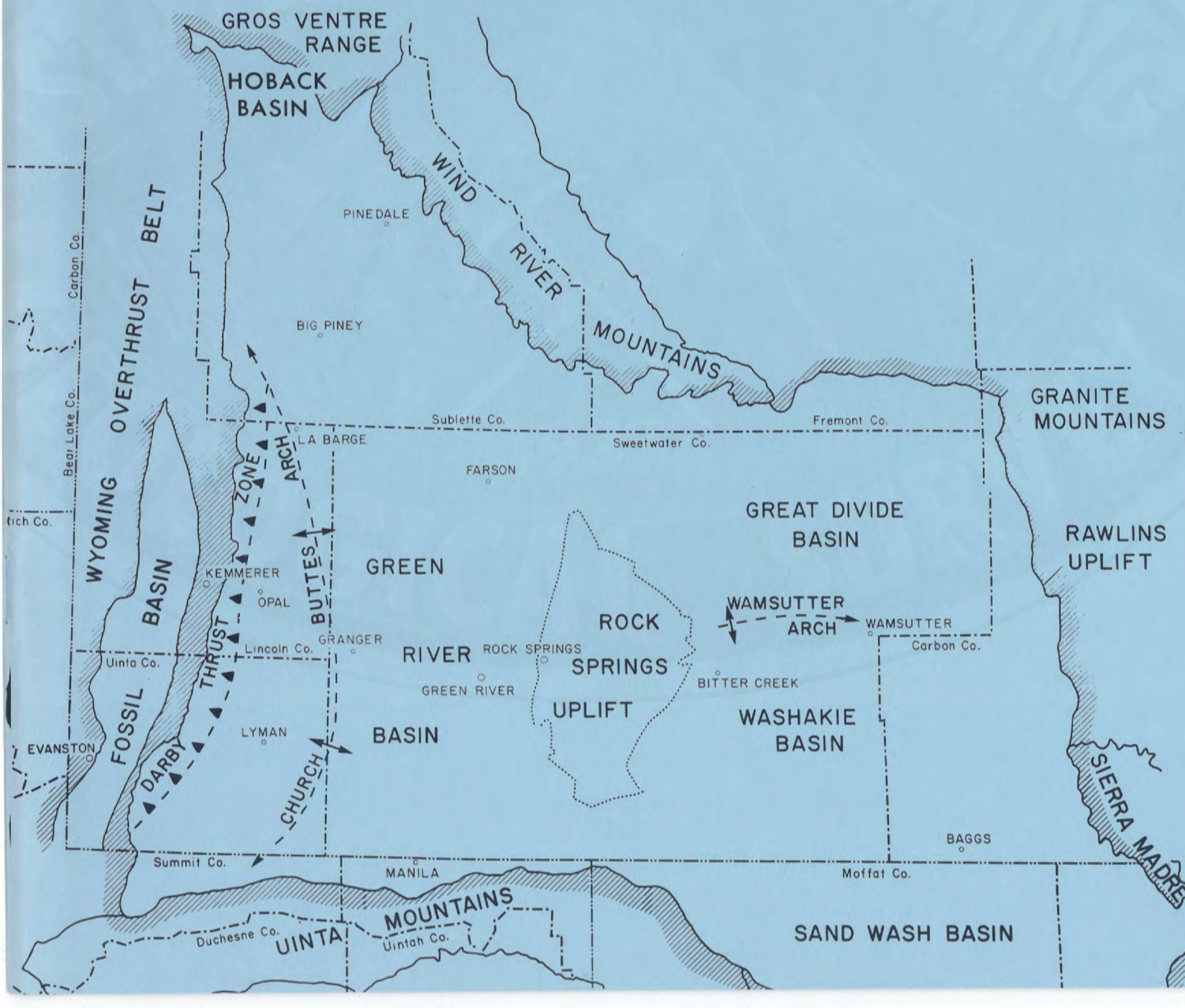
THE GEOLOGICAL SURVEY OF WYOMING
Daniel N. Miller, Jr., State Geologist

REPORT OF INVESTIGATIONS No. 20

A STRATIGRAPHIC EVALUATION OF THE EOCENE ROCKS OF SOUTHWESTERN WYOMING

by

RAYMOND SULLIVAN



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RAYMOND SULLIVAN
Department of Geology
San Francisco State University

LARAMIE, WYOMING
1980

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ABSTRACT

The early Tertiary rocks in southwestern Wyoming comprise 10,000 to 20,000 feet (3,000 to 6,000 meters) of a basically conformable succession of Fort Union, Wasatch, Green River and Bridger-Washakie Formations. This sequence of rocks was deposited in an extensive intermontane basin system surrounded by high marginal uplands. Streams from the surrounding uplands deposited sediments to form the predominantly fluvial succession of Wasatch, Bridger and Washakie Formations. During the early and middle Eocene, continued downwarping caused a series of lakes (Lake Gosiute) to form in which was deposited a succession of lacustrine sediments of the Green River Formation. Throughout their history, the lakes fluctuated in size in response to climatic and tectonic changes. The oscillations of the lakes resulted in the Green River Formation intertonguing with rocks of the upper part of the Wasatch Formation and the lower part of the Bridger and Washakie Formations.

In southwestern Wyoming, the Green River Formation is made up of the Luman, Tipton Shale, Wilkins Peak, and Laney Members. Along the western margin of the Green River Basin, it is possible to subdivide the Laney Member into the Craven Creek Bed (new name) and the Cow Hollow Bed (new name): these beds are separated by a fluviatile clastic unit, the Whiskey Butte Bed (new name) of the Bridger Formation.

The main center for lacustrine deposition of the Green River Formation was along the front of the Uinta Mountains in the Green River and Washakie Basins. During the time of Wilkins Peak Member, however, a shift in the depositional pattern occurred, with the main center of lacustrine formation being located in the southern part of the Green River Basin. This change was accompanied by the development of rich saline deposits in the Green River Formation.

The intermittent uplifts of the marginal uplands are indicated by clastic tongues of the Wasatch Formation intertonguing with the Green River Formation. It can be demonstrated that these synorogenic deposits had variable sources and that the marginal uplands behaved as independent tectonic units. The Niland and Cathedral Bluffs Tongues had a provenance to the east and south in the Sierra Madre, Granite and Uinta Mountains. The New Fork Tongue had a source from the north and west in the Wind River Mountains and the Overthrust Belt. The Desertion Point Tongue (new name) had a source to the south in the Uinta Mountains. During mid-Eocene times, with the deposition of the Bridger and Washakie Formations, an increased influx of detrital volcanic sediments from the north resulted in the gradual filling of the intermontane basin, marking the development of the sedimentary cycle which continued into the Pliocene with the reestablishment of exterior drainage in the central Rocky Mountains.

INTRODUCTION

The present-day Green River, Hoback, Washakie, Sand Wash and Great Divide Basins are part of a larger Tertiary hydrographic basin system that covered about 48,500 square miles (77,300 square kilometers) (see Figure 2). The hydrographic basin formed in the central part of the Rocky Mountains due to crustal downwarping in early Tertiary times. In each of the basinal structures, the Precambrian basement is more than 20,000 feet (6,000 meters) below sea level; the basinal structures are filled with a thick succession of Paleozoic, Mesozoic and Cenozoic rocks. It is the early Tertiary continental deposits, formed in an intermontane setting, that are the main concern of the present account.

The intermontane basin was enclosed by a series of peripheral mountains formed by faulting of blocks of Precambrian quartzite and metaquartzite rocks in the Uinta Mountains, mainly Precambrian granitic rocks in the Sierra Madre, Granite, and Wind River Mountains, and Paleozoic-Mesozoic sedimentary rocks in the Wyoming Overthrust Belt. Erosion of these marginal structures during the early Tertiary provided varied sources of sediment for deposition in the subsiding basin.

The early Tertiary rocks comprise between 10,000 and 20,000 feet (3,000 and 6,000 meters) of a basically conformable succession of Fort Union, Wasatch, Green River and Bridger-Washakie Formations (see Figure 1). This sequence of rocks was deposited in an extensive alluvial plain within the intermontane basin. Streams from the surrounding upland deposited sediments to form the predominantly fluvial succession of Wasatch and Bridger-Washakie Formations. During the early and middle Eocene, continued downwarping caused a series of lakes (Lake Gosiute) to form in which was deposited a succession of lacustrine sediments of the Green River Formation. Throughout their history, the lakes fluctuated in size, the oscillations of the lakes resulting in the Green River Formation intertonguing with rocks of the upper part of the Wasatch Formation and the lower part of the Bridger-Washakie Formations. Volcanoes were active during the Eocene and extrusive material was widely distributed from sources in the Absaroka-Yellowstone and other areas. The climatic environment during the Eocene has been shown by Leopold and MacGinitie (1972, page 148-176) to have varied between mainly subhumid subtropical during drier times and humid subtropical during wetter periods.

This large intermontane system was subdivided into smaller structural basins by middle to late Eocene uplifts associated with the Laramide Orogeny (Braunagel and Stanley, 1978, page 1202). The resulting structural trends are thought to have been strongly influenced by the Precambrian basement framework (Sales 1971; Thomas 1971). In the terminology of Love (1961), the Green River Basin, together with the small subsidiary structure of the Fossil Basin, have a north-south synclinal form. The Green River Basin, however, changes to a northwest-southeast structure at its northern end along the front of the Wind River Mountains. The Hoback Basin is the northernmost extension of the Green River Basin; the two are separated by a distinct and continuous physiographic divide named "the rim". The Washakie and Great Divide basins are separated by the Wamsutter arch, and are, in turn, isolated from the Green River Basin by the Rock Springs uplift. The Sand Wash Basin is separated from the Washakie Basin by the anticlinal structure

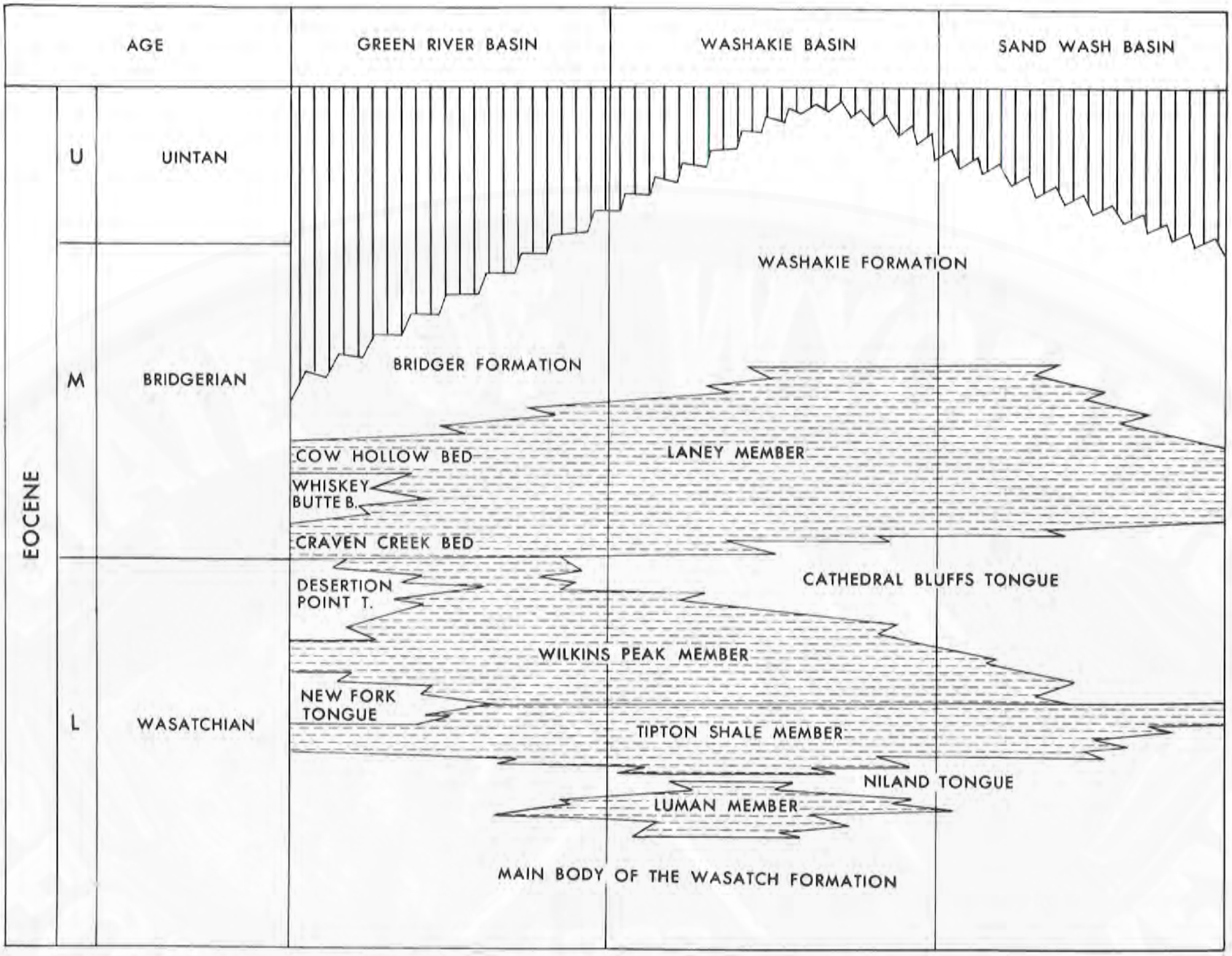


Figure 1. The age and stratigraphic relationships of the Wasatch, Green River, and Bridger-Washakie Formations in southwestern Wyoming (in part after Roehler, 1974).

of the Cherokee Ridge. The structural trends of the Washakie Basin and Rock Springs uplift are approximately north-south. The Great Divide and Sand Wash Basins, Wamsutter arch, and Cherokee Ridge have a general east-west trend (see Figure 2).

PURPOSE OF THE STUDY

The work was initiated as a study of the stratigraphic relationships of the early Tertiary rocks along the western margins of the Green River Basin. The area was one of the last major parts of the Green River Basin to be studied and, as a result, provided an opportunity for a regional synthesis of the early Tertiary stratigraphy of southwestern Wyoming.

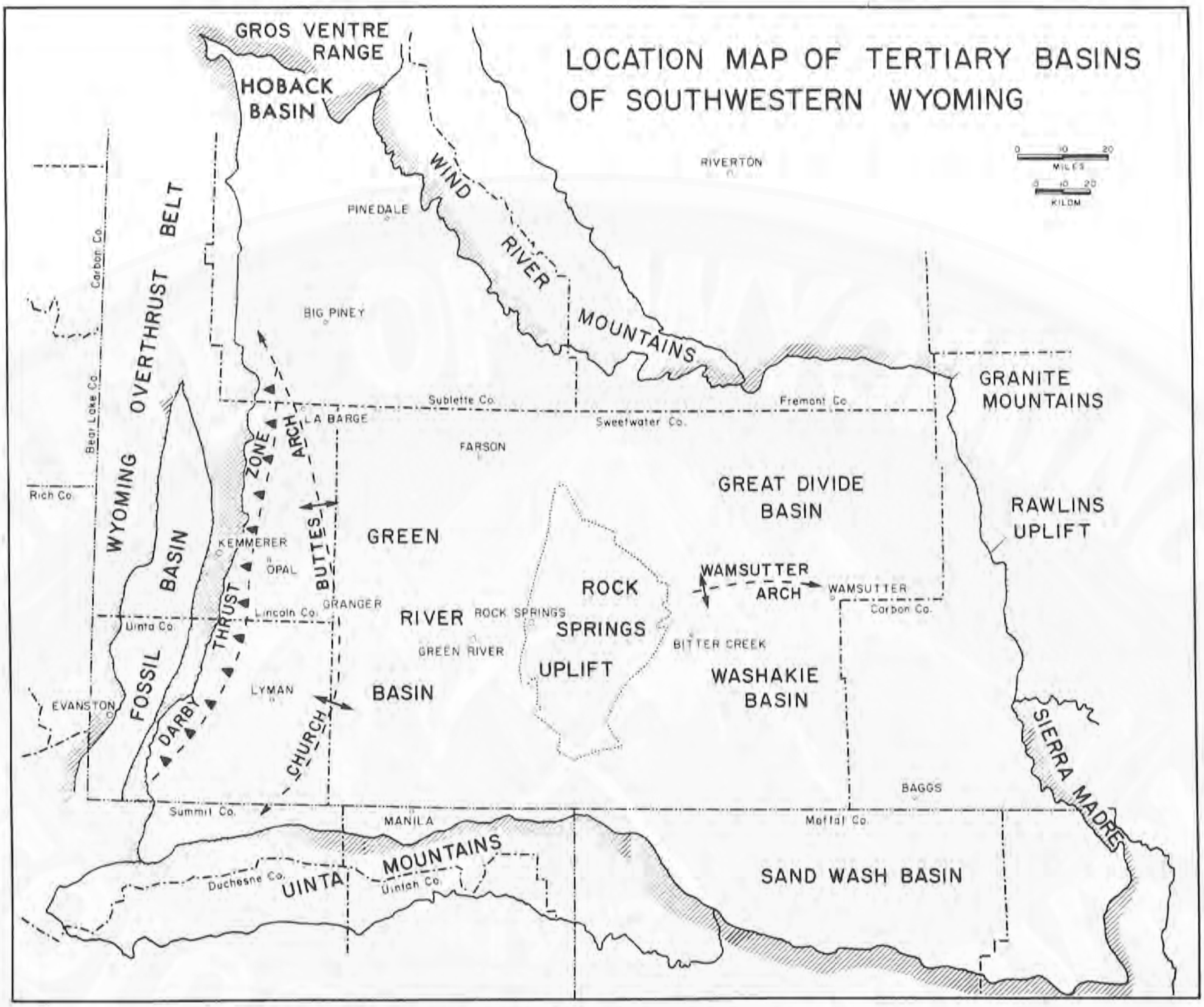


Figure 2. Location map of the Tertiary basins of southwestern Wyoming.

Much of the regional study entailed a compilation of previously published surface and subsurface data. As may be expected in such an analysis, the interpretation is only as good as the available data. One only has to compare the detailed subsurface correlations of Love (1964), Roehler (1968, 1969, 1973b) and Colson (1969) in the Washakie Basin to realize the varying interpretations that can be presented. In the present study, care has been taken to cross check the correlations with several published sources.

It is also evident that a great deal of unpublished stratigraphic work has been done by the numerous petroleum, chemical, and other exploration companies in this important economic area of the western United States. As a result, it is hoped that this study will encourage other workers to revise and update the stratigraphic evaluation of the early Tertiary rocks of southwestern Wyoming.

ACKNOWLEDGMENTS

I wish to express my thanks to Dr. P. O. McGrew for introducing me to the early Tertiary stratigraphy of southwestern Wyoming. Dr. McGrew has encouraged me in my work and provided invaluable assistance and advice. I also acknowledge with gratitude the help given to me by Dr. J. D. Love and Dr. G. B. Glass for reading and criticizing the manuscript; Gary Palmer and Maria DeCarvalho for assisting me in the drafting of the figures, and Kerry Davis for typing the manuscript.

WASATCH FORMATION

The Wasatch Formation was first described by Hayden (1869) for a thick succession of predominantly red colored fluviatile rocks of early Eocene age. The occurrence of the formation and its various members has been discussed by Bradley (1964). The Wasatch Formation is conformably underlain by the Fort Union Formation of Paleocene age over most of the central part of the basins. It is often difficult to separate the two formations in the subsurface, and unless local criteria have been established, they are commonly treated as a single lithological unit. At the margins of the basins the Wasatch Formation is often incompletely represented and lies unconformably on the Fort Union Formation or late Mesozoic rock.

Oriel (1962) and Bradley (1964), in order to simplify the terminology, have applied the term "main body of the Wasatch Formation" for this part of the succession that underlies the Green River Formation. Included in the main body of the Wasatch Formation are members that have been described in various parts of the basin, including the Hiawatha Member in the southern part of the Green River Basin (Nightingale, 1930), the Red Desert Tongue and Battle Spring Formation in the Great Divide Basin (Pipiringos, 1962), the Chappo and La Barge Members along the western margin of the Green River Basin (Oriel, 1962, 1969), the Pass Peak Formation in the Hoback Basin (Dorr et al., 1977), and the Nightingale Member in the southeastern part of the Green River Basin (Roehler, 1965).

The main body of the Wasatch Formation, of early Eocene age, was laid down in major depositional centers in southwestern Wyoming located in the Green River and Hoback, Great Divide, and Washakie Basins. Strong subsidence occurred in these centers and over 12,000 feet (3,700 meters) of Fort Union and main body sediment were deposited in the Hoback and the northern Green River Basins, and over 7,000 feet (2,100 meters) in the southern Green River, Great Divide, and Washakie Basins (see Figure 3).

The Fort Union and main body of the Wasatch Formation thin outwards from these centers toward the Rock

Springs uplift. Bradley (1964) and Roehler (1965) have suggested that this uplift was active along the Wamsutter arch and may have supplied detritus to the basins. It is also clear that the surrounding marginal uplands were the main source of sediments during this phase of the Laramide Orogeny.

The general lithology of the Wasatch Formation can be described as a sandstone-mudstone lithofacies. Roehler (1965, 1974) recognized three main types of sandstone-mudstone lithofacies in the Wasatch Formation: (i) a red-bed fluviatile facies, (ii) a pediment facies, and (iii) a non-red fluviatile-paludal facies.

