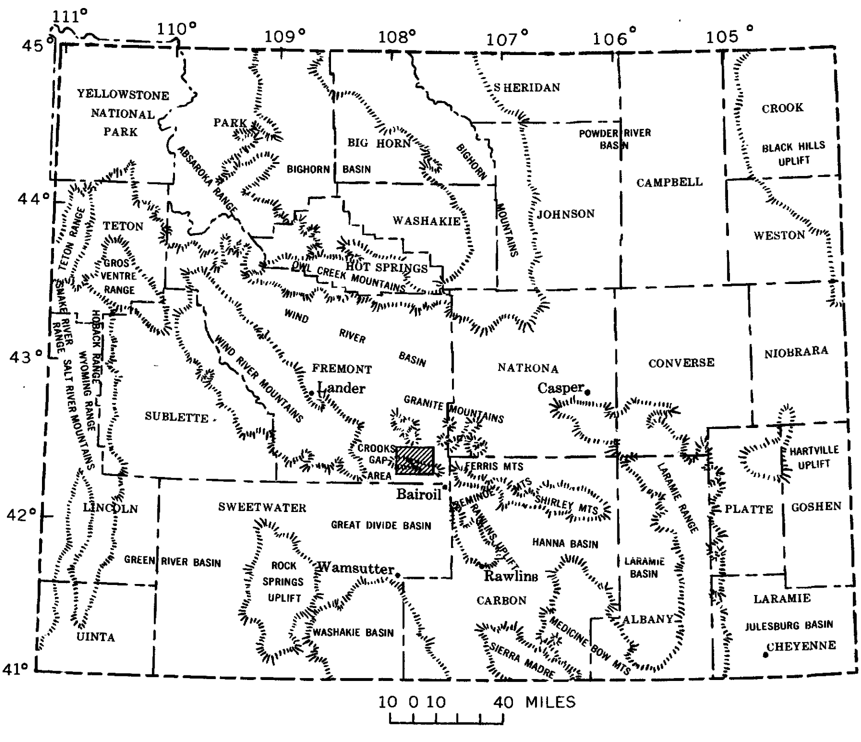


FIGURE 1.—Index map showing location of the Crooks Gap area, Fremont County, Wyo.

from Crooks Mountain to the west and from Green Mountain to the east. On the south side of Crooks Mountain a dissected surface slopes gently southward to merge with the surface of the Great Divide Basin. In contrast, a prominent escarpment forms the south side of Green Mountain, at the base of which is Crooks Creek.

Crooks Creek, a small spring-fed stream in its upper reaches, flows westward along the base of Green Mountain, and thence northward through Crooks Gap. After leaving the gap the stream is intermittent and is lost in sand before joining the Sweetwater River. Intermittent streams along the south side of Crooks Mountain flow southward into the Great Divide Basin, large topographic and structural basin that has interior drainage.

Vegetation at lower altitudes consists mostly of brush and short grasses. Cottonwood and aspen grow along the larger streams, and pine forests cover the mountain tops.

Livestock, oil, and uranium are the principal products of the area. Oil is produced from the Sheep Creek, Crooks Gap, and North and South Happy Springs fields.

STRATIGRAPHY

Rocks exposed in the Crooks Gap area range in age from Precambrian to Recent; however, inasmuch as known commercial uranium deposits are confined to rocks of Tertiary age, the stratigraphy of these rocks only is discussed in detail in this report. Brief descriptions and approximate thickness of all formations exposed in the area are presented in table 1.

Precambrian rocks consist of coarse-grained granite cut locally by basic dikes. The granite crops out discontinuously in an eastward-trending belt north of Sheep and Green Mountains. The rock is similar to that in the Granite Mountains immediately north of the map area, and is probably part of the same igneous mass.

Sedimentary rocks in the Crooks Gap area have a total thickness of approximately 17,500 feet. Folded and faulted sedimentary rocks of Paleozoic and Mesozoic age crop out in an area of about 16 square miles in Crooks Gap and eastward in the area of the Sheep Creek anticline. The Paleozoic formations consist mostly of limestone, sandstone, and some shale; they have a combined average thickness of about 2,000 feet. Mesozoic formations consist largely of shale and some sandstone; they have a combined average thickness of about 9,000 feet. Paleozoic and Mesozoic rocks in the Crooks Gap area are mostly of marine origin.

TABLE 1.—*Generalized section of formations exposed in the Crooks Gap area*

[Asterisk indicates oil-producing bed]

System	Series	Formation	Thickness (feet)	Lithology
Tertiary	Miocene	Split Rock	900–1,000	Grayish-pink fine- to medium-grained sandstone; rounded grains; poorly consolidated, tuffaceous; contains thin lenses of arkose near the base; weathers to subdued hills generally capped by pediment gravel.
		— Unconformity —		
Tertiary	Oligocene	White River	850–950	Grayish-pink friable clayey tuffaceous siltstone; weathers to blocky fragments; generally concealed by gravel.
		— Unconformity —		
Tertiary	Lower Eocene	Battle Spring	2,700–4,700	Interbedded arkosic sandstone, granite-boulder conglomerate, and lenticular carbonaceous siltstone; generally very light gray having brown and red iron staining; consists of an upper unfolded unit (member B) and a lower folded unit (member A); known uranium deposits at Crooks Gap occur in member A.
		— Unconformity —		
Tertiary	Paleocene	Fort Union	0–960	Predominantly silty mudstone; interbedded with thin units of carbonaceous shale, impure coal beds, and thin drab sandstone lenses; thin lenses of dark chert-pebble conglomerate near the base; weathers to gentle slopes.
		— Unconformity —		
Cretaceous	Upper Cretaceous	Cody Shale	5,000–5,500	Sandy shale and thin-bedded buff sandstone in upper half; gray to light-gray and tan shale and sandy shale in lower half; calcareous in part; nonresistant at Crooks Gap except for a few thin cross-laminated beds of sandstone that make small ledges; generally covered by alluvium or colluvial gravel.
Cretaceous	Upper Cretaceous	*Frontier	775–825	Sandstone and shale; sandstone is gray, fine to medium grained fossiliferous; contains abundant dark grains; shale is dark gray to black, sandy to silty; formation generally concealed by slope wash.
Cretaceous	Lower Cretaceous	Mowry Shale	450–525	Black to dark-gray siliceous shale; weathers light gray; contains fish scales: siltstone and bentonitic shale in upper part and bentonite beds in lower part.
Cretaceous	Lower Cretaceous	*Thermopolis Shale	125–135	Black soft flaky shale; some fine-grained rust sandstone, gray siltstone, and light-gray bentonitic beds. Muddy sandstone members* (20 to 40 ft thick) in upper half is light gray, fine grained; shaly in part, weathers rusty. Formation very poorly exposed or covered by slope wash in Crooks Gap area.
Cretaceous / Jurassic	Lower Cretaceous / Upper Jurassic	*Cloverly and Morrison Formations, undifferentiated.	350–425	Cloverly formation (Lower Cretaceous) sandstone and shale; sandstone is light gray, fine to coarse grained, sparkly; weathers rusty and contains some dark shale interbeds; sandstone underlain by conglomerate which is gray, weathers brown, contains black chert pebbles, is cross-laminated, and grades laterally into sandstone; sandstone and conglomerate form a prominent hogback around Sheep Creek anticline. Morrison Formation (Upper Jurassic) is variegated claystone having few sandstone ledges, usually poorly exposed. Lower contact is placed at base of 15-ft massive clean white sandstone which forms low ridge.
Jurassic	Upper Jurassic	Sundance	175–350	"Upper Sundance" is interbedded sandstone, shale, and limestone. Sandstone is green, highly glauconitic, shaly in part; contains numerous *Belemnites* in lower part; limestone is brown, glauconitic, shaly in part; includes coquinite of large pelecypods. "Lower Sundance" is sandstone and shale; sandstone is buff to light gray, near top includes two thin red shaly zones; shale is pale green, sandy in part, calcareous in part.

TABLE 1.—*Generalized section of formations exposed in the Crooks Gap area*—Con.

System	Series	Formation	Thickness (feet)	Lithology
Jurassic—Con.	Lower Jurassic	*Nugget Sandstone	225–300	Clean sparkly sandstone having large-scale cross-laminations; friable; weathered surface is pustulate or covered with small knobs; double maxima in grain size.
		Unconformity		
Triassic		Chugwater	1,285–1,340	Dark-red, sandstone and siltstone, shaly in part, calcareous in part; generally nonresistant. Alcova Limestone Member, which is about 6 ft thick, is about 330 feet below the top of the formation. The limestone is a gray, hard, laminated or ribboned, fine-grained limestone which forms hogback.
		Dinwoody	50–100	Upper half is shale and sandstone, gray to tan, calcareous; lower half is silty, dolomitic sandstone and shale. Poorly exposed or covered in Crooks Gap area. Chugwater and Dinwoody Formations were not subdivided in mapping, and the Triassic includes both formations.
Permian		*Phosphoria	300–375	Gray to brown, dolomitic siltstone and dolomite, having some bedded chert and thin phosphatic zones; exposed only in thrust slices.
		Unconformity		
Carboniferous	Pennsylvanian	Tensleep Sandstone	400–500	Gray to rust-colored fine- to medium-grained resistant sandstone, cross-laminated in part, calcareous in part; some white dolomite and cherty dolomite; exposed in Crooks Gap area only along reverse fault zones.
		Amsden	190	Red to gray sandstone and shale, silty near top and in lower middle part; cherty gray limestone and dolomite in upper middle part; sandstone at base, rust to reddish, fine grained, thick bedded, slightly calcareous. Unit is poorly exposed in Crooks Gap area.
	Mississippian	Madison Limestone	325	Light-gray fine-grained limestone, birdseye structure on weathered surface; beds 3 to 6 inches thick; dark chert lenses; very resistant; slightly fossiliferous.
Cambrian		Undivided	750	An upper thin-bedded reddish-brown siltstone and sandstone sequence, argillaceous, glauconitic poorly, fossiliferous; a middle sandy calcareous zone having thin gray glauconitic limestone beds separated by thin red shaly units and edgewise conglomerate; lower zone composed of red quartzite and quartzitic sandstone and cross-laminated arkosic conglomeratic sandstone.
		Unconformity		
Precambrian		Undivided		Predominantly granite, cut by basic dikes. Granite exposed in Crooks Gap area is similar to that of Granite Mountains north of the area. Metamorphic rocks also are prominent in the Granite Mountains.

Most of the Crooks Gap area is covered by nonmarine sedimentary rocks of Tertiary age, including the Fort Union Formation of Paleocene age, the Battle Spring Formation of Eocene age, the White River Formation of Oligocene age, and the Split Rock Formation of Miocene age. Thicknesses of individual formations vary considerably from place to place because of at least two angular unconformities within the Tertiary sequence. Moreover, poor exposures and structural complexities make accurate thickness measurements difficult, but the estimated maximum thickness of the lower Tertiary rocks (Battle Spring and Fort Union Formations) at Crooks Gap is 5,400 feet.

This thickness may increase directly south of the gap because of probable downfolding of the Great Divide Basin in Eocene time. Upper Tertiary rocks, in the central part of the area, may be as much as 1,900 feet thick.

TERTIARY SYSTEM

PALEOCENE SERIES

FORT UNION FORMATION

In Crooks Gap, the Fort Union Formation consists of nonresistant mudstone and subordinate amounts of sandstone and conglomerate in thin beds and lenses (fig. 2). The formation unconformably overlies the Cody Shale of Late Cretaceous age and is unconformably overlain by the Battle Spring Formation of Eocene age.

The Fort Union Formation is exposed in discontinuous narrow belts around the flanks of Crooks Gap, Spring Creek, and Sheep Creek anticlines. The upper contact is generally masked by arkosic debris derived from the weathering of the overlying Battle Spring Formation. The lower contact with the Cody Shale is masked by a mantle of soil or alluvium. Because of poor exposures, structural complexity, and unconformities both at the base and the top of the formation, it is difficult to determine its true thickness. In the N½ sec. 17, T. 28

FIGURE 2.—Exposure of Fort Union Formation, NE¼ sec. 17, T. 28 N., R. 92 W.

N., R. 92 W., the Fort Union has a minimum thickness of about 660 feet.

Silty mudstone interbedded with thin units of carbonaceous shale, impure coal beds, and thin lenticular cross-laminated beds of sandstone make up most of the Fort Union Formation. The lower part of the formation consists of light-gray mudstone and sandstone alternating with dark-gray beds of carbonaceous mudstone, and conglomeratic beds of dark chert-pebbles and light-gray siliceous shale chips; in the upper part, the mudstone and sandstone are pinkish and greenish gray, and the drab colors, carbonaceous zones, and conglomeratic lenses characteristic of the lower part of the unit are absent. Brown iron-oxide staining is found throughout the formation. Where exposures are lacking, the presence of the Fort Union is sometimes indicated by float containing black chert pebbles and white siliceous shale chips. Lithologic details are given in the following section.

Stratigraphic section of the lower part of the Fort Union Formation in N½ sec. 17, T. 28 N., R. 92 W., Fremont County, Wyo.

[The top of the measured section is the base of a gravel-covered slope and is about 300 feet stratigraphically below the break in topography mapped as the base of the Battle Spring Formation]

	Thickness (feet)
Fort Union Formation (part):	
Mudstone, silty, massive, pale red-brown; weathers to dull maroon	19
Mudstone, silty, light yellow-green; has red bands; bentonitic (?)	56
Mudstone, bentonitic (?); contains small iron-stained concretionary masses	52
Pebble conglomerate; contains iron-stained yellow-brown pebbles of black chert, white siliceous shale, and sandstone; lenticular	4
Mudstone, silty, light-gray; contains a few lenses of brown iron-stained, very fine to fine-grained sandstone and carbonaceous sandstone	239
Pebble conglomerate; pebbles of black chert, gray and brown sandstone, and siliceous shale in a matrix of light-brown to gray, poorly sorted sandstone; lenticular	17
Sandstone, very fine grained, clayey; carbonaceous streaks; iron stained in streaks; massive	49
Sandstone, very fine grained, light-gray, silty, carbonaceous; coaly streaks; irregular wavy bedding	3
Shale, carbonaceous, silty, light grayish-brown, soft	2
Mudstone, poorly exposed, silty; near middle of unit is layer of dark brown-purple ironstone concretions about 1 ft thick	66
Covered interval	120
Mostly covered; upper 0.5 ft is carbonaceous shale	6
Siltstone, very clayey, poorly exposed	27
Total	660
Unconformity.	
Cody Shale (part):	
Shale, sandy, dark-gray, iron-stained along bedding; strike N. 19° E., dip 20° NE	50+

The contact of the Fort Union Formation with the underlying Cody Shale is largely concealed, but the few exposures observed indicate slight discordance of dip, as in the SW¼ sec. 17, T. 28 N., R. 92 W. Similarly, the Fort Union-Battle Spring contact is poorly exposed, but an unconformable relation is shown by the truncation of the Fort Union Formation by the overlying Battle Spring Formation at several places in Crooks Gap (pl. 1).

The fine grain size of the rocks comprising most of the Fort Union Formation, together with the presence of carbonaceous shale and impure coal beds, suggests deposition by sluggish aggrading streams on a broad flood plain. Lenses of chert-pebble conglomerate probably represent channel deposits, and the carbonaceous and other fine-grained sediments represent deposits in areas marginal to the main streamflow.

The Fort Union Formation in the area is assigned to the Paleocene because of its stratigraphic position above folded Cretaceous rocks and below Eocene rocks. Lithologic similarity to dated Paleocene strata on the south side of Bison Basin (SE¼ sec. 28, T. 27 N., R. 95 W.) tends to support the designation (Bell, 1954; Gazin, 1956; Pipiringos, 1961).

R. W. Brown (written communication, 1958), of the U.S. Geological Survey, has identified *Metasequoia occidentalis* (Newberry) Chaney and *Platanus* sp. from a sandy ironstone layer in the Fort Union Formation near the base of the north-facing slope of the SE¼SE¼ sec. 17, T. 28 N., R. 92 W. Brown has tentatively identified the age of the fossils as Paleocene.

EOCENE SERIES

BATTLE SPRING FORMATION

The name Battle Spring Formation was applied by Pipiringos (1955, p. 103) to a thick sequence of arkosic sandstone of deltaic-fluviatile origin that underlies much of the Great Divide Basin directly south of the Crooks Gap area and ranges in age from earliest Eocene through early middle Eocene. The Battle Spring Formation of this report denotes an arkosic sequence of friable conglomerate, conglomeratic sandstone, and sandstone that, although of coarser grain size, is grossly similar in lithology to the rocks described by Pipiringos (1955, p. 103). In Crooks Gap, the Battle Spring Formation unconformably overlies the Fort Union Formation, or older rocks where the Fort Union is absent.

The Battle Spring Formation has the largest areal distribution of any formation mapped. It is exposed as the present topographic surface south of the central part of the area, except where overlain by Quaternary alluvium, alluvial fans, or pediment deposits. North of the central part of the area the subsurface distribution of equivalent rocks is only locally known. A thin arkosic sequence penetrated by oil tests in the north-central part of T. 28 N., R. 93 W., is thought to be equivalent to the Battle Spring of the southern part of the area. A test bore in the northwest corner of T. 28 N., R. 91 W., indicates that rocks of Oligocene age rest directly on Precambrian granite.

Thickness of the Battle Spring Formation is probably variable over the area. In the southern part of the area, the thickness probably ranges from 2,700 to 4,700 feet and is greatest at the southern entry to Crooks Gap. In the northern part of the area, the subsurface thickness of the Battle Spring (sec. 4, T. 28 N., R. 93 W.) is about 300 feet.

At Crooks Gap the unit is resistant to erosion because the coarse grain size and high permeability of the rock minimize the eroding effect of running water. Most of the formation is covered with weathered rock debris, and there are few natural outcrops. The formation generally weathers to rounded mountain slopes, although monuments and hoodoo remnants are left standing at a few places.

In Crooks Gap, the formation is divisible into two members—a lower one, referred to as member A, and an upper one, referred to as member B (fig. 3). In Crooks Gap, member B is characteristically much coarser than member A and has a reddish or orange tint due to iron staining, whereas rocks of member A appear bleached or almost white. In addition, member B is purer arkosic sediment; that is, it does not contain as much Cambrian quartzitic material and other Paleozoic debris as rock of member A. Before the southern end of Crooks Gap is reached, however, both members appear to grade to coarse-grained arkose and apparently are no longer lithologically distinct. Until these relations can be proved by evidence from additional excavations and drilling, the division into two members should be considered tentative.

Member A of the Battle Spring Formation

Member A of the Battle Spring Formation has been identified only in Crooks Gap where it occurs in the lower parts of the gap, part way up the slopes of Crooks Mountain on the west, and on the north and west lower slopes of Sheep Mountain to the east. A horizontal zone of denser vegetation on the mountain slopes is believed to mark the contact of the member with the overlying member B. Below this vegetation zone, a colluvial mantle of large granite boulders derived from the overlying member B commonly conceals most of member A. Known uranium deposits occur in member A.

Reliable thickness determinations of member A are not yet available because of its complex structure, poor exposures, and vague contact relations. An estimate based on available dips and map measurements

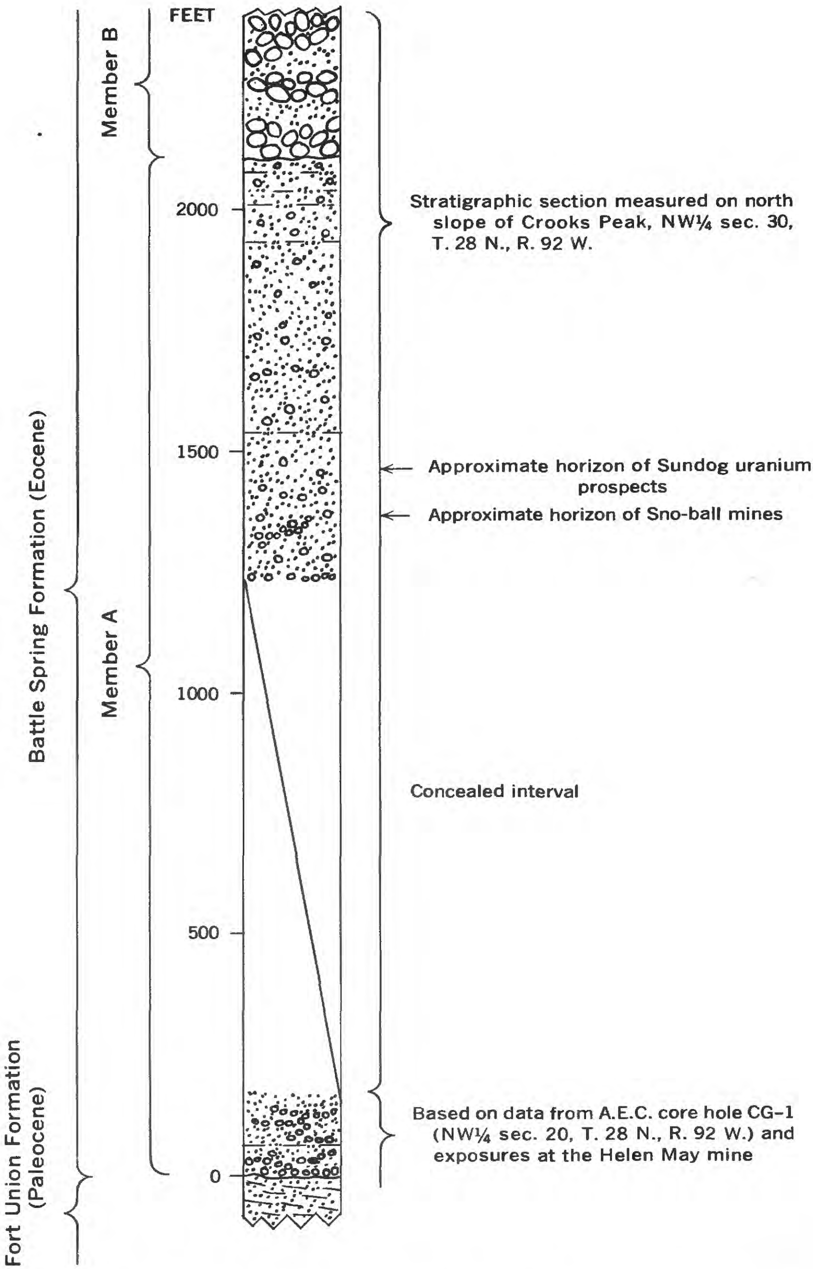


FIGURE 3.—Generalized stratigraphic section of part of the Battle Spring Formation, Crooks Gap.

indicates a thickness of at least 2,200 feet in the west slope of Sheep Mountain.

The unit is composed of three major rock types, which, in order of decreasing abundance, are: conglomeratic arkose, cobble and boulder conglomerate, and carbonaceous siltstone.

The conglomeratic arkose (fig. 4) is cross laminated, friable, stained by bands of iron oxides, and composed principally of angular grains of quartz, partly weathered feldspar, and mica. The rock is poorly sorted; granite pebbles are scattered throughout. Fine- and coarse-grained layers alternate and cut-and-fill structures are common. Cross-lamination is similar to types generally attributed to stream deposition.

Lenses of boulder- and cobble-conglomerate occur throughout the formation. In the lower part, the conglomerate lenses are sparse and the larger fragments average less than 6 inches in diameter. Higher in the member, the lenses are more abundant and the average diameter of the larger fragments increases to approximately 1 foot. The composition of the cobbles and boulders varies little throughout most of the member. The predominant lithologic type is granite that is similar to Precambrian granite exposed in the Granite Mountains to the north. At the northernmost exposures, however, marked variations may

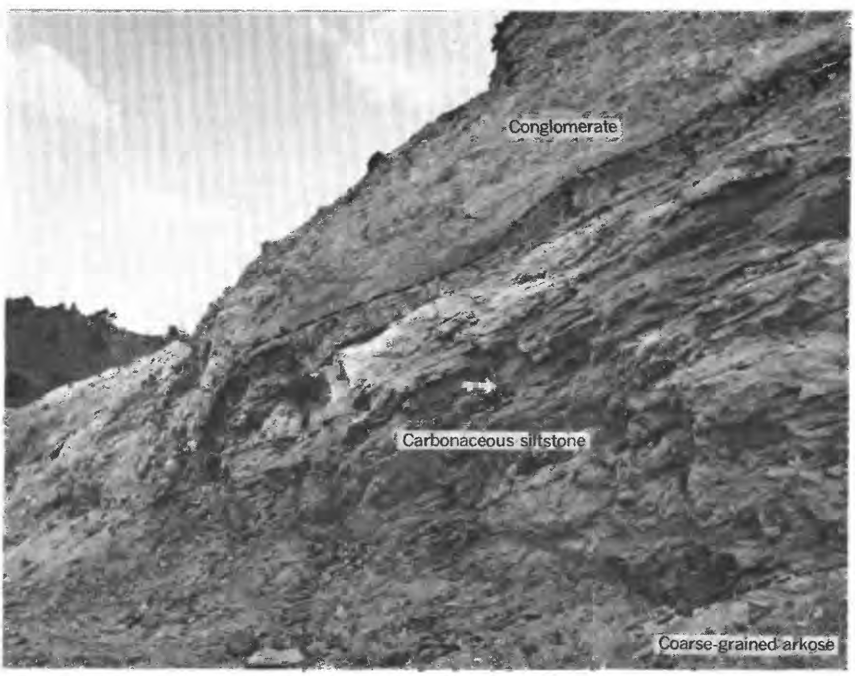


FIGURE 4.—Beds of member A of the Battle Spring Formation at the Sno-ball mines, SE¼ sec. 29, T. 28 N., R. 92 W.

occur in the type of boulders comprising the basal conglomerate. The basal 80 feet of member A, in the SE¼ sec. 8, T. 28 N., R. 92 W., is composed of large blocks of limestone, edgewise conglomerate, and red quartzite derived from erosion of Paleozoic beds (fig. 5). Granite boulders are rare at this exposure. Higher on the slopes at this locality, fragments of Paleozoic rocks are less numerous and granitic cobbles and boulders are abundant; progressive erosion of nearby Paleozoic formations and exposure of the granite during deposition of member A are thus indicated. A mile to the south, the larger fragments in the basal zone decrease in size to an average diameter of 3 to 6 inches and granite cobbles are fairly abundant.

