THE LANEY MEMBER OF THE GREEN RIVER FORMATION, SAND WASH BASIN, COLORADO, AND ITS RELATIONSHIP TO WYOMING

GARY L. KORNEGAY[1] AND RONALD SURDAM[2]

ABSTRACT

The Laney Member of the Green River Formation is a sequence of Eocene age rocks which are found in the southwest quarter of Wyoming and parts of northwest Colorado. In general, the Laney crops out along the margins of the Green River, Great Divide, Washakie and Sand Wash Basins of Wyoming and Colorado. The Laney is primarily a carbonate shale section which was deposited in or around ancient Lake Gosiute.

Time transgressive sequences within the Laney Member of the Green River Formation indicate that ancient Lake Gosiute migrated into the study area late in its history and eventually terminated there. The termination of Lake Gosiute was preceded by progradation, freshening, and the development of an outlet. Through these processes, the Laney sediments in this area acquired unique lithologic, mineralogic and paleontologic characteristics relative to Laney rocks elsewhere. Two specific mineralogic characteristics which are unique to the area are the presence of cristobalite in some units, and the absence of evaporite minerals. The most striking lithologic difference between the Laney rocks of Wyoming and the Laney rocks of Colorado is the overall abundance of non-kerogeneous shales in Colorado. The lithologic, mineralogic and paleontologic characteristics and the cyclic nature of these characteristics are typical of playa-lake deposition.

In summary, the Laney rocks of Wyoming were deposited in a large, penesaline playa lake; whereas, the Laney rocks of northwest Colorado were deposited in a much smaller and relatively fresher water lake. Since the Laney rocks of Wyoming and Colorado were deposited in the same lake, many Laney stratigraphic units cross time lines. The Laney rocks of northwest Colorado, therefore, represent the final stages of deposition in Eocene Lake Gosiute.

INTRODUCTION

The Laney Member of the Green River Formation is a sequence of lacustrine rocks which accumulated within the closed hydrographic basin of Eocene Lake Gosiute. The lake experienced a number of fluctuations in areal extent (Eugster and Bradley, 1969; Eugster and Surdam 1973) and was ultimately restricted to an area roughly equivalent to the present day Sand Wash Basin. As a result, the Laney, in the Sand Wash Basin, is not time equivalent to the Laney elsewhere. This is evidenced by onlapping and intertonguing of lower Laney sediments with Wasatch sediments, the absence of such time markers as the tuff beds typical of the Laney in Wyoming, and the distinct change in character of mid to upper Laney rocks within the Sand Wash Basin. Therefore, any correlation between the Laney in the Sand Wash Basin and the Laney elsewhere in the greater Green River Basin would cross time lines.

Two models have been proposed for the depositional environment of the Green River Formation. One involves a deep, permanently stratified lake (Bradley, 1931) and the other involves a playa-lake complex (Eugster and Surdam, 1973). It is the contention of this study that the playa-lake model is most accurate in explaining the characteristics of the Laney Member in both Wyoming and Colorado. The applicability of the playa-lake model to the Green River Formation has been demonstrated by several authors: Eugster and Surdam, 1973; Bradley, 1973; Wolfbauer and Surdam, 1974; Surdam and Wolfbauer, 1975; Eugster and Hardie, 1975; Lundell and Surdam, 1975; and Surdam and Stanley, 1976.

The Sand Wash Basin is located in northwest Colorado directly south of the Washakie Basin (Fig. 1). For the sake of simplicity, the Sand Wash Basin will be defined

[1]Geologist, Pennzoil Company, Denver, Colorado.
[2]Geology Professor, University of Wyoming, Laramie, Wyoming.