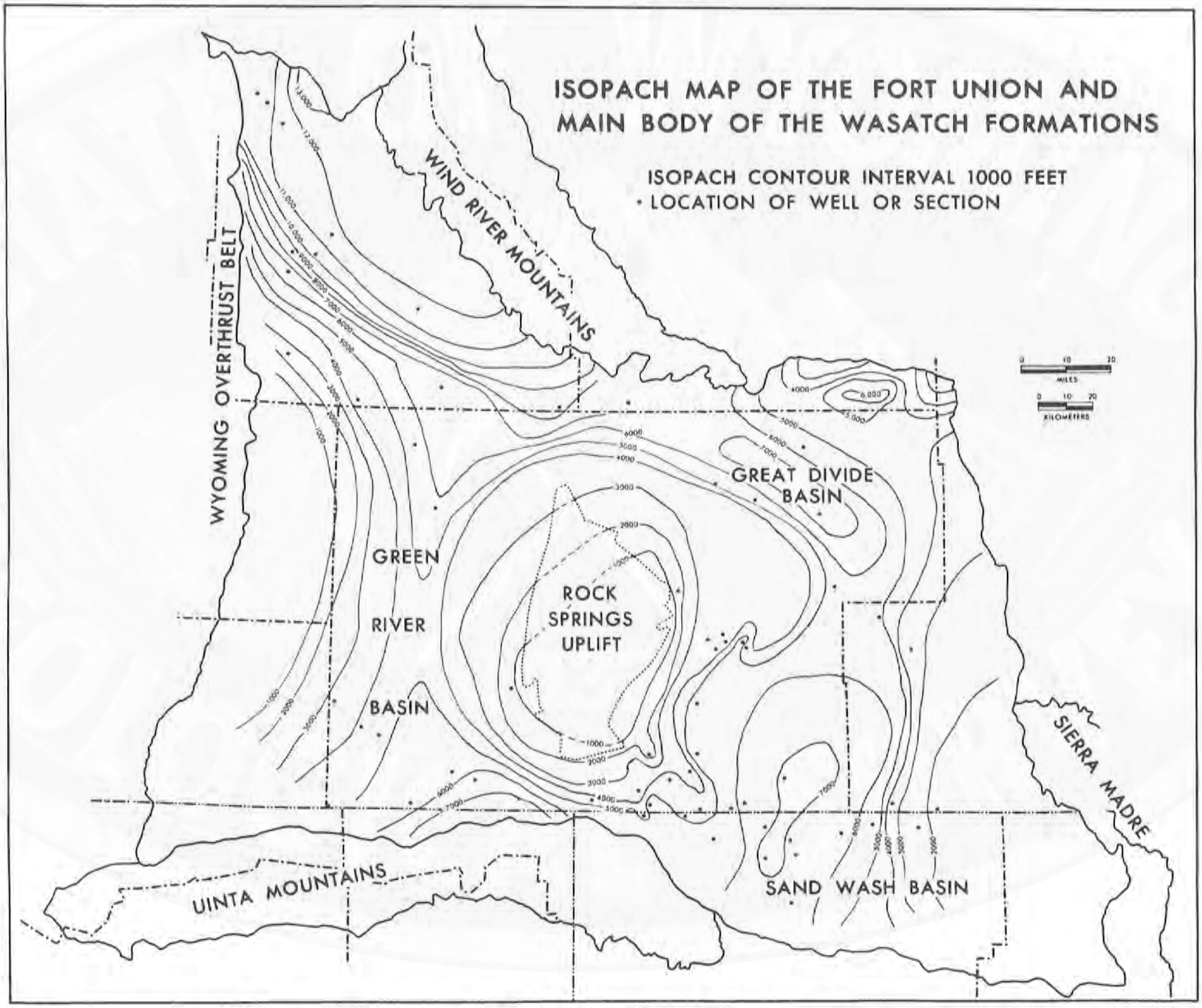


Figure 3. Isopach map of the Fort Union and main body of the Wasatch Formations. Data based on Bradley (1964), Colson (1969), Curry (1969, 1973), Dorr et al. (1977), Love (1964,1970), Masursky (1962), Spearing (1969), and Steidtmann (1969).

The lithology of the main body is typically represented in the basins of southwestern Wyoming by a heterogeneous sequence of brightly colored detrital rocks with some interbedded limestone and marlstone of the red-bed fluviatile facies. This facies shows abrupt variations and gradations in lithology and color when traced in outcrop. The most highly colored rocks are usually variegated mudstone with many shades of purple, red and orange. The colors, however, grade vertically and laterally into more subdued tones of pale yellow, tan, brown, green, and gray. The coarser clastic units of siltstone and sandstone are typically less brightly colored and occur in thin but extensive sheetlike bodies. Other coarser textured sandstones are irregularly lenticular with conglomeratic lenses containing rounded and subrounded clasts derived from the marginal uplands. In some areas the red-bed fluviatile facies contain rich arkosic detritus derived from the granitic rocks in the peripheral mountains. These are particularly well developed marginal to the Wind River and Granite Mountains. Pipiringos (1962, pages A34-A35) named this red colored, coarse arkosic development the Battle Spring Formation in the eastern and northern parts of the Great Divide Basin.

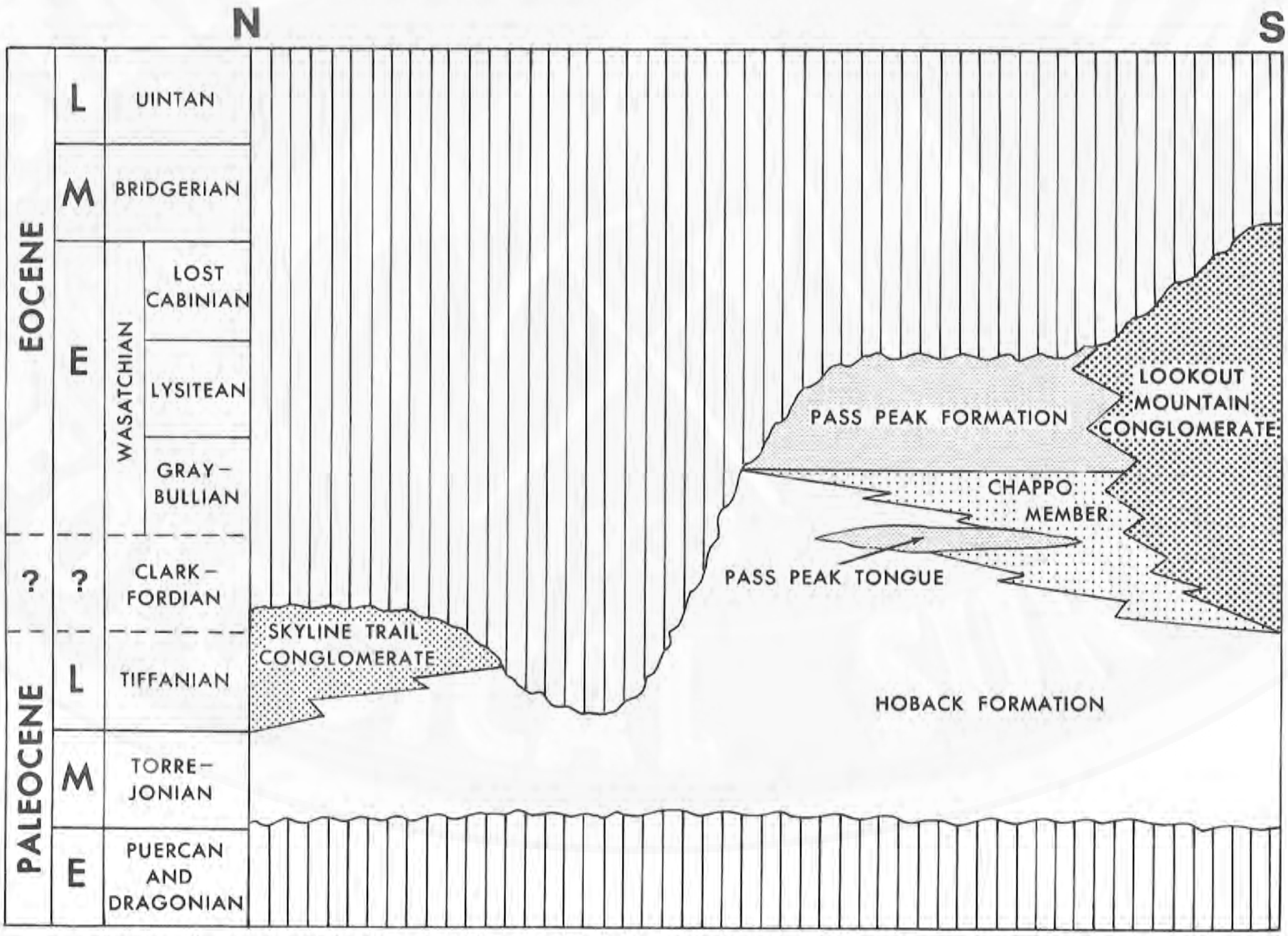


Figure 4. Generalized stratigraphic relationships in the Hoback Basin (after Dorr et al., 1977).

The red-bed fluviatile facies often grades toward the margin of the basins into a mountain front of pediment facies (see Figures 4 and 5). These deposits are often red colored fanconglomerates with interbedded sandstones. Various workers in the region have given the pediment facies various names, including the Crooks Gap Conglomerate in the Great Divide Basin (Love, 1970) and the Skyline Trail and Lookout Mountain Conglomerates in the Hoback Basin (Dorr et al., 1977). A conglomeratic succession was also identified along the southern margins of the Green River Basin by Bradley (1964, pages A22-A23) and Roehler (1965, page 144). Along the western margins of the Green River Basin Tracey et al. (1961) described a pediment (or diamictite) facies and related its occurrence to tectonic movement in the Overthrust Belt.

In other areas within the basins, the red-bed fluviatile facies is replaced by a non-red fluviatile-paludal development. It is characterized by

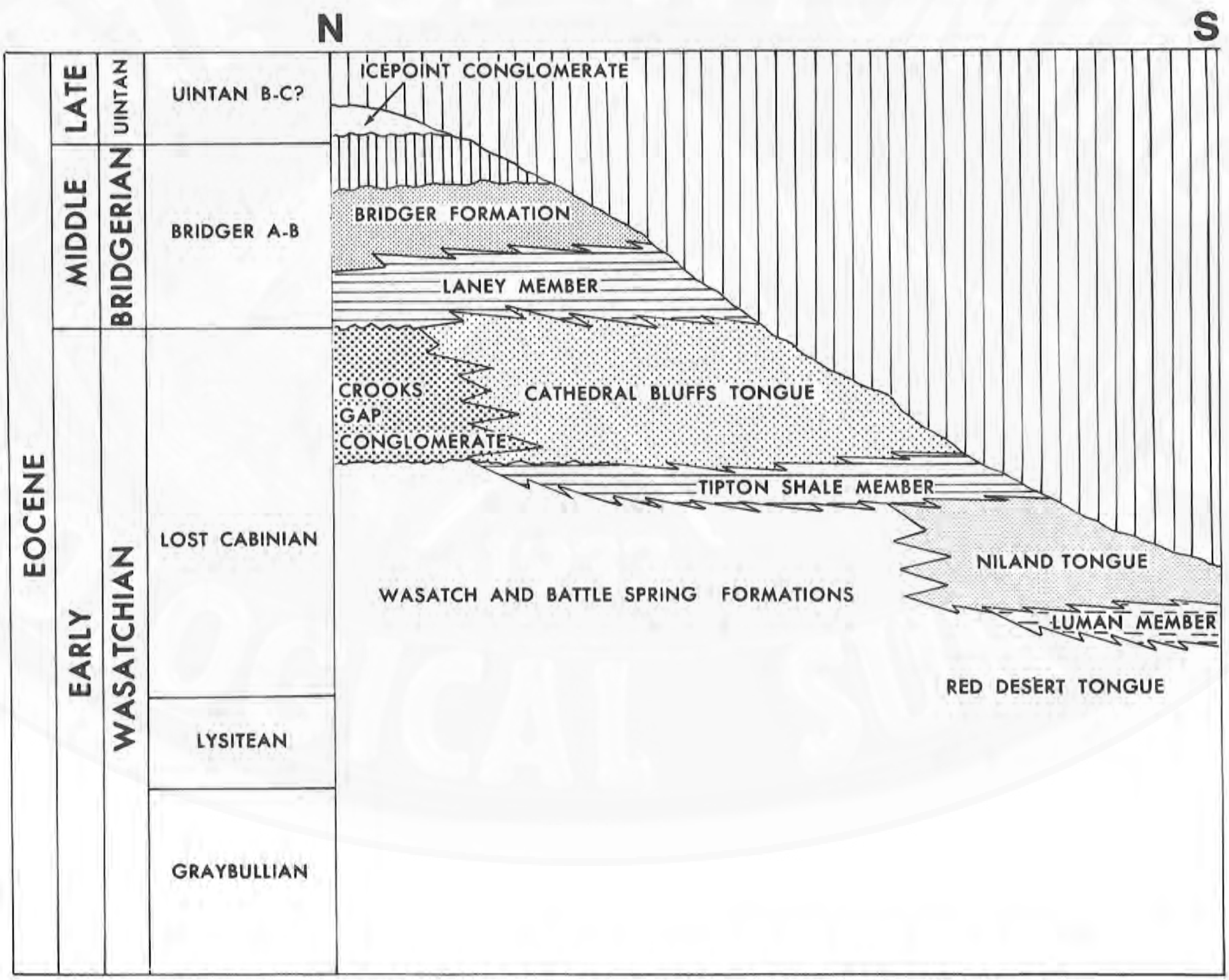


Figure 5. Genralized stratigraphic relationships in the Great Divide Basin (after Love, 1970).

gray and green colored sandstones and mudstones that are locally rich in carbonaceous shales and subbituminous coal deposits. Pipiringos (1962) named the non-red fluviatile-paludal facies in the Great Divide Basin the Red Desert Tongue of the Wasatch Formation. Southwest of the Rock Springs uplift in the Green River Basin, Roehler (1965, pages 144-145) described a non-red succession of the Wasatch Formation, which he termed the Nightingale Member.

In the upper part of the main body, tongues of the Wasatch Formation inter-

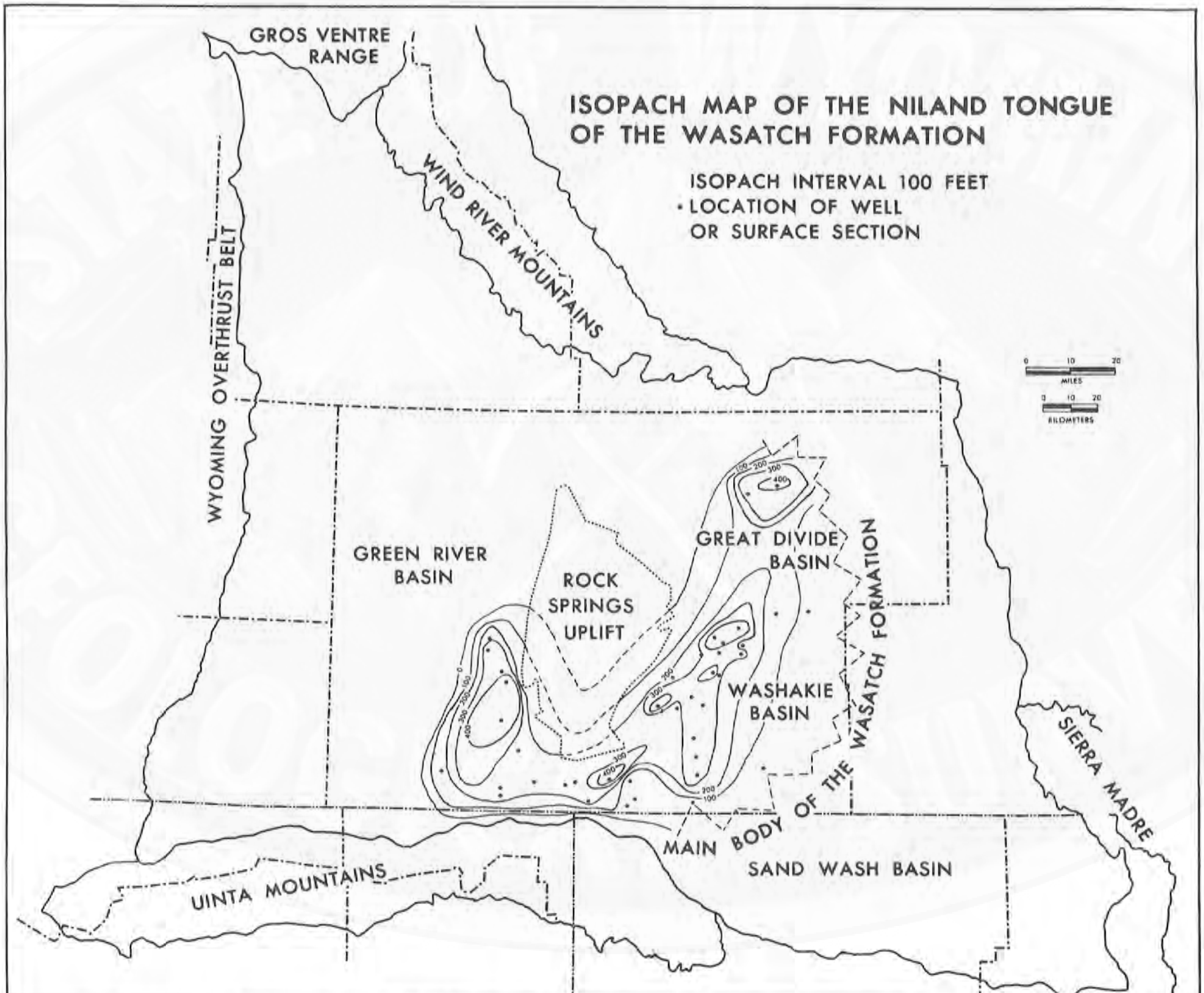


Figure 6. Isopach map of the Niland Tongue of the Wasatch Formation. Data based on Bradley (1964), Culbertson (1965), Love (1964), Pipiringos (1955, 1962), and Roehler (1965, 1969).

finger with the Green River Formation. These tongues have been individually named by various workers and include the Niland, New Fork, Cathedral Bluffs, and Desertion Point (new term proposed for the upper tongue of the Wasatch Formation of Oriel, 1961 and 1969, along the western margin of the Green River Basin).

Niland Tongue

The studies of Pipiringos (1962), Bradley (1964), and Culbertson (1965) indicate that the Niland Tongue is the first major tongue of the Wasatch Formation above the main body. The tongue has been dated as early Eocene (Lost Cabinian age), and is separated from the main body by the Luman Member and overlain by the Tipton Shale Member of the Green River Formation. The Niland Tongue was centered in the Washakie, Great Divide, and the southeastern part of the Green River Basin flanking the Rock Springs uplift (see Figure 6); it is not developed in the western and northern portions of the Green River Basin.

Pipiringos (1955, pages 100-102; 1962, pages A24-A29) described about 400 feet (120 meters) of the Niland Tongue at its type locality (T. 24 N., Rs. 95 and 96 W.) in the Great Divide Basin where it is represented by a non-red fluviatile-paludal facies. The Niland Tongue is predominantly composed of a sequence of drab-colored sandstone, siltstone, mudstone and coal beds. This mixed sequence of paludal and fluvial rocks grades westward into a predominantly lacustrine sequence of the Green River Formation. Eastward toward the margin of the basin the Niland Tongue loses its identity and becomes indistinguishable from the Battle Spring Formation.

Bradley (1964, pages A23-A26), Culbertson (1965, pages 151-155), and Roehler (1965, page 144; 1969, page 202) have described the Niland Tongue in the Washakie and Green River Basins, where it reaches a maximum thickness of over 400 feet (120 meters). In this depositional center, the tongue is also made up of a non-red, mixed sequence of fluvial and paludal rocks. The facies trend seen in the Great Divide Basin is, once more, established in this basin. Eastward and southward the mixed facies changes to fluviatile red mudstone and sandstone of the main body of the Wasatch Formation. In the Green River Basin, Culbertson (1965, page 154) considered that this mixed facies was developed in a low, elongated depression that was centered on the north line of T. 13 N. In the low lying area, swamps and lacustrine conditions persisted in front of the Uinta Mountain for much of the early Eocene.

The facies distribution of the Niland Tongue, therefore, indicates that it was deposited on an extensive alluvial plain stretching eastward from the Sierra Madre and Granite Mountains. The thickening of the tongue in the vicinity of the Rock Springs uplift could indicate that the structure may have been a local source of sediment for the Niland Tongue. There is no evidence in the literature, however, that the uplift was active at this time.

