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The Muddy Creek Formation: Depositional environment, provenance, and tectonic significance in the western Lake Mead area, Nevada and Arizona

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Order Number 1335897

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THE MUDDY CREEK FORMATION: DEPOSITIONAL ENVIRONMENT, PROVENANCE, AND TECTONIC SIGNIFICANCE IN THE WESTERN LAKE MEAD AREA, NEVADA AND ARIZONA

By

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A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science

in

Geoscience

Department of Geoscience
University of Nevada, Las Vegas
August 1988

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ABSTRACT

The Muddy Creek Formation is a clastic sedimentary unit of Miocene-Pliocene(?) age deposited in interiorly-drained basins during the last stages of Basin and Range extension.

In the River Mountains, the Muddy Creek Formation is informally divided into four members; the River Mountain conglomerate, the Boulder Basin conglomerate, the Lakeshore member, and The Cliffs member. The Boulder Basin conglomerate unconformably overlies the River Mountain conglomerate and The Cliffs member and interfingers with the Lakeshore member.

The conglomerates in the Muddy Creek Formation were deposited during the waning stages of extension in the Lake Mead area, as indicated by growth faults developed in the Muddy Creek conglomerates, and the decrease in structural rotation upsection.

Clasts in the Muddy Creek Formation are composed of andesite, dacite, basalt, rhyolite, quartz monzonite, and granite. Based on paleocurrent indicators, distribution of clast types, and geochemical fingerprinting, the provenance for the clasts was the River Mountains. Paleocurrent data for the basal River Mountain conglomerate suggest that the transport direction was to the southeast, parallel to the regional strike of high-angle normal faults. The River

Mountain conglomerate may have been transported along the axes of basins that were controlled by these faults. Paleocurrent indicators in the younger Boulder Basin conglomerate suggest that these sediments were transported to the east and northeast across the strike of fault controlled basins.

The River Mountain conglomerate is a distal alluvial fan facies deposited primarily by sheetflooding or hyperconcentrated flood flow. The Boulder Basin conglomerate is a proximal alluvial fan facies deposited predominantly by sheetflooding and hyperconcentrated flood flow with subordinate braided stream and debris-flow deposition. The Lakeshore member and The Cliffs member are composed of sandstone and siltstone interbedded with gypsum and are interpreted to be lacustrine or playa deposits.

The River Mountain conglomerate was probably deposited during a period of active extensional faulting. Block rotation during faulting resulted in the formation of half-graben basins with coarse-grained sediments of the River Mountain conglomerate forming alluvial fans that were constrained to the basin margins. When extension subsided, coarse-grained material prograded into the basin, forming the Boulder Basin conglomerate.

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ACKNOWLEDGMENTS

I would like to thank E. I. Smith and M. N. Rees for their substantial and invaluable contributions of time and effort toward this project. I gratefully acknowledge F. W. Bachhuber, D. L. Weide, E. I. Smith and C. M. Murvosh for their guidance and suggestions in the revision of this manuscript. I also thank the UNLV Geoscience Department for providing financial support, employment, and laboratory facilities throughout my graduate career. I would also like to thank the Clark County Comprehensive Planning Department for the use of their computer and graphic facilities. I thank my fellow graduate students, especially Jack Deibert, for all the help they have given me over the last few years. Finally, a special thanks to Casey Schmidt and my parents whose patience and emotional support have been invaluable. Financial support for this work was provided in part by the Center for Volcanic and Tectonic Studies and a grant from the Graduate Student Association.

INTRODUCTION

Distribution and Study Area

The Muddy Creek Formation is a clastic sedimentary unit of Miocene-Pliocene(?) age comprised of conglomerate, sandstone, and siltstone, with interbedded clay beds, limestone, evaporite deposits, and basalt flows. The units crop out on the flanks of mountain ranges and in the intermontane valleys throughout southeastern Nevada, northwestern Arizona, and southwestern Utah (Fig. 1). The primary study area lies directly east of the River Mountains, along the west shore of Lake Mead. It extends north from the main aqueduct of the Alfred Merritt Smith Water Treatment Plant, to the Las Vegas marina just south of the mouth of Las Vegas Wash (Fig. 2). Its topography is shown on the Boulder Beach 7½ minute quadrangle.

Mapping in the River Mountains area was undertaken to establish the distribution of the Muddy Creek Formation and to locate structures that disrupt the unit. Mapping was done at a scale of 1:12,000 and lithologic units were based on Smith (1984). A geologic map is included as Plate 1 (in pocket).

In addition to the River Mountain area, reconnaissance studies were completed south of the Gale Hills and west of