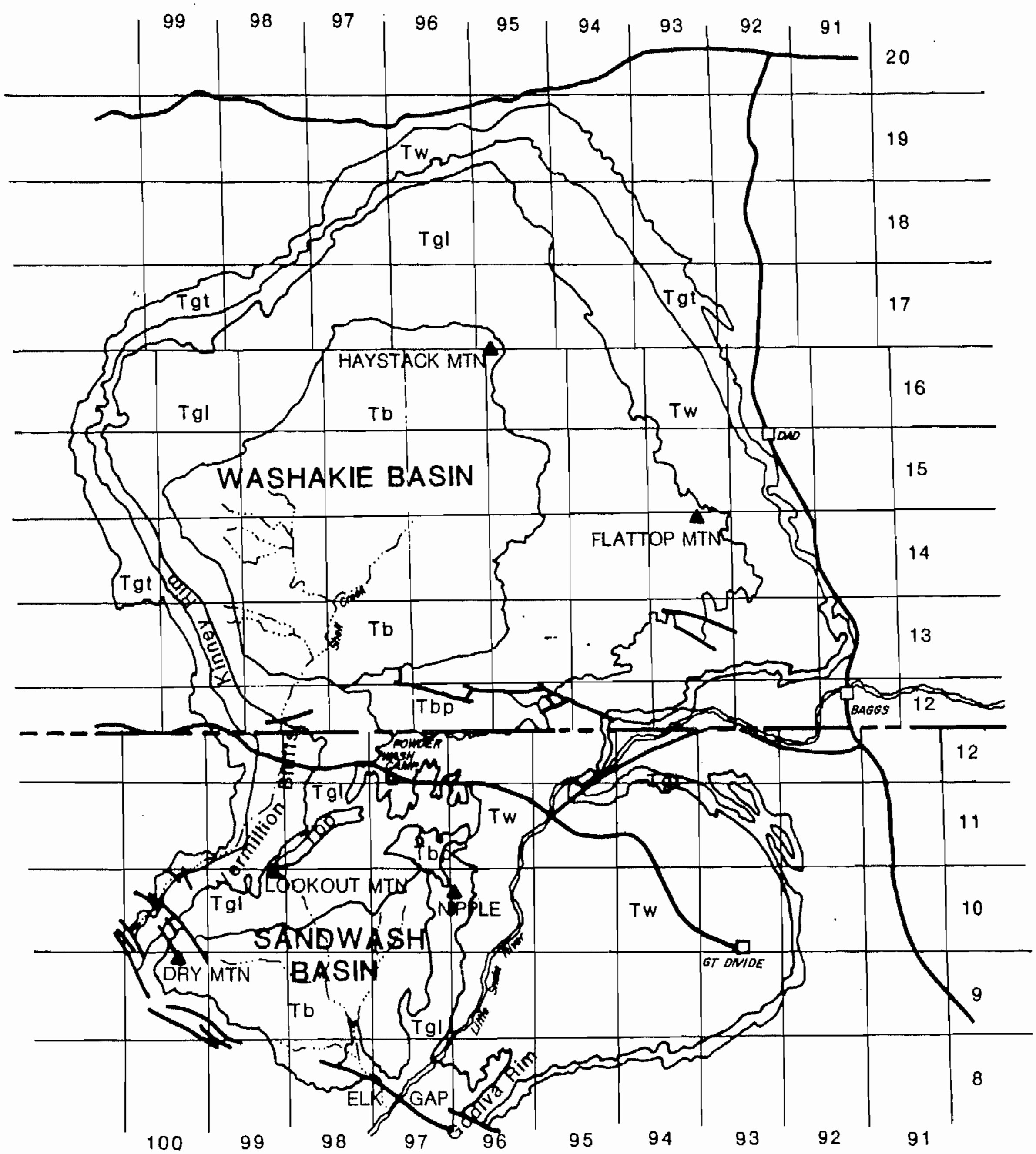


Figure 1: Geologic map of the Sand Wash and Washakie Basins, Colorado and Wyoming. Adapted from Roehler 1973; Tb-Bridger Fm., Tbp-Bishop Congl., Tgl-Laney Member Green River Fm., Tgt-Tipton Member Green River Fm., Tw-Wasatch Fm.

in this paper as the area encompassed by the outcrop of the Laney on the east, north, and west and bounded by faults along the south. The faulting along the southern margin has obscured the Laney outcrop.

This basin is typified by little water, sparse vegetation, and poor roads except in areas of recent drilling. Hydrocarbons and uranium are the obvious economic resources of the area. Some of the significant fields in the area are Hiawatha, Powder Wash, Cherokee, Baggs, State Line, and Craig fields. Production is primarily from Tertiary and Cretaceous horizons in the form of gas and condensate.

The field work for this study was done in mid-1975 and the lab work was done in late 1975 and early 1976. Several detailed stratigraphic sections were measured and critical intervals sampled. Numerous analytical techniques were employed including X-ray diffraction, petrographic analysis, geochemical analysis, and scanning electron microscopy. Comparisons to the Laney in Wyoming were drawn from personal observation, personal communication and literature.

We wish to thank the following people for their assistance: Ken Stanley, who aided in the field, and Paul Buchheim and John Hanley who aided in paleontologic identifications.

STRATIGRAPHY AND SEDIMENTATION

A total of eight detailed stratigraphic sections were measured in the study area. The location of the sections are shown in Figure 4. The stratigraphic sections can be subdivided into four major lithologic groups that are easily recognized in the field. The lithologic groups are: 1) siliciclastic and argillaceous rocks, 2) kerogenous rocks, 3) non-kerogenous carbonate rocks, and 4) volcanogenic clastic rocks (Table 1). The first group is part of the Wasatch Formation and the other three are components of the Laney Member. In the Sand Wash Basin the Laney attains a maximum thickness of 850 feet (260 m) at the outcrop (Plate 1).

In 1973, Roehler subdivided the Laney in the Washakie Basin into three beds: the Laclede bed, composed mainly of oil shales; the Sand Butte bed, composed of volcanogenic clastic rocks; and the Hartt Cabin bed, a heterogenous sequence composed mainly of mudstones. It is difficult to relate the Laney sediments of the Sand Wash and southern Washakie Basins to the stratigraphic divisions that Roehler proposed; however, the following is a reasonable classification. The Laclede and Sand Butte beds are present, but not as Roehler suggested. The Hartt Cabin would consist of non-kerogenous carbonate rocks, mainly shales and conquinas rich in ostracod tests. This unit of non-kerogenous carbonate rocks is positioned between units similar to the Laclede and Sand Butte beds. Figure 2 illustrates Roehler's stratigraphic divisions and nomenclature and how they relate to the stratigraphy of the Sand Wash and southernmost Washakie Basins. The schematic cross-section in Figure 3 illustrates the relationship of the Laney in the Sand Wash Basin to the Laney in the Washakie Basin.

The Laney is underlain by the Wasatch Formation. Mudstones, in shades of red and green, are the dominant lithology of the upper Wasatch on the western margin of the Sand Wash Basin (Cathedral Bluffs Tongue); whereas siliciclastic sandstones and siltstones are the dominant lithology of the upper Wasatch on the eastern margin. These siliciclastic and argillaceous rocks are terrigenous sediments composed predominately of quartz, feldspars, micas and clays. The mudstones and siltstones were deposited on the flood plains or in fluvial channels. The relatively high percentages of calcite and the low percentages of dolomite in the mudstones (Table II) further indicate that the mudstones were deposited in the upper portions of the mud flats (Wolfbauer and Surdam, 1974). The siliciclastic and argillaceous rocks of the upper Wasatch are intertongued with the lower Laney throughout the area studied. Along the western flank of the Sand Wash Basin these rocks intertongue with kerogenous rocks, while on the eastern flank they intertongue with both kerogenous and non-kerogenous rocks. Current-direction measurements and onlapping of the lacustrine rocks indicate that Lake Gosiute migrated into the area from the northwest (Fig. 4).

The kerogenous rocks are lacustrine rocks which are visibly kerogenous regardless of lithology, and are composed predominately of carbonates, clays, detrital quartz and detrital feldspars. In the Sand Wash Basin, kerogenous rocks, particularly oil shales, are the dominant lithology of the lower Laney. These rocks were deposited in shallow saline-alkaline water under anoxic conditions. At the upper limits of the kerogenous rocks, a sharp boundary is formed with non-kerogenous rocks on the western margin of the basin. On the eastern margin the kerogenous and non-kerogenous rocks are extensively intertongued.

The non-kerogenous carbonate rocks are drab, lacustrine sediments that are void of kerogen and composed predominately of carbonates, detrital quarz, authigenic silica, and clays. Ostracod and mollusc tests are common sedimentary components. The non-kerogenous rocks are the dominant lithology of the middle Laney in the Sand Wash Basin and were deposited in shallow, relatively fresh water under oxidizing conditions. These rocks are overlain by, and occasionally interbedded with, volcanogenic clastic rocks.