The carbonaceous siltstone beds (fig. 4) in member A are lenticular and are generally less than 3 feet thick. The rock is sandy, poorly sorted, and has coarse grains of quartz, feldspar, and rock fragments scattered in a clayey silt matrix. Poorly preserved plant fossils and coaly streaks are abundant. The lower contacts of the siltstone lenses are generally sharp, whereas the upper contacts are gradational at many places. The carbonaceous beds are economically important, for uranium seems to be localized near them.

FIGURE 5.—Basal conglomerate of member A of the Battle Spring formation composed largely of boulders derived from Cambrian and Mississippian rocks, SE¼ sec. 8, T. 28 N., R. 92 W.

MEMBER B OF THE BATTLE SPRING FORMATION

Member B of the Battle Spring Formation is a sequence of conglomeratic arkose and giant boulder conglomerate. The very coarse grain size and the reddish to orange tint serve to identify the member at Crooks Gap. Member B has the largest areal distribution of any unit studied in the area. Crooks Mountain, Crooks Peak, and Sheep and Green Mountains are capped by rocks tentatively assigned to the member.

The member has considerable variation in thickness because of an unconformity at the base and an erosional surface at the top. The member is at least 500 feet thick at the north end of Sheep Mountain, but it may be as much as 2,500 feet thick directly south of Crooks Gap.

The best exposures of member B of the Battle Spring Formation are on the north slope of Sheep Mountain, sec. 21, T. 28 N., R. 92 W. There the rock is a granite boulder conglomerate that contains many boulders 6 feet across and some as much as 20 feet across. In places the conglomerate weathers to pinnacles as much as 40 feet high (fig. 6).

The conglomeratic unit apparently becomes finer grained southward, and at the south end of Sheep Mountain the member is very

FIGURE 6.—Pinnacles on the north slope of Sheep Mountain showing the granite boulder conglomerate of member B o fthe Battle Spring Formation, NE¼ sec. 21, T. 28 N., R. 92 W. Scale line is 3.3 feet long.

coarse grained arkose similar to lithologic types found in member A.

Sedimentary studies of the Battle Spring Formation in the Crooks Gap area and studies made in the Great Divide Basin to the south (Masursky and Pipiringos, 1959; Masursky, 1962; Pipiringos, 1961) indicate a fluviatile origin for formation in this region. Erosion of the uplifted granite in the Granite Mountains block to the north provided abundant arkosic sediment that was transported southward and deposited as great alluvial fans. The decrease upward of fragments of Paleozoic rocks and the increase of granite record progressive stripping of Paleozoic and Precambrian rocks, and the size of the larger rock fragments suggests a nearby source. The arkosic sediments were transported by streams that, near the mountain fronts, were competent to move boulders. At many places these stream channels shifted, and the old channels, which contained boulders, were buried by finer material. In some places poorly drained abandoned stream channels were filled by fine sediments and organic debris that now constitute some of the carbonaceous plant-fossil-bearing clayey silt-stone beds. Some of the slightly carbonaceous beds may have been deposited as mudflows moving down the alluvial fan surface.

The giant boulders included in member B probably indicate increasingly steep gradients during late Battle Spring time, such as might be produced by an evolving steep fault escarpment. The Granite Mountains block was probably raised to mountainous heights and the great flood of arkosic material making up member B buried the older Battle Spring rocks. These alluvial fans were built out into the Eocene Green River lakes and presumably interfinger with the lacustrine deposits comprising the Green River Formation to the southwest (Bradley, 1926, 1945; Pipiringos, 1955, p. 101).

The abrupt thinning of the Eocene rocks in the northern part of the area has yet to be satisfactorily explained because of the lack of subsurface information over the greater part of the northern area. The hypothesis is suggested that during Eocene time the northern half of the area was covered by a granite thrust sheet that shed great amounts of arkosic debris into the low area to the south. Gradually the low area was filled, the granite thrust mass was reduced by erosion, and broad pediments were formed in the northern part of the area. The gravel veneer on the pediment surface would have been much thinner than the alluvial-fan material deposited in front of the thrust mass. The zone of later normal faulting occupied almost the same zone as that occupied by the earlier faults bounding the thrust sheet. This hypothesis and alternate ideas are considered more fully in the section on geologic history (p. F37).

Correlation of the Battle Spring Formation with rocks in adjacent areas is as yet speculative because of the lack of diagnostic fossils at Crooks Gap. Probably the rocks are in part equivalent to the Battle Spring Formation of the Great Divide Basin. A correlation also possibly exists with the Wind River Formation to the north, which in the Gas Hills area is uranium bearing (Zeller, Soister, and Hyden, 1956). The fine-grained facies described by Zeller as occurring in the lower part of the Wind River Formation has no apparent counterpart at Crooks Gap, and the upper coarse-grained facies of Zeller may correspond to the Battle Spring Formation of this report.

No identifiable fossils were found in the formation. Absence of volcanic constituents such as might have been derived from the Rattlesnake volcanic field 35 miles to the northeast, which was active in middle and late Eocene time (Carey, 1954), suggests that the formation does not include rocks of middle or late Eocene age.

OLIGOCENE SERIES

WHITE RIVER FORMATION

The White River Formation consists of nonresistant pinkish-gray clayey siltstone exposed discontinuously in a narrow zone trending eastward across the central part of the map. The formation is poorly exposed or is concealed by a thin veneer of debris in the map area. About 60 feet of White River crops out in the NE¼ sec. 9, T. 28 N., R. 92 W., in a validation pit and in the gentle slope to the east. The formation at this locality rests on Precambrian granite. Study of well cuttings from Happy Springs Unit 37 well, sec. 4, T. 28 N., R. 93 W., indicates a thickness of 890 feet (from depths of 930 to 1,820 ft) of Oligocene rock. The Tertiary rocks, penetrated between 1,820 and 2,100 feet in depth, may represent a coarse basal unit of the Oligocene, but the writer believes, on the basis of lithologic similarity, they are more likely equivalent to part of the Battle Spring Formation. Comparison of the electric log of Unit 37 with that of the Split Rock wildcat hole (sec. 5, T. 28 N., R. 91 W.) suggests that in the latter locality Oligocene rocks are about 700 feet thick and are resting on Precambrian granite.

The White River Formation in the Crooks Gap area is pinkish gray and is an argillaceous, tuffaceous siltstone that, on weathering, breaks down to small angular blocks (fig. 7). No bedding is evident in the limited exposure studied. The heavy-mineral suite (table 2) is characterized by abundant apatite, epidote, clinozoisite, and biotite.

Oligocene rocks in Crooks Gap are correlated, on the basis of similarity of lithology and heavy mineral content, with the White River Formation of Oligocene age described by Van Houten (1954) in the

TABLE 2.—*Heavy minerals identified in the White River Formation, NE¼ sec. 9, T. 28 N., R. 92 W., Fremont County, Wyo.*

[Heavy minerals separated in bromoform; minerals identified from 0.061–0.250 mm fraction. Mineral identifications by Wayne Chisholm]

Mineral	Grains counted	Percent of total nonopaque minerals	Mineral	Grains counted	Percent of total nonopaque minerals
Apatite	28	23	Andalusite	3	2
Epidote	21	17	Hornblende, brown	2	2
Clinozoisite	18	15	Zoisite	1	<1
Biotite:			Rutile, golden	1	<1
Red-brown	16	13	Tourmaline, light-brown	1	<1
Brown	14	12	Opaque minerals	79	
Green-brown	9	7			
Garnet:			Total	200	
Light-violet	4	3			
Colorless	3	2			

Long Creek-Beaver Divide area. Comparison of rapid rock analyses of the White River Formation in Crooks Gap with analyses of rocks of known Oligocene and Miocene age indicates a greater similarity to rocks of Oligocene age, as shown in table 3. No fossils were found at Crooks Gap to substantiate the Oligocene designation of these rocks.

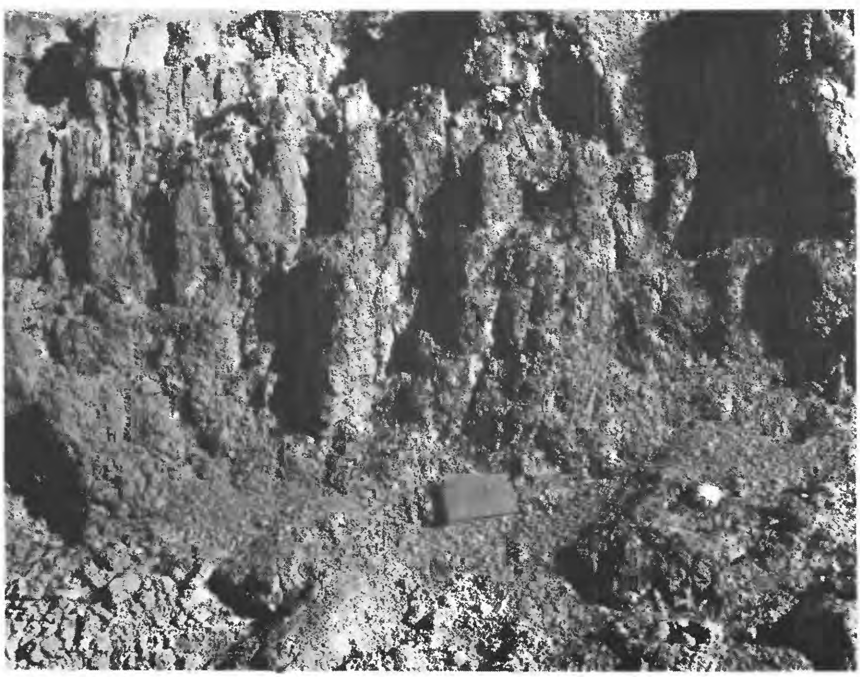


FIGURE 7.—Clayey tuffaceous siltstone of the White River Formation showing characteristic blocky weathering of the soft massive siltstone, NE¼ sec. 9, T. 28 N., R. 92 W. The long dimension of the notebook is 8.5 inches.

713–808 O—64——4

TABLE 3.—*Analyses, in percent, of representative samples of Oligocene and Miocene rocks from Wyoming*

[Analyses by S. D. Botts, Paul Elmore, and K. E. White. All samples except 14771 were collected by J. D. Love. Samples analyzed by rapid methods similar to those described by Shapiro and Brannock (1956)]

Laboratory	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O	CO_2
Oligocene rocks—Gas Hills area													
143215 [1]	62.6	14.2	2.3	0.63	1.8	2.2	1.5	3.5	0.37	0.23	0.04	10.4	0.12
143214 [2]	62.3	13.5	2.6	.44	1.6	3.8	1.7	3.4	.38	.22	.06	8.9	1.4
143216 [3]	62.8	13.8	2.5	.42	1.9	2.4	1.5	3.2	.36	.22	.06	10.5	.28
Average	62.6	13.8	2.5	.50	1.8	2.8	1.2	3.4	.37	.22	.05	9.9	.60
Oligocene rocks—Crooks Gap area													
14771 [4]	61.6	14.4	3.9	0.06	2.8	1.4	0.49	1.9	0.56	0.09	0.09	12.0	0.08
Middle Miocene rocks—Crooks Gap and Jackson Hole areas													
143218 [5]	72.0	12.1	1.1	0.90	0.19	0.81	2.1	6.0	0.22	0.14	0.02	4.9	<0.05
143217 [6]	69.2	12.5	1.5	.74	.70	1.1	1.2	6.0	.24	.13	.02	7.7	<.05
Average	70.6	12.3	1.3	.82	.45	.96	1.7	6.0	.23	.14	.02	6.3	<.05

[1] White River Formation, upper part; SE¼ sec. 3, T. 30 N., R. 96 W. (Van Houten, 1950, section 2).
[2] White River Formation, 50 feet above base of lower gray unit just above Beaver Divide Conglomerate Member; NW¼NE¼ sec. 2, T. 30 N., R. 96 W. (Van Houten, 1950, section 6).
[3] White River Formation, just south of Gas Hills uranium area; SW¼ sec. 22, T. 32 N., R. 89 W.
[4] White River Formation, Crooks Gap area; NE¼ sec. 9, T. 28 N., R. 92 W.
[5] Upper part of Split Rock Formation, Split Rock fossil locality; SE¼NW¼ sec. 25, T. 29 N., R. 89 W.
[6] Upper part of Colter Formation, Pilgrim Creek area, Jackson Hole; NE¼ sec. 29, T. 46 N., R. 114 W.

MIOCENE SERIES

SPLIT ROCK FORMATION

The Split Rock Formation (Love, 1961) is a sequence of tuffaceous sandstone of Miocene age that covers most of the northern half of the Crooks Gap area. The best exposures are at drilling excavations in the North Happy Springs oil field, particularly in the SW¼ sec. 19, T. 29 N., R. 93 W.

Light pinkish-gray fine- to medium-grained unconsolidated tuffaceous sandstone (fig. 8) makes up most of the Split Rock Formation in the area. The sand grains are mostly well rounded. Bedding is massive to cross laminated on a large scale, but is obscure at many outcrops. The basal part of the formation contains lenses of poorly cemented arkosic conglomerate that locally weathers to irregular honeycombed surfaces and indicates an irregular distribution of carbonate cement. Vertical cylinders of sandstone cemented by calcium carbonate also occur at a few outcrops. Green augite, green-brown hornblende, and hypersthene are the common heavy minerals (table 4).

TABLE 4.—*Heavy minerals identified in the Split Rock Formation, NW¼ sec. 36, T. 29 N., R. 90 W., Fremont County, Wyo.*

[Heavy minerals separated in bromoform; minerals identified from 0.061–0.250 mm fraction. Mineral identifications by Wayne Chisholm]

Mineral	Grains counted	Percent of total nonopaque minerals	Mineral	Grains counted	Percent of total nonopaque minerals
Augite, green	49	43	Apatite	1	<1
Hornblende, green-brown	25	22	Hornblende:		
Hypersthene	22	19	Red-brown	1	<1
Hornblende, brown	7	6	Green	1	<1
Garnet, light-violet	3	3	Opaque minerals	56	
Epidote	2	2			
Clinozoisite	2	2	Total	169	

The Split Rock Formation lies unconformably on Precambrian granite in secs. 1, 11, and 12, T. 28 N., R. 92 W.; it is faulted against Battle Spring Formation of Eocene age or older formations at other places in the central part of the Crooks Gap area and overlies rocks mapped as Oligocene at still other places. Detailed observations of the Split Rock Formation are not possible because of the generally poor exposures. Gentle southward dips probably characterize these rocks in the northwest part of the area. In the northeastern part of

FIGURE 8.—Massively bedded tuffaceous sandstone of the Split Rock Formation in the NE¼SE¼ sec. 5, T. 28 N., R. 93 W.

the map area, however, structural complexities exist, such as the faults in sec. 4, T. 28 N., R. 91 W.

The formation is correlated with lithologically similar rocks of Miocene age in the Long Creek-Beaver Divide area 17 miles to the north, described by Van Houten (1954), and with similar rocks of Miocene age at Split Rock 6 miles to the east, described by Schultz and Falkenbach (1940), McGrew (1951), and Love (1961, p. I19). The snout of a skull identified by G. E. Lewis (written communication, 1955) as *Procamelus* or a *Hesperocamelus*-like species of probable Miocene age (late Hemingfordian to early Barstovian provincial ages of wood and others, 1941) was found in the upper part of the formation in the SW¼ sec. 10, T. 29 N., R. 93 W., and tends to substantiate the correlation. As much as 300 feet of fossiliferous Miocene rock of similar lithology in the northern part of the Great Divide Basin, a few miles to the south, has also been described by Pipiringos (1955).

Miocene rocks in the Long Creek-Beaver Divide area have a thickness of at least 275 feet (Van Houten, 1954), but the sequence thickens southward and in Happy Springs Unit 37 well, sec. 4, T. 28 N., R. 93 W., the Split Rock Formation is at least 930 feet thick.

QUATERNARY SYSTEM

WINDBLOWN SAND

An area of 16 square miles of windblown sand was mapped in the north-central part of the Crooks Gap area. The surface contains numerous shallow deflation depressions in a pattern evidently controlled by vegetation. Source areas of the sand include exposures of unconsolidated Miocene rocks to the west, and the large area of Eocene arkosic rocks to the south from which sediment was transported by Crooks Creek. The carrying power of Crooks Creek is reduced by seepage as the stream leaves the surface of Cody Shale on which it flows in the gap and enters the thick porous Tertiary rocks north of the gap. Sediment deposited by the stream in this area is subsequently shifted eastward by the westerly wind. The course of Crooks Creek as a result in deflected eastward and the stream is lost in sand before joining the Sweetwater River.

Windblown sand also occurs locally along the south flank of Green Mountain.

ALLUVIUM AND ALLUVIAL-FAN DEPOSITS

Alluvium mapped in the Crooks Gap area is largely restricted to the flood plains that border the major drainage. Deposits of silt, sand, and gravel as much as half a mile wide are shown along the course of Crooks Creek in Crooks Gap and to the south. Additional alluvium is shown in the southwest corner of the area.

Mapped alluvial-fan deposits include arkosic material on the slopes of Crooks Peak and along the east side of Crooks Gap. The sediment derived from exposures of the Battle Spring Formation accumulated in preexisting drainages where streams were incompetent to transport the large amount of material. The area mapped as alluvial fan on the east side of Crooks Gap in secs. 20 and 21, T. 28 N., R. 92 W., is about half a square mile in extent.

PEDIMENT AND TERRACE GRAVELS, UNDIFFERENTIATED

Gravel-mantled dissected planar surfaces having gentle northward slopes cover much of the southern part of the outcrop area of Miocene rocks. Only the larger remnants are mapped. The gravel covering is composed for the most part of granite cobbles and boulders, but in some areas concentrations of boulders of basic dike rock are present. A decrease in size northward indicates that the boulders were derived from the Battle Spring Formation to the south. Commonly the boulders are faceted by windblown sand.

LANDSLIDE MATERIAL

Four landslides, all on the north slope of Green Mountain, have been mapped in the area. The largest slide extends from the SE¼ sec. 24, T. 28 N., R. 92 W., northeastward 1.3 miles into sec. 18, T. 28 N., R. 91 W., and consists of arkosic debris and Mesozoic rock fragments in an argillaceous matrix. The slide follows the course of a preexisting valley. The smaller slides are in the SW¼ sec. 23 and the S½ sec. 24, T. 28 N., R. 92 W., and similarly follow the courses of earlier valleys. Usually the slides occur at the contact of Eocene arkose on folded Cody Shale, but a single slide in the N½ sec. 24, T. 28 N., R. 92 W., involves only the Cody Shale.

STRUCTURE

PREVIOUS WORK

The Crooks Gap area lies across the boundary separating the Granite Mountains structural block on the north from the Great Divide Basin on the south (pl. 3). The folds and faults affecting the Precambrian, Paleozoic, and Mesozoic rocks along the boundary are exposed at several places; but only in excavations for mining or oil development, as at Crooks Gap, can much of the structural detail of the disturbed Tertiary rocks be observed.

Complex folding and faulting in the region has been recognized for many years. W. C. Knight (1900, p. 229–230) was one of the first to suggest that the Granite Mountains block had been depressed in post-Eocene time, that the block was bounded by parallel faults (the southern bounding fault passes through the Crooks Gap area), and that the block was subsequently buried by Miocene sediments.

Bauer (1934) briefly discussed the geologic relations along the southern boundary of the Wind River Basin and made a few specific references to the Crooks Gap-Green Mountain area. He recognized a regional uplift of central Wyoming subsequent to the deposition of the Tertiary sedimentary blanket and consequent collapse of the Granite Mountain structural block (Sweetwater arch). He (p. 686, 688) estimated the vertical displacement of the normal faulting near Crooks Gap to be more than 2,500 feet, and also noted (p. 686) the presence in the Crooks Gap area of an older thrust fault parallel to the normal fault, which presumably resulted from compression from the north. Bauer discussed (p. 680) the presence of two Tertiary conglomerates on the east side of Crooks Gap; he described the Sweetwater Member of the White River Formation (Oligocene) as capping much of Green Mountain and as resting on the Eocene Wasatch Formation (Battle Spring Formation of this report) in Crooks Gap. Although the present author believes the upper conglomerate to be Eocene in age, fossils have not been found, and Bauer's Oligocene designation of the upper conglomerate may be correct. Bauer (p. 680) also noted the inverted order of erosional detritus that constitutes the lower part of his Sweetwater Member; this inverted order indicates the progressive erosional stripping of sedimentary rocks from the ancient Granite Mountains, which then lay at a greater height to the north.

S. H. Knight (1937) interpreted the structural import of the large granite boulders in the thick arkosic sequence at Crooks Gap and suggested that the boulders, some of which are as much as 40 feet across, were shed from a southward-moving thrust sheet during the time of thrusting. Knight recognized the progressive erosional stripping of older beds, as shown by the succession of the debris incorporated in the Fort Union and lower part of the Battle Spring Formations at Crooks Gap.

Blackstone (1951) presented an excellent summary of the development of ideas on the structural geology of central Wyoming. Regional tectonic features are discussed and thrusting and normal faulting at Crooks Gap are noted.

Van Houten (1950; 1954; 1955) and Van Houten and Weitz (1956) presented the results of structural and stratigraphic studies of the Beaver Divide-Sweetwater Plateau region northwest and north of Crooks Gap.

Reports by Bradley (1926), Masursky (1962), and Pipiringos (1955; 1961) discuss the structure and stratigraphy in the Great Divide Basin south of Crooks Gap.

In 1955, W. G. Bell [1] completed a study of an area extending from just west of the Crooks Gap area to the south end of the Wind River Mountains (fig. 9). In a second paper, Bell (1956) extended some of his previous conclusions into the Crooks Gap area. He (p. 82) explained the previously called normal fault zone of the Crooks Gap

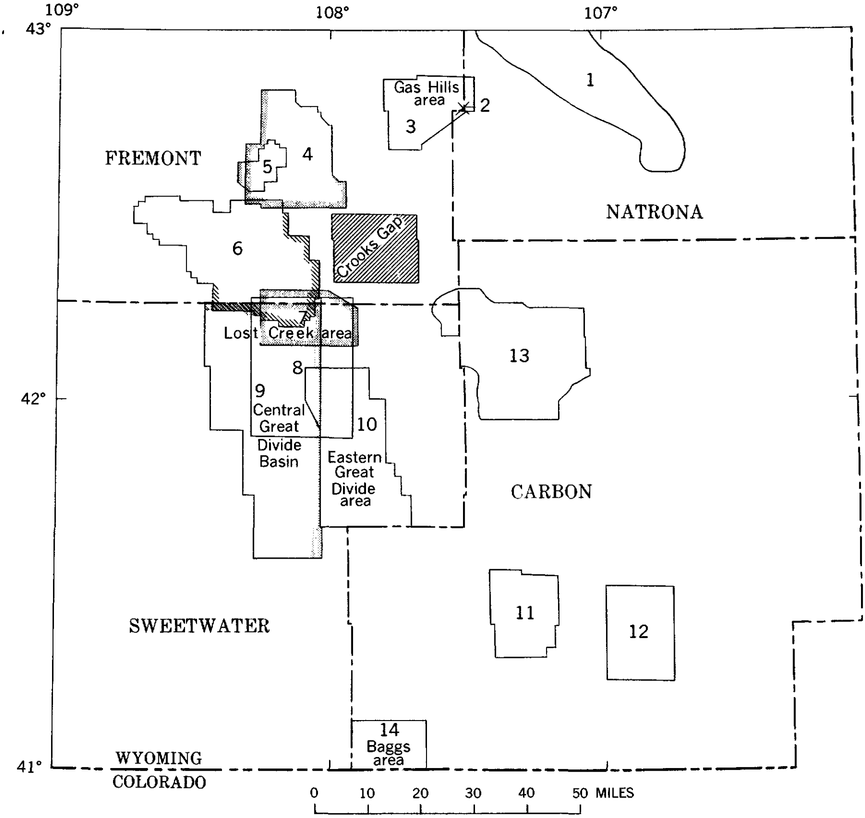


FIGURE 9.—Index map of south-central Wyoming showing relation of Crooks Gap area to nearby areas where related geologic studies have been made.

Related geologic studies

1. Rich (1962)
2. Van Houten (1955)
3. Zeller and others (1956)
4. Van Houten (1954)
5. Van Houten (1950)
6. Bell, W. G., 1955, Geology of the southeastern flank of the Wind River Mountains, Fremont County, Wyoming: Wyoming Univ. Ph. D. thesis.
7. Sheridan and others (1962)
8. Wyant and others (1956)
9. Pipiringos (1961)
10. Masursky (1962)
11. Vine and Prichard (1959)
12. Stephens and Bergin (1959)
13. Fath and Moulton (1924)
14. Vine and Prichard (1954)

[1] Bell, W. G., 1955, The geology of the southeastern flank of the Wind River Mountains, Fremont County, Wyoming: Wyoming Univ. unpublished Ph. D. thesis, 204 p.

area as a shear zone formed between two stable blocks reacting to eastward-directed compressive forces. The "shear zones" and the folds of the Crooks Gap area were thought by Bell to have formed at the same time. Bell (p. 85) concluded: "It is apparent that there is neither a low-angle thrust fault nor a large-throw normal fault in this district, as has been reported by various writers." Bell's interpretations do not agree with those presented in this report.

