Uraniferous Phosphatic Lake Beds of Eocene Age in Intermontane Basins of Wyoming and Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 474-E

Prepared in cooperation with the Geological Survey of Wyoming and the Department of Geology, University of Wyoming, and partly on behalf of the U.S. Atomic Energy Commission

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By J. D. LOVE

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By J. D. Love

ABSTRACT

Syngenetic concentrations of uranium and phosphate occur in thin persistent lacustrine zones of Eocene age in four areas in southwestern and central Wyoming and in the Uinta basin of Utah. Uraniferous phosphatic beds known elsewhere are of marine origin; thus, their discovery in lacustrine rocks indicates a new geologic environment in which deposits of both scientific and economic interest might occur, not only in structural basins in the Rocky Mountain region but also in similar basins elsewhere in the world.

In the Green River area, which comprises the southeastern part of the Green River basin in southwestern Wyoming, the Wilkins Peak Member of the Green River Formation contains more than 35 radioactive zones, of which 25 are known to be uraniferous and phosphatic. The member, which is of late early Eocene and middle Eocene age, is about 1,000 feet thick, and is composed of highly tuffaceous lacustrine dolomitic marlstone, limestone, claystone, shale, siltstone, sandstone, trona beds, and oil shale. Maximum uranium content is 0.15 percent and P_2O_5 is 18.2 percent. Average for the 25 sampled zones, which range in thickness from 3 inches to 6 feet, is about 0.005 percent uranium and 2.2 percent P_2O_5.

The unique and varied mineral assemblages include rare-earth minerals and several silicates that are known elsewhere only in igneous and metamorphic rocks. Twenty-three major trona beds, one of which has a maximum thickness of 40 feet, and about a dozen halite beds, one 20 feet thick, are present. Most of the trona beds are closely associated stratigraphicallly with the uraniferous phosphatic zones, but some zones occur in parts of the section where there is no trona.

In the Pine Mountain area, 10 miles east of the southeast margin of the Green River area, there is one uraniferous phosphatic zone from a few inches to more than 4 feet thick in sandstone and siltstone in the lower part of the Cathedral Bluffs Tongue of the Wasatch Formation. The age of this tongue is latest early Eocene to early middle Eocene, about the same as that of the Wilkins Peak Member. Maximum uranium content is 0.29 percent, and P_2O_5 is 19.04 percent. Average of all 20 samples from the zone is 0.06 percent uranium and 5.7 percent P_2O_5. No evaporites are present in the Cathedral Bluffs Tongue.

In the Beaver Divide area of south-central Wyoming, the middle and upper Eocene rocks (upper 250 ft of the Aycross equivalent and the lower 100 ft of the Tepee Trail equivalent) consist of green and brown fine-grained tuffaceous claystone, carbonaceous shale, siltstone, and sandstone. These strata contain 7 or more radioactive zones, 5 of which have at least 1 percent phosphate. The thickness of these zones ranges from a few inches to 2 feet. Maximum uranium content is 0.042 percent, and P_2O_5 is 5.67 percent. No evaporites have been recognized in these strata. The lateral surface and subsurface extent of these zones has not been determined.

In the Lysite Mountain area of north-central Wyoming, seven uraniferous phosphatic zones ranging in thickness from a few inches to several feet were sampled. Four zones are in the Aycross(?) equivalent of probable middle Eocene age, and three are in the Tepee Trail equivalent of late Eocene age. Maximum uranium content is 0.040 percent, and P_2O_5 is 7.25 percent. The zones are part of an oil shale and analcitized tuffaceous lacustrine sequence that is, except for the lack of evaporites, similar to the Green River Formation. The areal distribution and continuity of the zones are not known.

The Green River Formation in the Uinta basin of northeastern Utah is as much as 7,000 feet thick, is lithologically similar to that formation in the Green River basin of Wyoming, and likewise contains many radioactive zones. One has 0.07 percent uranium and 8 percent P_2O_5. A lithologically similar section, 2,000 feet thick, of the Green River Formation is present in the Piceance Creek basin of northwestern Colorado. Several weakly radioactive zones are known, but none contains a significant quantity of either uranium or phosphate.

The origin of the uraniferous phosphatic zones is unknown. Inasmuch as trona is associated with them only in the Green River basin, evaporitic environment is apparently not necessary for the concentration of uranium and phosphate. "Average" shale contains less than 0.0004 percent uranium and 0.16 percent phosphate, not a tenth as much as that in most of the uraniferous phosphatic zones. Similarly, the marine Upper Cretaceous Pierre Shale, which was arbitrarily selected as a standard for comparison, contains about 0.0005 percent uranium and 0.14 percent phosphate. The Wilkins Peak Member contains abundant dacitic-andesitic volcanic debris, and igneous rocks of this general composition contain about 0.003 percent uranium and 0.2 percent phosphate. The strata between the zones have so little uranium and phosphate that the member as a whole contains no more of these elements than the "average" shale. Therefore, the presence of the zones does not necessarily require either sporadic floods of uranium- and phosphate-rich debris from adjacent exposed source rocks or wind- or water-borne volcanic ash abnormally rich in these elements. The zones may well have developed entirely as a result of unique geochemical conditions that were widespread only during parts of Eocene time.

Each zone in the Green River basin probably represents a synchronous deposit, and with so many time lines available, the

sedimentary and structural history of the area can be reconstructed in detail. If the geochemical conditions that fostered development of the zones were not confined to individual basins but were of regional extent, as has been postulated for certain tuff beds in the Green River Formation, simultaneous concentrations of uranium and phosphate could occur in unconnected lake basins with similar environments. Geochemical time lines formed in this manner would be of major value in interbasin correlation and interpretation of regional geologic history during the Eocene Epoch.

Localities in which high uranium and phosphate content are coincident with low-cost strip mining might eventually be of economic interest. Thicker richer deposits may be present in unexplored parts of the four described areas in Wyoming or in the other intermontane basins that contain Eocene lacustrine strata of this type. The economic potential of the phosphate-rich bradleyite and radioactive rare-earth and other exotic minerals in the zones in the Green River basin has not been investigated.

INTRODUCTION

Syngenetic concentrations of uranium and phosphate occur in thin persistent lacustrine zones [1] of Eocene age in four areas in southwestern and central Wyoming (fig. 1) and in the Uinta basin of Utah (fig. 22). The known uraniferous phosphatic zones are too thin to be minable, and only in a few localities does the uranium content exceed 0.1 percent and the phosphate content 14 percent. Nevertheless, the occurrence of these elements is of geologic interest, for uraniferous phosphatic beds known elsewhere are of marine origin, and

[1] Ashley and others (1933, p. 430) state that "zones imply a time element as an essential feature in their discrimination." "Zone" is delibrately used in this sense in this report. Evidence is presented that indicates these uraniferous phosphatic zones are for the most part "geochemical time lines." Many are not megascopically separable from overlying and underlying strata. Usage of "zone" in this sense is likewise in accord with that recommended by the American Commission on Stratigraphic Nomenclature (1961, p. 655–657).

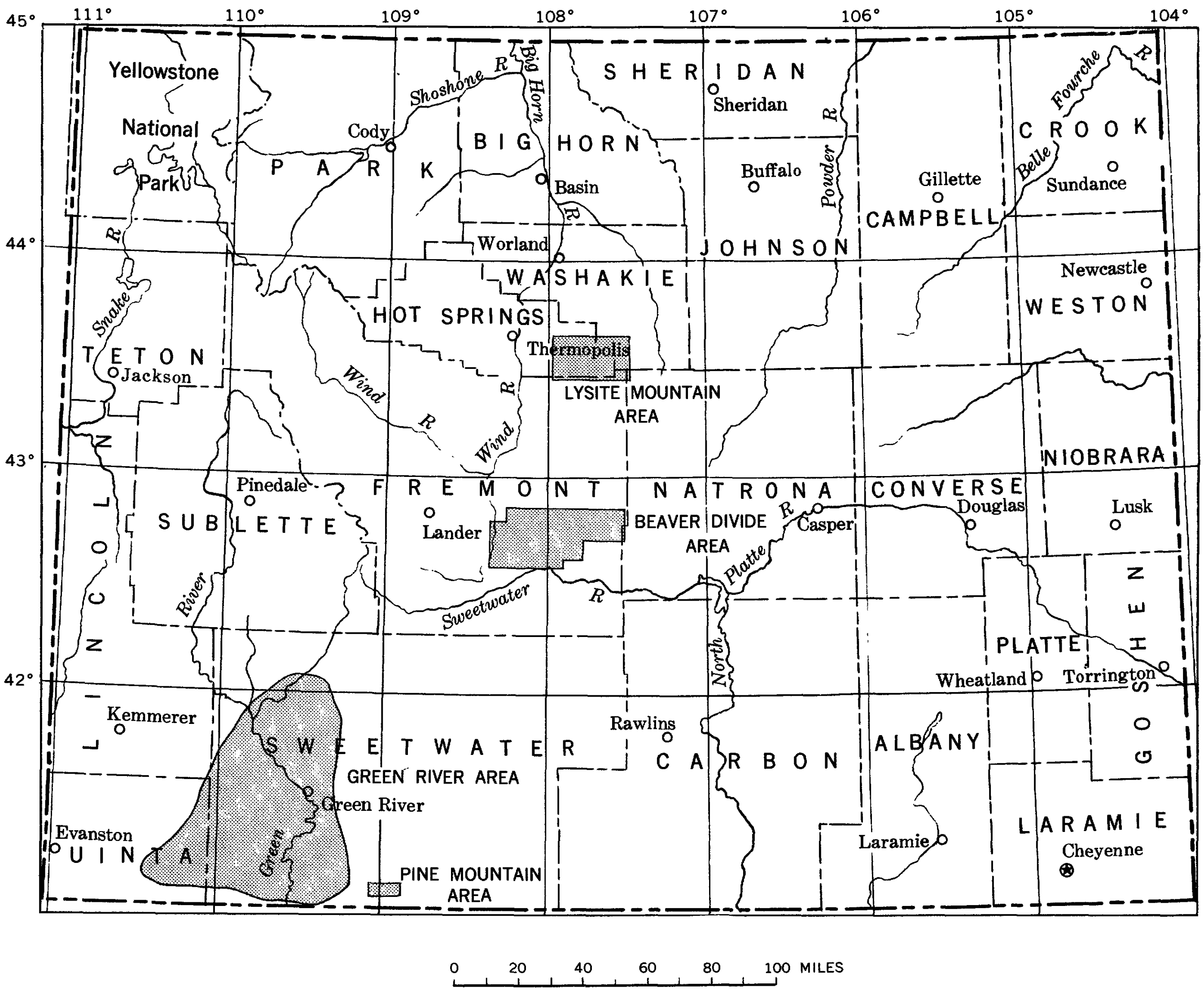

FIGURE 1.—Index map of Wyoming showing areas of lacustrine uraniferous phosphatic Eocene strata described in this report.

their discovery in lacustrine rocks indicates a new geologic environment in which uraniferous phosphorites of minable thickness and quality might occur, not only in structural basins in Wyoming, Colorado, and and Utah but in similar basins elsewhere in the world.

This paper summarizes data obtained in a reconnaissance study whose objectives were to determine (1) the stratigraphic and geographic distribution, continuity, and general physical and geochemical characteristics of the uraniferous phosphatic zones, (2) their origin, (3) their usefulness in interpreting the environment and history of sedimentation of the large intermontane basins in which they occur, and (4) their economic potential. The part dealing with the Green River area is coordinated with the following investigations of the Green River Formation and associated strata: (1) a series of papers in preparation by W. H. Bradley on the geology, paleoecology, and paleolimnology of this formation; (2) quadrangle mapping by W. C. Culbertson (1961), along the east margin of the Green River area; and (3) regional investigation of the mineralogy, petrology, and geochemistry of the Green River Formation by Charles Milton.

HISTORY OF INVESTIGATION

The study of uranium in the Green River Formation was begun in 1951. Preliminary investigation resulted in a recommendation for airborne radioactivity reconnaissance of 10 townships south of Rock Springs. Part of this area was flown in 1952 by the U.S. Geological Survey (Meuschke and Moxham, 1953), and several anomalies were recorded in the Green River Formation. Additional airborne reconnaissance was made by the U.S. Atomic Energy Commission in 1954 and more anomalies were located (Magleby and Meehan, 1955). Ground checks of these anomalies showed no commercial-grade uranium deposits but because the occurrences appeared to be unique, stratigraphic studies, reconnaissance mapping, and systematic sampling of radioactive beds were begun in 1955 (Love, 1955, p. 263) and were continued for short intervals during 1956, 1958, 1959, and 1960.

There was widespread drilling for trona in the Green River basin during 1959 and 1960, and gamma ray-neutron logs were run on most of these holes. Cores on some of the logged intervals were given to the Geological Survey for uranium and phosphate analysis. These core analyses and logs provided confirmation of the subsurface extent and continuity of the zones hitherto recognized only on outcrops. Spectrographic analyses made in 1955 and 1956 showed abnormally high concentrations of phosphorus as did subsequent chemical analyses (tables 2, 4; Love and Milton, 1959). Milton, who had studied the mineralogy of the Green River Formation for many years, began specific research on the uraniferous phosphates in 1959.

Because of the lithologic similarity of Eocene strata in parts of Central Wyoming, Utah, and Colorado to those containing uranium and phosphate in the Green River basin, the investigation was extended during 1959–61 to include these areas.

ACKNOWLEDGMENTS

The personal interest and knowledge of the Green River Formation contributed freely by W. H. Bradley have been of major value in every phase of this investigation. Charles Milton also gave invaluable advice on the mineralogy (including recognition of several unnamed minerals), petrology, and geochemistry of the Eocene strata. The paleontologic and stratigraphic data acquired by C. L. Gazin and by P. O. McGrew during many field seasons of work in southwestern and central Wyoming have helped to establish the time classification of the complex Eocene sequence. H. A. Tourtelot provided comparative chemical and spectrographic data on the Pierre and other Cretaceous shales. Tourtelot, C. O. Johnson, and W. R. Keefer aided in the field study of the Lysite Mountain area. The assistance of L. B. Riley and L. F. Rader, of the U.S. Geological Survey, in providing the numerous chemical and spectrographic analyses is acknowledged with gratitude. P. D. Blackmon made X-ray diffractometer studies of clay beds in the post-Eocene strata of the Green River area. W. C. Culbertson has generously made available his surface sections and other data in the Green River area. D. C. Duncan furnished samples of marker beds and radioactive zones in the Piceance Creek basin. Theodore Botinelly, F. B. Van Houten, V. E. Swanson, G. N. Pipiringos, R. J. Hackman, and W. B. Gazdik, also of the U.S. Geological Survey, have contributed data and ideas. Consulting geologists J. M. Perkins, Robert Ford, P. T. Jenkins, E. V. Simons, and M. L. Krueger made available unpublished data on the stratigraphy of the Green River area. The following company geologists provided data and otherwise facilitated the study of surface and subsurface sections: D. L. Deardorff, of Diamond Alkali Co., J. P. Simons, of Union Pacific Railroad Co., J. W. Strickland, of Continental Oil Co., H. W. Roehler, of Mountain Fuel Supply Co., M. L. Nielsen, of Sinclair Oil & Gas Co., and D. E. Lawson, of Forest Oil Co. J. W. Smith, H. B. Jensen, and Ben Short, of the U.S. Bureau of Mines, furnished several sample and core descriptions and analyses of oil shales in the Green River Formation. Other individuals who have assisted this study in various ways are Frank Mau, R. G. Millice, Henry Novicki, Robert Tynsky, and Martin Undem.

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It is a pleasure to acknowledge the cooperation of S. H. Knight, chairman of the Geology Department, University of Wyoming, and H. D. Thomas, State Geologist of Wyoming, throughout the years of this investigation.

From 1951 to 1955, the part of the study that is related to uranium was done on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

GREEN RIVER AREA

The Green River area (figs. 1, 2) is in the southeastern part of the Green River basin.[2] No basinwide study was attempted, but it is known that within an area of 2,500 square miles in the southeastern part of the basin, the lower half of the Green River Formation contains many thin persistent radioactive zones. Of these, 35 are shown on illustrations accompanying this report (pls. 3–5) and 24 are known to be uraniferous and phosphatic (table 2). Surface sections were measured and sampled, a reconnaissance geologic map (pl. 2) was made, and electric logs, gamma ray-neutron logs, and (or) drill cuttings and cores from about 75 wells drilled for oil and gas or trona were studied.

This report is designed to avoid duplication of the previously mentioned studies by W. H. Bradley,, W. C. Culbertson, and Charles Milton. Therefore only brief descriptions are given of some aspects of stratigraphy, petrology, mineralogy, geochemistry, paleolimnology and paleoecology in the ensuing discussion of the Green River area.

[2] The nomenclature applied to the structural basins in southwestern Wyoming has been haphazard and inconsistent. The writer (Love, 1961) reviewed the various usages and recommended a terminology based on historical precedent and basin structure. The recommended names and areas to which they apply are shown on figure 2 and are so used in this report.

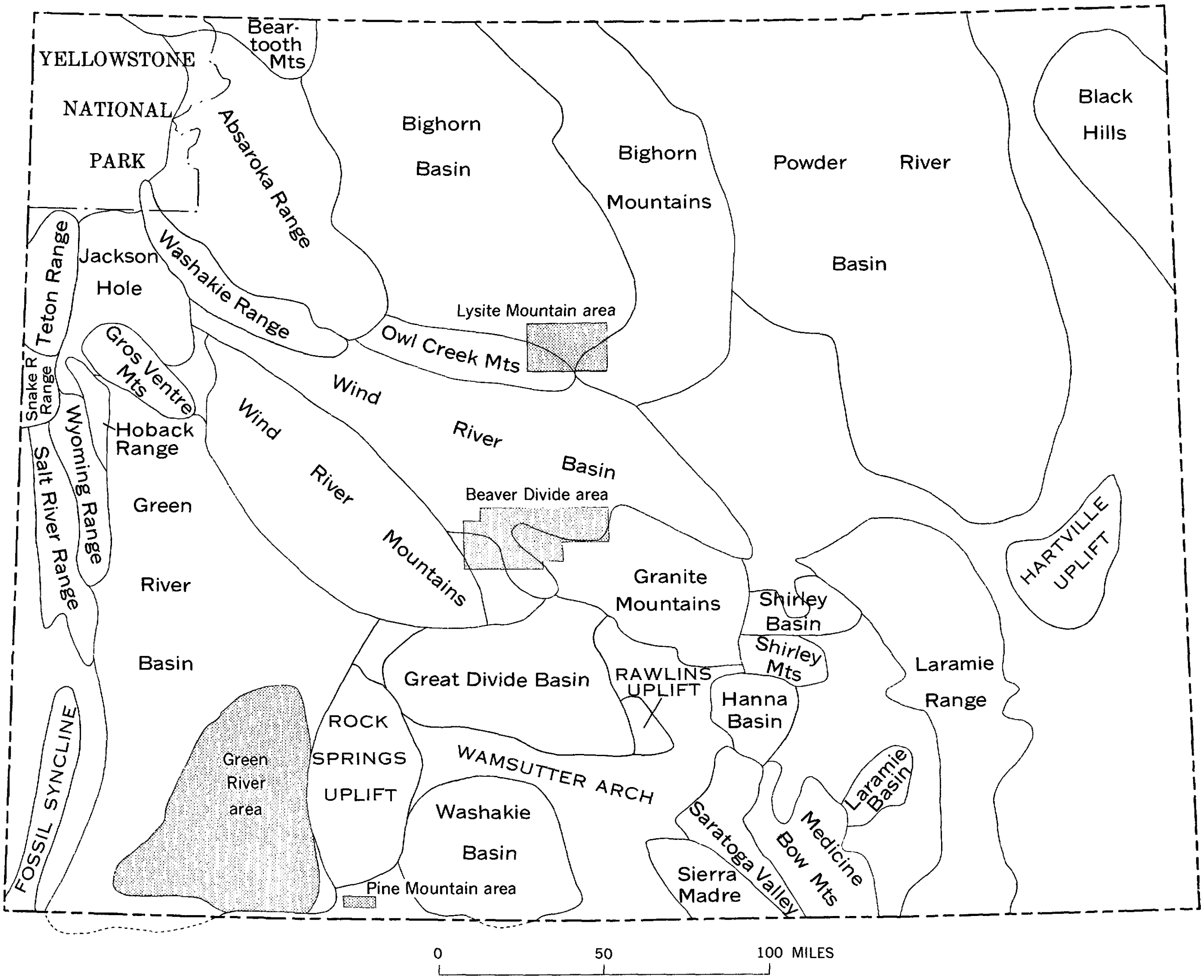

FIGURE 2.—Map of Wyoming showing relation of areas in which Eocene lacustrine uraniferous phosphatic strata were sampled to major structural basins containing Paleocene and Eocene rocks and to major Eocene and younger uplifts. Unnamed blank areas are neither major uplifts nor major basins.

STRATIGRAPHY

The Tipton Shale, Wilkins Peak, and Laney Shale Members of the Green River Formation are especially pertinent to the study of the Green River area and are described in some detail. Data on overlying and underlying strata are summarized in table 1.

The Wasatch and Green River Formations intertongue. Plate 1 correlates type surface sections of various units with subsurface sections in the Green River and Washakie basins and demonstrates some of the problems of nomencloture.

TIPTON SHALE MEMBER OF GREEN RIVER FORMATION

The Tipton Shale Member of the Green River Formation was named and defined by Schultz (1920, p. 30–31); the type area of the member is in the vicinity of section 26, plate 1. Sears and Bradley (1924, p. 99) redefined it as a tongue in the area where it is overlain by the Cathedral Bluffs Tongue of the Wasatch Formation (sections 7–26, pl. 1). The top of the Tipton Shale Member provides the most useful datum for stratigraphic and structural surface and subsurface studies in the Green River area, because it is widespread and easily recognized on outcrops and in drill cuttings, cores, electric logs, and gamma ray-neutron logs, except in the area northwest of the Rock Springs uplift (pl. 3, sections *C–C′* and *D–D′*). Plate 2 is a geologic map showing outcrops of the Tipton Shale Member and younger members of the Green River Formation in the southeastern part of the Green River area. Figures 3 and 4 show characteristic appearance of these outcrops.

The Tipton Shale Member (or Tongue, in areas where the Cathedral Bluffs Tongue is recognizable) consists of gray to brownish-black oil shale and gray paper shale, containing local lenses of oolite, coal, and sandstone. These strata were deposited in Gosiute Lake (King, 1878, p. 446), when it extended throughout a large part of southwestern Wyoming. At the base of the member is 1–10 feet of coquina (chiefly the high-spired gastropod *Oxytrema* and the clam *Unio*), locally called the *Goniobasis* marker bed, which is remarkably widespread and easily recognized in both surface and subsurface sections. Near the top of the member is a tough, very hard gray clayey marlstone 1 to 5 feet thick (fig. 7). Several analcitized tuff beds, ranging in thickness from ½ inch to more than 2 inches, can be traced for many miles in both surface and subsurface sections (W. C. Culbertson, oral communication, 1961).

Near the southern margin of the Green River basin (fig. 2), the oil shales become progressively more clayey, intertongue with red claystone, and farther south these, in turn, grade into sandstone and conglomerate. This coarse clastic facies was the result of uplift and erosion of the Uinta Mountains (fig. 22), directly south of the Green River basin during Tipton time. The apron of coarse clastic debris extended northward from the mountain front only a short distance, commonly less than 15 miles, and intertongued rather abruptly with the fine-grained strata being deposited in Gosiute Lake. At approximately the same time, the Wind River Mountains along the north margin of Gosiute Lake were providing gravel and sand that extended in long tongues south and southwest into the central part of the Green River basin. Bradley (1926, p. 123–125, pl. 61*A*), described and illustrated one of these sandstones within the Tipton Shale Member. The sandstone wedges out southward along outcrops just north of the area shown on plate 2, but is recognizable in subsurface sections as far southwest as section 17, plate 3, about 4 miles northwest of the town of Green River. East of a line between sections 17 and 22 (pl. 3), this sandstone apparently pinches out updip, suggesting the possibility of potential oil and gas traps.

As is indicated in sections 22–29, on plate 3, the oil shale in the upper part of the Tipton above the sandstone thins northward and disappears. Where it is completely replaced by sandstone and siltstone, the contact between the Tipton Shale and Wilkins Peak Members can no longer be distinguished. Sandstone was also deposited in the northwestern part of Gosiute Lake, northwest of the Green River area during the latter part of Tipton time.

The oil shales in the Tipton have been described elsewhere (Winchester, 1916; 1923, p. 124–126; Schultz, 1920, p. 30–31, 54–65; Sears and Bradley, 1924; Bradley, 1926, 1930, 1945; Jaffé, 1962).

The maximum area covered by Gosiute Lake, during the deposition of the Tipton Shale Member, was probably more than 12,000 square miles. Eastward and northward thinning of the Tipton in places along the west flank of the Rock Springs uplift suggests that the northern part of the uplift may have been an island during at least part of Tipton time. The shore phases of the Tipton Shale Member farther north have been described by Bradley (1926), who also reconstructed the regional setting of Gosiute Lake (Bradley, 1930, p. 88–90; 1948, p. 649–670). This was a time of remarkable crustal stability in the area of the lake, despite the upwarping of the Uinta Mountains along its southern margin and the Wind River Mountains along its northern margin. There is slight thickening of the Tipton Shale Member (or Tongue) in what are now the structurally deeper parts of the present Green River and Washakie basins and slight thinning on the arch between them (pl. 1). There is also evidence of thinning of the Tipton Shale Member across the crest of the Firehole anticline that trends southwest from Wilkins Peak (fig. 11; pl. 5, section 8).

TABLE 1.—*Summary description and correlation of rock sequences in the Green River and Pine Mountain areas, Wyoming*

Age		Green River area: Mappable unit	Green River area: Lithologic description	Green River area: Thickness (feet)	Green River area: Fossils [1]	Pine Mountain area: Mappable unit	Pine Mountain area: Lithologic description	Pine Mountain area: Thickness (feet)	Pine Mountain area: Fossils [1]
Quaternary		Alluvial deposits	Gravel, sand, silt, and clay	0–50					
Quaternary		Landslide debris	Unsorted rock fragments	0–200					
Tertiary	Post-Eocene	~~ Unconformity ~~ Unnamed sequence	Sandstone, light-gray, tuffaceous, siliceous in part; locally white, pink, and green alunite-kaolinite-halloysite claystone and gray algal limestone near base.	0–350	Unfossiliferous.	~~ Present erosion surface ~~ Bishop Conglomerate.	Conglomerate composed of founded fragments of red Precambrian sandstone and quartzite.	0–300	Unfossiliferous.
Tertiary	Post-Eocene	Bishop (?) Conglomerate.	Conglomerate of locally derived angular fragments of Cretaceous sandstone; may overlie or intertongue with the Bishop Conglomerate.	0–250					
Tertiary	Post-Eocene	Bishop Conglomerate.	Conglomerate of rounded fragments of red Precambrian sandstone, quartzite, and locally, Paleozoic rocks.	0–200					
Tertiary		~~ Unconformity ~~ No record. ~~~ Unconformity ~~				~~~~ Unconformity ~~~~			
Tertiary	Eocene	Bridger Formation: Upper member	Pale-green and buff tuffaceous mudstone and sandstone, coarse gray pumiceous crystal tuff, some white limestone. Volcanic material is chiefly andesitic; some rhyolitic tuff near top. Upper White Layer of Matthew (1909), a calcareous cyrstal tuff, at base.	500–800	Vertebrate fossils of middle Eocene age.	No record.			
Tertiary	Eocene	Bridger Formation: Middle member	Light-green fine-grained tuffaceous mudstone, crystal tuff, pumiceous tuff, marl, and thin lignites. Volcanic material chiefly oligoclase, andesine, hornblende, biotite, and glass. Cottonwood White Layer of Matthew (1909), a calcareous crystal tuff, at base.	400–500	Vertebrate fossils of middle Eocene age.				
Tertiary	Eocene	Bridger Formation: Lower member	Upper sequence: 600 to 1,300 ft of buff tuffaceous channel sandstone, finer grained and more clayey near top. Lower sequence: 100 to 150 ft of light- to dark-brown tuffaceous limestone and marl, and light brown tuffaceous sandstone and siltstone.	700–1,400	Abundant vertebrate fossils of middle Eocene age.				
Tertiary	Eocene	?——?——? Green River Formation: Laney Shale Member	Brown oil shale, light-colored marlstone, siltstone, analciti-ed tuff, and thick, lenticular buff tuff, such as Tower Sandstone Lentil of former usage, and tuffaceous sandstone.	1,000–1,500	Vertebrate fossils of probable early middle Eocene age in northeastern part of Green River basin (McGrew, 1959).	~~~~ Unconformity ~~~~			
Tertiary	Eocene	Green River Formation: Wilkins Peak Member	White shale and dolomitic marlstone, thin oil shales, gray, green, and white mudstones, with some zones containing shortite crystals; trona beds in northern part of area; some thin buff sandstones; five or more thin uraniferous phosphatic zones; lower part grades southward into green siltstone sequence. Thickness is 275 to 600 ft. Green blocky siltstone and claystone interbedded with gray slabby dolomitic siltstone and crossbedded buff sandstone; contains six or more thin uraniferous phosphatic zones; some trona and salt beds. Thickness is 250 to 650 ft. Dolomitic siltstone and hard ferruginous ledge-forming silty sandstone at base, overlain by gray, green, and tan claystone, siltstone, marlstone, analcitized tuff, and thin brown oil shales; contains as many as eight thin uraniferous phosphatic zones in some localities; several trona and salt beds. Thickness is 250 to 350 ft.	900–1,400	Pollen, sparse ostracodes, and mollusks.	Cathedral Bluffs Tongue of Wasatch Formation	Red and buff sandstone interbedded with brightly variegated claystone that becomes predominantly green in western part of area; rusty ledge-forming sandstones and green claystones in lower part contain uranium and phosphate.	900–1,000	Vertebrate fossils in Washakie basin east of Pine Mountain are probably transitional between early and middle Eocene.

Tertiary—Continued	Eocene—Continued	Green River Formation—Continued: Tipton Shale Member	Gray to black oil shale, gray paper shale thin persistent beds of gray marlstone and analcitized tuff; gastropod coquina at base.	120–400	Vertebrate fossils of late early Eocene age (Lost Cabin) in northeastern part of Green River basin (McGrew and Roehler, 1960).	Green River Formation: Tipton Tongue	Chiefly gray paper shale with lesser amounts of brown oil shale, coal, and lenticular buff sandstone; gastropod coquina at base.	300–350	No fossils recorded.
		Niland Tongue (Wasatch Formation)	Niland Tongue: Buff crossbedded to thin-bedded sandstone, gray to dully variegated claystone, and thin lignite beds. Apparently intertongues with and loses identity in oil shale sequence in deep part of Green River basin west of Green River area.	0–200		Niland Tongue (Wasatch Formation)	Niland Tongue: Buff to greenish-gray, thin-bedded to crossbedded sandstone, gray claystone, and thin lignite beds.	200–400	Vertebrate fossils of late early Eocene (Lost Cabin) age 40 miles northeast of Pine Mountain area (McGrew and Roehler, 1960).
		Luman Tongue	Luman Tongue: Gray paper shale, oil shale, thin variegated claystone. Intertongues with, and grades laterally into, part of Niland Tongue.	0–175	Vertebrate fossils of early Eocene (Lysite) age, underlain by those of earliest Eocene (Indian Meadows-Gray Bull) age in sandy lateral equivalent (McGrew and Roehler, 1960).	Luman Tongue	Luman Tongue: Gray paper shale, brown oil shale, thin variegated claystone. Intertongues with, and is replaced laterally by, part of Niland Tongue.	0–200	
		Wasatch Formation (Upper part only, of some geologists; entire formation of others.)	Gray to purple and red sandstone, gray to variegated claystone, thin coal beds, some oil shale in upper 1,000 ft.	1,500–2,000	Vertebrate fossils of earliest Eocene (Indian Meadows-Gray Bull) age (McGrew and Roehler, 1960).	Hiawatha Member of Nightingale (1930): Wasatch Formation (Upper part only, of some geologists; entire formation of others.)	Variegated claystone and buff sandstone.	1,400–1,900	No fossils recorded.
	— ? — Paleocene	— ? — Lower part of Wasatch Formation of some geologists; Fort Union Formation, in part or entirely, of others.	Gray sandstone, gray, black, and brown shale, and thin coal beds.	1,000–1,500	No fossils recorded.	— ? — Lower part of Wasatch Formation of some geologists; Fort Union Formation, in part or entirely of others.	Gray claystone and shale, white to buff sandstone; coal beds in lower part.	1,800–2,300	Lateral equivalent contains flora of late Paleocene age (R. W. Brown, written commun., 1958).
		Fort Union Formation (Lower part, of some geologists, entire formation of others.)	Dark-gray shale and gray hard sandstone, locally conglomeratic.	0–1,000	No fossils recorded; age interpreted on basis of regional overlap across eroded section of Cretaceous rocks.	Fort Union Formation (Lower part of some geologists; entire formation of others.)	Dark-gray to black shale, white to dark-gray sandstone.	0–600	No fossils recorded.
Late Cretaceous		~~ Unconformity ~~ One or more sequences of strata not sufficiently well known to permit precise correlation.	Gray sandstone interbedded with gray shale and siltstone, some coal and carbonaceous shale.		No fossils recorded.	~~~~ Unconformity ~~~~ Lance Formation	Greenish-gray to brown shale; gray fine-grained sandstone; thin coal beds.	0–600	Dinosaur bones and leaves in lateral equivalent on easts flank of Rock Springs uplift.
						Lewis Shale and older Cretaceous rocks.			

[1] "Arikareean," "Hemingfordian," "Chadronian," "Uintan," "Bridgerian," and "Tiffanian" are provincial age terms used by vertebrate paleontologists (Wood and others, 1941, p. 1–48). The terms have not been adopted by the U.S. Geological Survey.

FIGURE 3.—Green River Formation on White Mountain between Rock Springs and Green River. A, Contact between Wasatch Formation and Tipton Shale Member of the Green River Formation. B, Contact between Tipton Shale and Wilkins Peak Members at base of uraniferous phosphatic zone 1. C, Sandstone lentil (formerly called Tower Sandstone Lentil) in Laney Shale Member. D, Uraniferous phosphatic zone 7 and top of sandstone and siltstone unit D. View is northwest from U.S. Highway 30.

In the Washakie basin the Tipton Tongue overlies the Niland Tongue of the Wasatch Formation (Pipiringos, 1955, p. 100) with apparent conformity (pl. 1). Both sequences contain vertebrate fossils of late early Eocene (Lost Cabin) age (McGrew and Roehler, 1960; see also section 22, pl. 1; table 1). In the vicinity of section 10 (pl. 5) the upper part of the Wasatch Formation directly below the Tipton Shale Member contains a vertebrate fauna likewise of Lost Cabin provincial age (Gazin, 1952, p. 13; McGrew and Roehler, 1960). Arikareean, Hemingfordian, Chadronian, Uintan, Bridgerian, and Tiffanian are provincial age terms used by vertebrate paleontologists (Wood and others, 1941, p. 1–48). The terms have not been adopted by the U.S. Geological Survey.

WILKINS PEAK MEMBER OF GREEN RIVER FORMATION

The Wilkins Peak Member of the Green River Formation is one of the most unusual stratigraphic sequences in the Tertiary System of the Rocky Mountain region. It contains more than 35 thin but widespread radioactive zones, of which 25 are known to be uraniferous and phosphatic, as well as oil shale, evaporites, including halite and commercial deposits of trona, and "one of the world's most remarkable mineral assemblages" (Milton and Fahey, 1960a, p. 159).

The name Wilkins Peak was proposed by Bradley (1959) as a substitute for Laney Shale Member where that name had been applied incorrectly to about 1,000 feet of strata directly overlying the Tipton Shale Member in the Green River basin. No change in nomenclature of the Laney Shale Member in the type locality, Washakie basin, (pl. 1, section 26) is involved. The Wilkins Peak Member is a partial western equivalent of the Cathedral Bluffs Tongue of the Wasatch Formation. In the Green River basin the name Laney Shale Member is now applied to strata overlying the Wilkins Peak Member.

The type locality of the Wilkins Peak Member is on Wilkins Peak (fig. 5; pl. 3), where it is 875 feet thick (Culbertson, 1961). It is present in subsurface sections throughout the southern half of the Green River basin. In only a few localities is the member more than 1,000 feet thick. It thins northward and northeastward (pl. 3).

Deardorff (1959), Millice (1959), and Textoris (1960) subdivided the Wilkins Peak Member into three sequences, which are, from oldest to youngest, (1) dolomitic marlstone, rusty siltstone, and sandstone; (2) green siltstone and sandstone; and (3) white shale

FIGURE 4.—Green River and Wasatch Formations, Green River area. A, Contact between Wasatch Formation and Tipton Shale Member of Green River Formation. B, Contact between Tipton Shale and Wilkins Peak Members. Skyline at left is dip slope of resistant sandy marlstone of uraniferous phosphatic zone 1. View is north along scarp forming west side of Little Firehole valley, NW¼NW¼ sec. 23, T. 17 N., R. 106 W.

and limestone. Studies by Culbertson (1961) and the writer indicate that apparently logical boundaries in one locality may be unsatisfactory 10 or 20 miles away. Culbertson recognized 9 widespread sequences, designated by letters A through I on plate 3, sections *A–A′* and *B–B′*, of gray, brown, and green cross-bedded medium-grained ledge-forming sandstone and lesser amounts of soft-green and gray sandy siltstone and claystone.