Volcanogenic clastic rocks are identified as clastic sediments ranging from siltstones to coarse-grained sandstones containing detrital quartz, detrital feldspar, detrital mica, clay and distinguishable quantities of volcanogenic minerals. The volcanogenic clastic rocks are easily recognized in the field by their rusty-cream color. These rocks were deposited as a prograding clastic wedge during the final stage of deposition in Lake Gosiute. The volcanogenic clastic rocks onlap non-kerogenous rocks in the Sand Wash Basin. Paleocurrent directions and the onlapping contact with non-kerogenous rocks indicate that the prograding wedge moved into the area from the north (Fig. 4). At their upper limits, the volcanogenic clastic rocks are in contact with the Bridger or Washakie Formations. However, due to an erosional unconformity at

TABLE I

LITHOLOGIC GROUP	ROCK TYPE	ROCK ASSOCIATIONS	SEDIMENTARY FEATURES	DISTRIBUTION
I Siliciclastic & Argillaceous Rocks	1) sand-stones & siltstones	Groups I, II, III & type 16	cross stratification (planar, simple, trough); massive & parallel bedding; ripple-laminated flow structure	Typical of Upper Wasatch Fm.
	2) mudstones	Groups I, II, III & type 16	mud-cracks; massive & parallel bedding; ripple marks; conchoidal fracture; occasional parallel laminations	Cathedral Bluffs
II Kerogenous Rocks	3) oil shales Laney	Groups I, II, III & type 16	fine laminations; mud-cracks; distorted bedding; gradational contacts; loop bedding	Lower to middle Laney, most abundant in lower
	4) kerogenous dolomicrites	Groups I, II, III & type 16	indications of parallel bedding	Lower to middle Laney, most abundant lower Laney
	5) kerogenous claystones	Groups I, II, III & type 16	massively bedded; conchoidal fracture	Lower to middle Laney, most abundant lower Laney
	6) kerogenous limestones	Groups I, II, III & type 16	massively bedded	middle to upper Laney
	7) kerogenous siltstones	Groups I, II, III & type 16	parallel bedding; distorted bedding	middle to upper Laney
III Non-kerogenous Carbonate Rocks	8) ostracod shales	Groups: All listed lithologies	fine laminations; mud-cracks; distorted laminations and bedding; ripple marks; some gradational contacts; loop bedding	middle to upper Laney
	9) ostracod coquinas	Groups: All listed lithologies, not closely or frequently with Group II	parallel bedding; distorted bedding; incomplete mud-cracks	middle to upper Laney
	10) ostracod & molluscan claystones	Groups: All listed lithologies	massive bedding; conchoidal fracture	lower middle Laney
	11) molluscan coquinas	Groups: III, IV, & type 16	none	middle to upper Laney

	12) dolomicrites	Gruops: All listed lithologies	mud-cracks; massive bedding; occasional ripple or parallel laminations; some gradational contacts; salt casts	throughout section
	13) oolitic-pisolitic limestones	Groups: All listed lithologies, frequently paired with type 14	oscillation ripples; occasional graded bedding; some gradational contacts with algal limestone	throughout section
	14) algal limestone	Groups: All listed lithologies frequently paired with type 13	planar bedding or domed heads or both; some gradational contacts with oolitic-pisolitic limestones; algal encrusted logs	throughtout section
IV Volcanogenic Clastic Rocks	15) sandstone and siltstone	Groups: III, IV, & type 16	cross stratification (planar, simple and trough); ripple laminations; parallel and massive bedding; mudcracks; distorted bedding; salt casts; flow structure	upper Laney
Heterogenous	16) Flatpebble conglomerate	Groups: All listed lithologies	turbulent bedding; sometimes graded bedding	throughout section

various localities, a quartzitic conglomerate known as the Bishop Conglomerate is in contact with the non-kerogenous rocks of the middle Laney.

LITHOLOGIC VARIATIONS

There are numerous lithologic variations within the area studied that occur both horizontally and vertically. Many variations occur in cyclic patterns typical of shallow lacustrine or playa deposition. These variations can be interpreted according to their position in the lake complex. This involves delineating depositional environments according to sedimentary structures, paleontologic indicators and lithologic character.

Horizontal lithologic variations occur within all the major lithologic groups in the area studied. One easily recognized horizontal variation is that of the upper Wasatch described previously. The red and green mudstones of the Cathedral Bluffs tongue give way laterally to siliciclastic rocks eastward across the Sand Wash Basin. These rocks were deposited on the mud flats and flood plains marginal to Lake Gosiute. This lateral change in character of the upper Wasatch reflects the different environmental regimes which existed at the time of deposition. The mudstones on the western flank of the basin were deposited closer to the lake than the clastic rocks on the eastern flank of the basin. This relationship indicates that Lake Gosiute was located to the northwest of the Sand Wash Basin at the time of deposition of the upper Wasatch.

Laterally the contact between the Wasatch and the Laney shows considerable variation, especially west to east across the basin. Basically the Laney-Wasatch boundary is characterized by intertonguing of oil shales and mudstones on the west, and non-kerogenous shales and siliciclastic sandstones on the east. In between, there is a zone of intertonguing where all four of these lithologies are involved. The zone of intertonguing represents a major transgression of lacustrine deposition across the adjoining mud flats and flood plains with minor regressions. This transgression appears to have progressed from the northwest (Fig. 4).

Another lateral variation occurs at the boundary between the kerogenous rocks of the lower Laney and the non-kerogenous carbonate rocks of the middle Laney. On the western margin of the basin this contact is a sharp boundary with only a few feet of interbedding, while on the east the contact is characterized by extensive interbedding. The alternation between kerogenous and non-kerogenous