GENERAL FEATURES

The map area discussed in this report (fig. 10) may be subdivided into three parts: a northern part largely blanketed by Miocene rocks; a central part characterized by faulted and folded Mesozoic and Paleozoic rocks partly covered by lower Tertiary rocks; and a southern unit comprising the north edge of the Great Divide structural basin, which is entirely concealed by Eocene rocks. An east-trending zone of normal faults of large displacement separates the northern and central tectonic units. North of this fault zone Eocene, Oligocene, and Miocene rocks conceal what appears to be a granite thrust sheet (part of the Granite Mountains structural block) displaced southward and southwestward over Mesozoic and Paleozoic rocks. Late Tertiary subsidence produced large-scale normal faults along the southern boundary of this tectonic unit and imparted gentle southward dips to the overlying Tertiary rocks.

The central tectonic zone is composed of Paleozoic and Mesozoic rocks folded into a series of northwest-trending asymmetrical anticlinal folds, some of which are broken on the southwest side by high-angle reverse faults. These folds are partly concealed by Paleocene and Eocene rocks.

The southern tectonic zone includes part of the northern flank of the Great Divide Basin. The basin configuration is largely unknown because of concealment by unconformable lower Tertiary rocks.

One of the major unanswered questions in the report area concerns the nature of the concealed boundary between the belt of northwest-trending folds that extend eastward through Crooks Gap and the northern part of the Great Divide Basin. A concealed structural break hidden by surface rocks is suggested by the northwest alinement of the folds north of the general area of Crooks Peak in contrast to an east-west trend in the surface structure of the northern Great Divide Basin. Results of widely spaced deep drilling in the area provide some data for consideration. The Continental Oil Co. East Antelope 1 test (sec. 26, T. 27 N., R. 93 W.), drilled 3.1 miles south of the map area, penetrated an almost complete section of Upper Cretaceous rock before reaching the Cody Shale at 6,532 feet. The Cody

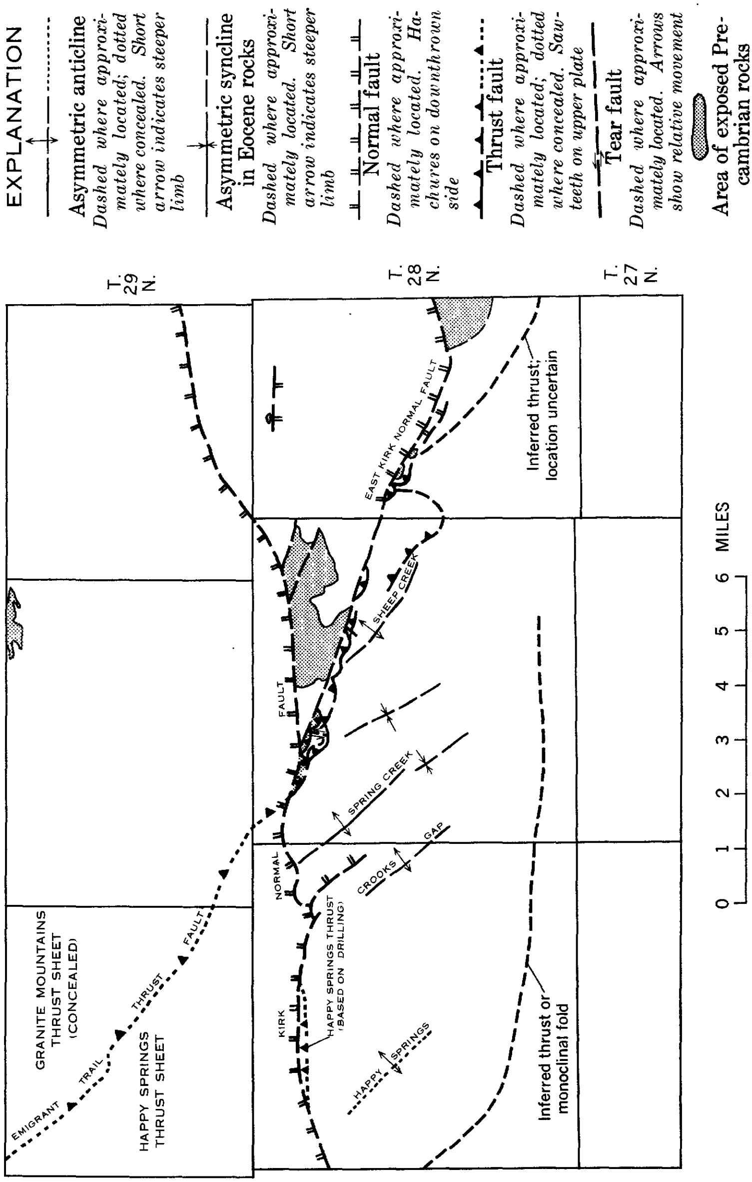


FIGURE 10.—Tectonic map of the Crooks Gap area.

Shale is exposed at the south end of Crooks Gap (sec. 29, T. 28 N., R. 92 W.) and is overlain unconformably by Paleocene and Eocene rocks. The hypothesis is here presented that the belt of northwest-trending anticlines in Crooks Gap constitutes a thrust sheet moved southward over the northern part of the Great Divide Basin. The sheet is bounded on the south by a major thrust, which is believed to have an eastward trend and to cross the area in the vicinity of the south side of Crooks Peak. An alternate hypothesis postulates a monocline in the same position and the folded Mesozoic rocks to the north being folded downward under the Great Divide Basin; thus the northwest-trending folds in Crooks Gap might be considered part of the northern flank of the Great Divide Basin.

Data for interpretation of the concealed structure in the area are provided by logs of oil and gas tests and wells and by a gravity survey (p. F75). Because detailed data are still unavailable for several critical areas, the interpretations of concealed structure as herein outlined must be considered tentative.

Plates 1 and 2 and figure 10 illustrate the structural discussion that follows.

FOLDS

Cretaceous rocks in the Crooks Gap area are tightly folded into a series of four northwest-trending anticlines, some of which are broken to the southwest by high-angle reverse faults. Although these folds are separated from the overlying Tertiary rocks by an angular unconformity, some of the Tertiary rocks are folded in a pattern similar to that of the Cretaceous fold system.

SHEEP CREEK ANTICLINE

Sheep Creek anticline (pl. 1, section *D–D′*; fig. 10) is a sharply folded, doubly plunging structure about 1 mile wide and 3 miles long that extends southeastward from the SW¼ sec. 10. to sec. 24, T. 28 N., R. 92 W. To the southeast it is concealed by landslide deposits and unconformably overlying Tertiary rocks, and to the northwest the structure terminates abruptly against a small granite thrust mass. The steeper limb of the southwest has dips as high as 75° overturned, whereas the dips on the northeast side are no greater than 41°. On the northeast side the fold is bordered by a narrow, tightly folded syncline, which is broken to the southeast by a reverse fault. The oldest rock exposed in the Sheep Creek anticline is the Chugwater Formation of Triassic age.

Oil is produced on the Sheep Creek anticline from the Phosphoria Formation at a depth of about 2,000 feet.

SPRING CREEK ANTICLINE

Spring Creek anticline (pl. 1, section *B–B′*; fig. 10) is a tightly folded structure extending southeastward for about 3 miles from sec. 1, T. 28 N., R. 93 W., to sec. 17, T. 28 N., R. 92 W. Because surface exposures are of nonresistant Cody Shale, surface mapping is difficult. Subsurface data indicate that the fold is asymmetric to the southwest and broken by a high-angle reverse fault on that side. The surface trace of the reverse fault, if present, could not be mapped because of poor exposures. To the southeast the fold plunges beneath Tertiary rocks, but the relations of the fold to the large-scale faulting to the northwest are unknown.

Oil has not been produced from the Spring Creek structure.

CROOKS GAP ANTICLINE

Crooks Gap anticline (pl. 1, section *C–C′*; fig. 10) is in the central part of the area and extends southeastward for about 3 miles from sec. 11, T. 28 N., R. 93 W., to sec. 19, T 28 N., R. 92 W. The fold is similar to other folds in the area in that it is asymmetric to the southwest where steep to overturned dips are characteristic. Dips on the northeast flank range from 19° to 35°. The Cody Shale is the only rock exposed in the structure. To the southeast the fold plunges beneath a cover of Eocene rocks, whereas to the northwest poor exposures mask the relations of the fold to the zone of large-scale faulting. Subsurface data indicate that the fold is broken on the southwest by a high-angle reverse fault.

Oil production from the Crooks Gap anticline is from the Frontier Sandstone, the Muddy Sandstone Member of the Thermopolis Shale, the Cloverly Formation, and the Nugget Sandstone at depths ranging from 3,538 to 5,600 feet.

SOUTH HAPPY SPRINGS ANTICLINE

South Happy Spring anticline (fig. 10) is concealed by unconformable Tertiary rocks; it is approximately 2 miles long, extending southeastward from sec. 8 to sec. 21, T. 28 N., R. 93 W. The fold is asymmetrical, and the steeper limb is to the southwest. Subsurface information indicates possible rupture of the fold by a high-angle reverse fault on the southwest side. The Cody Shale is believed to be the oldest rock uncovered by erosion prior to deposition of the Tertiary strata.

Oil is produced from the Frontier Formation and the Muddy Sandstone Member at depths ranging from 5,630 to 6,570 feet.

NORTH HAPPY SPRINGS ANTICLINE

The North Happy Springs oil field (pl. 1, section *A–A′*) is in the north-central part of T. 28 N., R. 93 W. The structure, which is concealed by Tertiary rocks, is about 1 mile wide and 2½ miles long, and it has an eastward elongation parallel to the Kirk normal fault. Both reverse and normal faulting are present in the anticline. The reverse fault cuts the north side of the anticline and duplicates part of the Mesozoic section. Later normal faulting (Kirk normal fault) appears to have occupied nearly the same zone of displacement. The oil-producing anticline may have resulted from compression before a southward-advancing thrust sheet. An alternate interpretation is to attribute the origin of the anticline to drag produced by normal faulting that modified a preexisting northwest-trending fold.

Oil is produced in the north Happy Springs field from the Frontier Formation, the Muddy Sandstone Member of the Thermopolis Shale, the Cloverly Formation, and the Phosphoria Formation at depths ranging from 3,200 to 6,280 feet.

FOLDS IN MEMBER A OF THE BATTLE SPRING FORMATION

The northwest-trending asymmetrical fold system is reflected in rocks of member A of the Battle Spring Formation. The system is discernible in an area of about 5 square miles in secs. 16, 20, 21, 28, and 29, T. 28 N., R. 92 W. (pl. 2). Two unnamed synclines are believed to be present. The larger one, in secs. 9, 16, and 21, T. 28 N., R. 92 W., is asymmetric; it has dips as high as 65° on the northeast side and less than 20° on the southwest limb. The smaller syncline, in sec. 20, T. 28 N., R. 92 W., is concealed for the most part by alluvial-fan deposits. It is thought to be asymmetrical, the steeper limb on the southwest side. To the southeast the anticlinal nose separating the two southeastward-plunging synclines is thought to become less pronounced and the two synclines to merge at depths into a single synclinal structure. The structural relations of the lower Eocene rocks in the rest of the gap are not clear. However, member A seems to dip away from the Crooks Gap anticline, and another syncline paralleling those described above may be present under the east flank of Crooks Mountain.

THRUST SHEETS

Two major thrust sheets are believed to have formed in Eocene time in the Crooks Gap area. The sheets and the bounding thrust faults are mostly concealed except in the northern part of T. 28 N., R. 92 W., where parts of the Emigrant Trail thrust and the Granite Mountains in the Crooks Gap area. The sheets and the bounding thrust faults that bound the two sheets are shown on plate 1 and figure 10.

GRANITE MOUNTAINS THRUST SHEET

The Granite Mountains thrust sheet (Van Houten, 1954), the northernmost recognized, is considered to have been displaced southwestward from the main mass of the Granite Mountains structural block. Meager seismic and drill-hole data indicate that the concealed upper surface of the thrust sheet is granite. A single north-south seismic traverse, which extends from Crooks Gap northward to U.S. Highway 287 (p. F76), indicates that the buried top of the thrust sheet has little relief and dips gently southward.

The thickness of the sheet has been determined in sec. 32, T. 30 N., R. 93 W., 2.3 miles northwest of the mapped area. The Carter Oil Co.'s Immigrant Trail 1 test hole penetrated 1,230 feet of Tertiary rocks and 1,800 feet of granite before passing through 900 feet of overturned Paleozoic and Mesozoic rocks (fig. 11). Variation in thickness of the sheet is suggested by a gravity anomaly 2 miles north of the map area (secs. 25, 26, 34, 35, T. 30 N., R. 92 W.; pl. 9). There, in the vicinity of exposed granite knobs, a low gravity anomaly suggests that the concealed granite sheet may be very thin.

The Granite Mountains thrust sheet is bounded on the southwest by the Emigrant Trail thrust (Blackstone, 1951, p. 25). This concealed fault enters the mapped area in the northwest corner, 2 miles from the Carter well, and is traceable by gravity measurement (pl. 10) to the north entry of Crooks Gap (NW part of T. 28 N., R. 92 W.). It is postulated that the thrust fault continues east-southeast beyond this point at least 9 miles to the east edge of the map area and generally parallels the younger East Kirk normal fault (fig. 10). Several small discontinuous thrust masses involving rocks of different ages are exposed directly south of the East Kirk normal fault (fig. 12) and are thought to have been emplaced by this thrusting.

Where exposed, the Granite Mountain thrust sheet or related slivers rest on Cretaceous rocks, principally the Cody Shale, or on older Mesozoic rocks. No data, other than those from the Carter test hole, are available concerning the rocks below the thrust sheet in the area blanketed by Miocene and earlier Tertiary rocks.

HAPPY SPRINGS THRUST SHEET

Mesozoic and Paleozoic rocks concealed by Miocene and earlier Tertiary rocks in the North Happy Springs oil field and northward as far as the Emigrant Trail thrust may constitute a second thrust sheet, here named the Happy Springs thrust sheet. The sheet is bounded on the south by the buried Happy Springs thrust, which extends eastward under the north slope of Crooks Mountain (fig. 10). The existence of this fault is known from drill-hole data in the North Happy

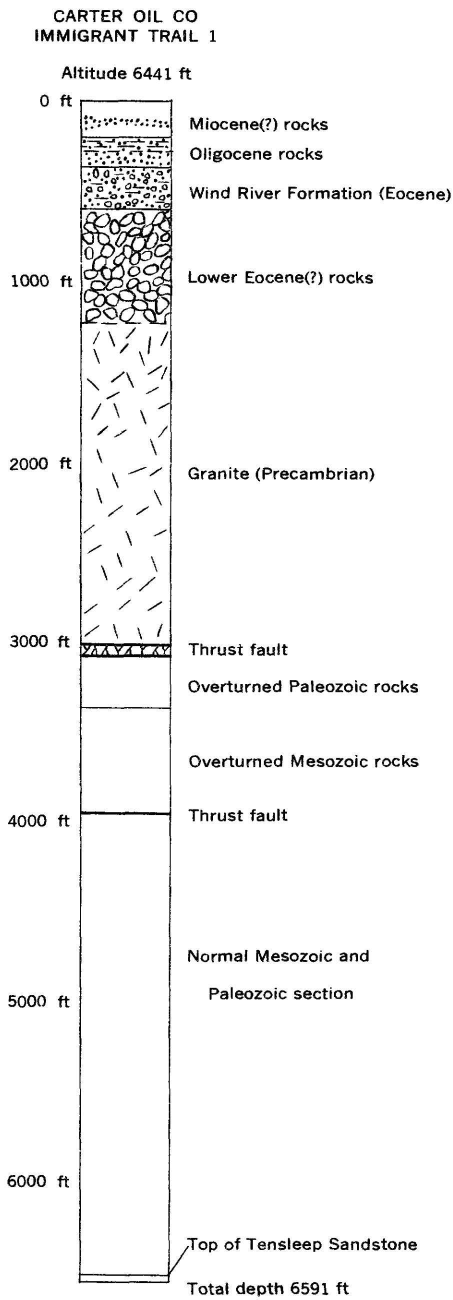


FIGURE 11.—Section penetrated in Immigrant Trail 1 test hole, sec. 32, T. 30 N., R. 93 W. (after Van Houten, 1954).

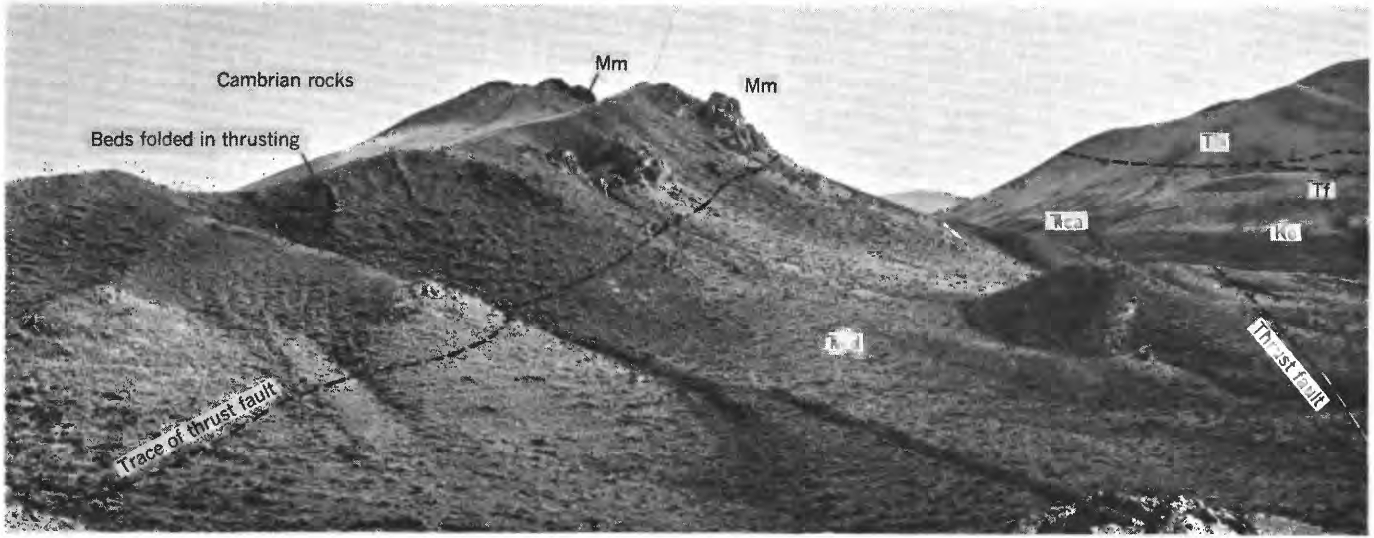


FIGURE 12.—Two thrust faults in the Crooks Gap area. Tb, Battle Spring Formation; Tf, Fort Union Formation; Kc, Cody Shale; Ꞧcd, Chugwater and Dinwoody Formations; Ꞧca, Alcova Limestone Member of the Chugwater Formation; Mm, Madison Limestone. Looking southeast from the NE¼ sec. 8, T. 28 N., R. 92 W.

Springs oil field where the Frontier Formation is repeated in wells (pl. 1, section *A–A′*). Only a small part of the east-trending fault is found in the drill holes because of its lateral truncation by the Kirk normal fault. No data are available concerning the lateral extent of the fault. Presumably the Granite Mountains thrust sheet overrode the Happy Springs thrust sheet from the northeast. Movement along the Happy Springs thrust apparently was southward. Reverse faulting detected in the well in the SE¼ sec. 6, T. 28 N., R. 92 W., could be a continuation of the faulting in the Happy Springs oil field, or it might be related to the Emigrant Trail thrust.

The structural importance of this fault sheet and the lateral extent of the Happy Springs thrust are not apparent from data in the Crooks Gap area.

NORMAL FAULTS

A prominent east-trending zone of normal faulting developed across the central part of the Crooks Gap area attendant to the collapse of the Granite Mountains sheet to the north. Southward tilting, which accompanied the collapse, imparted gentle southward dips of 2° to 3° to the Miocene rocks in the northern part of the Crooks Gap area.

KIRK NORMAL FAULT

The Kirk normal fault, as here named, enters the map area in sec. 7, T. 28 N., R. 93 W., and extends generally eastward in an irregularly curved pattern for 12 miles to sec. 1, T. 28 N., R. 92 W. Geomorphic features, such as an abrupt linear break in topography along which are many springs, indicate the position of the fault at the surface. Gravity measurements (p. F70) show that a large anomaly parallels the trace of the fault throughout its extent. Surface evidence of faulting seems to die out in sec. 1, T. 28 N., R. 92 W., but the gravity anomaly continues east-northeastward to the east boundary of the map area.

A fault in Miocene rocks exposed in the NW¼ sec. 4, T. 28 N., R. 91 W., may be related to the Kirk fault. Drag on this fault indicates, however, that the south side was downdropped. A small exposure of Precambrian granite near the same locality, but on the opposite side of West Cottonwood Creek, is believed to be on the north side of the fault, although field evidence is inconclusive. That the faulting in sec. 4, probably reflects downdropping on the south side of a largely concealed granite block is well shown by gravity measurements. A core hole in the SW¼ sec. 5, 0.8 mile from the granite exposures in sec. 4 penetrated 1,165 feet of Tertiary rocks before reaching granite. This relief could be attributed to old topography, to faulting, or to both.

The Kirk normal fault is well exposed in the SE¼SE¼ sec. 4, T. 28 N., R. 93 W., at the drill site of the Sinclair Oil Co.'s producing well (Happy Springs Unit 22) on the south side of the fault where a boulder conglomerate in the Battle Spring Formation is in contact with nearly vertical beds of sandstone of the Split Rock Formation of Miocene age (fig. 13).

Along the western part of the Kirk fault, Miocene rocks on the north are downdropped against Eocene rocks on the south. Along the central part of the fault trace, from sec. 11, T. 28 N., R. 93 W., eastward to sec. 6, T. 28 N., R. 92 W., greenish-gray and pinkish-gray clayey siltstone tentatively identified as Oligocene in age is faulted against the Battle Spring Formation and the Cody Shale. To the east, Miocene rocks are in fault contact with Precambrian granite.

The amount of displacement along the fault is unknown. Bauer (1934, p. 687) estimated a movement greater than 2,500 feet. An estimate of the minimum displacement is possible if it is assumed that basal rocks of the Mioecne once covered Crooks Mountain. The minimum displacement is then the difference in elevation between the top of Crooks Mountain and the base of the Miocene to the north, or a difference of about 2,250 feet. Seismic data (pl. 9) indicate a possible displacement of as much as 2,000 feet at the north entry of Crooks Gap, sec. 5, T. 28 N., R. 92 W.

A post-middle Miocene through Pliocene age for the normal faulting in the Crooks Gap area is suggested by the relation of Miocene to Pliocene rocks near the Split Rock area, 6 miles east of the Crooks Gap area. In sec. 33, T. 30 N., R. 89 W., lake deposits of the Pliocene Moonstone Formation dip gently southward at a lesser angle than the underlying southward-dipping Split Rock Formation of Miocene age (Love, 1961); this difference in dip suggests that the normal faulting, which began in post-middle Miocene time, may have continued through Pliocene time.

EAST KIRK NORMAL FAULT

The East Kirk normal fault, as here named, extends from the NE¼ sec. 14, T. 28 N., R. 92 W., east-southeastward 6½ miles to sec. 22, T. 28 N., R. 91 W., where it leaves the map area . The change in direction of large-scale normal faulting from the eastward trend of the Kirk fault to the east-southeastward trend of the East Kirk fault may have been influenced by the subsurface distribution of a Precambrian granite fault block. The large granite mass exposed in the northeast part of T. 28 N., R. 92 W., trends east-northeastward in the subsurface, as indicated by gravity studies, and possibly this granite block caused the zone of major displacement to be offset from the Kirk fault southward to the East Kirk fault. A fault system in the basement rock may also have influenced the surface pattern of faulting.

713-808 O—64——6

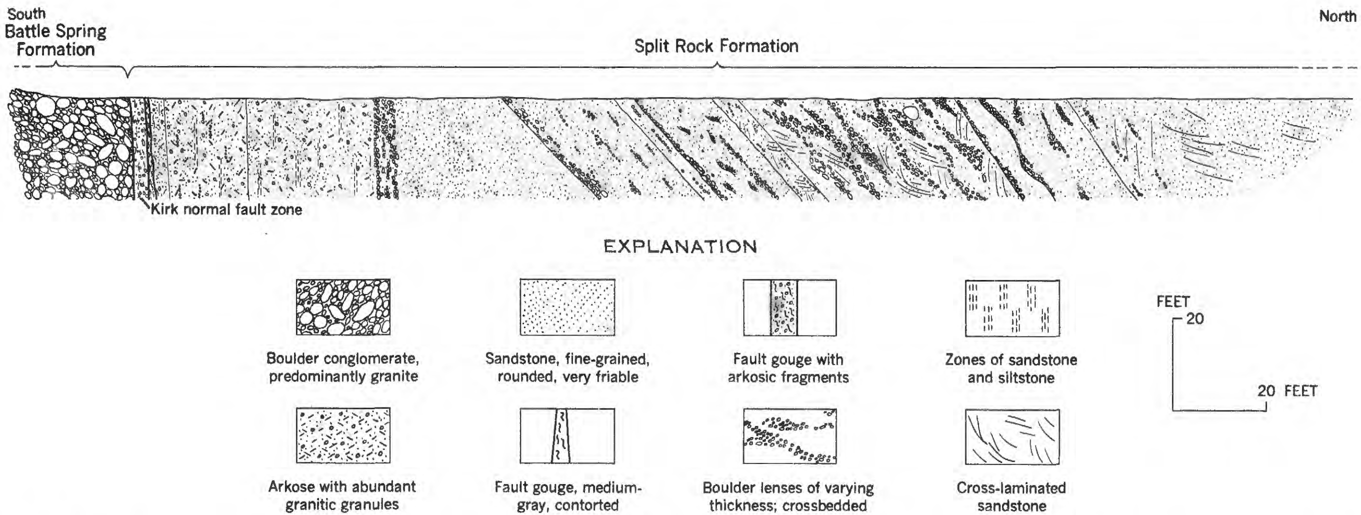


FIGURE 13.—Cross section showing normal fault along which the Split Rock Formation (Miocene) is placed against the Battle Spring Formation (Eocene), SE¼SE¼ sec. 4, T. 28 N., R. 9 W.