Sections *A–A′* and *B–B′* show on plate 3 the correlation of these beds from surface outcrops to subsurface sections; plate 4 shows the gamma ray-neutron characteristics of the member downdip from the outcrops shown on plate 2. The lower 100–150 feet of section was studied in more detail than the rest of the member, because it contains several of the most widespread, most uraniferous, and most phosphatic beds (pls. 3, 5). The following measured section (section 7, loc. L–22, pls. 2, 5; figs. 6, 12) is an example of typical lithology:

Section of lower part of Wilkins Peak Member on Lulu claim 2, NE¼SW¼ sec. 10, T. 17 N., R. 106 W. (section 7, loc. L–22, pls. 2 and 5; figs. 6 and 12; table 2)

[Measured by J. D. Love. Beds above unit 14 not measured]

	Thickness (feet)
Wilkins Peak Member (part):	
14. Oil shale, dark-brown, laminated, hard; weathers white; uraniferous phosphatic zone 3. (See tables 2, 4, lab. No. 274006; and table 5, lab. No. L55–111, for analyses)	0.5
13. Shale, gray, soft, fissile	11.0
12. Firehole Bed, gray (weathering rusty brown), very hard, massive, medium-grained; crops out as a ledge that breaks into angular blocks. These make a conspicuous litter downslope from outcrops. (See pl. 5 for stratigraphic position and lateral continuity and fig. 8 for appearance on outcrop)	.4
11. Shale, claystone, and siltstone, gray to greenish-gray, chippy; moderately hard but forms slope	16.0
10. Dolomitic marlstone, tan, slabby, hard, fissile; forms ledge	2.0
9. Claystone and siltstone, green, blocky, slightly radioactive near top; uraniferous phosphatic zone 2a, about 3 ft below top but not megascopically distinct from remainder of unit	9.0
8. Dolomitic marlstone, tan (weathering gray), hard, slabby, fissile; forms conspicuous ledge; grades down into underlying unit	5.0
7. Claystone and siltstone, green, blocky; forms slope; uraniferous phosphatic zone 2, 6 in. thick, is 3 ft below top and not megascopically distinct from overlying and underlying part of unit. (See sample 29, table 2)	11.0
6. Shale and marlstone, greenish-gray, hard, fissile; forms slope	5.0
5. Dolomitic marlstone, gray (weathering tan), hard, thin-bedded, fissile; interbedded with gray soft fissile calcareous shale; forms slope broken by weak ragged ledges	30.0
4. Dolomitic marlstone, bluish-gray (weathering rusty brown at top); thin gray shale partings; irregularly bedded in lower half and laminated in upper; top 5 ft forms widespread hard brown ledge that comprises most radioactive part of uraniferous phosphatic zone 1. (See analyses for section 7, table 2, and rock analyses, table 4; also pl. 3, section 13; pl. 5, section 7; fig. 13, section 7)	8.0
3. Shale, gray, marly, soft, fissile	3.0
2. Marly sandy siltstone, gray (weathering brown), hard, slabby, fissile; forms weak ledge	6.0
Total thickness (approx.) of measured part of Wilkins Peak Member	107
Contact between Wilkins Peak and Tipton Shale Members of Green River Formation. Contact appears to be conformable but is marked by a conspicuous change in lithology (fig. 6)	
1. Oil shale, dark-brown (weathering gray), fissile, thin-bedded	14+

The Firehole Bed (unit 12 in the section) is here named from exposures in Little, Middle, and South Firehole Canyons (pl. 2). It is the "first tuff" of Culbertson (1961, p. D171–D172). The bed ranges in thickness from 3 inches to 1 foot throughout a distance of 30 miles along outcrops (pl. 5; fig. 8) and is readily recognized in well cores. It maintains a nearly constant position with respect to the base of the Wilkins Peak Member and also to the overlying and underlying uraniferous phosphatic zones. It is useful as a conspicuous marker bed in outcrops, for it breaks into hard brown rectangular brick-sized blocks that litter the slopes. The Firehole Bed consists largely of analcite and lesser amounts of authigenic euhedral albite(?) or other feldspar, and some pyrrhotite.

Sandstone and siltstone unit A (Culbertson, 1961; also pl. 3 this report) is 175–225 feet above the base of the Wilkins Peak Member. In South Firehole Canyon (loc. L–32, section 2 on pls. 2, 5) it locally forms a conspicuous brown cliff 50 feet high. Thin sections show the sandstone to be an arkosic aggregate of quartz, feldspar, biotite, and blue-green amphibole. Farther north along outcrops and in subsurface sections, the unit becomes thinner (30–40 ft), more silty and shaly, and less resistant.

In the northern part of the Green River area, the lower part of the Wilkins Peak Member contains arkosic conglomerate and sandstone deposited by streams flowing southwest from the Wind River Mountains into Gosiute Lake. These coarse clastics merge with similar ones in the upper part of the Tipton Shale Member. Conglomeratic debris in the Wilkins Peak Member extends to and southwest of well 29, plate 3, and equivalent sandstones continue for at least 20 miles farther southwest.

Sandstone and siltstone units B and C are similar in appearance and composition to those in A. Unit D, however, is 60–80 feet thick and forms the most conspicuous dark-green band on outcrops (figs. 3, 5, 9), directly below the white and light-gray part of the Wilkins Peak Member. In the southern part of the Green River area, additional dark-green beds are present above D, but these beds are lighter colored to the north. All these green units are difficult to distinguish 15 miles north of Rock Springs.

White marlstones and limestones and light-gray shales are more abundant, thicker, and more conspicuous in the upper half of the Wilkins Peak Member. Sandstones and siltstones are thinner and less numerous. Color change is locally a useful criterion for subdivision of the Wilkins Peak Member, but it cannot be used regionally; for example, the top of unit D on figure 5 seems a logical place to separate the dark-green part from the overlying white part, but 10 miles to the south,

FIGURE 5.—Green River Formation in the Green River area. A, Pilot Butte, composed of Pliocene alkalic lava. B, Sandstone lentil (formerly called Tower Sandstone Lentil) in Laney Shale Member. C, Top of sandstone and siltstone unit D and uraniferous phosphatic zone 7 in Wilkins Peak Member. D, Contact between Tipton Shale and Wilkins Peak Members at base of uraniferous phosphatic zone 1. E, White and light-colored strata in upper part of Wilkins Peak Member on north spur of Wilkins Peak. View is north across valley of Bitter Creek.

FIGURE 6.—Uraniferous phosphatic zones in lower part of Wilkins Peak Member. A, Contact between Tipton Shale and Wilkins Peak Members. B, Prospect pit in uraniferous phosphatic zone 1 on Martin Undem, Lulu claim 2. C, Uraniferous phosphatic zone 2. D, Uraniferous phosphatic zone 3. View is north in SE¼NE¼SW¼ sec. 10, T. 17 N., R. 106 W. (loc. L-22, section 7).

this contact disappears into a green sequence. Culbertson (1961, fig. 348. 3) tabulates the ideas of previous workers regarding subdivision of the member.

The lower 100–150 feet of the light-colored sequence above unit D is, in general, white marlstone interbedded with white to pale-green shale and siltstone and thin analcitized tuff beds. In the northern half of the area shown on plate 2, a white limestone 1–2 feet thick marks the top of this lower marlstone sequence. The overlying beds of the Wilkins Peak Member consist of white marlstones, white/shales, pale-green siltstones, and lenticular brown crossbedded sandstones. A conspicuous green sandstone and siltstone with an average thickness of 30 feet, about 100 feet below the top of the member, has been distinguished by Culbertson (1961) as the youngest of the sandstone and siltstone units. It is designated as unit I on plate 3, sections *A–A′* and *B–B′*. Shortite ($Na_2Ca_2(CO_3)_3$) crystals, or

FIGURE 7.—Contact between Tipton Shale and Wilkins Peak Members (indicated by arrows). Light-colored bed 6 feet below arrows is a clayey marlstone marker bed between two oil shales; uraniferous phosphatic zone 1 extends from arrows to top of cut; sandstone lentil (formerly called Tower Sandstone Lentil) forms cliffs on skyline U.S. Highway 30 is in foreground. Cut is in SW¼SE¼NW¼ sec. 15, T. 18 N., R. 106 W. (loc. L-7, section 14).

their molds, are abundant in all lithologies in this part of the member.

In the interval between 10 and 30 feet below unit I are several persistent light-colored tuff beds. One of these, about 30 feet below uraniferous phosphatic zone 10 (which is in unit I) is called the "main tuff" (fig.14) by geologists working with the trona deposits. This bed is white to light gray, weathers orange, is slightly limy, and contains some pyrite and biotite.

Oil shales, which are present in all parts of the member, are sparse and thin; most of them are relatively low in oil content.

The Wilkins Peak Member contains one of the most unusual mineral assemblages known in sedimentary rocks. Milton and Eugster (1959) give a discussion and bibliography of papers on the mineralogy of the Green River Formation. Additional papers have subsequently been published (Milton, Mrose, Chao, and Fahey, 1959; Milton, Chao, Axelrod, and Grimaldi, 1960; Milton, Chao, Fahey, and Mrose, 1960; Milton and Fahey, 1960a, b; and Fahey, 1962).

Regis and Sand (1957) reported the bulk mineral composition of approximately the upper half of the Wilkins Peak Member (that part above trona bed 17, fig. 14) in the Westvaco mine shaft (fig. 11), in order of decreasing abundance, as follows: quartz, calcite, dolomite, montmorillonite and illite, feldspar, shortite, searlesite, trona, and loughlinite.

The most abundant carbonates in the lower half of the Wilkins Peak Member are dolomite, calcite, trona ($Na_2CO_3 \cdot HNaCO_3 \cdot 2H_2O$), and shortite ($Na_2Ca_2(CO_3)_3$). Of these carbonates, trona is of major economic significance; it has also provided the stimulus that resulted in much of the drill-hole data presented here. Beds of

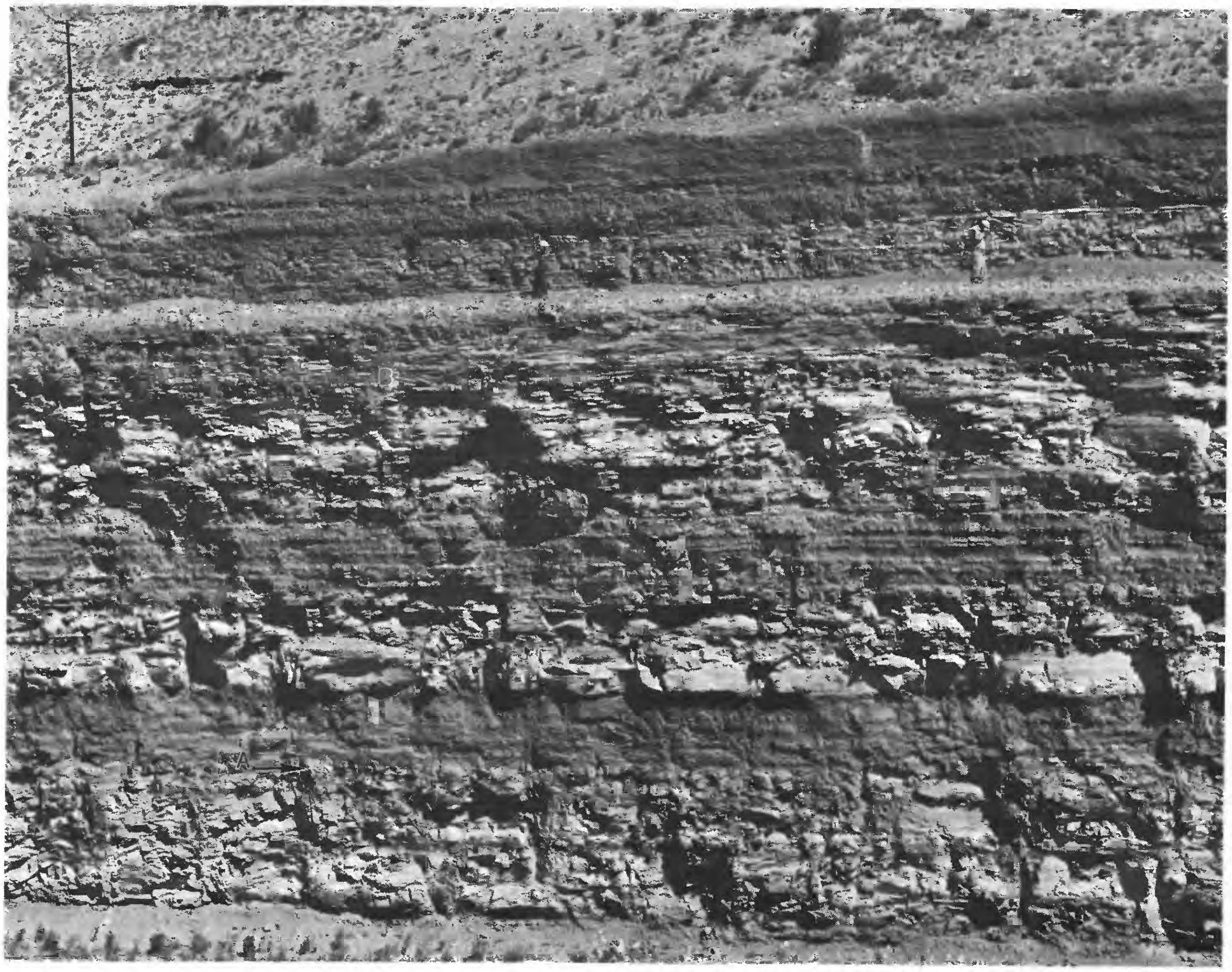

FIGURE 8.—Uraniferous phosphatic zones 2 and 3 and Firehole Bed in Wilkins Peak Member. Zone 2 is at A, Firehole Bed is at B, and zone 3 is at C. North side of cut along U.S. Highway 30, SE¼SE¼SW¼ sec. 16, T. 18 N., R. 106 W. (loc. L-8, section 13). Men near top give scale.

trona occur in the Wilkins Peak Member in an area of at least 2,000 square miles within and west of the area shown on figure 11. Trona and other evaporites are, at least physically, so closely associated with the uraniferous phosphatic zones that a summary of pertinent data is presented.

Deposition of the Tipton Shale Member was terminated by the shrinking of Gosiute Lake from an area of 12,000 to 4,500 square miles. This relict lake, confined to the southern half of the Green River basin, was the site of evaporite precipitation. If it is assumed that the uraniferous phosphatic zones shown on plate 3, as well as many of the trona beds, are for the most part time lines—and evidence supporting this assumption is presented—the depositional history of the lake during Wilkins Peak time can be reconstructed in minute detail.

Deardorff (1963) discussed 7 of the lower 17[3] major evaporite beds and presented maps showing their areal distribution. Trona was first precipitated in bed 1 (fig. 14) after only 10–20 feet of strata included in uraniferous phosphatic zone 1 had been deposited. This bed is locally one of the thickest (as much as 40 ft) in the basin, but the area of deposition is only about 200 square miles. Sixteen more major trona beds were precipitated in the lower half of the Wilkins Peak Member. The younger ones have greater areal extent; for example, bed 17 is at least 1,000 square miles. The continuity of the trona beds and their relative purity are interpreted as indicating intervals of crustal

[3] Deardorff designated the Westvaco trona bed as No. 1 and the lowest trona bed in the Wilkins Peak Member as 17. He did not describe the 6 major trona beds above the Westvaco. In the present report, the oldest trona bed is No. 1 (fig. 14, this report; Deardorff's bed 17) and the youngest is 23 (the 6th trona bed above Deardorff's No. 1).

stability in the area of evaporite deposition. After bed 17 was deposited, the locus of major trona precipitation shifted northwest about 20 miles from the area southwest of the town of Green River (bed 18, fig. 14). During the latter part of Wilkins Peak time, the locus of trona precipitation again shifted, this time eastward, and the youngest two major trona beds (22, 23) were confined to a narrow northwest-trending trough about 20 miles long centering in the area of the Stauffer trona mine (fig. 11). The top of the Wilkins Peak Member is, in most places, marked by the upper limit of saline minerals.

Deardorff was the first to describe the relation of trona and salt. He stated (1963): "The salt is usually mixed with the trona; however, occasionally thin units of almost pure salt occur as part of a larger bed of trona and salt mixed. These pure salt units are usually only a few inches thick."

During 1962, after Deardorff's paper was written, three trona wells were drilled by Stroock and Rogers Co. (W. T. Rogers 1, sec. 19, T. 15 N., R. 111 W.; Marta Stroock 1, sec. 14, T. 15 N., R. 111 W.; Keating Rogers 1, sec. 17, T. 15 N., R. 110 W.) 3 miles north and northwest of wells 2 and 3 (pl. 1). Several beds of crystalline salt,[4] one of which is 20 feet thick (E. V. Simons, written commun., 1962), were cored. The middle part of this bed has more than 92 percent by weight NaCl. Salt was likewise cored in well 3 (pl. 3, section *5A–A′*), and these data extend the known area of salt precipitation 3 miles south and 12 miles southwest of that shown by Deardorff (1963, figs. 4, 6–12).

There is no evidence of an unconformity at either the base or top of the Wilkins Peak Member. As is shown on plate 3, sections *C–C′* and *D–D′*, the base cannot be defined in the northern part of the area. The top, in the east-central part of the Green River basin, is an arbitrary contact between evaporite-bearing light-colored lacustrine strata below and brown fish-bearing oil shale and brown fresh-water clastic strata above (fig. 10). In places where the upper part of the Wilkins Peak Member contains few or no saline minerals, and where more oil shales are present, the contact is somewhat arbitrary. In subsurface sections for which no cores are available the contact may be somewhere within an interval of several hundred feet (dashed contact in parts of pls. 1, 3). Electric and gamma ray–neutron logs are not always so definitive in this part of the section as they are farther down in the Wilkins Peak Member.

The Wilkins Peak Member is probably transitional in age between late early and middle Eocene. No vertebrate fossils have been found in it. The abundant pollen assemblage present has not been stratigraphically zoned or studied in detail. Invertebrate fossils are sparse, but they have been recognized in several zones. (See discussion of uraniferous phosphatic zones 9–b, 10, and 11.) The underlying Tipton Shale Member contains a late early Eocene (Lost Cabin) vertebrate assemblage (McGrew and Roehler, 1960), and the uppermost part of the overlying Laney Shale Member or lower part of the Bridger Formation (depending on interpretation of position of contact) has middle Eocene vertebrate fossils. The eastern equivalent of the Wilkins Peak Member, the Cathedral Bluffs Tongue of the Wasatch Formation (pl. 1), has a vertebrate fossil assemblage that appears to contain both latest early and early middle Eocene elements (McGrew and Roehler, 1960, p. 158; Gazin, 1959; Morris, 1954).

[4] Salt is used in this report for any deposit that is predominantly NaCl. Mineralogic and chemical studies of the salt are insufficient to determine whether it is all halite.

LANEY SHALE MEMBER OF GREEN RIVER FORMATION

Rocks now included in the Laney Shale Member of the Green River Formation (Bradley, 1959) west of the Rock Springs uplift were previously called the Morrow Creek Member. He recommended that the name Morrow Creek be abandoned. This change in nomenclature does not involve the Laney Shale Member in the type area in Washakie basin (pl. 1, section 26).

The Laney Shale Member in the Green River basin consists of 1,000 feet or more of oil shale, marlstone, sandstone, siltstone, and tuff. It is typically brown, and thus contrasts with the green and white of the underlying Wilkins Peak Member. Oil shale is relatively abundant in the lower 500 feet of the Laney Shale Member, but it is sparse in the upper part. Fossil fish are common near the base. Algal reefs, beds of ostracodes and oolites, chert nodules, oil-stained sandstones, and analcitized tuffs are also common. No shortite crystals or trona beds have been reported. However, B. L. Short (oral commun., 1960) reports 60 feet of white massive anhydrite (identified by X-ray) containing sparse gray-green siltstone partings, near the top of the Laney Shale Member, about 11 miles southwest of section 3, plate 1, in the Northern Natural Gas Co., Govt. B-1 dry hole, sec. 10, T. 13 N., R. 112 W., at a depth of 2610–2670 feet. This zone might be placed in either the uppermost part of Laney or lowermost part of Bridger.

Thick lenses of brown tuffaceous sandstone occur in several parts of the Laney Shale Member. One of these lenses near the base was formerly called the Tower Sandstone Lentil. Several radioactive zones in the Laney Shale Member are recorded on gamma ray–neutron logs, but these zones are more localized than the ones in the Wilkins Peak Member (pls. 3, 4), and were not studied in detail.

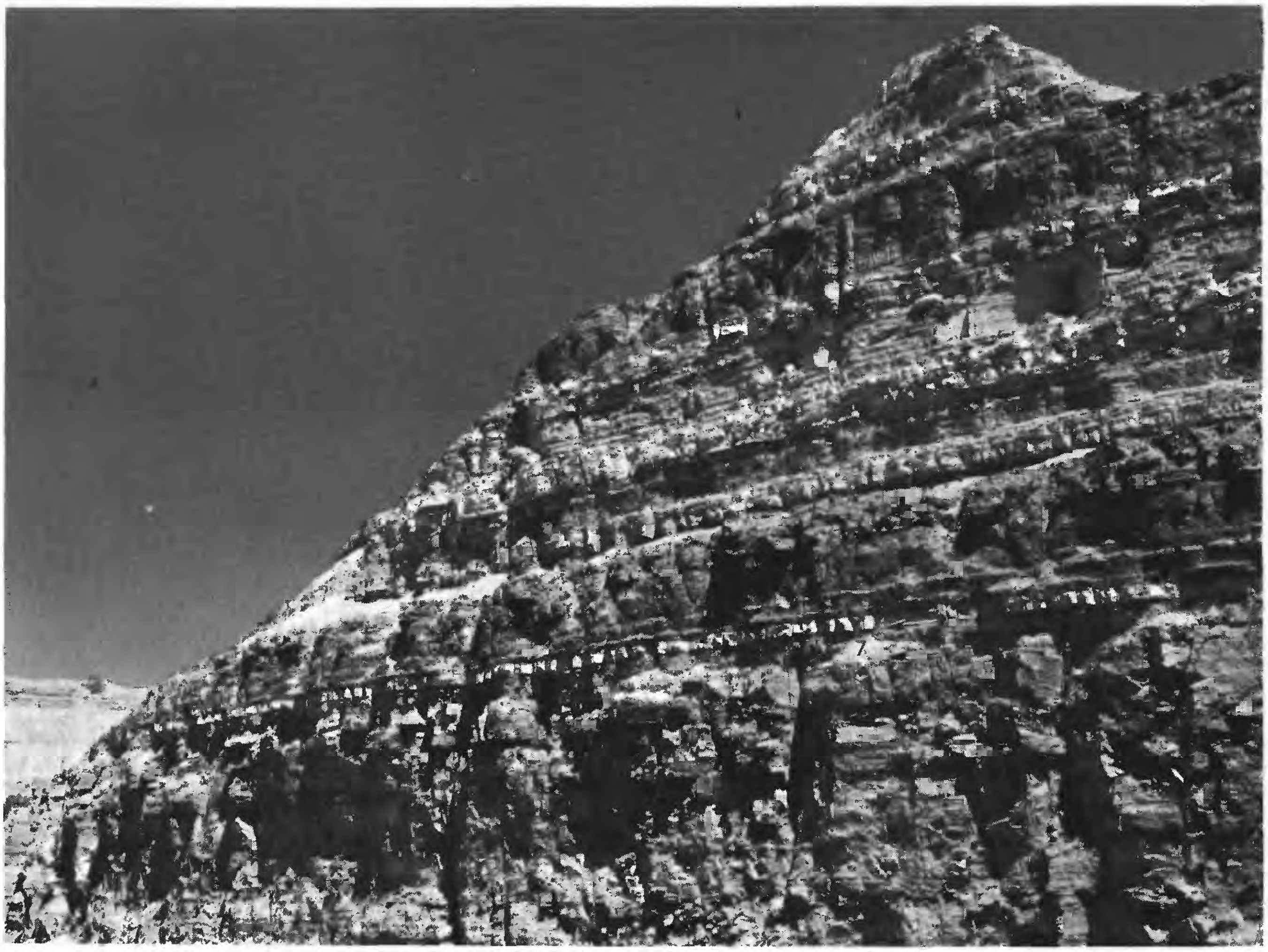

FIGURE 9.—Uraniferous phosphatic zone 7 in middle of Wilkins Peak Member. Zone 7 marked by short arrows; dark beds in lower half of photograph are part of sandstone and siltstone unit D. Light-colored strata in upper half are beds above color change at horizon (but not locality) indicated at C in figure 5. Photograph is at locality L-11, north side of U.S. Highway 30 at east edge of Green River townsite, NE¼SW¼ sec. 23, T. 18 N., R. 107 W. Height of cliff is 70 feet.

The Wilkins Peak and Laney Shale Members are conformable. There is little agreement as to the most logical contact between the Laney Shale Member and the overlying Bridger Formation. About 1,000 feet of strata is involved in the various interpretations, both in the type area of the Laney Shale Member in the Washakie basin (pl. 1, sections 12, 26) and in the Green River basin (pl. 1, section 3). The physical relationships and gross lithologies are indicated on plate 1, but the details of stratigraphy and a decision as to the precise contact in either basin are not within the scope of the present study.

Vertebrate fossils indicate that the Laney Shale Member in the northeastern part of the Green River basin is of early middle Eocene age (McGrew, 1959, p. 128–129). McGrew and Roehler (1960, p. 157) reported a large vertebrate fauna from "near the top of the Laney Member" about 25 miles southwest of the town of Green River. The fossiliferous beds are about 1,700 feet above the base of the Laney Shale Member, in strata that some geologists call Laney and others call Bridger. These fossils are of middle Eocene age and occur throughout the overlying part of the Bridger Formation.

BRIDGER FORMATION

The type area of the Bridger Formation is in the southern part of the Green River basin, where it comprises the surface rocks in an area of about 3,000 square miles. The name was first used by Engelmann (1858), and it was subsequently defined more specifically by Hayden (1873, p. 191). Because of its prolific vertebrate fauna in the southwestern part of the Green River area, it has been described by many vertebrate paleontologists and stratigraphers (Osborn, 1929, p. 43–140; Wood, 1934, p. 241–242; Koenig, 1960).

The lithology and thickness of the various subdivisions of the Bridger Formation are summarized in

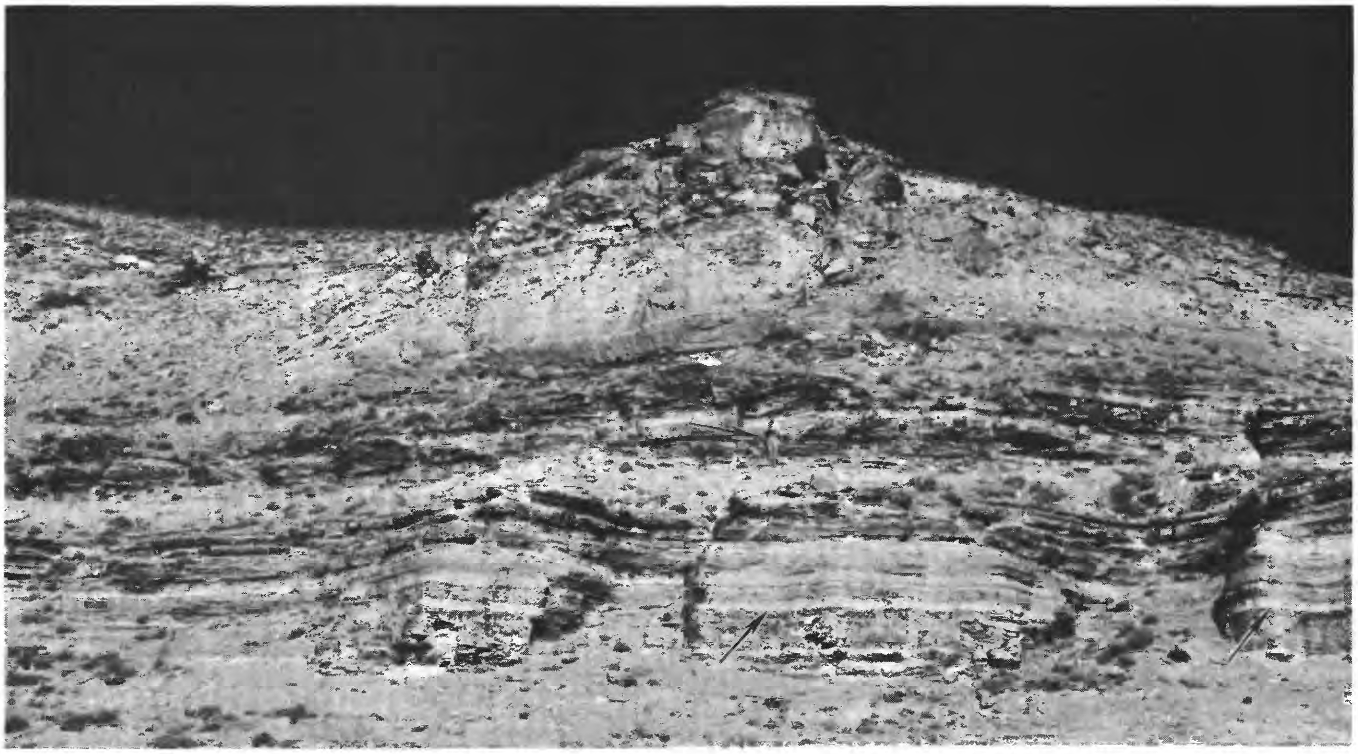

FIGURE 10.—Contact between Wilkins Peak and Laney Shale Members of Green River Formation. Arrows at base of gray analcitic tuff in lower part of exposure mark contact. Above this, another arrow indicates man for scale. Rock at top of cliff was formerly called Tower Sandstone Lentil. View is west in SW¼NW¼ sec. 9, T. 18 N., R. 107 W.

table 1, and the regional relationships are shown on plate 1. The Bridger Formation is of middle Eocene, and the uppermost part may be of late Eocene age. It is the youngest Eocene sequence in the southern part of the Green River basin. Several radioactive zones are recognized, one of which is known to be phosphatic. This zone is described elsewhere in the text.

POST-EOCENE ROCKS

Most of the folding of the Rock Springs uplift and downwarping of the Green River basin occurred before deposition of the post-Eocene rocks, which thus, in a structural sense, are pertinent to the present study. Three sequences are present: (1) red quartzite cobble conglomerate; (2) gray and brown conglomerate composed chiefly of locally derived angular fragments of Cretaceous sandstone, capped by white limestone; and (3) white and pink alunite-bearing claystone interbedded with light-gray siliceous and tuffaceous sandstone (Love and Blackmon, 1962).

The red conglomerate, which is present in the southeastern part of the area shown on plate 2, has been described and illustrated by Bradley (1936, p. 172–174 and pl. 39) and correlated with the Bishop Conglomerate. The red conglomerate consists of 100 feet or more of dull-red highly rounded quartzitic sandstone and quartzite fragments, having maximum size of 3 feet (average about 3 in.), in a quartz sandstone matrix. Lesser amounts of vein quartz, schist, and Paleozoic limestone are present. All these rock types were derived from the Uinta Mountains, 15 miles to the south. The conglomerate rests unconformably on the Bridger, Green River, and all older formations, dips northward about 1° (Bradley, 1936, pl. 34), and has not been involved in the folding of the Rock Springs uplift. No fossils have been found in it; therefore, the age is uncertain and it is classified as Miocene(?) (Bradley, 1936, pl. 34).

The gray and brown conglomerate, which is 25 to 250 feet thick and composed of angular fragments of locally derived Cretaceous sandstone, lies with angular uncomformity across eroded edges of folded Cretaceous rocks of the Rock Springs uplift, and is present on and adjacent to the south slope of Aspen Mountain, about 12 miles east-southeast of Wilkins Peak (pl. 1 index map; pl. 2). The conglomerate has been illustrated, described, and also called Bishop by Rich (1910), Sears (1926, pl. 3; p. 21–22), and Bradley (1936, p. 173). They described intertonguing of this locally derived conglomerate with the red quartzite conglomerate in the Aspen Mountain area. The gross lithologies are so different, however, that it seems possible that the gray and brown conglomerate is younger and contains some fragments reworked from the red one. No intertonguing was observed in a

250-foot section of conglomerate measured at the southwest end of Aspen Mountain. Above the basal conglomerate at this locality are lenses of light-gray dense limestone as much as 75 feet thick, exposed in an area one-half mile in diameter (Sears, 1926, p. 20–21; Love and Blackmon, 1962). Some contain "bulbs" and laminated structures resembling algal reefs. The limestone is overlain by 20–50 feet of conglomerate similar to the underlying one. Above the conglomerate is a yellow-brown soft clayey tuffaceous sandstone with large frosted rounded quartz grains. This variable sequence, which has been warped into a gentle west-trending syncline, extends southwestward from Aspen Mountain to Antelope Butte (pl. 1, index map) where a 250-foot section is exposed. It is chiefly highly tuffaceous soft porous sandstone with some gray crystal vitric tuff composed of sodic plagioclase, biotite, amphibole, sanidine, sphene, curved colorless shards, obsidian, and pumice.

On the south flank of Aspen Mountain, a drill hole penetrated 327 feet of conglomerate and sandstone, and in the upper part, white and pink alunite-bearing claystone. The upper 30 feet of this section was exposed in a trench (Love and Blackmon, 1962, p. D11–D15). One 8-foot claystone contains 60 to 90 percent alunite ($KAl_3(SO_4)_2(OH)_6$). At least 4 feet of additional alunite-bearing claystone is present below the analyzed bed. These rocks are downfaulted against highly silicified marine Cretaceous sandstones comprising the greater part of Aspen Mountain.

The limestone, claystone, and alunite were sampled for pollen and diatoms, but all proved barren. The age of the strata is, therefore, uncertain, but they are younger than the post-middle Eocene arching of the Rock Springs uplift, may possibly be of Oligocene age (Love, 1960, p. 209) or could be as young as Pliocene.

STRUCTURE

The Green River area lies within a broad gentle closed part of the Green River basin. Figure 11 shows the structure developed after Tipton time. Deep wells and geophysical data indicate that the trough line of the post-Tipton downwarp is roughly parallel to, but 10–15 miles west of, that in pre-Tertiary rocks. Three anticlines—Church Buttes, Firehole, and Marston—project into the southern part of the basin.

The Church Buttes anticline, on which the gas field of the same name is located, is by far the longest, and has the greatest amplitude. It is the southern part of the Moxa arch of Krueger (1960, p. 194), has about 100 feet of closure on the top of the Tipton Shale Member, and more than that on pre-Tertiary rocks. Geophysical and well data indicate that it was an old fold along which there was recurrent movement from Mesozoic, and perhaps Paleozoic, time on through Bridger time. This anticline divides the southern part of the Green River basin into two structural segments. The post-Tipton stratigraphy and structure of the eastern segment are well known because of recent drilling for trona, but the western one is almost unknown. As of May 1961, only one well had been drilled through the Tipton Shale Member—Mohawk-Fitzpatrick, Mountain View No. 1, sec. 8, T. 14 N., R. 115 W., in the southern part of the western segment about 20 miles southwest of the Church Buttes gas field (pl. 1, section 1)—and it did not reach Cretaceous rocks. At least 12 of the uraniferous phosphatic zones are recognizable in the Wilkins Peak Member in this well, but it is not known whether trona is present.

The Firehole anticline (fig. 11), here named after the Firehole Basin (pl. 2), trends west-southwest from outcrops on the south side of Wilkins Peak. This fold was rising at least as early as Tipton time, for the Tipton Shale Member thins across it (pl. 5, section 8), and movement continued into post-Bridger time. The fold is also reflected in the widespread marlstone beds of the Bridger Formation in outcrops as far southwest as T. 15 N., R. 110 W.

The Marston anticline, here named after Marston station on the Union Pacific Railroad near the Westvaco mine (fig. 11), trends northwest at right angles to the Firehole anticline. Only the south and east sides are adequately delimited. The Marston anticline is reflected in the Tipton Shale Member and younger rocks, but no deep wells have been drilled in the vicinity; so its older history is not known.

When the younger Tertiary beds on Aspen Mountain and Antelope Butte are dated, the time of post-Bridger uparching of the Rock Springs uplift and downwarping of the Green River basin can be established, for little or none of this movement is reflected in these younger strata.

URANIFEROUS PHOSPHATIC ZONES

PRE-WILKINS PEAK ROCKS

A few samples of lacustrine beds of pre-Tipton Eocene age were analyzed for uranium and phosphate (table 12). The maximum values, 0.003 percent uranium and 0.46 percent P_2O_5, were found in samples from the Red Desert Tongue of the Wasatch Formation (Pipiringos, 1955, p. 100; pl. 1 of the present report). Gamma ray-neutron logs in both the Washakie and Green River basins indicate a number of moderately persistent radioactive zones in several Paleocene and pre-Tipton Eocene sequences. No study of these zones was made because cores are not available for analysis, and most drill cuttings are too contaminated to be definitive.