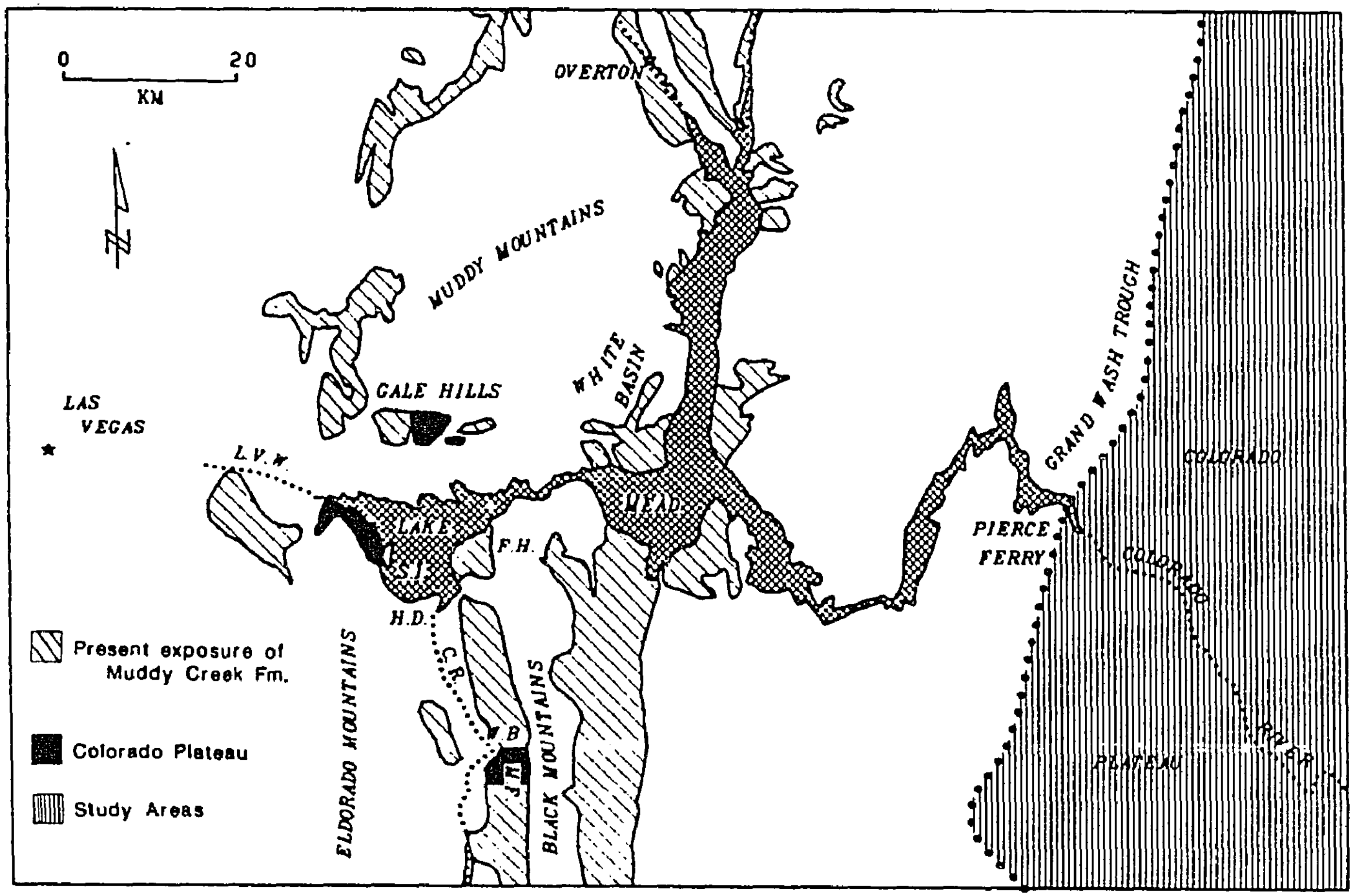


Figure 1. Regional location map showing the present exposures of the Muddy Creek Formation in the western Lake Mead area. Also shown are names and locations of some of the areas discussed in this thesis: LVW = Las Vegas Wash, FH = Fortification Hill, SI = Saddle Island, CR = Colorado River, HD = Hoover Dam, WB = Willow Beach, MF = Malpais Flattop. (Modified from Anderson, 1978a and Bohannon, 1984).

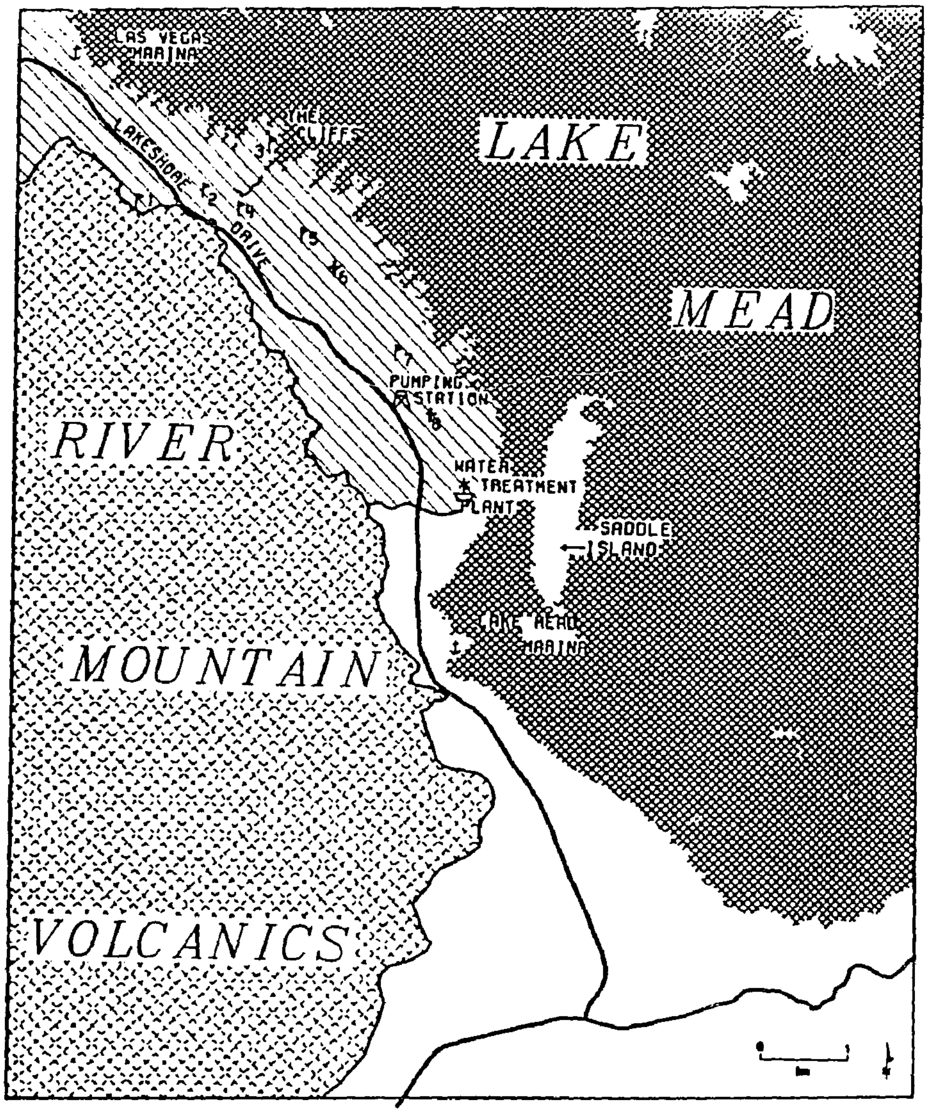


Figure 2. Location map of the River Mountain field area. The striped area represents the present exposure of the Muddy Creek Formation. The numbered flags are sites of exposures used for photographs in the depositional analysis. The crosses are sites where stratigraphic sections were measured and the curved line at station four is the site used for the architectural analysis (see Fig. 6 for more detail of the outcrop used for the architectural analysis).

Malpais Flattop (Fig. 1). Field work included measurement of stratigraphic sections, the study of sediment lithology, depositional environments, sediment transport direction, and measurement of fault attitudes.