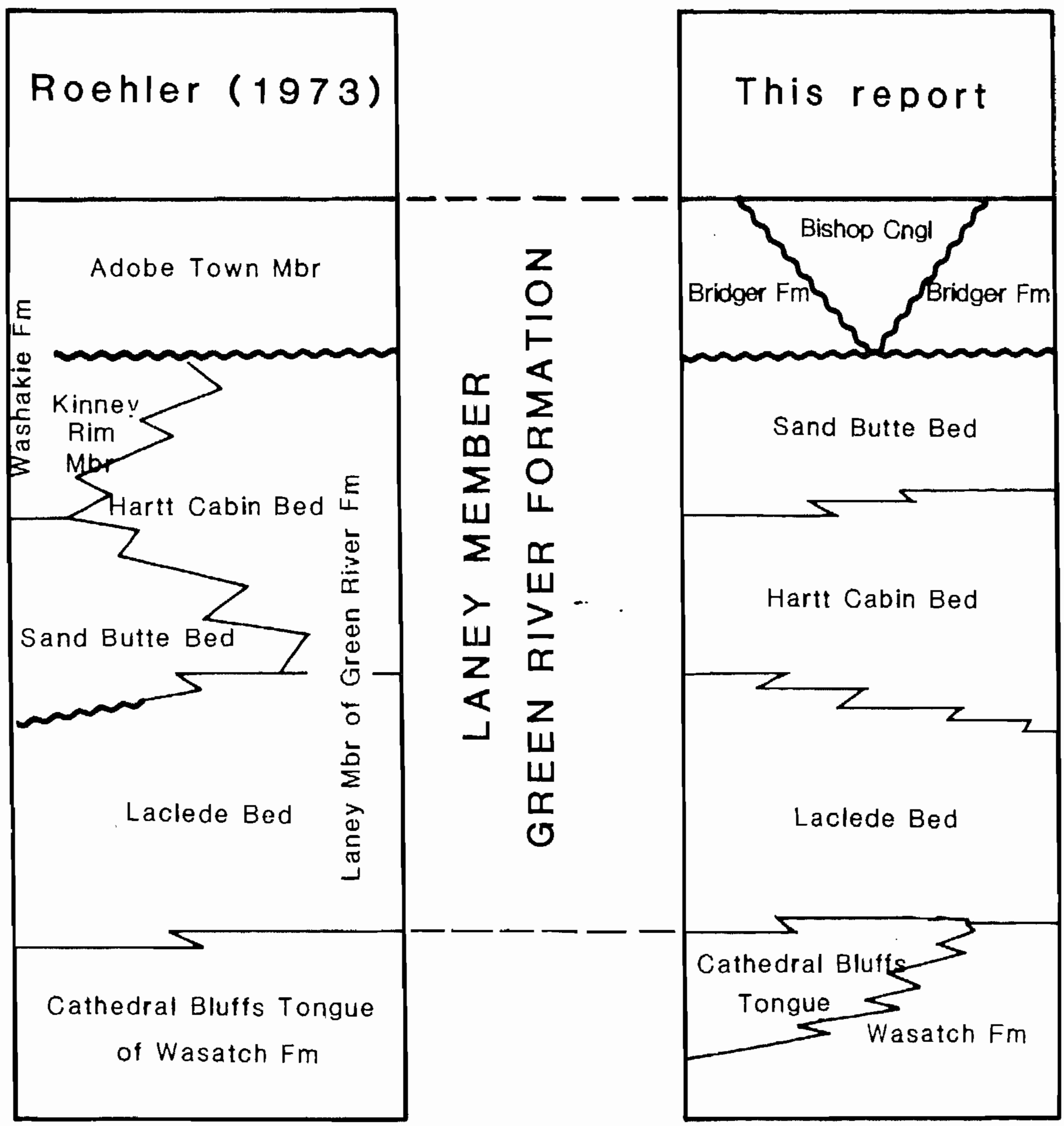


Figure 2: Chart showing stratigraphic divisions and nomenclature of the Laney Member of the Green River Formation and adjacent formations in the Sand Wash and Washakie Basins.

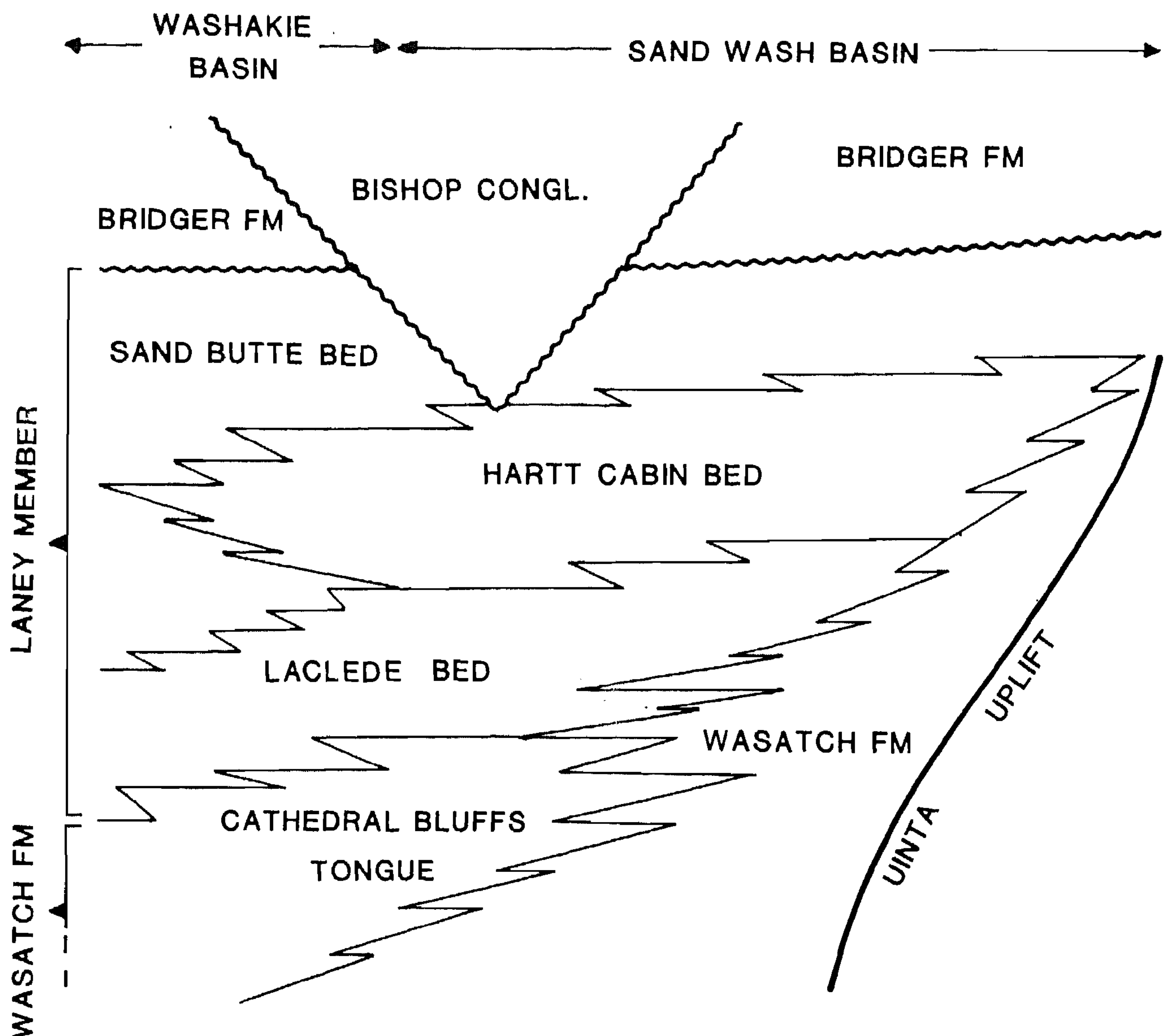


Figure 3: A schematic cross-section illustrating the relationship of the Laney Member in the Sand Wash and Washakie Basins (no scale inferred).

rocks represents fluctuations in conditions favorable to the deposition and preservation of kerogenous material. These conditions were directly related to the salinity and alkalinity of the lake. During fresher water times the lake supported algae as well as algal grazers. During saline-alkaline times the lake still supported algae, but algal grazers such as gastropods and pelecypods diminished considerably if not totally. As a result, more organic material was available to be incorporated in the sediment column. The probable existence of anoxic conditions at or near the sediment-water interface during saline-alkaline times further enhanced the preservation of organic material. The organic material was later converted to kerogen.