New Fork Tongue

The New Fork Tongue of early Eocene (Lost Cabinian) age is the lowermost of a series of clastic wedges of the Wasatch Formation along the western margins of the Green River Basin. It was first described by Donavan (1950) and redefined by Oriel (1961) in the Fort Hill-La Barge area. It is separated at its base from the main body by the Tipton (Fontenelle) Shale Member and is overlain by the Wilkins Peak (middle) Member of the Green River Formation. As the Green River tongues thin to a feather edge near the Overthrust Belt, the New Fork

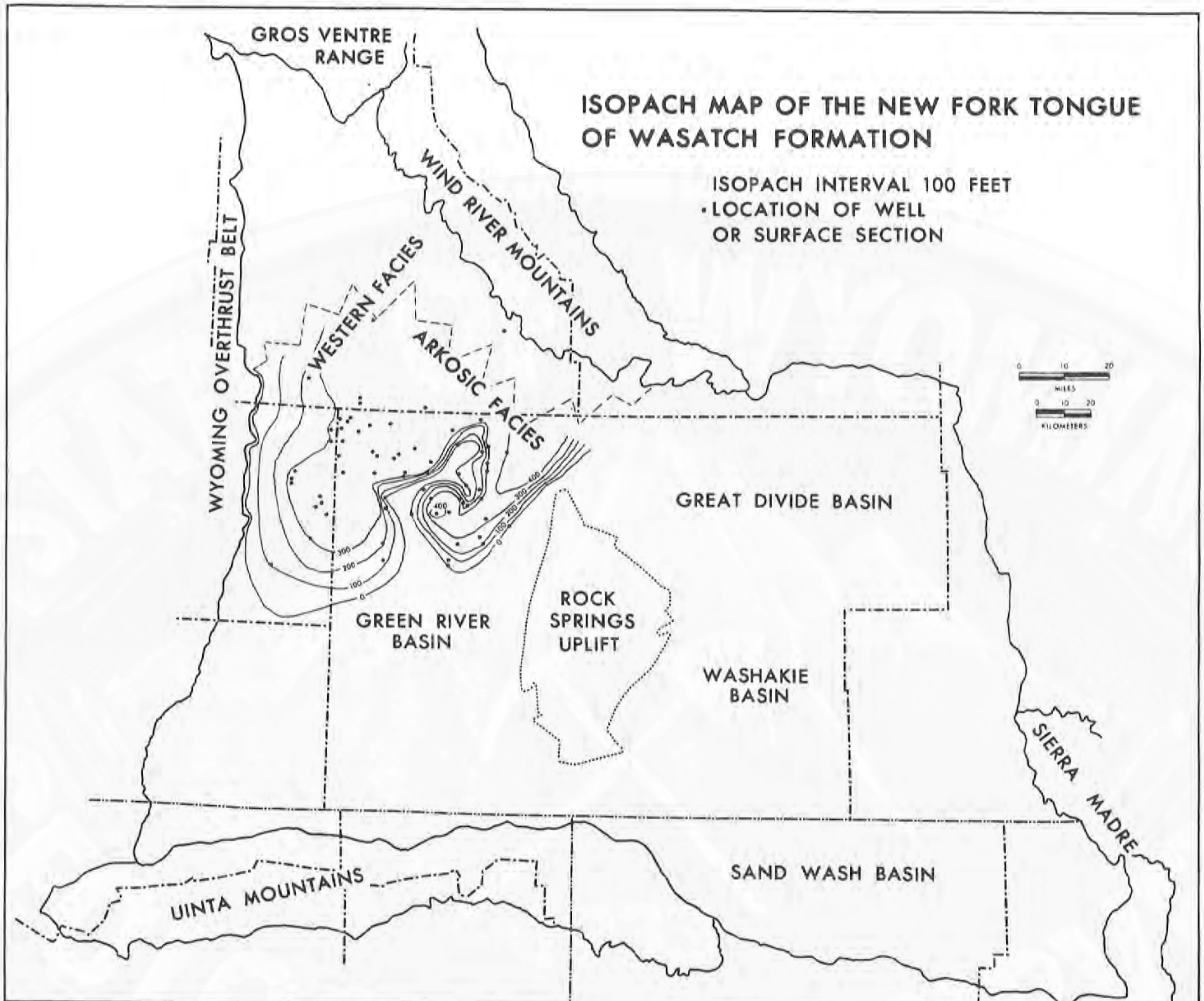


Figure 7. Isopach map of the New Fork Tongue of the Wasatch Formation. Data based on Dana and Smith (1973), Donavan (1950), Lawrence (1962, 1963, 1965), Oriel (1961, 1962, 1969), and West (1969b).

merges with the main body of the Wasatch Formation.

In its type section near Big Piney, the New Fork Tongue is about 250 feet (76 meters) in thickness and is composed predominantly of green and gray mudstone with interbedded buff and brown sandstone of the nonred fluviatile facies. In lithology it resembles the underlying main body but generally lacks the characteristic bright red and purple rock coloration. The study of Dana and Smith (1973) has shown that this member has a wide distribution over the northern half of the Green River Basin (see Figure 7). The New Fork Tongue occurs as two distinct lobes that differ in lithology, reflecting the sources of detritus from the marginal uplands. These two facies have been termed the western and eastern (arkosic) facies by West (1969a, pages 83-85).

The western facies is represented in the type section of the New Fork as described by Donavan (1950) and Oriel (1961, 1969). This non-red fluviatile facies has a source to the west, and the composition of the detritus is affected locally by the lithology of the Paleozoic and Mesozoic source rocks in the Overthrust Belt. In extreme western exposures close to the source, this facies grades into red-bed fluviatile rocks.

The term eastern or arkosic facies is applied to a sequence of red-bed fluviatile arkosic rocks with a source in the Precambrian crystalline rocks of the Wind River Range. The arkosic facies when traced westward from the flanks of the mountains grades laterally into the western facies and the Tipton (Fontenelle) Shale Member of the Green River Formation. Both facies reach a maximum thickness of about 400 feet (120 meters) in the northern part of the Green River Basin. The New Fork Tongue thins southwards and, in the surface, dies out in the vicinity of Little Muddy Creek, north of Hampton (T. 19 N., R. 114 W.). In the subsurface it can be traced toward the northwestern margin of the Rock Springs uplift and eventually dies out along a line through T. 21 N.

Cathedral Bluffs and Desertion Point Tongue

The stratigraphic relationship of the Cathedral Bluffs Tongue with the New Fork and upper tongue of the Wasatch Formation has been a concern of workers in this region for many years. These members occur in widely separated areas of the intermontane system and have a generally early Eocene (Lost Cabinian) age assigned to them. It was uncertain from the stratigraphic relationships across the region as to the precise correlation of these various units of the Wasatch Formation. West (1969a, pages 85-86), however, was able to demonstrate that a feather edge of the Cathedral Bluffs Tongue could be traced into the northwestern part of the Green River Basin along the Big Sandy River and overlies the eastern or arkosic facies of the New Fork Tongue. As a result, the Cathedral Bluffs is younger than the New Fork and is the approximate equivalent of the upper tongue (Desertion Point) of the Wasatch Formation.

The Cathedral Bluffs Tongue, first described by Schultz (1920), is well developed in the southeastern and eastern portions of the Washakie, Sand Wash, and Great Divide Basins, where it is underlain by the Tipton Shale Member or the Wilkins Peak Member and overlain by the Laney Member of the Green River Formation. Roehler (1968) and Braunagel and Stanley (1977) have described the detailed stratigraphic relationships of the tongue in the Washakie Basin (see Figure 9). In outcrops, the tongue is typically between 600 and 1,300 feet (180 and 400 meters) in thickness. It thickens irregularly toward the center of the basin, where it attains a maximum thickness of nearly 2,300 feet (700 meters) in the Sun Oil Co. No. 1 Jenkins well located in sec. 12, T. 14 N., R. 96 W. (see Figure 8).

Two major depositional units have been identified within the Cathedral Bluffs Tongue. A red mudstone facies predominates in the north and west parts of the Washakie Basin. This facies is well represented in the area of the type section of the Cathedral Bluffs Tongue in T. 19 N., Rs. 95 and 96 W. It attains a maximum thickness of about 1,500 feet (460 meters) in

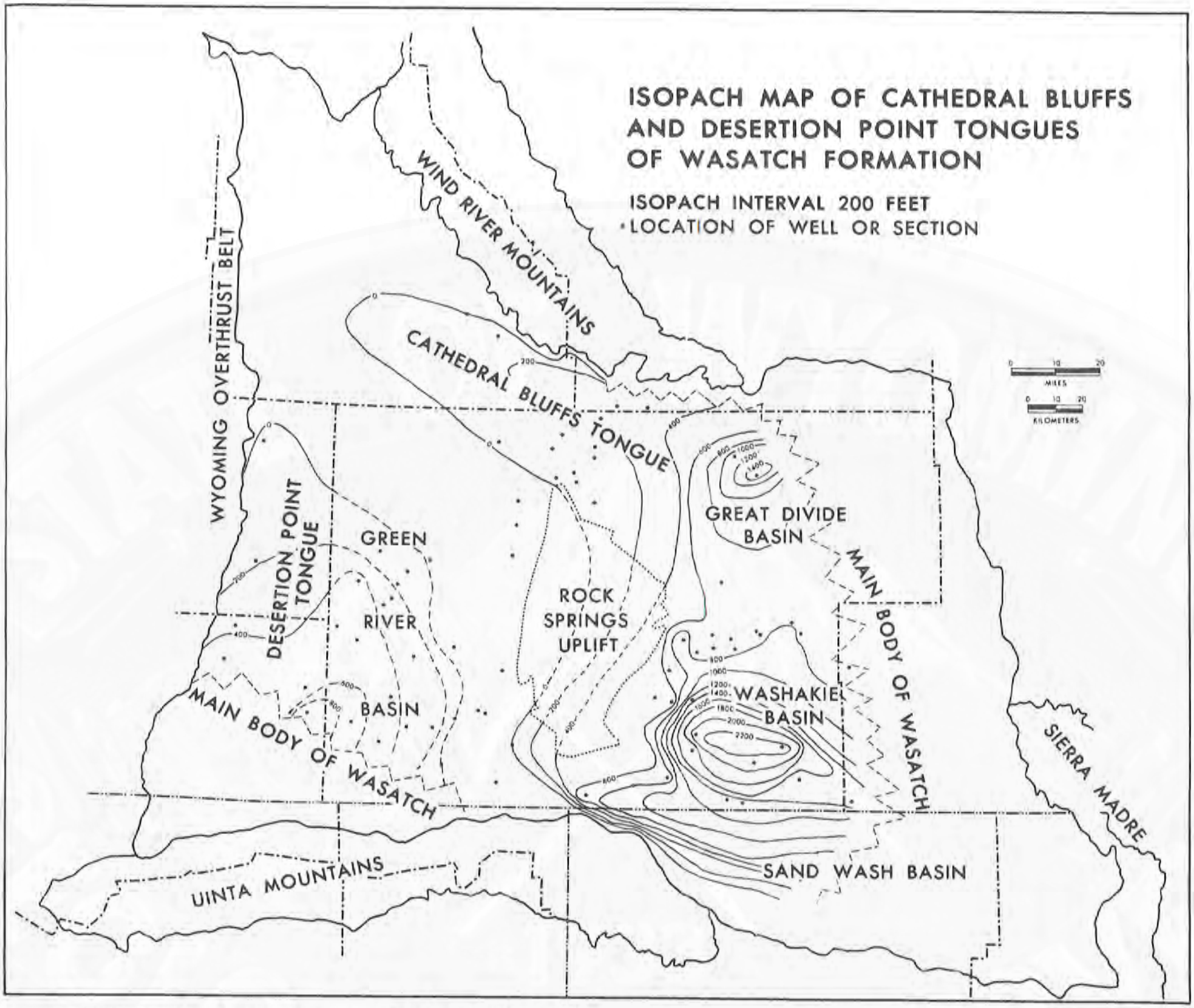


Figure 8. Isopach map of the Cathedral Bluff and Desertion Point Tongues of the Wasatch Formation. Data based on Bradley (1926, 1964), Braunagel and Stanley (1977), Colson (1969), Culbertson (1966, 1971), Deardorff and Mannion (1971), Lawrence (1962, 1963, 1965), Love (1964), Nace (1939), Oriel (1961, 1969), Pipiringos (1962), Roehler (1969, 1973a), Schultz (1920), Stuart (1963, 1965), and West (1969).

Shell Oil Co. 33-35, Pine Butte well in sec. 35, T. 15 N., R. 99 W. The red mudstone facies originated in an alluvial plain environment and is made up predominantly of variegated red and green mudstone and siltstone with intercalated lenses of greenish or brownish sandstone. The facies thins and the predominance of red colored units decreases westward across the Washakie Basin.

A red arkosic sandstone facies is the second depositional unit in the Cathedral Bluffs Tongue. This facies has a source in the Sierra Madre and represents an alluvial slope assemblage. It is best developed in the southeastern part of the Washakie Basin and attains a thickness of 1,500 feet (460 meters) in C. E. Brehm, 1-A Shell Creek well in sec. 16, T. 13 N., R. 95 W. Roehler (1969, Figure 3, page 200) showed that the arkosic sandstone facies thins rapidly north and west across the Washakie Basin.

A similar stratigraphic relationship within the Cathedral Bluffs Tongue in the Great Divide Basin has been described by Pipiringos (1955 and 1962). The arkosic sandstone facies at the eastern side of the basin is represented in the upper part of the Battle Spring Formation. It grades north and west into the red mudstone facies, which attains a thickness of between 1,400 and 1,600 feet (430 and 490 meters) along the Cyclone Rim in T. 26 N., R. 95 W. West (1969a and b) was able to trace the mudstone facies as it thins rapidly northwestward into the Green River Basin. Accompanying this thinning of the Cathedral Bluffs Tongue, the mudstone facies loses its red units and becomes drab colored in shades of green and brown. The northernmost exposures of the tongue are represented by 60 to 125 feet (18 to 38 meters) in sec. 4, T. 29 N., R. 105 W.

The term "upper tongue of the Wasatch Formation" was applied by Oriel (1961, 1969) to a fluvial clastic unit along the western margins of the Green River Basin in the vicinity of the Fort Hill-La Barge area (see Figure 24). The age of the tongue has not been firmly established and is considered by West (1969b, pages 184-196) to be intermediate between Lost Cabinian and Bridger A. It is proposed in the present account to formally name this unit of the Wasatch Formation the Desertion Point Tongue, because it is now clear it is a distinct and well definable stratigraphic unit. It has, moreover, a widespread distribution along the western margins of the Green River Basin. The type locality is near Desertion Point (sec. 26, T. 19 N., R. 115 W.) and eastward to Little Muddy Creek in the Mulkay Spring 7½-minute quadrangle (see Figure 20). In this locality the member is about 250 feet (76 meters) in thickness of the red-bed fluviatile facies and is composed of variegated colored siltstone and sandstone with occasional interbeds of marlstone and limestone (see Figure 21). The bright coloration, once more, is variable in the Desertion Point Tongue as in other members of the Wasatch Formation. The red coloration is reduced rapidly as the unit is traced eastward away from the margins of the basin. This color change can be seen in the escarpments in the vicinity of the type section.

The Desertion Point Tongue thins to the north and east and intertongues with the Wilkins Peak (middle) Member of the Green River Formation. It is approximately 180 to 200 feet (55 to 60 meters) in thickness in the Fort Hill-La Barge area (Oriel, 1961, 1969), and Lawrence (1965) showed the tongue losing its identity north of Facenelli Ranch (T. 25 N., R. 114 W.) as this northward thinning continues in the basin. In contrast, the tongue thickens southward from the type section toward its source in the Uinta Mountains, and this thickening is accompanied by an increase in coarser clastics within the succession. The tongue is about 500 feet (150 meters) in thickness near Carter, and Lawrence (1965) believed that the Desertion Point Tongue eventually may be correlated with the "Cathedral Bluffs Tongue" of Anderman (1955) in the

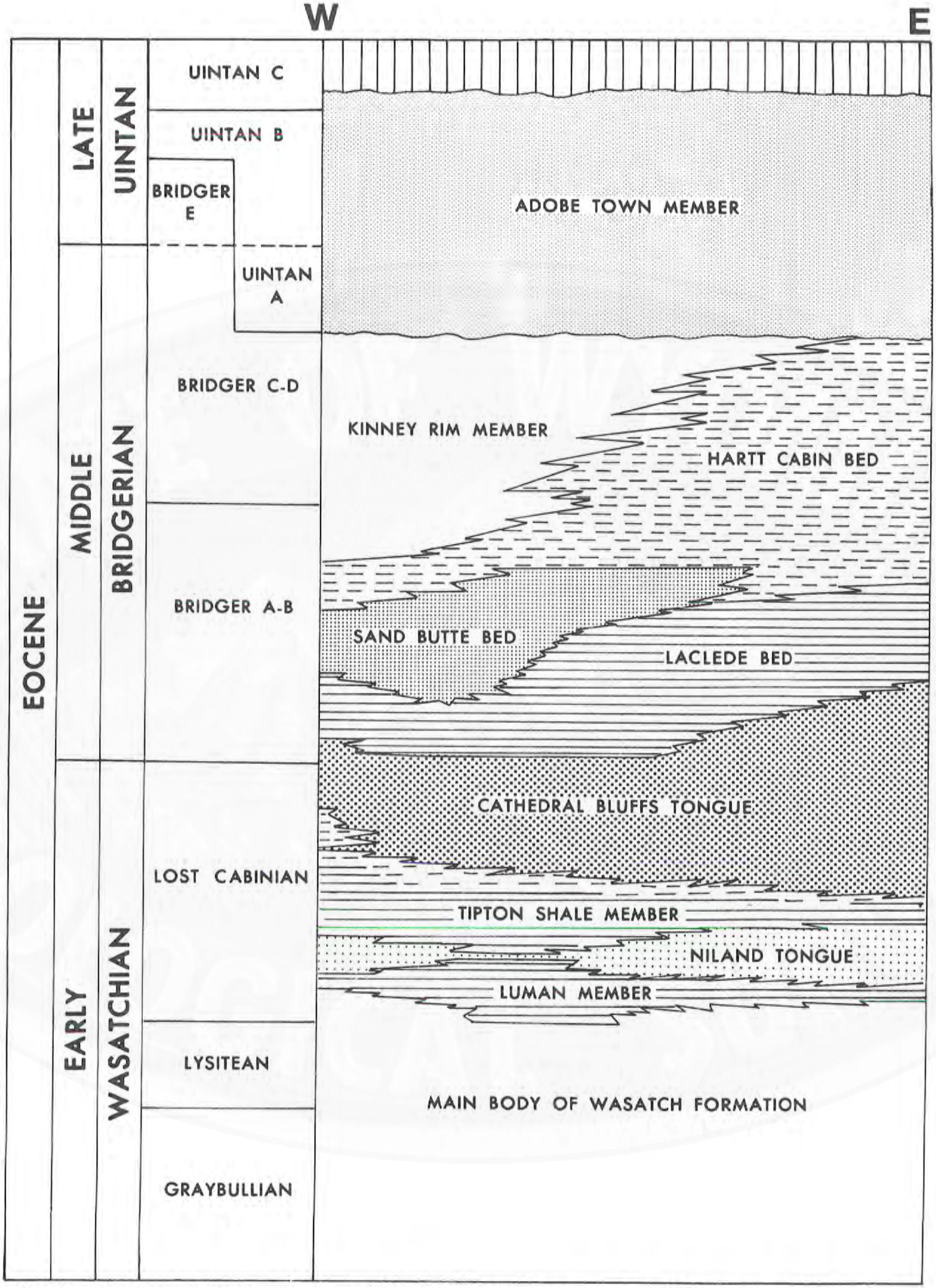


Figure 9. Generalized stratigraphic relationships in the Washakie Basin (after Roehler, 1974).

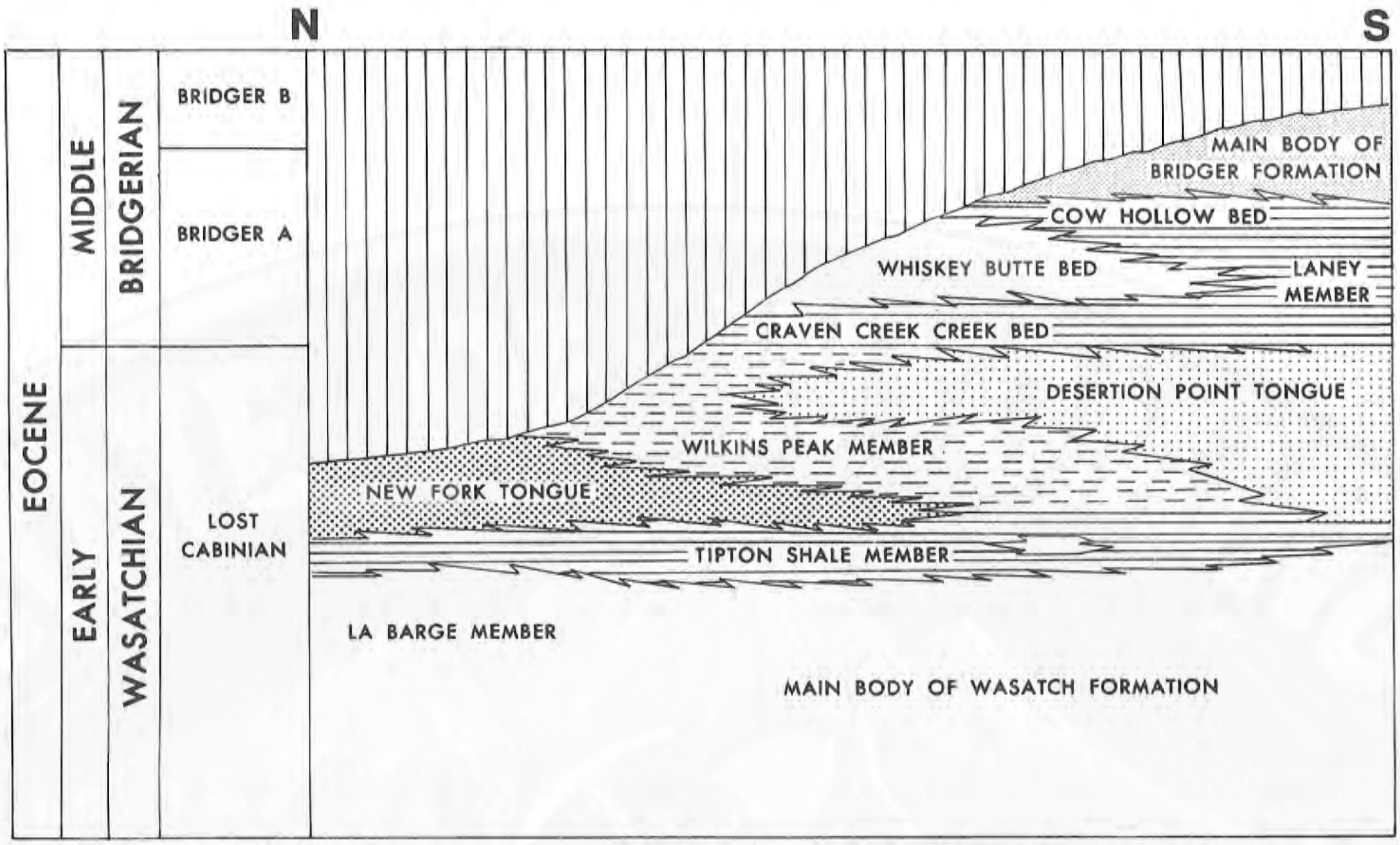


Figure 10. Generalized stratigraphic relationships along the western margins of the Green River Basin.