Previous Work

The Muddy Creek Formation was named by Stock in 1921 for a group of well indurated, red to brown sandstone, siltstone, and clay beds in Lincoln County, Nevada, and on the southwest side of the Muddy River near Overton, Nevada. The Overton locality is the type section. Longwell (1928, 1936, 1963) expanded the definition of the Muddy Creek Formation to include evaporites, conglomerates, siltstones and sandstones that crop out in the large intermontane valleys surrounding the Muddy Mountains, the Grand Wash trough (east of Muddy Valley), the Lake Mead area near Fortification Hill, and the area south of Hoover Dam along the Colorado River between the Black and the Eldorado Mountains (Fig. 1). Longwell (1936) first correlated the sedimentary units in the Las Vegas Wash area (west of the Muddy Mountains, and adjacent to the River Mountains) to known deposits of the Muddy Creek Formation. Longwell (1963) described the geology between Lake Mead and Davis Dam and first correlated late Tertiary deposits in the vicinity of Willow Beach and Malpais Flattop with the Muddy Creek deposits of the Fortification Hill area (Fig. 1). He suggested that the abundant evaporite beds in the Muddy

Creek Formation were probably a result of deposition in interior basins. Muddy Creek beds that crop out between Fortification Hill and Willow Beach were probably deposited before the establishment of the Colorado River as an integrated drainage system (Longwell et al., 1965). Anderson (1978b) also mapped the Muddy Creek Formation in the Willow Beach area.

Lucchitta (1972) proposed that the Hualapai Limestone in the Pierce Ferry area, a unit originally named by Longwell (1963), be included as the youngest member of the Muddy Creek Formation. According to Lucchitta, the limestone was deposited in several internally drained lake basins. Blair (1978), Bradbury and Blair (1979), and Blair et al. (1979) suggested that the Hualapai Limestone was deposited at the north end of a late Miocene Gulf of California. Their findings are based on the presence of the ostracodes Cyprideis locketti, and Cyprideis stephensoni; diatoms Navicula halophila, Melosira moniliformis, Amphora hyalina, Amphora arcus var. sulcata; and chert-bearing cristobalite lepispheres that apparently represent a brackish-water environment.

Bohannon (1984) reevaluated the Tertiary sedimentary stratigraphy of the Lake Mead area and redefined the Muddy Creek Formation to include only those rocks that are stratigraphically continuous with the original type section of Stock (1921) along the Muddy River. Bohannon (1984) mapped the Muddy Creek Formation in the area north of Lake

Mead as part of a comprehensive study of Tertiary sedimentary rocks in the Lake Mead area. He restored the Hualapai Limestone to formational status, and removed the rocks of the Grand Wash Trough and the red sandstone unit of White Basin from the Muddy Creek Formation (Fig. 1).

Deposits of the Muddy Creek Formation east of the River Mountains have been mapped by Smith (1984) and further described by Scott and Weber (1986).

Age of the Muddy Creek Formation

The age of the Muddy Creek Formation is controversial, but most stratigraphic and geochronological data indicate that it was deposited during the late-Miocene and early-Pliocene (Lucchitta, 1972; Anderson et al., 1972; Blair et al., 1977; Blair, 1978; Damon et al., 1978, Bohannon, 1984). Stock (1921) dated the Muddy Creek Formation as early Pliocene, based upon camel remains in Muddy Creek deposits near Overton. Longwell (1928, 1936, 1965) referred to the Muddy Creek as Pliocene(?), based on fossil evidence of Stock (1921) and the fact that the Muddy Creek beds were known to be younger than the Miocene Horse Spring Formation. Van Houton (1956) assigned a late-Miocene age to the Muddy Creek Formation, but he cited no evidence to support this contention. Lucchitta (1972) suggested that the deposition of the Muddy Creek Formation began in the late Miocene and extended into the early Pliocene. He based this conclusion

on previous age dating and structural and sedimentological evidence from the Grand Wash Trough.

Blair (1978) obtained an age date of 10.6 Ma on a basalt from the lower Muddy Creek Formation and a date of 8.4 Ma on an air-fall tuff in the Hualapai Limestone, that he interpreted as the uppermost member of the Muddy Creek Formation. These dates indicate that the Muddy Creek Formation is late-Miocene in age. Damon et al. (1978) dated the basal basalt flow at Fortification Hill at 5.88 Ma (Fig. 1). This flow unconformably overlies the uppermost sedimentary deposits of the Muddy Creek Formation. Bohannon (1984) dated an ash within the red sandstone unit, directly below the Muddy Creek at 10.6 Ma. Therefore the Muddy Creek Formation in the Lake Mead area was deposited between 10.6 Ma and 5.88 Ma.

Objectives

The objectives of this thesis are to: (a) describe the lithology and provenance of the clasts within the conglomerate facies of the Muddy Creek Formation to the northeast of the River Mountains, (b) describe the depositional environments of the formation, and (c) determine the importance of regional structures in controlling the deposition of the Muddy Creek Formation.

STRATIGRAPHY OF MUDDY CREEK FORMATION AND QUATERNARY UNITS

Muddy Creek Formation

The members of the Muddy Creek Formation as informally defined in this thesis are from youngest to oldest: Lakeshore member (Tml), the Boulder Basin conglomerate (Tmbb), the River Mountain conglomerate (Tmrm), and The Cliffs member (Tmc). Lithologic characteristics for each are summarized in Table 1.

Lakeshore Member

The Lakeshore member (45 m thick) crops out primarily in the eastern part of the study area (Plate 1). The base of the unit is not exposed. The Lakeshore member is mostly silty sandstone and siltstone (Fig. 3) with interbedded pebbly lenses and beds containing angular clasts up to 20 cm in diameter. The Lakeshore member overlies and laterally interfingers with the Boulder Basin conglomerate. In an outcrop just south of the Pumping Station, the Lakeshore member grades into the Boulder Basin conglomerate (Plate 1). The transition zone contains abundant gravel lenses.

There are at least five ash beds in the Lakeshore member that are exposed at The Cliffs and in the wash just south of the Pumping Station (Fig. 2). They range in thickness from 5 to 10 cm and are laterally extensive in the exposures at The Cliffs.