Intertonguing of kerogenous and non-kerogenous rocks at certain localities can be explained by periodic water stratification. During stratification, non-kerogenous sediments were deposited along the inner lake margin while kerogenous sediments were being deposited in the central portion of the lake. The small scale of the intertonguing indicates that periods of stratification were short lived.

Freshening of the lake waters and the subsequent deposition of non-kerogenous sediments can be explained by several mechanisms. One involves a progradational and tectonic restriction of the hydrographic basin accompanied by deepening of the lake waters; thereby decreasing the water surface exposed to evaporation. Another mechanism involves an increased supply of fresh water to a restricted hydrographic basin; whereas, another involves the development of an outlet. There are no abrupt grain size changes to indicate a deepening of the lake, nor does the thickness of the beds indicate an increase in water depth (Gilbert, 1890; Twenhofel, 1961). Small scale deltaic deposits indicate that

TABLE II

Lithologic group	Rock type	Carb.	C/D	Qtz.	Felds.	Zeo	Clay	Source of Major Sedimentary Constituents
Siliciclastic argillaceous rocks	sandstone & siltstone	2-3	5/1	3	1	0	1	terrigenous
	mudstones	2	3/1	1	0	0	2-3	terrigenous
kerogenous rocks	oil shale	2-3	1-2/1	1-2	0	0	1-2	both terrigenous and chemogenic
	kerogenous dolomicrites	5	D	0	0	0	0	chemogenic
	kerogenous claystones	2	1/6	1	0	0	3	terrigenous
	kerogenous limestones	4-5	10/1	0-1	0	0	0	chemogenic
	kerogenous siltstones	1-2	C	3	1-2	0	1	terrigenous
non-kerogenous carbonate rocks	ostracod shales	2-3	5/1	1-2	0-1	0	2	both terrigenous and chemogenic
	ostracod coquina	3-4	C	1-2	0	0	0-1	chemogenic
	ostracod molluscan claystones	2-3	10/1	1-2	0-1	0	3	terrigenous
	molluscan coquinas	3-4		0-1	0	0	0-1	chemogenic
	dolomicrites	5	D	0-1	0	0	0-1	chemogenic
	algal lime-stones	4-5	C	0-1	0-1	0	0	chemogenic
volcanogenic clastic rocks	sandstones & siltstones	1-2	5-10/1	2-3	1-2	2-3	0-1	terrigenous
chert		0	0	5	0	0	0	chemogenic

carb - carbonate includes calcite, dolomite, aragonite, and rhodochrosite
C/D - calcite to dolomite ratio
Qtz. - quartz
Felds - feldspar
Zeo - zeolites and related minerals

0 - not present or in very small amounts
1 - present
2 - significant mineral species
3 - major mineral species
4 - dominant mineral species
5 - rock composed entirely, or almost entirely, of this mineral

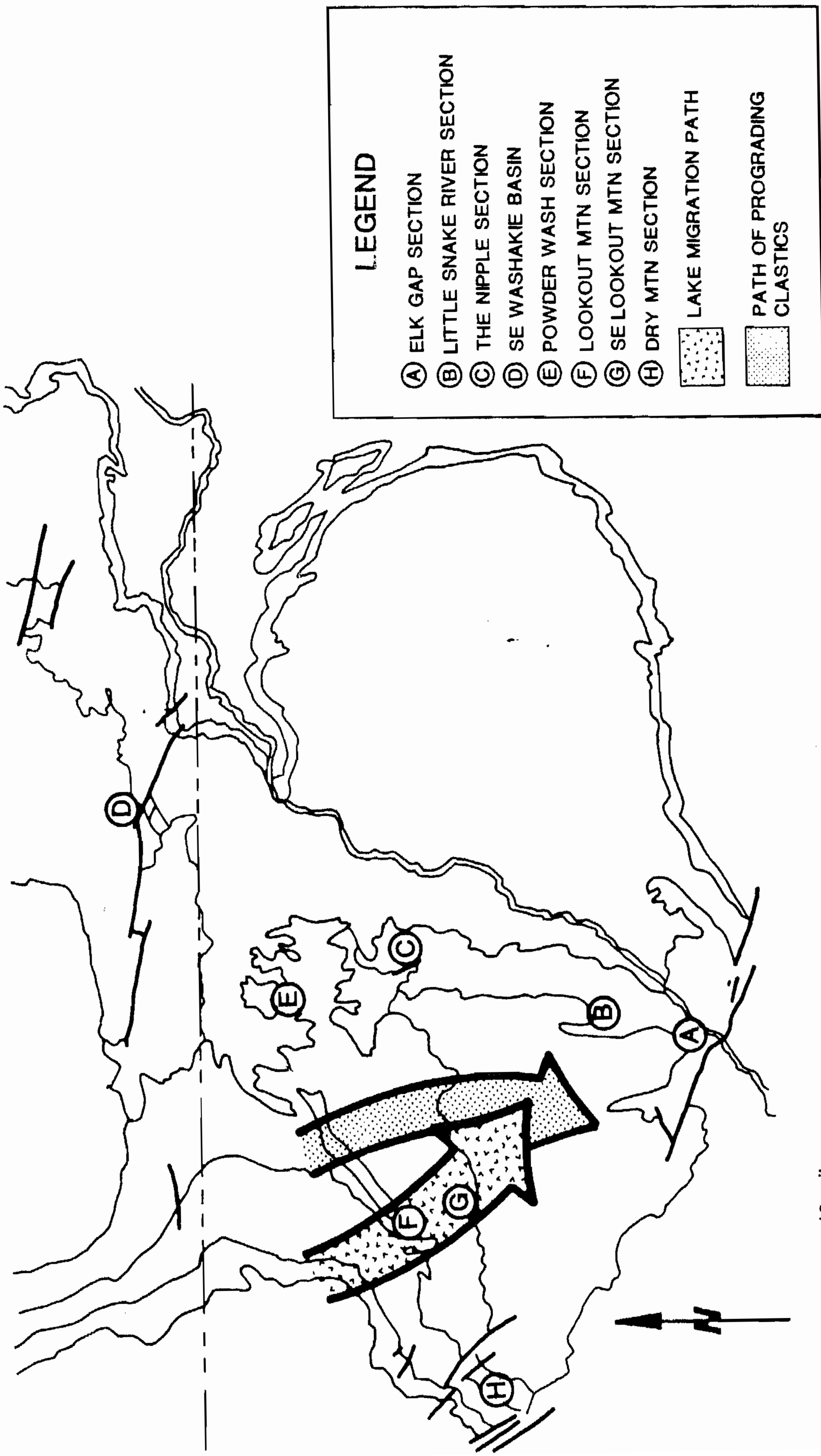


Figure 4: Map of the Sand Wash Basin showing location of measured sections, the migration path of Lake Gosiute, and the path of the prograding volcanogenic clastics.