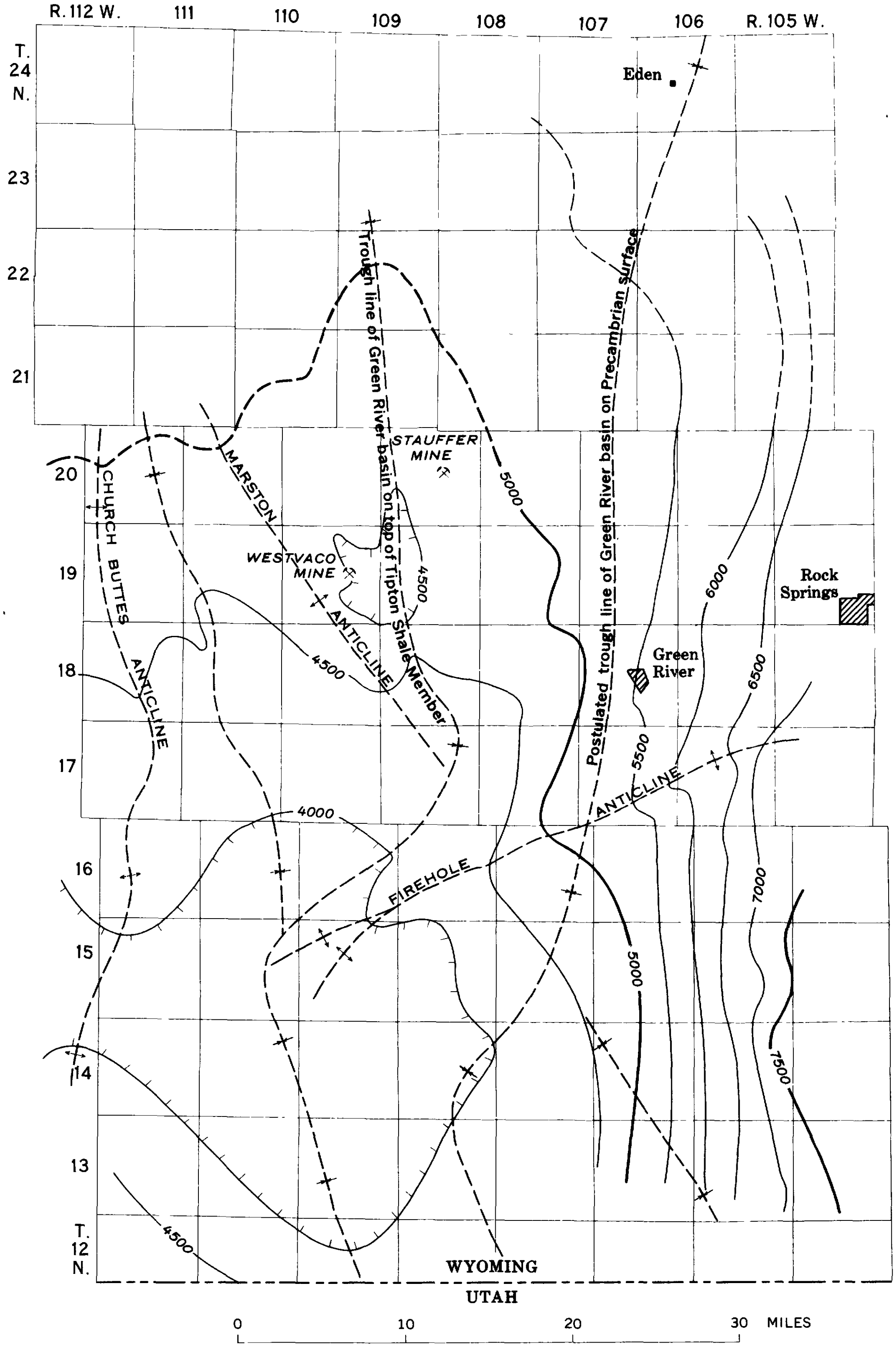

FIGURE 11.—Structure-contour map of southeastern part of Green River basin. Contours are on top of Tipton Shale Member of Green River Formation; dashed where shale in upper part of member grades into sandstone, making contour horizon indistinguishable. In these places, position of contour horizon is estimated from younger marker beds. Datum is mean sea level. Anticlines and synclines are in Tipton Shale Member. Control points (circles) are shown on plates 1 and 3.

The average P_2O_5 content of 17 samples from the Tipton Shale Member (tables 2, 3) is 0.11 percent. At locality L–5, plate 2, the P_2O_5 content of the shale diminishes markedly from bottom to top (table 3). No analysis of the Tipton Shale Member shows more than 0.001 percent uranium.

TABLE 2.—*Uranium and phosphote analyses of samples from uraniferous phosphatic zones in Wilkins Peak Member of Green River Formation, Green River area, Wyoming*

[Zones and samples within zones are arranged in stratigraphic order. Analysts: C. G. Angelo, G. T. Burrow, R. P. Cox, E. J. Fennelly, D. L. Ferguson, Mary Finch, W. D. Goss, L. M. Lee, H. H. Lipp, D. L. Schafer, J. P. Schuch, J. S. Wahlberg, J. E. Wilson. Spectrographic analyses for each zone are used (but not listed by number) in determining modal values in table 17 and these are plotted graphically on fig. 21. Equivalent uranium (eU) was determined by beta-gamma scaler, uranium was determined fluorimetrically, and P_2O_5 was determined volumetrically. Equivalent uranium is a measure of total radioactivity and does not distinguish between the radioactive elements]

Measured stratigraphic section	Section No. on pls. 2, 5	Locality No. on pl. 2	Location: Section	Location: T.N.	Location: R.W.	Zone	Sample	Laboratory No.	Rock Analysis (No. on table 4)	Spectrographic analysis No.	Interval sampled: Thickness (inches)	Interval sampled: Depth (feet)	Analyses (percent): eU	Analyses (percent): U	Analyses (percent): P_2O_5	Remarks
South Firehole Basin	1	L-33	Center west line 34	16	106	3	1	274041	16	274041	3		0.010	0.008	7.78	
						2a	2	37			3		.010	.005	5.52	
						2	3	38			3		.004	.002	.52	
						1	4	43			3		.002	.001	.18	3 ft above Tipton Shale Member.
South Firehole Canyon.	2	L-32	Center SE¼ 20	16	106	4?	5	237256	20	237256	18		.005	.005	3.3	40 ft above 3a.
						3a	6	55		237255	12		.005	.004	1.9	9.5 ft above 3.
						3	7	274007		237285	3		.012	.008	6.22	
						2a	8	08	13	274008	3		.016	.009	10.56	Sample taken 0.3 mile west of No. 9.
							9	237253		237284	6		.015	.009	3.1	
						2	10	274004			3		.002	.002	.26	
						1	11	237252			3		.003	.003	5.6	
Middle Firehole Canyou.	3	L-30	SW¼SE¼ 32	17	106	3	12	274046			3		.018	.015	8.02	
						2	13	30			3		.003	.002	.34	
						1	14	05	3		2		.023	.018	8.41	
							15	40			3		.1	.007	2.73	
Slippery Jim Canyon	5	L-29	NW¼SE¼ 22	17	106	1	16	236302			6		.014	.009	9.1	
Oro Claim 1	6	L-28	SW¼NW¼ 14	17	106	4aa	17	282874	21	282874	3		.006	.004	3.2	
						4	18	73			3		.005	.002	1.35	Zone is 12 ft below 4a.
						3	19	72			2		.02	.015	9.83	Zone is 46 ft below 4.
						2b	20	71			3		.004	.001	2.04	Zone is 21 ft below 3.
						2a	21	70			3		.003	<.001	.24	Zone is 10 ft below 2b.
						2	22	69			3		.009	.006	2.78	Zone is 12.5 ft below 2a.
						1	23	236307			2		.037	.037	1.6	Top of sampled part of zone.
							24	272051			3				5	Split of No. 25, P_2O_5 check.
							25	236306		236381	3		.1	.12	4.4	<0.5 gal oil per ton, table 5.
							26	05			.5		.089	.1	4.4	
							27	04			2		.073	.082	4.1	
							28	03			2		.025	.024	1.6	Base of sampled part of zone; 5 ft above top of Tipton Shale Member.
Lulu Claim 2	7	L-22	NE¼SW¼ 10	17	106	3	29	274006	14	274006	3		.016	.015	9.98	11 gal per ton oil, table 5.
						2	30	09			6		.006	.003	1.36	
						1	31	39			2		.002	<.001	.18	Top of sampled part of zone in pit; see photograph, fig. 12.
							32	36			1.5		.002	.001	.17	
							33	22			2		.004	.002	.19	
							34	29			4		.009	.006	.58	
							35	25			4		.013	.013	.67	
							36	28	7		1.2		.022	.018	1.37	
							37	44	6	236382	1.5		.06	.04	12.9	
							38	13			2		.009	.005	1.99	
							39	45			1.2		.007	.004	3.16	
							40	19			1.5		.006	.003	1.47	
							41	21	5		1.5		.002	<.001	.05	
							42	24			4.5		.002	<.001	.1	
							43	31			4.5		.001	<.001	.12	Base of sampled part o fzone in pit.
Ridge section	8	L-24	NE¼NW¼SE¼ 11	17	106	3	44	32	17	274032	3		.017	.012	10.47	Westernmost X, pl. 2
						1	45	237270			5		.005	.003	.16	Southernmost X, pl. 2. Top of sampled part of zone in pit.
							46	71			5		.02	.017	1.2	
							47	72			2.5		.12	.10	9.7	
							48	73	4	237280	2		.1	.093	12.6	
							49	74			5		.063	.059	6.3	
							50	75			7		.016	.012	1	
							51	76			5		.004	.003	<.05	Bottom of sampled part o fzone.
Northeast Wilkins Peak.	10	L-14	SE¼NW¼SW¼ 25	18	106	2	52	65	9	237265	4		.013	.012	3.7	
						1	53	63			8.5		.015	.015	.59	Top of sampled part of zone.
							54	62		237281	3		.068	.068	3.6	
							55	61			4.5		.012	.009	.42	Base of sampled part of zone.
Dugway section	11	L-13	SW¼SW¼SE¼ 22	18	106	3	56	278363			3		.006	.005	7.03	
						2a or b	57	62			3		.003	.002	3.26	
						2	58	61	10	278361	3		.023	.023	5.15	
Mountain Fuel Supply Co. Road.	12	L-12	SE¼SE¼SE¼ 8	18	106	1	59	252625			3		.025	.025	6.5	
U.S. 30, west cut	13	L-8	SE¼SW¼ 21	18	106	3	60	274017	15	274017	3		.013	.01	5.98	10.4 gal oil per ton, table 5.
						2	61	14			3		.004	.001	.39	
US 30, east cut	14	L-7	SW¼SE¼NW¼ 22	18	106	1	62	237250			3		.02	.016	8.9	
Old highway	15	L-6	SE¼NE¼SE¼ 10	18	106	1	63	51			4		.019	.016	4.8	

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TABLE 2.—*Uranium and phosphate analyses of samples from uraniferous phosphatic zones in Wilkins Peak Member of Green River Formation, Green River area, Wyoming*—Continued

Measured stratigraphic section	Section No. on pls. 2, 5	Locality No. on pl. 2	Location: Section	Location: T.N.	Location: R.W.	Zone	Sample	Laboratory No.	Rock Analysis (No. on table 4)	Spectrographic analysis No.	Interval sampled: Thickness (inches)	Interval sampled: Depth (feet)	Analyses (percent): eU	Analyses (percent): U	Analyses (percent): P_2O_5	Remarks
Old Log Inn	16	L-4	NE¼NW¼SW¼ 1	18	106	7	64	236318			12		0.007	0.004	2.2	435 ft above top of Tipton Shale Member.
		L-5	SW¼SW¼SE¼ 1	18	106	3	65	17			3		.02	.016	12.9	
						2	66	16			3		.009	.004	4.2	
			NW¼NW¼-NE¼ 12	18	106	1	67	15		236383	4		.073	.081	15.4	
Television Tower Road.	17	L-2	SE¼NW¼-NW¼ 31	19	105	11a?	68	282868			2		.004	.003	2.55	Zone is 46 ft below Laney-Wilkins Peak contact and 106 ft below Tower Sandstone Lentil of former usage.
						10?	69	67	25	282867	2		.01	.01	4.1	Zone is 98 ft below 11a?
						7	70	66			2		.004	.002	1.52	Zone is 16 ft below top of green sequence at this locality.
		L-3	SW¼NE¼ 31	19	105	3	71	276863			3		.023	.019	8.7	
						2	72	62			2		.003	.001	1.46	
		L-9	NW¼SW¼ 16	18	106	3	73	272057			3		.014	.015	8.7	107 ft below lowest olive-drab bed in Wilkins Peak Member at this locality.
		L-10	NE¼ 18	18	106	11a	74	282861			2		.004	.004	3.82	Zone is 72 ft below Wilkins Peak-Laney contact.
						11	75	60	26	282860	2		.006	.002	2.87	Zone is 38 ft below zone 11a.
East edge Green River townsite.		L-11	SW¼SW¼-NW¼ 23	18	107	7	76	59	23	282859	3		.007	.005	2.32	Zone is 18 ft below top of green sequence at this locality; photograph of locality on pl. 9.
		L-14A	SE¼NW¼-SW¼ 25	18	106	1	77	237264			3		.042	.036	6.5	Same locality as L-14 (section 10), but 100 ft east of where those samples were taken, 25 ft above Tipton Shale Member.
Wilkins Peak		L-15	SE¼NE¼-NW¼ 35	18	106	10	78	282862			2		.003	.001	1.41	
		L-16	SE¼NE¼-SW¼ 35	18	106	7	79	58			3		.006	.003	1.22	Zone is 15 ft below top of green sequence at this locality.
		L-17	NW¼NW¼-NE¼ 2	17	107	10	80	63			2		.003	.007	1.33	
Cordwood Canyon		L-18	NE¼NW¼NE¼ 5	17	106	7	81	55			3		.009	.005	2.11	15 ft below top of green sequence.
			NE¼SW¼NE¼ 5	17	106	4	82	54			3		.004	.004	2.11	59 ft above zone 3 (see analysis from zone 3 at loc. L-21, this table).
Logan Draw		L-19	SE corner 12	17	107	10	83	65			2		.003	.001	1.5	
		L-20	SE corner 7	17	106	7	84	64			2		.01	.005	1.34	Zone is 17 ft below top of green sequence at this locality.
		L-21	SW corner 4	17	106	3	85	237267		237282	3		.021	.019	9.7	11.0 gal oil per ton, table 5.
						2	86	66		237283	6		.016	.01	4.8	
			NW¼NE¼-NW¼ 9	17	106	1	87	68			3		.066	.049	3.6	10 ft above Tipton Shale Member.
North Ridge Section		L-23	SW¼SW¼SE¼ 2	17	106	4aa	88	282857			3		.005	.003	1.6	
						4	89	56	19	282856	3		.006	.005	3.07	Zone is 13 ft below 4a? and 51 ft above 3. (See analyses for Ridge section, No. 8, this table.)
		L-24A	NW¼SE¼-NE¼ 11	17	106	1	90	274015			4		.002	<.001	.09	200 yards NNE of L-24 at northernmost X on pl. 2. Top of sampled part of zone in pit.
							91	274023			3.5		.002	.001	.15	
							92	20			2		.003	.001	.22	
							93	16			2		.004	.001	.21	
							94	42			2		.003	.001	.35	
							95	34			3.5		.003	.001	.38	
							96	18			4.5		.046	.025	5.05	
							97	26			1		.058	.03	5.62	<0.5 gal oil per ton, table 5.
							98	47			3		.009	.004	1.02	
							99	27			1		.004	.001	.29	Base of sampled part of zone.
		L-24B	NE¼NW¼SE¼ 11	17	106	1	100	237269					.16	.15	18.2 15.6 15.3	All splits of same sample.
							101	272058	2	154181	3		.15	.14	14.7	Pit 57 ft NNE of L 24.
							102	44							17.6	
							103	46							13	
		L-25	SE¼NW¼SE¼ 11	17	106	1	104	252621	1	C1198	1		.086	.085	9.5	
		L-27	Center S line 10	17	106	1	105	236308			8		.032	.023	8.1	Lulu Claim 1.
		L-31	Center S½ 24	16	107	7?	106	237257			6		.008	.005	1.4	Upper part of Wilkins Peak Member, several hundred feet above zone 3.
		L-34	NW¼SW¼-NE¼ 15	15	107		107	252623			6		.009	.003	2	Upper part of Wilkins Peak Member, several hundred feet above zone 3.
		L-35	SW¼SW¼ 1	14	106	1	108	270192			3		.022	.019		
							109	272052							4.9	Split of No. 108.

		L-37	Center W½E½..19	14	105	2?	110	237259			12		.02	.008	2.5	90 ft above No. 112; lithology similar to zone 2.
							111	60			4		<.001		<.05	White tuff 27 ft above No. 112.
						1?	112	58			6		.014	.01	2.2	Possibly upper part of zone 1, but could be higher.
		Off map.	Center S line.....18	20	105	1	113	236319			8		.011	.009	2.7	Farthest north sample from zone 1.
		Off map.	SE¼NE¼.......22	13	107		114	252622			6		.007	.004	2.4	Upper part of Wilkins Peak Member, several hundred feet above zone 3.
							115	272053							3.6	Split of No. 114.
		Off map.	NE¼............33	21	105	3?	116	276864			3		.004	.002	.27	Farthest north sample in area.
J. M. Perkins, Green River 2.			NE¼............32	15	109	11	117	286003			2	1746	.002	.001	.36	Probably just above or below zone 10.
J. M. Perkins, Green River 3.			SW¼.............8	17	107	11a	118	286416			2	856	.002	.001	.26	
							119	281684		281684	2	857	.011	.006	5.5	
							120	286417			2	858	.002	<.001	.06	
						9b	121	18			2	1136	.002	<.001	.09	
							122	281685		281685	2	1137	.005	.005	4.52	
							123	286419			2	1138	<.001	<.001	.16	
						9	124	20			2	1226	.003	.001	.9	
							125	281686	24	281686	2	1227	.004	.002	2.26	
							126	286421			2	1228	.004	.002	1.8	
						8a	127	281687		281687	2	1268.5	.004	.001	1.41	
						7	128	286422			2	1324.5	.003	.002	.92	
							129	281688	22		2	1325.5	.012	.008	5.75	
							130	286423			2	1326.5	.001	<.001	.36	
						6	131	281689			2	1368	.004	.002	.81	
						5	132	90			2	1476.5	.006	.003	.8	
						4c	133	91		281691	2	1515	.012	.009	<.05	
						4b	134	92		281692	2	1535	.003	.002	1.0	
						4a	135	93			2	1553	.009	.004	.34	
						3	136	286426			2	1665.5	.002	<.001	.08	
							137	281694			2	1666.5	.004	.001	9.83	
							138	286427			2	1667.5	.002	<.001	<.05	
						2a	139	281695			2	1713	.004	.001	.19	Zone is at 1710 ft.
						2	140	286428			2	1722.3	.004	.001	2.72	
							141	281696	11	281696	2	1723.3	.01	.007	7.89	
							142	286429			2	1724.3	.003	<.001	.65	
						1	143	281697			2	1761	.002	.001	<.05	
							144	286424			2	1783	.003	<.001	<.05	
							145	281698			2	1784	.005	<.001	<.05	Rare-earth mineral present; mineral extracted before analysis; so effect on analysis not known.
							146	286425			2	1785	.001	.001	<.05	
Reid 2			SE¼ SE¼.......32	17	107	3	147	279660	18	279660	2	1299	.016	.01	5.62	
						2a	148	61	12	279661	2	1331	.032	.021	5.34	
						1	149	281700			2	1422.5	.007	.005	.22	Do.
Diamond Alkali Co., Daco 3			NW¼ NW¼....17	18	108	1	150	281699			2	1369	.007	.006	1.21	Do.
Grierson 1			NW¼ NW¼.....4	16	109	1	151	282876			2	2081.2	.008	.004	4.38	
Butler 1			NW¼ NW¼....12	18	108	11	152	75			2	543	.002	.001	.32	
Jenkins, Pittman 2			NE¼ SW¼......34	23	107	9aa	153	287950			2	736	.001	<.001	.53	
						9	154	52			2	763.5	.003	.001	.76	
							155	51			2	764	.003	.002	3.24	
						7a	156	53			2	787.5	.002	<.001	.19	
							157	54			2	788	.006	<.001	.21	
							158	55			2	803.5	.004	<.001	.2	
							159	56			2	804	.004	.001	.2	
Berger 1			SE¼ SE¼.......28	20	108	See remarks.	160	288502			24	1396.4–1398.4	.002	<.001	<.05	Core samples are oil shale. According to gamma ray-neutron log, these samples should span the contact between Wilkins Peak and Tipton Shale Members. Possibly as a result of discrepancy between core and log measurements, these samples are thought to be from uppermost part of Tipton.
							161	03			31	1398.4–1401.0	.002	.001	.08	
							162	04			16	1401.0–1402.3	.003	<.001	.06	
							163	05			30	1402.3–1404.8	.003	.001	<.05	
							164	06			38	1404.8–1408.0	.003	.001	.07	
							165	07			32	1408.0–1410.7	.002	.001	.08	
							166	08			16	1410.7–1412.0	.001	.001	<.05	
Jenkins, Grierson 1			NE¼ NE¼.......4	20	107	7a	167	09A			120	1060–1070	.004	.003	.16	Drill cuttings.
						5a	168	10A			120	1150–1160	.001	.001	.13	Do.
						5	169	11A			120	1200–1210	.001	<.001	.14	Do.
						2?	170	12A			120	1260–1270	.001	<.001	.06	Do.
						1	171	13A			120	1280–1290	.001	<.001	.09	Do.
						1	172	14A			120	1290–1300	<.001	<.001	.08	Do.
							173	15A			120	1300–1310	<.001	.001	.08	Do.
							174	16A			120	1310–1320	.001	.001	.12	Do.
						Upper Tipton.	175	17A			120	1320–1330	.003	.001	.08	Drill cuttings (top of Tipton Shale Member at 1324 ft).

TABLE 2.—*Uranium and phosphate analyses of samples from uraniferous phosphatic zones in Wilkins Peak Member of Green River Formation, Green River area, Wyoming*—Continued

Measured stratigraphic section	Section No. on pls. 2, 5	Locality No. on pl. 2	Location			Zone	Sample	Laboratory No.	Rock Analysis (No. on table 4)	Spectrographic analysis No.	Interval sampled		Analyses (percent)			Remarks
			Section	T.N.	R.W.						Thickness (inches)	Depth (feet)	eU	U	P_2O_5	
						Lower Tipton.	176	18A			120	1530–1540	0.001	0.001	0.14	Drill cuttings (base of Tipton Shale Member at 1558 ft).
Jenkins, Dymond 1			SW¼SE¼ 18	21	107	7a	177	19A			120	1350–1360	<.001	<.001	.18	Drill cuttings.
						6	178	20A			120	1390–1400	.002	.001	.19	Do.
						Upper Tipton.	179	21			120	1590–1600	.002	.001	.09	Do.
Jenkins, V. Reeves 1			SW¼SW¼ 30	22	106	6	180	22A			120	1020–1030	<.001	<.001	.11	Do.
							181	23			120	1030–1040	.002	.001	.46	Do.
Jenkins, W. Reeves 1			SE¼SE¼ 28	22	106	6	182	24A			120	1010–1020	.002	.001	.31	Do.
U.P.R.R. Oil Development Co., U.P. 8.			SE¼SE¼ 35	22	110	6	183	289230			2	1058.7	.004	.001	.44	
							184	31			2	1059.3	.02	.017	3.11	
							185	32			2	1060	.02	.011	2.34	
							186	33			2	1060.6	.007	.002	.61	
						5a	187	34			2	1088	.004	.003	1.01	
						5	188	35			2	1152	.003	.002	.34	
						1	189	36			2	1279	.005	.005	.64	
J. M. Perkins Green River 1.			NW¼ 32	15	108	11a?	190	297267			2	913.5	.052	.059	2.92	
						9b?	191	73			2	1152.5	.006	.004	10.1	
						9a?	192	74			2	1178.8	<.001		3.11	
						5	193	75			2	1560.2	.004	.004	1.72	
							194	76			2	1575.3	.003	.001	.29	
						2a	195	77			6	1830.4	.006	.002	2.82	
						1	196	78			2	1954	.009	.007	4.94	
West Side Green River Basin.		Off map	5	22	114		197	252624			6		.006	.007	.69	Gastropod-bearing limy sandstone.

TABLE 3.—*Phosphate analyses of random samples from Wilkins Peak and Tipton Shale Members of Green River Formation in Green River area*

[No samples are from uraniferous phosphatic zones (compare with analyses in table 2)]

Location of sample	Member	Stratigraphic position or depth (feet)	P_2O_5 (percent)	Source of data and remarks
Mountain Fuel Supply Co., Hay no. 1, sec. 2, T. 18 N., R. 110 W.	Wilkins Peak	1275–1713:		Analyses of all samples from this well by J. J. Fahey (1962, p. 15).
		1275. 0–1276. 0	0. 22	
		1320. 0–1321. 0	. 17	
		1365. 0–1365. 2	. 02	
		1390. 0–1391. 0	. 00	
		1623. 5–1641. 5	. 04	
		1646. 0–1647. 0	. 01	
		1654. 5–1654. 6	. 02	
		1663. 0–1663. 2	. 00	
		1668. 0–1668. 1	. 01	
		1700. 0–1700. 2	. 01	
		1710. 0–1711. 0	. 03	
		1711. 0–1712. 0	. 01	
		1712. 0–1713. 0	. 01	Bottom sample is 107 ft above base of member.
Intermountain Chemical Co., Westvaco mine, sec. 15, T. 19 N., R. 110 W.	do	Main trona bed	. 041	J. J. Fahey, unpublished analyses, average of 23 samples (max 0.12, min 0.00).
		Oil shale at base of main trona bed.	. 02	J. J. Fahey, unpublished analyses.
		Dolomitic marlstone overlying main trona bed.	. 02	Do.
Loc. L–9, pl. 2, sec. 16, T. 18 N., R. 106 W.	do	Tuff beds in middle part of member.	. 05	W. H. Bradley, written commun., 1961.
			. 13	Do.
Loc. L–5, pl. 2, sec. 12, T. 18 N., R. 106 W.	do	Tuffaceous marlstone near base of member.	. 02	Do.
	Tipton	Top	. 08	Each figure is an average of duplicate samples. Each pair was taken at approx 20-ft intervals (W. H. Bradley, written commun., 1961).
			. 05	
			. 06	
			. 18	
			. 06	
			. 34	
		Basal bed	. 38	
Sinclair Oil and Gas Co., Federal 1, sec. 6, T. 15 N., R. 108 W.	Wilkins Peak	1790–1802:		Core samples analyzed by G. T. Burrow. Pale-green claystone midway between uraniferous phosphatic zones 1 and 2:
		1790	<. 05	Lab. No. 287957
		1792	<. 05	287958
		1793	. 17	287959
			<. 05	287966, split of 287959
		1794	. 15	287960
		1796	. 12	287961
		1798	<. 05	287962
		1799	<. 05	287963
		1801	. 16	287964
		1802	. 18	287965

WILKINS PEAK MEMBER

The Wilkins Peak Member and its shore-phase equivalents are present in an area of about 6,000 square miles in the Green River basin. Data presented here are on uraniferous phosphatic zones in this member in the southeastern 2,500 square miles of the basin. In the remainder, only fragmentary information is available. Data on 90 (of about 150) wells and core holes that completely or partly penetrated the Wilkins Peak Member in this area were studied. As of 1962, information on many of the other wells and trona core holes was not available.

In most localities, the member has from 10 to 50 abnormally radioactive zones; 35 are shown on pls. 3–5, and of these, 25 were analyzed chemically (table 2) and are known to contain significant amounts of both uranium and phosphate. Tentative correlations of the zones indicated on plate 3 were made in the following manner. The zones were identified in surface sections, some were measured by W. C. Culbertson and others by the writer. These sections were compared, on the basis of lithology and intervals, with the closest subsurface sections, such as Perkins, Green River No. 3 core hole (pl. 4), on which both cores and gamma ray-neutron logs are available. The cores were sampled, and both chemical and spectrographic similarities with the zones on outcrop were noted. Away from the subsurface control points, correlations are based on matching gamma ray-neutron curves, supplemented by company core- and drill-sample descriptions, firsthand study of cores and cuttings where available, and use of core logs made by W. C. Culbertson. Wherever possible, correlation traverses were closed both in subsurface sections and from subsurface to outcrop sections, in order to check for possible errors.

Because this study was in progress during a period of intense economic interest in trona, gamma ray-neutron logs and core data on many wells were not available for study; others were not available for reproduction on plate 3. This plate plus the data on plate 4 provide enough control for correlation with gamma ray-neutron and core logs on the included wells and others when they are released to the public.

Table 6 presents a summary of analytical data on the uraniferous phosphatic zones. Because of the paucity of analyses (even zone 1, which is the best known, has less than one for each 20 sq mi), computation of the total amount of uranium and phosphate present in any zone is little more than a guess. Tonnage estimates were made for seven zones, using the following assumptions: (1) That one or two beds in each zone contain most of the uranium and phosphate, as is shown on figure 13, (2) that there are places where the zones are abnormally thin and the grade of uranium and phosphate below average, (3) that a conservative way to compensate for these areas of lower grade in a given zone is to consider all the uranium and phosphate in each zone at each locality as the amount contained only in the thickness of the richest bed sampled there.

Uranium content is approximately 80 percent of equivalent uranium (equivalent uranium is a measure of total radioactivity and does not distinguish between the radioactive elements). No evidence of a significant amount of near-surface enrichment of uranium was noted, and no uranium minerals were observed.

Rock analyses and mineral determinations by X-ray are given in table 4, and spectrographic analyses in table 17. Figure 20 compares the average content of common oxides in the uraniferous phosphatic zones in the Wilkins Peak Member with similar zones in other areas in Wyoming and with the Pierre Shale of Late Cretaceous age. The Pierre Shale was selected as a standard of reference because many analyses are available (Tourtelot, 1962), it is several thousand feet thick, and has an areal distribution of thousands of square miles. Figure 21 compares the spectrographic analyses of 27 elements in uraniferous phosphatic zones in the four areas in Wyoming with those in the Pierre and similar marine Cretaceous shales. The comparisons of both the oxide and the elemental content in the marine Cretaceous shales with those in lacustrine Eocene strata serve to emphasize differences and similarities that are probably of genetic significance.

In the following discussion the stratigraphic position of the uraniferous phosphatic zones with respect to trona beds, tuffs, and other types of marker beds is given to facilitate surface and subsurface identification of the zones.

ZONE 1

Zone 1 is the oldest, thickest, richest, and most easily recognized of those in the Wilkins Peak Member. The entire zone, locally including trona bed 1 (fig. 14), ranges in thickness from 5 to 50 feet; but concentrations of uranium and phosphate are, in most sections, confined to a few inches to 1 foot of strata (figs. 12, 13; pl. 5). Zone 1 can be recognized in surface and subsurface sections within an area of about 2,000 square miles extending southward from about 12 miles north of Green River to the State line, eastward to outcrops on the west flank of the Rock Springs uplift, and westward at least as far as a well 20 miles southwest of the Church Buttes gas field (section 1, pl. 1 is in this field; pls. 3, 5).

The zone crops out as a brown ledge or as prominent brown dip slopes (figs. 3–7) that directly overlie gray steep slopes and cliffs of the Tipton Shale Member. It is well bedded and weathers into hard inch-thick plates. The rock is very fine grained dense argillaceous dolomite ranging to dolomitic sandy siltstone (table 4). There are some concentrations of biotite and iron sulfides. Beds of oil shale are present locally, and in a few subsurface sections the siltstones are oil saturated; the most uraniferous and most phosphatic strata, however, contain very little oil (table 5). Shortite crystals are abundant throughout the zone.

Cores from zone 1 in 3 wells (Nos. 5 and 6, pl. 3; pl. 4 and Diamond Alkali Co., Daco 3, NW¼NW¼ sec. 17, T. 18 N., R. 108 W.) contain small quantities of a new green-to-black rare-earth barium-sodium-uranium carbonate mineral that occurs as piles of tabular crystals in small vugs. These crystals were extracted by Charles Milton for mineralogic study before the cores were analyzed for uranium and phosphate. As is indicated on table 2 and Plate 4, the uranium and phosphate content of the enclosing rock is low, yet the cores were the most radioactive of any checked by scintillator in the entire study. The radioactivity is due to the uranium in the new mineral, as is shown by the relatively insignificant radioactivity.

FIGURE 12.—Relation of physical appearance to chemical content, uraniferous phosphatic zone 1, Green River area. Rock is fine-grained dolomitic marlstone. Prospect pit on Martin Undem, Lulu claim 2, SE¼NE¼SW¼ sec. 10, T. 17 N., R. 106 W. (loc. L–22, section 7).

The green mineral has also been found in the trona-bearing strata directly overlying zone 5 in the Intermountain Chemical Co. Westvaco mine, sec. 15, T. 19 N., R. 110 W. (fig. 11). In this locality it is associated with many other additional authigenic minerals, such as labuntsovite (K, Ba, Na, Ca, Mn) (Ti, Nb) $(Si, Al)_2$ $(O, OH)_7$ (H_2O) and leucosphenite $(CaBaNa^3BTi^3$-$Si^9O^{29})$.

Trona bed 1 (fig. 14), which locally attains a maximum thickness of 40 feet, was precipitated within zone 1 in an area of about 200 square miles southwest of the town of Green River. Zone 1 is directly overlain by trona bed 2, which is nearly as thick as bed 1, but is more widespread, having an areal extent of about 500 square miles.

A total of 87 uranium and phosphate analyses were made of the richest parts of zone 1 in 27 localities (table 2). On outcrops, the distribution of uranium and phosphate ranges from barely detectable traces to 0.15 percent uranium and 18 percent P_2O_5. Figure 13 shows the close quantitative relationship of uranium and phosphate within individual sections.

The surface distribution of both uranium and phosphate is erratic (pl. 5) within very short distances. For example, several samples of a 3-inch bed in one small pit (loc. L–24B, pl. 2 and table 2) contain 13 to 18 percent P_2O_5. Not enough subsurface information

TABLE 4.—*Rock analyses of outcrop samples and cores, selected on the basis of uranium and phosphate content, from uraniferous phosphatic zones in Wilkins Peak Member of Green River Formation in Green River area, Wyoming*

[Location and stratigraphic position of samples are shown in table 2]

	Zone 1								Zone 2			Zone 2a	
	1	2	3	4	5	6	7	8	9	10	11	12	13
Laboratory No.	[1] C1198	IRC-365	274005	274010	274021	[2] 274044	[3] 274028	274026	158061	158062	158067	158064	274008
eU	0.086	0.15	0.023	0.10	0.002	0.060	0.022	0.058	0.013	0.023	0.010	0.032	0.016
U [4]	0.085	0.14	0.018	0.093	<0.001	0.040	0.018	0.030	0.012	0.023	0.007	0.021	0.009
P_2O_5 [4]	9.5	14.7	8.41	12.6	0.05	12.9	1.37	5.62	3.7	5.15	7.89	5.34	10.56
SiO_2	53.3	31.8	24.2	41.0	31.6	29.3	40.2	43.4	35.3	29.2	17.5	36.2	36.2
Al_2O_3	11.4	10.7	6.9	9.6	9.8	8.4	10.0	13.3	9.4	8.6	3.7	9.1	9.6
Fe_2O_3	2.51	1.6	1.0	2.6	1.2	1.0	1.0	2.3	2.6	1.8	.94	1.3	3.1
FeO	.50	.76	3.3	.94	4.2	1.7	3.3	.68	1.1	1.7	1.6	2.3	.8
MgO	1.4	3.2	6.4	2.4	7.4	3.4	5.7	2.6	6.5	7.7	3.5	6.1	4.1
CaO	11.56	22.2	23.5	17.7	15.5	23.3	13.5	12.4	13.5	16.5	17.2	14.9	18.8
Na_2O	3.69	3.1	2.8	3.1	2.8	3.4	3.4	3.8	.71	.64	18.3	3.3	3.2
K_2O	2.87	3.1	1.6	2.4	2.8	1.9	2.6	3.9	5.7	5.1	1.8	3.1	2.2
H_2O	2.01	3.3	1.8	2.3	2.1	2.8	1.8	4.3	4.6	4.3	1.0	2.5	5.1
TiO_2	.45	.40	.28	.34	.34	.29	.39	.48	.37	.34	.15	.31	.36
P_2O_5	5.8	13.5	7.8	8.9	.15	11.8	1.3	5.1	3.8	4.7	7.1	5.4	9.4
MnO	.04	.08	.08	.06	.10	.06	.09	.06	.08	.08	.04	.06	.07
CO_2	3.83	6.5	19.4	7.3	22.3	11.0	16.6	7.0	11.6	14.6	25.6	12.4	6.8
Loss on ignition [5]									21.0	23.7	26.5	16.9	
Less H_2O+CO_2									16.2	18.9	26.6	14.9	
Organic matter									4.8	4.8		2.0	
Total (approx)	99	100	99	99	100	98	100	99	100	100	98	99	100
Minerals identified by X-ray analysis [6]	Quartz Feldspar Apatite Mica Dolomite		Apatite Dolomite Quartz	Dolomite Quartz Plagioclase Apatite Mica Analcite(?)	Dolomite Analcite Apatite Plagioclase Quartz Mica	Apatite Dolomite Analcite Quartz Plagioclase	Dolomite Quartz Plagioclase Analcite(?) Calcite(?)	Analcite Dolomite Quartz Plagioclase Mica(?)					Apatite Analcite Dolomite Quartz Plagioclase

	Zone 3					Zone 4	Zone 4?	Zone 4aa	Zone 7		Zone 9	Zone 10?	Zone 11
	14	15	16	17	18	19	20	21	22	23	24	25	26
Laboratory No.	274006	274017	274041	274032	158063	158068	158060	158072	158066	158069	158065	158071	158070
eU	0.016	0.013	0.010	0.017	0.016	0.006	0.005	0.006	0.012	0.007	0.004	0.010	0.006
U [4]	0.015	0.010	0.008	0.012	0.010	0.005	0.005	0.004	0.008	0.005	0.002	0.010	0.002
P_2O_5 [4]	9.98	5.98	7.78	10.47	5.62	3.07	3.3	3.2	5.75	2.32	2.26	4.10	2.87
SiO_2	24.6	30.3	26.2	27.0	24.4	24.5	23.6	27.7	30.1	33.4	37.6	20.6	39.6
Al_2O_3	6.7	8.6	7.1	7.7	4.9	4.5	5.1	5.4	6.4	5.6	7.3	2.6	4.9
Fe_2O_3	.8	2.1	1.9	2.2	.90	2.1	2.2	2.8	1.6	1.7	2.0	1.0	3.2
FeO	1.1	1.4	1.1	1.0	1.5	.63	.52	.56	.89	.46	.88	.24	.48
MgO	5.0	5.2	5.8	4.1	8.6	10.0	7.8	6.1	6.5	8.2	7.6	7.8	7.4
CaO	22.8	17.7	22.3	21.2	21.9	23.3	26.3	24.9	22.6	20.7	13.8	30.4	18.2
Na_2O	2.2	2.6	2.1	2.5	2.8	1.1	1.2	1.3	2.7	1.9	4.8	.52	.62
K_2O	1.6	2.2	1.7	1.8	2.2	1.3	1.2	1.4	1.9	1.6	2.6	1.1	1.9
H_2O	4.4	4.1	3.9	5.2	2.6	5.0	5.0	6.4	4.5	8.0	9.4	3.6	8.6
TiO_2	.24	.34	.28	.30	.18	.22	.23	.26	.24	.23	.30	.11	.22
P_2O_5	9.1	5.4	7.2	9.8	5.7	3.0	3.4	3.2	5.1	2.2	1.8	3.7	2.8
MnO	.08	.08	.10	.06	.08	.18	.20	.16	.17	.12	.08	.07	.19
CO_2	12.0	11.7	14.5	8.8	21.3	22.5	21.1	18.6	16.0	15.4	10.6	26.4	11.2
Loss on ignition [5]	23.8	23.2	23.4	20.6	25.1	28.2	27.8	25.5	21.8	23.6	21.2	30.8	20.6
Less $H_2O + CO_2$	16.4	15.8	18.4	14.0	23.9	27.5	26.1	25.0	20.5	23.4	20.0	30.0	19.8
Organic matter	7.4	7.4	5.0	6.6	1.2	.7	1.7	.5	1.3	.2	1.2	.8	.8
Total (approx)	98	99	99	98	97	100	100	99	100	100	100	99	100
Minerals identified by X-ray analysis [6]	Apatite Dolomite Clay Quartz Plagioclase	Apatite Dolomite Quartz Plagioclase Mica	Apatite Dolomite Plagioclase Calcite Quartz Clay(?)	Apatite Dolomite Analcite Plagioclase Calcite Clay(?)									