Manila area along the front of the Uinta Mountains.

In the southern part of the Green River Basin, Culbertson (1971, pages 15-23) has identified a thick non-red sandstone-mudstone facies in the upper part of the Wilkins Peak Member with a source to the southwest. The fluvial part of this clastic sequence has been correlated by Culbertson with the upper tongue of the Wasatch Formation. Additional studies will be needed to determine the precise stratigraphic relationships of these clastic units, particularly in view of the problem already discussed by Oriel (1961), and others, of defining stratigraphic units in an intertonguing succession. A tentative interpretation, given in Figure 8, is that the tongue attains a maximum thickness of about 950 feet (290 meters) in T. 15 N., R. 113 W., and passes southward into the main body of the Wasatch Formation along the front of the Uinta Mountains. The tongue thins northward and eastward, and Culbertson (1971, page 21) indicates that it extends as far north as the Sublette County-Lincoln County boundary and east to R. 107 W.

The Desertion Point Tongue, as a result, is approximately the time equivalent of the Cathedral Bluffs Tongue but has a different provenance and distribution in the intermontane system.

Environment of Deposition of the Wasatch Formation

The depositional environments of the Wasatch and Bridger Formations were probably very similar in as much as they both represent an alluvial plain complex in the intermontane system. The variegated red coloration and lack of volcanic sediments are typical of the Wasatch Formation and distinguish it from the Bridger Formation. The conditions of formation of the Wasatch Formation, therefore, involved fluviatile and paludal processes active in a subhumid savanna floodplain. The formation of variegated red-beds in this environment has been presented by Braunagel and Stanley (1977, pages 1201-1219).

The origin of red-beds has long been a subject of considerable controversy among geologists. The various theories can be grouped into those that involve depositional processes and others involving postdepositional changes or a combination of both. In the case of the Wasatch Formation, the explanation of the origin of variegated red-beds must also explain the usual peripheral distribution of this facies. Moreover, the red-beds do not appear to differ mineralogically from the gray and greenish mudstones. The reddish coloration is due to hematite in the matrix or coating the detrital grains. Some workers have derived the red coloration from the erosion and redeposition of sediment from pre-existing red rocks such as those of Mesozoic age in the peripheral mountain ranges. Other workers would explain the distribution by edaphic variation. Red-beds would form in areas, such as on the alluvial slope and plain in front of the peripheral mountains, where the soils are well drained and the water table low. Conversely, the absence of bright colors in the Wasatch Formation would reflect a water-logged environment of mud flats around lakes, ponds, and swamps in topographically low alluvial areas.

Braunagel and Stanley (1977) have presented a syndepositional origin for the variegated red-beds of the Cathedral Bluffs Tongue. They indicate that the tongue is typically composed of interbeds of green clayey siltstone and red silty claystone that occur in upward-fining sequences. They formed on an alluvial plain that was subjected to periodic flooding followed by desiccation and an interval of nondeposition. This seasonally wet and dry subhumid climate was favorable for the formation of hematite in the sediment. The hematite was thought to have formed from the dehydration of iron hydroxides associated with alluvial clays. The hematite tended to be concentrated in the clay-rich sediments where it occurred in the matrix or coated the detrital grains. Soon after deposition, the iron oxide was removed from the water-saturated, silt-rich sediment and further concentrated in the alluvium clays. The process was completed before the deposition of the next couplet.

The heterogeneity of the rocks in the Wasatch Formation indicates a broad range of environments and tectonic activity in the intermontane system. The peripheral coarse clastic red-bed facies of the formation was formed in an alluvial complex along the front of the uplands. The agents involved in transporting the sediment from the uplands included flash floods, mud flows, and rock slides. Streams flowing out of the uplands also contributed to building up an extensive sedimant platform out into the basins. The floors of the basins were broad and flat, so that the streams meandered across the plain. At times of flood, several hundred square kilometers of the basin floor would be inundated by flood water, and sediments were deposited during these periodic events. Swamps and ponds were often formed in the areas near the streams or in low-lying parts that were frequently covered by flood water. During the later stages of the deposition of the Wasatch Formation, lakes became more extensive on the floors of the basins. These lakes fluctuated in size in response to regional tectonic and climatic changes. At the times of extensive lakes, streams entered the bodies of water in a series of deltas. The meandering streams often displayed braided channel systems as they entered the delta of the lake. Clastic sediments were deposited in the deltas, beaches, and off-shore bars of the lake.

The presence of considerable relief around the margin of the basins is indicated by the coarse clastic peripheral pediment facies of the Wasatch Formation. The distribution of this facies suggests that the marginal uplands behaved as independent tectonic units. In the Hoback Basin, for example, middle Paleocene to early Eocene tectonic activity in the Overthrust Belt provided a western source for the Hoback Formation. This was followed by uplift of the Wind River Mountains and the block north of the Gros Ventre Range, which provided a provenance for the Pass Peak Formation. Tectonic activity in the Wind River Mountains and the Overthrust Belt provided the source for the New Fork Tongue. Uplift of the Sierra Madre and Granite Mountains supplied the main part of the detritus for the Niland and Cathedral Bluffs tongues. The Uinta Mountains, and to a lesser extent the Overthrust Belt, were the provenance for the Desertion Point Tongue. Armstrong and Oriel (1965, pages 1847-1866) consider that movement on the thrust faults of the Overthrust Belt had ceased before the deposition of the Wasatch Formation and that block faulting, active in the Eocene, produced fault scarps as a local source of detritus along the western margins. Studies of the mineral assemblage of these clastic units by Denson and Pipiringos (1969), Spearing (1969), and Roehler (1970) indicate variations in the source of the sediments in the Eocene formations in southwestern Wyoming.

GREEN RIVER FORMATION

The Green River Formation is made up of a succession of predominantly lacustrine rocks that stratigraphically occur between and intertongue with the Wasatch and Bridger Formations. The stratigraphic relationships and subdivisions of the Green River Formation have been detailed by Bradley (1959, 1964) and Roehler (1965, 1968).

Surdam and Wolfbauer (1975, pages 338-339) and Surdam and Stanley (1979, pages 95-106) have recognized three major lithofacies for the Green River Formation: (i) the carbonate facies, (ii) the laminated carbonate or oil shale facies, and (iii) the evaporite or trona facies.

The carbonate facies consists of thin bedded calcareous and dolomitic mudstone together with stromatolitic and oolitic limestone, marlstone, siltstone, and oil shale. Mud cracks and other desiccation structures are commonly found in these deposits. Fossils, on the other hand, are rare, but include algae, ostracodes, mollusks, and, locally, bird bones and tracks. Surdam and Wolfbauer (1975, pages 338-339) found that the carbonate facies changes laterally when traced into the basin. The outer or marginal carbonate deposits are calcite rich and are mainly lime sandstone and siltstone. The carbonate rocks in the interior of the basin, in contrast, have a higher amount of dolomite and are composed of dolostones.

The carbonate facies typically pass laterally toward the depositional center into a varved succession of laminated carbonates or oil shales. The varve sequence is made up of alternating layers of dark kerogen-rich and lighter colored kerogen-poor carbonates. Surdam and Stanley (1979, pages 101-102) noted that the kerogen-rich layers are commonly calcitic in composition while the kerogen-poor beds are a mixture of calcite and dolomite. Interbedded in the oil shale succession are beds of ostracodal and oolitic limestone, dolostone, and marlstone.

The evaporite facies, in southwestern Wyoming, consists of bedded trona deposits commonly associated with oil shale and dolomitic mudstone. Halite is also present in some of the beds. This facies is well developed in the Wilkins Peak Member in the Green River Basin, and the deposits have been described by Bradley and Eugster (1969), Culbertson (1966, 1971), and Deardorff and Mannion (1971). The occurrence of a thin development of evaporite facies in the Laney Member in the Washakie Basin was described by Surdam and Stanley (1979, pages 98-99).

These facies of the Green River Formation are enclosed around the basin margins by the sandstone-mudstone facies of the Wasatch and Bridger Formations. Thin but often extensive clastic beds developed locally in the Green River Formation include the siliciclastic sandstones in the Wilkins Peak Member as described by Culbertson (1972, page 21) and Eugster and Hardie (1975, page 325). The major exception to this limited development of the sandstone and mudstone facies in the Green River Formation is present in the Laney Member throughout southwestern Wyoming.

The interbasin correlations and age datings of volcanic tuffs in the Green River Formation have been given by Mauger (1977, pages 36-37). This work has provided a general time frame for the main geological events in the Eocene rocks of the central Rocky Mountains. It also enables a correlation to be made between the various members of the Green River Formation in the Green River, Washakie, and Uinta Basins.

Luman Member

The Luman Member is restricted to the southern and eastern parts of the region (see Figure 11). The Luman Member was named by Pipiringos (1955, page 100; 1962, pages A14-A24) for exposures on the south slope of Luman Butte (sec. 34, T. 24 N., R. 97 W.) in the Great Divide Basin. At its type locality the tongue is about 180 feet (55 meters) in thickness. It is underlain by the main body of the Wasatch Formation (Red Desert Tongue) and is overlain by the Niland Tongue, which indicates an early Eocene (Lost Cabinian) age for the member.

Pipiringos (1962, Figures 3, 4, 6) showed in the type section a mixed facies of laminated carbonates (oil shales) and sandstone-mudstone, shoreline-deltaic development. This facies predominates around the western edge of the Great Divide Basin. A coarser clastic fluviatile facies of the main body of the Wasatch Formation forms the marginal clastics on the eastern and northern sides of the basin. In the center of the basin is the laminated carbonate (oil shale) facies, which attains a maximum thickness of 390 feet (120 meters) in the Great Divide Basin. A similar facies relationship has been described in the Luman Member in the Washakie Basin by Roehler (1969, page 203) and the Green River Basin by Culbertson (1965) and Roehler (1965, page 145). The member attains a maximum thickness of about

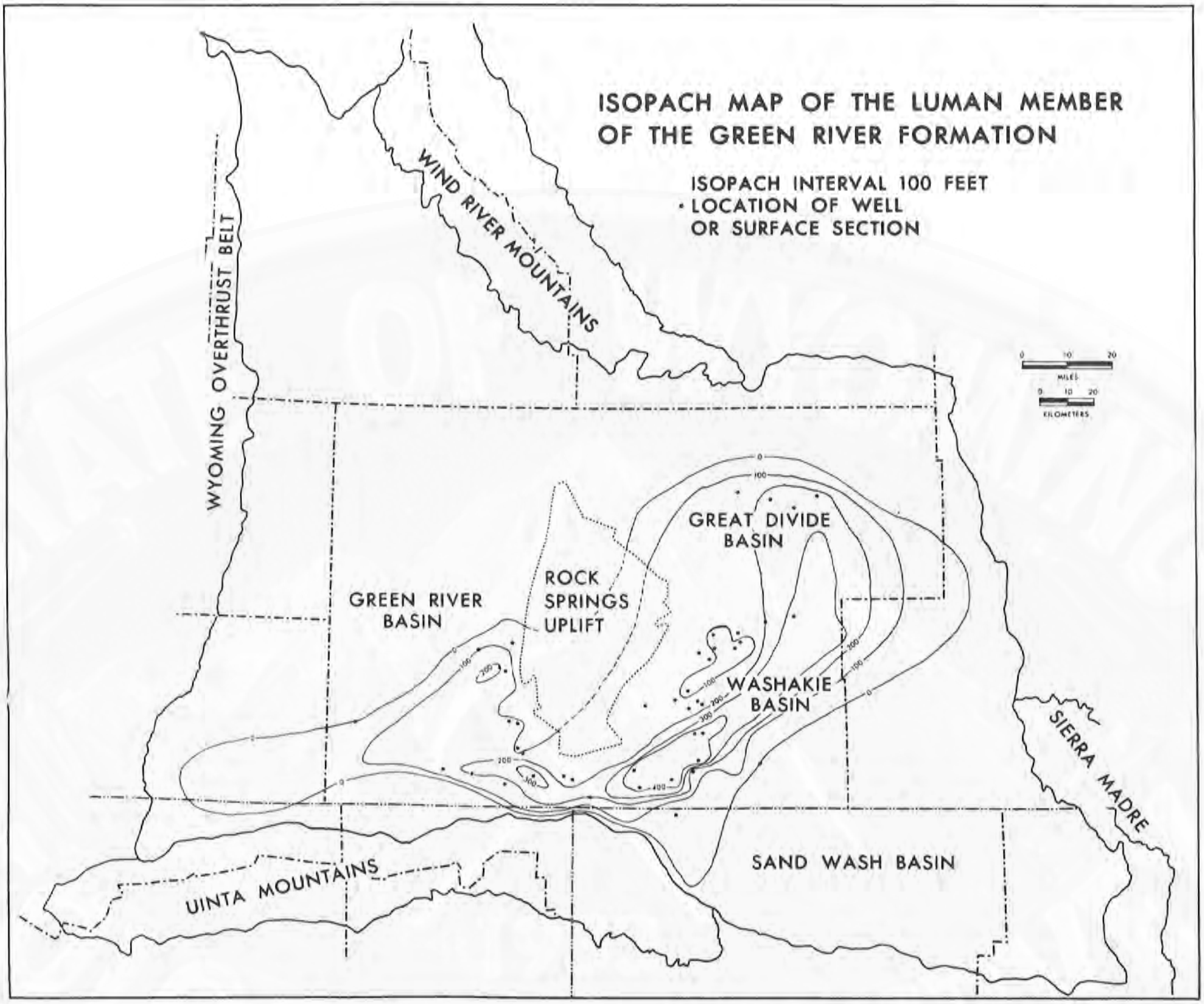


Figure 11. Isopach map of the Luman Tongue of the Green River Formation. Based on Bradley (1964), Culbertson (1965, 1969), Love (1964), Pipiringos (1955, 1962), and Roehler (1965, 1969).

400 feet (120 meters) in these basins. The Luman Member contains little evidence of the widespread carbonate facies characteristic of the Tipton Shale and Wilkins Peak Members.

Tipton (Fontenelle) Shale Member

The Tipton Shale Member of the Green River Formation, of early Eocene (Lost Cabinian) age, was named by Schultz (1920, page 30) for exposures near Tipton Station in sec. 18, T. 19 N., R. 96 W. It is underlain by the Niland Tongue of the Wasatch Formation and overlain by the Wilkins Peak Member of the Green River Formation. The member occurs over the greater part of southwestern Wyoming and beyond the limits of the underlying Luman Member into the western and northern Green River Basin.

In the area of the type section in the Washakie Basin, Roehler (1968, pages 2252-2254) has described about 160 feet (49 meters) of the laminated carbonate (oil shale) facies in the Tipton Shale Member. At the base of the member is a prominent marker bed, a layer rich in *Goniobasis*, other mollusks, and ostracodes. In the upper part of the sequence several beds of stromatolites interbed with the oil shale. Surdam and Wolfbauer (1975,

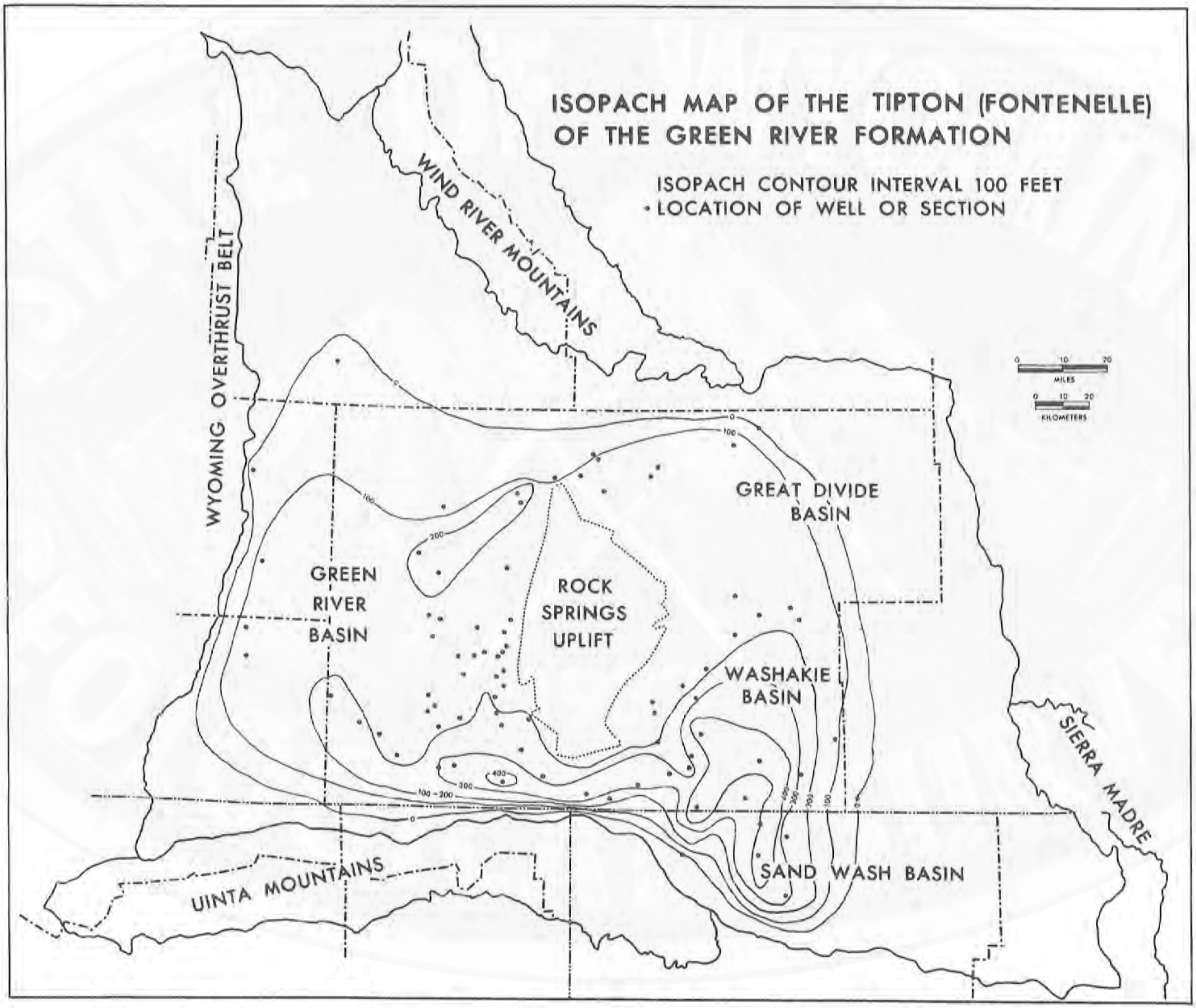


Figure 12. Isopach map of the Tipton (Fontenelle) Shale Member of the Green River Formation. Data based on Bradley (1926, 1929, 1964), Colson (1969), Culbertson (1969), Lawrence (1962, 1965), Love (1964), Nace (1939), Oriel (1961, 1969), Pipiringos (1955, 1962), Roehler (1965, 1968, 1969), Schultz (1920), Sears and Bradley (1924), Stuart (1965), and Zeller and Stephens (1969).