water depth near the lake margin did not greatly exceed ten to fifteen feet (3 to 4.5 m.). Evidence of mudcracks in non-kerogenous carbonate shales further indicate that the lake had not deepened. Another indication that the lake did not deepen are the abrupt lithologic variations that occur within the "fresher" water deposits. These abrupt lithologic variations reflect rapid fluctuations in sedimentary conditions typical of shallow water deposition.

The change in water chemistry of Lake Gosiute probably occurred as a result of progradational restriction and the development of an outlet. As a result the drainage of the old hydrographic basin collected in a much small area. Channel deposits and associated cross stratification of the upper Laney in the southern Sand Wash Basin indicate an outlet developed in this area. The presence of volcanogenic clastics in the upper Green River Formation in the Piceance Creek Basin (Surdam and Stanley, 1976) lends support to a southern outlet. At various times the outlet was restricted or the water level dropped to the point where the lake was no longer drained; ultimately the salinity and alkalinity increased, producing kerogenous sediments. During these times the lake may have actually separated into smaller bodies producing greater lithologic variations. Smaller ponds on the periphery of the main lake body achieved higher salinities and alkalinities sooner than the main body of the lake.

The last major lateral variation occurs in the volcanogenic clastic rocks of the upper Laney, as a lens of non-kerogenous carbonate rocks approximately forty feet (12.2 m) thick. The lens is isolated in the volcanogenic clastic rocks at the eastern-most outcrop. These lacustrine sediments were most probably deposited in a small lake or pond after Lake Gosiute had disappeared.

Vertical variations can be related to the same depositional conditions as the horizontal variations. Basically, the vertical variations are related to changes from one major lithologic group to another. Generally, the overall vertical trend in the sections measured is from non-lacustrine to saline-alkaline lacustrine, then to fresh lacustrine. The fresh lacustrine phase was later flooded with clastics.

When considering the individual units of the stratigraphic sections rather than large lithologic groups, numerous small scale lithologic variations emerge. These small scale variations occur both horizontally and vertically, and are related to specific fluctuations within the overall depositional system. The small scale lithologic variations are the result of minor transgressions, regressions, and fluctuations in the salinity and alkalinity of the lake. Many of these variations are cyclic and are frequently found in the transition zones between lithologies (Fig. 5).

MINERALOGY AND PETROLOGY

Qualitative estimates of the relative abundances of various minerals were made using X-ray diffraction and petrographic examination. X-ray diffraction analyses were performed on approximately one hundred and seventy samples and petrographic analyses were performed on thirty five samples which were representative of the important lithologies in the area studied (Table II). The X-ray diffraction analyses were performed using a G.E. XRD-3 diffractometer to determine the mineral composition of various samples; and in conjunction with petrographic studies, to determine the relative abundances of the various minerals. Samples were powdered and dry mounted on an aluminum holder to be X-rayed. The area under each individual mineral peak was calculated using the method described by D. F. Bloss, 1971, pp. 491-492. Clay peak areas were multiplied by factors of 1 for montmorillonite, 2 for kaolinite and 4 for illite. Ratios of peak areas and petrographic evaluations were used to estimate the relative abundances of various minerals. These estimates are purely qualitative and should not be taken to represent the exact quantities present.

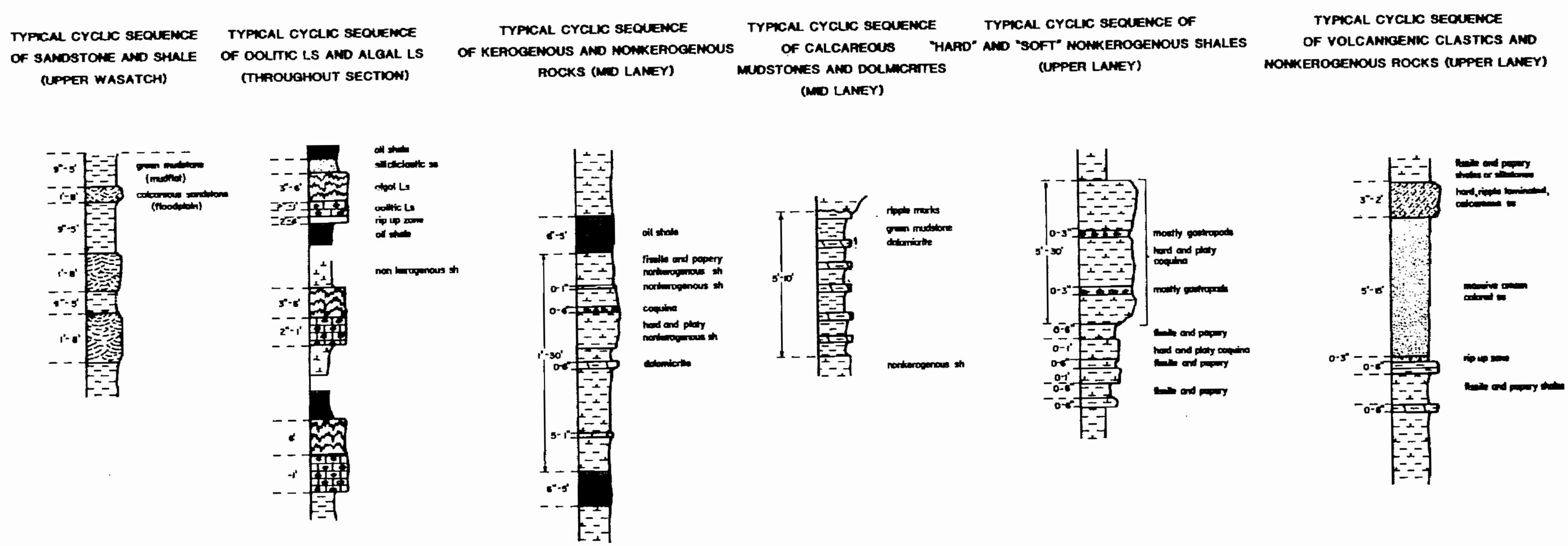
When the mineralogy and petrology of Laney rocks are compared, some definite variations emerge. One of the first variations that becomes apparent involves the relationship between clay minerals and carbonate minerals throughout the measured sections. Basically, the clay minerals increase in abundance as the carbonate minerals decrease in abundance; as the clays decrease, the carbonates increase. This inverse relationship is probably the result of fluctuations in sediment supply to Lake Gosiute. When carbonate dominates the clay/carbonate ratio, the sediment supply was low, and represents a period of arid conditions. When the clay/carbonate ratio increases, the sediment supply increased, indicating more humid conditions. The abundance of detrital minerals such as quartz and feldspar appears to parallel the clay fraction.