Table 1.
Summary of the characteristics of the
Muddy Creek Formation

Clasts			Beds			
Size	Shape	Lithology	Thickness	Contacts	Lithologic Description	Sedimentary Structures
RIVER MOUNTAIN CONGLOMERATE						
ave: 1-2cm largest: 1m	sub-angular to sub-rounded	Moderately to highly altered Dacite Andesite Basalt and Rhyolite	Unit: 10.25m Bedding: ave: 30 cm range: 20cm - 1m	Planar and laterally continuous or planar and lense shaped	Red to buff clast-supported pebble conglomerate interbedded with pebbly sandstone and siltstone. Clasts are sorted and massive to crudely bedded. Beds are well cemented. Fining upward sequences are common.	Massive, planar bedded and trough cross-bedded conglomerate beds and lenses. Planar bedded and trough and planar cross-bedded sandstones. Desiccation cracks and soft-sed. deformation.
BOULDER BASIN CONGLOMERATE						
ave: 10cm largest: 1m	angular to sub-angular	highly weathered Andesite Basalt Dacite Rhyolite Granite and Quartz Monzonite	Unit: 26.5m Bedding: ave: 0.8m range: 0.3-1.8m	Planar and laterally continuous Some lense shaped deposits.	Brown to buff coarse-grained clast-supported conglomerate beds. Clasts can be sorted or unsorted and are massive to crudely bedded. Beds are tabular shaped and are well cemented. Some coarsening upward beds. Massive, matrix supported, conglomerate beds.	Massive and planar bedded conglomerate beds. Planar bedded sandstone beds.

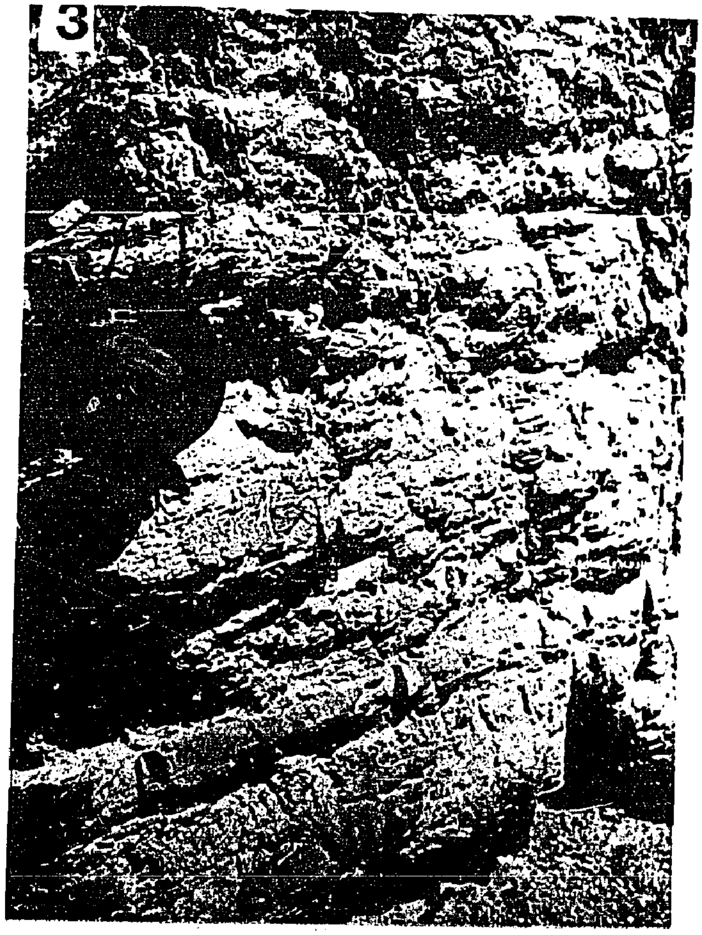
Table 1. Characteristics of the Muddy Creek Formation in the River Mountains field area.

Table 1.
Summary of the characteristics of the
Muddy Creek Formation

Clasts			Beds			
Size	Shape	Lithology	Thickness	Contacts	Lithologic Description	Sedimentary Structures
LAKESHORE MEMBER						
Silt and sand sized		Mostly quartz and silt and alabaster granules with minor mafic minerals	Unit: 45m Bedding: ave: 40cm range: 10-75cm	Planar and laterally continuous	Massive, thin-bedded silty sandstone. Beds are tabular, laterally continuous, and moderately cemented. Several thin-bedded ash layers observed	Thin, massive beds.
THE CLIFFS MEMBER						
Silt sized		Silt and gypsum	Unit 4.5m Beds ave: 2cm range: 1-5cm	Planar nonerosive and laterally continuous	Massive, thin-bedded red siltstone and white massive sheet-like gypsum beds. Beds are poor moderately cemented.	

Figure 3. A typical exposure of the Lakeshore member.

Figure 4. The angular unconformity (A) between the Boulder Basin conglomerate (B) and the River Mountain conglomerate (C).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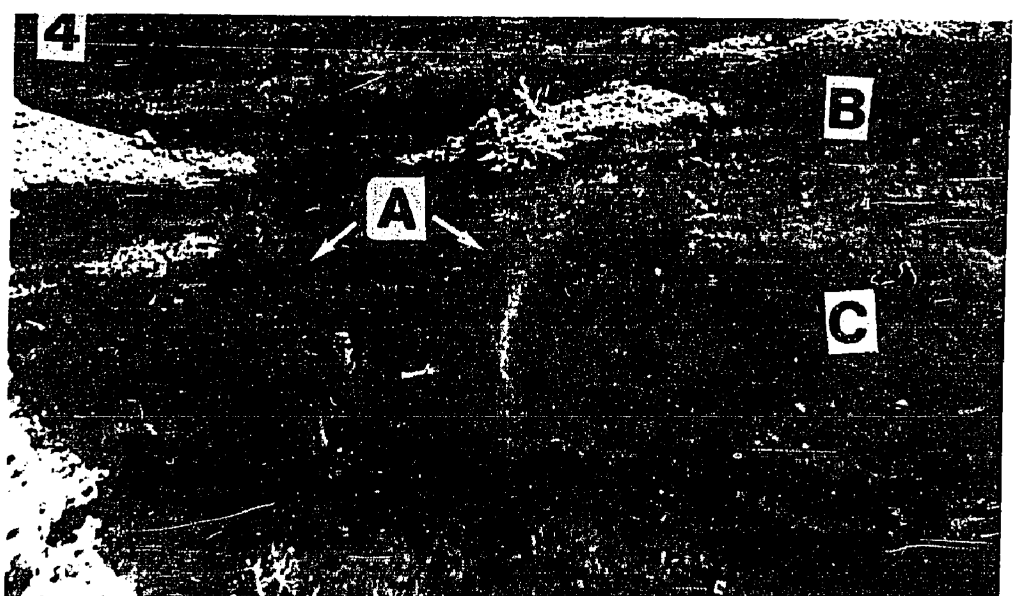
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B
A
C

Boulder Basin Conglomerate

The Boulder Basin conglomerate is primarily moderate brown to moderate yellowish-brown, thick-bedded conglomeratic unit. Exposures of the Boulder Basin conglomerate are widespread to the west and north of Saddle Island (Plate 1). The thickest measured section of the Boulder Basin conglomerate is 26.5 m. East of The Cliffs and north of the Pumping Station (Plate 1), the conglomerate contains at least two ash layers. About 1.5 km directly north of the pumping station, an ash bed is cross-bedded and is most likely a water-laid deposit. Ash layers vary from 10 to 40 cm in thickness. These ash beds could not be correlated to the ash beds found in the Lakeshore member due to their limited outcrop exposure.