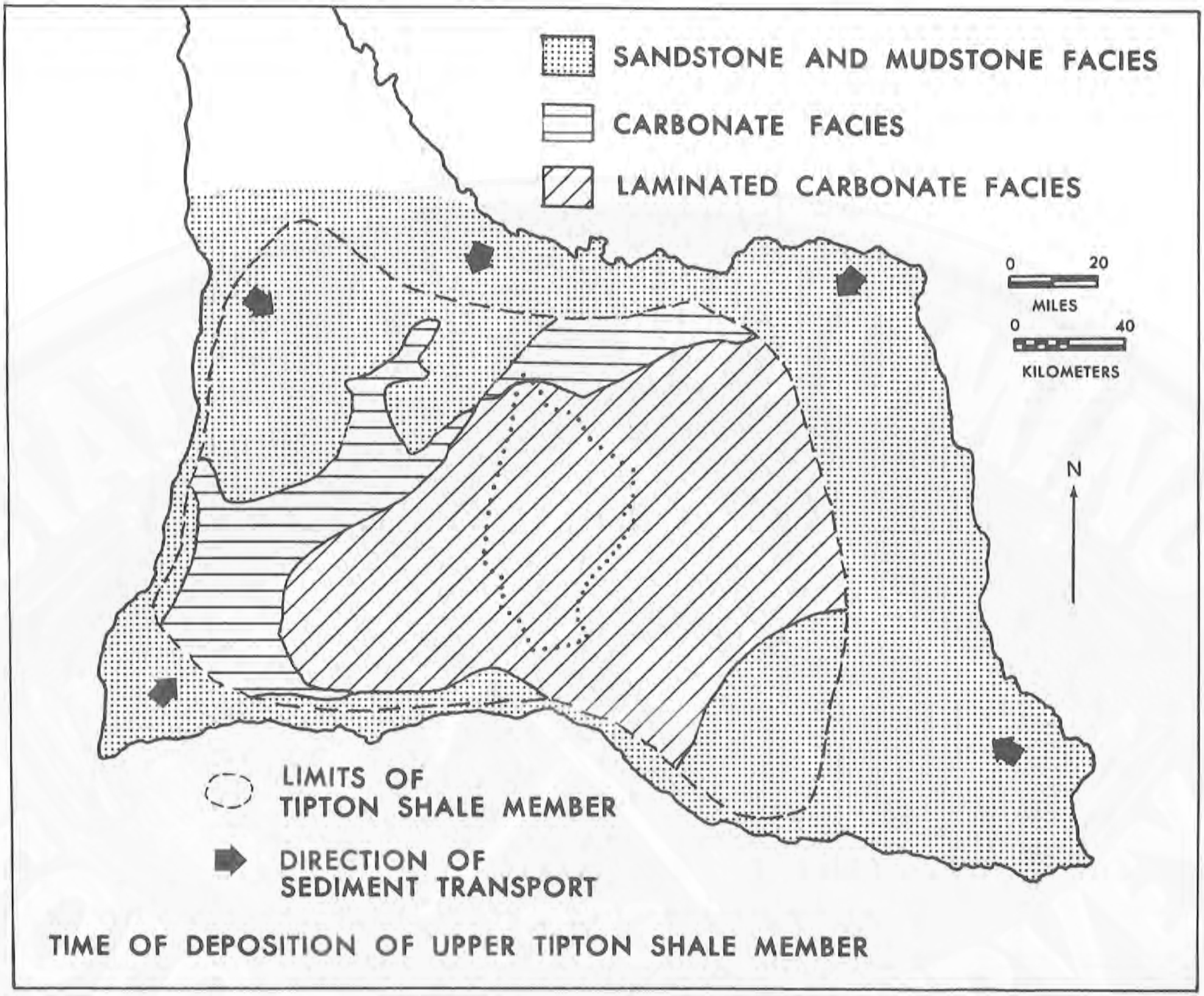


Figure 13. Lithofacies map of the upper Tipton Shale Member (after Wolfbauer, 1973).

page 340) showed that the laminated carbonate (oil shale) facies extends over a large part of the region. The laminated carbonate (oil shale) facies thickens to over 400 feet (120 meters) when traced into the center of the Washakie Basin. This basinward thickening of the Tipton Shale Member was also well documented in the Sand Wash Basin by Roehler (1968, Figure 3, page 2255) and Colson (1969, Plates II and III). At the basin margins this facies grades into the carbonate facies on the west and east and sandstone-mudstone facies of the Wasatch Formation on the north and south (see Figure 13).

An elongated area with a thick development of the laminated carbonate (oil shale) facies of the Tipton Shale Member also exists in the southeastern part of the Green River Basin. Love (1964, Plate I) records a maximum thickness in the Green River Basin of approximately 410 feet (130 meters) in Phillips Petroleum Federal Hobson #1 in sec. 27, T. 12 N., R. 106 W. The Tipton Shale Member has a remarkable uniformity of thickness on the order of 100 to 200 feet (30 to 60 meters) over the remainder of the basins (see Figure 12).

The term Fontenelle Member or Tongue was first applied by Donavan (1950, pages 63-67) to a carbonate facies in the lowest part of the Green River Formation along the western margins of the Green River Basin. The type locality is in sec. 13, T. 24 N., R. 114 W., about one mile south of Fontenelle Creek. The stratigraphic limits of the member were redefined by Oriel (1961, page B-151) and only the lower 50 to 60 feet (15 to 18 meters) of the strata assigned by Donavan as the type section were retained. The member consists of laminated argillaceous limestone, marlstone, calcareous mudstone, and sandstone (see Figure 22). It is overlain by the New Fork Tongue and underlain by the main body of the Wasatch Formation.

The member varies in thickness from an edge to 150 feet (46 meters) along the western margins of the Green River Basin and thickens in a basinward direction in the subsurface. The stratigraphic relationships have been described by Lawrence (1965, pages 181-183) and Oriel (1969, page M.19). The work of Textoris (1963), Love (1964), Surdam and Wolfbauer (1975), and others has demonstrated that the Fontenelle Tongue is an equivalent of the Tipton Shale Member in the main part of the Green River Basin and, as a result, the use of the term "Fontenelle" should be discarded.

The Tipton Shale Member, therefore, represents the first widespread development of the Lake Gosiute system into the northern and western parts of the Green River Basin. Roehler (1965, page 145) indicated that about 12,000 square miles (19,000 square kilometers) of the intermontane basin was effected by the extension of lacustrine influences during this time in the latter part of the early Eocene.

Wilkins Peak Member

Bradley (1959) revised the stratigraphic nomenclature of the Green River Formation in southwestern Wyoming and introduced the name Wilkins Peak Member for the lacustrine succession above the Tipton Shale Member. The type locality of the Wilkins Peak is in T. 18 N., R. 106 W., where the member is approximately 900 feet (270 meters) in thickness of the carbonate facies. It is overlain by a laminated carbonate (oil shale) facies development of the Laney Member and grades laterally into the Desertion Point and Cathedral Bluff Tongues of the Wasatch Formation; as a result, its stratigraphic position would indicate an early Eocene (Lost Cabinian) age.

Culbertson (1961, 1966, 1969, 1971), Deardorff (1963), Textoris (1963), Bradley (1964), Bradley and Eugster (1969), and Eugster and Hardie (1975) have provided detailed stratigraphic information on the Wilkins Peak Member in the main part of the Green River Basin. Culbertson (1961) has recognized the presence of marker beds of volcanic tuff and clastic units that aid in correlation because they can be traced for hundreds of miles across the southeastern part of the Green River Basin. Mauger (1977, pages 17-41) has dated some of the volcanic tuffs in the Wilkins Peak Member and has shown that saline deposition was in progress 49 m.y. ago and ended about 48 m.y. ago.

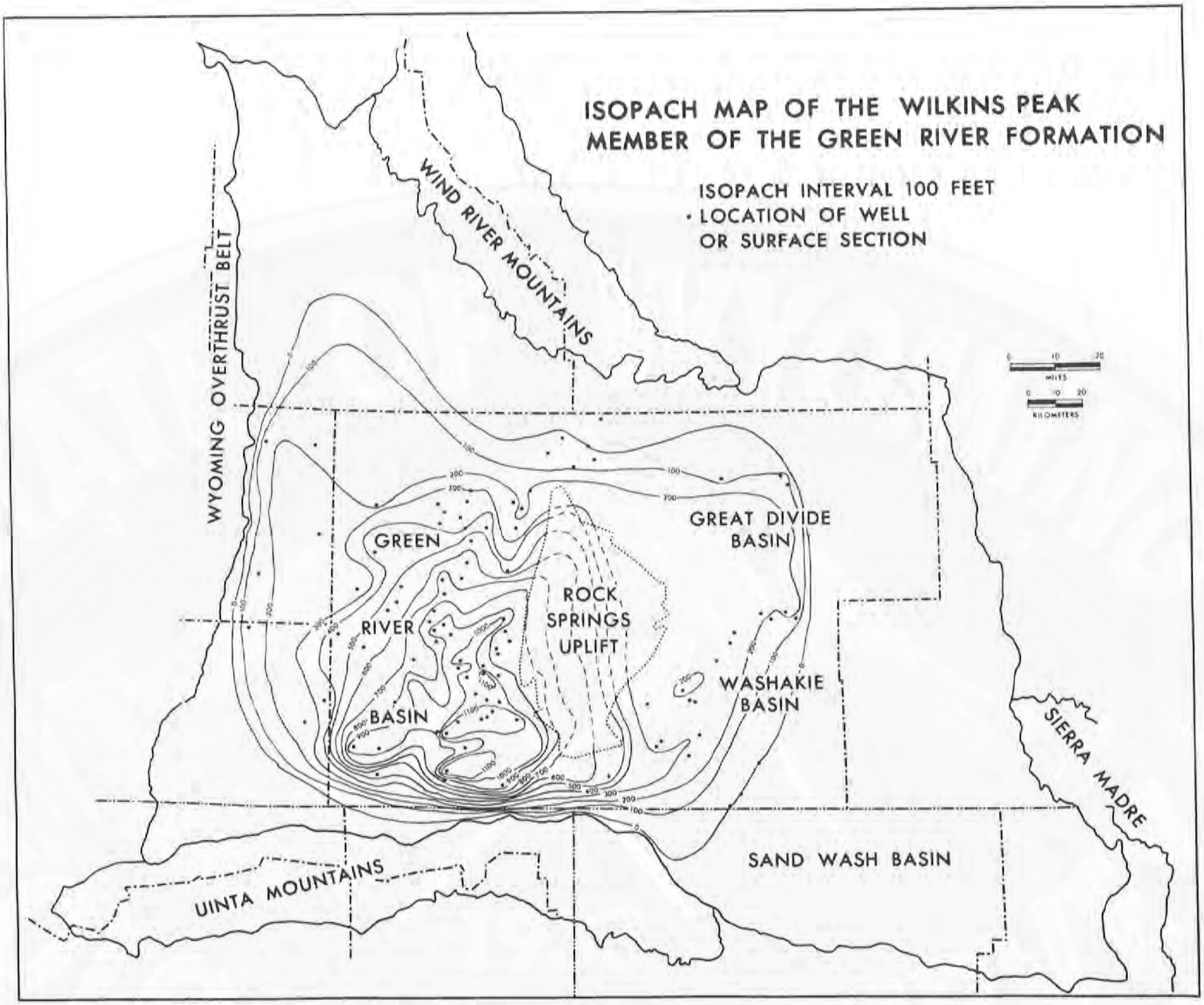


Figure 14. Isopach map of the Wilkins Peak Member of the Green River Formation. Data based on Bradley (1926, 1964), Bradley and Eugster (1969), Colson (1969), Culbertson (1961, 1966, 1969, 1971), Lawrence (1962, 1965), Love (1964), Oriel (1961, 1969), Roehler (1965, 1968, 1969), Sears and Bradley (1924), Schultz (1920), Stuart (1963, 1965), West (1969), and Zeller and Stephens (1969).

Surdam and Wolfbauer (1975, page 340) have outlined the lithofacies distribution in the Wilkins Peak Member. The evaporite facies was restricted to the southern part of the Green River Basin. By late Wilkins Peak time the depositional center for this facies had become even more restricted and had moved 25 miles northeastward. Surrounding the evaporite facies, over a large part of the region, was deposited a broad belt of carbonate rocks (see Figures 15 and 16). The sandstone and mudstone facies of the Wasatch Formation, once more, were located around the basin margins.

The Wilkins Peak Member reaches a maximum thickness of between 1,200 and 1,300 feet (370 and 400 meters) in the Green River Basin at the southeastern edge of the trona belt in T. 13 N., R. 108 W. The member maintains a broad uniformity of thickness of between 1,000 and 1,100 feet (310 and 340 meters) in the southeastern part of the Green River Basin (see Figure 14). Culbertson (1971, pages 15-23) described the thinning of the member away from this depositional center. Northwards, the Wilkins Peak completely thins out because of onlap and wedging out of the sandstone, carbonate, trona, and halite beds. Westward, the Wilkins Peak Member intertongues with clastic sediments of the Desertion Point Tongue.

Along the western margins of the Green River Basin, an attenuated succession of the carbonate facies, that varies between 100 and 250 feet (30 and 76 meters) in thickness, occurs in the approximate position of the Wilkins Peak Member (see Figure 22). This unit has been termed the "middle tongue of the Green River Formation" by Oriel (1961, 1969). A correlation between the middle tongue and the Wilkins Peak Member has been made by many workers including Textoris (1963, page 247), Lawrence (1963, page 154), Bradley (1964, page A38), Culbertson (1969, page 193; 1971, page 21), and Surdam and Wolfbauer (1975, page 338). The precise correlation has not been determined, but Textoris believed that it is equivalent to the lower part of the member in the area further east. Culbertson, on the other hand, equated the middle tongue with the middle unit of the Wilkins Peak in the main part of the basin.

The Wilkins Peak Member, when defined by Bradley (1959), was thought to be restricted to the Green River Basin. The work of Roehler (1965, 1968) clearly demonstrated that an attenuated succession of the carbonate facies of the member also exists in the Washakie and Great Divide Basins. In this region, the Wilkins Peak Member is represented by about 200 feet (60 meters) of dolomitic mudstone with interbedded sandstone beds. The member intertongues eastward with the Cathedral Bluff Tongue and eventually is replaced by fluvial rocks.

The occurrence of numerous and widespread beds of trona and other associated saline deposits of the evaporite facies of the Wilkins Peak Member in the Green River Basin are of particular economic importance and value in synthesizing the paleoenvironment of the region during Eocene times. The main concentration of saline minerals is toward the center of the basin, to the west and southwest of the type area (see Figures 15 and 16). Culbertson (1971) has recognized three major episodes of saline deposition in the Wilkins Peak Member which are particularly well developed in the lower part of the succession.

Major changes must have taken place in the intermontane basin to initiate the formation of the saline deposits. These changes may also be reflected in the modification of the depositional pattern established at the onset of the development of the Green River Formation. There was clearly an important change in paleogeography resulting from uplift of the Sierra Madre and Uinta Mountains. The center of lacustrine deposition changed from an elongated belt in front of the Sierra Madre and Uinta Mountains during Luman and Tipton times to a main center in the southern part of the Green River Basin. A series of broad expanding alluvial units of the Cathedral Bluffs and Desertion Point Tongues was deposited along the southern and southeastern margins of the intermontane basin.

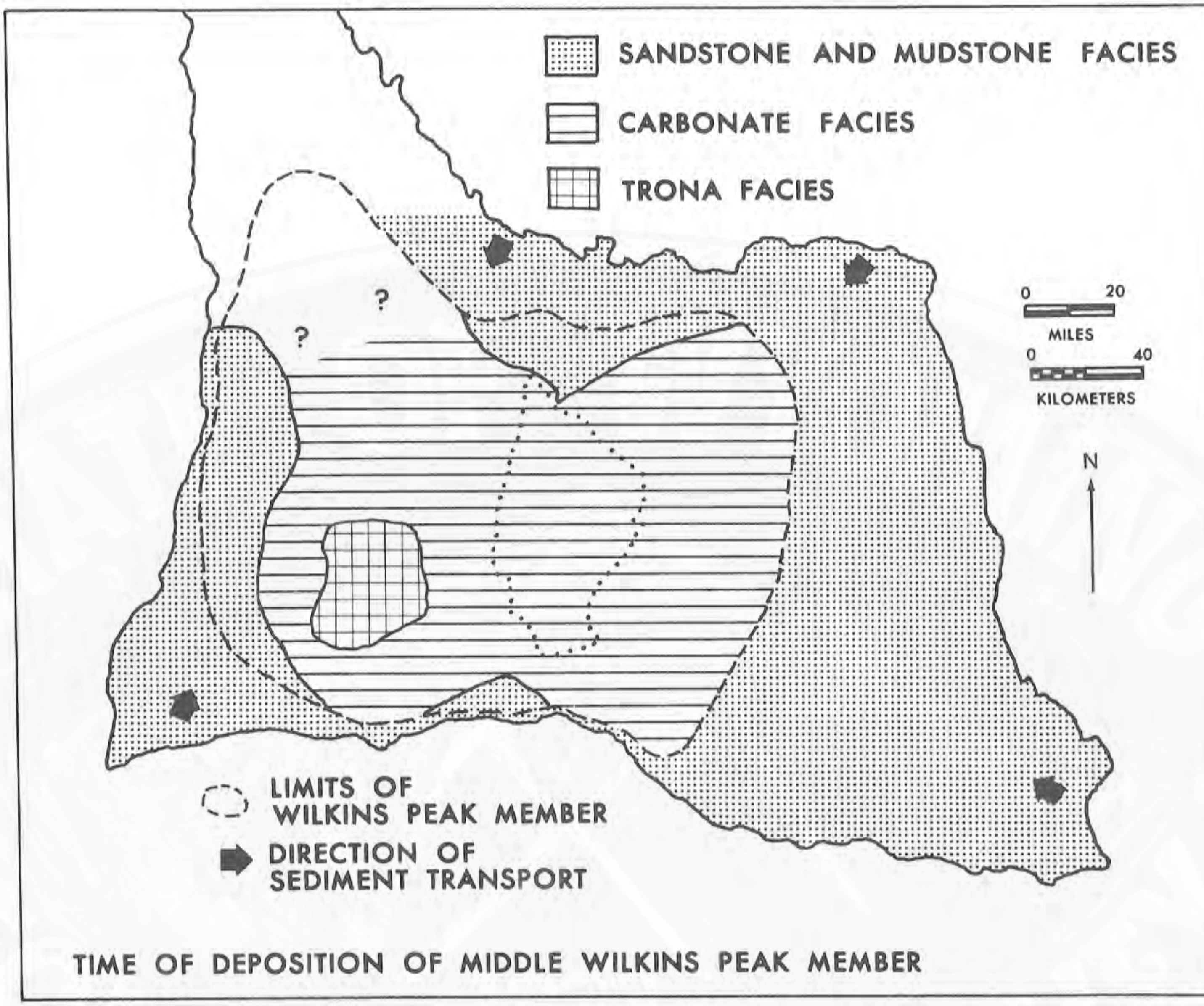


Figure 15. Lithofacies map of the middle Wilkins Peak Member (after Surdam and Wolfbauer, 1975).

The extensive alluvial plain reduced the size of the area of lacustrine deposition, and it has been estimated that, at a maximum, lake influences were reduced to 9,500 square mile (15,000 square kilometers of southwestern Wyoming.

Laney Member

This member of middle Eocene (Bridger A-B) age was named the Laney Shale Member by Schultz (1920, pages 27-28) from exposures along the Laney Rim in the Washakie Basin. It was redefined by Bradley (1959, pages 1072-1075) to include beds in the Green River Basin that had been assigned to the Morrow Creek Member. The part of the succession that had been previously named to the Laney Shale Member in the Green River Basin was now grouped into the newly created Wilkins Peak Member. This strati-

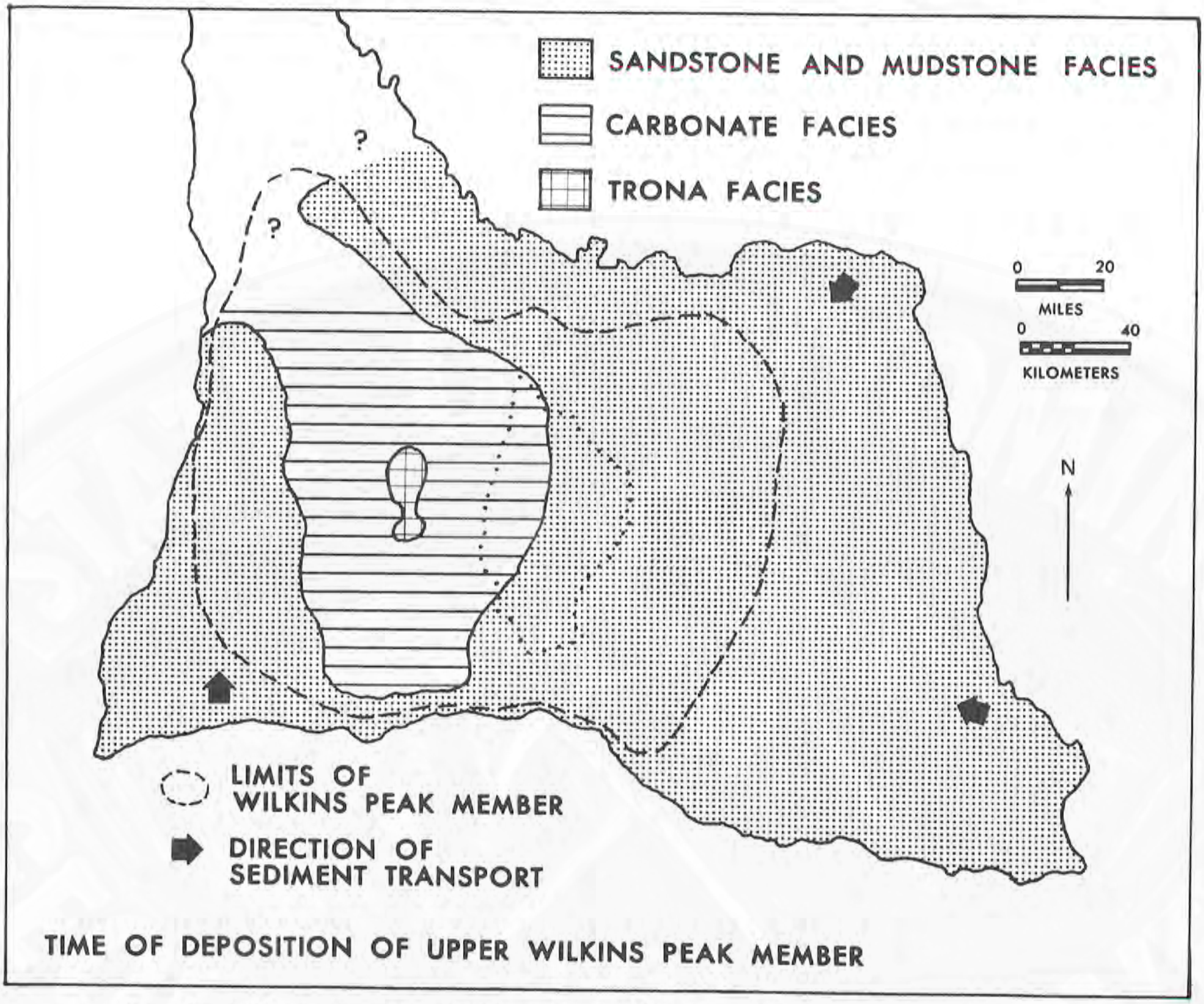


Figure 16. Lithofacies map of the upper Wilkins Peak Member.

graphic reevaluation by Bradley greatly cleared up the nomenclature confusion in the Eocene rocks of southwestern Wyoming. Roehler (1973a, pages E2-E5) advocated additional revisions of the stratigraphic nomenclature of the members of the Green River Formation. He included in the Laney a thick succession of volcanic lithic sandstone that he named the Sand Butte Bed. The addition of this sandstone sequence resulted in the proposal to modify the terminology by dropping the "shale" and for the unit to be known as the Laney Member.