[1] Sample 1 is a complete rock analysis by M. Balazs; 2 is a complete rock analysis by W. W. Brannock; all others are rapid rock analyses by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, using methods similar to those described by Shapiro and Brannock (1956).

[2] Sample of 1.5-in. interval beginning 4.7 inches above sample 5.

[3] Sample of 1.2-in. interval directly overlying sample 6.

[4] Splits of each sample except 1, 2, and 4, analyzed independently for eU, U, and P_2O_5 by L. M. Lee, D. L. Ferguson, and G. T. Burrow. Separate sample of No. 1 collected from approximately the same bed as that used in rock analysis; analyzed by C. G. Angelo, E. J. Fennelly, and H. H. Lipp. Separate sample collected for No. 4, analyzed by L. M. Lee, D. L. Ferguson, and G. T. Burrow. Minor differences in sampled interval may account for discrepancy between these P_2O_5 values and those in the rock analyses. Split of sample 2 analyzed by L. M. Lee, D. L. Ferguson, and H. H. Lipp.

[5] Samples have significant amounts of organic matter. Ignition loss (at 1,000° C) is given for purpose of summation.

[6] Minerals listed in order of decreasing abundance from top down. Sample 1 analyzed by A. J. Gude III; all others by Theodore Botinelly.

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TABLE 5.—*Oil analyses of uraniferous phosphatic zones*

Area	Location	Zone	Sample	Laboratory No.	Oil (Gal per ton)	Remarks
Green River	SW cor. sec. 4, T. 17 N., R. 106 W	3	1	146663	11.0	See also sample 85, table 2.
	SE¼SW¼ sec. 21, T. 18 N., R. 106 W	3	2	SBR60-318X	10.4	U.S. Bureau of Mines analysis; see also sample 60, table 2.
	NE¼SW¼ sec. 10, T. 17 N., R. 106 W	3	3	L55-111	11.0	See sample 29, table 2.
	SW¼NW¼ sec. 14, T. 17 N., R. 106 W	1	4	146665	$<.5$	See sample 25, table 2.
	NW¼SE¼NE¼ sec. 11, T. 17 N., R. 106 W	1	5	146664	$<.5$	See sample 97, table 2.
Beaver Divide	SW¼NE¼NW¼ sec. 34, T. 32 N., R. 95 W	SD-2	6	SBR60-325X	1.2	U.S. Bureau of Mines analysis; see also sample 4, table 11.
Lysite Mountain	SE¼SE¼NW¼ sec. 20, T. 42 N., R. 90 W	C	7	SBR60-324X	6.3	U.S. Bureau of Mines analysis; see also sample 5, table 13.

is available to determine whether the erratic distribution on outcrops is primary or the result of weathering.

Zone 1 grades northward and northwestward into sandstone (pl. 3, sections *C–C′* and *D–D′*) and loses its identity. The farthest northwest sample tentatively assigned to zone 1 (pl. 3, section 30, sample 289236; table 2, sample 189) contains 0.005 percent uranium and 0.64 percent P_2O_5.

Tonnage estimates of uranium and phosphate and analytical data for zone 1 are given in tables 4, 6, 16, and 17. On the basis of seven spectrographic analyses zone 1 appears to contain more of the following elements than any other uraniferous phosphatic zone in the Wilkins Peak Member: Ti, Zr, Cu, La, Y, Sc, Ga, Nb, Yb, Ce, and Nd, and is the only one in Wyoming that shows Sn and Sm. It also has the highest Al_2O_3 and TiO_2 content of any zone in the Wilkins Peak Member.

ZONE 1a

Zone 1a, which is 10–20 feet above zone 1, is known from subsurface sections in an area of about 200 square miles north and northwest of Green River (pl. 3, section *C–C′*). In subsurface sections, the zone consists of 2–4 feet of pale-green and tan siltstone; it has not been examined on outcrop. Available drill cuttings are inadequate for uranium and phosphate analyses. Trona bed 2 (fig. 14) does not occur in the area where zone 1a has been identified. Gamma ray-neutron logs suggest that the greatest radioactivity of zone 1a is in the area northwest of Green River, diminishing and then disappearing about 15 miles still farther north.

ZONE 2

Zone 2 is 15–40 feet above zone 1, but is not present north of Green River where zone 1a has been recognized. Zone 2 is known in an area of about 900 square miles (pls. 3–5). It is not lithologically distinct from strata that directly overlie and underlie it (see unit 7, measured section at loc. L–22). It consists of 6 inches to 1 foot of dark-green soft blocky sandy siltstone and claystone that is part of a single lithologic unit 10–15 feet thick. In outcrop sections (pl. 5; fig. 6), it appears as part of a dark-green smooth slope below a weak ledge. In fresh cuts (fig. 8), it is the upper part of a poorly bedded blocky sequence directly overlain by dark-green crumbly claystone and siltstone. Cores in some localities contain abundant shortite and bradleyite ($Na_3PO_4 \cdot MgCO_3$) crystals in a green finely micaceous tuffaceous sandy siltstone matrix. Trona beds 3 and 4 (fig. 14) each with a maximum thickness of about 10 feet, underlie zone 2 in the area southwest of the town of Green River. Tonnage estimates of uranium and phosphate and analytical data for zone 2 are given in tables 4, 6, 16, and 17. This zone has the highest Na_2O, K_2O, and boron content of any of the uraniferous phosphatic zones in the Green River area.

ZONE 2a

Zone 2a is 15–40 feet above zone 2. It is apparently discontinuous (pls. 3, 5), but it has been recognized in an area of about 500 square miles south of the town of Green River.

Zone 2a is lithologically so similar to zone 2 that it is difficult to distinguish them in areas of poor exposures. It is 6 inches to 1 foot thick and consists of dark-green blocky claystone and siltstone which is distinguishable in the field from overlying and underlying beds only by its radioactivity. Biotite and shortite are present in cores.

Trona bed 5 directly overlies zone 2a (fig. 14) in the area southwest of the town of Green River, reaches a maximum thickness of about 20 feet, and has an areal extent of 500 square miles. As much as 12 feet of salt is interbedded with the trona in the southwestern part of the Green River area. Tonnage estimates of uranium and phosphate and analytical data for zone 2a are given in tables 4, 6, 16, and 17. Zone 2a contains the second highest yttrium and ytterbium content of any of the uraniferous phosphatic zones in this area.

ZONE 2b

Zone 2b is a green blocky claystone of local extent about 10 feet above zone 2a and the same amount below the Firehole Bed (pl. 5, sections 6, 11). It was sampled in one, and possibly two localities, if correlation is correct. Analyses of these two samples are shown on plate 5 and in tables 2 and 6.

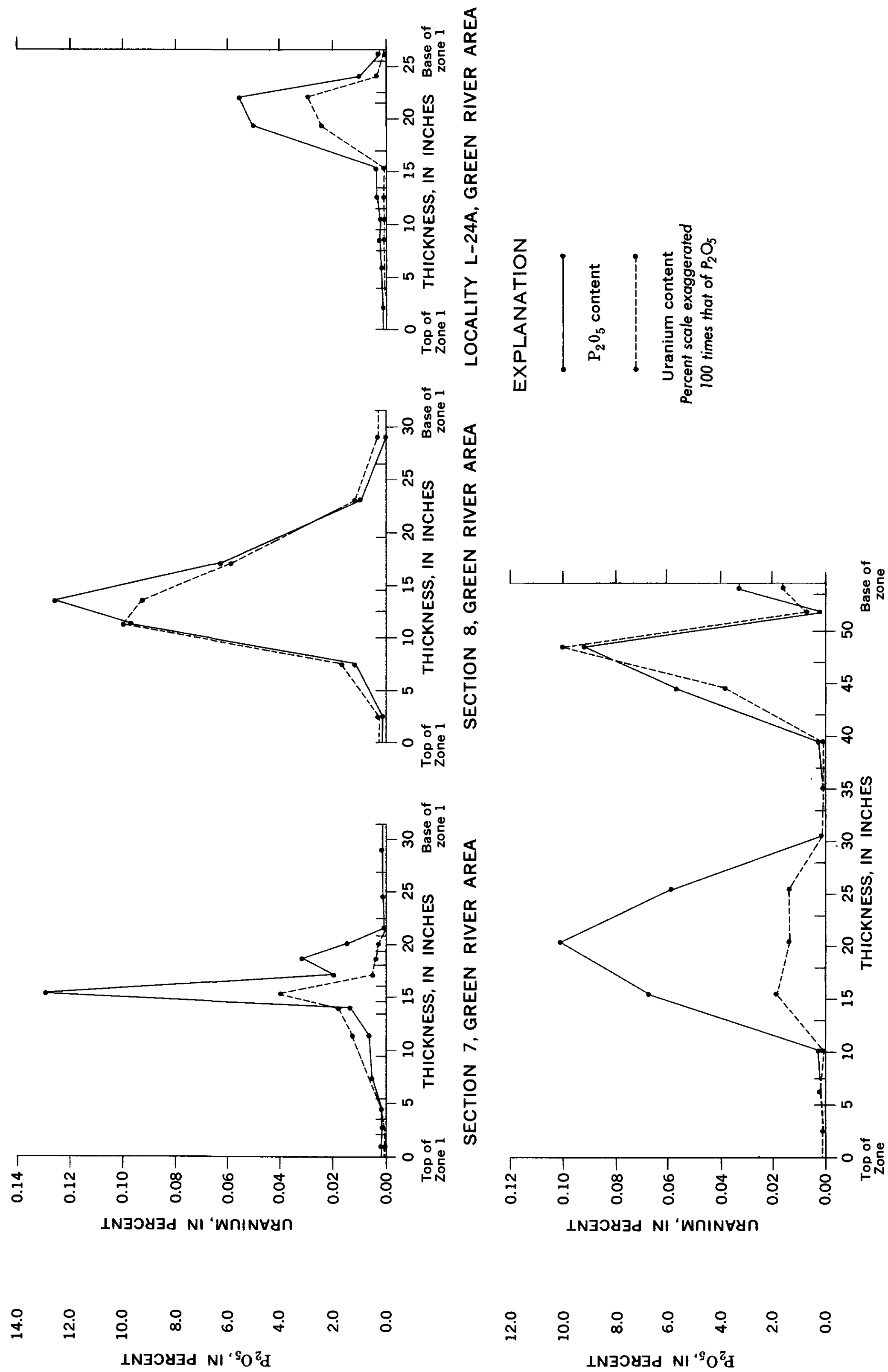
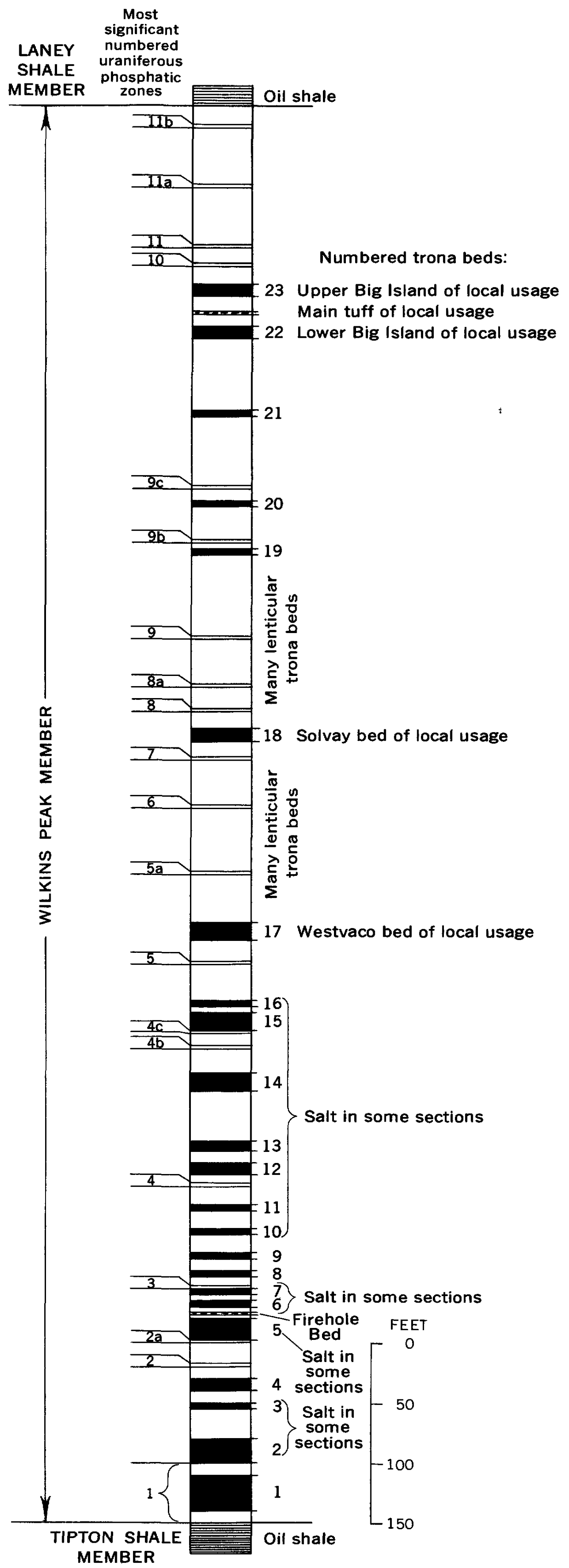


FIGURE 13.—Comparative distribution of uranium and phosphate in surface sections sampled in detail in Green River and Pine Mountain areas.



ZONE 3

Zone 3 is unique in that it is the only widespread uraniferous phosphatic oil shale that has been recognized in the Wilkins Peak Member or in the Green River Formation. It is 10–18 feet above the Firehole Bed (pl. 5), and ranges in thickness from 3 inches to 1 foot (fig. 8). It has been identified in an area of about 1,000 square miles east, south, and southwest of the town of Green River (pls. 3, 5).

Zone 3 crops out as white-weathering chips in the middle of a soft smooth slope formed on nonresistant rocks (fig. 6; unit 14 in measured section at loc. L–22). It consists of hard platy brown homogeneous oil shale that contains about 10 gallons of oil per ton (table 5). A 50-pound sample of this oil shale from locality L–8 (lab. No. SBR60–318X, table 5) was analyzed by the U.S. Bureau of Mines and found to have a much lower pour point, a lower sulfur content, and a higher nitrogen content than those in the Mahogany ledge of local usage in the Piceance Creek basin (this basin is discussed on page E58). No oil analyses are available from subsurface sections, but if the oil content is as uniform there as it is on outcrop, the zone would contain about 130,000 bbl of oil per square mile.

In some localities the oil shale contains partings of less petroliferous gray shale. Pyrrhotite is common. Shortite crystals are present in cores. Trona beds 5, 6, and 7 are between zones 2a and 3; bed 7 directly underlies zone 3 (fig. 14) in the area southwest of the town of Green River. Beds 6 and 7 are only locally as much as 15 feet thick, whereas bed 5 is, in places, 20 feet thick. All three contain salt in the southwestern part of the area. The maximum known thickness of salt in bed 6 is 10 feet, and bed 7 has much less.

Tonnage estimates of uranium and phosphate and analyical data are given in tables 4, 6, 16, and 17. Zone 3 has the highest average phosphate content (8.6 percent) of any zone in the Wilkins Peak Member.

ZONE 3aa

Zone 3aa is known only from subsurface sections in an area of about 75 square miles, 25 miles north of Green River (plate 3, sections *C–C′* and *D–D′*). No samples have been analyzed. The zone has not been recognized on outcrop, although it may be present east of wells 24 and 25 (plate 3, section *D–D′*). The relationship of zone 3aa to zones 3 and 3a is not known, because they do not occur in the same localities. Gamma ray-neutron logs show zone 3aa to be moderately radioactive and 3–6 feet thick.

FIGURE 14.—Idealized composite section showing stratigraphic relations of some of the most widespread uraniferous phosphatic zones to major trona beds in the Wilkins Peak Member of the Green River Formation in the southeastern part of the Green River basin. Many trona beds in the middle part of the member are not shown because they are lenticular or inadequately known.

TABLE 6.—*Summary of data on uraniferous phosphatic zones in Green River area, Wyoming*

[Zones are arranged in stratigraphic sequence]

Zone	Areal extent of zone (sq mi)	Lithology	Thickness (inches)		Number of analyses	Average specific gravity	Uranium				P_2O_5				Remarks
			Most radioactive beds	Thickness used in tonnage estimate			Percent		Estimated tons per sq mi [1]	Estimated tons in area of zone [1]	Percent		Estimated tons per sq mi [1]	Estimated tons in area of zone [1]	
							Max	Avg			Max	Avg			
11a	700	Greenish-gray siltstone and shale and brown oil shale.	24	6	4	[2] 2.5	0.059	0.018	40	30,000	5.50	3.7	40,000	30,000,000	Samples bracketing zone in core section not included.
11	1,200	Pale- to mottled-green silty claystone; some oil shale.	24		2		.002	.0015			2.87	1.6			One sample may be from margin of zone and not representative. Abundant ostracodes present.
10	900	Pale- to dark-green silty claystone.	24	6	4	[2] 2.5	.010	.005	50	50,000	4.10	2.1	20,000	20,000,000	Sample 11, table 2, not included because it is probably on the margin of the zone. Sparse mollusk fragments and ostracodes present.
9b	500	Mottled green and brown claystone.	24		2		.005	.005			10.1	7.3			Analyses of samples bracketing zone are not used. Tiny ostracodes present.
9a?	250	Light-green marly claystone.	24		1										Too few analyses for tonnage estimate.
9aa	900	Pale-green flaky shale	24		1		<.001				.53				Do.
9	1,500+	Pale-grayish-green claystone.	24		5		.0016	.002			3.24	1.8			Do.
8a	1,000+	Greenish-brown crumbly claystone.	24		1		.001				1.41				Do.
7a	700	Pale-green claystone	24		4		.003	[2] .001			.21	.2			Samples not considered representative; too few analyses for tonnage estimate.
7	2,500	Dark- to light-green silty claystone.	12–24	6	8	[2] 2.5	.008	.005	50	130,000	5.75	2.2	20,000	50,000,000	Analyses from sample 287955 and 287956 not used in computations.
6	2,500	Greenish-brown siltstone	24–72		9		.017	.006			3.11	1.5			Analyses of drill cuttings not used in average. Too few analyses for tonnage estimate.
5a	2,000	Green-gray siltstone	24		2		.003	.003			1.01	1.0			Too few analyses for tonnage estimate.
5	2,000+	Green-brown siltstone and claystone.	24		3		.004	.003			1.72	1.0			Data based on 2 core samples. Too few analyses for tonnage estimate.
4c	300	Dark-greenish-gray carbonaceous claystone.	24		1		.009				<0.05				Too few analyses for tonnage estimate.
4b	1,000+	Green and brown petroliferous silty claystone.	24		1		.002				1.00				Do.
4a	300	Pale-green limy claystone	24		1		.004				.34				Sample may not be representative of zone as a whole.
4aa	10	Gray clayey marlstone and limy claystone.	12		2		.004	.0035			3.20	2.4			Too few analyses for tonnage estimate.
4	1,000+	Gray limy claystone	3–18		4		.005	.004			3.3	2.5			Do.
3a		Olive-green claystone	12		1		.004				1.9				Do.
3	1,000+	Brown oil shale	3–12	3	14	2.27	.019	.012	60	60,000	12.90	8.6	40,000	40,000,000	Contains 11 gal oil per ton.
2b		Green claystone	6–12		2		.002	.0015			3.26	2.7			Too few analyses for tonnage estimate.
2a	500+	Dark-green claystone and siltstone.	6–12	3	7	2.41	.021	.007	40	20,000	10.56	4.0	20,000	10,000,000	
2	900+	do	6–12	3	13	2.37	.023	.006	30	30,000	7.89	2.7	10,000	10,000,000	
1a	200	Green and tan siltstone	24–48		1		<.001				.09				Sample not considered representative. Too few analyses for tonnage estimate.
1	2,000+	Pale-tan and greenish-gray dolomitic silty sandy marlstone.	6–24	6	88	2.62	.15	.03	350	700,000	18.2	4.6	50,000	100,000,000	Contains trona and rare-earth minerals.

[1] Number and geographic distribution of analyses are adequate only for a very rough estimate, and totals merely indicate relative significance of each zone. It was assumed that all uranium and phosphate in a given zone are concentrated in the thickness specified, and that average grade of all analyzed samples is the average for the zone throughout the area in which it has been identified.
[2] Estimated.

ZONE 3a

Zone 3a has been identified and sampled in only one locality (L–32, pl. 2), where is consists of about 1 foot of olive-green blocky claystone. Detailed stratigraphic study may indicate that this zone has a much greater extent. The single analysis of a 1-foot channel sample contains 0.004 percent uranium and 1.9 percent P_2O_5 (table 2). Spectrographic analysis is given in table 17.

ZONE 4

Zone 4, which is 45–75 feet stratigraphically above zone 3, has about the same distribution in the area of 1,000 square miles east, south, and southwest of Green River (pl. 3). Zone 4 consists of 2 feet of gray limy weakly fissile blocky claystone which, in outcrop sections, is overlain by a weak ledge of gray silty fissile hard tuffaceous analcitic marlstone. The interval between zones 3 and 4 is chiefly marly gray shale, in the upper part of which is a 5-foot marlstone that crops out as a ragged ledge.

Trona beds 8, 9, 10, and 11 (fig. 14) are between zones 3 and 4 in the area southwest of the town of Green River. These beds are commonly less than 10 feet thick, although in the southwestern part of the area, bed 10 is 20 feet thick. Beds 10 and 11 locally contain as much as 8 feet of salt 3 miles north of well 2 (pl. 3). Analytical data on the uraniferous phosphatic zones are given in tables 2, 4, 6, 16, and 17. Zone 4 has the highest MgO content of any uraniferous phosphatic zone, and MnO and lithium content equal to the highest in the Green River area.

ZONE 4aa

Zone 4aa is known only from outcrop sections in an area of 10 square miles (pl. 3), but its extent may be much greater. It is 10–15 feet above zone 4 and consists of about 1 foot of soft gray clayey marlstone interbedded with very limy fine-grained blocky grayish-green claystone. Analytical data are given in tables 2, 4, 6, 16, and 17.

ZONE 4a

Zone 4a is 40 to more than 70 feet above zone 4; the thickest interval between them is along the southeast margin of the Green River basin. The zone is recognizable in an area of about 300 square miles (pl. 3) chiefly east and south of the town of Green River, has a thickness of 2–3 feet, and consists of pale-green soft slightly calcareous claystone.

Zone 4a is in the lower middle part of Culbertson's (1961) sandstone and siltstone unit A (pl. 3), which is about 35 feet thick. Directly below zone 4a is a thin yellowish-brown tuff (Culbertson's "second tuff") interbedded with oil shale. Shortite crystals are common.

Zone 4a has not been sampled in outcrop and only one core analysis is available (pl. 4; tables 2, 6). This sample contains 0.004 percent uranium and 0.34 percent P_2O_5. Gamma ray-neutron logs suggest a greater radioactivity than is indicated by this analysis, so that it may not be representative of the zone as a whole. As is shown by analyses of other zones in Perkins, Green River No. 3 core hole (table 2) and on figure 13 samples within 6 inches to 1 foot of a uraniferous phosphatic zone may contain relatively small amounts of uranium and phosphate; thus, minor discrepancies in gamma ray-neutron log or core measurements may have resulted in the inadvertent sampling of only the marginal part of zone 4a.

ZONE 4b

Zone 4b, which is 10–40 feet above 4a, has nearly the same areal distribution as zones 3 and 4 (pl. 3). It becomes indistinguishable north and northwest of the town of Green River, and is recognized in an area of about 1,000 square miles. It consists of 2 feet of mottled green and brown petroliferous silty claystone at the top of sandstone and siltstone unit A. Shortite crystals are common in some sections. Three relatively thick trona beds (12, 13, and 14, fig. 14) are present between zones 4 and 4b southwest of the town of Green River. All three trona beds locally contain salt, but in places, bed 14 has as much as 20 feet of salt and lesser amounts of trona.

Zone 4b has not been sampled in outcrop sections and only one core analysis is available (pl. 4; tables 2, 6, 17). The spectrographic analysis indicates an unusually high sodium and strontium content.

ZONE 4c

Zone 4c, which is 10–20 feet above 4b, has an areal distribution of about 300 square miles. It does not extend as far south and southwest as 4b, and it becomes unrecognizable north and northwest of the town of Green River (pl. 3). It consists of about 2 feet of dark-greenish-gray slightly limy claystone. In some localities the claystone contains abundant macerated plant remains and a few entire leaves. Shortite crystals are common. The zone is directly overlain by trona bed 15 southwest of Green River (fig. 14). In some places this bed consists of 15 feet of trona, and in others it is largely salt of nearly the same thickness.

The one available analysis (pl. 4; tables 2, 6) from zone 4c differs from those in other zones in that it contains more than an average amount of uranium (0.009 percent but less P_2O_5 ($<$0.05 percent). A spectrographic analysis (table 17) indicates an unusually high sodium and strontium content.

ZONE 5

Zone 5 is 30–50 feet above zone 4c where that zone is present. South and southwest of the town of Green River, zone 5 is 250–350 feet above the Tipton Shale

Member but north and northwest of Green River the interval thins to 100 feet. The zone is 2–6 feet thick. It is thinnest and least radioactive in the southern part of the Green River basin, but it becomes thicker and more radioactive north and northwest of the town of Green River. This relationship of thickness to radioactivity is just the reverse of that of all older zones. The zone has been identified in an area of more than 2,000 square miles.

Zone 5 consists of greenish-brown dense hard slightly calcareous siltstone and silty claystone with abundant iron-sulfide crystals. Some sections contain carbonized plant fragments. It is 17 feet or less below trona bed 17 (fig. 14), which is mined at Westvaco (fig. 11). Bed 17, which is the most widespread trona bed in the Green River basin, has been recognized in an area of 1,000 square miles; locally it is 20 feet thick. Fahey (1962) studied this bed and adjacent strata in detail. Zone 5 is near the top of sandstone and siltstone unit B (pl. 3), which is 25–30 feet thick east and south of Green River. Analytical data on the zone are in tables 2 and 6.

ZONE 5aa

Zone 5aa occurs in an area of about 100 square miles south of Eden (pl. 3, section *C–C′*). This zone is not known where zone 5 has been identified, but it is probably in a stratigraphic position about 25 feet above it. Zone 5aa consists of 2–10 feet of dull-gray soft sandy siltstone. Only one subsurface section (well 28, pl. 3, section *C–C′*) is intensely radioactive and no samples suitable for analysis were obtained from it. The zone has not been identified on outcrop.

ZONE 5a

Zone 5a, which is 40–70 feet above zone 5, has approximately the same areal extent (2,000 sq mi) and geographic distribution. It consists of 2–4 feet of massive to thin-bedded greenish-gray to brown limy siltstone with green shale partings. Sections south of the town of Green River contain shortite crystals. Some sections north and northwest of the town contain fine-grained sandstone partings. Zone 5a is near the top of sandstone and siltstone unit C (pl. 3).

No surface samples have been analyzed. A core from the extreme northwest corner of the area studied (well 30, pl. 3, section *D–D′*) contains 0.003 percent uranium and 1.01 percent P_2O_5 (tables 2, 6).

ZONE 6

Zone 6 is the oldest zone that has been recognized throughout the 2,500 square miles of the Green River area. Its maximum extent farther west and north is not known. It is about 60 feet above zone 5a in the southern part of the area and 25 feet above it in the northern part. The zone consists of 2–6 feet of dense greenish-brown hard limy siltstone and claystone. Finely macerated plant fragments are abundant in some sections. Fine sand and abundant shortite crystals occur in the northern part of the Green River area. The zone is near the base of sandstone and siltstone unit D (pl. 3).

Zone 6 has not been sampled in detail. Five core samples representing 2 localities average 0.006 percent uranium and 1.5 percent P_2O_5 (tables 2, 6). Gamma ray-neutron logs show zone 6 to be abnormally radioactive in the area extending south and west of Eden for 20 miles. In the vicinity of the Westvaco mine (fig. 11) and farther southwest, it is overlain and underlain by thin trona beds.

ZONE 7

Zone 7, which is present throughout the Green River area, crops out directly below the most conspicuous lithologic and color break in the type section of the Wilkins Peak Member (figs. 5, 9). The zone is near the top of sandstone and siltstone unit D (pl. 3) and is underlain by dark-green ledge-forming sandstone and siltstone. About 15–18 feet above the zone is the base of the white marlstone sequence on Wilkins Peak and White Mountain (pl. 2). Zone 7 is 30–50 feet above zone 6 in the southern part of the Green River area and about 15 feet above it in the northernmost part.

Zone 7 consists of 2–3 feet of dark-green dense hard slightly limy silty claystone in cores and light-green to greenish-gray fissile to blocky soft limy silty claystone on outcrops. The dark-green ledge-forming sandstone and siltstone beds in unit D below zone 7 (directly below those illustrated in fig. 9) show broad channel cut-and-fill features in roadcuts along U.S. Highway 30 east of the town of Green River.

Analytical data are given in tables 2, 4, 6, 16, and 17. The lithium content is higher than that in most zones. The Solvay trona bed of local usage (bed 18, fig. 14), which in places is 14 feet thick, overlies zone 7 in the area north and west of the Westvaco mine (fig. 11).

ZONE 7a

Zone 7a is 10–20 feet above zone 7 and is present north and northwest of Green River (pl. 3, sections *C–C′* and *D–D′*), within an area of about 700 square miles. It consists of 2 feet of pale-green slightly limy claystone with siltstone partings, finely disseminated biotite along some bedding planes, and sparse macerated plant fragments. Shortite crystals are abundant in some sections, and thin trona beds are present in the sequence containing this zone northwest of Green River.

Equivalent uranium is comparable to that in other zones, but uranium and phosphate content appears to be low (tables 2, 6), perhaps because of incomplete sampling. Thin trona beds underlie zone 7a northwest of Green River.

ZONE 8

Zone 8, identified throughout 1,600 square miles, is 30–50 feet above zone 7 and 15–20 feet above zone 7a. Zone 8 becomes sandy and loses its identity in the Eden area (pl. 3, section *C–C′*). Elsewhere, it consists of 2 feet of thin-bedded pale-green fine-grained claystone, shale, and siltstone, with light-gray marlstone partings. Thin oil shale beds are present directly below the zone in many sections. It is within the lower part of sandstone and siltstone unit E (pl. 3). No analyses are available from zone 8, but gamma ray-neutron log characteristics are similar to those in overlying and underlying uraniferous phosphatic zones. It is least radioactive in the northern part of the Green River area.

ZONE 8a

Zone 8a, which is 15–30 feet above zone 8, has approximately the same areal extent (1,000 sq mi) and geographic distribution as zones 3, 4, and 4b. It loses its identity north and northwest of the town of Green River. Zone 8a consists of 2 feet of soft crumbly limy greenish-brown to dark-green claystone that breaks into small conchoidally fractured fragments. Pyrite is common in some sections. The zone is in the upper part of sandstone and siltstone unit E (pl. 3). Analytical data are given in tables 2, 6, and 17.

ZONE 9

Zone 9 is 30–40 feet above zone 8a south of the town of Green River. To the north, where 8a is absent and this part of the Wilkins Peak Member is thinner, zone 9 is only 15–50 feet above zone 8. Zone 9 loses its identity about 20 miles south of Green River, but it is recognized throughout the remaining 1,500 square miles of the area.

The zone consists of 2–6 feet of pale-grayish-green slightly limy claystone which locally contains shortite. In the northern part of the area fine-grained sandstone and siltstone partings and small flakes of biotite are present. A thin white tuff is 5–10 feet below zone 9 in some sections. The zone is within sandstone and siltstone unit F (pl. 3). Analytical data are given in tables 2, 4, 6, 16, and 17.

ZONE 9aa

Zone 9aa is 25–60 feet above zone 9, and the interval between them thins northward (pl. 3, section *C–C′*) The zone is discontinuous but is recognized within an area of about 900 square miles north of the town of Green River; it consists of about 2 feet of pale-green soft flaky slightly limy shale. Small pyrite crystals are abundant. The one core sample (well 22, pl. 3, section *C–C′*; table 2) contains <0.001 percent uranium and 0.5 percent P_2O_5; but inasmuch as the top of the core is at the base of the zone, the grade of the main part of the zone is not known.

ZONE 9a

Zone 9a has not been recognized in the same sections as 9aa (pl. 3, section *C–C′*), but is thought to be about 10–20 feet stratigraphically higher. It is 70-80 feet above zone 9 and is known only south and southwest of the town of Green River within an area of about 250 square miles (pl. 3, sections *A–A′* and *B–B′*). It consists of 2 feet of light-green massive slightly pyritic clayey marlstone or marly claystone. One analysis for uranium and phosphate was made (table 2, sample 192), probably of zone 9a. The sample shows no significant amount of uranium, but it contains 3.11 percent phosphate. Zone 9a is in the middle part of sandstone and siltstone unit G (pl. 3, sections *A–A′* and *B–B′*).

ZONE 9b

Zone 9b, which is present both south and north of Green River, is 15 feet above 9a and 25 feet above 9aa. Zone 9b is known in an area of about 500 square miles (pl. 3, sections *A–A′*, *B–B′*, and *C–C′*); it consists of 2 feet of mottled bright-green and brownish-green soft limy claystone. This is 1 of 3 uraniferous phosphatic zones in which ostracodes have been found, and this one contains the smallest specimens. They are abundant and the shells of some have been replaced by pyrite.

Analytical data are given in tables 2, 6, and 17. The highest value of uranium is 0.005 percent, and that of P_2O_5, probably from 9b, is 10.1 percent. It is not known whether the very small size of the ostracodes bears any relationship to this rather unusual chemical environment. Trona bed 19 underlies zone 9b northwest of Green River. The zone is near the top of sandstone and siltstone unit G in the type area of the Wilkins Peak Member (pl. 3, sections *A–A′* and *B–B′*).

ZONE 9c

Zone 9c is 30–45 feet above 9b, where the latter is present, and elsewhere 20–45 feet above 9aa; the intervals between thin northward (pl. 3, section *C–C′*). Zone 9c, recognized only in an area of about 700 square miles north and northwest of the town of Green River, consists of 1–4 feet of greenish-brown to greenish-gray limy claystone with partings of brown oil shale. Crystals of shortite are present in at least one section. No uranium or phosphate analyses were made, but gamma ray-neutron logs indicate that the radioactivity of this zone is comparable to that of 9aa and less than that of 9. Trona bed 20 occurs in the sequence containing this zone northwest of Green River.

ZONE 9d

Zone 9d is a minor zone known only in the subsurface, 30–45 feet above 9c in an area of about 250 square miles north and northwest of Green River (pl. 3, section *C-C′*). Drill cuttings indicate that the zone consists of 1–2 feet of pale-green claystone. No analyses for uranium or phosphate were made, but gamma ray-neutron logs indicate a moderate amount of radioactivity.

ZONE 9e

Zone 9e is 60 feet above 9d and 50–100 feet above 9c. The interval between 9e and 9c diminishes northward (pl. 3, section *C-C′*). Zone 9e has been recognized only in the subsurface and in a 200-square-mile area extending south from Eden for 20 miles. The north and east margins have not been determined. Drill cuttings indicate that the zone consists of 2–4 feet of pale-green claystone and silstone. No analyses for uranium and phosphate were made, but gamma ray-neutron logs show some sections of zone 9e to be moderately radioactive.