Evidence for the East Kirk fault is primarily geomorphic. A rectilinear topographic break along which are many springs, as well as a few poorly developed hogback ridges eroded on upturned Miocene, Oligocene(?) and Eocene rocks (sec. 21, T. 28 N., R. 91 W.), provides evidence of faulting. An alternate interpretation is that the Miocene and Oligocene rocks are not downfaulted but were deposited in a low area bounded on the south by an old fault scarp that produced the rectilinear topographic break now seen in the field. If the latter hypothesis is correct, erosional valleys should have been formed in the fault scarp, and the Oligocene and Miocene deposits should have filled these valleys and produced an irregular contact between the upper Tertiary beds to the north and the rocks of the eroded fault scarp to the south. Because this relation is not seen and because the Miocene and Oligocene rocks are believed to have steep dips near the rectilinear break, the author favors the fault hypothesis. Throughout the extent of the fault in the Crooks Gap area, Miocene rocks form the downdropped northern side.

Evidence indicating the amount of displacement along the East Kirk normal fault is lacking. The amount of displacement is believed to decrease toward the west end of the fault where it intersects the Kirk normal fault. The age of faulting represented by the East Kirk normal fault is believed to be the same as that of the Kirk normal fault.

NORMAL FAULTS IN MEMBER A OF THE BATTLE SPRING FORMATION

At the Sno-ball mines, sec. 29, T. 28 N., R. 92 W., member A of the Battle Spring Formation is broken by a system of normal faults (pl. 6). Two well-exposed fault planes in mine workings are nearly vertical, and strikes average N. 40° W.

Slickensides indicate that the last movement along the faults was vertical. Displacements along the faults were not measured because of the lack of identifiable offset beds. However, movement is thought to be minor, that is, not more than 50 feet along a given fault surface. The fact that fault planes are almost parallel with the axial trend of the Crooks Gap anticline suggests that the faults are genetically related to the folding of member A rocks in early Eocene time.

Faulting of Eocene rocks is not apparent at other uranium excavations, nor is it evident in surface exposures.

STRUCTURAL HISTORY

Field data indicate several periods of structural activity: (1) folding during Late Cretaceous time, (2) possible folding in late Paleocene time, (3) thrust faulting in Eocene time, and (4) tensional faulting in post-middle Miocene to post-Pliocene time. The geologic history outlined in the following pages is summarized diagrammatically in plate 4.

LATE CRETACEOUS FOLDING

During the Laramide Revolution the Mesozoic and Paleozoic rocks in the area were compressed into a series of folds. Presumably the structures were open, symmetrical folds and were not tightly compressed at that time. Regional stratigraphic relations permit rather precise dating of the period of folding. Although the Mesaverde Formation, Lewis Shale, and Lance Formation of Late Cretaceous age are not exposed in the Crooks Gap area, they are present in contiguous areas to the south and southeast. In sec. 26, T. 27 N., R. 93 W., 3 miles south of the map area, the Continental Oil Co.'s East Antelope 1 well penetrated both the Lewis Shale and Mesaverde Formation and possibly part of the Lance Formation. In the Lost Soldier-Wetz dome area 5 miles southeast of the Crooks Gap area, all of these Upper Cretaceous formations are exposed (Love, Weitz and Hose, 1955). This relation suggests that in the Crooks Gap area these formations were involved in the folding, but were removed prior to the deposition of the unconformably overlying Fort Union Formation, and indicates a post-Late Cretaceous and pre-Paleocene age for the folding.

PALEOCENE (FORT UNION) DEPOSITION AND FOLDING

Breaching of the Upper Cretaceous folds at least to the Cloverly Formation prior to Paleocene time is indicated by identifiable fragments of the older rocks in the Fort Union Formation. Pebbles of dark chert from the Cloverly Formation and chips of light-gray silicified shale from the Mowry are common in the lower part of the Fort Union. The fine-grained character of the clastics in the Fort Union, together with the carbonaceous zones and impure coal beds, suggests a depositional environment of aggrading streams having sluggish drainage and covering a topography of low relief carved on the folded Mesozoic rocks. Obscure structural relations with the overlying Battle Spring Formation indicate that the Fort Union Formation may have been folded prior to Eocene time (pl. 4A). The hypothesis that the Fort Union rocks were stripped from structurally high areas prior to Eocene time is suggested by remnants of the formation apparently being limited, for the most part, to present synclinal areas, as in sec. 16, T. 28 N., R. 92 W., and sec. 12, T. 28 N., R. 93 W. In the southern part of the gap area, the Fort Union was completely removed from the flanks of the Crooks Gap anticline, and the Battle Spring Formation rests directly on the Cody Shale. An alternate hypothesis is that the Fort Union Formation was eroded by the agents which later deposited the lower member of the Battle Spring Formation.

EARLY EOCENE THRUSTING AND FOLDING

Early in the Eocene Epoch, uplift in the Granite Mountains area occurred and resulted in the development of large-scale imbricate thrust sheets that moved southward and southwestward. Accelerated progressive stripping of the sedimentary cover and deep erosion of the granite core of the Granite Mountains sheet are recorded by the composition of the sediments of the Battle Spring Formation, and the very coarse texture of much of those sediments suggests great relief in the uplifted area and vigorous erosion.

Little is known concerning the surface on which the Battle Spring Formation was deposited in the area south of the thrust sheet. Relief of as much as 600 feet on the surface is suggested by the difference in elevation of the Battle Spring-Cody contact between sec. 23, T. 28 N., R. 92 W., and sec. 19, T. 28 N., R. 91 W. There is no evidence of faulting between the two localities.

The structure, as well as the composition, of the beds of the Battle Spring Formation sheds some light on the geologic history of the epoch. Beds in the lower part of the Battle Spring (member A) are strongly deformed, whereas the younger beds (member B) are believed to be little disturbed, and thus the dying out of the compressive forces is recorded.

The northwest trends of the synclinal folds in member A parallel to those of the sharp anticlines in pre-Tertiary rocks indicate that they are genetically related. Whether the present anticlines existed as such before Battle Spring deposition began cannot be definitely determined from surface evidence, but the intensity of folding of member A, as indicated by dips as high as 65° in the syncline between the Sheep Creek and Spring Creek anticlines, shows that at least a major part of the present structural relief of the anticlines was formed after deposition of the lowest beds of the Battle Spring Formation. Folding contemporaneous with the deposition of member A is indicated at the southwest side of Crooks Gap where beds stratigraphically low in the member dip 50° to 60°, whereas beds higher in the member have average dips of less than 20°.

Relaxation of the compressive forces that caused the thrusting and intense folding is indicated by the relative lack of deformation of the younger beds (member B) of the Battle Spring, which apparently blanketed the structures formed earlier. Thus, the Happy Springs anticline in the western part of the area is not reflected in the upper Battle Spring rocks at the surface. Near the east edge of the area these generally flat-lying rocks are believed to conceal the southeastward extension of the Emigrant Trail thrust (fig. 10).

The abrupt thinning of the Eocene rocks immediately north of the north Happy Springs oil field and presumably over much of the concealed northern area poses one of the major unanswered problems in the area. Three hypotheses are suggested as possible explanations:

1. The east-trending zone of large-scale late Tertiary normal faults occupies almost the same zone as that occupied by the Eocene thrusts. North of this zone, pediment surfaces were carved on the Eocene thrust mass; south of it, eroded debris was dumped into the topographically lower area. Gravel deposited on the pediment surface should be thinner than the equivalent deposits to the south. This hypothesis is supported by a single seismic traverse made along the main gap road from Jeffrey City southward to the main entry of the gap (pl. 9). The reflections indicate the top of the granite thrust to be a gently sloping surface of little relief. The large granite block exposed in the northern part of T. 28 N., R. 92 W., and generally concealed in the northern part of T. 28 N., R. 91 W., may represent a "rock island" left behind as the pediment was formed. The island protruded above the Eocene pediment gravels and was not buried until Miocene sediments covered it.
2. The Battle Spring Formation was deposited in the northern part of the area, but was removed by erosion prior to deposition of Oligocene rocks. Such a drainage system presumably would have had an east-west trend in the area and would have been located between the Granite Mountains to the north and the Battle Springs escarpment to the south. Two conditions oppose such a concept: (1) Seismic reflections indicate no channeling or gorgelike features in the traverse that presumably would cross the ancient drainage. (2) If considerable thickness of Eocene rocks were eroded away in pre-Oligocene time, much of the relief of the area should have been formed at that time—an east-trending eroded valley to the north and an erosional escarpment of arkose to the south—and tributary streams from the south should have cut deep gorges into the Eocene escarpment. Oligocene and Miocene rocks should have filled these gorges and made a sinuous contact between the Eocene and younger Tertiary rocks. This sinuous pattern has not been found in the area.
3. The third hypothesis, similar to that proposed by Bell (1956), would postulate a large-scale lateral shifting of the northern part of the area relative to the southern part. If such shifting occurred, there should be little relation between the geologic history of the adjacent blocks. No evidence of large-scale lateral shifting has been found in the area studied.

Of the three hypotheses presented, the author favors the first, but data are still insufficient to say which, if any, of the hypotheses is correct.

MIDDLE AND LATE EOCENE GEOLOGIC HISTORY

No record of middle and late Eocene time is preserved in rocks of the Crooks Gap area (pl. 4). About 12 miles to the north, however, rocks as much as 550 feet thick were deposited at this time. These rocks are mostly sandstones containing abundant volcanic debris derived for the most part from the Rattlesnake volcanic field 35 miles northwest of Crooks Gap. Rocks of middle and late Eocene age are believed absent in the Crooks Gap area. These sediments may have been restricted to the area north and northwest in the ancestral Wind River Basin.

LATE TERTIARY AND QUATERNARY GEOLOGIC HISTORY

Information concerning the late Tertiary history of the region is meager in the Crooks Gap area (pl. 4). However, Van Houten (1950; 1954; 1955), J. D. Love (written communication, 1952), Zeller (1956), and Zeller and others (1956) presented data from adjacent areas that are probably applicable, at least in part, to the Crooks Gap area. Van Houten has shown that the White River Formation of Oligocene age was deposited on a surface of considerable relief and that the aggraded blanket was distributed widely on the eroded Granite Mountains sheet. Silicic vitric tuff is an important constituent of the upper sediments of the White River. Deposition of Oligocene sediments ended with regional uplift sufficient only to result in local erosion but insufficient to cause a regional unconformity with overlying rocks.

Miocene rocks, consisting mostly of well-rounded and well-sorted tuffaceous sandstone and limestone, were deposited on slightly eroded Oligocene rocks. Deposition on a wide plain, mainly by the wind, is suggested. Vertebrate fossils from the Miocene deposits are types that inhabited semiarid environments. Higher peaks of the Granite Mountains projected above the aggrading Miocene strata.

Pliocene rocks indicate continued accumulation of tuffaceous sediments and, except for a few of the higher peaks, the Granite Mountains sheet was almost completely buried. Pliocene rocks measured by Love (1961, p. I25–I29) in T. 30 N., R. 89 W., Natrona County, are approximately 1,350 feet thick and rest unconformably on the underlying Miocene beds. Several beds of tuff as much as 40 feet thick were measured by Love in the Pliocene rocks. Laminations and the varvelike character of some of the rocks indicate deposition in bodies of still water.

Probably during the later stages of, and following, this extensive period of aggradation there was extensive relative downfaulting of a large crustal block that included the Granite Mountains and the northern part of the Crooks Gap area. The Kirk and East Kirk faults were formed at this time. The throw of the bounding faults was much greater on the south side of the downthrown block; it presumably tilted the block to the south and caused the regional southward dips now observable in the upper Tertiary rocks (Van Houten, 1954). The fact that Pliocene rocks dip southward at a lesser angle than the underlying Miocene rocks (J. D. Love, written communication, 1952) suggests that the faulting began before deposition of the Pliocene rocks and continued through their period of deposition.

Zeller (1956) reported normal faulting of post-Miocene age and movement continuing into Recent time in the Gas Hills area 15 miles to the north. Recent adjustment is indicated also in the Crooks Gap area by an offset pediment surface in secs. 20–21, T. 28 N., R. 91 W. However, in the Crooks Gap area, Pleistocene and Recent times have primarily been epochs of erosion, during which great thicknesses of Tertiary rocks were stripped.

Dissection of the present topographic surface by the superimposed Sweetwater drainage system has taken place during late Tertiary and Quaternary time. Superposition is indicated by the arbitrary manner in which the river flows from nonresistant Miocene rocks through deep gorges cut in granite, only to return to the nonresistant rocks. The general course of the stream is believed to have been determined in Miocene and Pliocene time during the formation of the large-scale normal faulting. Several hundred feet of upper Tertiary rocks have been stripped from the area and multiple, gently sloping erosional surfaces, believed to be old pediment surfaces, were carved on the Miocene and Eocene rocks north of the Green Mountain-Crooks Mountain lineament.

It also seems likely that Crooks Gap was carved during this period, perhaps as the result of superposition of Crooks Creek across the Green Mountain-Crooks Mountain lineament. An alternate hypothesis of simple headward erosion for the course of Crooks Creek is also tenable. As erosion reduced the land surface after the large-scale normal faulting, the structurally elevated Cretaceous Cody Shale at Crooks Gap was exposed in fault contact with soft Miocene rocks. The relatively resistant Eocene arkose, which overlay the nonresistant shale, was then subjected to sapping, and any stream that may have developed at the northern entry of the gap could have made rapid progress in headward erosion to the south. This structural situation is not repeated for several miles on either side of Crooks Gap. As the stream worked headward into the Green Mountain-Crooks Mountain lineament, it could have captured streams draining into the Great Divide Basin (pl. 5). Capture of other parts of the Great Divide drainage system by tributaries of the Sweetwater River is evident around the southwestern flank of Crooks Mountain.

URANIUM DEPOSITS

HISTORY OF PROSPECTING AND DEVELOPMENT OF DEPOSITS

Uranium was discovered in Crooks Gap in December 1953. The discovery was made in the area of exposed reverse faults at the northeast entry of Crooks Gap where uranium minerals were found coating fracture planes in faulted Cambrian shales.

Detection of radioactivity anomalies by prospectors using privately owned airborne instruments followed in February 1954, and the Sno-ball mines area was located as a result of this discovery. Until midsummer 1955, development of the area consisted primarily of surface prospecting and mining of small bodies of ore. In July 1955, a core hole drilled by the U.S. Atomic Energy Commission found ore-grade rock in the area of the Sundog prospects at 470 feet, and private operators subsequently reported similar discoveries in adjacent areas at depths of more than 100 feet. The following discussion of uranium deposits is limited to the surficial deposits known at the time of the field investigation. Although important ore deposits were reported from deep drilling in the area, data available at the termination of fieldwork in October 1955 were inadequate to assess the geologic relations of the deposits.

As of September 1957, prior to the opening of the larger deposits at depth, about 4,200 tons of ore had been produced from Crooks Gap. Production from individual deposits has ranged from as much as 1,900 to 275 tons of ore which assayed from 0.18 to 0.23 percent U_3O_8.

Since the completion of fieldwork, a few large concealed ore bodies have been found. The Phelps-Dodge Corp. reportedly discovered a large deposit by drilling in sec. 16, T. 28 N., R. 92 W. Additional deposits are reported from the northern half of sec. 21 in the same township.

GENERAL DESCRIPTION

Known uranium deposits in the area occur in a belt 2 miles wide and 4 miles long in the east side of Crooks Gap (pl. 2). The deposits are found in the lower member (member A) of the Battle Spring Formation, where they occur through a stratigraphic range of as much as 1,500 feet. Deposits at the Sno-ball mines and on the Sundog prospects lie about 1,500 feet above the base of the member, whereas those at the Helen May mine occur at or near the base.

Near-surface deposits in the area are of small size and irregular shape, and are erratically distributed. Individual occurrences have produced only a few hundred tons of ore. Near-surface uranium ore in the Crooks Gap area is varied in appearance. Generally the ore is a coarse-grained medium- to light-gray arkose containing some brown iron staining. Zones of carbonaceous siltstone and zones rich in carbonaceous fragments are present in many places. Impregnations of uranophane, autunite, and uraninite characterize some of the ore, whereas other ore shows no visible uranium minerals. Uranium minerals identified from the Crooks Gap area are listed in table 5.

TABLE 5.—*Uranium minerals identified in the Crooks Gap area*

[Mineral determinations by William Outerbridge, J. W. Adams, J. Stone, R. Wack, Daphne Riska, E. A. Cisney, G. Ashby, K. E. Valentine, R. Smith, and Richard Marquiss (except where noted)]

Minerals	Chemical composition
Oxides:	
Becquerelite [1]	$7UO_3 \cdot 11\ H_2O$
Uraninite	$(U^4{}_{1-x}U^6{}_x)O_{2x}$
Phosphates:	
Autunite	$Ca(UO_2)\ (PO_4)_2 \cdot 10\text{–}12\ H_2O$
Meta-autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 2\tfrac{1}{2}\text{–}6\tfrac{1}{2}\ H_2O$
Phosphuranylite	$Ca(UO_2)_4(PO_4)_2(OH)_4 \cdot 7\ H_2O$
Silicates:	
Coffinite	$U(SiO_4)^1{}_{-x}(OH)_{4x}$
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5\ H_2O$
Unidentified uranium silicate	
Sulfates:	
Schroeckingerite	$NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10\ H_2O$
Uranopilite [1]	$(UO_2)_6(SO_4)(OH)_{10} \cdot 12\ H_2O$
Vanadates:	
Metatyuyamunite	$Ca(UO_2)(VO_4)_2 \cdot 5\text{–}7\ H_2O$

[1] Mineral identification by Gruner and Smith (1955).

Near-surface uranium deposits are found in various stratigraphic environments at Crooks Gap. The Helen May deposit was found near the base of the Battle Spring formation in what is believed to be a channel deposit. The Sno-ball deposits seem to be near carbonaceous siltstone beds of the Battle Spring Formation, especially where faults of minor displacement are sealed by gouge. Ground water seems to have been important in localizing the deposits. The location of these deposits seems to support the hypothesis that important uranium deposits at Crooks Gap occur in the troughs of synclines in member A of the Battle Spring Formation. Small amounts of uranium also are found in Paleozoic and Mesozoic rocks near some of the major faults. However, lack of subsurface information has prohibited evaluation of these occurrences.

INDIVIDUAL DEPOSITS

SNO-BALL MINES

The Sno-ball mines are on a low spur that extends westward from Sheep Mountain in sec. 29, T. 28 N., R. 92 W., near the south entrance to Crooks Gap. Extensive drilling and exploration have made these mines geologically the best known in the area.

The deposits occur in arkose in the lower folded sequence of the Battle Spring Formation (member A). A series of northwest-trending faults, generally less than 40 feet apart, cut the host rocks into a series of variously tilted blocks (pl. 6). The displacements along the faults appear to be minor, although the absence of key beds makes accurate measurement impossible. Many of the faults parallel the fold axis in the lower member of the Battle Spring Formation and presumably were formed at the time of the folding.

Four types of ore bodies are present at the Sno-ball mines: (1) a tabular type in which a mineralized zone a few feet thick parallels beds of carbonaceous siltstone, (2) an oblate concretionary type in which the mineralized zones and zones of iron-oxide staining alternate in irregular concentric bands, (3) irregularly shaped bodies associated with thin impermeable gouge zones provided by faults of small displacement, and (4) uranium occurrences of small size found at a few places where coarse-grained sandstone grades abruptly to finer grained sandstone and siltstone.

A tabular ore body consists of uranium-impregnated arkose directly below a carbonaceous siltstone. One ore body of this type, now mined out, was 2 feet thick and 12 feet wide. Strip mining exposed about 10 feet of the body before thick overburden halted the operations. The total length of the body is not known. The ore was richest adjacent to the carbonaceous siltstone bed and the grade diminished downward.

Oblate concretionary bodies are characterized by concentric bands of alternating iron staining and visible uranium minerals. At a few places a boulder of carbonaceous siltstone forms a nucleus for the concentric bands. Mineral bands surrounding some of the nuclei are symmetrically arranged, but those around other nuclei may be displaced toward one side of the ore body. This type of ore body is generally less than 10 feet across and produces less than 200 tons of ore.

Ore bodies are associated with minor faults and are near the intersections of dipping carbonaceous siltsone beds and fault zones made impermeable by argillaceous gouge. This type of ore body generally produces only a few tons of ore and is erratic in distribution.

Subsurface deposits have been outlined by private drilling a quarter of a mile north of the mine, but none were exposed by mine workings at the time of the field study. Reported depths to the ore range from 60 to 120 feet.

The most abundant uranium mineral in the Sno-ball mines is uranophane, although much ore has no visible uranium minerals. Small specks in some of the impermeable carbonaceous siltstone beds and small nodules in the adjacent sandstone have been identified as uraninite and coffinite. Phosphuranylite and uranopilite also have been identified. The uranium minerals in the deeper deposits are mostly unknown, although uraninite has been identified in a few samples.

At least three factors seem to control uranium deposition at the Sno-ball mines: (1) The carbonaceous siltstone beds provided a local reducing environment where uranium might be precipitated from uranium-bearing ground water; (2) solution dams formed by impermeable gouge along fault zones effectively controlled the rate of circulation of uranium-bearing ground water and permitted mineralization in some favorable environments; (3) uranium enrichment is found at a few places where coarse-grained sandstone grades to finer grained sandstone and siltstone. The uranium minerals impregnate the coarser grained beds, and the deposits are believed to have resulted from changes in rate of circulation of the ground water as indicated by variation in porosity.

SUNDOG PROSPECTS

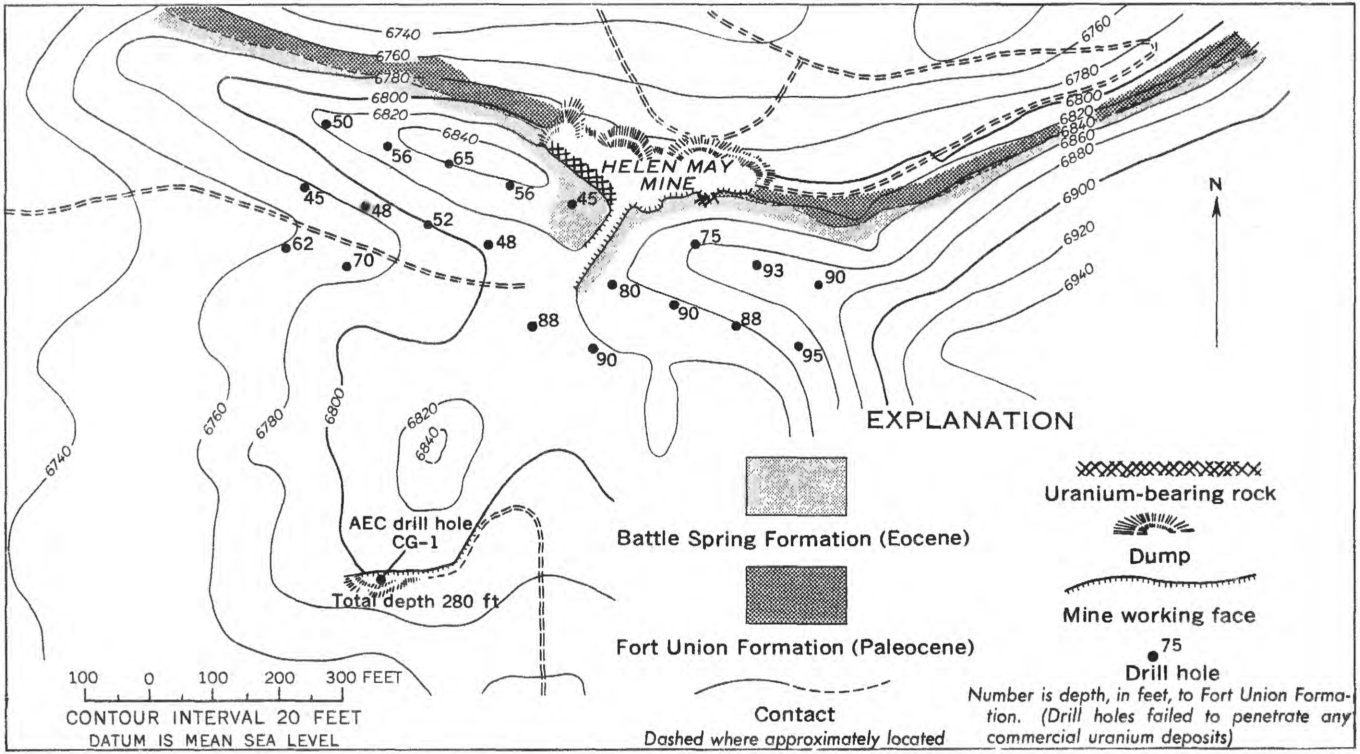
The discovery pit of the Sundog prospects is in the SW¼NW¼ sec. 28, T. 28 N., R. 92 W., on the west flank of Sheep Mountain (pl. 7). The uranium occurs in a sequence of hematite-stained arkose interbedded with carbonaceous siltstone beds in member A of the Battle Spring Formation. The beds strike northwestward and dip 25° to 30° NE along the east flank of the Crooks Gap anticline. No faults were observed in the discovery pits. However, variable dip and strike readings and close spacing of joints to the north of the pits suggest the possibility of unobserved faulting.