The Laney Member extends over 15,000 square miles (24,000 square kilometers) of southwestern Wyoming and is the thickest and most extensive of the units of the Green River Formation. The onset of Laney time was marked by a rapid expansion of Lake Gosiute over the region, an event dated by

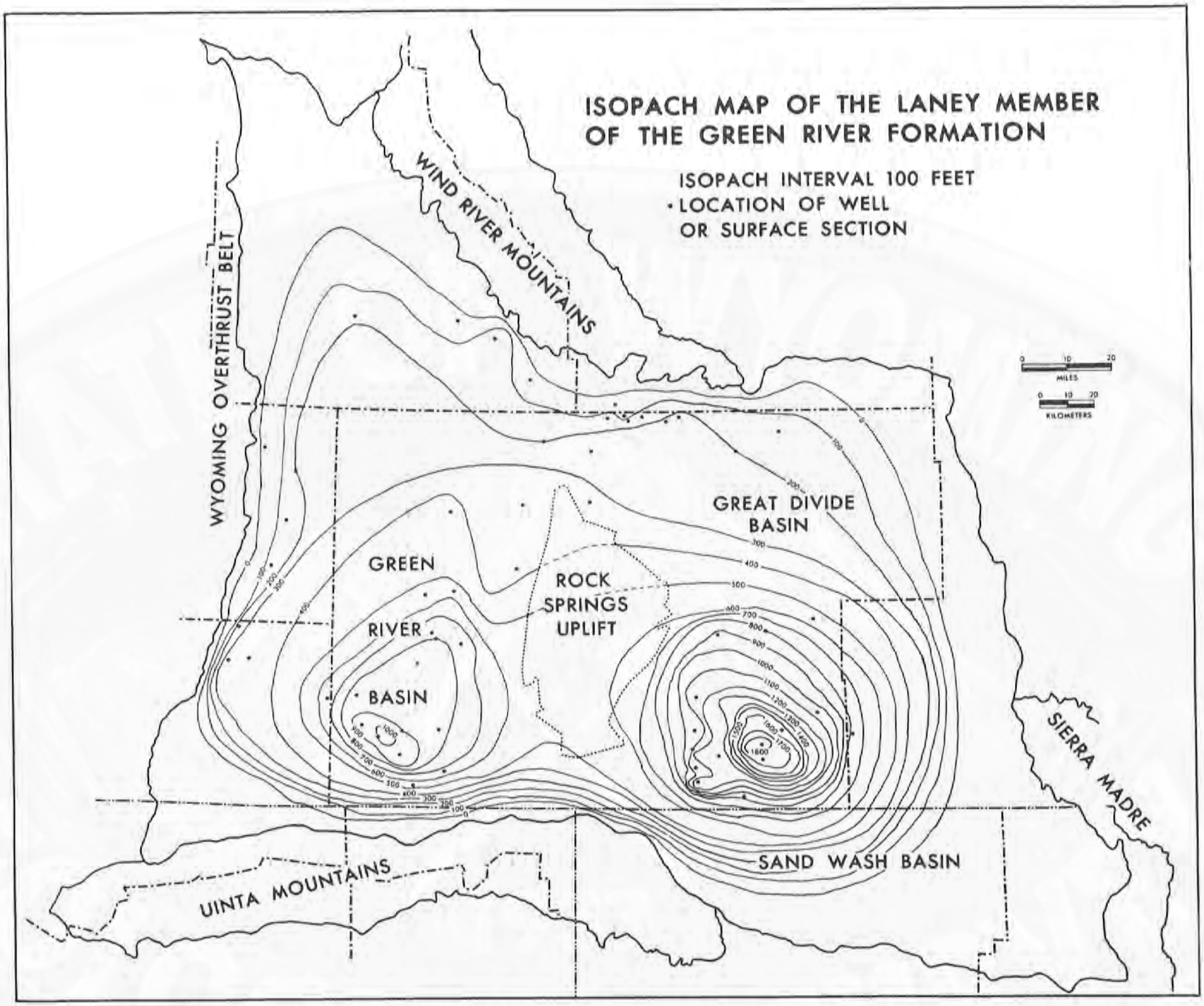


Figure 17. Isopach map of the Laney Member of the Green River Formation. Data based on Bradley (1926, 1959, 1964), Culbertson (1962, 1969), Lawrence (1962, 1965), Love (1964), McGrew and Sullivan (1970), Oriel (1961, 1969), Roehler (1973a, 1973b), and Zeller and Stephens (1969).

Mauger (1977) to have occurred between 48 and 47 m.y. ago. Its maximum development is in two depositional centers in the Washakie-Sand Wash Basins and southern Green River Basin where it reaches a thickness of 1,800 feet (550 meters) and 1,000 feet (310 meters), respectively. In the type section in the Washakie Basin, Pipiringos (1962, page A33 and Plate I) estimated that its thickness was between 600 and 700 feet (180 and 210 meters).

A similar but greatly reduced succession of the Laney Member occurs in the Great Divide Basin. Pipiringos (1955, page 103; 1962, pages A.33-34) measured about 200 feet (60 meters) of the laminated carbonate facies. Love (1970, pages C42-C43) described a major unconformity at the base of the Laney Member in this basin. The unconformity is the result of uplift and erosion of the block north of the Flattop fault.

The Laney Member in southwestern Wyoming is characterized by a lower unit made up of laminated carbonate (oil shale) facies and an upper one of volcanic lithic sandstone of the sandstone and mudstone facies. Surdam and Stanley (1979) have shown the occurrence of an evaporite facies development within the middle of the laminated carbonate (oil shale) facies of the Washakie Basin and eastern Green River Basin. This evaporite facies is made up of rippled lime sandstone and mudcracked laminated calcareous mudstone similar to parts of

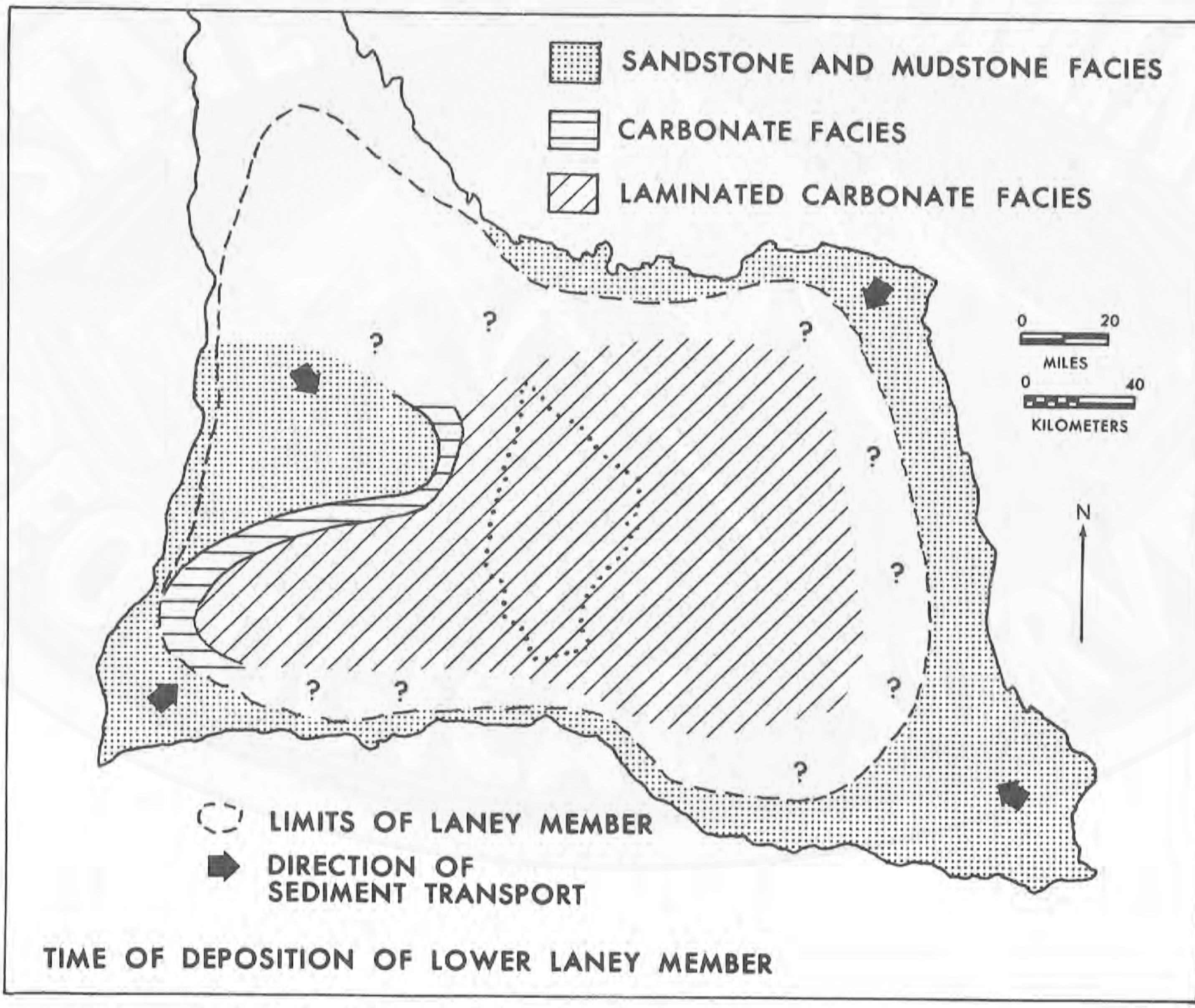


Figure 18. Lithofacies map of the lower Laney Member.

this development in the Wilkins Peak Member as described by Eugster and Hardie (1975). Another characteristic of the Laney Member is the limited occurrence of the carbonate facies (a molluscan-ostracodal calcareous mudstone sequence). It is, however, developed in the upper part of the succession in the Sand Wash Basin where it is underlain by laminated carbonates (oil shales) and overlain by volcanic lithic sandstones. The volcanic lithic sandstones (Sand Butte-Tower sandstone) form a diachronous series with a source in the northern end of the Green River Basin. There is a progradation of the deltaic-alluvial volcanic clastic sequence into laminated carbonate (oil shale) rocks and carbonates southward in the Green

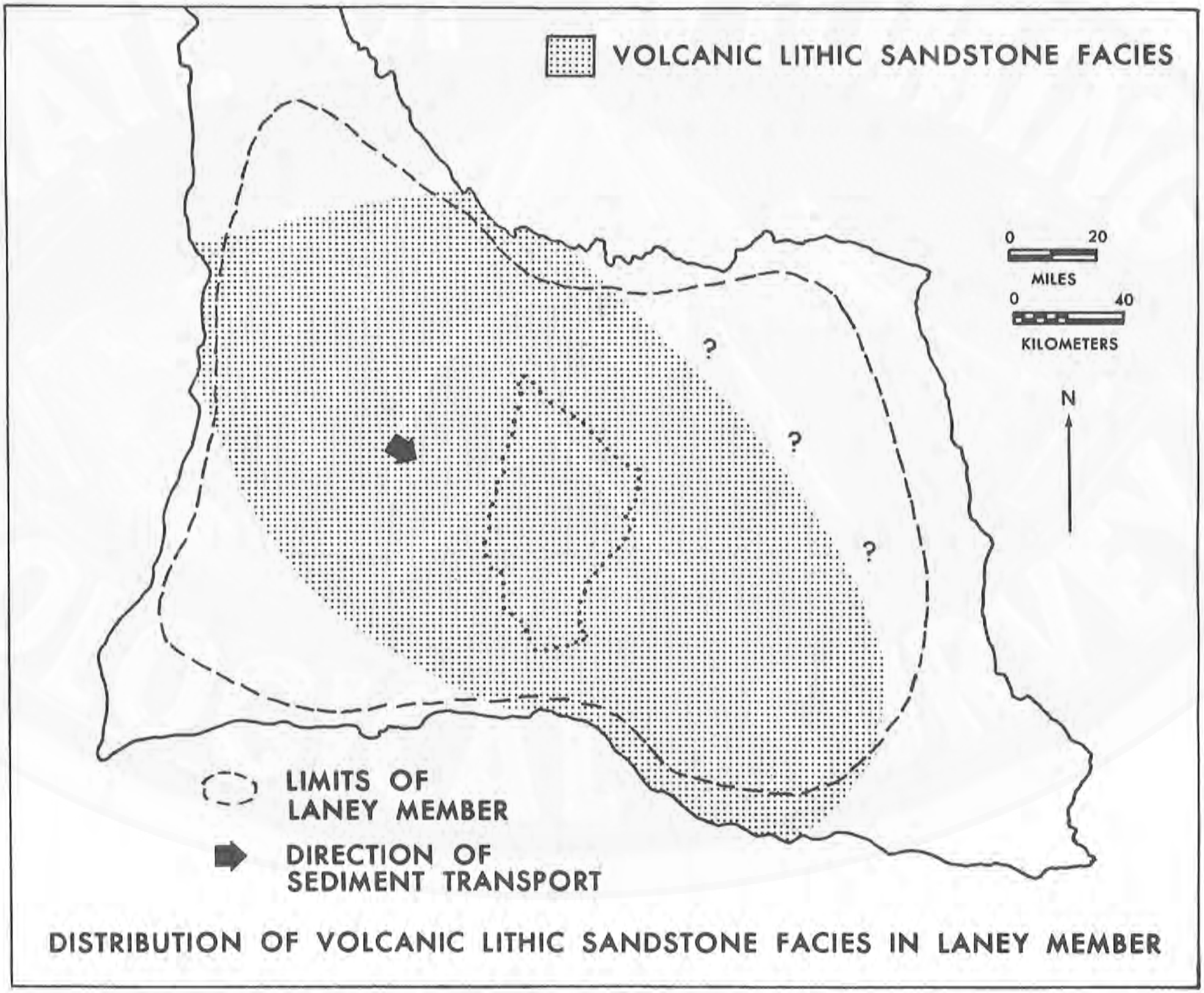


Figure 19. Distribution of volcanic lithic sandstone of the sandstone-mudstone facies of the Laney Member (after Surdam and Stanley, 1979).

River, Washakie, and Sand Wash Basins and beyond into the Piceance Basin.

Along the western margins, the laminated carbonate (oil shale) facies passes in carbonate rocks and eventually intertongues with the uppermost part of the Wasatch Formation and the lowermost part of the Bridger Formation. This intertonguing relationship means that the Laney Member along the western margin of the Green River Basin can be subdivided into two lacustrine units of the carbonate facies with an intervening clastic tongue of the Bridger Formation. The lowermost unit of the Laney Member was termed the upper tongue of the Green River Formation by Oriel (1961, 1969), and the uppermost was named Marker Unit V by McGrew and Sullivan (1970), Hams Fork Lacustrine Layer by Pledge (1969), and the Opal Tongue by Kistner (1973). McGrew and Sullivan (1970) demonstrated that these two lacustrine units are equivalent to the Laney Member in the main part of the basin. Following the example of Roehler (1973a and b) in the Washakie Basin, it is proposed to name these lacustrine units. The need for clarification of terminology has become necessary, following the rejection of the term Hams Fork Lacustrine Layer because the name had been previously assigned by Oriel and Tracey (1970) to a Cretaceous member in this region. The term Opal Tongue is abandoned because it was also used by Wolfbauer (1972) for a white tuff layer (Opal Tuff) near the base of the Bridger Formation. The unit is named the Craven Creek Bed in the present account from exposures along Craven Creek, north of the Hams Fork, in T. 21 N., R. 114 W. in the Opal 7½ minute quadrangle. In its type locality, the bed is about 110 feet (36 meters) in thickness and is composed predominantly of buff-colored calcareous silty shale, laminated siltstone, and sandstone with occasional interbedded marlstone (see Figure 23). The shale is typically dolomitic with common remains of fish, mollusks, and ostracodes (see Surdam and Wolfbauer, 1975). Other shales are not calcareous, but carbonaceous with abundant plant debris. Southward from the Hams Fork, the Craven Creek Bed thins, and four miles north of Little Muddy Creek it is represented by only 21 feet (6.5 meters) of lacustrine rocks above a greatly thickened succession of the Desertion Point Tongue of the Wasatch Formation. The Craven Creek Bed gradually merges with the laminated carbonate facies of the main body of the Laney Member in a southward and eastward direction in the Green River Basin.

The upper unit of the Laney Member is named the Cow Hollow Bed in the present account after exposures along Cow Hollow Creek in T. 21 N., R. 113 W. in the Cow Hollow 7½ minute quadrangle. It is a persistent lacustrine unit of the carbonate facies, about 30-50 feet (9-15 meters) in thickness, and outcrops in the vicinity of the Hams Fork and westward in the escarpment of Whiskey Basin to the Big Island-Blue Rim area. The bed is typically made up of buff-weathering shale, marlstone, sandstone, and siltstone similar to the underlying Craven Creek Bed. The bed thickens southward from the Hams Fork, at the expense of the associated fluvial rocks of the Bridger Formation, and eventually merges with the main body of the Laney Member.

The Laney Member, therefore, has the most widespread distribution of the various members of the Green River Formation. It represents a time of an extensive laminated carbonate (oil shale) development over most of the region and is further characterized by the restricted occurrence or absence of the carbonate facies. Profound changes in the intermontane basin finally brought to an end this cycle of lacustrine sedimentation. These changes included a new source of volcanic lithic sediments which were introduced into the basin from the north. This marked the beginning of basinal infilling as the increased influx of volcanic detritus was accompanied by cessation of regional uplift and subsidence, factors which had produced and maintained the hydrographic basin. In the Washakie Basin, Mauger (1977) has dated the influx of volcanic detritus into the region at 45.5 m.y. ago.

Environment of Deposition of the Green River Formation

A great deal has been written on the environment of deposition of the Green River Formation, and the present account is intended as a brief outline of the subject. The topic has been covered more recently in Bradley (1964, 1973), Bradley and Eugster (1969), Eugster and Surdam (1973), Wolfbauer and Surdam (1974), Smith (1974), Surdam and Wolfbauer (1975), Eugster and Hardie (1975), Lundell and Surdam (1975), Desborough (1978), Surdam and Stanley (1979), and others.

The regional setting was clearly an intermontane basin system of low relief surrounded by high peripheral mountains. Within the basin was an extensive lake, Lake Gosiute, that fluctuated in size due to tectonic and climatic changes. Climatic conditions, in particular, greatly changed the nature of composition of the lake. During humid periods, the drainage of the hydrographic basin was external and a relatively large freshwater lake occupied the region. At times of drier subhumid climate, the drainage was internal and the lake more restricted and saline.

The depositional history invoked a constant interplay between the fluvial influences along the margin and lacustrine ones within the basin. Extensive alluvial fans developed along the front of the uplands and spread out onto the broad floor of the basin. Numerous streams with a source in the uplands meandered across the alluvial plain and entered the lake in a series of deltas. Clastic sediments were deposited in the lake in off-shore bars and along sandy beaches. These areas were characterized by an increased rate of sedimentation, compared with other parts of the lake. The sediments in the deltas were usually unsorted and the fine sand intimately mixed with silt and mud. In the off-shore bars and nearby beaches, the sediments were often better sorted because of winnowing by the waves. The lacustrine delta-fill sediments are identified in the succession by laminated or well bedded sandstone and mudstone with interbedded shale. The beach and off-shore bar deposits are represented by lenticular sandstone that grades laterally into siltstone and shale.

The lake varied greatly in size and periodically transgressed and regressed great distances across the floor of the basin. The warm surface waters of the lake enhanced the growth of algae which, when added to the carbonate muds, formed rich oil shale deposits. At other times, evaporating conditions dominated the environment and resulted in the formation of saline minerals. Algae were also abundant on the margins of the lake and developed algal flats and mounds along the shoreline. The shoreline was the nesting ground of large populations of flamingoes and other shore birds. Beyond the margin of the lake were mud flats and swamps in the better watered localities. Scattered over the mud flats were small and irregular ponds in the lower depressions. In the areas around the streams and ponds, and in the slopes of the alluvial fan and upland, there was, at times, a luxuriant vegetation that supported a rich and varied vertebrate fauna.