ZONE 10

Zone 10 is 180–250 feet above 9b, the next oldest widespread underlying zone (pl. 3) with similar areal distribution. Zone 10 has been identified in surface and subsurface sections in an area of more than 900 square miles, chiefly south and southwest of the town of Green River. The zone consists of 2–3 feet of dark- to pale-green limy soft silty claystone. Some sections contain small clay pellets, sparse poorly preserved ostracodes, and fragments of small mollusk shells. These are the only mollusks observed in the Wilkins Peak Member during this study. Analytical data are given in tables 2, 4, 6, 16, and 17. This zone has the lowest average content of Al_2O_3, Fe_2O_3, FeO, Na_2O, K_2O, and TiO_2 and highest CaO of any that have been analyzed.

In the area 10–15 miles northwest of the town of Green River, trona bed 23, locally known as Upper Big Island (fig. 14), occurs 10-15 feet below zone 10 About 10–30 feet below this bed is the widespread "main tuff" of local usage, and other tuffbeds mentioned in the description of the Wilkins Peak Member. About 5 to 10 feet below the "main tuff" is trona bed 22, locally known as Lower Big Island. The Big Island trona beds are the youngest extensive ones known in the Wilkins Peak Member, and they are exploited at the Stauffer mine (fig. 11). Zone 10 is in the upper part of sandstone and siltstone unit I, the highest one in the type area of the Wilkins Peak Member (pl. 3). About 5 feet above zone 10 in section 7, plate 3, section *A-A′*, is a persistent limy hard fine-grained ledge-forming brown sandstone composed of quartz, feldspar, biotite, muscovite, and green amphibole. This bed is locally useful in determining the position of zone 10 on outcrop.

ZONE 11

Zone 11, which is 10–30 feet above zone 10, does not extend as far south, but is present much farther to the north and northwest (pl. 3). It has been identified within an area of more than 1,200 square miles. The zone consists of 2–4 feet of mottled bright- and pale-green blocky silty claystone. In the northwesternmost part of the area (well 30, pl. 3, section *D-D′*), drill cuttings indicate that the zone contains some oil shale. Shortite crystals are common in the subsurface. Large well-preserved ostracodes are abundant, and in one surface section (loc. L–10, pl. 2 and table 2) they are associated with sparse fish spines. Analyses are given in tables 2, 4, 6, 16, and 17. The zone contains the highest SiO_2 and Fe_2O_3 of any uraniferous phosphatic zone in the Green River area.

ZONE 11aa

Zone 11aa is a minor local zone about 30–40 feet above zone 11, and is limited to an area of about 200 square miles south of Eden (pl. 3, sections *C–C′* and *D–D′*). The zone is 2 feet thick and is moderately to strongly radioactive in some sections. No analyses were made.

ZONE 11a

Zone 11a, which is about 15 feet above 11aa and 40–60 feet above 11, is present both north and south of the town of Green River; it has been recognized in an area of about 700 square miles (pl. 3). The zone consists of 2–3 feet of pale-greenish-gray noncalcareous siltstone and gray soft shale. A core of this interval (pl. 4) has oil-shale partings interbedded with hard gray shale in which shortite crystals are abundant. This section also contains gray claystone pebbles, as much as 1 inch in diameter, with random orientation. Analytical data are given in tables 2, 6, and 17. The barium analysis is higher than that of any other zone in the area.

ZONE 11b

Zone 11b is the youngest radioactive zone in the Wilkins Peak Member. It is 35–50 feet above 11a and 10–50 feet below the top of the member. The areal distribution and stratigraphic position of the zone are shown on plate 3. It has been recognized in an area of about 1,500 square miles. The lithology of the zone has not been studied and no analyses were made.

POSSIBLE URANIFEROUS PHOSPHATIC ZONES IN LANEY SHALE MEMBER AND BRIDGER FORMATION

Radioactive zones 11c and 12 (pls. 3, 4) are in the lower part of the Laney Shale Member. The areal extent of 11c is about 300 square miles and that of 12 is 150 square miles; neither zone was studied and no analyses were made. In the area 20 miles or more west and southwest of Green River, gamma ray-neutron logs indicate several other zones in the lower part of the Laney Shale Member, whose thickness and radioactivity are comparable to those of uraniferous phosphatic zones in the Wilkins Peak Member. South and southwest of Church Buttes (pl. 1, section 1), several radioactive zones are present in the Laney-Bridger transition sequence (pl. 1 section 3). These have not been cored or analyzed.

In the vicinity of locality 3–A, shown on the index map for plate 1, the middle part of the Bridger Formation contains a thin zone of radioactive coaly shale that has lateral continuity for at least 12 miles (Vine and Flege, 1953, p. 8–10). The highest analyses from this zone have 0.007 percent uranium and 1.88 percent phosphate (table 7).

PINE MOUNTAIN AREA

The small Pine Mountain area (figs. 1, 2) is in southwestern Wyoming, about 10 miles east of the southeast margin of the Green River area. During a brief reconnaissance, a geologic map was made (fig. 15), and a single uraniferous phosphatic zone was sampled in 4 localities. This zone, which is recognizable on outcrops in an area of at least 20 square miles, has been identified in gamma ray-neutron logs in the Middle Mountain gas field, 3 miles to the south (pl. 1, section 7). No. descriptions or analyses of uraniferous phosphatic rocks in this area have been published. It is not known whether other zones are present.

STRATIGRAPHY

The Tipton Tongue of the Green River Formation and the transitional strata from the Wilkins Peak Member of the Green River Formation to the Cathedral Bluffs Tongue of the Wasatch Formation are the only stratigraphic units investigated in the Pine Mountain area. Data on these and other rocks are summarized in table 1, and regional relations are shown on plate 1.

The Tipton Tongue, which is about 330 feet thick, consists of gray oil shale and paper shale and some thin lenticular ledge-forming sandstones. It crops out in prominent banded slopes in the northern part of the area.

The transition between variegated fluviatile strata of the Cathedral Bluffs Tongue, typical of the region to the east, and green and brown lacustrine strata of the Wilkins Peak Member, typical of the region to the west, occurs in the Pine Mountain area. This transitional sequence is called Cathedral Bluffs Tongue, however, because the variegated lithology predominates. The tongue is about 1,000 feet thick and of this, 200 feet in the lower part was studied. Unit 6 of the following measured section is the only one containing appreciable quantities of uranium and phosphate:

Section of lower part of Cathedral Bluffs Tongue of Wasatch Formation, SW¼SW¼ sec. 23, T. 13 N., R. 103 W., Pine Mountain area, Sweetwater County, Wyo. (fig. 13; section 2, fig. 15; fig 16; tables 8 and 9)

[Measured by J. D. Love (Beds above unit 8 not measured)]

Cathedral Bluffs Tongue (part):	*Thickness (feet)*
8. Claystone and siltstone, dull red; interbedded with red and tan ledge-forming sandstone	Not measured.
7. Claystone and siltstone, dull red, soft; forms slope	50±
6. Shale, claystone, and siltstone, greenish-gray, soft; forms slope	50±
5. Sandstone, rusty-brown, hard, coarse- to fine-grained, thin-bedded; forms ledges and most prominent dip slope in area. This is the uraniferous phosphatic zone in the Pine Mountain area. Intervals sampled in detail shown on figs. 13 and 16 and in tables 7 and 8. Contact with underlying unit sharp and undulatory	10–20

TABLE 7.—*Uranium and phosphate analyses of a carbonaceous shale and coal zone in the middle part of the Bridger Formation in the Green River basin, Wyoming*

[Samples were collected in 1952 by J. D. Vine and analyzed for uranium (Vine and Flege, 1953, table 1). Phosphate analyses were made in 1962 by H. H. Lipp]

Location	Laboratory No.	Analyses (percent)			Interval Sampled (Inches)	Remarks
		eU	U	P_2O_5		
Sec. 28, T. 13 N., R. 111 W	D74334	0.003	0.001	0.36		Coal.
Sec. 27, T. 13 N., R. 111 W	101063	.002		.55		
Sec. 27, T. 14 N., R. 110 W	D74335	.004	.003	.68	4	Coal, top of zone.
	74336	.007	.002	.10	6	Claystone.
	74337	.003	.004	.59	11	Coal.
	74338	.005	.003	1.88	11	Coal, base of zone.
	74339	.005	.005	1.49		Selected grab sample.
Sec. 32, T. 14 N., R. 109 W	101059	.003		.53		
	101060	.007	.007	.98		
Sec. 33, T. 14 N., R. 110 W	101061	.004	.002	.26	12	
	101062	.002	.003	.13		

Cathedral Bluffs Tongue (part)—Continued

	Thickness (feet)
4. Shale and claystone, gray and grayish-green, soft, fissile to blocky; no oil shales noted; upper 1 in. radioactive and contains 0.01 percent uranium and 3.25 percent P_2O_5	18
3. Siltstone and marlstone, tan to gray, hard, brittle, sandy; grades laterally into analcitic(?) sandstone; weathers to weak chippy ledges	9
2. Claystone, siltstone, and fine-grained sandstone, green, pink, dark-red, and purple, blocky, soft; forms smooth slope above underlying ledge-forming unit	62
1. Sandstone, pink and tan, fine-grained, crossbedded, micaceous, sparkly, analcitic (?)	7
Total thickness of measured part of Cathedral Bluffs Tongue, about	210

The Cathedral Bluffs Tongue is overlain unconformably by the Bishop Conglomerate, which is composed predominantly of boulders of red quartzite and sandstone derived from the Uinta Mountains 10 miles to the south. The age of the Cathedral Bluffs Tongue, discussed in connection with the Green River area, is considered to be transitional between latest early and early middle Eocene. No fossils have been found in the tongue in the Pine Mountain area.

STRUCTURE

Strata shown on figure 15 are folded into the west-trending Red Creek syncline (Schultz, 1920, pl. 1), the limbs of which dip 5°–10°. Structure of the pre-Tertiary rocks is considerably different, for the area lies athwart a major southward extension of the Rock Springs uplift that separates the Green River and Washakie basins. No faulting of significance involves the Tipton and Cathedral Bluffs Tongues.

URANIFEROUS PHOSPHATIC ZONE

One uraniferous phosphatic zone (unit 5, measured section) has been recognized on outcrop in the Pine Mountain area, and it probably correlates with a radioactive zone in subsurface sections in the Middle Mountain gas field (pl. 1, section 7), 3 miles south of the area shown on figure 15. This zone is at least locally the richest in both uranium (0.3 percent) and P_2O_5 (19 percent) known in the Eocene rocks of Wyoming. Four localities were sampled (fig. 15), on the basis of conspicuous radioactivity. In most intervening areas the radioactivity is much less. Three of the four sampled localities are on the margins of extensive dip slopes held up by resistant sandstone and siltstone of the uraniferous phosphatic zone, and thus have been ex-

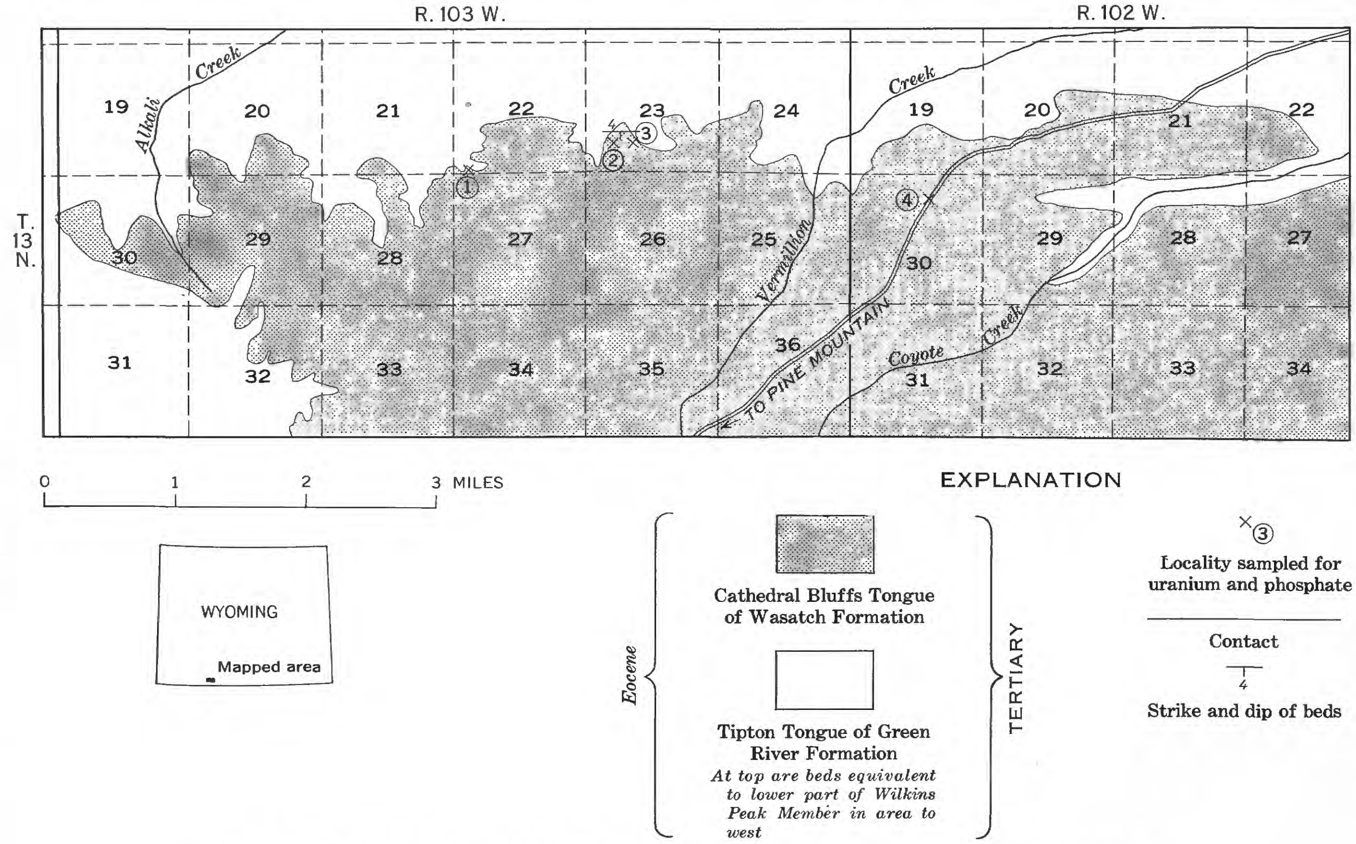


FIGURE 15.—Geologic map of north slope of Pine Mountain showing localities sampled for uranium and phosphate.

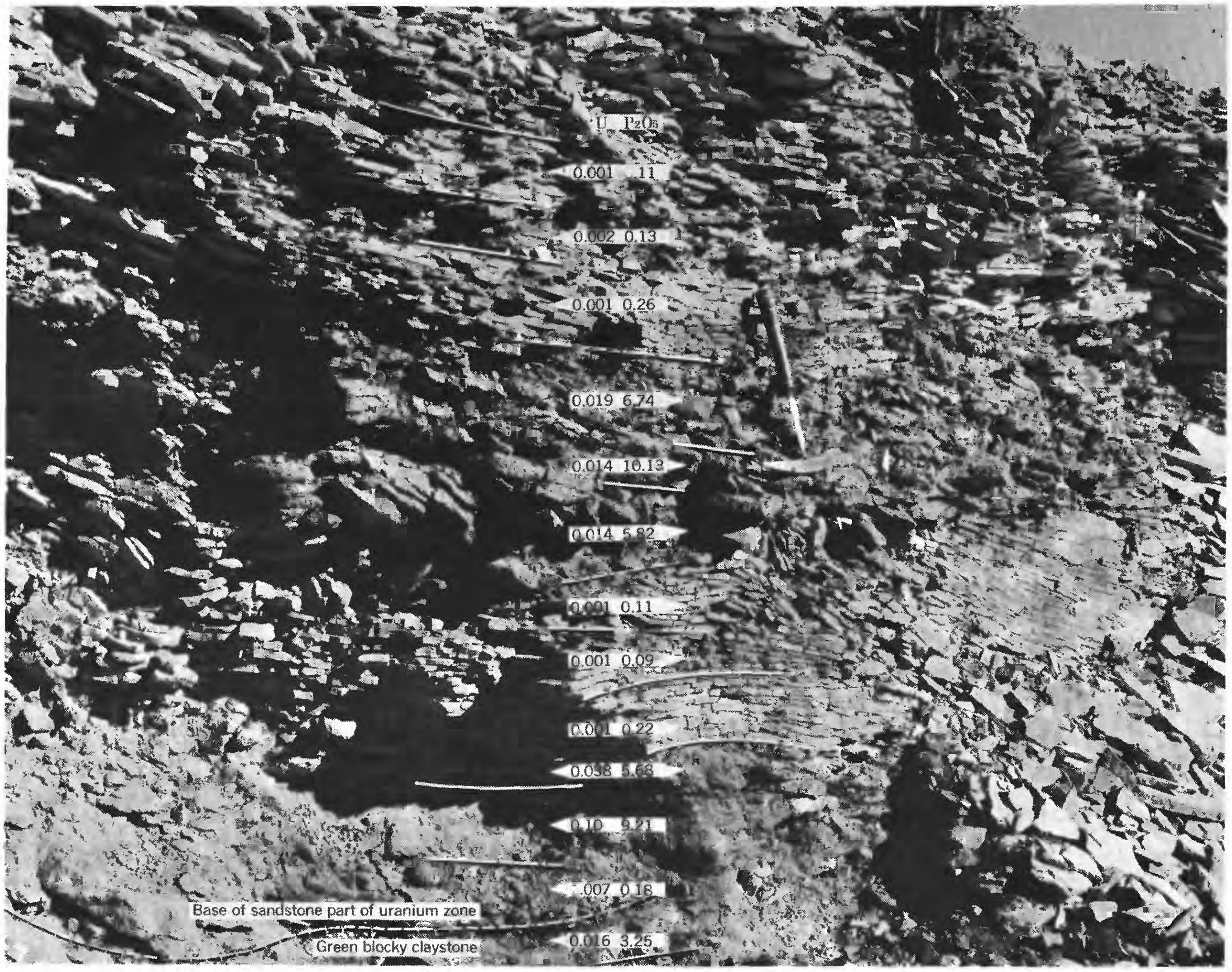


FIGURE 16.—Relation of physical appearance to chemical content, uraniferous phosphatic zone, Pine Mountain area. Rock, except the lowest bed, is sandstone. Prospect pit, NE¼SW¼SW¼ sec. 23, T. 13 N., R. 103 W. (loc. 2).

posed to weathering for a long time; possibly this accounts for the erratic distribution of uranium and phosphate. Zone 1 in the Green River area has a comparable physiographic expression on outcrop, but is stratigraphically lower in the section. The relationship between equivalent uranium and uranium in the two zones is markedly different. In the Pine Mountain area, equivalent uranium is approximately 95 percent of the uranium whereas in the Green River area, uranium is about 80 percent of equivalent uranium.

Uranium and phosphate analyses are shown in table 8, rock analyses in tables 8 and 16, and spectrographic analyses in table 17. The thickest section (4.5 ft) is at locality 2 (figs. 13, 16) where a fresh vertical face in a bulldozer cut was sampled. The beds in this section are somewhat contorted. The reason for this is not known, for adjacent strata are nearly flat and unfaulted. There is some suggestion that uranium and phosphate are concentrated in the contorted parts of the zone. The green soapy-textured dense noncalcareous claystone (sample 14, table 8) directly underlying the sandstone part of the zone contains 0.016 percent uranium and 3.25 percent P_2O_5. These may be secondary concentrations leached from the more porous overlying strata.

The richest parts of the zone in the Pine Mountain area are dark-gray dense siltstone in localities 1 and 4 and yellow coarse-grained arkosic sandstone in localities 2 and 3. The siltstone is dolomitic, slightly petroliferous, and has a mottled appearance caused by oolitic or pseudo-oolitic structures. The sandstone contains angular to subangular pink feldspar and clear quartz grains, is porous, noncalcareous, and has a matrix of limonite-stained yellow claystone and siltstone.

TABLE 8.—*Uranium and phosphate analyses of samples from Cathedral Bluffs Tongue of Wasatch Formation, Pine Mountain area, Wyoming*

[Samples in each locality are arranged in stratigraphic order. Spectrographic analyses are used (but not listed by number) in table 17, and these analyses are plotted graphically on fig. 21. Analysts: L. M. Lee, H. H. Lipp, and E. J. Fennelly]

Sampled section	Locality (fig. 15)	Location	Zone	Sample	Laboratory No.	Analyses (percent) eU	U	P_2O_5	Interval sampled (inches)	Remarks
West Pine Mountain	1	SW cor. sec. 22, T. 13 N., R. 103 W.	1	1	278341	0.034	0.028	19.04	3.0	Rock analysis 1, table 9. Spectrographic analysis 278341.
Pine Mountain	2	NE¼SW¼SW¼ sec. 23, T. 13 N, R. 103 W.	1	2	278359	.002	.001	.11	5.0	Top of sampled part of zone.
				3	278358	.005	.002	.13	2.5	
				4	278357	.003	.001	.26	5.5	
				5	278356	.019	.019	6.74	5.0	
				6	278355	.014	.014	10.13	5.0	
				7	278354	.013	.014	5.82	5.0	
				8	278353	.002	.001	.11	5.0	
				9	278352	.002	.001	.09	4.0	
				10	278351	.003	.001	.22	5.0	
				11	278350	.037	.038	5.68	5.0	
				12	278349	.10	.10	9.21	3.0	Rock analysis 2, table 9. Spectrographic analysis 278349.
				13	278348	.007	.007	.18	3.5	Basal bed of zone.
				14	278347	.016	.016	3.25	1.0	Green claystone.
Pine Mountain east prospect.	3	NW¼SE¼SW¼ sec. 23, T. 13 N., R. 103 W.	1	15	278346	.089	.090	3.38	3.5	Top of sampled part of zone.
				16	278345	.23	.26	8.73	3.5	
				17	278344	.29	.29	11.72	5.0	Rock analysis 3, table 9. Spectrographic analysis 278344.
				18	278343	.12	.14	6.25	3.5	
				19	278342	.11	.11	5.35	3.0	Base of sampled part of zone.
Pine Mountain Road	4	SW¼NW¼NE¼ sec. 30, T. 13 N., R. 102 W.	1	20	278360	.077	.080	17.76	6.0	Rock analysis 4, table 9. Spectrographic analysis 278360.

TABLE 9.—*Rock analyses of outcrop samples, selected on the basis of uranium and phosphate content, from uraniferous phosphatic zones in Pine Mountain, Beaver Divide, and Lysite Mountain areas, Wyoming*

[Location and stratigraphic position of samples are shown in tables 8, 11, and 13]

	Pine Mountain				Beaver Divide	Lysite Mountain				
	1	2	3	4	5	6	7	8	9	10
Laboratory No.	[1] 158073	158075	158074	158076	158077	158079	158081	158080	158078	158082
Zone					SD-3	G	D	A		
eU [2]	0.34	0.10	0.29	0.077	0.016	0.01	0.019	0.02	0.037	0.017
U [2]	0.28	0.10	0.29	0.08	0.042	0.007	0.016	0.023	0.04	0.012
P_2O_5 [2]	19.04	9.21	11.72	17.76	5.67	2.28	3.17	5.18	5.06	5.94
SiO_2	17.4	51.8	47.8	36.8	45.5	54.6	63.2	48.2	6.8	40.7
Al_2O_3	5.3	7.3	6.5	7.7	13.5	15.2	13.0	11.4	1.9	7.5
Fe_2O_3	4.2	3.5	3.4	1.6	3.2	3.8	2.1	3.0	.92	1.3
FeO	1.3	.08	.14	.38	.18	.2	.68	.56	.44	.33
MgO	2.6	.6	.53	.52	2.4	1.4	1.2	1.2	1.5	.5
CaO	31.8	15.4	17.9	24.4	10.9	4.2	5.1	3.0	43.3	22.2
Na_2O	2.2	2.8	2.5	3.0	2.2	.55	4.2	4.3	.71	.44
K_2O	.52	1.1	.99	1.2	4.4	12.3	1.8	.88	.3	5.8
TiO_2	.20	.34	.29	.34	.41	.56	.44	.28	.10	.12
P_2O_5	18.7	9.2	11.0	16.3	6.0	2.8	3.0	4.9	4.9	6.0
MnO	.54	.15	.18	.16	.16	.06	.03	.02	.31	.27
H_2O	4.6	4.0	3.8	3.2	6.2	3.4	3.8	9.9	2.0	2.3
CO_2	8.8	2.9	2.6	2.8	2.5	.58	.5	.18	32.2	11.0
Loss on ignition [3]	13.5	6.8	6.9	6.0	9.6	4.3	4.8	21.1	35.7	13.4
Less H_2O+CO_2	13.4	6.9	6.4	6.0	8.7	4.0	4.3	10.1	34.2	13.3
Organic matter	.1		.5		.9	.3	.5	11	1.5	.1
Total (approx)	98	99	97	98	98	100	100	99	97	99

[1] Rapid rock analyses by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, using methods similar to those described by Shapiro and Brannock (1956).
[2] Splits of each sample analyzed independently for eU, U and P_2O_5 by L. M. Lee, H. H. Lipp, D. L. Ferguson, and E. J. Fennelly.
[3] Samples have significant amounts of organic matter. Ignition loss (at 1,000° C) is given for purpose of summation.

There are also many rounded to irregular-shaped masses of claystone with random orientation, which are as abundant in barren rock as in the most uraniferous phosphatic rock. Dead oil staining and carbonaceous trash are conspicuous. At locality 3 the most barren samples are the finest grained and thinnest bedded.

The 20 analyses from 4 selected localities cannot be considered representative of the Pine Mountain area as a whole. Nevertheless, they are of value in making relative comparisons with samples taken in the same manner from the other three areas in Wyoming. Using the same basic assumptions that were made for the Green River area, all the uranium and phosphate in the entire stratigraphic thickness of the zone as a whole are computed as if they were concentrated in a single bed with averages as follows: Sampled thickness 9.4

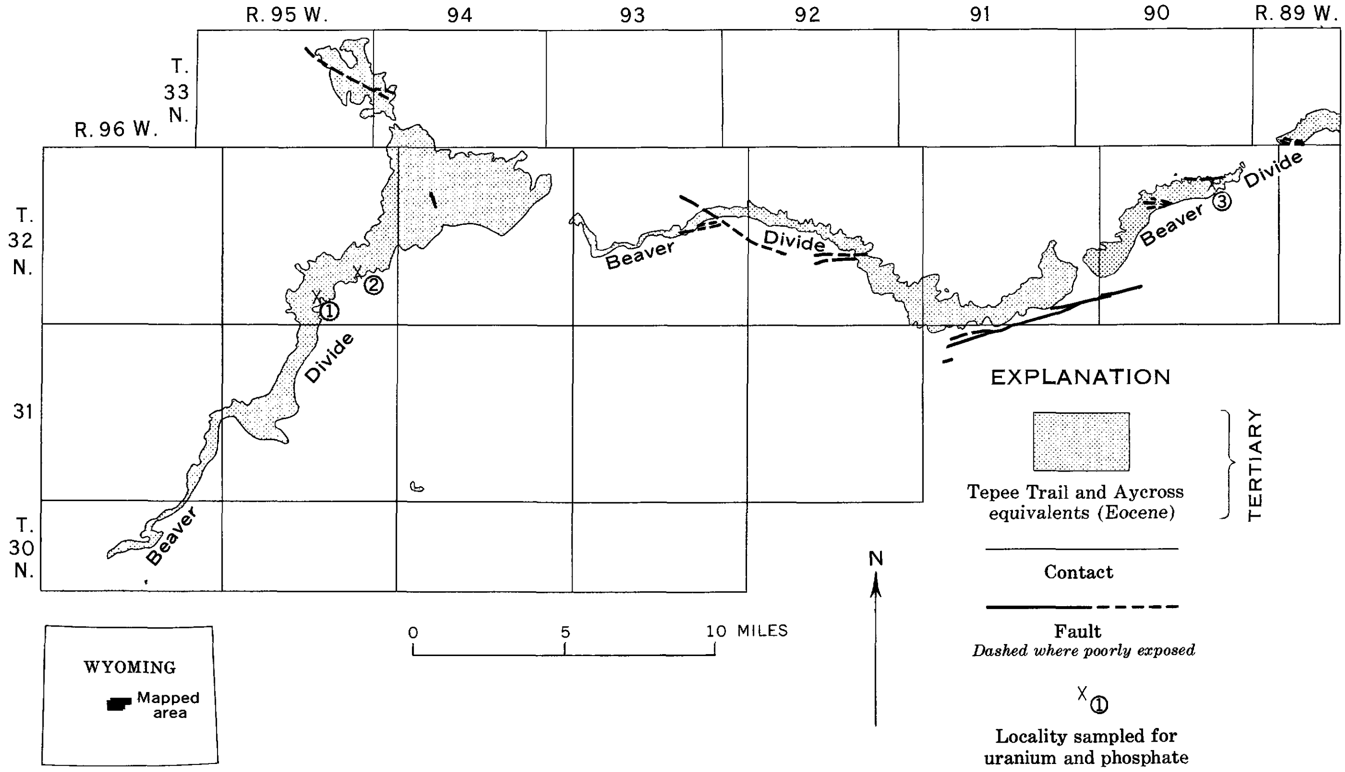


FIGURE 17.—Geologic map showing major outcrops of middle and upper Eocene rocks equivalent to the Aycross and Tepee Trail Formations and localities sampled for uranium and phosphate along the Beaver Divide, central Wyoming. Geology and geography from Van Houten (1954) and Van Houten and Weitz (1956).

inches, uranium content 0.087 percent, P_2O_5 content 8.65 percent, and specific gravity 2.5. If these assumptions are correct, the area would contain 1,470 tons uranium and 146,000 tons phosphate per square mile, compared with 350 tons uranium and 50,000 tons phosphate per square mile for zone 1, the richest of those in the Green River area (table 6). However, as is true for the Green River area, the paucity of samples makes this estimate little better than a guess.

Figures 20 and 21 and tables 16 and 17 compare content of common oxides, and spectrographic data on 27 elements in this zone with those in other areas in Wyoming and with the arbitrary standard, the Pierre Shale. The zone in the Pine Mountain area has a higher MnO and cobalt, and lower MgO and K_2O content than any zone in the Green River area. Boron is absent, whereas it is present in all zones in the Green River area.

BEAVER DIVIDE AREA [5]

The Beaver Divide area (figs. 1, 2; Van Houten, 1954; Van Houten and Weitz, 1956) is in central Wyoming, along the southern margin of the Wind River basin. The data presented here are based on a reconnaissance of two sections in the western part of the area of outcrop of middle and upper Eocene rocks (locs. 1 and 2, fig. 17), and one section in the eastern part (loc. 3, fig. 17). The middle and upper Eocene rocks may include equivalents of the Aycross and Tepee Trail Formations. Five radioactive zones in the Aycross equivalent [6] of middle Eocene age and two in the Tepee Trail equivalent of late Eocene age were sampled; of these seven, five contain significant quantities of phosphate (table 11). No descriptions or analyses of uraniferous phosphatic rocks in this area have been published. Data on the pertinent Tertiary formations are summarized in table 10.

STRATIGRAPHY

ROCKS OF MIDDLE AND LATE EOCENE AGE

AYCROSS EQUIVALENT

Rocks equivalent to the Aycross Formation are present in the lower part of the Beaver Divide escarpment throughout nearly all the area of outcrop of middle and upper Eocene rocks on figure 17. The type locality of the Aycross (Love, 1939, p. 66–73) is 90 to 100 miles northwest, along the northwest margin of the Wind River basin. Van Houten (1950,

[5] Figure 17 in the present report is taken directly from published maps by Van Houten (1954) and Van Houten and Weitz (1956).

[6] Because no contact is shown between the middle and upper Eocene rocks on the geologic maps of the Beaver Divide and Lysite Mountains areas (figs. 22, 20), the Geological Survey refers to these lithic units as "equivalents" rather than as "formations."

1954, 1955) and Van Houten and Weitz (1956) mapped and described these rocks along more than 50 miles of the Beaver Divide and assigned them to an unnamed sequence of middle and late Eocene age.

The lithology and thickness of the Aycross equivalent are summarized in table 10 and in the measured sections along Sand Draw and Sand Draw pipeline roads.

Section of upper part of Aycross equivalent along the Sand Draw road. The lower beds were measured in the steep draw on the west side of the road and the upper beds on the east side, SW¼ NE¼NW¼ sec. 34, T. 32 N., R. 95 W., Fremont County, Wyo.

[Measured by J. D. Love. This section is in the approximate location of section 26 of Van Houten (1950, 1954)]

	Thickness (feet)
White River Formation (part):	
Big Sand Draw Sandstone Lentil (part):	
11. Conglomerate, light gray, soft; composed of rounded fragments of granite and andesitic volcanic rocks	5.0+
Contact between Big Sand Draw Sandstone Lentil and Aycross equivalent. Regional relations described by Van Houten (1954) indicate that this is an unconformity; lowest Oligocene rocks apparently rest on middle Eocene; upper Eocene rocks locally removed by erosion.	
Aycross equivalent:	
10. Siltstone, sandstone, and claystone, pale-yellowish- and bluish-green and brown, very soft; 3 ft hard greenish-brown siliceous siltstone forms ledge in middle of unit; uraniferous phosphatic zone SD-5 is a weakly radioactive 3-in. white to light-gray tuffaceous slightly limy siltstone about 35 ft below the top of the unit; contains 0.006 percent eU. 0.002 percent U, and 1.15 percent P_2O_5 (sample 1, table 11)	44.0
9. Siltstone and sandstone, olive-drab, ferruginous, siliceous, tuffaceous; forms ledge	1.0
8. Sandstone, siltstone, and claystone, pale-green to yellowish-green; crops out in slope broken by weak ledges; uraniferous phosphatic zone SD-4 is a radioactive 2-ft green claystone, 34 ft below the top of the unit; the most radioactive 3 in. contains 0.012 percent eU, 0.009 percent U, and 3.62 percent P_2O_5 (sample 2, table 11)	151.0
7. Siltstone, and silty claystone, greenish-gray, hard, blocky, tuffaeous; forms slope; uraniferous phosphatic zone SD-3 is 6 in. of dark-greenish-brown blocky dense limy siltstone and claystone within this unit; contains 0.016 percent eU, 0.042 percent U, and 5.67 percent P_2O_5 (sample 3, table 11; also rock analysis, table 9)	11.5
Aycross equivalent—Continued	
6. Shale, brown, carbonaceous, thin-bedded, moderately fissile, silty, noncalcareous, slightly petroliferous; finely macerated plant fragments; much secondary jarosite(?); uraniferous phosphatic zone SD-2 is most radioactive 3 in. of this unit and contains 0.008 percent eU, 0.004 percent U, 0.22 percent P_2O_5, and 1.2 gal oil per ton (sample 4, table 11; oil analysis SBR60-325X, table 5)	1.0
5. Siltstone, gray, hard, chippy, tuffaceous; forms slope	26.0
4. Shale, brown, carbonaceous; with 6-in. gray siltstone parting in middle	1.5
3. Siltstone and sandstone, rusty-brown, hard tuffaceous, micaceous; forms conspicuous brown ledge; rusty stain is only on weathered surfaces	12.0
2. Coal and carbonaceous shale, brown; with 6 in. grayish-brown leaf-bearing noncalcareous tuffaceous slightly petroliferous shale and siltstone in middle; uraniferous phosphatic zone SD-1 is most radioactive 3 in. of this unit and contains 0.008 percent eU, 0.007 percent U, and 0.98 percent P_2O_5 (sample 5, table 11)	1.5
1. Siltstone, gray, hard, blocky, tuffaceous	10.0
Total thickness of measured part of Aycross equivalent	259.5
Underlying beds not measured.	

Section of Tepee Trail and Aycross equivalents along Sand Draw pipeline road, NE¼SW¼NE¼ sec. 26, T. 32, N., R. 95 W., Fremont County, Wyo.

[Measured by J. D. Love. This is the locality of section 28 of Van Houten (1954) He shows about 55 feet of strata between the cherty white siltstone (unit 6) and the Beaver Divide Conglomerate Member, whereas this section shows 95 ft. The difference is accounted for by erosion that cut out units 8–11 in 200 yd from east to west before deposition of the conglomerate.]