Generally, beds in the Boulder Basin conglomerate are laterally continuous. Beds are clast supported and poorly sorted. Secondary gypsum occurs along fault planes, bedding planes, and fractures within the conglomerate. The secondary gypsum occurs as selenite (2-3 cm) and alabaster.

Clasts of the Boulder Basin conglomerate are composed of subrounded to angular dacite, basalt, andesite, rhyolite, and plutonic rocks. Dacite clasts vary from black, aphanitic, and slightly-weathered, to light grey, biotite and pyroxene-bearing clasts that are moderately to highly weathered. The andesite clasts are grey to light brown, moderately weathered, and contain phenocrysts of hornblende, with minor amounts of pyroxene. Basalt clasts are light

grey, and slightly to moderately weathered. They are totally aphanitic or contain phenocrysts of pyroxene, and minor plagioclase. Rhyolite clasts are black, glassy, and occur sporadically throughout the upper conglomeratic unit. The plutonic clasts range from granite to quartz monzonite. The granite clasts compose 90 percent of the plutonic component and are pink or red, coarse grained, and composed primarily of orthoclase and plagioclase, (up to 2 cm in length), with subordinate quartz, and biotite. Quartz monzonite clasts are white and usually much finer grained, and contain much less quartz than the granite clasts. Plutonic clasts only occur in the Boulder Basin conglomerate, and have a limited areal distribution.

River Mountain Conglomerate

The River Mountain conglomerate is separated from the overlying Boulder Basin conglomerate by an angular unconformity (Fig. 4)(Plate 1) and consists of conglomerate and sandstone beds. It is finer-grained and has thinner beds than the Boulder Basin conglomerate. Beds of the River Mountain conglomerate exhibit more frequent lateral facies changes than beds of the Boulder Basin conglomerate. Clast lithologies are similar to those in the Boulder Basin conglomerate, however, no plutonic clasts were observed.

The Cliffs Member

The Cliffs member is a moderate-red siltstone deposit that crops out only in a single wash in the northern portion of the field area (Plate 1). Here it is found in fault contact with the Boulder Basin conglomerate. Because the Cliffs member occurs in the footwall of the normal fault it lies stratigraphically below the Boulder Basin conglomerate (Fig. 5). The Cliffs member contains abundant gypsum in thin, laminated beds within the upper part of the unit, and as secondary selenite crystals throughout the deposit. The unit is at least 4.5 m thick.

Older Alluvial Deposits

Deposits that unconformably overlie the Muddy Creek Formation but are older than Quaternary deposits cannot be directly correlated with any of the known Quaternary or Tertiary deposits and are therefore designated as Quaternary-Tertiary deposits (QTg) in agreement with the mapping of Smith (1984). They consist of unlithified, unsorted, and unstratified, thin (10 m) sandy-gravel deposits that usually cap the Muddy Creek Formation.

Quaternary Units

The Quaternary sediments are divided into two informal units; older pediment or fan deposits of the River Mountains (Qr) and recent gravel deposits (Qa)(Smith, 1984)(Plate 1). They are distinguished from the Muddy Creek Formation on the