While there has been general agreement on the broad setting, there are two quite different models which have been proposed for the lacustrine origin of the Green River Formation. The first model involves a meromictic or permanently stratified lake, and has been discussed in recent years by Bradley (1948, 1964), Bradley and Eugster (1969), Smith (1974), and Desborough (1978). The other model involves a playa lake complex and was proposed by Eugster and Surdam (1973) and enlarged upon in numerous more recent articles. Much of the discussion of both models centers around the origin of trona and oil shales in the Green River Formation.

In the meromictic lake model, the lake is thought to have been over 100 feet (30 meters) deep in the center, and chemically and thermally stratified. The lake gradually shallowed toward the margin and may have included shoals and other shallow areas in the vicinity of intrabasinal structures such as the Rock Springs uplift. The lake was freshened by rivers flowing in from the uplands, particularly along its northern end, and at times overflowed at the southern end.

The shallow water sediments of this meromictic lake are thought to include a series of calcareous and dolomitic mudstone, fine clastic sandstone, marlstone, and limestone units of the carbonate facies. The facies is sometimes rich in stromatolitic algal structures, ostracodes, mollusks, and fish and turtle remains.

The deeper lacustrine deposits in the meromictic lake are considered to be the laminated carbonate (oil shale) facies. The source of the rich organic content of the oil shale was in the upper or euphotic zone of the lake where plant and animal life was abundant. The conditions in the lower stagnant layer were unsuitable for organisms to survive, but became the site of accumulation of the organic matter that originated in the surface water. The varved, laminated structure of the oil shale is characteristic of the Green River Formation and consists of carbonate laminae alternating with organic-rich ones. The varves have been interpreted as representing a yearly cycle in the subtropical lake. The organic-rich accumulation on the floor of the deeper parts of the lake was modified in the summer months with a carbonate influx from the increased photosynthetic activity of blue-green algae in the warmer surface waters of the lake.

The deposits of trona often associated with oil shales in the Wilkins Peak Member in the Green River Basin are difficult to explain in the meromictic lake model. As a result, Bradley and Eugster (1969) proposed a complicated series of climatic and geographic changes in the basins. In order to take into account the widespread distribution of lacustrine rocks, these changes must not have significantly reduced the size of the lake. The major geographic change involved subdividing Lake Gosiute into two basins with the formation of shoals and bars along the trend of the Rock Springs uplift. The northern and eastern parts of the lake remained fresh water due to the main inflow of streams at this end from the marginal uplands. In contrast, the basin on the southern and western side of the shoal area did not receive major stream inflows and became a sink for the concentration of salines. Under these conditions of high evaporation south and west of the Rock Springs uplift, widespread deposits of trona periodically formed during Wilkins Peak time and interrupted the formation of oil shale deposits.

Eugster and Surdam (1973) challenged this model and proposed a new one based on the playa lake model that exists today in such regions as the East Africa Rift Valley and the desert area of the western United States.

The inconsistencies of the deep stratified lake model include: (i) the absence of a modern analog of Lake Gosiute; (ii) an assemblage of sedimentary structures which are consistent with a shallow water rather than a deep water origin; (iii) the close association of oil shale and trona which suggests a related environment of deposition for these sediments; (iv) the presence of Magadi-type chert similar to occurrences in the alkaline lakes of East Africa; and (v) the predominance of dolomite over calcite in the sediments, which is consistent with a shallow playa lake environment.

The setting of the playa lake model is, once more, an intermontane basin surrounded by high mountains in a subtropical climate. The mountains collected heavy amounts of rainfall and at the same time cut off precipitation from the basin floor. The mountains were flanked by extensive alluvial fans that graded into broad playa flats. In the center of the basin was a shallow, perennial lake maintained by ground water and springs. The alluvial fans on the margins of the basin trapped the coarse sediment brought in by sheet wash, and only the fine detritus found its way onto the playa flats.

The playa flats on the basin floor were areas of high evaporation of the water flows from the subsurface of the alluvial fans into the center of the basin. Evaporation in the capillary zone above the water table on the playa produced an efflorescent crust of alkaline salts. As a result, in the playa flats were deposited dolomitic and calcareous mudstone of the carbonate facies.

In the playa lake model, only the evaporite (trona) and laminated carbonate (oil shale) deposits are truly lacustrine in origin. The trona was precipitated in the lake because of evaporation of the lake water, in a similar manner as trona is being formed today in Lake Magadi in East Africa. It is assumed that laminated carbonates (oil shales) formed in the shallow lake under less arid conditions. Such an environment would support abundant microscopic aquatic plants because of the high nutrient content of the water. It is from the accumulation of this algal ooze that oil shale originated.

The playa-lake model of Eugster and Surdam (1973), therefore, explains the unusual sedimentary structures and geochemistry of the Green River Shale sediments. It indicates that the rich deposits of trona in the Wilkins Peak Member represent the most arid conditions of the Eocene with the largest accumulation of saline minerals and the widest expanse of playa flats and internal drainage. Some other lacustrine sequences of the Green River Formation, such as those in the Tipton Shale Member, were explained in a similar but less extreme fashion. The lacustrine sequences of the Luman and Laney Members, with their widespread laminated carbonate (oil shale) facies, proved difficult to assign to a playa lake model. Surdam and Stanley (1979), as a result, in studying the Laney Member, have returned to the permanent stratified lake model for this part of the succession.

Smith (1974) and Desborough (1978) have challenged most aspects of the playa lake model and support instead a modified version of the stratified lake model. Smith, studying the geochemistry of the oil shale genesis in the Piceance Creek Basin in Colorado, came to the conclusion that these kerogen-rich laminated carbonate rocks could be best explained in a stratified lake. Only such an environment could account for such unique aspects of the laminated carbonate (oil shale) facies as: (i) the continuous formation of relatively large quantities of hydrogen-rich organic matter under conditions capable of reestablishing themselves after interruption, (ii) the development of minute seasonal laminations, (iii) the lateral persistence and correlation of the varved deposit over distances of the order of 40 miles, (iv) the mineral association and texture of the oil shale sequences that suggest an authigenic origin, and (v) the limited development of the clastic sediments that would be present in a playa lake with extensive mud flats.

Smith (1974, pages 77-78) explained the formation of an evaporite facies of dawsonite, nahcolite, and halite in the Piceance Creek Basin by the addition to the lower layer of the lake of saline waters during periods of high evaporation. The concentration began by evaporation along the margins of the lake producing a saline ring around the edge. The salts were added to the lake during higher lake stands or by rain water. The heavier salt-charged waters sank to the lower stagnant waters of the lake. The presence of abundant carbon dioxide, derived from the organic matter, resulted in the formation of dawsonite and nahcolite.

Desborough (1978) critized the purely chemical playa lake model because it did not take into account the biogenic processes effective in Lake Gosiute. The principal argument against the stratified lake model was the enrichment in the carbonate rocks of magnesium compared with calcium. Desborough considered that the biogenic activity of algae was responsible for this enrichment, rather than chemistry on the playa flats and detrital deposition in the lake. Another important argument of Eugster and Surdam was their concern about the absence of a modern day analog to Lake Gosiute where oil shale and trona are being formed in a permanently stratified lake. This is answered by Desborough, who points out that the absence of a modern analog could be expected because of the uniqueness and rarity of such sequences as the Green River Formation in the geological column.

Love (1961) has also emphasized the uniqueness of the environment of deposition of the Green River Formation. It has become evident that much further research is needed on the chemical and biogenic aspects of the rocks. In particular, the presence of widespread uranium phosphate zones in the Wilkins Peak Member must be taken into account. These geochemical syngenetic zones, associated with the evaporite facies, can be traced for great distances across the basin and are a measure of the tranquility of deposition over an area of 1,000 to 2,000 square miles (1,600 to 3,200 square kilometers). It is important to explain if these geochemical concentrations can take place in a lake or on a subaerial playa mud flat environment.

In summary, Lake Gosiute existed for about 4 to 8 million years in southwestern Wyoming during Eocene time. The lake fluctuated in size in response to tectonic and climatic changes. The onset of lacustrine sedimentation is seen in the Luman Member of the Green River Formation. The major high stands of the lake correspond to the Tipton Shale and Laney Members. The high stands of the lake were separated by a low stand represented by the Wilkins Peak Member. The influx of volcanic detritus, combined with cessation of regional uplift and subsidence, brought an end to Lake Gosiute in mid Eocene time. Mauger (1977) has dated the end of lacustrine deposition in the Washakie Basin between 45 and 44 m.y. ago.

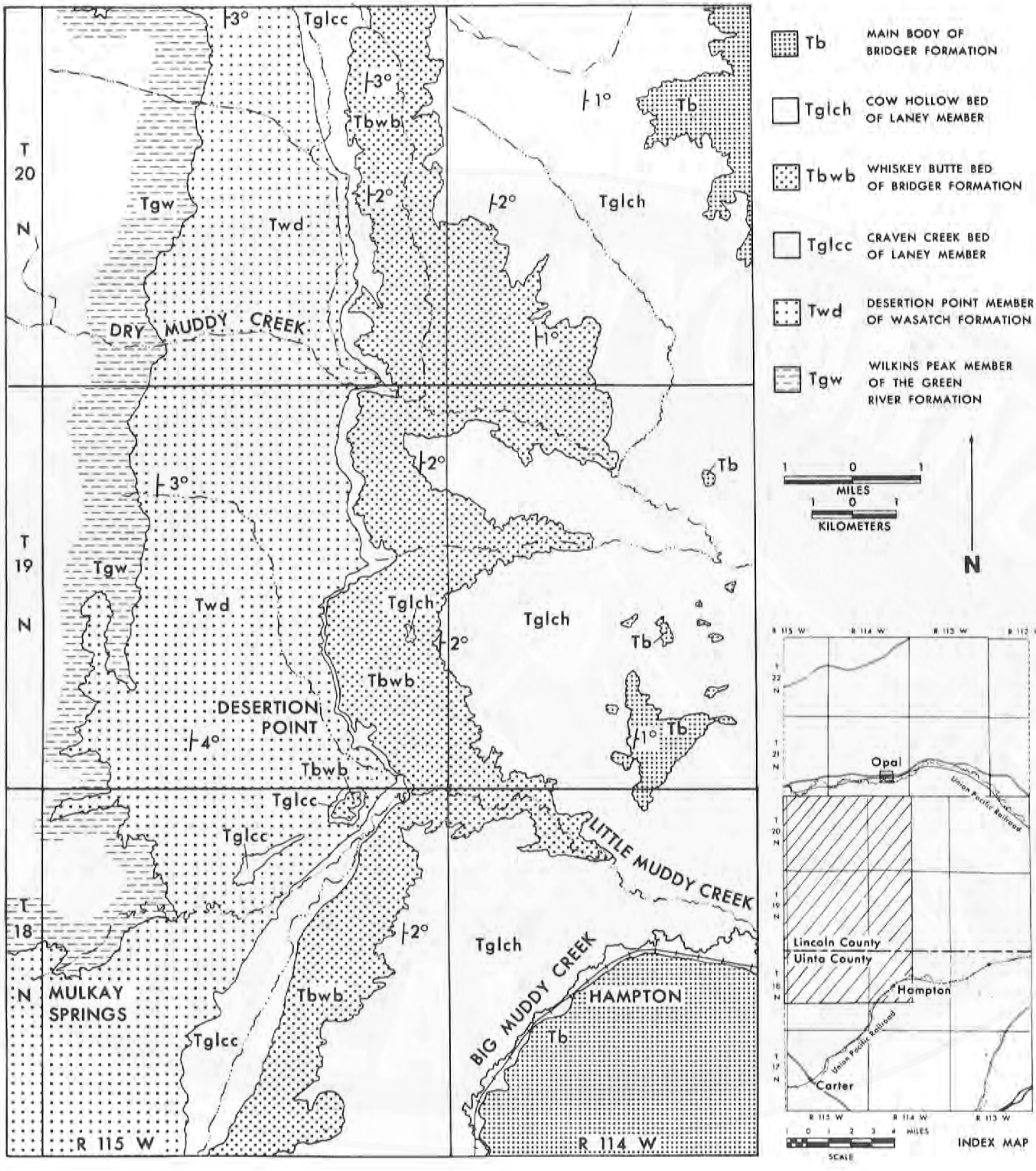
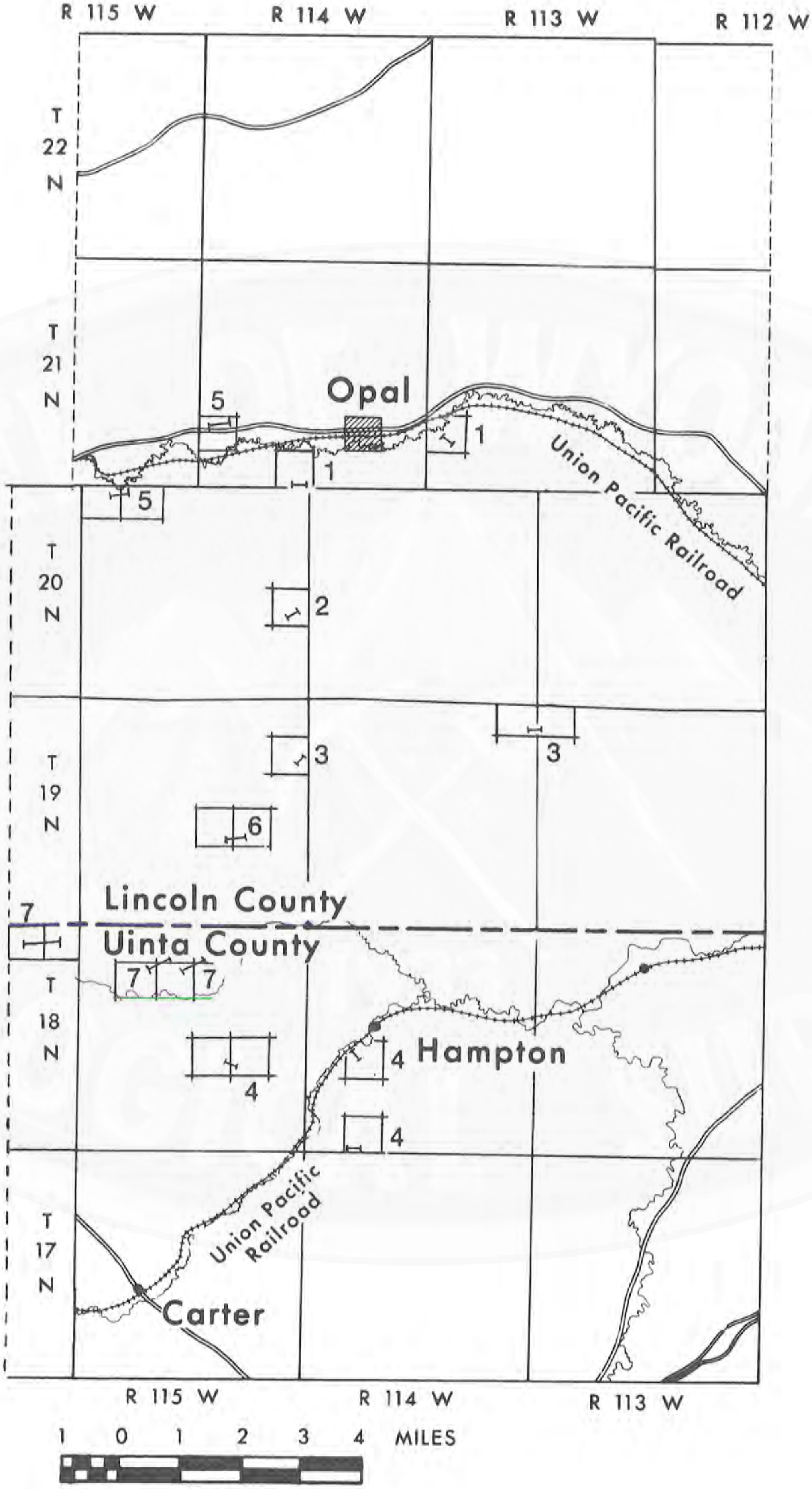


Figure 20. Geological map of the Desertion Point area, Wyoming.


R 115 W
R 114 W
R 113 W
R 112 W
T 22 N
T 21 N
T 20 N
T 19 N
T 18 N
T 17 N
Opal
Union Pacific Railroad
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Uinta County
Hampton
Union Pacific Railroad
Carter
R 115 W
R 114 W
R 113 W
1 0 1 2 3 4 MILES
SCALE

THE BRIDGER FORMATION

The Bridger Formation, of middle (Bridger A-B) and later (Bridger C-D) age, was named by Hayden (1873) for rocks of a non-red fluviatile sandstone and mudstone facies exposed along the Union Pacific Railroad in the central part of the Green River Basin. The formation occurs in erosional remnants in the Green River Basin, and it has been estimated that the total thickness is approximately 2,000 feet (600 meters). In general lithology it resembles the Wasatch Formation, but differs in the abundance of volcanic material and the general absence of red coloration in the succession.

Roehler (1973b) has reestablished the term Washakie Formation for the rocks in the Washakie Basin that had previously been assigned by Bradley (1964) and others to the Bridger and Uinta Formations. The Bridger and Washakie Formations are approximately the same age but differ in detailed lithology and stratigraphic relationships. The Washakie Formation is restricted to the east side of the Rock Springs uplift where it reaches a maximum thickness of 3,200 feet (980 meters). Unlike the Bridger Formation, the rocks are brightly colored and rich in arkosic sediments with a source in Paleozoic and Mesozoic sedimentary rocks and plutonic rocks in the Sierra Madre. The sources of sediments in the Bridger Formation were the Paleozoic and Mesozoic sedimentary rocks in the Wind River Mountains to the north and the Precambrian quartzites and metaquartzites of the Uinta Mountains to the south. As a result, they are generally siliciclastic sandstones and, for the most part, lack a high content of arkosic sediments. Both formations, however, have abundant volcanic sediments with a common source in the Absaroka Range. Stratigraphically, they can be distinguished by their intertonguing relationships with the Green River Formation and the presence of a regional unconformity within the Washakie Formation which is absent in the Bridger Formation. The Washakie Formation has been described in detail by Roehler (1973b) and will not be discussed further in this present account.

Figure 21. Index map showing location of measured sections in the Desertion Point area along the western margins of the Green River Basin.

The Bridger Formation has received little attention since the poineer work of Granger and Matthew (*in* Matthew, 1909), when a subdivision of the formation into five "horizons", designated Bridger A, B, C, D, E was established, utilizing several marker beds. H. E. Wood (1934) used the marker beds of Granger and Matthew to subdivide the formation into two members, the Blacks Fork (A and B) and the Twin Buttes (C and D). It has been evident from the outset that these terms were not intended to be used as rock stratigraphic units but as biostratigraphic ones. The fauna from these biostratigraphic units have been extensively studied by the vertebrate paleontologists and the terms continue to be used as a basis for zonation of the Bridger Formation. In general, however, these terms have not been accepted by stratigraphers, and have been rejected by Koenig (1960), who proposed instead a threefold subdivision into lower, middle and upper Bridger Formation based on lithological variation.

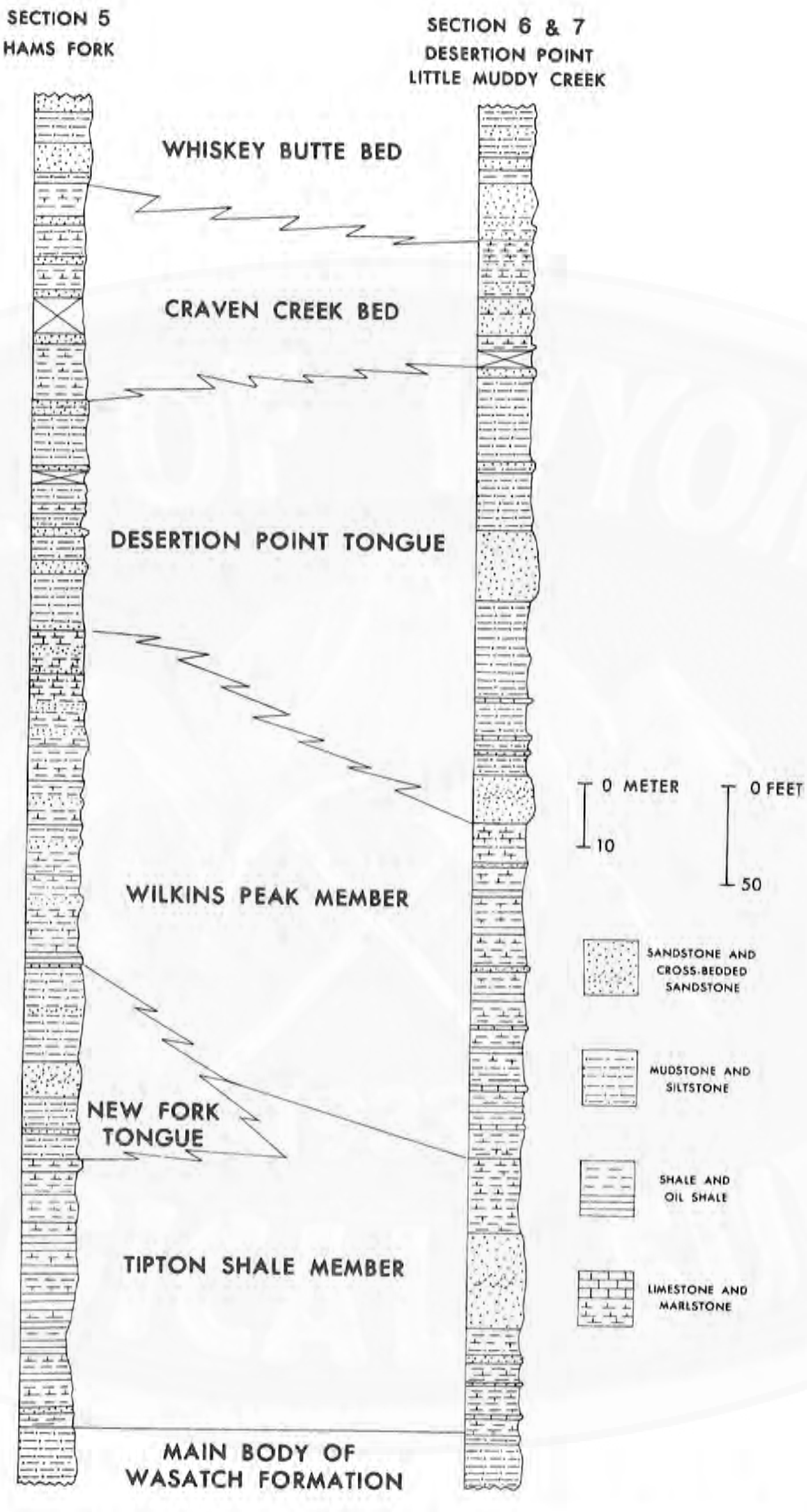

Figure 22. Stratigraphic sections of the Green River and Wasatch Formations in the Desertion Point area along the western margin of the Green River Basin (in part after Lawrence, 1962).