Uraninite and coffinite make up specks and small nodules in carbonaceous siltstone beds, and uranophane impregnates the adjacent arkosic sandstone. Concretionary masses less than a foot in diameter and consisting of concentric halos of rich uranophane and uraninite impregnations are present in some of the sandstone beds. Metatyuyamunite encrusts fossll plants and coaly streaks in the carbonaceous siltstone beds.

Drilling 500 feet east of the discovery pit is reported to have penetrated ore-grade sandstone at a depth of 470 feet.

HELEN MAY MINE

The Helen May mine is in the NW¼NE¼ sec. 20, T. 28 N., R. 92 W., on the north face of a low east-trending ridge (fig. 14). The mine is



Map from Wyoming Uranium Co. and DMEA. Published with permission

FIGURE 14.—Geologic and topographic map of the Wyoming Uranium Co. Helen May mine, NW¼ NE¼ sec. 20, T. 28 N., R. 92 W.

in the lower 80 feet of the Battle Spring Formation (member A). At the mine the Battle Spring is composed of conglomeratic arkose and conglomerate lenses and is characterized by abundant cut-and-fill structures. The beds strike approximately east and dip 15° S. along the nose of the Spring Creek anticline.

The Helen May mine is believed to be in a southward-trending ancient channel because of the abundant cut-and-fill structures exposed in a 70-foot-high working face and because of abrupt vertical changes in grain size between adjacent beds. A 20-foot rise of the base of the Battle Spring Formation just east of the mine is believed to mark part of the east wall of the channel.

The ore body in the Helen May area strikes east and is approximately 135 feet long, 40 feet wide, and 6 to 12 feet thick. No continuation of the ore body downdip was indicated by drilling on 100-foot centers for 400 feet south of the ore face (fig. 14). The ore body in the Battle Spring Formation parallels the contact between the Battle Spring and the underlying Fort Union. Changes of lithology have little apparent effect on the distribution of the ore, which occurs in siltstone, sandstone, and conglomerate.

Most of the ore from the Helen May mine contained no visible uranium minerals, although antunite and meta-autunite locally coat some cobbles and pebbles.

Proximity to the base of the Battle Spring Formation seems a likely control on the Helen May ore body. The impermeable nature of the underlying Fort Union Formation could have effectively controlled the movement of ground water. The east-west elongation and abrupt southward termination of the ore body may reflect the configuration of an ancient perched water table near the top of which the ore was deposited.

DEPOSITS ASSOCIATED WITH THRUST FAULTS

Weakly mineralized rock is associated with at least two of the thrust faults at the north end of Crooks Gap. A pit in the SW¼NE¼ sec. 9, T. 28 N., R. 92 W., exposes weakly mineralized gouge along one of two parallel faults at this locality (fig. 15). No uranium minerals are visible in the gouge, but a rounded concretionlike body of Cody Shale containing schroeckingerite was found in a brecciated zone 3 feet south of the gouge zone. The exposed section of the body was about 1.5 feet wide.

A thrust fault that brings Precambrian granite in contact with Cambrian rocks contains weakly mineralized gouge in the NW¼NW¼ sec. 9, T. 28 N., R. 92 W. (fig. 16). The Cambrian rocks consist primarily of bedded gray limestone and intercalated hematitic shale and siltstone. Two adits have been driven along the fault. The western adit parallels the fault for 80 feet, but no mineralized rock was found once the surface was penetrated. The eastern adit follows a narrow mineralized zone in the fault zone for about 17 feet, but attempts at mining have been discontinued because of the low grade of the material.

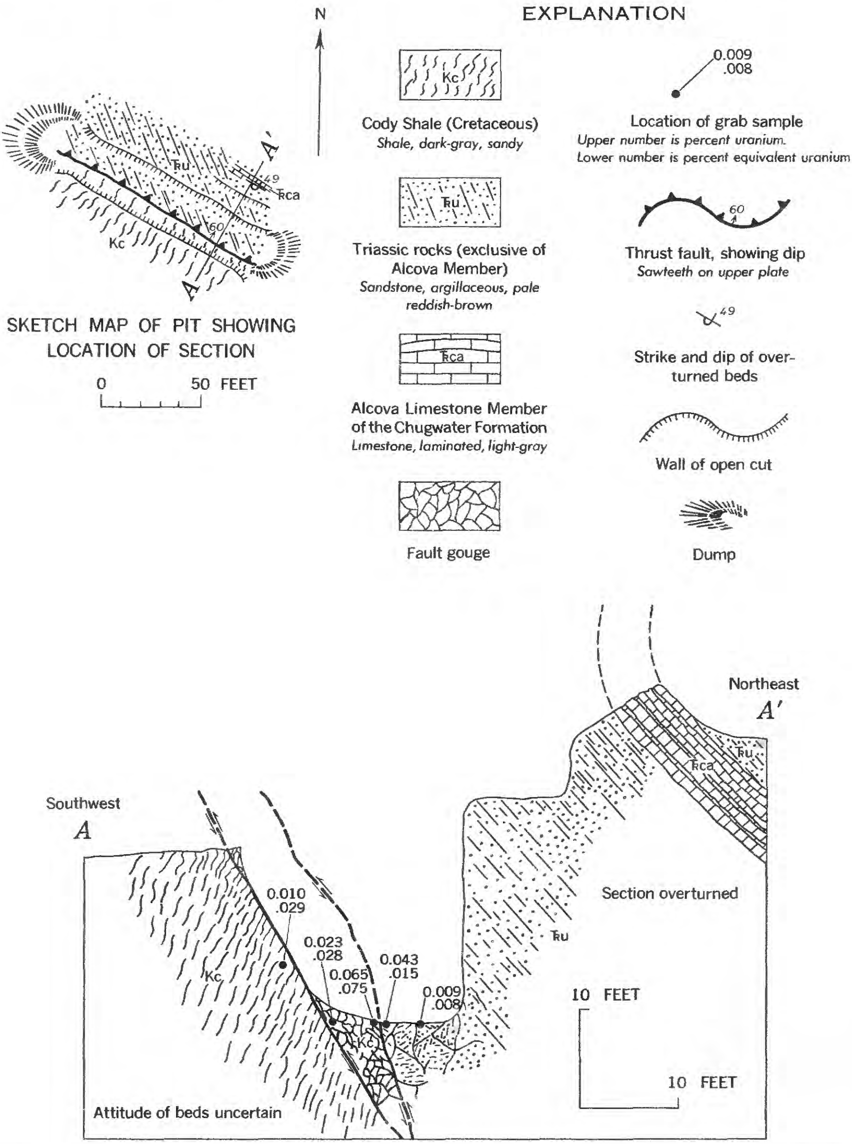


Figure 15.—Cross section of uranium prospect, Hazel claim, SW¼NW¼ sec. 9, T. 28 N., R. 92 W.

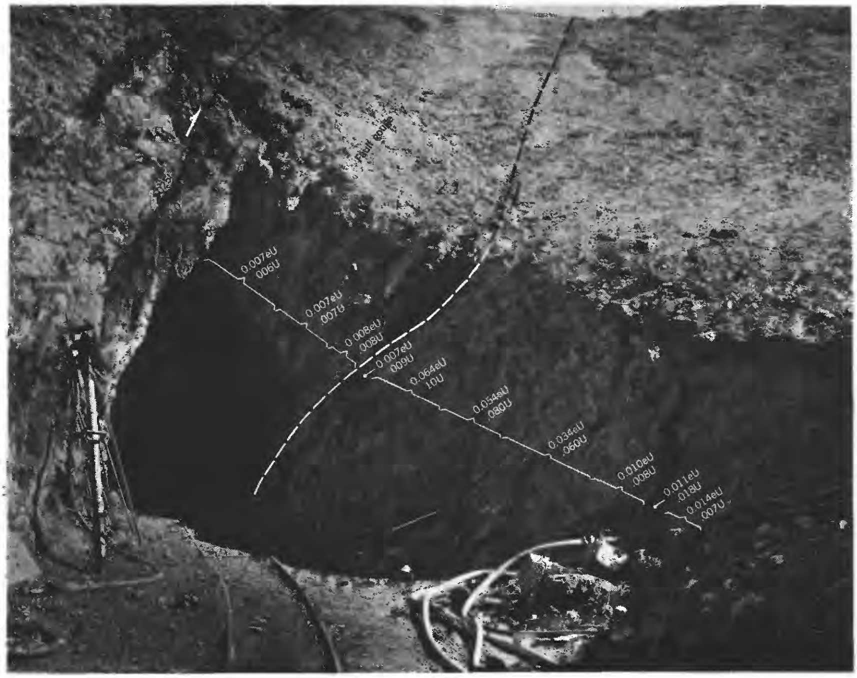


FIGURE 16.—Adit in gouge zone of thrust fault, NW¼NW¼ sec. 9, T. 28 N., R. 92 W. Percent equivalent uranium (eU) and uranium (U) shown for chipped samples collected along zone indicated by bracketed line.

ORIGIN OF THE DEPOSITS

Preliminary studies of exposed uranium occurrences in the area indicate that the uranium was introduced by ground water and that mineralization occurred in and near carbonaceous rocks. Precipitation of the uranium from ground water is believed to have been in a reducing environment created by the carbonaceous rocks that are interbedded with the arkose. A few small uranium occurrences along faults of large displacement indicate that these faults may have acted as conduits either for ascending or descending uranium-bearing solutions.

Three hypotheses are suggested for the source of the uranium: (1) leaching of mildly uraniferous tuffaceous rocks of Pliocene, Miocene, and Oligocene age, (2) leaching of the arkosic sediments of the Battle Spring Formation, and (3) uranium-bearing water from a deep-seated primary source. According to the first hypothesis, the uranium was introduced into the ground water by leaching of tuffaceous Oligocene, Miocene, and Pliocene rocks that once covered most of the Crooks Gap area. The water moved downward into the porous Battle Spring Formation and, in reaching reducing environments created by the carbonaceous beds, deposited uranium. The second hypothesis, leaching of the arkosic sediments of the Battle Spring Formation, is supported mainly by a few relatively high uranium analyses (0.002 to 0.003 percent uranium, Masursky, 1962) of granite of the Granite Mountains, the source of the Battle Spring sediments. Leaching of fragments of granite in the Battle Spring may have provided uranium for the ground water that was moving southward down the dip. The granite samples analyzed, however, are from the outer surface of large granite boulders, and the uranium content may reflect surficial enrichment of the granite by ground water that derived uranium from the mildly radioactive overlying tuffaceous rocks. The third hypothesis is supported by occurrences of a few small uranium deposits along faults; these deposits suggest that the fault zones may have acted as conduits for rising mineralizing solutions. If so, these solutions must have entered permeable beds of the Battle Spring Formation where the uranium was introduced into the ground-water system and carried to its site of deposition.

RELATION TO SURROUNDING URANIUM DEPOSITS

Uranium occurrences have been studied in several areas surrounding Crooks Gap. The locations of these areas are shown on figure 9, and the uranium occurrences are compared in table 6.

URANIUM CONTENT IN NATURAL WATER

The Crooks Gap area contains abundant seeps and springs so that an opportunity was afforded to test the method of prospecting for uranium by water sample analyses (Denson, Zeller, and Stephens, 1956, p. 673). The sampling had two purposes: (1) to delimit areas suitable for intensive prospecting by noting samples of anomalously high uranium content, and (2) to obtain data concerning the possible source of the uranium deposits.

One hundred twenty-six water samples were collected from the region surrounding Crooks Gap. The location and uranium contents of selected samples are shown on plate 8, and data for all samples are presented in table 7. The results of analyses for selected trace elements of residues from four bulk water samples are shown in table 8.

Average uranium contents of water samples varied. Samples from Pliocene, Miocene, and Oligocene rocks averaged 14 ppb (parts per billion) and had an average pH of 7.5. Water from the Battle Spring arkose averaged 4.8 ppb uranium and had an average pH of 7.4. Samples from pre-Eocene rocks averaged 9.1 ppb uranium and had an average pH of 7.7.

TABLE 6.—*Comparison of uranium deposits at Crooks Gap to deposits of surrounding areas*

Area (fig. 9)	Uranium minerals	Accessory elements	Stratigraphic position of deposit	Stratigraphic position of tuff in section	Relation of mineralization to faults	Regional structural setting of deposits
Crooks Gap	Probably uraninite in unoxidized zone; uranophane, autunite, metatyuyamunite phosphuranylite, uraninite, coffinite, uranopilite, becquerelite, beta uranotil, and schroeckingerite in oxidized zone.	None apparent	Battle Spring Formation (lower Eocene).	Oligocene, Miocene, Pliocene.	Faults of small displacement, together with gouge, effectively controlled ground-water movement; thrust fault of large displacement has minor occurrences.	At boundary between Great Divide Basin and Granite Mountains Sheet.
Gas Hills	Primary minerals are uraninite and coffinite in unoxidized zone; meta-autunite, uranophane, and phosphuranylite in oxidized zone.	Selenium	Wind River Formation (lower Eocene).	Middle Eocene, Oligocene, Miocene, Pliocene.	Secondary enrichment adjacent to faults of post-Miocene age where ground-water dams are formed by fault gouge.	South-central part of the Wind River Basin.
Lost Creek	Schroeckingerite	None	Quaternary alluvium and Cathedral Bluffs Tongue of the Wasatch Formation (lower Eocene).	Miocene	Mineralized area is within and north of the Cyclone Rim zone of faulting.	Great Divide Basin.
Central part of Great Divide Basin.	Uranium in coal; little or no visible minerals.	do	Battle Spring Formation (lower Eocene).	do	Area of highest uranium content along axis and on east side of Great Divide syncline; also coincides with zone of intertonguing or permeable arkosic beds and less permeable shale and coal-bearing sequence.	Do.
Baggs	No unoxidized zone exposed; meta-autunite, uranophane, tyuyamunite, carnotite, schroeckingerite, metatorbernite, phosphuranylite, uranocircite, and coffinite in oxidized zone.	Selenium	Browns Park Formation (Miocene?).	do	Along axis of Poison Basin syncline.	Southern part of Washakie Basin.

TABLE 7.—*Location and uranium content of water samples collected in the Crooks Gap area*

[Locations and geologic unit designations of samples not shown on plate 1 are uncertain. Analyses made by the following: H. E. Bivens, G. T. Burrow, R. Daywitt, R. Deming, J. McClure, J. P. Schuch, J. E. Wilson]

Laboratory analysis	Location				Geologic unit		Source	pH	Uranium (ppb)
	Section		Township N.	Range W.	Name	Age			
217607	SW¼	1	27	90	Battle Spring	Eocene	Spring	7.7	8
217605	NE¼	2	27	90	Fort Union	Paleocene	do	7.1	1
217606	SE¼	2	27	90	do	do	do	8.1	3
217611	Center	25	27	90	Mesaverde	Cretaceous	do	7.8	4
217609	NE¼	26	27	90	do	do	do	7.4	10
217610	SE¼	26	27	90	do	do	do	7.6	2
217608	NE¼	34	27	90	do	do	do	7.9	28
214183	SE¼	17	27	91	Battle Spring	Eocene	do	7.0	1
214185	SW¼	18	27	91	do	do	Stream	7.3	1
214181	SE¼	21	27	91	do	do	do	7.3	1
214182	SW¼	21	27	91	do	do	do	7.0	2
214179	SE¼	22	27	91	do	do	Spring	7.1	2
214180	NW¼	22	27	91	do	do	do	7.6	1
214178	NE¼	23	27	91	do	do	do	7.0	1
214175	SE¼	1	27	92	do	do	do	7.3	1
214169	NW¼	2	27	92	do	do	do	7.4	5
214170	SE¼	3	27	92	do	do	do	7.5	1
214174	NE¼	11	27	92	do	do	do	7.3	1
214172	NE¼	11	27	92	do	do	Stream	8.0	10
214173	NW¼	12	27	92	do	do	Spring	7.6	3
214188	NW¼	5	27	93	do	do	do	7.2	1
220317	NW¼	13	27	93	do	do	do	8.4	11
220316	NW¼	13	27	93	do	do	do	8.1	16
220318		36	27	93	do	do	do	7.8	1
231682	NE¼	6	28	88	Sandstone	Miocene	Well	7.4	18
231683	SW¼	10	28	89	do	do	do	7.1	9
214177	NW¼	19	28	90		Miocene(?)	Spring	7.4	1
217601	NE¼	29	28	90		do	do	7.4	2
217602	NE¼	34	28	90	Mesaverde	Cretaceous	do	7.4	4
217603	NE¼	35	28	90	do	do	do	8.3	60
217604	SW¼	35	28	90	do	do	do	7.9	4
214176	SE¼	13	28	91		Miocene	do	7.0	10
214895	NW¼	9	28	92		Precambrian	do	7.4	24
220320	SE¼	10	28	92	Cloverly	Cretaceous	do	7.9	5
220319	SE¼	10	28	92	do	do	do	7.8	2
214166	SE¼	14	28	92	do	do	do	7.7	1
214167	SE¼	14	28	92	do	do	do	7.4	1
217614	NE¼	15	28	92	do	do	do	7.8	1
217615	NE¼	15	28	92	Sundance	Jurassic	do	8.2	28
214168	SE¼	15	28	92	Frontier	Cretaceous	do	7.6	1
232675	SW¼	20	28	92	Battle Spring	Eocene	Stream	8.2	10
214890	SE¼	22	28	92	do	do	Spring	7.3	6
214891	SE¼	22	28	92	do	do	do	7.1	9
214893	SE¼	22	29	92	do	do	do	7.1	21
214889	NW¼	22	28	92	Cody	Cretaceous	do	7.6	1
217612	SW¼	23	28	92	do	do	do	8.4	1
217613	NW¼	26	28	92	Battle Spring	Eocene	do	7.7	4
214892	NE¼	27	28	92	do	do	do	7.2	6
220313	NW¼	28	28	92	do	do	do	8.3	255
220315	NE¼	30	28	92	do	do	do	7.8	1
207697	NE¼	32	28	92	do	do	do		250
214157	SE¼	2	28	93		Miocene	do	7.6	3
214155	SW¼	2	28	93	Battle Spring	Eocene	do	7.4	1
214156	SE¼	3	28	93	do	do	Stream	8.1	5
214151	SW¼	5	28	93			Well	9.3	1
214153	SE¼	8	28	93	Battle Spring	Eocene	Spring	7.0	1
214150	NW¼	8	28	93	do	do	do	7.2	3
214152	NW¼	8	28	93	do	do	do	6.9	1
214888	NE¼	11	28	93	do	do	do	7.2	1
220321	NE¼	11	28	93	do	do	do	8.5	2
214158	NW¼	12	28	93	do	do	do	7.9	2
214160	SW¼	13	28	93	Cody	Cretaceous	do	7.4	1
214159	NE¼	14	28	93	do	do	do	7.8	1
232668	SE¼	14	28	93	Battle Spring	Eocene	do	7.4	12
232674	SE¼	14	28	93	do	do	Stream	7.4	16
214154	NE¼	16	28	93	do	do	do	7.8	1
214147	NW¼	17	28	93	do	do	Spring	6.8	1
214148	SE¼	18	28	93	do	do	do	6.9	1
214149	NW¼	18	28	93	do	do	Stream	7.7	2
232671	NE¼	23	28	93	do	do	Spring	7.1	9
214887	NE¼	23	28	93	do	do	Stream	7.5	32

TABLE 7.—*Location and uranium content of water samples collected in the Crooks Gap area*—Continued

Laboratory analysis	Location				Geologic unit		Source	pH	Uranium (ppb)
	Section		Township	Range	Name	Age			
232672	NE¼	23	28	93	Battle Spring	Eocene	Spring	7.4	23
232673	SE¼	23	28	93	do	do	do	7.5	34
232669	SE¼	23	28	93	do	do	do	7.6	2
214897	SE¼	24	28	93	do	do	do	7.1	8
214883	SW¼	24	28	93	do	do	do	7.1	19
214885	NW¼	24	28	93	do	do	Stream	7.2	148
214886	NW¼	24	28	93	Cody	Cretaceous	Spring	7.7	1
214884	NW¼	25	28	93	Battle Spring	Eocene	do	7.2	2
232670	NE¼	26	28	93	do	do	do	8.2	460
214189	SW¼	32	28	93	do	do	do	7.4	2
214187	SE¼	33	28	93	do	do	do	7.1	8
214186	SE¼	34	28	93	do	do	do	7.2	4
214164	SW¼	2	28	94	do	do	do	7.8	1
214163	NE¼	11	28	94		Miocene	do	7.2	5
214161	SE¼	14	28	94	Battle Spring	Eocene	do	7.2	1
231653	NW¼	11	28	97		Precambrian	do	7.3	1
231652	NW¼	21	28	97		do	do	7.6	5
231650	SE¼	21	28	98		do	do	7.4	1
231651	NW¼	24	28	98		do	do	7.7	6
D-78136	SE¼	17	29	90		Miocene	Well		25
231684	NW¼	7	29	91		Precambrian	do	8.8	1
D-78134	SW¼	15	29	91		Miocene	do		50
D-78135	SE¼	16	29	91		do	do		6
D-78133	NE¼	17	29	91		do	do		39
D-78132	NW¼	19	29	91		do	do		44
231667	SE¼	11	29	94		do	do	7.5	1
231656	NE¼	15	29	95		do	Spring	7.7	4
231657	SE¼	35	29	95	Madison	Mississippian.	do	7.6	8
231655	SW¼	21	29	96		Miocene	do	7.8	11
231654	SW¼	30	29	96		do	do	7.7	14
231649	NE¼	24	29	100		Precambrian	do	7.3	1
231686	NE¼	7	30	89		Pliocene	Well	7.6	30
236344	NW¼	31	30	89		do	Spring	7.5	4
231685	SW¼	22	30	90		Miocene	do	6.7	45
231668	NE¼	13	30	95		do	do	7.7	8
231665	SW¼	31	30	96		Cretaceous	do	8.0	4
231661	NW¼	35	30	98		Cambrian	do	7.7	9
231680	SW¼	7	31	89		Miocene	do	7.4	5
231687	SE¼	27	31	89		do	do	7.5	8
231688	SE¼	27	31	89		do	do	8.2	5
231689	NW¼	24	31	90		do	do	7.3	13
231690	NE¼	32	31	91		do	do	7.4	8
231675	SW¼	29	31	92		Precambrian	do	7.4	19
231673	NE¼	9	31	93		do	do	7.8	36
231674	SW¼	24	31	93		do	do	7.6	2
231670	SE¼	15	31	95	White River	Oligocene	Well	7.6	11
231669	SE¼	31	31	95		Oligocene or Miocene.	do	7.7	8
231658	SE¼	24	31	98	Chugwater	Triassic	Spring	7.8	20
231679	NW¼	29	32	89		Miocene	do	7.7	8
231678	NW¼	25	32	90		do	do	7.8	5
231672	SW¼	34	32	94	White River	Oligocene	do	7.5	2

TABLE 8.—*Analyses of selected trace elements from water and residues of four bulk samples, in the vicinity of Crooks Gap, Wyo.*

[Chemical analyses by G. T. Burrow, R. P. Cox, Irving Frost, S. P. Furman, W. D. Goss, C. J. Huffman, Wayne Mountjoy, J. P. Schuch, D. L. Skinner, James Wahlberg, J. E. Wilson; semiquantitative spectrographic analyses by P. J. Dunton and J. C. Hamilton. Asterisk (*) indicates determination by chemical analyses. Other determinations by semiquantitative spectrographic analysis]

Sample	U	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	As^{+1}	Se^{+1}	Sr	Mo	Ba	Pb
Trace element content in residue, in parts per million																								
1	*12	300	150	*30,000	70,000	300	70,000	*1,232	70,000	*200,000	7	30	15	30	1,500	<5	30	*250	----	----	1,500	15	150	----
2	*250	300	300	*60,000	30,000	1,500	70,000	*800	30,000	*170,000	7	15	7	30	1,500	7	70	*<10	----	----	1,500	15	150	15
3	*1,000	300	150	*80,000	30,000	1,500	70,000	*282	70,000	*170,000	15	15	15	15	150	7	30	*<10	9	----	3,000	10	150	15
4	*970	300	700	*110,000	70,000	3,000	30,000	*50	15,000	*194,000	15	7	3	3	300	1.5	30	70	----	----	3,000	<10	300	15
Trace element content (computed) in water, in parts per billion																								
1	2	42	21	4,230	9,870	42	9,870	174	9,870	28,200	1	4	2	4	212	<1	4	35	<10	<1	212	2	21	----
2	23	28	28	5,520	2,760	138	6,440	74	2,760	15,640	1	1	1	3	138	1	6	<1	<10	<1	138	1	14	1
3	112	34	17	8,960	3,360	168	7,840	32	7,840	19,040	2	2	2	2	17	1	3	<1	1	----	336	1	17	2
4	255	79	184	28,930	18,410	789	7,890	13	3,945	51,022	4	2	1	1	79	<1	8	18	<3	1	789	<3	79	4

Laboratory number, location, and description of samples

Sample	Laboratory analysis	Location: Section		Location: Township N.	Location: Range W.	Volume evaporated (liters)	Weight of residue (grams)	Source rock	pH	Solids (ppm)
1	236344	NW¼	31	30	89	24.9	3.5	Pliocene(?)	7.5	141
2	235238	SW¼	22	30	90	26.14	2.4	Miocene	6.7	92
3	234102	SE¼	14	28	93	25.87	2.9	Eocene	7.9	112
4	220712	NW¼	28	28	92	19.0	5.0	do	8.3	263

Water samples having a high uranium content are concentrated in member A of the Battle Spring Formation in Crooks Gap. Uranium content of water from springs near mines is as much as 50 times the average content. Water from the spring half a mile southeast of the Sno-ball mines contains 250 ppb uranium, or 52 times the average of water from the Battle Spring, and that from the spring near the Sundog prospects in NW¼ sec. 28, T. 28 N., R. 92 W., contains 225 ppb, or 47 times the average. The significance of the high uranium content of ground water sampled on the west side of Crooks Gap has not yet been determined due to lack of detailed exploration. These highly uraniferous samples may indicate the existence of concealed uranium deposits.