	Thickness (feet)
White River Formation (part):	
Beaver Divide Conglomerate Member (part):	
12. Conglomerate, gray, hard; forms cliff; composed of rounded fragments of granite and porphyritic andesite as much as 3 ft in diameter but commonly 3 in. or less embedded in a tuffaceous arkosic sandstone matrix	20+
Erosional unconformity; overlying conglomerate deposited on a very irregular surface cut in underlying strata.	
Tepee Trail equivalent:	
11. Siltstone, green, hard, blocky, tuffaceous	16
10. Conglomerate, dull green, soft, arkosic	3
9. Claystone, green, blocky; at base is a 3-in. bed that contains 0.015 percent eU, 0.004 U, and 1.44 percent P_2O_5 (sample 6, table 11). Another sample from this same bed 200 ft west contains 0.004 percent eU, 0.010 percent U, and 3.37 percent P_2O_5 (sample 7, table 11)	3

	Thickness (feet)
Tepee Trail equivalent—Continued	
8. Siltstone, pale-green, sandy, blocky; basal 4 ft radioactive. A 3-in. sample 4 ft above base contains 0.005 percent eU, 0.004 percent U, and 0.63 percent P_2O_5 (sample 8, table 11). A 3-in. sample 2 ft above base contains 0.005 percent eU, 0.003 percent U, and 0.46 percent P_2O_5 (sample 9, table 11). A 3-in. sample at base of unit contains 0.005 percent eU, 0.003 percent U, and 0.45 percent P_2O_5 (sample 10, table 11)	20
7. Siltstone and sandstone, pale-green and gray, soft	53
Total	95
Possible contact between Tepee Trail and Aycross equivalents.	
Aycross equivalent:	
6. Siltstone, tan and white, limy, hard, cherty; forms ledge that weathers with reticulate pattern; can be identified along outcrop for several miles	15
5. Shale and siltstone, gray and gray-green, soft	10
4. Shale, brown, thin-bedded; upper 6 in. has extremely thin lanimae (150 per in.) and looks like oil shale in the Green River Formation of southwestern Wyoming but yields only 2.4 gal oil per ton. X-ray patterns of the white clay between dark organic layers show heulandite and montmorillonite (F. B. Van Houten, written communication, 1960)	3
3. Claystone, green, blocky; a 3-in. bed contains 0.003 percent eU, 0.001 percent U, and 0.50 percent P_2O_5 (sample 11, table 11)	1
2. Siltstone and claystone, pale-green, soft, blocky	11
1. Siltstone, light-greenish-tan, blocky, radioactive throughout; most radioactive 3 in. contains 0.014 percent eU, 0.006 percent U, and 0.14 percent P_2O_5 (sample 12, table 11)	4
Total	44
Lower part of Aycross equivalent not measured.	

Included in the basal part of the Aycross equivalent is a sequence of transition beds (table 10) that ranges in thickness from 25 to 185 feet and consists of unfossiliferous greenish- and grayish-yellow arkosic sandstone and sandy tuffaceous mudstone with a waxy clayey matrix. Van Houten (1954) put these in the underlying Wind River Formation in his stratigraphic charts but, because of poor exposures, included them in the younger sequence on his geologic map east of locality 1, figure 17. Regional relations indicate that the transition beds are more closely allied genetically to the younger rocks in areas south and west of the Beaver Divide.

In the western part of the Beaver Divide area, the volcanic rock fragments in the lower part of the Aycross equivalent consist chiefly of pyroxene andesite; in the middle and upper parts they are of hornblende-biotite andesite. In the eastern part of the area, however, the formation contains a flood of locally derived trachytic debris from volcanoes in the Rattlesnake Hills, about 10 miles east of the area shown on figure 17.

The Aycross equivalent, including the transition beds, ranges in thickness from 230 to 650 feet except where it laps out against high areas of pre-Tertiary rocks.

Some parts of the Aycross equivalent, preserved as remnants on both the northwest and south sides of the Wind River basin, are of lacustrine origin. No oil shales have been found on the northwest side, but a laminated brown shale similar to some in the Green River Formation is present in the Sand Draw pipeline road section (unit 4). Despite the physical appearance of the shale, it has only 2.4 gallons oil per ton. This unit contains the zeolite heulandite (variety clinoptilolite) and montmorillonite (F. B. Van Houten, written commun., 1960; Deffeyes, 1959a). Other beds in this part of the sequence contain erionite ($H_2CaK_2Na_2Al_2Si_6O_{17}\cdot 5H_2O$; Deffeyes, 1959a, p. 508). Although the record of sedimentation during middle Eocene time in the greater part of the Wind River basin has been removed by erosion, it can be inferred by comparison of marginal remnants with the almost completely preserved sequence in the Green River basin and with similar strata in the Lysite Mountain area. Probably during at least some of middle Eocene time, a large part of the Wind River basin was occupied by a lake comparable to Gosiute Lake (Love, McGrew, and Thomas, 1961). The middle Eocene age of the Aycross equivalent is based on vertebrate fossils whose identification and stratigraphic position are shown by Van Houten (1954).

Biotite from a tuff in the lower part of the measured section along Sand Draw road has a potassium-argon age of 45.4 million years (Evernden and others, 1964, sample KA 1018, p. 165, 189). Another biotite sample from a bluish-gray marker ledge at the top of the so-called transition beds between the Aycross equivalent and Wind River Formation has a potassium-argon age of 49.0 million years (Evernden and others, 1964, sample KA 1021, p. 165, 189).

TEPEE TRAIL EQUIVALENT

Rocks equivalent to the Tepee Trail Formation are present in the upper part of the Beaver Divide escarpment along most of the outcrop shown as middle and upper Eocene rocks on figure 17; they are, however,

TABLE 10.—*Summary description and correlation of Tertiary rock sequences in the Beaver Divide and Lysite Mountain areas, Wyoming*

Age			Beaver Divide area: Mappable unit	Beaver Divide area: Lithologic description	Beaver Divide area: Thickness (feet)	Beaver Divide area: Fossils [1]	Lysite Mountain area: Mappable unit	Lysite Mountain area: Lithologic description	Lysite Mountain area: Thickness (feet)	Lysite Mountain area: Fossils [1]
Tertiary	Miocene		Split Rock Formation	Sandstone, gray, coarse- to medium-grained, soft, porous, tuffaceous: contains pyroxene andesite volcanic material; rounded frosted quartz grains; small rounded magnetite grains; many lenticular beds of granitic conglomerate in lower part; sparse beds of limestone, claystone, and pumicite in upper part.	0-1,000+	Mammalian fossils of early Miocene age (Arikareean) in lower sandstones east of area shown on figure 17. Mammalian fossils of middle Miocene age (Hemingfordian) 10-15 miles south of area shown on figure 17. in upper part of sequence.				
			——Unconformity——							
Tertiary	Oligocene		White River Formation	Claystone, siltstone, and sandstone, white to pale-grayish-orange, tuffaceous; contains hornblende andesite volcanic material; massive to thick-bedded; locally contains arkoses and conglomerates with large granite boulders.	160-700	Mammalian fossils of early Oligocene (Chadronian) and middle Oligocene (Orellan) ages.				
Tertiary	Oligocene		White River Formation: Beaver Divide Conglomerate Member	Conglomerate, gray, hard; angular to rounded pebbles, cobbles, and boulders of black, green, red, and gray andesite, basalt, and Precambrian crystalline rocks in a gray tuffaceous matrix; grades laterally into granitic conglomerate.	0-125	Mammalian fossils of early Oligocene age (Chadronian).				
Tertiary	Oligocene		White River Formation: Big Sand Draw Sandstone Lentil	Sandstone, pale-greenish-yellow to yellowish-gray, soft tuffaceous; lenticular conglomerates of small rounded pebbles of Tertiary volcanic rocks and Precambrian crystalline rocks; grades up into Beaver Divide Conglomerate Member.	0-75	Mammalian fossils of earliest Oligocene (early Chadronian) age.				
			——Unconformity——				—Present erosion— surface			
Tertiary	Eocene	Late	Tepee Trail equivalent	Sandstone and siltstone, greenish-yellow to yellowish-gray, massive, siliceous; some lenticular siliceous arkoses; some chert beds; some conglomerates with pyroxene and hornblende andesite pebbles. Local erosional unconformity at base.	0-120	Mammalian fossils of late Eocene (Uintan) age. Unit not present in measured section along Sand Draw road.	Tepee Trail equivalent	Conglomerate, sandstone, siltstone, and claystone, green, brown, and white; contains abundant pyroxene andesite debris from Absaroka Range; thin siliceous limestones near top.	0-650	Mammalian and molluscan fossils of late Eocene (Uintan) age. Lower 200 ft contains uraniferous phosphatic zones E, F, G (table 13), in northwest Lysite Mountain section.
			—?—Local unconformity—				—Unconformity—			
Tertiary	Eocene	Middle		Claystone, siltstone, and sandstone, yellowish-gray to pale-olive, soft; contains hornblende andesite volcanic material; middle and lower parts contan conspicuous green claystone beds; some chert and sandstone beds in upper part; southeast of Big Sand Draw oil and gas field, uppermost 30 ft contains laminated organic paper shale interbedded with heulandite and montmorillonite; widespread marker ledge of siliceous greenish-gray sandstone and limestone at top.	0-180	No mammalian fossils; volcanic material is like that in acidic part of Aycross Formatin in Absaroka Mountains 90 miles to the northwest. Contains uraniferous phosphatic zones SD-4 and SD-5 (table 11) in measured section along Sand Draw road.				
Tertiary	Eocene	Middle		Tuff, tuffaceous siltstone and sandstone, yellowish-orange to yellowish-gray (limonite stained on outcrops), fine-grained; some soft white to light-gray claystone beds; thin coal and carbonaceous shale beds; volcanic material is chiefly biotite hornblende andesite; locally contains heulandite and erionite beds.	110-200	Mammalian fossils of middle Eocene (Bridgerian) age. Contains uraniferous phosphatic zones SD-1, SD-2, and SD-3 (table 11) in measured section along Sand Draw road.		Oil shale, brown, interbedded with felsic tuff, gray and brown carbonaceous paper shale, thin coal beds, analcitized sandstones, and siltstones; thin lenses of silicified algal growths.	0-350	Undiagnostic fish, reptilian molluscan, and plant fossils; lithology is similar to that in Green River Formation. Abundance of volcanic debris, high-grade oil shale (highest analysis about 40 gal per ton oil), and analcite distinguished this se-

TABLE 10.—*Summary description and correlation of Tertiary rock sequences in the Beaver Divide and Lysite Mountain areas, Wyoming*—Continued

Age			Beaver Divide area: Mappable unit	Beaver Divide area: Lithologic description	Beaver Divide area: Thickness (feet)	Beaver Divide area: Fossils [1]	Lysite Mountain area: Mappable unit	Lysite Mountain area: Lithologic description	Lysite Mountain area: Thickness (feet)	Lysite Mountain area: Fossils [1]
Tertiary—Continued	Eocene—Continued		Aycross equivalent	Sandstone, arkosic, and sandy mudstone, light-greenish to yellowish-gray; locally contains boulders 3 ft in diameter; much bentonite and small rounded pyroxene andesite fragments; some brown to gray chert nodules.	0–40	No fossils found.	Aycross(?) equivalent			quence from Tatman Formation, which has none of these features in its nearest outcrops 60 miles to the northwest. Aycross(?) Formation wedges out southward against topographically high areas of pre-Tertiary rocks forming divide between Wind River basin to south and Bighorn basin to north. Sequence contains uraniferous phosphatic zones A, B, C, D (table 13) in measured section along northwest Lysite Mountain.
				Marker ledge, siliceous bluish-green and yellowish-gray mudstone forming persistent ledge along entire Beaver Divide area; some beds of felsic biotite tuff.	10–20	No fossils found. This is basal bed of "middle and upper Eocene rocks" of Van Houten (1950, 1954, 1955).				
				Transition beds, greenish- and grayish-yellow arkosic sandstone and sandy tuffaceous mudstone with a waxy clayey matrix; crops out in fluted cliffs or lumpy hills that support a scattered growth of evergreen trees; some arkosic conglomerates locally present.	25–185	No fossils found. Sequence resembles overlying rocks more closely than underlying rocks; contains several local radioactive zones, but none has abnormally high amount of P_2O_5.				
		—?—	—?—?—?—?—?—?—?—				Angular unconformity			
		Early	Wind River Formation	Arkosic sandstone, sandy siltstone, and claystone, with thin lignite and carbonaceous shale beds; locally variegated, with red, green, gray, and white colors predominating; commonly more conglomeratic in upper part; beds of giant granite boulders locally present near top; three zones of light-gray acidic tuff in upper part north of western segment of Beaver Divide; montmorillonite locally present in matrix.	0–2,500+	Mammalian fossils of late early Eocene (Lost Cabin) age present along western part of Beaver Divide; older rocks present farther north in deep part of Wind River basin.	Absent			
			Angular unconformity				Angular unconformity			
	Paleocene		Fort Union Formation	Sandstone, siltstone, and shale, gray and brown, ferruginous; conglomeratic in lower part, with rounded pebbles of noncalcareous Paleozoic rocks; some coal beds; on some anticlinal noses are one or more local angular unconformities, above which are arkosic sandstones and lenticular conglomerates.	0–1,000+	Mammalian fossils of late middle Paleocene (Tiffanian) age 20 miles south of west end of area and also 60 miles north.	Fort Union(?) Formation	Conglomerate, gray, soft; coarse-grained sandstone matrix; roundstones of noncalcareous hard Mesozoic and Paleozoic rock. Fragments average 1 in. in diameter.	0–20	No fossils found. Lithology similar to that of conglomerate in Fort Union Formation in adjacent areas.
							? ? ? ? ?			
							Absent			
			Angular unconformity				Angular unconformity			

[1] "Arikareean," "Hemingfordian," "Chadronian," "Uintan," "Bridgerian," and "Tiffanian" are provincial age terms used by vertebrate paleontologists (Wood and others, 1941, p. 1–48). The terms have not been adopted by the U.S. Geological Survey.

absent in the southwestern part of the map area and at locality 1. The type area of the Tepee Trail Formation is across the Wind River basin, 100 miles northwest (Love, 1939, p. 73–79). Van Houten (1950, 1954, 1955; Van Houten and Weitz, 1956) mapped and described these rocks and included them in the upper part of an unnamed formation of middle and late Eocene age.

The lithology of the Tepee Trail equivalent is summarized in table 10, and local details are given in the measured section along the Sand Draw pipeline road. The formation ranges in thickness from an eroded edge to 120 feet along the western part of the Beaver Divide and to 300 feet in the eastern part and consists of greenish-yellow siliceous tuffaceous sandstone, conglomerate, siltstone, and claystone. In bulk composition, it is much more mafic than the Aycross equivalent; pyroxene andesite rock fragments are characteristic. Andesite fragments in the western part of the Beaver Divide area were probably derived from the Absaroka Range near the type area of the Tepee Trail Formation; those in the eastern part were locally derived from vents in the Rattlesnake Hills.

Although the Tepee Trail Formation has been entirely removed from the major part of the Wind River basin, the position of remnants and equivalents in the Absaroka Range, Beaver Divide, and along the northeast margin (Tourtelot, 1957), indicate that the basin was completely filled by the end of Tepee Trail sedimentation (Love, 1960, p. 209). The lithology and continuity of many stratigraphic units and the local abundance of fresh-water mollusks indicate lacustrine deposition, even along the basin margins. The uraniferous phosphatic zones are in some of these deposits.

In the western part of the Beaver Divide area, the Tepee Trail equivalent was deposited on an erosion surface that truncates the upper half of the Aycross equivalent. In the eastern part the contact is more obscure and may not everywhere be mappable. An unconformity is present at the top of the formation. Pre-Oligocene erosion removed the entire sequence from the western part of the Beaver Divide area and elsewhere was responsible for marked variations in thickness. The late Eocene age of the Tepee Trail equivalent is based on vertebrate fossils whose identification and stratigraphic position are shown by Van Houten (1954, 1955).

STRUCTURE

The Aycross and Tepee Trail equivalents in the Beaver Divide area have a southward regional tilt and are gently warped locally; dips rarely exceed 5°. Many small and some large normal faults cut the Eocene rocks in the eastern half of the area. The regional structure has been described by Van Houten (1954) and Van Houten and Weitz (1956).

URANIFEROUS PHOSPHATIC ZONES

The transition beds at the base of the Aycross equivalent have above-average radioactivity in both the western and the eastern parts of the Beaver Divide area, but analyses (sample 13, table 11; samples 35 and 36, table 12) show abnormally low contents of phosphate.

The upper half of the Aycross equivalent in the measured section along Sand Draw road contains 5 zones with above-average radioactivity and 4 of these have approximately 1 percent or more phosphate. The lithology of these zones, designated SD–1 to SD–5, is given in the measured section, uranium and phosphate content in table 11, rock analysis of zone SD–3 in tables 9 and 16 and on figure 20, oil analysis of SD–2 in table 5, and spectrographic analysis of SD–3 in table 16 and on figure 21. Two radioactive zones in the upper part of the Aycross equivalent, units 1 and 3 of the measured section along Sand Draw pipeline road, were analyzed for uranium and phosphate. The highest phosphate analysis is 0.5 percent. No correlation of these zones with those in the measured section along Sand Draw road has been established.

The Tepee Trail equivalent in the measured section along the Sand Draw pipeline road contains 2 radioactive zones (units 8, 9). Lithologic descriptions and analyses of these are given in the measured section and in table 11.

The one chemical and spectrographic analysis of zone SD–3 in the Aycross equivalent shows higher SiO_2, Al_2O_3, K_2O, TiO_2, lanthanum, and cerium, and lower FeO, CaO, and CO_2 content than the average for each of the three other areas in Wyoming. This spectrographic analysis is the only one from any zone in Wyoming that contains dysprosium, erbium, and gadolinium. A spectrographic analysis of a nonphosphatic radioactive bed in the upper part of the Tepee Trail equivalent (sample 15, table 12) 5 miles northeast of locality 2 is similar to that of the Aycross equivalent in content of major elements but shows considerable difference in content of minor ones. For example, in the Tepee Trail equivalent, Mg, Y, Cu, Zr, Ba, La, and Yb contents are much lower, Ce, Nd, Th, Dy, Er, and Gd are absent, and B and Mo are higher than in the Aycross equivalent. More analyses are necessary to determine the significance of these differences.

The middle and upper Eocene rocks were investigated in the eastern part of the Beaver Divide area (loc. 3, fig. 17) along the south margin of the Gas Hills uranium district (Zeller and others, 1956). Two samples, one quarter of a mile apart, of a 1-foot radioactive pale-

TABLE 11.—*Uranium and phosphate analyses of samples from Tepee Trail and Aycross equivalents, Beaver Divide area, central Wyoming*

[Samples are arranged in stratigraphic order. Spectrographic analysis is used in table 17 and plotted graphically on fig. 21 (but not listed by number). Analysts: L. M. Lee, H. H. Lipp, D. L. Ferguson]

Measured stratigraphic section	Locality (fig. 17)	Location	Zone	Sample	Laboratory No.	Analyses (percent)			Interval sampled (inches)	Remarks
						eU	U	P_2O_5		
Sand Draw road	1	SW¼NE¼NW¼ sec. 34, T. 32 N., R. 95 W.	SD-5	1	282890	0.006	0.002	1.15	3	Aycross equivalent approx 35 ft below base of Big Sand Draw Sandstone Lentil.
			SD-4	2	290157	.012	.009	3.62	3	79 ft below top of Aycross equivalent.
			SD-3	3	282889	.016	.042	5.67	6	Approx 196 ft below contact between Aycross equivalent and Big Sand Draw Sandstone Lentil. Rock analysis 5, table 9. Spectrographic analysis 282889.
			SD-2	4	88	.008	.004	.22	3	12 ft below sample 3. Contains 1.2 gal oil per ton.
			SD-1	5	87	.008	.007	.98	3	40 ft below sample 4.
Sand Draw pipeline road	2	NE¼SW¼NE¼ sec. 26, T. 32 N., R. 95 W.	--------	6	290150	.015	.004	1.44	3	Tepee Trail equivalent, stratigraphic position of samples 6–12 given in measured section along Sand Draw pipeline road.
				7	49	.004	.010	3.37	3	
				8	51	.005	.004	.63	3	
				9	52	.005	.003	.46	3	
				10	53	.005	.003	.45	3	
				11	54	.003	.001	.50	3	Uppermost zone in Aycross equivalent at this locality.
				12	55	.014	.006	.14	3	
Gas Hills	3	NE¼NW¼ NW¼ sec. 11, T. 32 N., R. 90 W.	--------	13	285744	.003	.001	.05	3	Transition beds near base of Aycross equivalent.
		NE¼NE¼ sec. 10, T. 32 N., R. 90 W.	--------	14	297259	.004	.001	.03	3	Same bed as sample 13 but 1,500 ft SW.
				15	60	.005	.001	.03	3	Aycross equivalent, 175 ft above base.
	N of NE cor. fig. 15.	NW¼SW¼ sec. 17, T. 33 N., R. 89 W.	--------	16	D-99212	.060	.078	.94	6	Ferruginous sandstone in lower part of Aycross equivalent (Love, 1954, table 1 and p. 8).

green claystone in the transition beds in the lower part of the Aycross equivalent contain 0.05 and 0.03 percent P_2O_5 (samples 13 and 14, table 11). About 175 feet higher in the section is a radioactive pale-olive-drab siltstone about 4 feet thick. The most radioactive part contains 0.001 percent uranium and 0.03 percent P_2O_5 (sample 15, table 11). No radioactive strata were found in the overlying 150 feet of Eocene rocks. Five miles northeast of locality 3, just beyond the margin of the area shown on figure 17, a ferruginous sandstone in the lower part of the Aycross equivalent contains 0.07 percent uranium and 0.94 percent P_2O_5 (sample 16, table 11). A stratigraphic section and analyses of samples from this locality have been published (Love, 1954, p. 8 and table 1).

In the northern part of the Wind River basin, between the Beaver Divide and Lysite Mountain areas, are several radioactive zones in downfaulted outcrops of the Tepee Trail Formation. Analyses of some of these are given in table 12. Maximum phosphate content is 1.21 percent.

These widespread occurrences of uraniferous phosphatic zones in middle and upper Eocene rocks along the margins of the Wind River basin suggest that they, and probably many others, were once present in the main part of the basin. No evaporites have been recognized.

LYSITE MOUNTAIN AREA

The Lysite Mountain area (figs. 1, 2) is in north-central Wyoming, along the southeast margin of the Bighorn basin. No detailed study of the stratigraphy of the area was made, and the geologic map (fig. 18) is very generalized. Three sections of the Tertiary strata were measured and two were sampled for uranium and phosphate. Seven uraniferous phosphatic zones were sampled in the section along the northwest escarpment of Lysite Mountain (see measured section; loc. 1, figs. 18, 19), 4 at locality 4, 3 at locality 5, and 1–3 zones in 2 other localities (table 13). The areal extent of these zones has not been determined. No descriptions or analyses of uraniferous phosphatic rocks in this area have been published.

STRATIGRAPHY

The Aycross(?) and Tepee Trail equivalents contain uraniferous phosphatic zones in the Lysite Mountain area. Generalized descriptions of these and underlying rocks are given in table 10 and details are in the measured section.

ROCKS OF MIDDLE AND LATE EOCENE AGE

AYCROSS(?) EQUIVALENT

The Aycross(?) equivalent comprises a sequence of oil shale, coal, and finely tuffaceous lacustrine beds

TABLE 12.—*Uranium and phosphate content of radioactive and nonradioactive beds in formations of Paleozoic, Mesozoic, and Cenozoic ages in Wyoming, for comparison with that of uraniferous phosphatic zones in middle and upper Eocene lacustrine strata shown in tables 2, 7, 9, 11, 13, 14, and 15*

[Samples are arranged in stratigraphic order. Analysts: G. T. Burrow, E. J. Fennelly, D. L. Ferguson, L. M. Lee, H. H. Lipp, and Wayne Mountjoy]

Formation and age	Location	Sample	Laboratory No.	Analyses (percent)			Interval sampled (inches)	Remarks
				eU	U	P_2O_5		
Pleistocene	NE¼SE¼ sec. 32, T. 39 N., R. 116 W.	1	276868	0.07	<0.001	<0.03	1	Radium-bearing hot spring deposit.
Late Pliocene	NW¼NW¼NE¼ sec. 5, T. 30 N., R. 87 W.	2	270196	.023	.018	.16	3	Thorium-bearing limestone.
Moonstone, early or middle Pliocene	SW¼SE¼ sec. 24, T. 30 N., R. 90 W.	3	99513	.028	.023	.23	3	Largest thorium-bearing limestone mass in area.
	NE¼NE¼NW¼ sec. 25, T. 30 N., R. 90 W.	4	99514	.024	.001	.15	3	Farthest west thorium-bearing limestone.
	NW¼NW¼SW¼ sec. 19, T. 30 N., R. 89 W.	5	99516	.011	.013	.10	3	White shale.
	SW¼SE¼ sec. 24, T. 30 N., R. 90 W.	6	99520	.034	.007	.18	3	Same locality and horizon as sample 3.
	NW¼NW¼SW¼ sec. 19, T. 30 N., R. 89 W.	7	285751	.007	.005	.15	3	Radioactive white limestone 7 ft above dark-gray tuff marker bed.
	SW¼NW¼ sec. 19, T. 30 N., R. 89 W.	8	276866	.020	.020	.03	3	Type area of the Moonstone Formation.
		9	276867	.014	.014	<.03	3	200 yd west of sample 8 same horizon.
Middle or late Miocene	SW¼NW¼ sec. 26, T. 18 N., R. 84 W.	10	276873	.006	.005	<.03	3	17 ft above sample 11.
		11	276872	.014	.017	<.03	3	Organic shale with abundant pollen.
Lower part of White River, early Oligocene.	Sec. 14, T. 32 N., R. 93 W.	12	286430	.001	<.001	.10	2	Calcareous chert.
Tepee Trail equivalent, late Eocene.	SE cor. sec. 3, T. 39 N., R. 92 W.	13	203459	.59	.80	1.21	12	1 ft claystone.
	Sec. 27, T. 40 N., R. 92 W.	14	206976	.58	.58	.69	12	1 ft channel from conglomerate.
	SW¼SE¼ sec. 6, T. 32 N., R. 94 W.	15	239489	.11	.10	.16	12	200 yd northwest of Asbell triangulation station.
	NE¼ sec. 4, T. 43 N., R. 104 W.	16	292306	.004	.002	.25	3	Top 3 in. of radioactive part of coaly zone, 650 ft above base of section at type locality of Tepee Trail Formation.
		17	292307	.016	.010	.13	3	Directly below 16.
		18	292308	.017	.012	.05	3	Directly below 17.
		19	292309	.009	.006	<.05	3	Shiny laminated coal; directly below sample 18.
		20	292310	.012	.010	.16	3	Directly below and similar in lithology to 19.
		21	292311	.022	.022	.11	2	Peacock and yellow secondary stains on laminated coal; directly below sample 20.
		22	292312	.003	.001	.13	2	Bottom 2 in. of zone sampled; carbonaceous siltstone directly below sample 21.
Tepee Trail, type section, late Eocene.	NE¼SE¼ sec. 4, T. 43 N., R. 104 W.	23	292303	.013	.010	.14	3	Top 3 in. of zone sampled; tan sandstone 250 ft above base of section in type area of Tepee Trail Formation.
		24	292304	.033	.050	.28	1	Lenticular coal; directly below sample 23.
		25	292305	.009	.005	.12	3	Bottom 3 in. of zone sampled; tan sandstone directly below sample 24.
Tepee Trail, late Eocene	NE¼ sec. 3, T. 39 N., R. 92 W.	26	297264	.34	.10	.15	3	Arkosic sandstone 60 ft below surface, Shoni pit.
		27	297263	.15	.14	.07	3	Gray claystone 80 ft below surface, Shoni pit.
		28	297262	.008	.005	.07	3	Gray claystone 90 ft below surface, Shoni pit.
		29	297261	.16	.17	.03	3	Arkose 100 ft below surface, Shoni pit.
	NE¼SW¼SE¼ sec. 27, T. 40 N., R. 92 W.	30	297265	.51	.78	.05	12	Arkose, average uranium ore, Hilmer-Cummings mine.
		31	297266	29.5	31.6	.62	3	High-grade ore, Hilmer-Cummings mine.
Tepee Trail(?) equivalent, late(?) Eocene.	NW¼SE¼ sec. 6, T. 45 N., R. 100 W.	32	292315	.003	.001	.16	----------	White bentonitic tuff.
	NW¼SE¼ sec. 35, T. 45 N., R. 101 W.	33	286415	.001	<.001	.56	1	12.3 gal oil per ton.
Aycross equivalent, middle Eocene.	SE¼NW¼SE¼ sec. 35, T. 31 N., R. 96 W.	34	285748	.010	.009	.07	2	62 ft below contact between Aycross equivalent and White River Formation.
		35	285749	.005	.004	.08	2	Transition beds, approximately 60 ft above base of Aycross equivalent.
		36	285750	.007	.005	.15	2	4 ft above contact between Aycross equivalent and Wind River Formation in transition beds.
Aycross, type section, middle Eocene.	SW¼ sec. 5, T. 7 N., R. 5 W.	37	292295	.013	.008	<.05	24	Gray plastic claystone.
		38	292296	.015	.013	<.05	3	Same bed as sample, 37, 300 ft to northeast.
	NE¼ sec. 7, T. 7 N., R. 5 W.	39	292297	.003	.004	.24	3	Top 3 in. of zone, 100 ft above base of type section, Aycross Formation.
		40	292298	.028	.030	.26	3	Directly below sample 39.
		41	292299	.14	.17	.09	1	Carbonaceous shale directly below sample 40.
		42	292300	.010	.012	.14	3	Directly below sample 41.
		43	292301	.005	.005	.18	3	Bottom 3 in. of zone sampled; directly below sample 42.
		44	292302	.004	.006	<.05	3	Part of 2 ft wavy carbonaceous claystone supporting dense growth of selenium indicator plants.
Aycross, middle Eocene	SE¼NW¼ sec. 16, T. 43 N., R. 100 W.	45	292313	.006	.004	.13	3	Lower middle part of 6 ft coal and carbonaceous shale 200 ft above base of exposures.
Aycross(?) equivalent, middle(?) Eocene.	sec. 33, T. 40 N., R. 94 W.	46	292316	.003	.003	<.05	3	Carbonaceous bed in variegated claystone sequence.

TABLE 12.—*Uranium and phosphate content of radioactive and nonradioactive beds in formations of Paleozoic, Mesozoic, and Cenozoic ages in Wyoming, for comparison with that of uraniferous phosphatic zones in middle and upper Eocene lacustrine strata shown in tables 2, 7, 9, 11, 13, 14, and 15*—Continued

Formation and age	Location	Sample	Laboratory No.	Analyses (percent)			Interval sampled (inches)	Remarks
				eU	U	P_2O_5		
Aycross equivalent or Wind River.	Center sec. 27, T. 33 N., R. 89 W.	47	D-99211	0.078	0.062	0.16	12	Carbonaceous shale with flora (Van Houten, 1955, p. 5-6); possibly transition beds between the two formations (Love, 1954, table 1 and p. 9).
Tatman, early Eocene	Center north line NW¼SW¼ sec. 3, T. 45 N., R. 100 W.	48	292314	.002	.001	<.05	3	Coaly shale 50 ft above top of Willwood Formation.
	NW¼SW¼SE¼ sec. 23, T. 48 N., R. 98 W.	49	282877	.003	.002	<.05	6	Tatman Formation on Squaw Teats.
Wind River, early Eocene	SW¼SE¼NE¼ sec. 22, T. 4 N., R. 3 W.	50	285745	.003	.001	.09	2	9 ft below top of Wind River Formation, Crowheart Butte.
		51	285746	.002	.001	.09	3	18 ft below sample 50 Crowheart Butte.
		52	285747	.004	.002	.11	3	25 ft below sample 51, Crowheart Butte.
	NW¼NE¼ sec. 10, T. 42 N., R. 108 W.	53	292291	.16	.18	.06	3	Fossil leaf bed (Keefer, 1957, p. 191).
	Center NW¼ sec. 6, T. 42 N., R. 107 W.	54	292294	.003	.003	<.05	3	Claystone 1 ft above 10 ft coal and carbonaceous shale.
		55	292293	.004	.003	.34	3	Red claystone 120 ft below sample 54.
		56	292292	.015	.015	<.05	3	Red claystone 6 ft below sample 55.
	SW¼SW¼ sec. 5, T. 38 N., R. 93 W.	57	292317	.003	.001	.13	2	Gray leaf-bearing shale in Lost Cabin Member ((Tourtelot, 1946, loc. 5).
	SW¼SW¼ sec. 31, T. 35 N., R. 85 W.	58	290147	.009	.009	.06	2	Black plastic claystone in Lost Cabin Member.
	SW cor. NW¼SE¼ sec. 11, T. 34 N., R. 85 W.	59	290148	.004	.005	.09	3	Carbonaceous shale in Lost Cabin Member.
Tipton Tongue of Green River Formation, late early Eocene	Center sec. 17, T. 24 N., R. 95 W.	60	287284	<.001	<.001	.11	3	Limestone in lower part of Tipton Tongue.
Luman Tongue of Green River Formation, early Eocene	NE¼NE¼ sec. 18, T. 15 N., R. 105 W.	61	286004	<.001	.0003	.24	3	Fetid limestone in upper part of Luman Tongue.
	SE¼NE¼ sec. 6, T. 22 N., R. 94 W.	62	287285	.001	<.001	.21	3	Basal limestone in Luman Tongue.
Red Desert Tongue of Wasatch Formation, early Eocene	NE¼SE¼ sec. 22, T. 20 N., R. 95 W.	63	287283	.002	.003	.46	3	Limestone 200 ft below top of tongue.
Hoback (Dorr, 1952), Paleocene.	NE¼NW¼ sec. 28, T. 38 N., R. 113 W.	64	238863	.011	.012	.39	6	Carbonaceous shale, type section.
		65	238864	.009	.012	.13	6	Do.
Cody, Lake Cretaceous	SE¼SE¼ sec. 20, T. 28 N., R. 90 W.	66	292326	.050	.010	<.05	3	Cody Shale directly below Precambrian granite thrust plate.
Phosphoria, Permian	NE¼SW¼ sec. 15, T. 41 N., R. 116 W.	67	297271	.008	.006	26.9	18	Oolitic phosphate bed.
		68	297269	.008	.005	35.1	15	Oolitic phosphate bed 26 ft below sample 67.
		69	297270	.005	.004	25.2	18	Oolitic phosphate bed 10 ft below sample 68.
	SW¼ sec. 21, T. 32 N., R. 118 W.	70	297272	.017	.017	24.0	3	Black shale in vanadiferous zone.
Rocks equivalent to the upper part of Mission Canyon Limestone, Late Mississippian	NW¼ sec. 2, T. 38 N., R. 115 W.	71	276871	.003	.001	<.03	3	Black shale above anhydrite.
Darby, Middle and Late Devonian	Sec. 22, T. 43 N., R. 118 W.	72	276869	.003	<.001	<.03	3	Type area of Darby Formation.
		73	276870	.004	.001	<.03	3	3 ft below sample 72.

lying unconformably on Paleocene, Cretaceous, and older rocks and overlain unconformably by strata of late Eocene age along the north-facing escarpment of Lysite Mountain. The Aycross(?) equivalent was deposited on a surface of high relief cut in Mesozoic and Paleozoic rocks on the north side of the structural uplift that connects the Owl Creek and Bighorn Mountains (fig. 2). No outcrops of the Aycross(?) equivalent have been identified with certainty on the south (Wind River basin) side of this uplift. As the Tertiary deposits have been stripped from all but the eastern end of the north flank of the Owl Creek Mountains and from the west flank of the Bighorn Mountains northeast of Lysite Mountain, there is no specific information as to the former areal extent of the Aycross(?) equivalent in this part of the Bighorn basin.

Because of the unconformities at the base and top, the thickness of the Aycross(?) equivalent is variable, commonly ranging from 200 to 350 feet. The measured section shows details of lithology at locality 1 (figs. 18, 19).

Section of Tepee Trail and Aycross(?) equivalents on northwest escarpment of Lysite Mountain, sec. 20, T. 42 N., R. 90 W.

[Measured with planetable, tape, and Brunton compass by J. D. Love, H. A. Tourtelot, and C. O. Johnson; petrography by H. A. Tourtelot. Strata are nearly horizontal. Some units have considerable lateral continuity and are sufficiently distinctive to permit local use as marker beds, whereas others are highly lenticular. Several erosional unconformities are present and sections measured as little as 100 ft apart may differ in detail in intervals between marker beds]

	Thickness (feet)
Tepee Trail equivalent (part):	
53. Conglomerate, sandstone, and claystone, dark- to light-green (weathering brown), very tuffaceous throughout; sparse greenish-white fine-grained beds; unit forms precipitous cliffs at top of scarp	150

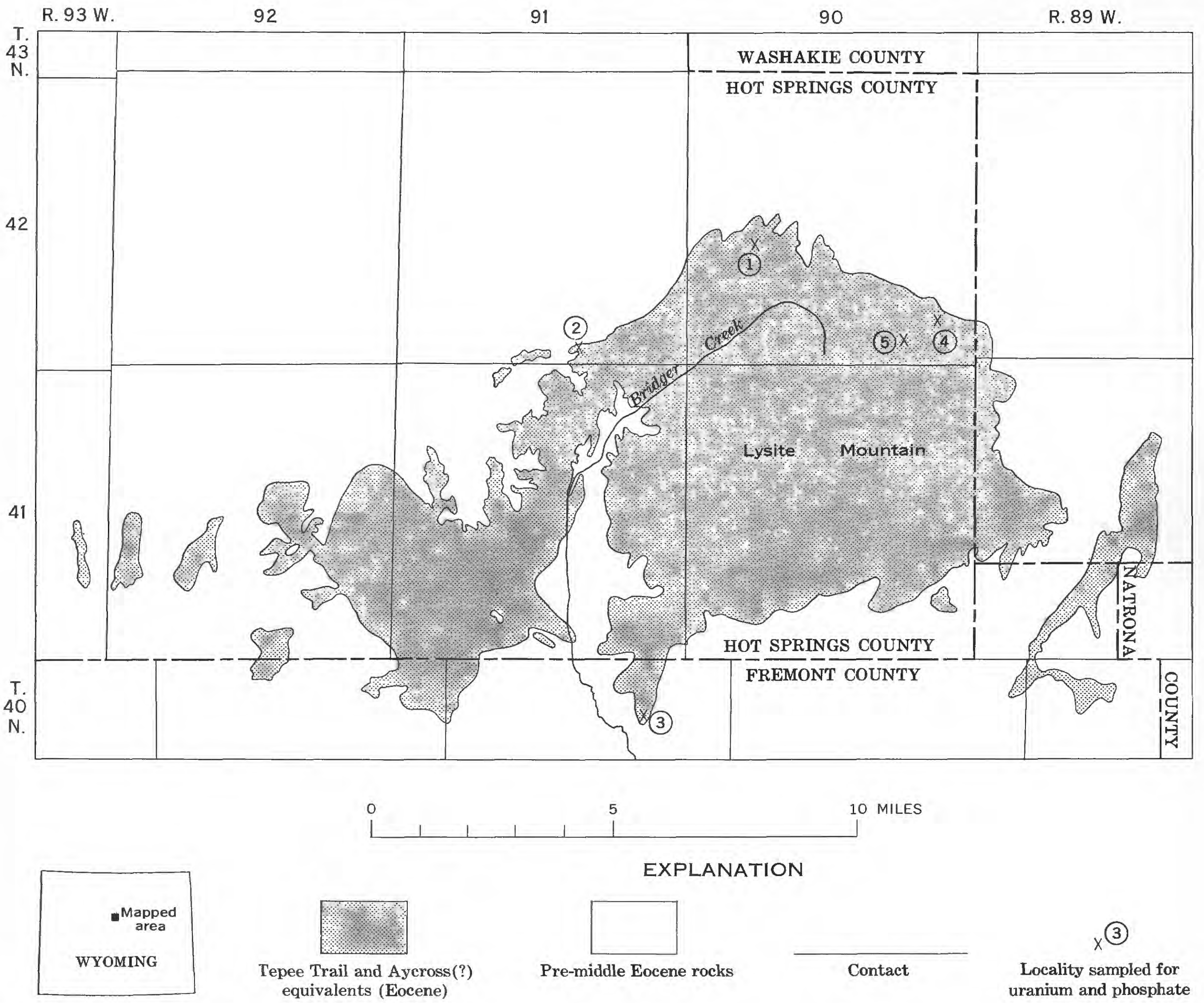


FIGURE 18.—Geologic map of Lysite Mountain area showing localities sampled for uranium and phosphate. Geology from published and unpublished maps by J. D. Love and H. A. Tourtelot.