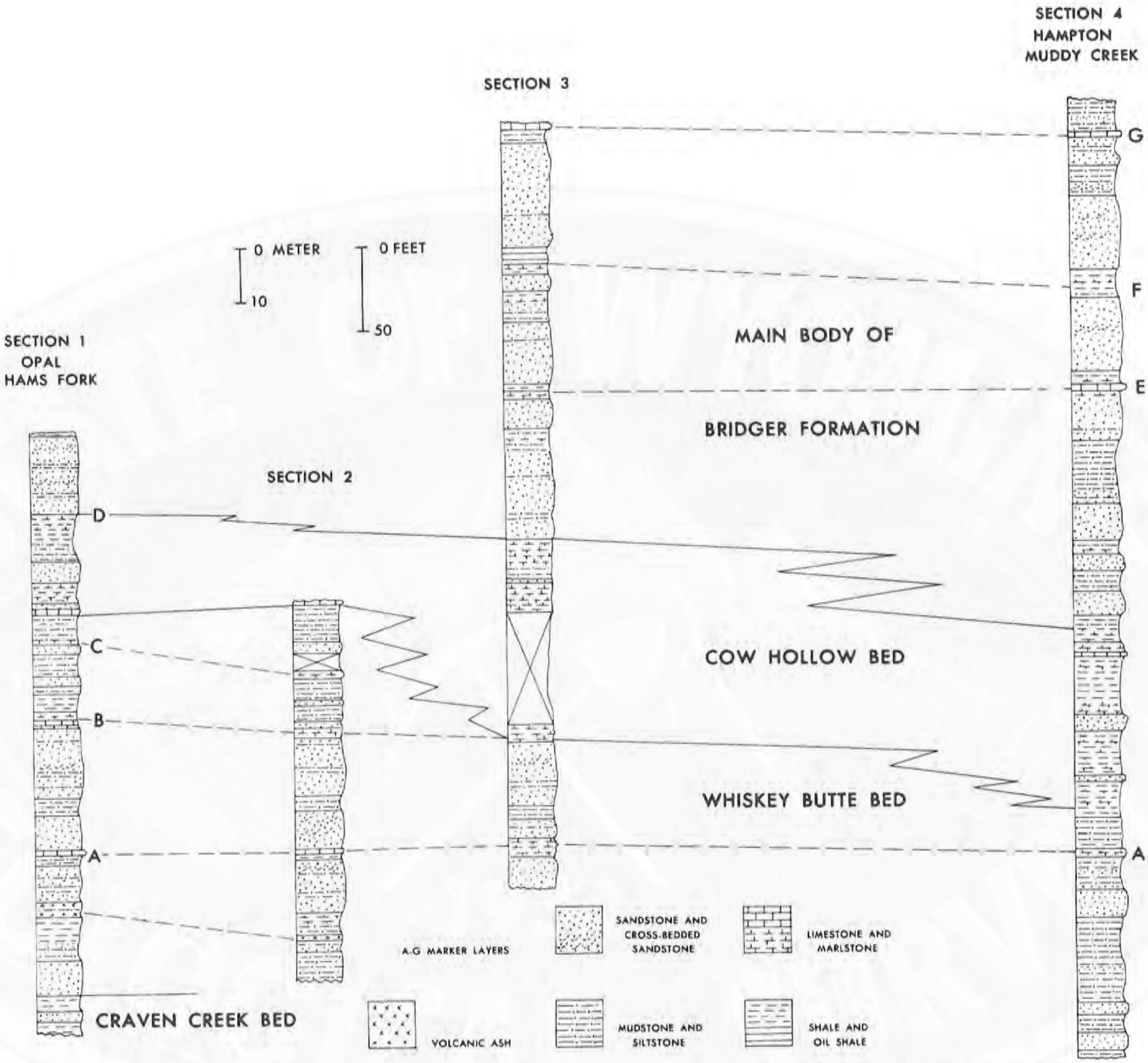

Figure 23. Stratigraphic sections of the Green River and Bridger Formations in the Desertion Point area along the western margin of the Green River Basin.

It is clear that an extensive restudy of the Bridger Formation is needed to establish subdivision into rock stratigraphic units following the criteria determined by Roehler (1973b) in the Washakie Basin. Such a subdivision would enable a more precise description of the facies and paleoenvironmental variations represented in the Bridger Formation. The present account is mainly concerned with the lowermost part of the Bridger

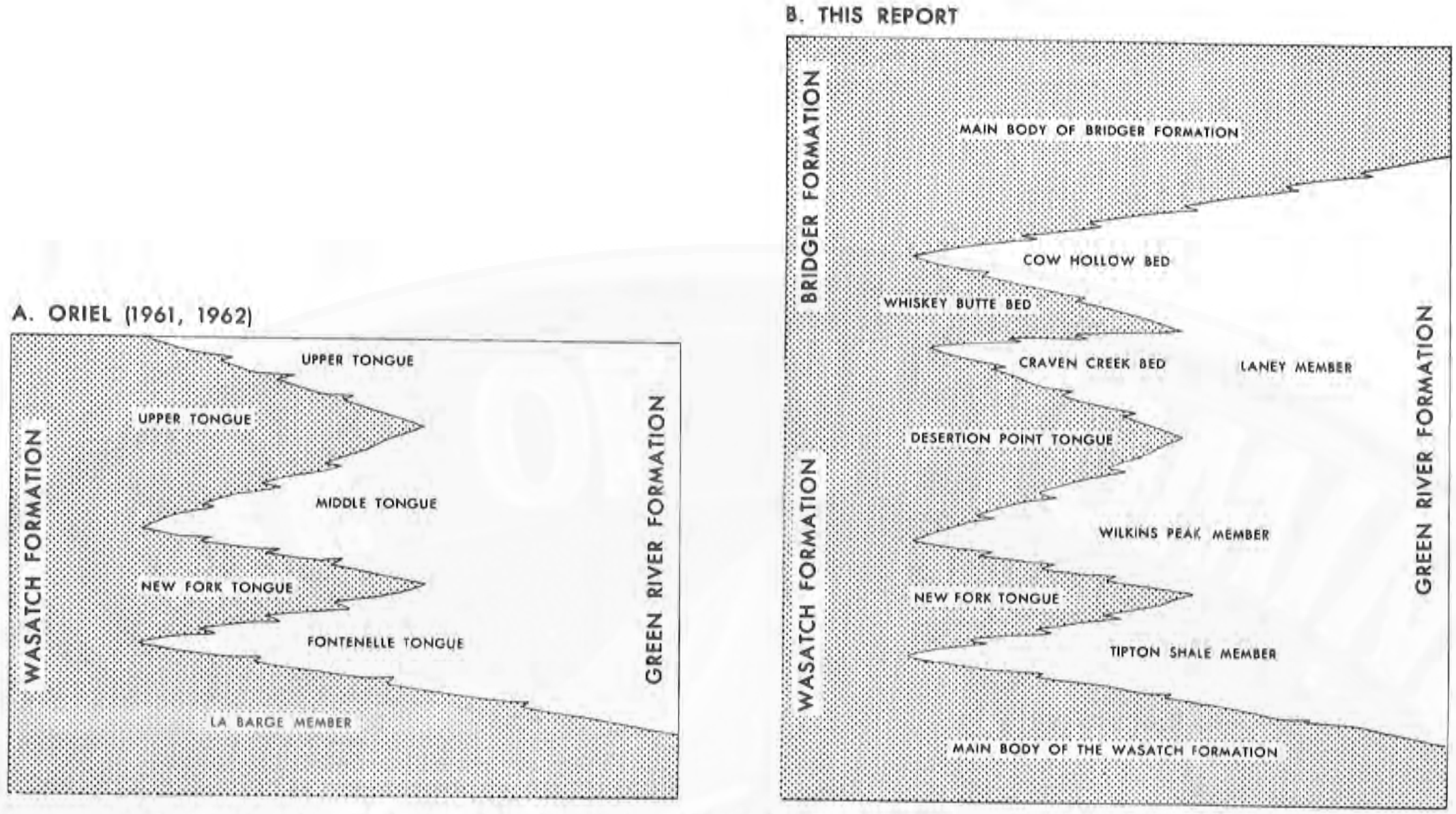

Figure 24. Comparison of the terminology for the subdivisions of the Wasatch, Green River and Bridger Formations along the western margin of the Green River Basin. A. Oriel (1961, 1962). B. This report.

Formation exposed along the western margins of the Green River Basin. In this area, it is possible to separate from the main body a fluvial unit of the Bridger Formation that can be traced over a wide part of the region. It is proposed to begin subdivision by naming this unit the Whiskey Butte Bed of the Bridger Formation. It is separated from the main part of the Bridger Formation by the Cow Hollow Bed of the Laney Member (see Figures 1 and 23).

Whiskey Butte Bed of the Bridger Formation

The Whiskey Butte Bed is named after the locality in T. 21 N., R. 111 W., in the Whiskey Butte 7½-minute quadrangle, where the first description of the unit was made by C. B. Wood (1966). The unit was termed the "lower Bridger A" by Pledge (1969), McGrew and Sullivan (1970), Wolfbauer (1972), and Kistner (1973). McGrew and Sullivan (1970) subdivided the unit using carbonate marker layers, and included in the bed marker layers A to C and the intervening fluvial units I to IV.

The Whiskey Butte Bed attains a maximum thickness of 230 feet (70 meters) along Hams Fork near Opal. Kistner (1973) has shown that this thickness and the fluvial lithology of the bed are maintained as it is traced eastward across the Whiskey Basin to the Green River. In contrast, when the bed is traced southwards from Hams Fork, it is gradually replaced by the carbonate facies of the Laney Member. The fluvial rocks in the upper part of the unit are the first to show evidence of the the southerly facies change; it gradually spreads lower in the succession until the bed loses its identity and merges with the Laney Member south of Carter. The Whiskey Butte Bed is clearly a fluvial unit at the base of the Bridger Formation with a source to the north and west of the Green River Basin.

The rocks of the Whiskey Butte Bed are generally light gray or greenish colored siltstone, mudstone, and claystone. Coarser clastic units tend to increase in importance upwards in the succession. Little detailed petrographic work has been done on the clastic rocks of the Bridger Formation since the early studies of Sinclair (1906) and Johannsen (1914). They postulated a volcanic origin for much of the formation, with a probable source of the volcanics being the Absaroka Range, and this has been supported by recent studies by Koenig (1960), Denson and Pipiringos (1969), Roehler (1970), and Wolfbauer (1972). Most of the volcanic debris has been reworked by streams and highly weathered, so that only rarely in the formation are pure volcanic tuffs preserved. Well rounded cobbles of andesite have been described by Kistner (1973, page 41) from channel sandstone in the Whiskey Butte Bed, and they are thought to have been floated in by root rafting in streams.

Roehler (1970) and Surdam and Stanley (1979) have shown that the large influx of volcanics in the Washakie Basin had a marked effect on the environment of deposition. Volcanism began during the early Eocene, but intensified during middle and late Eocene time and resulted in the final filling of the depositional center. This change in volcanism took place in the upper part of the Laney Member in the Washakie and the Green River Basins.

Thin layers of marlstone, ostracodal or algal limestone, and calcareous and dolomitic mudstone occur at many levels in the Whiskey Butte Bed. The most obvious feature of the limestone and marlstone is their thin but widespread extent, which allows them to serve as marker beds. Wolfbauer and Surdam (1974) studied the origin of these carbonate layers and concluded that they originated along the margins of a playa lake. The dolomitic and calcareous mudstones were considered to be deposited in mud flats, as described for these sediments in the Green River Formation.

The volcanic lithic sandstones in the Whiskey Butte Bed occur as channel and sheetlike bodies. The channel sandstone is abundant at many levels in the succession, particularly in the middle part of the bed. The sandstone is fine- to coarse-grained and is poorly sorted, with varying amounts of silt and clay. Conglomeratic layers are common, and frequently consist of clay and mud balls or pebbles in a sandy matrix. The mineralogy of the sand fraction is quite variable and includes quartz and subhedral feldspar with the non-opaque heavy minerals including biotite, augite, amphibole, and epidote. Calcite is often present as a cement. The channel sandstones occur as lenticular bodies, and most are cross-bedded, with erosional surfaces at their base. The lenticular bodies vary in width from only a meter to several meters. Outcrop patterns often indicate a sinuous longitudinal distribution that represents the narrow meandering belts of streams that flowed across the broad basin floor into a delta complex. Pledge (1969) has shown that in the Opal area, the direction of the channels indicates a southward flowing stream system.

The sheet sandstones are more or less tabular bodies that are continuous over a fairly wide area. They are much thinner vertically than the channel sandstones and often grade laterally into siltstone and mudstone. Lithologically, the sheet sandstones are similar to the channel deposits, but typically have a finer texture and appear to represent sediments of the natural levees.

Main Body of the Bridger Formation

The main body of the Bridger Formation is not subdivided in the present account, and the stratigraphic variation has been described by Koenig (1960) and Bradley (1964). Extensive erosion of the Bridger Formation throughout southwestern Wyoming has made it extremely difficult to determine detailed stratigraphic relationships. The most complete sections are in the southern part of the Green River Basin and Bradley (1964) described the maximum development of the formation at 2,285 feet (696 meters) near Sage Creek Butte. It appears that the Bridger Formation thins eastwards along the southern margins and 1,560 feet (475 meters) is represented at Twin Buttes due to replacement of the fluvial succession by the thickening Laney Member. Pipiringos (1962) measured outliers of the Bridger Formation in the northern part of the Great Divide Basin.

Along the western margins of the Green River Basin, erosion has allowed only the lower part of the main body of the Bridger Formation to be preserved. McGrew and Sullivan (1970) described 280 feet (85 meters) of beds assigned to "upper Bridger A" in the area of Hampton, and Kistner (1973) measured 310 feet (94 meters) in the vicinity of the Green River near Big Island-Blue Rim. A similar regional stratigraphic relationship to that described for the Whiskey Butte Bed is present in the lower part of the main body. Once more, the so-called "upper Bridger A" maintains its lithology eastward from the Overthrust Belt toward the Green River and the Rock Springs uplift. Southward, however, the lower part of the main body thins and interfingers with the Laney Member. This relationship indicates that, at least, the lower part of the main body of the Bridger Formation also has a source to the north and west of the Green River Basin.

Environment of Deposition of the Bridger Formation

Much of the detail of the depositional history of the Bridger Formation has been outlined in the discussion of the Wasatch and Green River Formations. The regional setting continued to be an intermontane basin in a subtropical and humid climate. The early part of the Bridger Formation saw the continuation of the interplay between fluvial influences from the marginal uplands and lacustrine influences within the intermontane system. The fluvial influences gradually dominated the regional setting as Lake Gosiute eventually became more restricted to the southern end of the Washakie and Green River Basins. The restrictions of the lake were probably related to the infilling of the depositional centers by the greater influx of fluvial sediments from the marginal uplands and wind blown volcanic debris from northwestern Wyoming. The main sources of nonvolcanic detritus for the Bridger Formation appear to be from the north in the Wind River Range, but the Washakie Formation was derived from the Sierra Madre east of the Washakie Basin.

The regional setting, therefore, was a fluctuating Lake Gosiute that transgressed and regressed across the southern part of the Green River and Washakie Basins. The lake was probably shallow and surrounded by mud flats and alluvial plains rising to the marginal uplands. Regression of the lake left an area of wide mud flats with scattered swamps and ponds in the lower depression. The environment on the mud flats was often a complex association of subaerial and subaqueous conditions. These areas were periodically covered by flood waters during the wetter climatic periods, then dry and subject to high evaporation during more arid cycles. On the whole, it would appear that the climate was warm and humid during the deposition of the Bridger Formation and that parts of the basin floor and marginal uplands were covered with a luxuriant vegetation. Streams meandered across the plain and entered the lake by a series of deltas. Periodically, volcanic debris was blown into the basin by the winds, and ash mixed with the sediments in the lakes, ponds, and streams. As a result, the volcanic debris was worked and resorted by water and mixed with the clastic sediments. The great influx of volcanic and fluvial sediment helped to fill in the depositional basin, and in the final stage, Lake Gosiute was probably represented by scattered shallow lakes and ponds. Occasional return of more widespread lacustrine conditions during deposition of the upper part of the Bridger Formation in the southern part of the intermontane basin is represented by a series of "white layers" which serve as markers in the Bridger Formation. The most prominent of these have been identified by Matthew (1909) and McGrew and Sullivan (1970). One of the most extensive of these lacustrine marker beds is the Cottonwood white layer, which Koenig (1960) used to subdivide the lower and middle units of the Bridger Formation, and the upper white layer which subdivides the middle and upper units. These layers represented the final stages of lacustrine deposition in the Green River Basin.

CONCLUSIONS

The heterogeneity of the Eocene rocks of southwestern Wyoming indicates a broad range of continental environments and tectonic activity in the intermontane system of the central Rocky Mountains. Strong subsidence occurred within the basin, together with intermittent uplifts of the marginal uplands and intrabasinal structures associated with the Laramide Orogeny.

A lacustrine complex of Lake Gosiute developed in the intermontane system during early Eocene time following the deposition of the thick succession of red colored fluvial rocks that formed the main body of the Wasatch Formation. Throughout most of its history, Lake Gosiute was centered along the southern margins of the intermontane system along the front of the Uinta Range in the Washakie and Green River Basins. In these centers, approximately 3,000 to 3,500 feet (900 to 1,100 meters) of the Green River Formation were deposited. During the deposition of the Wilkins Peak Member, however, an important change in the depositional pattern in the intermontane system can be demonstrated, with a shift to a major center of lacustrine formation in the southern end of the Green River Basin. The lake was probably a shallow saline one that fluctuated in size in response to climatic and tectonic conditions. At times during the deposition of the Luman, Tipton Shale, and Laney Members, the lake freshened and deepened, spreading out over a large area of the intermontane system.

Tongues of the Wasatch Formation interfinger, along the margins of the basins, with the lacustrine deposits of the Green River Formation. In studying the stratigraphic relationships, it is clear that intermittent uplifts of the marginal uplands strongly influenced the distribution of the clastic units within the Eocene succession. It can be demonstrated that the clastic units had variable sources and it is suggested that the marginal structures behaved as independent tectonic units during this phase of the Laramide Orogeny. The Niland and Cathedral Bluffs Tongues have main sources from the south and east in the Uinta and Sierra Madre Mountains. The New Fork Tongue had a source to the north in the Wind River Range and west in the Overthrust Belt. The Desertion Point Tongue had a provenance from the south in the Uinta Mountains.

During the deposition of the Bridger and Washakie Formations, the lake system gradually became more restricted again and was limited to the southern part of the Green River and Washakie Basins. Lacustrine sedimentation finally ended with a major influx of volcanic detritus. The Bridger Formation of the Green River Basin attains a maximum thickness of 2,000 feet (600 meters) along its southern margins, but the main part of the formation has been removed by erosion over the greater part of the basin. The Washakie Formation is the equivalent of the Bridger Formation and reaches a maximum thickness of 3,200 feet (980 meters). The main sources of the sediment in the Bridger Formation were volcanic, from the Absaroka Range. Local sources of detrital sediment were also the Paleozoic and Mesozoic sedimentary rocks in the Wind River Range to the north and the Precambrian quartzites and metaquartzites in the Uinta Range to the south. The Washakie Formation was derived mainly from Paleozoic and Mesozoic sedimentary rocks on the west flanks, and plutonic rocks in the core, of the Sierra Madre. Filling of the depositional centers took place in late Eocene time and brought an end to this phase of early Tertiary history in the central Rocky Mountains. This marked the development of the sedimentary cycle which continued into the Pliocene with the reestablishment of exterior drainage in the central Rocky Mountains.

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