The assumption that the present uranium content of the water from a particular formation indicates the original potential of that formation as a source of uranium is questionable. A possible explanation of the low average uranium content of the water of the Battle Spring Formation is that much of the uranium in the source area (Granite Mountains sheet) may have been concentrated in the heavy minerals. Segregation of the uranium minerals in weathering debris, or leaching during the period of weathering in place and during deposition as part of the Battle Spring Formation, may have removed much of the original uranium. The present meager uranium content of the average water from the Battle Spring Formation may be released by the additional weathering of the coarser constituents of the formation. At one time the Battle Spring Formation may have contributed significant amounts of uranium to the ground water.

At the present time it is believed that water sampling in the Crooks Gap area is of little use in solving the problem of origin of the uranium deposits, but the method does have a great potential as a rapid and inexpensive method of delimiting areas worthy of further uranium prospecting.

SPECTROGRAPHIC ANALYSES

Semiquantitative spectrographic analyses of 150 samples of arkose of Eocene age from the area were studied to determine whether a correlation exists between the concentration of various elements relative to the variation in percentage of uranium. Tables 9, 10, and 11 present the basic analytical data for samples collected from three areas of mining activity in the gap. Table 12 presents the same type of data for samples collected from varied locations in the gap not associated with mining areas. The geometric means of these data are plotted on figure 17.

In tables 9, 10, 11, and 12, the theoretical subgroup range and subgroup midpoint for concentrations of the elements detected by semiquantitative spectrographic method in the Geological Survey laboratory are reported by code numbers as shown in the following list:

Code	Subgroup range (percent)	Subgroup midpoint (percent)
1	10.0 -100.	----------
2	4.6 - 10.0	6.8
3	2.1 - 4.6	3.2
4	1.0 - 2.1	1.5
5	.46 - 1.0	.68
6	.21 - .46	.32
7	.10 - .21	.15
8	.046 - .10	.068
9	.021 - .046	.032
10	.010 - .021	.015
11	.0046 - .010	.0068
12	.0021 - .0046	.0032
13	.0010 - .0021	.0015
14	.00046- .0010	.00068
15	.00021- .00046	.00032
16	.00010- .00021	.00015

Differences in trace element composition between mineralized and nonmineralized (less than 0.003 percent uranium) samples are not striking. A positive correlation between uranium and copper is indicated and a negative correlation between uranium and nickel and titanium is shown. Other correlations are less probable. A possible explanation for the lack of correlation may be that the samples are all from surficial rocks where weathering may have altered the trace element composition.

TABLE 9.—*Semiquantitative spectrographic, chemical, and radiometric analyses*
Sno-ball mines area SE¼

[Spectrographic analyses by Charles Annell, Mona Frank, Joseph Haffty, and R. G. Havens; chemical and
Moore, James Wahlberg, and J. E. Wilson. Boron

Laboratory analysis	Equivalent uranium (percent)	Chemical uranium (percent)	Semiquantitative spectrographic analyses													
			Be	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co
146118	1.7	2.4	0	4	6	3	1	3	6	0	10	12	15	13	5	0
217671	1.2	1.96	0	4	6	1	1	4	6	0	8	12	12	11	4	----
217688	.55	.98	0	5	6	2	1	3	6	0	9	12	13	11	4	----
217689	.69	.96	0	5	6	2	1	4	6	0	9	12	13	11	4	----
217690	.77	.40	16	5	6	1	1	4	6	0	8	12	13	10	2	----
217691	.54	.25	16	4	6	1	1	4	6	0	8	12	13	10	2	----
217654	.13	.21	0	4	6	2	1	4	7	0	9	12	13	11	4	----
146119	.036	.21	0	4	6	3	1	3	7	0	10	12	15	13	5	0
217653	.12	.18	16	4	6	1	1	3	6	14	8	12	13	11	4	----
217687	.13	.13	15	4	5	1	1	3	6	14	7	11	13	11	3	----
146146	.054	.13	0	4	7	3	1	3	7	13	9	12	14	13	6	0
217692	.21	.11	16	4	6	1	1	4	6	0	9	12	13	11	3	----
217652	.057	.089	15	4	6	1	1	4	6	14	7	12	13	11	4	----
217672	.11	.073	0	4	6	1	1	4	7	0	9	12	13	11	4	----
217651	.046	.068	16	4	6	1	1	4	6	14	7	12	14	11	4	----
146148	.13	.049	0	4	7	3	1	3	7	0	10	13	14	13	4	0
146156	.034	.046	0	4	7	3	1	3	8	13	9	12	14	13	5	13
146144	.031	.030	0	4	7	3	1	3	7	13	9	12	14	13	5	0
146111	.025	.028	0	4	6	2	1	3	7	13	8	12	14	13	4	0
217693	.091	.028	0	4	6	1	1	4	6	0	9	12	13	10	4	----
146154	.030	.026	0	4	7	3	1	3	8	0	10	12	14	13	5	0
146120	.038	.025	0	4	6	3	1	3	7	0	10	12	14	12	5	0
146145	.014	.021	0	4	7	3	1	3	7	13	9	12	14	13	5	0
217657	.026	.019	16	4	6	1	1	4	6	0	8	12	14	11	3	15
217656	.016	.016	0	4	6	1	1	4	7	0	8	12	13	11	4	15
146155	.016	.016	0	4	7	3	1	3	8	13	10	12	14	13	5	0
217649	.014	.014	16	4	6	1	1	4	6	14	7	11	13	11	4	15
146150	.075	.012	0	4	7	3	1	3	7	0	10	12	14	13	5	0
217664	.011	.012	15	4	5	1	1	4	6	13	7	11	13	10	4	14
146110	.020	.011	0	4	6	3	1	3	7	13	9	12	15	13	5	0
217650	.014	.011	0	4	6	1	1	4	7	0	8	12	14	12	4	15
146152	.033	.010	0	4	7	3	1	3	8	0	10	12	14	13	5	0
217680	.009	.010	15	4	6	1	1	4	6	13	7	11	13	11	4	15
217673	.041	.009	0	4	6	1	1	4	7	0	9	12	13	11	4	15
217685	.016	.009	0	4	6	2	1	4	6	0	9	12	13	11	4	15
217681	.010	.009	15	4	5	1	1	4	6	13	7	11	13	11	4	15
217674	.033	.008	0	4	6	1	1	4	7	0	9	12	13	11	4	15
217679	.012	.008	16	4	6	1	1	4	6	14	7	13	14	11	4	15
217655	.011	.008	0	5	7	2	1	4	7	0	9	11	13	11	4	15
146153	.036	.006	0	4	7	3	1	3	8	0	10	12	14	13	6	0
217678	.013	.006	16	4	5	1	1	4	6	14	7	12	13	11	4	15
217682	.006	.006	16	4	6	1	1	4	6	14	8	12	13	11	4	15
146151	.066	.005	0	4	7	3	1	3	7	0	10	12	14	13	5	0
217667	.008	.005	15	5	5	1	1	4	6	13	7	12	13	10	4	14
217665	.007	.005	16	4	6	1	1	4	6	14	7	12	14	10	2	15
146147	.016	.004	0	4	7	3	1	3	7	13	9	13	14	13	5	0
146109	.013	.004	0	4	7	3	1	3	7	0	10	12	15	13	6	0
217648	.006	.004	0	4	6	1	1	4	7	0	8	12	13	11	4	15
217663	.006	.004	16	5	5	1	1	4	6	14	7	12	13	11	4	15
217662	.005	.004	16	5	5	1	1	4	6	13	7	12	13	11	4	15
146116	.010	.003	0	4	7	3	1	3	7	0	10	12	15	13	5	0
217683	.008	.003	0	5	6	1	1	4	6	0	9	12	13	11	4	15
217677	.007	.002	0	4	7	1	1	4	7	0	9	12	13	10	4	15
217670	.007	.002	Tr.	4	6	1	1	4	6	14	7	12	13	10	4	14
217676	.006	.002	0	4	7	1	1	4	7	0	9	12	13	10	4	15
217669	.005	.002	0	5	6	1	1	4	6	0	8	12	13	11	4	15
217666	.007	.001	0	4	6	1	1	4	7	0	8	12	13	11	4	14

of 57 grab samples of arkose from member A of the Battle Spring Formation, sec. 29, T. 28 N., R. 92 W.

radiometric analyses by Grafton Daniels, Mary Finch, S. P. Furman, W. D. Goss, B. A. McCall, Roosevelt was looked for in all samples, but was not found]

Semiquantitative spectrographic analyses—Continued

Ni	Cu	Ga	Ge	Sr	Y	Zr	Nb	Mo	Sn	Ba	La	Ce	Nd	Yb	W	Pb	U
0	10	13	0	11	12	13	0	0	13	9	0	0	0	16	8	12	3
14	13	13	0	11	12	10	0	14	0	8	10	Tr.	Tr.	14	0	12	4
14	13	13	0	11	12	10	0	0	0	8	10	9	Tr.	15	0	11	6
14	13	13	0	11	13	10	0	14	0	8	12	0	0	15	0	11	5
14	12	13	0	10	12	10	Tr.	14	0	8	11	0	Tr.	14	0	10	6
14	12	13	0	10	12	11	Tr.	14	0	8	12	0	0	15	0	10	6
14	13	14	0	11	12	10	Tr.	14	0	8	0	0	0	15	0	11	6
0	10	13	0	11	12	13	0	0	13	9	0	0	0	16	8	12	6
14	13	13	0	11	12	9	13	14	0	8	10	Tr.	Tr.	14	0	10	7
14	13	13	0	10	12	9	13	Tr.	0	8	11	0	0	14	0	9	7
13	10	13	0	11	12	12	0	0	13	9	0	0	0	16	0	12	7
14	13	13	0	10	13	10	Tr.	14	0	8	12	0	0	15	0	11	7
15	13	13	0	11	10	9	13	14	0	8	10	Tr.	Tr.	13	0	10	8
14	13	13	0	11	13	11	Tr.	14	0	8	0	0	0	15	0	11	8
15	14	13	0	11	12	9	13	0	0	8	11	Tr.	Tr.	14	0	10	8
13	10	13	12	11	12	13	0	0	0	9	0	0	0	16	8	10	9
13	9	13	0	11	12	12	0	0	13	9	10	9	10	16	8	12	9
13	10	13	0	11	12	10	0	0	13	9	11	0	0	16	0	13	9
0	10	13	0	11	12	12	0	13	13	9	10	9	10	16	8	13	9
14	13	13	0	10	13	11	Tr.	14	0	8	12	Tr.	0	16	0	11	9
13	10	13	0	11	12	12	0	0	13	9	0	0	0	16	8	12	9
13	10	13	0	11	12	13	0	0	12	9	11	0	0	16	8	12	9
13	10	13	0	11	12	12	0	0	13	9	0	0	0	16	0	13	9
15	14	13	0	11	11	9	13	0	0	8	9	8	10	14	0	11	10
14	13	13	0	11	13	10	Tr.	Tr.	0	8	12	0	0	16	0	12	10
13	10	13	0	11	12	12	0	0	13	9	11	0	0	16	8	12	10
14	14	13	0	11	12	9	13	14	0	8	11	Tr.	Tr.	0	0	11	10
13	9	13	12	11	12	12	0	0	13	9	0	0	0	16	8	12	10
14	12	12	0	11	10	9	12	14	0	8	10	9	10	13	0	11	10
0	10	13	0	11	12	12	0	0	13	9	10	9	10	16	8	13	10
15	14	13	0	11	12	9	13	0	0	8	12	0	0	14	0	11	10
13	10	13	0	11	0	12	0	0	13	9	0	0	0	0	8	12	10
15	13	13	0	11	11	9	13	0	0	8	10	9	10	14	0	11	10
14	13	14	0	11	19	10	Tr.	14	0	8	12	0	0	15	0	11	11
14	13	14	0	11	12	11	Tr.	14	0	8	0	0	0	15	0	12	11
15	12	13	0	11	12	9	13	0	0	8	10	9	Tr.	14	0	11	11
14	13	14	0	11	12	10	Tr.	14	0	8	11	Tr.	Tr.	15	0	12	11
15	14	13	0	11	11	9	13	0	0	8	10	9	10	14	0	11	11
14	13	14	0	11	13	10	Tr.	14	0	8	12	0	0	16	0	12	11
13	9	13	0	11	12	12	0	0	13	9	11	0	0	0	8	12	11
15	14	13	0	11	12	10	13	0	0	8	10	9	Tr.	14	0	11	11
14	13	13	0	11	12	10	13	Tr.	0	8	11	Tr.	Tr.	15	0	11	11
12	10	13	13	11	12	12	0	0	13	9	0	0	0	0	8	12	11
14	13	13	0	11	11	9	12	14	0	8	10	9	Tr.	14	0	11	11
14	14	13	0	11	10	9	13	0	0	8	10	Tr.	Tr.	13	0	11	11
13	10	13	0	11	12	13	0	0	13	9	10	0	0	16	8	13	12
13	10	13	0	11	12	13	0	0	13	9	0	0	0	16	8	13	12
14	13	13	0	11	13	10	Tr.	14	0	8	0	0	0	16	0	12	12
14	13	13	12	11	12	9	12	14	0	8	10	9	Tr.	14	0	11	12
14	13	13	0	11	12	9	12	14	0	8	10	9	Tr.	14	0	11	12
0	10	13	0	11	12	13	0	0	13	9	11	0	0	16	8	13	12
14	13	14	0	11	13	11	Tr.	14	0	8	0	0	0	16	0	12	12
14	12	14	0	11	12	10	0	14	0	8	12	0	0	15	0	12	12
14	13	13	0	11	12	10	13	14	0	8	10	9	10	14	0	11	12
14	13	14	0	11	13	11	Tr.	14	0	8	0	0	0	16	0	12	12
14	13	13	0	11	12	11	13	14	0	8	12	0	0	15	0	11	12
13	12	14	0	11	11	11	Tr.	12	0	8	0	0	0	14	0	10	13

TABLE 10.—*Semiquantitative spectrographic, chemical, and radiometric analyses*
Sundog prospects, NW¼

[Spectrographic analyses by Charles Annell, Mona Frank, Joseph Haffty, and R. G. Havens; chemical
Roosevelt Moore, James

Laboratory analysis	Equivalent uranium (percent)	Chemical uranium (percent)	Semiquantitative spectrographic analyses														
			Be	B	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co
146195	0.39	1.1	16	0	4	7	3	1	3	7	0	9	12	14	10	6	10
146132	.96	.91	16	0	4	7	3	1	3	7	13	10	11	14	12	5	0
146169	.64	.53	16	0	4	6	3	1	3	7	0	9	12	14	10	4	0
146175	.37	.53	16	0	4	7	3	1	3	7	13	8	11	14	11	4	0
146206	.014	.24	16	0	4	7	2	1	3	7	13	7	12	13	13	5	13
146210	.20	.20	16	0	4	7	3	1	3	7	13	9	11	13	13	5	0
146174	.11	.18	16	0	4	7	3	1	3	7	13	8	11	14	12	4	0
146191	.068	.14	0	0	4	7	3	1	3	7	0	10	12	14	13	6	0
146208	.059	.10	0	0	4	7	3	1	3	7	0	10	12	14	13	5	13
146194	.043	.07	16	0	4	7	3	1	3	7	0	9	12	14	11	5	13
146167	.10	.063	0	0	4	6	3	1	3	7	0	10	12	14	10	4	0
217706	.059	.058	16	0	4	6	1	1	4	7	Tr.	8	12	13	11	4	-----
146131	1.3	.050	16	0	4	7	3	1	3	7	0	10	12	15	10	4	0
146207	.050	.026	16	0	4	7	3	1	3	7	13	7	12	13	13	5	13
146188	.025	.026	16	0	4	7	3	1	3	7	13	9	12	14	13	5	0
217707	.057	.019	15	0	5	6	1	1	4	6	14	8	11	13	11	3	15
146133	.029	.015	0	0	4	7	3	1	3	7	0	10	13	15	13	5	0
146172	.021	.015	0	0	4	7	3	1	3	7	0	10	12	14	12	4	0
146196	.013	.014	16	0	4	7	3	1	3	7	0	9	12	14	13	6	0
146200	.026	.013	15	0	4	7	2	1	3	6	13	7	12	13	11	3	11
146130	.016	.013	0	0	4	7	3	1	3	7	13	10	13	14	13	6	0
146187	.010	.010	16	0	4	6	3	1	3	6	13	8	12	14	13	4	0
146190	.010	.009	0	0	4	7	3	1	3	7	0	9	11	14	13	6	0
146170	.067	.008	0	0	4	7	3	1	3	7	0	10	13	14	11	4	0
217711	.021	.007	15	0	4	6	1	1	3	6	13	7	13	13	10	3	15
146189	.006	.007	0	0	4	7	3	1	3	7	0	10	12	14	13	6	0
146129	.011	.006	0	0	4	7	3	1	3	7	0	10	13	15	13	6	0
146186	.009	.006	0	0	4	7	3	1	3	7	0	10	12	14	13	5	0
217705	.014	.005	0	0	4	6	2	1	4	7	Tr.	8	12	13	11	4	Tr.
146205	.014	.005	16	11	5	7	3	1	3	7	0	9	12	14	10	5	0
146184	.004	.005	0	0	4	7	3	1	3	7	0	9	12	14	13	6	0
217702	.022	.004	Tr.	0	5	6	1	1	4	7	Tr.	8	12	13	11	4	15
146204	.009	.004	16	0	4	7	3	1	3	7	0	8	12	14	12	4	0
146212	.006	.004	16	0	4	7	3	1	3	7	13	9	11	13	12	5	0
146197	.006	.004	16	0	4	6	1	1	3	6	13	7	10	12	12	3	0
146198	.006	.004	16	11	4	7	3	1	3	7	13	8	12	13	13	5	0
217714	.005	.004	0	0	5	6	1	1	4	6	0	8	12	13	11	4	15
217696	.006	.003	0	0	5	7	2	1	4	7	0	10	12	13	11	4	15
146203	.004	.003	16	0	4	7	3	1	3	7	0	9	12	14	13	5	0
217701	.014	.002	0	0	4	7	1	1	4	7	0	9	12	13	11	4	15
146201	.008	.002	0	0	4	7	3	1	3	8	0	9	12	14	13	5	0
146202	.006	.002	16	11	4	7	2	1	3	7	13	7	12	13	12	4	0
217699	.006	.002	0	0	5	6	1	1	3	6	0	8	11	13	11	4	15
217708	.006	.002	0	0	4	7	2	1	4	7	0	9	12	13	11	4	15
217694	.006	.002	0	0	5	7	1	1	4	7	0	8	11	13	11	4	15
217695	.005	.002	16	0	5	6	1	1	4	7	0	8	12	13	11	4	15
217710	.005	.002	Tr.	0	4	6	1	1	4	6	0	8	12	13	11	4	15
146185	.004	.002	0	0	4	8	3	1	3	7	0	10	12	14	13	6	0
217715	.006	.001	0	0	5	7	1	1	4	7	0	8	12	13	11	4	15
217700	.005	.001	0	0	4	7	1	1	3	7	0	8	12	13	11	4	15
217716	.005	.001	0	0	5	7	1	1	4	7	0	9	12	13	11	4	15
217718	.004	.001	16	0	4	6	1	1	4	6	14	8	12	13	11	3	15
217719	.002	----------	16	0	4	6	1	1	4	5	14	7	11	13	10	3	15

of 53 grab samples of arkose from member A of the Battle Spring Formation, sec. 28, T. 28 N., R. 92 W.

and radiometric analyses by Grafton Daniels, Mary Finch, S. P. Furman, W. D. Goss, B. A. McCall, Wahlberg, and J. E. Wilson]

Semiquantitative spectrographic analyses—Continued

Ni	Cu	Ga	Ge	Sr	Y	Zr	Nb	Mo	Sn	Ba	La	Ce	Nd	Yb	W	Pb	U
10	10	13	0	11	13	12	0	0	13	9	10	9	0	16	8	10	5
0	10	13	0	10	12	12	0	0	13	9	11	0	11	16	0	10	5
13	13	13	0	11	12	11	0	0	0	9	10	0	0	16	0	12	6
13	13	13	0	11	12	11	0	0	0	9	11	0	0	16	0	10	6
13	10	13	0	11	13	11	0	0	13	9	10	0	11	16	0	12	6
0	10	13	0	11	12	12	0	0	13	9	11	0	0	16	8	11	7
13	13	13	0	11	12	11	0	0	0	9	11	0	0	16	0	12	7
13	10	13	0	11	12	12	0	0	13	9	11	0	0	16	8	12	7
0	9	13	0	11	12	12	0	0	13	9	11	0	0	16	8	12	7
13	9	13	0	11	12	11	0	0	13	9	10	0	10	16	8	11	8
13	13	13	0	11	12	11	0	0	0	9	11	0	0	16	0	13	8
15	13	13	12	10	12	10	Tr.	14	0	8	11	Tr.	0	14	0	11	8
13	10	13	0	11	10	12	0	0	13	9	11	0	11	13	0	10	0
13	12	13	0	11	13	10	0	0	0	9	10	9	10	16	0	12	0
0	10	13	0	11	12	12	0	0	13	9	11	0	0	16	8	11	0
14	13	13	0	10	12	10	13	14	0	8	11	0	0	15	0	10	0
0	10	13	0	11	12	13	0	0	13	9	11	0	0	0	0	13	0
13	13	13	0	11	12	12	0	0	0	9	10	9	10	16	0	13	0
13	10	13	0	11	13	12	0	0	13	9	10	0	0	0	8	12	0
10	12	13	0	10	12	10	0	0	13	9	10	9	10	15	0	11	0
0	10	13	0	11	12	13	0	0	13	9	0	0	0	0	0	12	0
13	10	13	0	11	12	11	0	0	13	9	10	0	0	16	0	10	0
13	10	13	0	11	12	11	0	0	13	8	11	0	0	16	8	12	0
13	13	13	0	11	12	12	0	0	0	9	10	9	10	16	0	13	0
15	14	12	0	10	12	10	13	0	0	8	10	9	10	14	0	11	0
13	9	13	0	11	12	12	0	0	12	9	11	0	0	16	8	12	0
0	10	13	0	11	0	13	0	0	13	9	0	0	0	0	8	13	0
13	10	13	0	11	12	12	0	0	12	8	0	0	0	16	8	12	0
15	13	13	0	10	13	10	13	0	0	8	12	Tr.	0	15	0	11	0
13	10	13	0	11	13	11	0	0	13	9	11	0	11	16	8	12	0
13	9	13	0	11	12	12	0	0	12	8	11	0	0	16	8	12	0
14	13	13	0	10	13	10	13	14	0	8	11	Tr.	0	15	0	11	0
0	10	13	0	11	13	11	0	0	13	9	10	9	10	16	0	12	0
13	9	13	0	11	12	12	0	0	13	9	10	0	0	16	8	11	0
13	10	13	0	11	11	10	0	0	13	8	10	8	10	15	0	12	0
13	10	13	0	11	12	11	0	0	13	8	10	9	10	16	0	12	0
14	13	13	0	11	13	10	Tr.	Tr.	0	8	0	0	0	16	0	11	0
14	13	14	0	11	13	10	Tr.	Tr.	0	8	0	0	0	16	0	11	0
13	9	13	0	11	13	12	0	0	13	9	10	0	11	16	8	12	0
14	11	13	0	10	12	10	Tr.	14	0	8	10	9	10	15	0	11	0
13	10	13	0	11	13	12	0	0	13	9	10	0	11	16	8	12	0
13	10	13	0	10	11	10	0	0	13	9	10	9	10	14	0	12	0
14	13	13	0	10	13	10	Tr.	14	0	8	12	0	0	16	0	11	0
14	13	13	0	11	13	10	Tr.	14	0	8	0	0	0	16	0	11	0
14	12	13	0	11	12	10	Tr.	0	0	8	10	Tr.	Tr.	15	0	11	0
15	13	13	0	11	12	10	13	0	0	8	10	Tr.	Tr.	15	0	11	0
14	13	13	0	10	12	10	13	14	0	8	12	0	0	15	0	11	0
13	9	13	0	11	12	12	0	0	12	9	0	0	0	16	8	12	0
14	13	13	0	11	13	10	13	14	0	8	11	0	0	16	0	11	0
14	13	13	0	11	14	11	Tr.	Tr.	0	8	0	0	0	16	0	11	0
14	13	13	0	11	13	10	Tr.	14	0	8	11	Tr.	0	16	0	11	0
14	12	13	0	10	12	10	Tr.	14	0	8	9	8	9	15	0	11	0
14	12	13	0	9	12	10	13	14	0	8	11	0	0	15	0	11	0