5a

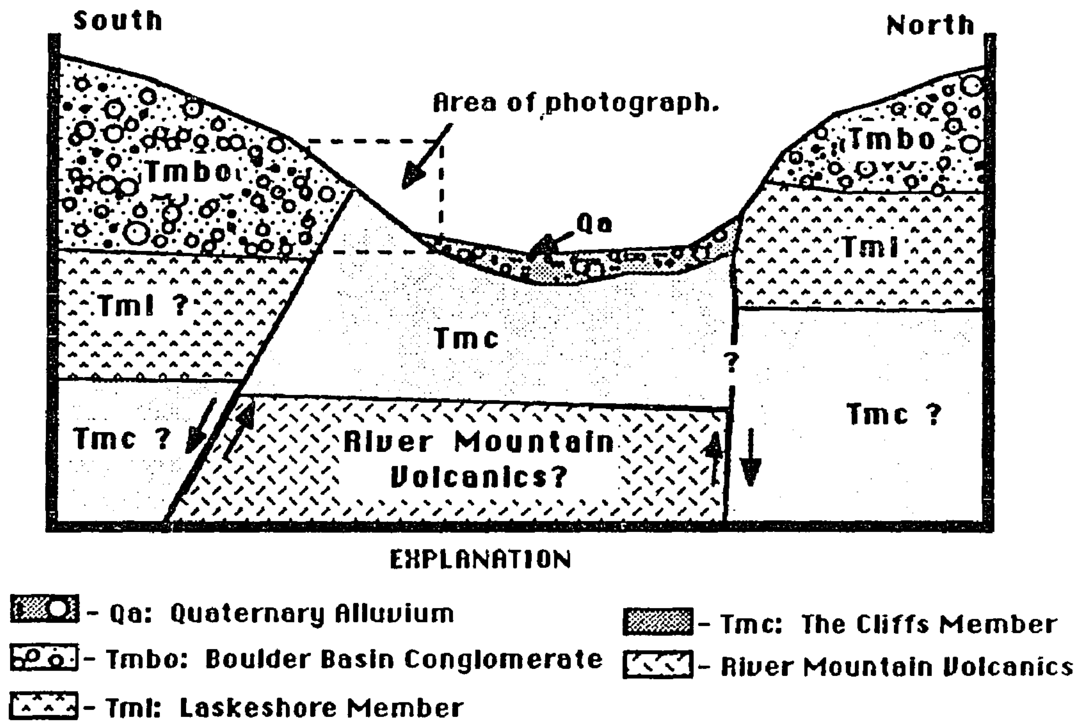
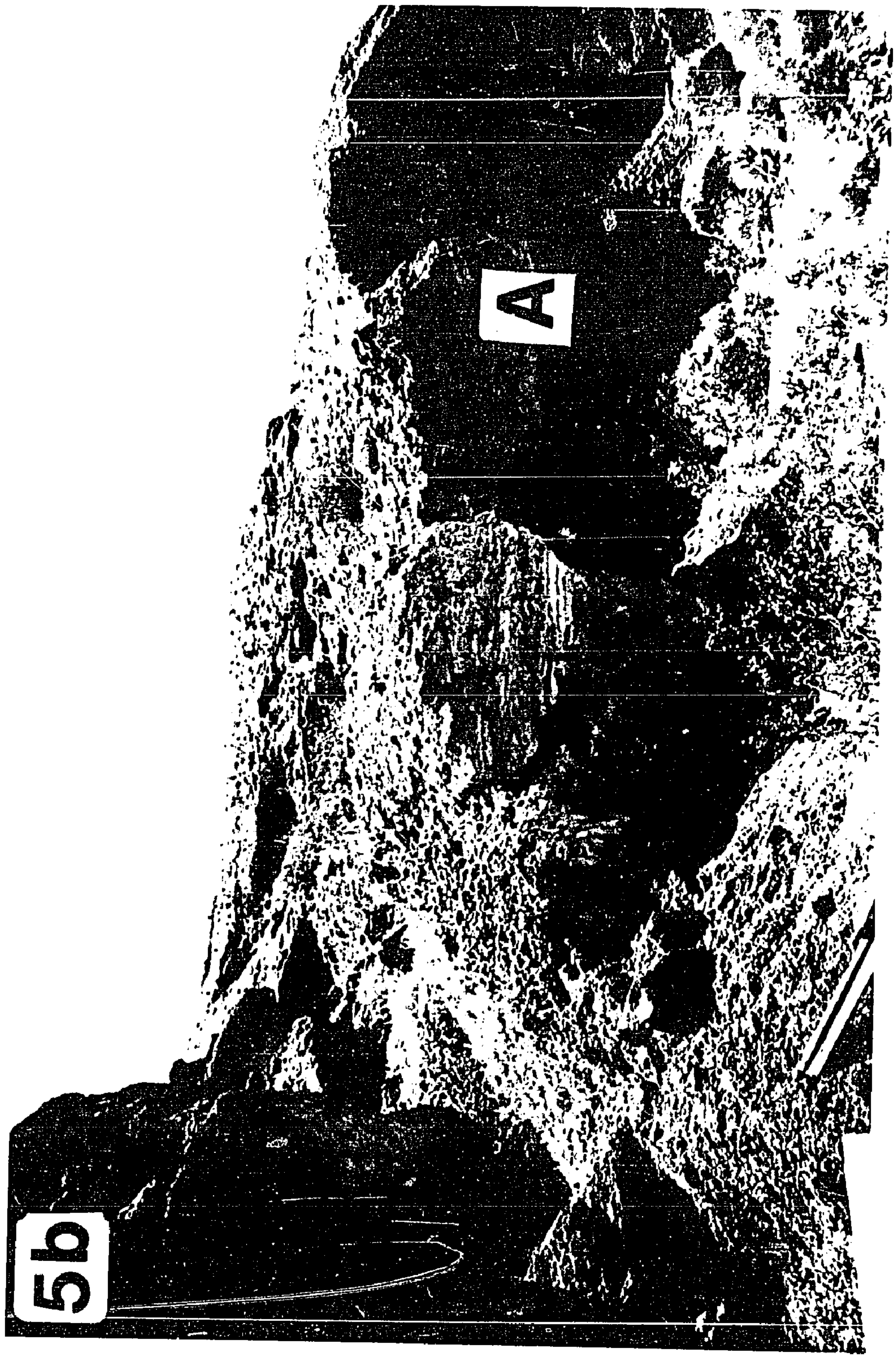


Figure 5. Cross section (5a) and photograph (5b) of The Cliffs member showing the geometry of the exposure.


5b
A

basis of their unlithified and unbedded nature and by their lack of structural rotation. These deposits are unlithified and are composed of coarse unsorted gravels. Clasts are mostly andesite, dacite and basalt. Qr consist of sediment that is not currently being transported or deposited (Plate 1). The unit occurs as terrace deposits east and northeast of Pumping Plant No. 2, and overlies both the Lakeshore member and Boulder Basin conglomerate along the shore of Lake Mead, between the Pumping Station and the Water Treatment Plant (Plate 1). Qr is massive or crudely bedded and contains angular clasts that are commonly coated with thin calcite. Qr also contains varying amounts of fine-grained sediments, occurring as matrix material, beds, and lenses. Qr unconformably overlies the Boulder Basin conglomerate and is dissected by washes containing the younger Quaternary alluvium (Qa).

The sediments that are being actively transported, or deposited today are mapped as Quaternary alluvium (mapped as Qa by Smith, 1984). Qa consists of unlithified gravel and sand that is commonly deposited in the larger washes, (Plate 1). Qa sediments are unsorted. Clasts are angular and up to 0.5 m in diameter.

IGNEOUS ROCKS OF THE RIVER MOUNTAINS

The volcanic rocks of the River Mountains are part of the mid-Miocene Powerline Road volcanic sequence of Bell and Smith (1980), and Smith (1982, 1984) and consist of dacite, andesite, basalt, and volcaniclastic deposits (Plate 1). The dacite is flow-banded, contains plagioclase, biotite and hornblende phenocrysts, and usually occurs as domes and autobrecciated flows. Dacite flows are interbedded with basalt containing large phenocrysts of pyroxene and olivine. This basalt lithology is unique to the northern River Mountains and is not exposed in neighboring ranges (Smith, 1982). Andesite flows frequently contain large hornblende phenocrysts (up to 1.5 cm in length; Smith, 1984). Volcaniclastic units include epiclastic sandstone, conglomerate, debris flows, carapace breccia, and pyroclastic flows (Smith 1982, 1984).

Plutonic rocks consist of granite and quartz monzonite from the River Mountain stock. The stock crops out 8 km southwest of the field area. The quartz monzonite is coarse grained and contains plagioclase, quartz, and biotite (Smith, 1984).

DEPOSITIONAL ANALYSIS

A lithofacies analysis of conglomerate units within the Muddy Creek Formation indicates that these rocks represent a fluvial depositional system. Most of these rocks display features common in fluvial deposits such as abundant clast-supported, tabular conglomerates; channel-fill sediments; cross-bedded, fine-grained deposits; desiccation cracks in fine-grained sediments; and rare massive, unsorted matrix-supported conglomerates. Consequently, Miall's lithofacies definitions (1977, 1978) and architectural elements (1985) have been employed to describe the rocks and serve as a basis for the analysis and interpretation of the depositional environment of the Muddy Creek Formation.