Tepee Trail equivalent (part)—Continued — *Thickness (feet)*

52. Sandstone, light-orange-brown to brown, highly tuffaceous, coarse- to fine-grained; with lenses of conglomerate consisting of same type of material as matrix, plus rounded fragments of weathered very fine grained tuff and tuffaceous claystone; basal contact is sharp and irregular with as much as 10 ft of local relief — 20–30
51. Sandstone, siltstone, and claystone, dark-green, highly tuffaceous; forms slope interrupted by weak ledges; uraniferous phosphatic zone G is 30 ft below top of unit. A 3-in. section of nodular greenish-tan slightly limy siltstone comprising the most radioactive part of the zone contains 0.01 percent eU, 0.007 percent U, and 2.28 percent P_2O_5 (sample 1, table 13) — 40

Tepee Trail equivalent (part)—Continued — *Thickness (feet)*

50. Sandstone, conglomerate, siltstone, and claystone, green to tan, highly tuffaceous; conglomerate has many fragments of tuffaceous claystone and siltstone; basal contact sharp with as much as 50 ft of erosional relief in a horizontal distance of 150 ft — 15–55
    Thin section Wyo 56: 7 ft above base; lithic tuff contains fragments of labradorite, colorless pyroxene, green biotite, sparse red biotite.
    Thin section Wyo 55: 5 ft above base; crystal tuff contains labradorite, green hornblende, brown biotite, sparse sanidine, and quartz.
49. Siltstone, claystone, and thin sandstone, pale-green and gray (weathering rusty drab); forms slope; exposed in an intraformational erosion remnant whose margins were scoured

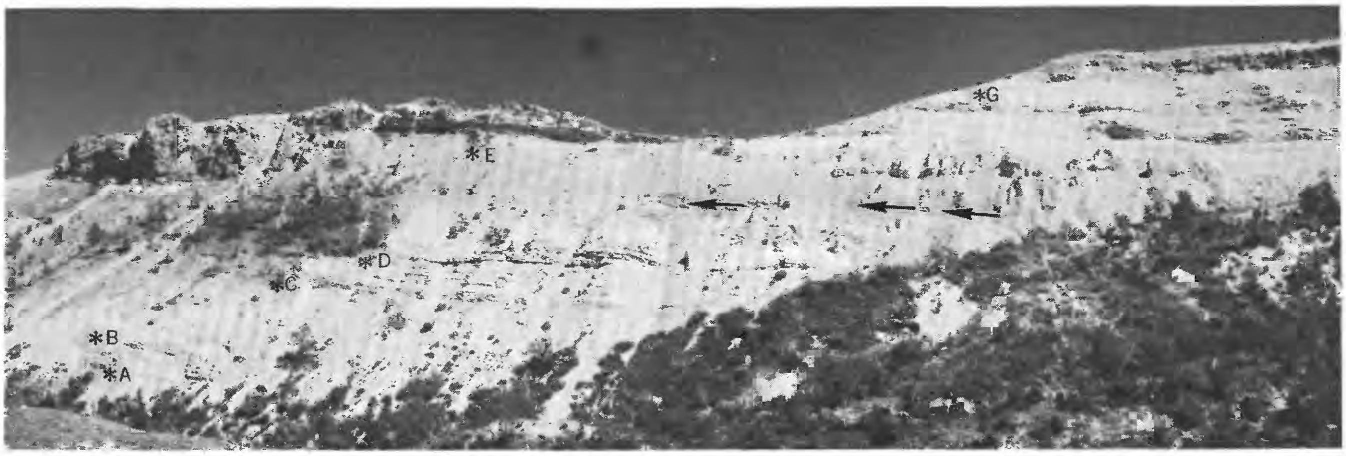


FIGURE 19.—Tepee Trail and Aycross(?) equivalents on Lysite Mountain. Contact is marked by arrows. Asterisks and letters indicate uraniferous phosphatic zones at localities where samples listed in table 13 were taken. Stratigraphic section in text was measured from lower left to upper right. Escarpment is in sec. 20, T. 42 N., R. 90 W., and is 700 feet high.

Tepee Trail equivalent (part)—Continued — *Thickness (feet)*

before deposition of unit 50; significance of erosional break not known 30

48. Coal, black, shiny to dull 2
47. Shale, gray, carbonaceous, hard, very fissile; contains abundant poorly preserved plant fragments 2
46. Siltstone, claystone, and sandstone, light-gray tuffaceous, nodular, soft; appears earthy on weathered surface; some green layers; lower part contains slightly calcareous oolites, many of which are soft and have hollow centers, in contrast with hard oolites in underlying rocks; upper part contains dark-green siliceous banded beds forming local cliffs and ledges (fig. 19); uraniferous phosphatic zone F is in ledge near top of unit and 7 ft above a green pelletal siltstone bed. A 2-in. zone of green siliceous sandy limy siltstone contains 0.009 percent eU, 0.002 percent U, and 2.90 percent P_2O_5 (sample 2, table 13); uraniferous phosphatic zone E is 5 ft below a green pelletal siltstone and 22 ft below zone F, in lower part of unit 46, and consists of 3 ft of dark-brown hard blocky dense noncalcareous carbonaceous siltstone in a bed with considerable lateral continuity. It contains numerous finely macerated plant fragments and fish bones. A 3-in. section of the most radioactive part contains 0.009 percent eU, 0.005 percent U, and 2.52 percent P_2O_5 (sample 3, table 13) 40

    Thin section Wyo 51: 8 ft below top of unit; very fine grained tuff consisting principally of idiomorphic analcite crystals in a calcareous clayey matrix; many grains of feldspar; sparse small quartz grains; unidentifiable ferromagnesian minerals.

    Thin section Wyo 53: near top of unit; crystal tuff with matrix of opal and chalcedony; sanidine and quartz, both with undulatory extinction; sparse plagioclase, possibly andesine.

Tepee Trail equivalent (part)—Continued — *Thickness (feet)*

    Thin section Wyo 54: Ledge in upper part of unit; coarse-grained tuffaceous sandstone, a hypersthene hornblende andesite tuff; contains labradorite, hypersthene, green and brown hornblende, and biotite.

    Thin section Wyo 52: Analcite tuff near base of unit 46; about 85 percent analcite, with some sanidine, plagioclase, and quartz in a green clayey matrix.

45. Sandstone and conglomerate, brown to olive-drab on weathered surfaces, green on fresh, highly tuffaceous; conglomerate contains angular fragments of tuffaceous sandstone; many nodules of green and black chert 1–2 in. long; unit weathers to castellated cliffs in places and to smooth slopes in others; grain size and amount of induration vary greatly in lateral distances of 200 ft 60–90

    Thin section Wyo 50: Pyroxene andesite tuff about 20 ft above base of unit 45; contains pyroxene, labradorite, glass, sparse quartz, and analcite crystals.

Thickness of measured part of Tepee Trail equivalent 359–439

Contact between Tepee Trail and Aycross(?) equivalents is marked by an erosional and possibly slight local angular unconformity.

Aycross(?) equivalent: — *Thickness (feet)*

44. Pelletal analcitic siltstone, bright-green, soft; cut out in places by erosional unconformity at top of Aycross(?) 0–10
43. Shale, siltstone, and sandstone; shale and siltstone are dark brown (weathering gray), carbonaceous, tuffaceous, platy; sandstone is buff, nodular, highly tuffaceous; unit crops out in ragged cliff 0–50
42. Sandstone, gray to dark-brown, fine-grained, tuffaceous, silty and clayey; analcite and pellets near base; contains fragments of gastropods and *Unio* shells; basal contact gradational 1. 1

Aycross (?) equivalent—Continued	Thickness (feet)
Thin section Wyo 49: tuffaceous siltstone with much organic matter; contains sparse labradorite, sanidine, biotite, quartz, enstatite(?), and secondary calcite, analcite masses, opal, and pyrite.	
41. Sandstone and siltstone, gray, very fine grained, probably tuffaceous; thin uneven bedding; contains *Unio* shell fragments near top	1.0
40. Sandstone, dark-brown (weathers white), petroliferous, fine-grained, tuffaceous, massive, blocky; many analcitic or pelletal layers; a sandy coal 2 in. thick at base and a thin coal lens near middle	4.2
39. Mudstone, dark-brown (weathers white), laminated but not fissile; sandy tuffaceous beds; nodular dark shale beds; two fine-grained soft sandstone beds in upper foot	3.4
38. Mudstone, dark-brown (weathers white), laminated but not fissile, fine-grained, petroliferous; large *Unio* shells and small low-spired gastropods	3.0
37. Sandstone and analcite or pelletal beds, white, fine-grained, clayey, ferruginous	1.1
36. Siltstone, brown, hard, well-bedded, nonfissile, noncalcareous, blocky, analcitic or pelletal; contains lenticular beds of sandy ferruginous rock; uraniferous phosphatic zone D is the most radioactive 3 in. and contains 0.019 percent eU, 0.016 percent U, and 3.17 percent P_2O_5 (sample 4, table 13)	2.6
35. Sandstone, brown, hard, fine-grained, tuffaceous	.4
34. Mudstone, dark-brown; some pellets; abundant analcite aggregates; hard, weakly fissile; fish spines and plates	.6
33. Coal, black, dull, grading up to carbonaceous shale	.4
32. Sandstone and mudstone, brown, tuffaceous, carbonaceous, gypsiferous, hard, moderately massive; some lenses of coal	1.6
31. Sandstone, dark-green to pale-brown, highly tuffaceous, fine- to medium-grained, massive; some ganoid scales; interbedded with organic shales and siltstones. Sample of organic shale 14 ft above base contains 10.3 gal oil per ton (U.S. Bur. Mines analysis SBR60–323X)	40.0±
30. Mudstone, dark-brown, carbonaceous, with 0.1 ft coal 0.8 ft above base; grades up to fine-grained white tuff with ferruginous staining; tiny pellets or analcite clusters in brown strata	1.6
29. Sandstone and quartzite, gray-brown, tuffaceous, hard, medium-grained, carbonaceous	.9
28. Mudstone, dark-brown, calcareous, well-bedded, very hard, fine-grained, blocky; petroliferous odor; some light-gray flecks and spots; abundant fish bones and plates. Sample of 6-in. zone contains 6.3 gal oil per ton (U.S. Bur. Mines analysis SBR60–324X, table 5); uraniferous phosphatic zone C is most radioactive 2 in. and contains 0.008 percent eU 0.006 percent U, and 1.11 percent P_2O_5 (sample 5, table 13)	1–2
Thin section Wyo 48: Analcite rock, consisting of subhedral to eudedral analcite crystals in a fine-grained clay matrix with much calcite; contains undeterminable plagioclase sparse sanidine, and biotite.	
27. Chert lens, black, very hard, brittle, fine-grained; grades laterally in 2 ft to white tuffaceous mudstone	.4
26. Sandstone, white, tuffaceous, soft, medium to coarse-grained, ferruginous	.7
25. Shale or mudstone, black to dark-brown, finely bedded, slightly porous, moderately hard; black coal parting one-half in. thick at top; thin lenses of gray quartzite as much as 1 in. thick	.5
24. Pellets and analcite, white, stained rusty, medium- to coarse-grained, loose, porous	.8
23. Mudstone, dark-brown, bedded, carbonaceous, slightly porous; contains fragments of coal	.3
22. Sandstone, white, tuffaceous, very soft, medium-grained	.5
21. Coal, brownish-black, brittle	.4
Offset on top of coal bed (unit 20). Underlying units measured 200 ft east.	
20. Coal, black, brittle, shiny, soft	.3
19. Mudstone, dark-brown, very carbonaceous, hard, thin-bedded	.9
Thin section Wyo 47: rock consists chiefly of analcite crystals in a brown to black clayey matrix; contains angular grains of sodic andesine, sanidine, altered red-brown biotite, and glass shards.	
18. Coal, black, hard, brittle; shiny in part	.7
17. Mudstone or siltstone, interbedded with tuffaceous sandstone; mudstone is fine grained, hard, massive, blocky; sandstone is brown, soft, porous, and in middle and upper parts of sequence	18.5
16. Coal, black, hard, shiny, with silty layer 1 in. thick near base. USGS distillation analysis: 4.2 gal oil per ton	1.0
15. Sandstone and mudstone, gray, tuffaceous, porous near middle, hard and finely silty near top and base; moderately well bedded; carbonaceous parting 1 in. thick 1 ft below top	5.5
14. Coal, black, shiny, light-weight, crumbly	.7
13. Siltstone, black to brown, hard, coaly, massive, blocky	1.0
12. Coal, black, silty, brittle, with abundant analcite(?) aggregates	.2
11. Siltstone and sandstone, brown, tuffaceous, blocky, hard, poorly bedded	5.5

Aycross(?) equivalent—Continued	Thickness (feet)
10. Coal, black, with middle 0.2 ft black coaly analcite(?), grading to analcitic(?) coal near top and bottom	0.4
9. Sandstone, analcite(?), and sandy siltstone, pale-green to rusty-gray, tuffaceous, hard, blocky; contains well-preserved pelecypods, gastropods, and leaves in white tuff in lower third. R. W. Brown identified the following plants: *Asplenium eoligniticum* Berry, cf. *Juglans alkalina* Lesquereux, cf. *Persea* sp., and seeds	65.0
8. Coal, black, analcitic(?), and brown coaly analcite(?)	.2
7. Sandstone, rusty-white, tuffaceous, medium-grained	1.0
6. Coal, brownish-black, with abundant white pellets or analcite clusters and 0.2 ft of coaly analcite(?) in middle	.5
5. Sandstone, siltstone, and analcite or pellet beds, pale-green to buff, tuffaceous; some tuff fragments as much as 1 in. in dimeter in medium- to coarse-grained matrix; poorly bedded, blocky, hard; oolites or analcite clusters form about half of rock in some layers, are silicified in part, round, pinhead size, in white to green groundmass; ganoid scales as much as 1 in. in diameter; uraniferous phosphatic zone B is about 35 ft above base of unit 5 and consists of olive-drab to brown limy nodular siltstone with many small biotite flakes. The most radioactive 2 in. contains 0.011 percent eU, 0.009 percent U, and 3.40 percent P_2O_5 (sample 6, table 13); uraniferous phosphatic zone A is a 2-in. brown to black very silty noncalcareous carbonaceous shale 1 ft above base of unit 5 and contains 0.02 percent eU, 0.023 percent U, and 5.18 percent P_2O_5 (sample 7, table 13)	61.0
4. Coal, black, 1.2 ft thick; with black and brown earthy and shaly partings containing some shiny layers; overlain gradationally by 0.3 ft of black to brown shaly coal containing gray tuffaceous lenses	1.5
Underlying beds measured one-half mile northeast. Because of poor exposures, the precise thickness of unit 3 is not known, but it is probably accurate within 20 ft.	
3. Sandstone, siltstone, and claystone, red, buff, and green; lower 30 ft is chiefly red plastic claystone with abundant analcite(?) aggregates; upper half is brilliant mottled red, yellow, and green ledge-forming tuffaceous siltstone and sandstone, much of which has apparently been secondarily analcitized	60.0±
Thickness of Aycross(?) equivalent	250–310

Angular unconformity. Contract between Aycross(?) equivalent and Fort Union Formation is sharp, but amount of discordance in dip is difficult to determine because of lack of good bedding planes in Fort Union Formation.

Fort Union Formation:	Thickness (feet)
2. Conglomerate, gray, soft, poorly indurated, with coarse-grained sandstone matrix, noncalcareous; rock fragments consist of Mowry Shale and of Paleozoic chert and quartzite, all rounded to subrounded; very little granite; roundstone size averages an inch or less	20
Thickness of Fort Union Formation	20

Angular unconformity.

Cretaceous rocks:	
1. Shale, gray, soft; with thin hard limy beds secondarily analcitized as in unit 3	10+

The Aycross(?) equivalent is composed of finely tuffaceous organic paper shale, oil shale, mudstone, thin beds of coal, and a few beds of analcite crystals embedded in a clay matrix. The paper shales are the weathered surface expression of nonfissile mudstones having faint laminar markings which thin sections show are thin short lenses of crystalline calcite. Unaltered plagioclase, sanidine, biotite, and shards are the most common Tertiary volcanic materials. The plagioclase grains are much clearer than those found in Precambrian rocks of the region. Other Tertiary volcanic minerals are orthoclase, sodic andesine, labradorite, quartz, hornblende, and pyroxene. Silicified algal growths are present in some mudstones. The beds of analcite crystals have an oolitic appearance because the crystal clusters are round and weather white, contrasting with the darker colored matrix.

Oil content of the oil shale beds reaches a known maximum of 38 gallons per ton, with as much as 23 gallons per ton for a thickness of 7 feet (loc. 5, fig. 18) The sequence has not been sampled in detail; it may have thicker richer shales. Conspicuous red masses of burned shale and clinker are present along the north escarpment of Lysite Mountain and similar remnants extend north of the mountain for more than a mile. The bedding of the Aycross(?) equivalent is crumpled and distorted, probably in part the result of compaction of shale, coal, and analcite beds.

No diagnostic fossils have been found in the Aycross (?) equivalent of the Lysite Mountain area. Abundant ostracodes, crushed mollusks, fish remains, fragments of a crocodilian(?), and leaves (listed in description of unit 9) are present. The formation is separated from overlying strata containing vertebrate fossils of late Eocene age by an erosional unconformity. The lithology of the Aycross(?) equivalent is unlike that of the nontuffaceous latest early Eocene Lost Cabin Member of the Wind River Formation at its type locality, 12 miles south of Lysite Mountain, but is comparable in some lithologic features and in stratigraphic position to the middle Eocene Aycross Formation at its type area, 85 miles to the west (Love, 1939, p. 66–73). The Aycross at the type locality unconformably overlies the Wind River Formation, is unconformably overlain by the Tepee Trail Formation of late Eocene age, and contains abundant mafic to felsic volcanic debris. The Aycross(?) equivalent on Lysite Mountain is chiefly intermediate to felsic but contains some mafic debris.

Van Houten (1944, p. 193) described humic (peaty) and sapropelic (bituminous or oil shale) strata in the 900-foot section of the Tatman Formation on the Squaw Teats in the southwestern part of the Bighorn basin, 60 miles northwest of Lysite Mountain. Both Tourtelot (1946; 1957, p. 17–19) and Hay (1956, p. 1886–1888) correlated the Tatman with the oil shale sequence on Lysite Mountain. Two significant differences, however, cast some doubt on this correlation. The lack of Tertiary volcanic debris and analcite beds in the Tatman Formation (Hay, 1956, p. 1886–1888) is in sharp contrast to their abundance in the Aycross(?) equivalent on Lysite Mountain. Oil shales are present in both sequences, but the maximum content in the four most bituminous-appearing beds on the Squaw Teats is less than 5 gallons per ton, as contrasted with 38 gallons per ton at Lysite Mountain. The Tatman Formation along the southwest margin of the Bighorn basin contains as much as 14 gallons oil per ton, but it has no volcanic debris or analcite. It is probable, therefore, that the Tatman Formation is older than either the volcanic-rich Aycross Formation at its type locality or the Aycross(?) equivalent on Lysite Mountain.

TEPEE TRAIL EQUIVALENT

The Tepee Trail equivalent in the Lysite Mountain area consists of 300–650 feet of green to brown mafic volcanic conglomerate interbedded with green and white fine-grained tuffaceous sandstone, siltstone, claystone, and limestone. Nearly all the Tertiary rocks cropping out on Lysite Mountain, except for those on the north-facing escarpment, are part of the Tepee Trail equivalent. It overlaps the Mesozoic and Paleozoic rocks of the Bighorn and Owl Creek Mountains. To the south along the northern margin of the Wind River basin, the Tepee Trail Formation is preserved in downfaulted blocks (Tourtelot, 1953).

The conglomerates are in the lower half of the Tepee Trail equivalent and are described in the measured section and in table 10. Thin-bedded green siltstones and claystones predominate in the middle part of the Tepee Trail equivalent. A few thin coal beds and carbonaceous shales are present. The upper part is progressively finer grained and lighter colored, and white limestone is dominant in the uppermost 100 feet of the Tepee Trail equivalent (loc. 4, fig. 18). Most lithologies contain finely disseminated tuffaceous material and abundant secondary silica in the form of large irregular masses of gray to green chert and chalcedony and lenses and nodules of black chalcedony.

Labradorite is the most abundant plagioclase. Biotite, green and basaltic hornblende, hypersthene, and other pyroxenes are common. Glass shards are abundant.

The lower part of the Tepee Trail equivalent is similar to the Aycross(?) equivalent in that both contain abundant tuffaceous debris, analcite beds, sparse thin coals, and uraniferous phosphatic zones. No oil shales have been found above the unconformity at Lysite Mountain, but 60 miles to the west a sequence that is probably correlative with the Tepee Trail Formation contains a highly tuffaceous ostracode- and mollusk-bearing oil shale (12 gal oil per ton and 0.5 percent P_2O_5, sample 33, table 12).

A few vertebrate fossils about 200 feet above the base of the Tepee Trail equivalent between localities 4 and 5 (fig. 18) are *Telmatherium* cf. *T. cultridens* (identified by G. E. Lewis), *Dilophodon* sp. (Gazin, 1956, p. 3), a ?brontothere, and crocodilian remains. Gazin (1956, p. 5–7) considers these fossils and a more extensive vertebrate fauna from a comparable stratigraphic sequence 15 miles to the southeast to be of late Eocene age (possibly Uinta C).

A fine-grained tuffaceous claystone and white limestone about 30–50 feet below the top of the Tepee Trail equivalent at locality 4 contain abundant gastropods and ostracodes and a few pelecypods. The mollusks were described by Yen (1946) and restudied by D. W. Taylor, who reported the following forms (written commun., 1962):

Lymnaea aff. *L. similis*
Anisus aff. *A. cirrus* (White)
Aplexa? n. sp.
Planorbina pseudoammonius (Schlotheim)
Drepanotrema n. sp.
Gastrocopta?
Gastrocopta n. sp.
Pupoides (*Ischnopupoides*)
Helminthoglyptidae

A white biotite-rich tuff collected by the author from a 90-foot bed about 400 feet above the base of the Tepee Trail equivalent at locality 4 (fig. 18) has a potassium argon age of 46.2 (±1.5) million years (R. S. Houston, written commun., 1962). This age would put the tuff at about the boundary between middle and late Eocene time as defined by Kulp (1961). His assignment, however, is tentative, and based on sparse samples, none of which are from this region. A similar biotite-rich tuff, possibly from a comparable stratigraphic position, at a vertebrate fossil locality in the Tepee Trail Formation as mapped by Tourtelot (1957) on Badwater Creek, 15 miles to the southeast (Gazin, 1956), has a potassium argon age of 43.9 million years (Evernden and others, 1964, sample KA 1024). These two samples should be of about the same age. Not only does the sample at locality 4 appear to be older than that on Badwater Creek, but it is also older than that previously described in the middle of the Aycross equivalent (44.3 million years) on the Beaver Divide. Either an unlikely error has been made in evaluation of data on fossils, as well as a miscorrelation of stratigraphic units, or the potassium argon age of one or more of these samples is subject to question.

The Tepee Trail equivalent on Lysite Mountain and the Tepee Trail in the type area 90 miles to the west, at the south end of the Absaroka Range, are correlated on the basis of lithologic similarity (Love, 1939, p. 78; Tourtelot, 1957, p. 5–6).

STRUCTURE

The Aycross(?) and Tepee Trail equivalents dip about 1°S. In the Lysite Mountain area, there is little reflection of the extensive tilting and normal faulting that involves the Tepee Trail Formation, 10 miles to the south along the northern margin of the Wind River basin.

URANIFEROUS PHOSPHATIC ZONES

Seven uraniferous phosphatic zones were sampled in one continuous section on the northwest escarpment of Lysite Mountain (pl. 7; loc. 1, fig. 18). The lower 4, designated A, B, C, and D, are in the Aycross(?) equivalent and the upper 3, E, F, and G, are in the Tepee Trail equivalent. The lithology of these zones is given in the measured section, uraniuum and phosphate content in table 13, rock analyses in tables 9, and 16, oil analysis in table 5, and spectrographic analyses in table 7. Only the most radioactive 2–6 inches of each zone was sampled; therefore the distribution pattern of uranium with respect to phosphate has not been determined, as it was in the Green River and Pine Mountain areas (fig. 13).

One zone in the Tepee Trail equivalent was sampled at locality 2 (fig. 18). It consists of a very hard dense brown massive limy carbonaceous mudstone about 4 feet thick. The most radioactive 6 inches contains 0.040 percent uranium and 5.06 percent P_2O_5. This zone is lithologically similar, except in carbonate content, to zone E at locality 1, 4 miles to the northeast, and possibly they correlate. At locality 2, the Tepee Trail equivalent overlaps hogbacks of Lower Cretaceous rocks and this zone is near the contact.

At locality 3, fig. 18, the Tepee Trail equivalent rests on a surface of high relief that is cut in red siltstones of the Chugwater Formation (Triassic). The uppermost sample is from a light-tan hard spongy very limy siltstone that contains abundant altered glass shards. This bed is in the lower part of a local 50-foot cliff of greenish-brown tuffaceous siltstone and sandstone. The most radioactive part was sampled (sample 9, table 13).

The lowest three samples at locality 3 are from the upper, most radioactive, half of a brown arkose about 20 feet thick, directly overlying the Chugwater Formation. The unweathered rock is dark gray, dense, siliceous, hard, pyritic, slightly limy, and is composed of angular to rounded fragments of quartz, feldspar, green clay balls, and Paleozoic and Mesozoic rocks embedded in a gray sandy siltstone matrix. Lenses of rounded pebbles, cobbles, and boulders of granite and volcanic rocks are present. The three samples, all from one prospect pit, average about 0.02 percent uranium and 6 percent P_2O_5.

At locality 4, figure 18, 4 radioactive zones in the Aycross(?) equivalent were sampled. Their ligtology, stratigraphic position, and uranium and phosphate content are given in table 13. The uppermost zone has very erratic distribution of both uranium and phosphate (samples 14 and 15, table 13). Three zones near the top of the Aycross(?) equivalent were sampled at locality 5. They are all above the thickest (200 feet), richest oil shale sequence in the Lysite Mountain area. Correlation of zones between localities 4 and 5 has not been established. No uraniferous phosphatic zones were found in the Tepee Trail equivalent in either locality.

Figures 20 and 21 compare content of common oxides and spectrographic data on 27 elements in several zones in this area with those in other areas in Wyoming and with the arbitrary standard, the Pierre Shale. The zones in the Lysite Mountain area have a high K_2O and low lead content, but otherwise they are not conspicuously different from zones in the other three areas in Wyoming.

OTHER MAJOR BASINS CONTAINING LACUSTRINE STRATA OF EARLY, MIDDLE, AND LATE EOCENE AGE

UINTA BASIN, UTAH

The Uinta basin in northeastern Utah (fig. 22) is about 125 miles long from east to west, is 50–80 miles wide, and has a gentle south flank and a steep north flank. It contains the largest volume of lacustrine Eocene rocks in the Rocky Mountain region. For ex-

TABLE 13.—*Uranium and phosphate analyses of samples from Tepee Trail and Aycross(?) equivalents, Lysite Mountain area, north-central Wyoming*

[Samples in each locality are arranged in stratigraphic order. Spectrographic analyses are used (but not listed by number) in table 17; these values are plotted graphically on fig. 21. Analysts: L. M. Lee, H. H. Lipp, D. L. Ferguson]

Measured stratigraphic section	No. (on fig. 18)	Location: Section	Location: T.N.	Location: R.W.	Geologic unit	Zone	Sample	Laboratory No.	Rock analysis (No. on table 9)	Spectrographic analysis No.	Thickness of interval sampled (inches)	Analyses (percent): eU	Analyses (percent): U	Analyses (percent): P_2O_5	Remarks
Lysite Mountain..	1	NE¼NE¼SW¼.. 20	42	90	Tepee Trail equivalent.	G	1	276979	6	276979	3	0.01	0.007	2.28	Unit 51, measured section.
		SE¼SE¼NW¼.. 20	42	90	.....do......	F	2	282882	......	....	2	.009	.002	2.90	Unit 46, measured section.
						E	3	81	......	....	3	.009	.005	2.52	Unit 46, measured section, 22 ft below zone F.
					Aycross(?) equivalent.	D	4	80	7	282880	3	.019	.016	3.17	Unit 36, measured section.
						C	5	83	......	....	2	.008	.006	1.11	Unit 28, measured section; contains 6.3 gal oil per ton.
						B	6	79	......	....	2	.011	.009	3.40	Unit 5, measured section.
						A	7	78	8	282878	3	.02	.023	5.18	Unit 5, measured section, 34 ft below zone B.
Bridger Pass road.	2	NE¼SE¼........ 34	42	91	Tepee Trail equivalent.	......	8	276865	9	276865	6	.037	.040	5.06	Prospect pit.
Arapahoe Butte...	3	NE corner........ 10	40	91	.....do......	......	9	282884	10	282884	3	.017	.012	5.94	About 100 ft above contact of Tepee Trail equivalent and Chugwater Formation.
		NW¼NW¼-NW¼.......... 11	40	91	.....do......	......	10	85	......	....	3	.002	.001	0.40	Weakly radioactive pale-green nodular tuffaceous claystone in prospect pit, about 50 ft below sample 9.
		SW¼NW¼-NW¼.......... 11	40	91	.....do......	......	11	86	......	....	3	.043	.036	5.64	Tuffaceous arkose 10 ft above contact between Tepee Trail equivalent and Chugwater Formation, in prospect pit.
							12	139624	......	....	3	.018	.016	4.81	Weathered tuffaceous arkose; same prospect pit as sample 11.
							13	25	......	....	3	.027	.020	7.25	Fresh tuffaceous arkose; same prospect pit as sample 11.
Hawks Butte.....	4	SW¼NE¼NW¼. 36	42	90	Aycross(?) equivalent.	......	14	292322	......	....	3	.009	.008	1.34	Greenish-white hard nodular limestone section.
							15	21	......	....	3	.003	.002	.19	Same bed as sample 14, 4 ft away; taken to show erratic distribution of U and P_2O_5 in this bed.
							16	20	......	....	3	.003	.002	.99	Gray-brown plastic bentonitic claystone 10 ft below sample 15.
							17	19	......	....	3	.025	.023	2.33	Gray plastic claystone 50 ft below sample 16.
							18	18	......	....	6	.003	.002	.36	Carbonaceous shale 100 ft below sample 17 and 50 ft below top of oil-shale sequence.
No Water Canyon.	5	Center north line.. 35	42	90	.....do......	......	19	25	......	....	3	.008	.007	1.55	Hard green siliceous concretions 7 ft below cliff of conglomerate at this locality.
							20	24	......	....	3	.005	.003	1.52	Tan blocky tuff 13 ft below sample 19.
							21	23	......	....	3	.005	.004	2.21	Pale-green tuffaceous silty limestone 40 ft below sample 20 and overlying brown oil-shale sequence.

example, the Green River Formation has a maximum thickness of more than 7,000 feet and the intertonguing and overlying Uinta Formation (of late Eocene age), more than 5,000 feet. The strata in these formations grade from predominantly lacustrine in the central part of the basin to fluviatile near the margins. The lacustrine beds in these two formations, combined, include as much as 1,000 feet of black and brown shortite-bearing shale, and additional thick sequences of oil shale, marlstone, limestone, and thin-bedded green and gray shale, siltstone, and mudstone.

Dane (1954, 1955), Ray and others (1956), Picard (1957), and Cashion (1959) described the Green River and Uinta Formations in some detail. As is indicated by Picard (1957, p. 125 and fig. 8), Uinta Lake reached its maximum development of more than 5,000 square miles in the Uinta basin during the time of deposition of the Evacuation Creek and Parachute Creek Members of the Green River Formation. These comprise the upper 1,000–2,000 feet of the Green River Formation in most deep parts of the basin. As the lake shrank, a saline facies with a maximum thickness of more than 1,500 feet was deposited. This facies is, in places, transitional between the Green River and Uinta Formations. The continuity of strata in the Evacuation Creek and Parachute Creek Members and in the saline facies

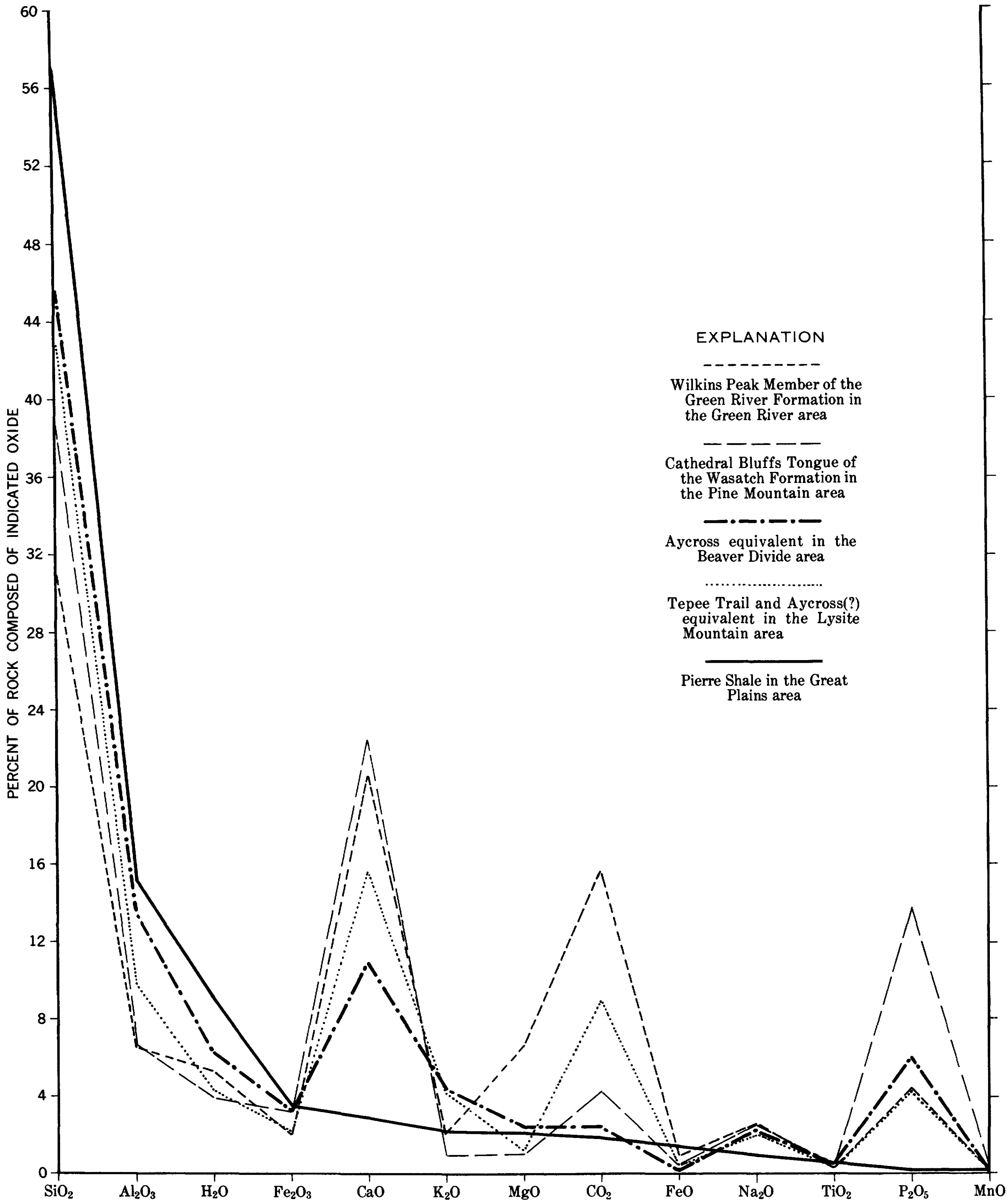


FIGURE 20.—Graphic comparison of 36 rock analyses of uraniferous phosphatic strata of Eocene age, representing four areas in Wyoming, with the Pierre Shale (Upper Cretaceous) of the Great Plains. Arithmetic averages are used; data on Pierre Shale were furnished by H. A. Tourtelot. The marine Pierre Shale is used as a standard of reference because it is several thousand feet thick, occupies an area of several thousand square miles, and its composition is known from many analyses. Oxides in Pierre Shale are plotted in decreasing abundance from left to right in order to facilitate contrast with those in Eocene rocks.