TABLE 11.—*Semiquantitative spectrographic, chemical, and radiometric analyses*
Helen May mine, NE¼

[Spectrographic analyses by G. W. Boyes, Jr.; chemical

Laboratory analysis	Equivalent uranium (percent)	Chemical uranium (percent)	Semiquantitative spectrographic analyses														
			Be	B	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co
146123	0.26	0.34	0	0	6	8	4	1	4	6	0	10	12	14	13	5	0
146126	.29	.30	0	10	8	7	4	1	4	6	0	10	13	13	13	5	0
146125	.38	.24	0	10	8	7	4	1	4	6	0	9	12	13	13	4	0
146122	.23	.19	0	0	6	7	4	1	3	6	0	9	12	14	13	4	0
146127	.76	.10	0	0	7	10	4	1	4	6	0	10	13	14	13	4	0
146124	.54	.10	0	10	7	7	4	1	4	6	0	8	12	11	13	4	0
146121	.025	.013	0	0	6	7	3	1	3	6	0	9	12	14	13	5	0
215021	.013	.001	Tr.	13	5	6	2	1	4	7	Tr.	8	12	14	11	4	14

TABLE 12.—*Semiquantitative spectrographic, chemical, and radiometric analyses*
Crooks

[Spectrographic analyses by Charles Annell, G. W. Boyes, Jr., Mona Frank, and Joseph Haffty; chemical
Roosevelt

Location			Laboratory analysis	Equivalent uranium (percent)	Chemical uranium (percent)	Semiquantitative spectrographic analyses											
Section	T.N.	R.W.				Be	B	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr
SW¼ 16	28	92	215020	0.065	0.13	16	Tr.	5	8	2	1	4	7	0	9	12	14
SW¼ 16	28	92	146139	.051	.087	0	10	6	7	3	1	3	8	0	8	12	13
SW¼ 16	28	92	146162	.26	.058	0	0	4	7	3	1	3	7	13	9	12	13
SW¼ 16	28	92	146163	.054	.036	0	10	6	7	3	1	3	7	13	8	12	13
SW¼ 16	28	92	146159	.048	.035	0	10	4	7	3	1	3	7	13	9	12	13
SE¼ 24	28	93	215009	.072	.028	16	Tr.	5	7	1	1	4	7	Tr.	8	9	13
SW¼ 16	28	92	215019	.015	.023	0	Tr.	5	8	2	1	4	7	0	9	12	14
SW¼ 16	28	92	146140	.035	.015	16	10	4	7	3	1	3	8	13	9	13	14
SE¼ 24	28	93	215008	.065	.014	16	Tr.	5	7	1	1	4	7	Tr.	8	10	13
SW¼ 16	28	92	146161	.13	.010	0	10	4	7	3	1	3	8	13	9	12	13
SW¼ 16	28	92	146141	.029	.009	0	10	4	7	3	1	3	6	0	9	13	14
NW¼ 30	28	92	215013	.009	.009	16	Tr.	5	7	1	1	4	7	Tr.	8	12	14
SE¼ 24	28	93	215004	.007	.007	16	Tr.	5	7	1	1	4	7	Tr.	8	12	13
NW¼ 21	28	92	215023	.026	.005	15	13	5	6	1	1	4	7	13	8	12	13
SE¼ 24	28	93	215005	.006	.005	16	Tr.	5	7	1	1	4	7	Tr.	8	12	13
SE¼ 24	28	93	215007	.009	.004	0	Tr.	5	7	1	1	4	7	0	9	12	13
SW¼ 9	28	92	139149	.064	.003	15	9	6	5	3	1	3	6	12	6	12	9
SW¼ 24	28	93	215001	.014	.003	16	Tr.	5	6	2	1	4	6	Tr.	7	11	13
SW¼ 19	28	92	215018	.005	.003	13	0	5	8	4	2	4	5	0	9	13	15
SW¼ 19	28	92	215017	.009	.002	13	0	5	6	3	1	4	7	0	9	13	14
SW¼ 9	28	92	139147	.009	.001	0	9	8	5	3	1	5	6	0	6	12	9
SW¼ 9	28	92	139151	.006	.001	15	9	8	5	2	1	3	5	12	6	12	9
SW¼ 19	28	92	215016	.006	.001	14	Tr.	5	7	1	1	4	7	Tr.	8	12	13
SW¼ 24	28	93	215000	.004	.001	0	Tr.	5	7	2	1	4	7	0	8	13	14
SW¼ 9	28	92	139148	.004	.001	0	9	9	5	5	1	6	3	0	9	12	9
SW¼ 9	28	92	139152	.002	.001	0	9	8	5	2	1	3	6	12	6	12	9
SW¼ 24	28	93	215003	.004	.001	16	Tr.	4	6	1	1	4	6	0	8	12	13
SW¼ 19	28	92	215015	.004	.001	15	13	5	7	2	1	4	7	Tr.	8	12	13
SW¼ 24	28	93	215010	.004	.001	16	Tr.	5	7	2	1	4	6	0	9	12	14
SW¼ 24	28	93	215011	.004	.001	16	Tr.	5	7	1	1	4	7	Tr.	8	12	14
SW¼ 24	28	93	215012	.003	.001	16	Tr.	5	7	2	1	4	7	0	8	12	14
SW¼ 19	28	92	215014	.003	.001	16	13	5	6	1	1	4	7	Tr.	8	12	13

of 8 grab samples of arkose from member A of the Battle Spring Formation, sec. 20, T. 28 N., R. 92 W.

and radiometric analyses by Mary Finch and S. P. Furman]

Semiquantitative spectrographic analyses—Continued																	
Ni	Cu	Ga	Ge	Sr	Y	Zr	Nb	Mo	Sn	Ba	La	Ce	Nd	Yb	W	Pb	U
13	9	0	0	11	12	12	0	0	13	9	0	0	10	16	8	13	6
13	10	0	0	11	12	12	0	0	13	10	0	0	0	16	8	13	6
13	10	13	0	11	0	11	0	0	13	9	0	0	0	16	0	13	6
13	9	13	0	11	12	12	0	0	12	9	11	0	0	16	8	13	7
13	10	0	0	11	0	12	0	13	13	9	0	0	0	16	8	10	7
13	10	13	0	11	12	10	0	0	0	9	0	0	0	16	0	12	7
13	10	13	0	11	11	13	0	0	12	9	0	0	0	15	8	13	10
12	13	Tr.	0	12	12	10	0	13	0	8	Tr.	0	0	15	0	12	13

of 32 grab samples ofarkose from member A of the Battle Spring Formation, Gap area

and radiometric analyses by Grafton Daniels, Mary Finch, S. P. Furman, B. A. McCall, P. Moore, and Moore]

Semiquantitative spectrographic analyses—Continued																				
Mn	Fe	Co	Ni	Cu	Ga	Ge	Sr	Y	Zr	Nb	Mo	Sn	Ba	La	Ce	Nd	Yb	W	Pb	U
11	3	14	12	13	Tr.	0	11	12	10	0	11	0	9	Tr.	0	0	15	0	11	7
13	5	0	12	9	13	0	11	12	10	0	12	13	9	0	0	0	16	8	13	8
10	4	0	13	13	13	0	11	12	12	0	13	0	9	0	0	0	16	0	10	0
10	4	0	13	13	13	0	11	12	11	0	11	0	9	0	0	0	16	0	13	0
10	4	0	13	13	13	0	11	12	12	0	0	0	9	11	0	11	16	0	13	0
11	3	13	12	13	Tr.	0	11	12	10	0	12	0	8	Tr.	0	0	0	0	10	0
11	4	Tr.	12	13	Tr.	0	12	13	10	0	12	0	9	0	0	0	15	0	12	0
12	5	0	13	9	13	0	11	12	11	0	0	13	9	0	0	0	16	8	13	0
11	4	Tr.	12	13	Tr.	0	11	12	9	0	13	0	8	Tr.	0	0	15	0	11	0
10	4	0	13	13	13	0	11	12	11	0	0	0	9	0	0	0	16	0	12	0
12	5	0	13	9	13	0	11	12	11	0	0	13	9	0	0	0	16	8	13	0
11	4	14	12	14	13	0	11	12	9	0	13	0	8	10	9	Tr.	15	0	12	0
11	4	14	12	13	13	0	11	13	10	0	13	0	8	Tr.	0	0	16	0	11	0
11	4	14	12	13	13	0	11	11	10	0	13	0	9	11	0	0	14	0	12	0
11	4	14	12	13	Tr.	0	11	12	10	0	13	0	8	Tr.	0	0	15	0	11	0
11	4	14	12	13	Tr.	0	11	12	10	0	13	0	8	Tr.	0	0	15	0	11	0
11	3	12	9	11	11	0	9	12	9	0	12	0	8	0	0	0	15	0	12	0
10	3	13	12	12	13	0	10	13	10	0	12	0	8	11	Tr.	0	16	0	12	0
12	3	Tr.	13	14	Tr.	0	12	13	12	0	Tr.	0	9	0	0	0	15	0	12	0
11	3	Tr.	13	13	Tr.	0	12	13	11	0	Tr.	0	9	0	0	0	15	0	12	0
11	3	0	9	9	12	0	11	12	9	0	12	0	8	0	0	0	15	0	12	0
9	5	12	9	11	12	0	9	12	9	0	12	0	8	0	0	0	15	0	12	0
12	3	Tr.	12	13	Tr.	0	10	12	10	0	13	0	8	11	0	Tr.	15	0	11	0
10	4	14	12	13	Tr.	0	11	11	10	0	13	0	8	11	Tr.	Tr.	14	0	12	0
8	6	0	9	9	12	0	11	0	12	0	12	12	9	0	0	0	0	0	12	0
9	3	12	9	11	12	0	9	12	9	0	12	0.	8	0	0	0	15	0	12	0
11	4	13	12	12	Tr.	0	10	13	10	0	13	0	8	Tr.	0	0	16	0	13	0
11	4	Tr.	12	13	Tr.	0	11	12	10	0	13	0	9	Tr.	0	0	15	0	12	0
10	4	14	12	13	Tr.	0	11	13	10	0	13	0	8	Tr.	0	0	16	0	12	0
11	4	Tr.	12	12	Tr.	0	11	13	10	0	13	0	8	Tr.	0	0	16	0	11	0
9	4	14	12	13	Tr.	0	11	13	11	0	13	0	8	11	Tr.	Tr.	16	0	12	0
11	4	Tr.	12	13	13	0	11	13	10	0	13	0	8	Tr.	0	0	15	0	12	0

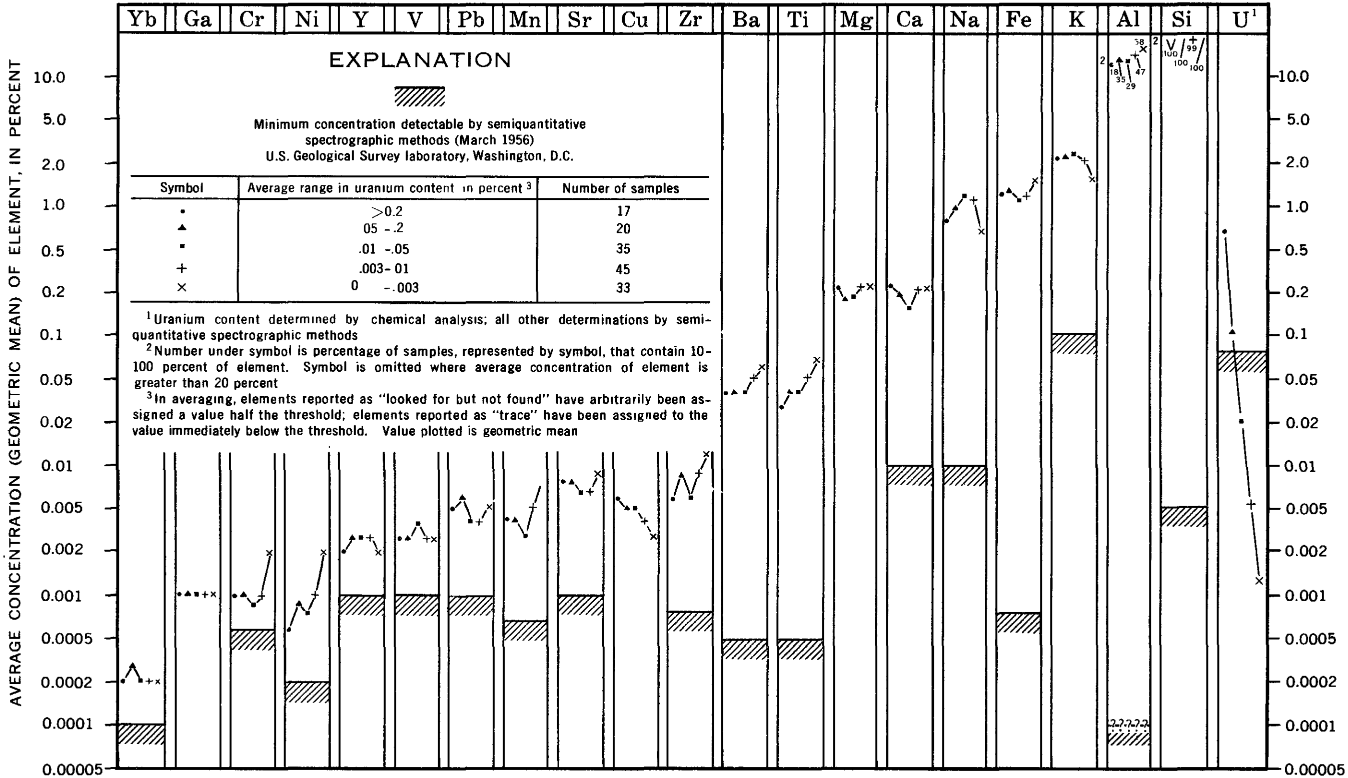


Figure 17.—Diagram showing variations in average element content compared with variations in uranium content in arkose of Eocene age, Crooks Gap area.

Listed below in order of decreasing abundance are the average (geometric mean) amounts (in percent) of elements detected by semiquantitative methods in the nonmineralized arkose of member A of the Battle Spring Formation at Crooks Gap. In averaging, elements reported as "looked for but not found" were arbitrarily assigned a value half the threshold; elements reported as "trace" were assigned to the value immediately below the threshold. Geometric means of elements in which more than 30 percent of the analyses fell into these categories were rejected as being of doubtful significance.

Element	*Average amount (percent)*
1. Silicon	Major constituent; 100 percent of samples contain more than 10 percent of the element.
2. Aluminum	Major constituent; 58 percent of samples contain more than 10 percent of the element.
3. Potassium	1.6
4. Iron	1.5
5. Sodium	.70
6. Magnesium	.23
7. Calcium	.21
8. Titanium	.07
9. Barium	.06
10. Zirconium	.012
11. Strontium	.009
12. Manganese	.008
13. Lead	.005
14. Copper	.003
15. Vanadium	.003
16. Yttrium	.002
17. Nickel	.002
18. Chromium	.002
19. Gallium	.001
20. Molybdenum	.0008
21. Ytterbium	.0002

GRAVITY AND SEISMIC STUDIES IN CROOKS GAP AREA

By DON L. HEALEY

To supplement the geologic mapping being done concurrently by James G. Stephens, a gravity survey and a brief seismic investigation were made in the Crooks Gap area during September and October 1955 and May 1956. The work was intended to delineate major geologic structural features and to determine depths to the Precambrian rocks in parts of the area overlain by unconsolidated Tertiary sediments; such knowledge was expected to contribute to the understanding of the structure and thus help to unravel the complex geologic history and to aid the formulation of hypothesis concerning the uranium deposits.

Frank E. Currey, Saul Schoenenberger, and James G. Williams assisted in computing the gravity field data. John C. Roller and Robert M. Hazlewood contributed the seismic field data.

The gravity survey includes the area of the Crooks Mountain, Crooks Creek NE (renamed Jeffrey City quadrangle in 1957), and Split Rock NW, 7½-minute topographic sheets and parts of the Soap Holes, Graham Ranch, Stampede Meadow, and Black Rock Gap 7½-minute sheets. An area south of Crooks Gap that extends 6 miles into the Great Divide Basin and for which no modern topographic coverage is available is also included (fig. 18). A total of 418 gravity-meter stations were established in an area of approximately 320 square miles for an average density of 1.3 stations per square mile.

The seismic reflection-refraction investigation was confined to the north-central part of the Crooks Gap area, after several unsuccessful attempts to obtain usable data were made in other parts of the area.

Topographically and geologically the Crooks Gap area[2] can be divided into four east-trending belts. Rounded knobs of Precambrian granite crop out across the northernmost belt, to the south of which lies a belt of unconsolidated Miocene rocks having very little topographic relief. The Green Mountains are south of the Miocene zone and are separated from it by the Kirk normal fault, which trends east and bisects the map area. The mountains rise 1,500 to 2,000 feet above the surrounding terrain and have steep north slopes and steep to gentle south slopes that extend into the Great Divide Basin, which has very little topographic relief. Geophysical measurements were made over each of these contrasting areas and station location was influenced by local conditions associated with each type of topography.

GRAVITY MEASUREMENTS

Gravity surveys determine the variation in the normal gravity field of the earth, the difference between the Bouguer and theoretical gravity being the anomaly (Nettleton, 1940). These small variations in the gravitational field are caused by irregularities in the distribution of mass within the earth's crust; the irregularities may be due to density changes, depth of burial, faulting, and folding. Successful employment of the gravitational method requires a suitable density contrast between the near-surface materials and some geologically significant interface within the stratigraphic section.

[2] The area of the geophysical studies is slightly larger than that of the geologic investigations; the two thus are not completely synonymous.

At Crooks Gap the gravity anomalies of the type observed are caused by several structural and stratigraphic conditions. The prevalent thrust faults of the area have moved large masses of dense material up near the surface, and the resultant increase in mass causes gravity highs. The Kirk normal fault, which has considerable verti-

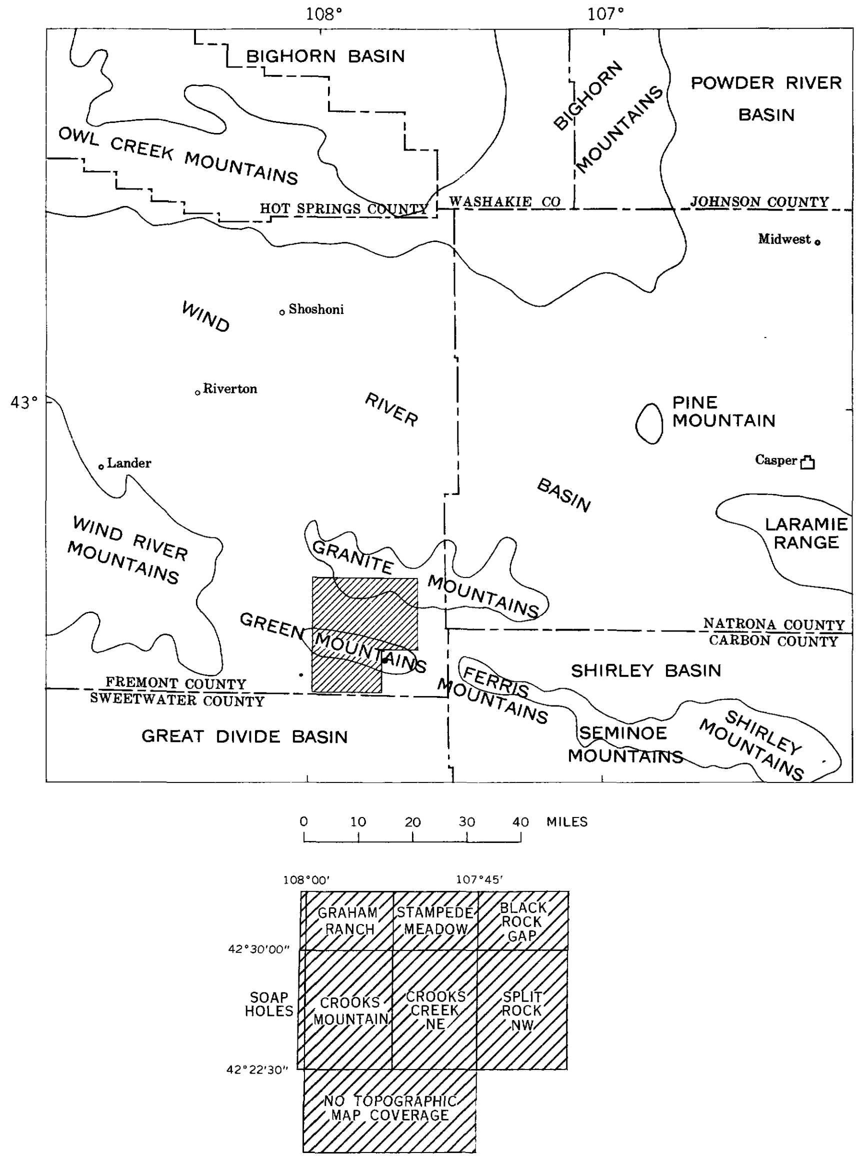


Figure 18.—Index map of a part of Wyoming showing location of Crooks Gap gravity survey in Fremont County.

cal displacement, is associated with a gravity low because of the increased amount of low-density Mesozoic rocks on the downthrown side.

The several anticlines, as expected, exhibit slight gravity highs because the folding brings some of the older, denser rocks closer to the surface. The synclines are generally associated with a gravity low because of the presence of large amounts of low-density material due to the downwarping of the older, denser rocks.

EQUIPMENT AND FIELD PROCEDURES

A gravity meter having a scale constant of 0.0729 mgal (milligal) per dial division was used throughout the gravity survey. A milligal is a unit of acceleration equal to 0.001 centimeters per second per second. Each instrument reading was made to the nearest tenth of a dial division, and the time of the reading was recorded to the nearest minute. The instrument was mounted in a station wagon equipped with a 4-wheel drive. When readings were taken, the gravity meter was placed on a tripod that was lowered through the floor of the station wagon to the ground.

The gravity meter is sensitive to temperature and was therefore maintained at a constant preset temperature by electric heaters thermostatically controlled and powered by an external 6-volt battery.

Gravity stations were established at points of known elevation, such as section corners, bench marks, and road intersections, to facilitate operations. In areas lacking elevation control, gravity stations were located and the elevation was determined by planetable surveying. Both horizontal and vertical control was carried on all surveyed lines. All stations south of lat. 42°22′30″ were established by planetable survey because no topographic maps were available for that area.

Base station 1, which was arbitrarily assigned an observed value of 100 mgal, was the reference point for the survey, and is located in sec. 17, T. 28 N., R. 92 W., in the center of the intersection east of the Sinclair pump station and adjoining the north end of the landing strip.

Three bases were established by the looping technique using three repeat readings, and numbered 1, 2, and 3. The mean value of the difference of these repeat readings was accepted as the base value of the station. The repeat readings for any one of the established bases varied less than 0.09 mgal, well within the allowable error of 0.3 mgal. As the network expanded, three additional bases—stations 58, 78, and 127—were established by repeat readings. During field operations, base stations were occupied every 3 hours to check instrument drift, and one previously occupied station was included in each loop. The reading at each tie station was required to agree with its previous reading to within 0.3 mgal, or the entire loop of stations was considered in error and reoccupied. In no instance did the error exceed the 0.3 mgal allowable, and most of these readings were 0.1 mgal.

REDUCTION OF GRAVITY DATA

The gravity data were corrected for instrument drift, latitude, free-air, Bouguer, and terrain effect. Corrections for instrument drift were made by linear interpolation, and except for short periods immediately following resetting of the gravity meter, instrument drift was almost negligible.

A latitude correction of 1.32 mgal per mile, or 1.50 mgal per minute, was included in the data reduction. Lat 42°30′ was arbitrarily set equal to 20.0 mgal to eliminate any negative corrections if the gravity survey was extended to the north.

A combination free-air and Bouguer factor of 0.066 mgal per foot, which corresponds to a near-surface density of 2.2 gm per cm^3 (grams per cubic centimeter), was used to correct the data to a datum elevation of 6,000 feet. A density of 2.2 gm per cm^3 was thought to be a good approximation for the density of the unconsolidated near-surface materials.

Terrain corrections through zone J on the Hammer chart (Hammer, 1939) were applied where necessary. Corrections for stations on the Green Mountains and adjacent areas were necessary because of the abrupt change in elevation associated with the mountains. The terrain corrections were estimated for stations in the northern half of the map area and were based on computed values of representative stations in this area. The terrain corrections range from 0.1 to 7.0 mgal, most of the corrections being between 0.5 to 1.5 mgal. The terrain-corrected Bouguer map is referred to herein as a complete Bouguer anomaly map (pl. 9).

To remove the regional effect from the gravity data, two grid-residual maps were prepared by the nine-point method (Henderson and Zietz, 1949). The first map was compiled using a 1-mile grid spacing (pl. 10), and the second map was compiled using a 2-mile grid spacing (pl· 11). Two maps were compiled because the smaller grid spacing emphasizes anomalies caused by relatively shallow features and the larger grid spacing emphasizes the anomalies associated with the more deeply seated features (Nettleton, 1954). The grid-residual maps are useful because they accentuate anomalies that may be overlooked on a complete Bouguer map, especially in an area of steep regional gradient such as Crooks Gap.

SEISMIC MEASUREMENTS

A brief reflection-refraction seismic survey was conducted at Crooks Gap to supplement the previously obtained gravity data.