The Muddy Creek Formation also exhibits many of the sedimentary features common to alluvial fan deposits (Table 2) that are not discussed by Miall (1977, 1985). However, an architectural and lithofacies analysis of these rocks was useful in delineating a depositional system. In the Muddy Creek Formation, sediments are compositionally immature (composed of unsorted grains and minerals that erode easily); clasts range in size from 1 cm to over a meter in diameter, are poorly sorted, and are subrounded to angular. These features collectively suggest deposition relatively close to the source area. The finer grained sediments and the matrix of the conglomerate are oxidized red or brown. Organic debris and fossils are absent.

Table 2. Features commonly observed in alluvial fan deposits. (compiled from Bull, 1972; Nilsen, 1982; Pridemore and Craig, 1982; Teel and Frost, 1982; and Smoot, 1983).

Features observed in the Muddy Creek Formation:

Sediments are compositionally immature and exhibit a wide range in clast size.

Sediments are usually transported short distances from the source rock.

Sediments are poorly sorted, and subrounded to angular, and oxidized to a red, tan, or brown color.

Organic debris and fossils are absent.

Alluvial fan material is usually deposited relatively close to the source area by unidirectional flow.

The beds can be tabular or wedge shaped with abrupt erosional contacts. Channelized deposits may also be present.

Sedimentary structures may include planar or trough cross-bedding and horizontal stratification in the conglomerates; laminar or horizontally bedded, or trough or planar cross-bedded sandstones. Fining upward or coarsening upward sequences may occur. Massive, matrix-supported conglomerates and sediment gravity flow deposits can be rare to common.

Desiccation cracks occur in fine-grained facies and are typically rare.

Deposits are commonly associated with fault-bounded basins such as grabens, half-grabens, and strike-slip fault bounded basins.

Features not found in the Muddy Creek Formation:

Flow direction vectors are usually distributed radially away from the apex of the fan.

Soil or caliche horizons may be present.

Clast size decreases down fan.

Lithofacies and architectural analysis in conjunction with paleocurrent data, suggest deposition of sediment in the Muddy Creek Formation by unidirectional flow. The source for the River Mountain conglomerate was the River Mountains to the northwest, and a source to the west or southwest for the Boulder Basin conglomerate.

Miall's Architectural Analysis

Lithofacies commonly present in rocks representative of fluvial deposition were summarized by Miall (1977) and modified by Miall (1978) and Rust (1978) (Table 3). Subsequently, Miall (1985) further refined the analysis of fluvial deposits by proposing the use of both the lateral and vertical distribution of eight three-dimensional architectural elements (Table 4). The elements represent the basic building blocks for any type of fluvial depositional system. The architectural elements are defined on the basis of: (1) grain size, (2) bedform composition, (3) internal sequence, and (4) external geometry. Each element is composed of one or more of the lithofacies previously defined by Miall (1977) (Table 4). The architectural elements also have a hierarchy, with one element commonly containing other elements.

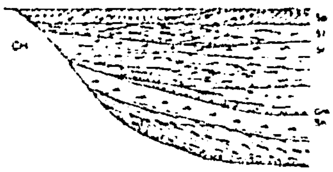
The purpose of architectural element analysis is to construct more accurate depositional models by using standardized facies assemblages and by using elements that

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to *Ss, Sh, Sp*	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

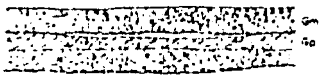
Table 3. Lithofacies classification codes (Miall, 1977 and Rust, 1978).

Table 4. Mialls' Architectural Elements (Miall 1985)

Channel deposits (CH): Have concave-up erosional bases, with an erosional or gradational upper surface. Cross-sectional geometry may vary greatly. Channel width may vary (<10 m to >10,000 m). Larger channels often contain a fining-upward series of other elements. Channel deposits can contain any variety of lithofacies assemblages (e. g., lower gravel bar (GB) overlain by forset macroforms (FM) followed by sandy bedforms (SB) and overbank fines (OF)).

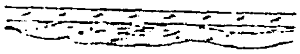


Gravel bars and bedforms (GB): Massive, or crudely bedded gravel (Gm), and stratified gravel (Gp and Gt). Gravel bar elements are usually transverse or longitudinal bar deposits. They may coarsen or fine upward depending on their environment of formation. These deposits usually occur in outcrop as multistory sheets up to hundreds of meters thick. Channel deposits within GB are usually obscure, because they commonly are filled with gravel of the same or similar composition. Gravel bars are commonly associated with sediment gravity flow (SG) and sandy bedform deposits (SB), and is gradually replaced by sandy bedforms and forset macroforms (FM) downstream.



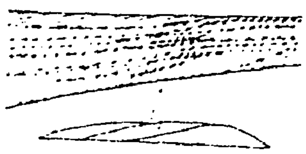
GB Gravel Bar and Bedform

Sandy bedforms (SB): Dunes, sand waves, linguoid and transverse bars, planar beds of the upper flow regime, and ripple marks make up the sandy bedforms (SB). These can be described as simple sedimentary structures within large primary river channels, comprising crevasse splay deposits, or distal braidplain deposits. Sandy Bedforms differs from the other two sandy elements (forset macroforms (FM) and lateral accretion deposits (LA)) in that it represents simple bedforms usually within much larger depositional systems.



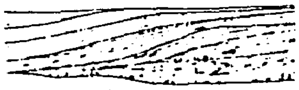
SB Sand Bedform

Forset macroforms (FM): Large deposits, usually hundreds of meters across. They represent the high-energy, depositional system. They are comprised of complex cosets of several sandy lithofacies and form compound bars in large rivers.



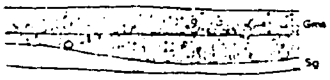
FM Foreset Macroform

Table 4 (cont.)



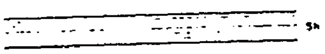
LA Lateral Accretion

Lateral accretion (LA): A complex deposit formed on the inner bank of a curve in a river by helical flow. Lateral accretion deposits can also be comprised of any type of sandy lithofacies and some gravelly lithofacies (Gm, Gt, and Gp). The lithofacies assemblage can vary greatly, depending upon the channel geometry and sediment load. These deposits can be up to thousands of meters thick and are much more common in high sinuosity rivers than in braided rivers.



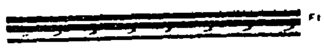
SG Sediment Gravity Flow

Sediment gravity flows (SG): Primarily matrix-supported debris flow and mudflow deposits. They occur in elongate lobes or sheets up to 3 m thick and are commonly associated with gravel bar elements GB. Beds resulting from sediment gravity flows usually have nonerosive lower contacts, and they sometimes follow existing channels. Their sediment is usually unsorted, however inverse or normal grading is common.