Another variation involves volcanogenic minerals such as analcime and zeolites. These minerals are almost entirely absent throughout the upper Wasatch and the lower two-thirds of the Laney. However, in the clastic rocks of the upper Laney these minerals have become a major mineralogic constituent. Since these minerals were formed by the alteration of volcanic glasses, it is apparent that the upper clastics were being supplied from an area characterized by volcanics. Geologic reconstruction of Wyoming and Colorado during Eocene time indicates that the most probable source of the volcaniclastics is the northwest corner of Wyoming. Current direction measurements and onlap features in the study area support a northwest source for the volcaniclastics.

Another mineral variation similar to that of the volcanogenic minerals involves cristobalite. Cristobalite is not a widespread mineral; but where it is present it is usually a major mineralogic species. Cristobalite occurs mainly in the fresh-water lithologies, but is also found in some of the low grade kerogenous units. We feel that the cristobalite is an alteration product of diatomite even though diatoms were not found.

Specific mineralogic variations were recognized when similar lithologies of the various sample localities were compared. The mineralogy of the siliciclastic rocks was found to be fairly consistent except in the case of the carbonates. The calcite to dolomite ratio fluctuates from one locality to

FIGURE 5. SOME TYPICAL SMALL SCALE CYCLIC SEQUENCES OF THE LANEY MEMBER GREEN RIVER FORMATION SAND WASH BASIN



another and is a function of the site of deposition on the playa. The smaller the calcite/dolomite ratio, the lower on the playa. Generally the calcite/dolomite ratio is small on the western margin of the Sand Wash Basin, while on the eastern margin the ratio is larger.

The mudstones of the upper Wasatch and the lower Laney seem to have a fairly consistent mineralogy, except for the clay fraction. The mudstones of the Laney usually have a higher clay content than the Wasatch mudstones. This may have been the result of an increase in the surface water movement across the playa. Ground water probably dominated the hydrology in this area during upper Wasatch time. However, during Laney time, surface water may have become more important due to a decrease in the porosity and permeability of surface deposits. This resulted in an increase in the amount of clay transported to the site of deposition.

The kerogenous rocks are typified by a fairly consistent mineralogy, except at the eastern-most outcrop where both the carbonate and clay fractions vary. These rocks exhibit a lower content of carbonate minerals, specifically calcite, and a higher content of clay minerals than kerogenous rocks elsewhere in the basin. Since only a few calcite crystals show evidence of having been transported to the site of deposition it is suspected that precipitation from lake water is the major source of calcite in the kerogenous rocks. Since the clays were supplied to the lake by tributaries, it can be assumed that an increase in the clay fraction indicates the deposition took place near a tributary. In the presence of saline-alkaline water, clays tend to flocculate and settle out early; whereas carbonates remain in solution. Therefore, a relatively small carbonate fraction and a large clay fraction would indicate proximity to a tributary.

Variations in quartz content were observed in the non-kerogenous carbonate rocks, specifically in the fresh water shales and coquinas. These rocks are generally higher in quartz at the northeast margin of the Sand Wash Basin and in the southeastern Washakie Basin than elsewhere in the study area. The increase in quartz at these locations is the result of an increase in detrital material supplied to the lake. During deposition these localities were near tributaries along the lake margin, and therefore received greater quantities of detrital minerals.

The petrographic analyses revealed some important and interesting features of various lithologies. The cyclic pattern of deposition characteristic of much of the stratigraphic sequences is also present on a microscopic level in many of the laminated sediments. Microscopic cyclic patterns are especially predominant in the oil shales and non-kerogenous shales. Generally the cycles involve dark, usually thin laminae, and lighter, much thicker, laminae containing considerable amounts of detritus. The dark laminae are probably kerogenous and represent a period of aridity. The light-colored laminae are less kerogenous and represent a period of increased water and sediment supply to the lake ie a period of flooding. These cyclic patterns are probably the result of seasonal variations in depositional processes.

Microscopic mud cracks in dolomicrites revealed some important information concerning dolomitization. The mud cracks are filled with detrital quartz grains, detrital feldspar grains, and ostracod tests. The ostracod tests have been dolomitized and cemented with calcite. This indicates that the ostracod tests were dolomitized during deposition or during early diagenesis prior to cementation.

Other information obtained through petrographic examination was whether certain minerals were detrital or authigenic. Quartz, feldspar, clays, and mica were the most abundant detrital minerals. Some detrital carbonate minerals were also present. Significant quantities of authigenic silica existed in some of the fresh-water shales and coquinas in the form of quartz and cristobalite. Some authigenic quartz originated as a result of diagenetic processes in which certain units were silicified. It appears that cristobalite has two sources in these types of rocks; one is the alteration of diatomite and the other is the alteration of volcanic glasses (Ernst and Calvert, 1969).

When the Laney sediments of the Sand Wash Basin are compared mineralogically and petrologically with the Laney sediments elsewhere, some distinct differences emerge. Probably one of the most noticeable differences is the overall increase in terrigenous material especially in the shales. Laney oil shales elsewhere are laminated carbonates (Eugster and Surdam, 1973; Surdam and Wolfbauer, 1973; Surdam and Stanley, 1976); whereas in the Sand Wash Basin the oil shales are relatively low in carbonate and relatively high in detrital minerals such as quartz, feldspar, and clay. Another general distinction related to the increase in terrigenous material is the overall greater abundance of clays in the Laney sediments of the Sand Wash and southern Washakie Basins. The overall increase in clay and detritus in these sediments indicates that the filtering capabilities of the adjacent playa fringe had decreased. This decrease may have been the result of a narrowing of the playa fringe, or an increase in water supply and therefore sediment load, or possibly an increase in gradient around the lake. Since there is no evidence to support the latter mechanism, a combination of narrowing the playa fringe and increasing the water supply seems to be the most reasonble explanation for the overall increase in terrigenous material.