The instruments used during this investigation were especially designed for reflection work, but could be readily adapted to refraction work. The equipment was truck mounted for portability. The amplifiers had filter frequencies ranging from 75 to 300 cycles per second, automatic gain control, and variable presuppression. High-frequency geophones having a natural frequency of 40 cycles per second were used.

Dynamite charges varying in size from 2½ to 50 pounds were exploded in shot holes ranging in depth from 15 to 95 feet. One multiple-hole pattern and numerous multiple-geophone patterns were tried with varying degrees of success. Shot-hole depths were determined entirely by drilling conditions and not by optimum shooting conditions. The seismic work was restricted to the northern half of the area after several attempts were made to get reflections in the vicinity of the Crooks Gap anticline. South of the Kirk normal fault the loose sand in the near-surface zone made it difficult to drill shot holes, which readily caved after completion. This loose sand and the unconsolidated nature of the material dissipated most of the energy from the explosion and precluded the recording of reflected energy. No usable data were obtained in this area. Sandy conditions also exist north of the Kirk normal fault zone where most of the seismic work, both reflection and refraction, was conducted. These shot holes were also difficult to drill, but here the Precambrian granite occurs at a much shallower depth and provides a suitable interface from which reflections and refractions can be obtained. In some locations reflections could not be recorded but refractions could be obtained, whereas at nearby sites the reverse might be true.

GRAVITY RESULTS

A composite gravity survey map shows many interesting and geologically significant anomalies which define the major structural features of the Crooks Gap area and the northern part of the Great Divide Basin. The complete Bouguer anomaly map (pl. 9) exhibits a strong north-south regional gradient of approximately 5.0 mgal per mile. The most prominent feature of the map is the gravity high which trends eastward across the middle part of the map area. This gravity high delineates the Kirk normal fault, as shown on the geologic map (pl. 1). The surface trace of this fault was mapped as far east as sec. 1, T. 28 N., R. 92 W.; however, the gravity data suggest further continuation of this normal fault east-northeastward to the central part of sec. 30, T. 29 N., R. 90 W. The anomaly indicates that the fault trends through the NE cor. sec. 1, T. 28 N., R. 92 W., and immediately north of stations 178 and 180 (sec. 34, T. 29 N., R.

91 W.). A subsidiary fault may extend through the saddle separating the gravity highs in sec. 1, T. 28 N., R. 92 W., and secs. 5 and 6, T. 28 N., R. 91 W., eastward to the vicinity of sec. 2, T. 28 N., R. 91 W.

The gravity high, centered near the SW cor. sec. 1, T. 28 N., R. 92 W., is associated with a thrust sheet of granite exposed on the surface. The associated high centered near the NE cor. sec. 5, T. 28 N., R. 91 W., is due to an eastward extension of the exposed thrust mass which has been downdropped by the faulting mentioned above. The existence of this concealed granite mass was proved when a test well drilled in the SW¼ sec. 5, T. 28 N., R. 91 W., penetrated granite at a depth of 1,163 feet, and during the subsequent geologic mapping an outcrop of granite was discovered between secs. 4 and 5, T. 28 N., R. 91 W. The gravity low, centered near the SW cor. sec. 15, T. 28 N., R. 91 W., is associated with a triangular downdropped block bounded by faulting on the southeast, southwest, and probably on the north.

The East Kirk normal fault bounds this gravity low on both the southeast and southwest sides. For more detail along this fault zone, see the geologic map (pl. 1).

The gravity relief across the Kirk normal fault ranges from 7.4 to 10.7 mgal (pl. 9). A gravity difference of 8.3 mgal occurs across sec. 2, T. 28 N., R. 92 W. The gravity data indicated that the displacement of the Kirk normal fault ranges from approximately 1,076 feet, for an assumed density contrast of 0.6 gm per cm^3, to approximately 3,240 feet, for an assumed density contrast of 0.2 gm per cm^3. These assumed density contrasts are considered to be extremes and must reflect the minimum and maximum displacements to be expected on the basis of the gravity data. A reasonable density contrast between the unconsolidated sediments and granite is 0.35 gm per cm^3, which indicates approximately 1,850 feet of displacement. Bauer (1934) estimated a displacement of 2,500 feet for this fault, but Stephens (p. F35) estimates 2,250 feet as a minimum.

A significant anomaly on the grid-residual map (pl. 10) is the elongate northwest-trending gravity low in T. 29 N., R. 93 W. This anomaly is thought to indicate the position of the buried Emigrant Trail thrust fault that extends into the area from the northwest, and whose gravity low occurs either (1) over a synclinal trough formed in front of the thrust sheet as it was pushed into position, or (2) associated with the abrupt density contrast between granite and that of the Mesozoic rocks at the edge of the thrust sheet. A similar anomaly is seen on plate 11. Because of the gravity information, the trace of this thrust fault was added to the gravity maps (pls. 9, 10, and 11) and also to the geologic map (pl. 1). Proof of the existence of a thrust fault in this region is established by the Immigrant Trail 1 test hole drilled in sec. 32, T. 30 N., R. 93 W. (Van Houten, 1954). This test hole penetrated 1,800 feet of granite, went through overturned Paleozoic rocks, overturned Mesozoic rocks, and then into a normal Mesozoic sequence (fig. 11). From the gravity information it is logical to assume a connection between the thrust found by drilling and the thrust exposed across secs. 1 through 6, T. 28 N., R. 92 W.

The hachured low which extends across the middle of both maps (pls. 10, 11) is associated with the Kirk normal fault and represents a fault trough filled with unconsolidated rocks. The trend of this normal fault actually is along the gradient between the highs and lows occurring along this zone, as shown by the plot of the fault trace on each map.

Five known anticlinal structures are present under or adjacent to the Green Mountains: (1) the south Happy Springs anticline in sec. 17, T. 28 N., R. 93 W.; (2) the north Happy Springs anticline, sec. 5, T. 28 N., R. 93 W.; (3) the Crooks Gap anticline, sec. 13, T. 28 N., R. 93 W.; (4) the Spring Creek anticline, sec. 7, T. 28 N., R. 92 W.; and (5) the Sheep Creek anticline, sec. 14, T. 28 N., R. 92 W. Of these five anticlines the Sheep Creek is most prominent gravimetrically and is expressed as a nose trending northwest which merges into an anomaly associated with the exposed Precambrian granite (pls. 10, 11).

The prominent gravity expression of the Sheep Creek anticline is due to the fact that older, denser rocks are closer to the surface. The oldest exposed rock is the Chugwater Formation of Triassic age, which is approximately 6,000 feet lower in the stratigraphic section than exposed rocks over the other anticlinal structures. This anticline is also well defined by surface outcrops (see pl. 1).

The gravity nose associated with the Sheep Creek anticline is shown (pl. 10) offset to the east approximately one-third of a mile. The larger part of the closed nose occurs northeast of the anticlinal axis. This offset is due to northeastward migration with depth of the Sheep Creek axial plane and by the proximity of the anticline to the granite block immediately northeast. The offset is not noticeable on plate 11.

The gravity nose associated with the Sheep Creek anticline may be related to a much larger feature, the exposed granite block to the north, and the gravity expression of the anticline itself may be small. Most of the gravity anomaly could be associated with this uplifted granite block.

Evidence obtained from the oil wells drilled into the Sheep Creek anticline indicates that the structure is broken by faulting, which may be thrusting. Therefore, a fault, which coincides with the axial plane of this anticline, might be added. The presence of this fault is not evident from the gravity data because its actual displacement is too small.

In the synclinal trough directly west of the Sheep Creek anticline, the beds dip very steeply and in places are vertical. A vertical fault in this area within the Cody Shale may be present but is not detectable by geologic methods. This postulated fault could make up some of the 6,000-foot difference in the stratigraphic section between the Sheep Creek anticline and the Spring Creek anticline only 2 miles to the west.

A second possible fault in this vicinity may originate in the NE cor. sec. 13, T. 28 N., R. 92 W., and trend northeastward along the east edge of the exposed Precambrian granite block (pls. 9–11). Such a fault would swing east near the SE cor. sec. 6, T. 28 N., R. 91 W., and terminate near sec. 3, T. 28 N., R. 91 W. These postulated faults would of necessity be buried, for no surface expression of either is discernible.

The two branches of the Kirk normal fault, which were traced by surface expression into secs. 1 and 12, T. 28 N., R. 92 W., probably continue eastward and tie to this proposed northeast-trending fault as shown on plates 9–11.

The Crooks Gap and Spring Creek anticlines have slight surface expression in the form of outcropping resistant beds of the Cody Shale. Neither the Crooks Gap anticline nor the Spring Creek anticline is defined by the gravity data. The positive anomaly north of these two anticlines is believed to be caused by a density contrast at depth associated with the thrust faulting so prevalent in the immediate area. This anomaly may even reflect structure in this area similar to the north Happy Springs anticline. Because the existence of neither anticline is evident from the gravity data, one possible explanation is that the basement complex was not involved in the anticlinal folding. The sedimentary section, which is approximately 10,000 feet thick in this locality, may have absorbed most of the compressional force without any associated upwarp to the basement.

The south Happy Springs anticline has an associated positive anomaly which is slightly offset to the north as shown on plate 10. Because this anticline plunges to the southeast, an associated anomaly would be expected to occur over its northern part. The anticline is much better defined by the gravity data on plate 10 (1-mile grid spacing) than on plate 11 (2-mile grid spacing) because plate 11 better defines the deeper conditions and does not accentuate the anticline to any extent.

The existence of the north Happy Springs anticline is not evident from the gravity data. The location of this anticline between a possible thrust fault on the south and the later normal fault to the north suggests that the anticline was formed by compressional folding associated with thrust faulting. The anticlinal folding probably occurred entirely within the sedimentary rocks.

The northwest-trending gravity high about 1½ miles east of the south Happy Springs high suggests the existence of another anticline. The position of this anomaly, halfway between the Crooks Gap and Happy Springs anticlines, supports this conclusion by eliminating the gap in the spacing sequence established by the four known anticlines in this vicinity (pl. 10).

Two alternate explanations for this anomaly are (1) error in the gravity data and (2) the presence of a buried Precambrian granite block associated with the Happy Springs thrust (p. F31).

Although the lack of topographic maps for the area south of lat 42°22′20″ on which to base the terrain corrections may have introduced some error into the data for this vicinity, such error probably does not exceed 0.2 mgal.

Introduced error might account for the 0.9 mgal anomaly shown on plate 10, but not for the 3.3 mgal anomaly on plate 11. Therefore, the presence of a buried Precambrian granite block emplaced during the thrusting is the more acceptable explanation.

The gravity low associated with the syncline in sec. 16, T. 28 N., R. 92 W. (pl. 1), is offset to the east by an amount equal to the offset on the Sheep Creek nose (pl. 10). The gravity anomaly of a syncline would occur over the intersection of the axial plane and the density contrast surface if the syncline were symmetrical or the axial plane vertical. Because of the sharply asymmetrical nature of this syncline, the axial plane dips eastward and the anomaly is offset east of the surface expression of the syncline. The small syncline in sec. 20, T. 28 N., R. 92 W., is well defined by a gravity low. The gravity data indicate a junction of these synclines, with their trend continuing to the southeast. The extensions of these small synclines are not expressed individually on plate 11; however, the synclinal trend to the southeast is still evident.

North of lat 42°30′ on the grid-residual maps, parallel elongate positive and negative anomalies trend northeast. This trend is noteworthy because it is at right angles to the trend in the southwestern part of the area. The trend over the southwestern part of the area reflects structural features previously formed, but perhaps more tightly folded, by the compressional forces of the thrusting which moved to the southwest. The northeast trend in the northern part of the area parallels the direction of thrusting and may indicate differential movement within the granitic mass during the period of thrusting.

All the gravity highs of plates 10 and 11 do not coincide with the exposed Precambrian granite, but one major low occurs, in part, over exposed granite (sec. 34, T. 30 N., R. 92 W.). These data suggest that the gravity gradient may reflect the relative thickness of the thrust mass itself, independent of the outcrop pattern.

In sec. 34, T. 30 N., R. 91 W. (pls. 10, 11), a gravity low trends northeastward toward the north edge of the map area. This anomaly could have several explanations: (1) it may be a graben-type imbricate fault filled with alluvial material, (2) it may represent a zone of thinning in the overriding thrust mass, or (3) it may represent a channel that drained to the north prior to the regional tilting to the south.

South of Crooks Mountain and beyond the area of modern topographic mapping, Stephens infers a buried thrust fault (fig. 10). Geologic evidence offered (p. F26) to support the existence of this thrust fault is a displacement in the Cretaceous Cody Shale of more than 6,000 feet between Crooks Gap and the Continental Oil Co. East Antelope 1 test in sec. 26, T. 27 N., R. 93 W. In an attempt to prove or disprove this possibility a series of gravity stations were located by planetable survey in this area.

The complete Bouguer anomaly map (pl. 9) shows a gravity low extending into the southeast corner of the area, and an anomalous area near Crooks Peak that trends southwest. The overall picture seems to be a steep regional dip to the south in the vicinity of lat 42°22′30″, but no definite evidence of faulting is discernible. Very little, if any, substantiation of the postulated buried thrust is apparent from either grid-residual map (pls. 10, 11). The largest anomaly is the 2.0-mgal low trending southeast toward the east edge of the area shown on plate 10. This low indicates a continuation of the synclinal low which extends into the area from the north.

On the basis of the gravity data it is not possible to make a definite statement concerning the presence or absence of a thrust fault in this area. It is very possible for a thrust fault having a small amount of throw (1,000 feet or less) to exist, but not be evident from the gravity data.

The largest anomaly expressed in the southern part of the area of plate 11 appears to be a synclinal trough trending southward from the vicinity of Crooks Peak. If the synclinal spacing sequence established by the synclines in secs. 16 and 20, T. 28 N., R. 92 W., is projected to the southwest, a third syncline would fall in the vicinity of Crooks Peak approximately where the gravity low shown on plate 11 occurs. Inasmuch as all the anticlines and synclines in the Crooks Gap area plunge to the south and southeast, perhaps a monoclinal fold is present across the south edge of Crooks Mountain.

Possibly there is no thrust fault south of Crooks Peak. The thrusting evident to the west of the map area may trend across the north face of Crooks Mountain and may be the thrust inferred by Stephens across secs. 7, 8, 9, and 10, T. 28 N., R. 93 W., in conjunction with the north Happy Springs anticline. Blackstone (1951, p. 25) suggested that the low-dipping thrust fault trending southeast to the vicinity of Happy Springs may pass on either side of the Happy Springs ridge of Paleozoic and Mesozoic rocks (west of the map area); if it does and if the fault does not trend south of Crooks Mountain, there is no disagreement between the gravity data and the structural geology.

Several unsuccessful attempts were made to construct, by graticule analysis, a geologic cross section that would agree with the gravity data obtained along a line parallel to cross section *C–C′* (pl. 1). Because of the numerous changes in density associated with the thick sedimentary section and because of the unknown magnitude and occurrences of the density contrasts, construction of a meaningful cross section was not feasible. However, cross section *C–C′* (pl. 1) would generally fit the gravity data if the proper density contrasts were chosen and applied.

SEISMIC RESULTS

During the course of the short-term seismic reflection-refraction study at Crooks Gap, seismic measurements were attempted at various locations. However, only the data obtained on traverse *A–A′* (pl. 9, cross section) could be used to determine the thickness of the sediments overlying the Precambrian granite. The computed seismic depths, in feet, are as follows: shot point 13, 156; 7, 780; 9, 1,260; and 11, 2,035.

The information obtained from this seismic traverse substantiated the conclusion previously drawn on the basis of the gravity data that a thrust sheet of Precambrian granite underlies the unconsolidated Miocene sediments and extends from the outcrops of granite on the north to Crooks Gap on the south.

CONCLUSIONS

The gravity data delineate the southwest edge of a buried thrust sheet (T. 29 N., R. 93 W.) that extends into the area from the northwest. This information is especially important because it establishes a definite tie between the thrusting exposed on the east side of Crooks Gap and the Emigrant Trail thrust penetrated by the Carter Oil Co.'s Immigrant Trail 1 test (sec. 32, T. 30 N., R. 93 W.). The gravity survey also indicates the presence of a thrust mass under the area north and east of the Kirk normal fault immediately north of Crooks Mountain.

The gravity contours along the northern part of both grid-residual maps (pls. 10 and 11) in the area of Precambrian granite outcrop exhibit a northeast lineation parallel to the direction of the thrust movement. This alinement may indicate either differential movement within the thrust mass proper or a zone of imbricate thrusting. Some of the gravity highs in this location are not associated with the outcropping granite, although some of the gravity lows occur over exposed granite. The magnitude of the gravity anomaly is probably indicative of the relative thickness of the thrust sheet itself.

Five anticlines are known to exist in the Crooks Gap area. Of these, the Sheep Creek is best defined by the gravity data. This anticline is exposed and well defined on the surface, and the older, denser formations and the basement complex are brought close to the surface. This mass of dense material may produce the anomaly associated with this structure. However, the gravity expression of the Sheep Creek anticline may be small, and the anomaly itself may be indicative of faulting associated with the Precambrian thrust sheet in this area.

The rocks exposed at the surface over the other anticlines are much higher in the stratigraphic sequence, and accordingly the older, denser rocks are more deeply buried. Although greater depth of burial would tend to decrease any anomaly associated with these anticlines, it is not the only reason why gravity expression is lacking. The reason the Crooks Gap and Spring Creek anticlines are not shown by the gravity data may be because the thick sedimentary section absorbed the horizontal compression and the basement complex was not involved in the anticlinal folding. If it is assumed that the basement complex is not involved in the anticlinal folding, the resultant lack of mass associated with these structures may explain the absence of gravity expression.

The south Happy Springs anticline is poorly defined by a gravity high which is offset to the north. This offset may be due to the southeast plunge and the asymmetry of the anticline.

The north Happy Springs anticline is not defined by the gravity data. This lack of definition suggests that the anticline may have been formed by compressional folding within the sedimentary section during the period of thrusting.

The gravity data suggest the possibility of a fifth anticline having the same trend as the four known northwest-trending anticlines in the Crooks Gap area. The indicated anticline would fill the gap between the south Happy Springs and Crooks Gap anticlines. Students of the area have long postulated an anticline here to complete the spacing sequence established by the known anticlines.

The presence of a buried thrust under the south edge of Crooks Mountain is not definitely proved or disproved by the gravity data because numerous stratigraphic situations would apply to the gravity expression in this area. The complete Bouguer gravity map (pl. 9) exhibits a steep gradient which rises to the south and indicates either a steep regional dip to the south or a fault. Neither grid-residual map substantiates the presence of a thrust fault in this vicinity.

REFERENCES CITED

Bauer, C. M., 1934, Wind River Basin [Wyoming]: Geol Soc. America Bull., v. 45, no. 4, p. 665–696.

Bell, W. G., 1950, Problems of the structure and stratigraphy of the upper Sweetwater Valley, west-central Wyoming [abs.]: Geol. Soc. America Bull., v. 61, no. 12, pt. 2, p. 1549–1550.

——— 1954, Stratigraphy and geologic history of Paleocene rocks in the vicinity of Bison Basin, Wyoming [abs.]: Geol. Soc. American Bull., v. 65, no. 12, pt. 2, p. 1371.

——— 1956, Tectonic setting of Happy Springs and nearby structures in the Sweetwater uplift area, central Wyoming, *in* Am. Assoc. Petroleum Geologists, Rocky Mountain Sec., Geol. Record: p. 81–86.

Blackstone, D. L. Jr., 1951, An essay on the development of structural geology in Wyoming, *in* Wyoming Geol. Assoc. Guidebook 6th Ann. Field Conf., 1951: p. 15–28.

Bradley, W. H., 1926, Shore phases of the Green River formation in northern Sweetwater County, Wyoming: U.S. Geol. Survey Prof. Paper 140–D, p. 121–131.

——— 1945, Geology of the Washakie Basin, Sweetwater and Carbon Counties, Wyoming, and Moffat County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 32.

Carey, B. D., Jr., 1954, A brief sketch of the geology of the Rattlesnake Hills, *in* Wyoming Geol. Assoc. Guidebook 9th Ann. Field Conf., 1954: p. 32–34.

Denson, N. M., Zeller, H. D., and Stephens, J. G., 1956, Water sampling as a guide in the search for uranium deposits and its use in evaluating widespread volcanic units as potential source beds for uranium, *in* Page, L. R., Stocking, H. E. and Smith, H. G., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 673–680.

Fath, A. E., and Moulton, G. F., 1924, Oil and gas fields of the Lost Soldier-Ferris district, Wyoming: U.S. Geol. Survey Bull. 756, 57 p.

Gazin, C. L., 1956, Paleocene mammalian faunas of the Bison basin in south-central Wyoming: Smithsonian Misc. Coll., v. 131, no. 6, 57 p.

Gruner, J. W., and Smith, D. K., Jr., 1955, Progress report no. 10 for period April 1 to October 1, 1955: U.S. Atomic Energy Comm., RME–3125, p. 14–16, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Hammer, Sigmund, 1939, Terrain corrections for gravimeter stations: Geophysics, v. 4, no. 3, p. 184–194.

Hares, C. J., and others, 1946, Geologic map of the southern part of the Wind River Basin and adjacent areas in central Wyoming: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 60.

Henderson, R. G., and Zietz, Isidore, 1949, The computation of second vertical derivatives of geomagnetic fields: Geophysics, v. 14, no. 4, p. 508–516.

Knight, S. H., 1937, Origin of the giant conglomerates of Green Mountain and Crook's Mountain, central Wyoming [abs.]: Geol. Soc. America Proc. 1936, p. 84.

Knight, W. C., 1900, A preliminary report on the artesian basins of Wyoming: Wyoming Univ. Expt. Sta. Bull. 45, p. 107–251.

Love, J. D., 1961, Split Rock Formation (Miocene) and Moonstone Formation (Pliocene) in central Wyoming: U.S. Geol. Survey Bull. 1121–I, p. I1–I39.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming: U.S. Geol. Survey.

Masursky, Harold, 1962, Uranium-bearing coal in the eastern part of the Red Desert area, Great Divide Basin, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 1099–B, p. B1–B152.

Masursky, Harold, and Pipiringos, G. N., 1959, Uranium-bearing coal in the Red Desert, Great Divide Basin, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 1055–G, p. 181–215 [1960].

McGrew, P. O., 1951, Tertiary stratigraphy and paleontology of south-central Wyoming, in Wyoming Geol. Assoc. Guidebook 6th Ann. Field Conf., 1951: p. 54–57.

Nettleton, L. L., 1940, Geophysical prospecting for oil: New York, McGraw-Hill Book Co., 444 p.

——— 1954, Regionals, residuals, and structures: Geophysics, v. 19, no. 1, p. 1–22.

Pipiringos, G. N., 1955, Tertiary rocks in the central part of the Great Divide Basin, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955: p. 100–104.

——— 1961, Uranium-bearing coal in the central part of the Great Divide Basin, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 1099–A, p. A1–A104 [1962].

Rich, E. I., 1962, Reconnaissance geology of the Hiland-Clarkson Hill area, Natrona County, Wyoming: U.S. Geol. Survey Bull. 1107–G, p. 447–540.

Schultz, C. B., and Falkenbach, C. H., 1940, Merycochoerinae, a new subfamily of oreodonts: Am. Mus. Nat. History Bull., v. 77, art. 5, p. 213–306.

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036–C, p. 19–56.

Sheridan, D. M., Maxwell, C. H., and Collier, J. T., 1962, Geology of the Lost Creek schroeckingerite deposits, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 1087–J, p. 391–478.

Stephens, J. G., and Bergin, M. J., 1959, Reconnaissance investigation of uranium occurrences in the Saratoga area, Carbon County, Wyoming: U.S. Geol. Survey Bull. 1046–M, p. 321–338.

Thomas, H. D., 1949, The geological history and geological structure of Wyoming: Wyoming Geol. Survey Bull. 42, 28 p.

——— 1951, Summary of Paleozoic stratigraphy of the region about Rawlins, south-central Wyoming, *in* Wyoming Geol. Assoc. Guidebook 6th Ann. Field Conf., 1951: p. 32–36.

Van Houten, F. B., 1950, Geology of the western part of the Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–113.

——— 1954, Geology of the Long Creek-Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–140.

VAN HOUTEN, F. B., 1955, Volcanic-rich middle and upper Eocene sedimentary rocks northwest of Rattlesnake Hills, central Wyoming: U.S. Geol. Survey Prof. Paper 274–A, p. 1–14.

Van Houten, F. B., and Weitz, J. L., 1956, Geologic map of the eastern Beaver Divide-Gas Hills area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–180.

Vine, J. D., and Prichard, G. E., 1954, Uranium in the Poison Basin area, Carbon County, Wyoming: U.S. Geol. Survey Circ. 344, 8 p.

——— 1959, Geology and uranium occurrences in the Miller Hill area, Carbon County, Wyoming: U.S. Geol. Survey Bull. 1074–F, p. 201–239 [1960].

Wood, H. E., 2d, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.

Wyant, D. G., Sharp, W. N., and Sheridan, D. M., 1956, Reconnaissance study of uranium deposits in the Red Desert, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 1030–I, p. 237–308 [1957].

Zeller, H. D., 1956, Gas Hills area, Fremont and Natrona Counties, Wyoming, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to November 30, 1956: U.S. Geol. Survey TEI–640, p. 115–116, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Zeller, H. D., Soister, P. E., and Hyden, H. J., 1956, Preliminary geologic map of the Gas Hills uranium district, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–83.

INDEX

[Italic page numbers indicate major references]

U.S. GOVERNMENT PRINTING OFFICE: 1964 O—713-808