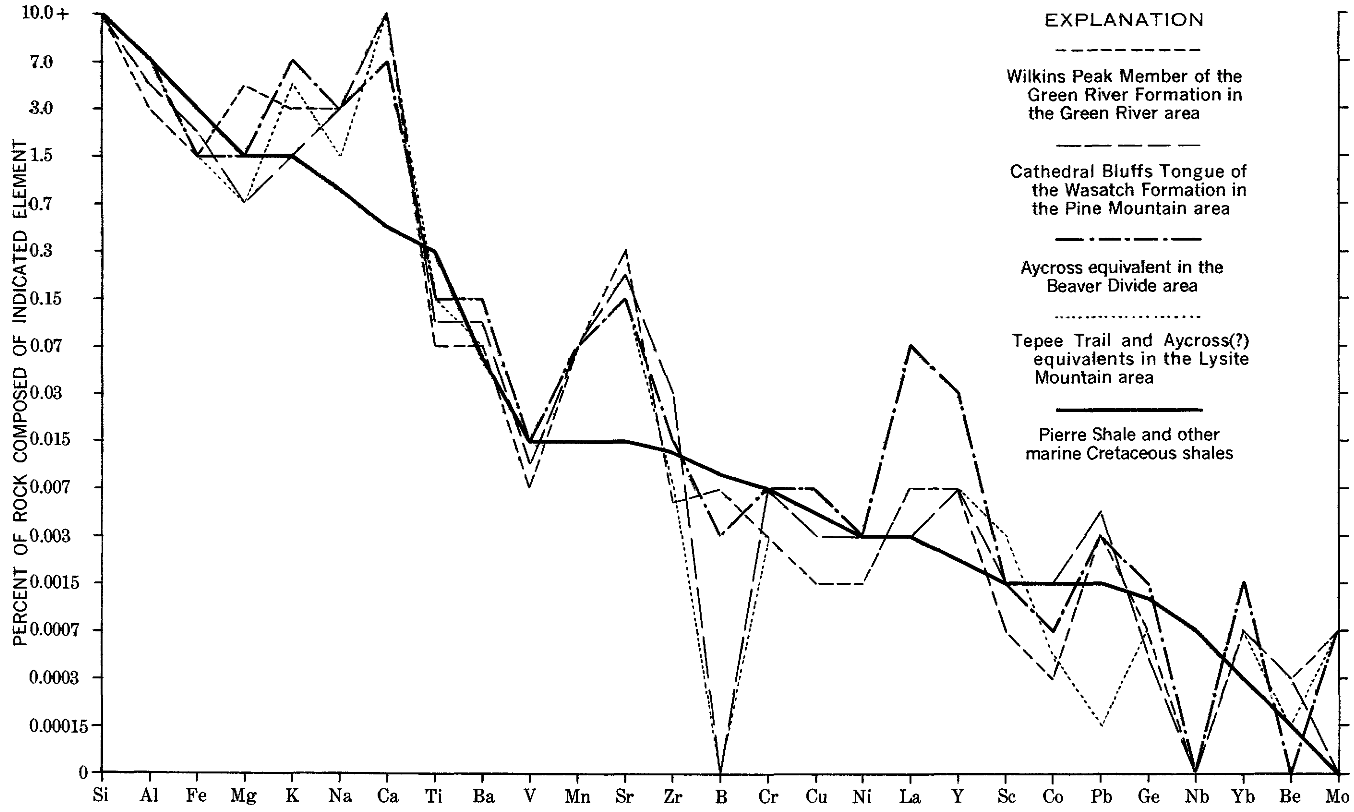


FIGURE 21.—Semiquantitative spectrographic analyses graphed to show distribution of selected elements in uraniferous phosphatic strata of Eocene age in Wyoming contrasted with those in the Pierre Shale and other marine Cretaceous shales. Values are reported in percent to the nearest number in the series 7, 3, 1.5, 0.7, and so on; at least 60 percent of results are expected to be in the correct range. Data on Cretaceous shales were furnished by H. A. Tourtelot. Elements in Cretaceous shales are plotted in decreasing abundance from left to right in order to facilitate contrast with those in Eocene rocks.

indicates that this was the time of most widespread stability of the basin region.

Uranium occurrences have been described in several places in the Green River Formation in the southern part of the Uinta basin (Noble and Annes, 1957, and in unpublished reports cited by them). One 2-foot uraniferous phosphatic zone of gray shale and green siltstone in a surface section of the Parachute Creek Member contains 0.07 percent uranium and 8 percent phosphate (table 14). Downdip to the north in subsurface sections, gamma ray-neutron logs of oil wells show several radioactive zones in the saline facies and many more in the upper 1,500 feet of the Evacuation Creek and Parachute Creek sequences. A few thin zones are present in the lower part of the Green River Formation. The high phosphate content of the uraniferous surface section suggests that these subsurface radioactive zones may likewise be phosphatic. If so, their number, thickness, and areal extent are probably comparable to, or greater than, those in the Wilkins Peak Member of the Green River Formation in the Green River basin.

Swanson (1960, p. 20 and table 1) found only very low uranium content of oil shales in the Mahogany ledge of local usage, Parachute Creek Member, in the Uinta basin and stated that the average (0.0006 percent) is not much higher than that for average shale. No phosphate analyses were reported.

Several limestone beds in the lower part of the Uinta Formation are widespread, and one is known to contain some uranium and phosphate (table 14). Butler and others (1920, p. 605–606) and E. P. Beroni and F. A. McKeown (written commun., 1952) studied copper-uranium deposits in sandstone about 1,200 feet above the base of the Uinta Formation. The phosphate content of these sandstones is above the average for sedimentary rocks, but is somewhat lower than that in most uraniferous phosphatic zones in the Green River Formation. (Compare analyses in table 14 with those in tables 2 and 12.) In this area, gamma ray-neutron logs of the underlying part of the Uinta Formation show several radioactive zones. Farther north, where the Uinta Formation is more than 3,000 feet thick, the upper 1,000 feet contains additional radioactive zones. It is not known whether any of these is phosphatic.

Table 17 compares spectrographic analyses of four samples with those from uraniferous phosphatic zones in other areas. These analyses show no unusual concentrations of elements except for lead, which is the

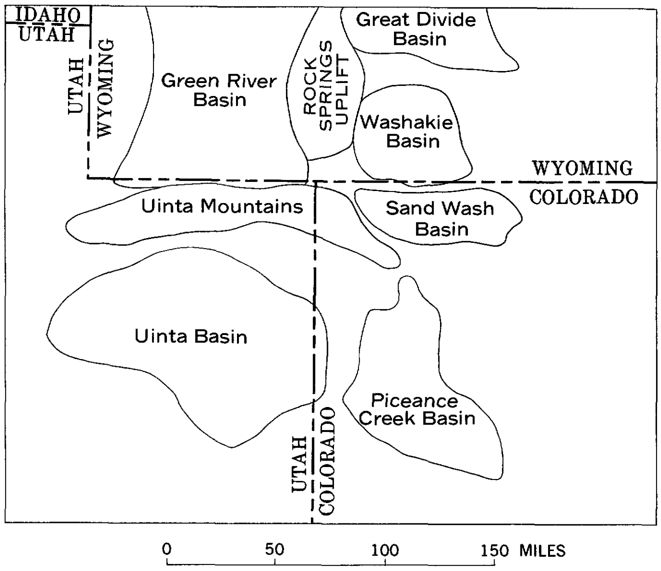


FIGURE 22.—Major structural basins containing lacustrine strata of middle and late Eocene age in northwestern Colorado, northeastern Utah, and part of southwestern Wyoming.

highest found in any area. Lithium and copper values are equal to the highest found in other areas.

PICEANCE CREEK BASIN, COLORADO

The Piceance Creek basin is about 100 miles long and 50 miles wide, and trends northwest in northwestern Colorado (fig. 22). It contains a maximum thickness of more than 3,500 feet of the Green River Formation, 2,000 feet of which is oil shale in the central part of the basin (Donnell, 1957). Gamma ray-neutron logs show several widespread radioactive zones, of which two occur directly above and below the Mahogany ledge, a distinctive high-grade oil shale unit (not to be confused with the locally known Mahogany marker, an analcite tuff in the upper part of the Mahogany ledge) in the Parachute Creek Member (Duncan and Denson, 1949). The upper zone is locally known as the A groove and the lower as the B groove. Analyses and X-ray mineral determinations of these and several adjacent radioactive and nonradioactive marker beds are shown in table 15.

None of the beds analyzed contains significant quantities of either uranium or phosphate (table 15). Apatite was identified in one sample from the B groove, yet the chemical analysis showed only 0.1 percent phosphate (sample 297496). The reason for this discrepancy has not been determined. Two samples from the B groove contain monazite and one a sodium zirconium titanium silicate (Charles Milton, written commun., 1961), which probably accounts for at least some of the radioactivity.

Swanson (1960, table 1) listed 34 uranium analyses, each representing 5- to 10-foot intervals of the Mahogany ledge in the Piceance Creek basin. Only 4 have as much as 0.001 percent uranium and none was higher. No phosphate analyses were made.

Six bulk samples of oil shale, representing the mined section in the Anvil Points demonstration mine (table

TABLE 14.—*Uranium and phosphate analyses of strata in the Green River and Uinta Formations in the Uinta basin, Utah*

[Analysts: L. M. Lee, D. L. Ferguson, G. T. Burrow]

Formation and age	Location	Laboratory No.	Analyses (percent)			Interval sampled (inches)	REMARKS
			eU	U	P_2O_5		
Uinta, late Eocene	Sec. 34, T. 10 S., R. 20 E.	290162	0.014	0.017	0.48	2	Sandstone collected by E. A. Noble.
	Sec. 4, T. 11 S., R. 22 E.	290164	.034	.036	.27	2	Brown sandstone collected by E. A. Noble.
	Sec. 18, T. 9 S., R. 16 E.	46594	.021	.019	.455	6	Sample collected by E. P. Beroni; limestone marker bed (Ray and others, 1956, bed 17, section 11).
	Sec. 11, T. 5 S., R. 2 E.	46595	.014	.017	.35	--------	Uteland copper mine; samples collected by E. P. Beroni.
		46596	.005	.007	.35	--------	
		46597	.006	.008	.315	--------	
		46598	.011	.013	.32	--------	
Green River, early and middle Eocene	Sec. 29, T. 12 S., R. 20 E.	290158	<.001	--------	.23	2	Oil shale collected by E. A. Noble.
		290159	<.001	--------	.09	2	Gray shale collected by E. A. Noble.
	Sec. 25, T. 14 S., R. 17 E.	290160	.070	.076	8.17	2	Do.
		290161	.066	.075	8.17	2	Green siltstone collected by E. A. Noble.
		297255A	.071	.060	8.80	--------	AEC. pulp sample 42846, White Rock 11 claim.
	Sec. 29, T. 12 S., R. 20 E.	297255	.004	.003	.97	--------	AEC. pulp sample 42847, Blue Knolls 28 claim.
		246944	--------	.004	1.12	--------	USGS. pulp, Blue Knolls 28 claim.

TABLE 15.—*Uranium and phosphate analyses and X-ray identification of minerals in several marker beds in the Parachute Creek Member of the Green River Formation, Piceance Creek basin, Colorado*

[Samples were collected by D. C. Duncan, and are arranged in stratigraphic order in each locality. Analyses by L. M. Lee, Wayne Mountjoy, E. J. Fennelly, and H. H. Lipp; identification of minerals by Theodore Botinelly except as noted under "Remarks"]

Columnar section	Location	Zone	Sample	Laboratory No.	Interval sampled (inches)	Analyses (percent)			Minerals (percent)								Remarks
						eU	U	P_2O_5	Quartz	Feldspar	Calcite	Dolomite	Clay	Mica [1]	Analcite	Apatite	
Anvil Points (Duncan and Denson, 1949, columnar section 7).	SW¼ sec. 12, T. 6 S., R. 95 W.	A groove	1	297500	3	0.003	<0.001	0.07	50–75	10–25	--------	10–25	10–25	--------	--------	--------	Tuffaceous analcitic siltstone 21 ft above Mahogany marker bed.
		Mahogany marker bed.	2	297500C	6	[2] <.001	--------	.03	25–50	?	--------	--------	--------	--------	50–75	--------	Analcite tuff in Mahogany marker bed, about 12 ft above main part of Mahogany ledge.
			3	297500B	12	<.001	--------	.03	10–25	<10	--------	>75	--------	--------	--------	--------	Crinkly carbonate bed 62 ft below Mahogany marker bed.
		B groove	4	297496	--------	.003	.001	.10	10–25	10–25	25–50	25–50	<10	--------	<10	<10	Sample from Anvil Points demonstration mine; calcareous siltstone 105 ft below Mahogany marker bed. Monazite identified by Charles Milton.
			5	297497	--------	<.001	--------	.08	50–75	<10	10–25	10–25	?	--------	10–25	--------	Sample from Anvil Points demonstration mine; tuffaceous sandstone 11.0 ft below Mahogany marker bed. Monazite identified by Charles Milton.
			6	297499	3	.002	<.001	.08	50–75	<10?	--------	10–25	<10	--------	25–50	--------	Analcitic tuffaceous siltstone 134 ft below Mahogany marker bed.
			7	297500A	3	([3])	([3])	([3])	25–50	<10	--------	10–25	<10	--------	25–75	--------	Analcitic tuffaceous siltstone 137 ft below Mahogany marker bed. Sample lost after X-ray and mineralogic study; not analyzed for uranium and phosphate.
Trapper Creek (Duncan and Denson, 1949, columnar section 12).	SW¼ sec. 2, T. 5 S., R. 94 W.	Above A groove	8	297498	--------	<.001	--------	.12	50–75	<10?	--------	--------	--------	--------	25–75	--------	Wavy-bedded analcitic tuff and marlstone 85 ft above Mahogany marker bed.
		B groove	9	297500D	10	.001	.001	.16	25–75	<10	--------	--------	--------	10	25–75	?	Gray analcitic tuff 66.5 ft below Mahogany marker bed; sodium zirconium titanium silicate identified by Charles Milton.

[1] Includes mica, hydromica, degraded mica. [2] Estimated. [3] No analysis.

15) in the Mahogany ledge, average 0.32 percent P_2O_5 and one contains 0.56 percent P_2O_5 (Stanfield and others, 1951, table 11). J. W. Smith (oral commun., 1962) said that an areal average is more nearly 0.2 percent. This phosphate content, coupled with radioactivity indicated in gamma ray-neutron logs, suggests that sampling of thinner units may show the presence of several lean uraniferous phosphatic zones.

Except for P_2O_5, which was not determined, the common oxide content of the Mahogany ledge in 10 cores representative of an area of 1,500 square miles in the Piceance Creek basin is almost identical to the average, cited on figure 20, for the uraniferous phosphatic zones in the Wilkins Peak Member in the Green River basin. The variation in content within this stratigraphic unit from one part of the Piceance Creek basin to another is so small that it is statistically insignificant (J. W. Smith, written commun., 1961).

SAND WASH, WASHAKIE, AND GREAT DIVIDE BASINS

The Sand Wash basin in northwestern Colorado (fig. 22) and the Washakie and Great Divide basins in southwestern Wyoming (fig. 2) contain between 1,000 feet (Great Divide basin) and 7,000 feet (Washakie basin) of middle and upper Eocene rocks. The few gamma ray-neutron logs of wells penetrating these strata indicate several moderately radioactive zones, but no uranium and phosphate analyses of outcrop samples or cores of these zones have been made. Their log characteristics, however, are similar to those of known uraniferous phosphatic zones in the Green River basin.

ORIGIN OF URANIFEROUS PHOSPHATIC ZONES

The origin of the uraniferous phosphatic zones has not been determined. The Wilkins Peak Member in the Green River basin exhibits a nearly complete sedimentary record of a lake basin with internal drainage, and the abundance of surface and subsurface data can be utilized to construct a three-dimensional picture showing distribution of the uraniferous phosphatic zones. Without the data from other areas, however, one can be led astray by certain spectacular, but not necessarily fundamentally significant, features of the deposits in the Green River basin. For example, the data shown on figure 14 suggest that the concentration of uranium and P_2O_5 is somehow linked with trona deposition, but the lack of trona and other evaporites in the Pine Mountain, Beaver Divide, and Lysite Mountain areas indicates that conditions fostering the deposition of trona are not a controlling factor.

The "average" shale in the earth's crust contains 0.00037 percent uranium and 0.16 percent P_2O_5 (computed from Turekian and Wedepohl, 1961, table 2). The Pierre Shale, which was used as an arbitrary standard of comparison on figures 20 and 21, contains about 0.0005 percent uranium (Rader and Grimaldi, 1961, p. 33) and 0.15 percent P_2O_5 (Tourtelot, 1962). The chemical composition of the zones in Eocene rocks differs in many respects from that of the Pierre Shale (fig. 20). These differences are probably caused in part by the abundance of volcanic debris, chiefly of dacitic and andesitic composition, in the Green River Formation. Igneous rocks of this general composition contain about 0.0003 percent uranium and about 0.2 percent P_2O_5 (Turekian and Wedepohl, 1961, table 2). Compared with "average" shale, Pierre Shale, or "average" dacitic-andesitic igneous rocks, the thin uraniferous phosphatic zones in the Wilkins Peak Member and those in other middle and upper Eocene

TABLE 16.—*Summary of rock analyses of samples selected on the basis of uranium and phosphate content, from uraniferous phosphatic zones in the Green River, Pine Mountain, Beaver Divide, and Lysite Mountain areas, Wyoming*

[Arithmetic means are given where two or more analyses are available; arithmetic deviations are indicated in tables 4 and 9. Samples were analyzed by methods similar to those described by Shapiro and Brannock (1956)]

Area	Zone	Number of samples	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	TiO_2	P_2O_5	MnO	CO_2
Green River	1	8	36.8	10.0	1.6	1.9	4.0	17.4	3.2	2.6	2.5	0.37	6.8	0.07	11.7
	2	3	27.3	7.2	1.7	1.4	5.9	15.7	6.5	4.2	3.3	.29	5.2	.06	17.2
	2a	2	36.2	9.4	2.2	1.5	5.1	16.8	3.2	2.6	3.8	.34	7.4	.06	9.6
	3	5	26.5	7.0	1.6	1.2	5.7	21.2	2.4	1.9	4.0	.27	7.4	.08	13.6
	4 and 4?	2	24.0	4.8	2.2	.57	8.9	24.8	1.2	1.3	5.0	.23	3.2	.19	21.8
	4aa	1	27.7	5.4	2.8	.56	6.1	24.9	1.3	1.4	6.4	.26	3.2	.16	18.6
	7	2	31.7	6.0	1.6	.67	7.3	21.6	2.3	1.8	6.2	.24	3.6	.15	15.7
	9	1	37.6	7.3	2.0	.88	7.6	13.8	4.8	2.6	9.4	.30	1.8	.08	10.6
	10?	1	20.6	2.6	1.0	.24	7.8	30.4	.52	1.1	3.6	.11	3.7	.07	26.4
	11	1	39.6	4.9	3.2	.48	7.4	18.2	.62	1.9	8.6	.22	2.8	.19	11.2
Average	----------	(1)	30.8	6.5	2.0	.94	6.6	20.5	2.6	2.1	5.3	.26	4.5	.11	15.6
Pine Mountain	(2)	4	38.4	6.7	3.2	.47	1.0	22.4	2.6	.95	3.9	.29	13.8	.26	4.3
Beaver Divide	SD-3 [2]	1	45.5	13.5	3.2	.18	2.4	10.9	2.2	4.4	6.2	.41	6.0	.16	2.5
Lysite Mountain	(3)	5	42.7	9.8	2.2	.44	1.2	15.6	2.0	4.2	4.3	.30	4.3	.14	8.9

[1] Average of 26. [2] Average for one zone. [3] Average for all zones analyzed.

TABLE 17.—*Semiquantitative spectrographic analyses from the four areas of Eocene rocks studied in Wyoming, and from the Uinta basin, Utah*

[Analysts: R. G. Havens, K. V. Hazel, J. C. Hamilton, and N. M. Conklin. Values are reported in percent to the nearest number in the series 7, 3, 1.5, 0.7, etc.; at least 60 percent of results are expected to be in the correct range. Elements looked for but not found: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, Hg, Ho, In, Ir, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Ta, Tb, Te, Tl, Tm, W, Zn. Elements not looked for: Cs, F, Rb. Values for U and P are omitted because splits of these samples were analyzed chemically and results given in tables 2, 8, 11, 13, and 14]

Area	Zone	Number of samples	Si	Al	Fe	Mg	K	Na	Ca	Ti	Ba	V	Mn	Sr	Zr	B	Cr	Cu	Ni	La
Green River	[1] 1	7	>10.0	7.0	1.5	3.0	5.0	7.0	>10.0	0.3	0.07	0.015	0.07	0.15	0.03	0.015	0.007	0.007	0.003	0.015
	[2] 2	4	>10.0	7.0	1.5	3.0	7.0	3.0	>10.0	.15	.07	.015	.03	.15	.003	.03	.007	.003	.003	.007
	[3] 2a	3	>10.0	7.0	3.0	3.0	5.0	3.0	>10.0	.15	.07	.015	.07	.3	.007	.015	.007	.003	.0015	.007
	[4] 3	8	>10.0	7.0	3.0	7.0	3.0	3.0	>10.0	.15	.07	.015	.03	.3	.005	.007	.007	.003	.003	.007
	3a	1	7.0	7.0	1.5	7.0	3.0	3.0	>10.0	.07	.07	.007	.07	.3	.003	.007	.007	.0015	.0015	.0
	4	2	>10.0	3.0	1.5	7.0	3.0	3.0	>10.0	.07	.07	.007	.07	.3	.003	.003	.003	.0015	.0015	.0
	4aa	1	>10.0	3.0	1.5	3.0	3.0	1.5	>10.0	.07	.07	.007	.07	.3	.003	.003	.003	.0015	.0015	.0
	4b	1	3.0	3.0	.7	3.0	3.0	>10.0	>10.0	.03	.07	.007	.03	.7	.0015	.003	.003	.0015	.0007	.0
	4c	1	1.5	.7	.3	1.5	1.5	>10.0	>10.0	.015	.07	.003	.007	.7	.0	Trace	.0015	.0003	.0003	.003
	7	1	>10.0	3.0	1.5	7.0	3.0	3.0	>10.0	.07	.07	.007	.07	.3	.003	.007	.003	.0015	.0015	.0
	8a	1	7.0	3.0	.7	7.0	3.0	3.0	>10.0	.07	.07	.003	.07	.15	.0015	.007	.003	.0015	.0007	.0
	9	1	>10.0	7.0	1.5	7.0	3.0	7.0	7.0	.07	.07	.015	.07	.15	.003	.015	.007	.003	.0015	.0
	9b	1	7.0	1.5	3.0	3.0	3.0	7.0	>10.0	.07	.07	.007	.15	.3	.0015	.007	.003	.0015	.0015	.0
	10	1	7.0	1.5	.7	7.0	3.0	.7	>10.0	.03	.07	.007	.03	.3	.0015	.0015	.003	.0007	.0015	.0
	11	1	>10.0	3.0	1.5	7.0	3.0	.7	>10.0	.07	.07	.007	.07	.3	.003	.007	.003	.0015	.0015	.0
	11a	1	7.0	3.0	.7	7.0	3.0	1.5	>10.0	.07	.15	.007	.03	.3	.003	.007	.003	.0015	.0015	.0
Pine Mountain	------	4	>10.0	5.0	2.0	.7	1.5	3.0	>10.0	.1	.1	.01	.07	.2	.03	.0	.007	.003	.003	.003
Beaver Divide	------	1	>10.0	7.0	1.5	1.5	7.0	3.0	7.0	.15	.15	.015	.07	.15	.015	.003	.007	.007	.003	.07
Lysite Mountain [5]	------	5	>10.0	7.0	1.5	.7	5.0	1.5	>10.0	.15	.07	.007	.07	.15	.007	.0	.003	.0015	.0015	.007
Uinta Basin	------	4	>10.0	7.0	3.0	3.0	3.0	3.0	>10.0	.15	.07	.015	.07	.07	.015	.007	.007	.007	.003	.003

Area	Zone	Number of samples	Y	Sc	Co	Pb	Ga	Nb	Yb	Be	Mo	Li	Ce	Nd	Th	Sn	Sm	Dy	Er	Gd
Green River	[1] 1	7	0.05	0.005	0.0007	0.007	0.0015	0.0015	0.007	0.0003	0.0003	0.0	0.05	0.03	0.03	0.01	0.015	0.0	0.0	0.0
	[2] 2	4	.015	.003	.0007	.007	.0007	.0	.0015	.00015	Trace	.02	.0	.007	.0	.0	.0	.0	.0	.0
	[3] 2a	3	.03	.0015	.0007	.003	.0007	.0	003	.0	.0	.03	.0	.015	.05	.0	.0	.0	.0	.0
	[4] 3	8	.015	.0015	.0007	.003	.0007	.0	.0015	.0	.0	.015	.0	.007	.03	.0	.0	.0	.0	.0
	3a	1	.007	.0007	.0007	.0	.0007	.0	.0007	.0	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0
	4	2	.007	.0007	.0003	.0	.0007	.0	.0007	.0	.0	.07	.0	.0	.0	.0	.0	.0	.0	.0
	4aa	1	.007	.0007	.0003	.0	.0007	.0	.0007	.0	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0
	4b	1	.003	.0015	.0003	.0	.00015	.0	.0003	.0	.0007	.0	.0	.0	.0	.0	.0	.0	.0	.0
	4c	1	.007	.0	.0	.0	.0	.0	.0007	Trace	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	7	1	.015	.0015	.0003	.0	.0003	.0	.0015	.0	.0	.07	.0	.0	.0	.0	.0	.0	.0	.0
	8a	1	.007	.0007	.0003	.0	.00015	.0	.0003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	9	1	.007	.0015	.0007	.0	.0007	.0	.0007	.0	.0	.015	.0	.0	.0	.0	.0	.0	.0	.0
	9b	1	.007	Trace	.0003	.0	.00015	.0	.0007	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	10	1	.007	.0	.0	.0	.00015	.0	.0003	.0	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0
	11	1	.015	.0015	.0003	.0	.0003	.0	.0007	.0	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0
	11a	1	.007	Trace	.0003	.0	.00015	.0	.0007	.0003	.0007	.015	.0	.0	.0	.0	.0	.0	.0	.0
Pine Mountain	------	4	.007	.0015	.0015	.005	.0005	.0	.0007	.0003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Beaver Divide	------	1	.03	.0015	.0007	.003	.0015	.0	.0015	.0	.0007	.0	.07	.03	.03	.0	.0	.007	.007	.007
Lysite Mountain [5]	------	5	.007	.003	.0005	.0015	.0007	.0	.0007	.00015	.0007	.0	.03	.015	.0	.0	.0	.0	.0	.0
Uinta Basin	------	4	.007	.0015	.0007	.015	.0007	.0	.0015	.0	.0	.07	.0	.0	.0	.0	.0	.0	.0	.0

[1] Nb in 1 sample; Be in 4 samples; Mo in 2 samples; Sm in 1 sample; Th in 1 sample; Sn in 1 sample; Li in 2 samples.
[2] Pb in 1 sample; Be in 1 sample; Nd in 1 sample.
[3] Nd in 2 samples; Th in 2 samples; Li in 2 samples.
[4] Nd in 4 samples; Th in 2 samples.
[5] Ce in 1 sample; Nd in 2 samples.

sedimentary rocks have abnormally high concentrations of uranium and phosphate. The much thicker intervals separating these zones are, on the other hand, abnormally low in phosphate and probably also in uranium. For example, in the Wilkins Peak Member, 41 samples from strata between the zones average 0.07 percent P_2O_5, or half that in the Pierre Shale. Comparative data on uranium are inadequate because analyses were carried only to 0.001 percent.

The total amount of uranium and phosphate in all the rich zones of the Wilkins Peak Member, plus that in the lean intervals between them within a given area, does not exceed the amount expected in an equal volume of "average" shale, Pierre Shale, or "average" dacitic-andesitic volcanic rock. The uranium and phosphate in the thin rich zones, alone, account for only one-tenth to one-third of this theoretical total.

It is concluded, therefore, that neither adjacent source rocks nor wind- or water-borne volcanic debris abnormally rich in uranium and phosphate is necessary to explain the presence of the uraniferous phosphatic zones. If anything, the source areas supplying clastic debris to the Green River basin were probably slightly deficient in phosphate in both Wilkins Peak and Tipton times. The average of 18 random samples from the Tipton is only 0.11 percent P_2O_5.

Table 12 shows analyses of radioactive and nonradioactive rocks of various geologic ages. Many of the post-Eocene samples are from lacustrine, in some instances saline, uranium-bearing beds. None shows abnormally high phosphate content. A comparison of the analyses in table 12 and the ones in table 3 with those in tables 2, 8, 11, 13, 14, and 15, indicates that most of the abnormally uraniferous rocks in the stratigraphic succession in Wyoming contain very little phosphate. One exception that has long been recognized is the marine Phosphoria Formation of Permian age (McKelvey and others, 1955, p. 520–524); the other is the lacustrine Eocene sequence described here. As far as is now known, only during Eocene time, in four or more unconnected lake basins, were thin zones formed that contain unusually high concentrations of uranium and phosphate separated by thicker units with average or below-average amounts.

A syngenetic interpretation of the origin of the uraniferous phosphatic zones is that they accumulated at the bottom of Gosiute Lake as the sediments were being deposited, and an epigenetic view is that they formed shortly after deposition of the enclosing strata. One syngenetic interpretation is based on the following combination of data and assumptions. Expulsion upward of connate water, enriched in some manner with uranium and phosphorus during initial stages of compaction of sediments could result in concentration of these elements along the bottom of Gosiute Lake. Unknown are the factors that might have kept uranium and phosphorus in solution while thick barren sedimentary units were being deposited; unknown also are factors that might have caused their widespread concentration in thin zones, many of which have for the most part the same lithology as overlying and underlying strata.

The chemical and thermal stratification of Uinta Lake in the Uinta basin and the lake in the Fossil syncline (fig. 2) during Eocene time have been described (Hunt and others, 1954, p. 1693–1697; Bradley, 1948, p. 644). The phosphorus expelled into the hypolimnion could be protected from seizure by organisms living in the upper fresher water by a barrier of stable layers of water charged with toxic salines or hydrogen sulfide. Perhaps temperature and humidity changes, in combination with ash falls of some special type or size, may have disrupted this stratification at times when the concentration of uranium and phosphorus reached a critical point, thereby causing a widespread deposition of these elements in a thin layer of sediment. Although some zones are closely associated with tuff beds, many others are not; so the mechanical influence of ash falls may not be important. However, if the ash was extremely fine grained, or of unusual chemical composition, and was disseminated or chemically altered before lithification, it could have been genetically significant without being physically conspicuous. It is interesting to note that fine-grained tuffaceous debris is abundant in all basins where uraniferous phosphatic zones have been recognized.

If only the Green River basin were considered, it could be inferred that the drastic shrinking of Gosiute Lake to a saline remnant at the beginning of Wilkins Peak time established conditions favorable to the emplacement of the uraniferous phosphatic zones. Some zones directly overlie or underlie beds of trona or salt; so undoubtedly these zones were deposited in very shallow water under extremely saline conditions. However, several other basins that contain uraniferous phosphatic zones lack evidence of salinity; therefore it cannot be the key factor.

W. H. Bradley (written commun., 1962) has brought to the writer's attention a chemical characteristic (other than the uranium and phosphate content) common to all the dolomitic rocks in these zones in the Green River basin. The zones have a much greater excess of CaO over MgO (3.1 vs 1.7) than have the interzone uranium- and phosphate-poor strata in the Wilkins Peak Member. This relationship can be illustrated by comparing CaO and MgO on figure 20 with values given by Fahey (1962, table 3) for random samples of nonphosphatic beds. Bradley suggested (written commun., 1962):

> that the thin phosphate-rich zones in the Wilkins Peak Member may simply represent times when calcium carbonate precipitation was very rapid and swept out the phosphorus from the lake water, depositing it as tricalcium phosphate.

He recognized, however, that while this line of reasoning might explain the abnormally rich zones, it does not account for the paucity of phosphorus in the intervening strata; nor does it explain why the uraniferous phosphatic zones are confined to Eocene rocks. After all, fresh-water limestones, limy shales, and limy siltstones containing normal amounts of phosphate and abundant tuffaceous debris are present in Oligocene, Miocene, Pliocene, and Pleistocene rocks of this region. Some thin beds have abnormally high concentrations of uranium (table 12), but none has a concentration of phosphate.

Rates of accumulation of various types of sediment during Green River time have been calculated by Bradley (1930, p. 107–109). On the basis of his data, each uraniferous phosphatic zone, depending on its individual lithology and thickness (a 3-in. layer of fine-grained rock would represent 500 yr), would have accumulated during a period of 500 to 10,000 years, if the syngenetic origin is correct.

An epigenetic interpretation is that the uraniferous phosphatic zones were formed shortly after deposition of the enclosing strata, by enriched connate water moving up, down, or laterally during compaction until it was trapped by porosity and permeability barriers or until the uranium and phosphate were precipitated in favorable host rocks (R. F. Beers and W. B. Heroy, quoted by McKelvey and others, 1955, p. 517). Data necessary to evaluate this interpretation have been obtained only in the Green River area where the process could explain some of the localized concentrations observed in zone 1. However, it is difficult to visualize conditions so uniform that zone after zone could develop in this manner throughout an area of 1,000 to 2,500 square miles in strata of low porosity and permeability. Zones do not appear to cross bedding planes (with the local exception of parts of zone 1). In addition, the zones consist of a variety of lithologies, such as oil shale, shale, siltstone, and dolomite, within sequences of similar lithology that are poor in uranium and phosphate; thus, the requirements for a favorable host rock are hard to recognize.

It is concluded that the origin of these zones can be determined only when geochemical and mineralogical data on samples taken at closely spaced stratigraphic intervals are obtained, both from the zones and from intervening barren strata in several localities in each of the known areas of occurrence. A beginning can then be made on a study of uranium and phosphate in nonmarine strata that will be comparable in objectives to the superb study by Swanson (1961) of marine black shales. Possibly the Uinta basin, with its thick section of the Green River Formation, numerous radioactive and probably numerous phosphatic zones, vast area, and abundant subsurface data, will yield enough critical information to determine the origin of the uraniferous phosphates.

GEOCHEMICAL TIME LINES

Plates 3 and 5 show in part and suggest in part the stratigraphic and geochemical continuity of thin uraniferous phosphatic zones in the Wilkins Peak Member throughout several hundred to several thousand square miles of the Green River basin. These zones also have widespread parallelism with thin nonradioactive marker units, such as certain tuff beds, oil shales, and trona beds, and probably represent time lines that can be utilized in stratigraphic and structural interpretation of the Green River basin.

If the main factors responsible for the uraniferous phosphatic zones—such as, perhaps, temperature, humidity, and the presence of very fine grained volcanic debris—are not confined to individual basins but involve regions, they could conceivably have caused simultaneous concentrations of uranium and phosphate in unconnected lake basins with similar environments. Such geochemical time lines would be of major value in interbasin correlation and interpretation of geologic history during the Eocene Epoch.

ECONOMIC SIGNIFICANCE OF URANIFEROUS PHOSPHATIC ZONES

The occurrence of uranium and phosphate in significant quantity in lacustrine strata is here demonstrated for the first time, and the information should encourage a search for similar deposits in basins containing lacustrine strata in other parts of the world.

Table 6 summarizes the grade and tonnage estimates of uranium and phosphate in the Green River area; not enough data are available for estimates in the other described areas. Deposits may be of economic interest in some localities where maximum thickness, maximum uranium, and maximum phosphate content coincide with conditions favorable to inexpensive strip mining. In most places, however, the zones sampled were not of economic interest under the market conditions of 1961. Richer thicker deposits may be present in other parts of the six described areas or in some of the uninvestigated intermontane basins.

Analyses of cores representing several thin stratigraphic intervals in the Green River area indicate at least local concentrations of more than 20 percent bradleyite ($Na_3PO_4 \cdot MgCO_3$), but the economic potential of this mineral has not been evaluated. A study of the rare-earth minerals and other unique mineral assemblages is in progress (Charles Milton, written commun. 1961).

The uraniferous phosphatic zones can be used as stratigraphic markers in structural studies related to the search for oil and gas in the Green River basin and probably also in the Uinta and Piceance Creek basins. For example, as previously mentioned in the discussion of the Green River area, a sandstone in the Tipton Shale Member merges with one in the lower part of the Wilkins Peak Member and extends south and southwest from the Wind River Mountains as far as section 17, plate 3, section *C–C′*. However, east of a line between sections 17 and 22, plate 3, section *C–C′*, this sandstone pinches out updip and is not exposed in the area shown on plate 2. The sandstone is porous and permeable in some cores and is underlain by oil shale. The possibility of shallow oil and gas traps in this sandstone has not been explored as of 1962.

A regional structural interpretation based on correlation of uraniferous phosphatic zones is presented on figure 11. Of the three anticlines involving the Green River Formation, Church Buttes has yielded gas in pre-Tertiary rocks. The Marston and Firehole anticlines have not been tested as of 1962.

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