Another distinctive characteristic of the Laney in the area studied is the absence of bedded evaporites, minerals such as trona and nacholite, and the near absence of volcanogenic minerals in the nonclastic lacustrine sediments. This minerologic characteristic lends support to the hypothesis that the Laney in the Sand Wash Basin is not time equivalent to the Laney elsewhere. The absence of bedded evaporite minerals further indicates that the Laney rocks in the area studied were deposited in "fresher" water. A final mineralogic characteristic, which distinguishes the Laney sediments in the area studied from those elsewhere, is the existence of cristobalite in some of the non-kerogenous carbonate sediments.

PALEONTOLOGY

Fossil remains of the biota of the Laney and upper Wasatch time provide significant clues to the physical and chemical conditions of the playa-lake complex. Remains of several faunal forms and some floral forms are preserved in the lithologies discussed.

Fish remains, both articulated and disarticulated, were found in the laminated oil shales of the lower Laney and in the hard, platy ostracodal coquinas of the middle to upper Laney. The fish remains in the laminated shales were identified as *Herring knightia* and fresh-water catfish. The herring were found only in low-grade shales along the northeast margin of the basin. Disarticulated catfish remains were found in non-kerogenous shales and coquinas. Overall, the fish that were found indicate a lacustrine environment. The *Herring knightia* were somewhat more tolerant of salinity and alkalinity than the catfish. Therefore, herring probably indicate moderately saline-alkaline conditions; whereas catfish indicate fresher conditions.

Numerous invertebrate tests were found in the Laney rocks. These invertebrates are fresh-water bivalves and gastropods. The bivalve *Uniondae* and gastropods *Goniobasis tenera, Valvata subumbilibata* and *Biomphalaria psuedoammonius* were identified with the aid of John Hanley of the U.S.G.S. These molluscs are found only in the non-kerogenous carbonate rocks and the volcanogenic clastic rocks of the middle to upper Laney. The gastropod *Goniobasis* is by far the most abundant of the molluscs and has a widespread distribution through the upper Laney. The bivalves are rare except in the very upper portions of the Laney. Molluscs are more frequently associated with the hard, platy ostracodal coquinas than any other non-kerogenous carbonate rock. The presence of these invertebrates indicates fresher water conditions at the time of deposition. There is a horizon in the Laney above which molluscs are far more abundant than below (Plate 1 in pocket). This horizon is interpreted as representing a time of significant freshening of lake waters.

Ostracods are by far the most abundant of all the fossils and the only conclusive microfossil. Evidence of diatoms was found, but the actual tests of the organisms were not. Ostracods are so abundant that certain lithologies are composed almost entirely of their tests. Ostracods are found throughout the measured sections but are far more abundant in the non-kerogenous carbonate rocks of the middle Laney. In the remainder of the stratigraphic section, the ostracods are most frequently associated with oolitic-pisolitic limestones. This indicates that the ostracods of Lake Gosiute thrived under turbulent conditions and greatly expanded their realm to less turbulent waters during the fresher times.

The presence of cristobalite is the major evidence for the existence of diatoms. Cristobalite is found in many of the upper middle Laney rocks such as the non-kerogenous shales, coquinas and mudstones. The source of cristobalite in these sediments is twofold; one is by the alteration of volcanic glasses, and the other is the alteration of diatomite (Ernst and Calvert, 1969). The latter of these is considered to be the most likely since tuff beds are absent in this portion of the section, and since glass shards were not found associated with the cristobalite when examined petrographically. Further evidence for the formation of cristobalite by alteration of diatomite was recognized when the X-ray patterns of the Laney rocks containing cristobalite were compared to the X-ray patterns of diatomaceous silica, and to X-ray patterns of altered diatomite presented by Ernst and Calvert in 1969. The patterns of the cristobalite peaks were almost identical. The existence of diatoms may be an indicator of the "freshest" lake water conditions. During the "freshest" times algal grazers, primarily molluscs, became very prolific and through continued grazing considerably decreased the amount of blue-green algae. By decreasing the amount of blue-green algae, a niche was created in which diatoms were able to survive and eventually become prolific. This theory is compatible with observations made by Bradbury (1975) concerning diatoms in Minnesota lakes. The fact that cristobalite is never found in kerogenous rocks, and similarly the absence of molluscs in kerogenous rocks, lends support to this theory.

Certain limestones are recognized as the product of colonized algae and represent another type of microfossil. Algal limestones exist as continuous planar beds, or as individual domed heads, or as a combination of both types of structures. Algal limestones are widely distributed throughout the measured sections and represent strand line deposition where encountered. The algal encrusted logs frequently represent a rapid transgression into a wooded area.

Bones of terrestrial and semi-terrestrial vertebrates were found in the clastic rocks of the Laney and the upper Wasatch. These bones were found in lag deposits associated with other fossil debris. Since these bones were transported to the site of deposition, no inference could be made as to depositional environment.

SUMMARY

The Laney Member of the Green River Formation is a sequence of lacustrine rocks which were deposited during Eocene time. In the Sand Wash Basin the Laney can be subdivided into 3 basic units; kerogenous carbonate rocks, non-kerogenous carbonate rocks, and volcanogenic clastic rocks. The lower unit is a sequence of kerogenous rocks dominated by oil shale, while the middle unit is dominated by non-kerogenous shales and coquinas. The upper unit is composed of volcanogenic clastic rocks which are easily recognized by their rusty-cream color. All of these units exhibit an onlapping contact with underlying rocks.

Through a variety of depositional processes, the Laney rocks in the Sand Wash Basin acquired unique lithologic, mineralogic, and paleontology characteristics as compared to Laney rocks elsewhere. Initially the area served as mud flats and flood plains for Lake Gosiute. Lake Gosiute was north of this region and covered a considerable area. A progradational clastic wedge of volcanogenic rocks began filling Lake Gosiute from the north, forcing the lake body southward. Eventually the lake migrated into the area and was ponded against the uplifting Uinta Mountains. Due to a variety of mechanisms, the lake began to freshen and an outlet developed to the south. Eventually the prograding clastics entered the area and Lake Gosiute came to an end. Finally the clastics spilled over the Uinta uplift into the Piceance Creek Basin.

In conclusion, the sedimentary and stratigraphic features of the Laney Member of the Green River Formation in the Sand Wash Basin best fit the playa-lake model proposed by Eugster and Surdam in 1973. The Laney in this area was deposited in the last remnant of Lake Gosiute prior to its termination. The lake had migrated into the area from the northwest. As a result the Laney in the Sand Wash Basin acquired unique lithologic, mineralogic and paleontologic characteristics as compared to the Laney elsewhere. Furthermore, the Laney in the study area is not time equivalent to the Laney to the north.

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