LS Laminated Sand

Laminated sand sheets (LS): Result from sand being deposited as planer beds in the upper-flow regime during flash flood conditions. They are tabular deposits, from 0.4-2.5 m thick with flat or slightly scoured basal contacts. Horizontally laminated sand (Sh) or low-angle, cross-bedded sand (Sl) are most dominant in LS deposits.



OF Overbank Fines

Overbank fines (OF): Massive or laminated clay or silt deposits most commonly formed by vertical aggradation on flood plains. Overbank fins form sheet-like deposits and also may fill abandoned channels. Sand, silt, and mud (lithofacies Fl) characterize these deposits.

do not carry any specific environmental implications. In the past, facies modeling of fluvial depositional environments has been based on "classic" depositional models proposed by Miall (1977; 1978) who examined the facies relationships of fluvial environments and made depositional interpretations from vertical sequences of rock. More recently, Miall (1985) concluded that vertical profiles alone cannot adequately define the depositional environment. Facies modeling through the study of vertical profiles has led to the "pigeon-holing" of certain depositional features to fit models, whether or not the models actually represent the depositional environment (Dott and Bourgeois, 1982; Miall, 1985). The architectural element analysis allows for both a vertical and lateral study of facies using fundamental units (architectural elements).

Once the architectural element analysis is completed, the elements can be grouped into depositional system models. Twelve models are proposed by Miall (1985). Miall used these models to show the variability of depositional styles possible in the fluvial systems and stressed that they should not be considered a comprehensive range for classification.

To apply Miall's technique to the Muddy Creek Formation, the following procedure was used. (1) An outcrop was selected for the architectural element analysis that had the largest exposure representing the full range of conglomerate facies in the study area; extended in two

directions, allowing a three dimensional view; contained a representation of all the architectural elements observed in the study area: and had substantial vertical relief. The outcrop selected, station 4 on Figure 2, is approximately 15 m high and 80 m long. (2) Overlapping black and white photographs were taken of the outcrop (Fig. 6). (3) A mosaic of these photographs was used as a base to map the various architectural elements exposed in the outcrop (Fig. 7). (4) This detailed analysis was then used as a basis of comparison for other areas where only measured vertical sections could be obtained or isolated observations could be made. Stratigraphic sections of the Boulder Basin conglomerate were measured at stations 6 and 8 in Figure 2. Vertical sections were not obtained for the River Mountain conglomerate because of its limited exposure in the field area (Plate 1). Photographs of isolated observations for both conglomeratic members were taken at stations 1, 2, 3, 4, 5, and 7.

Analysis of the Muddy Creek Formation

Separate analyses are made for the River Mountain conglomerate and the Boulder Basin conglomerate: Each is divided into three parts. First the composition of each architectural element is described; this is followed by a discussion of how the features may form; finally an interpretation of the depositional environment indicated by the association of these elements is presented.

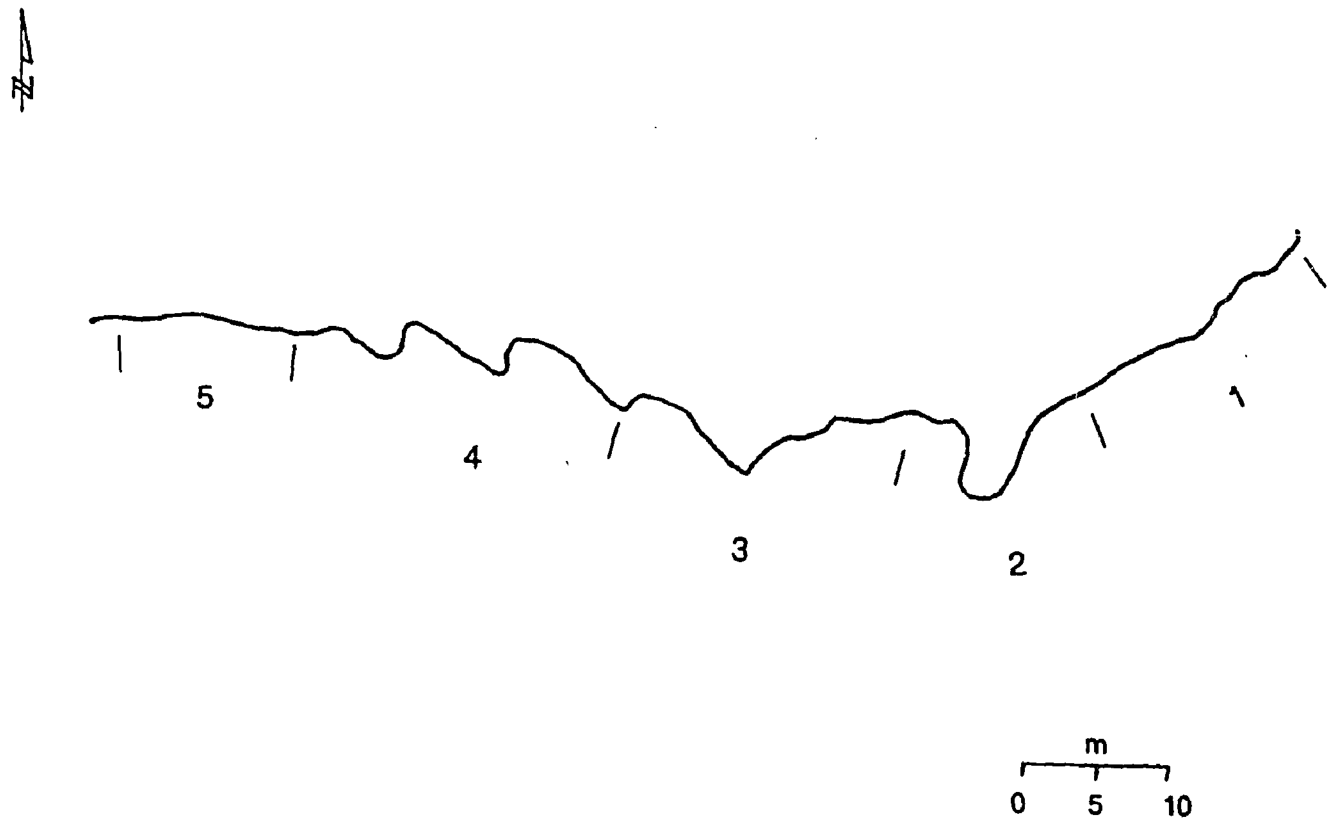
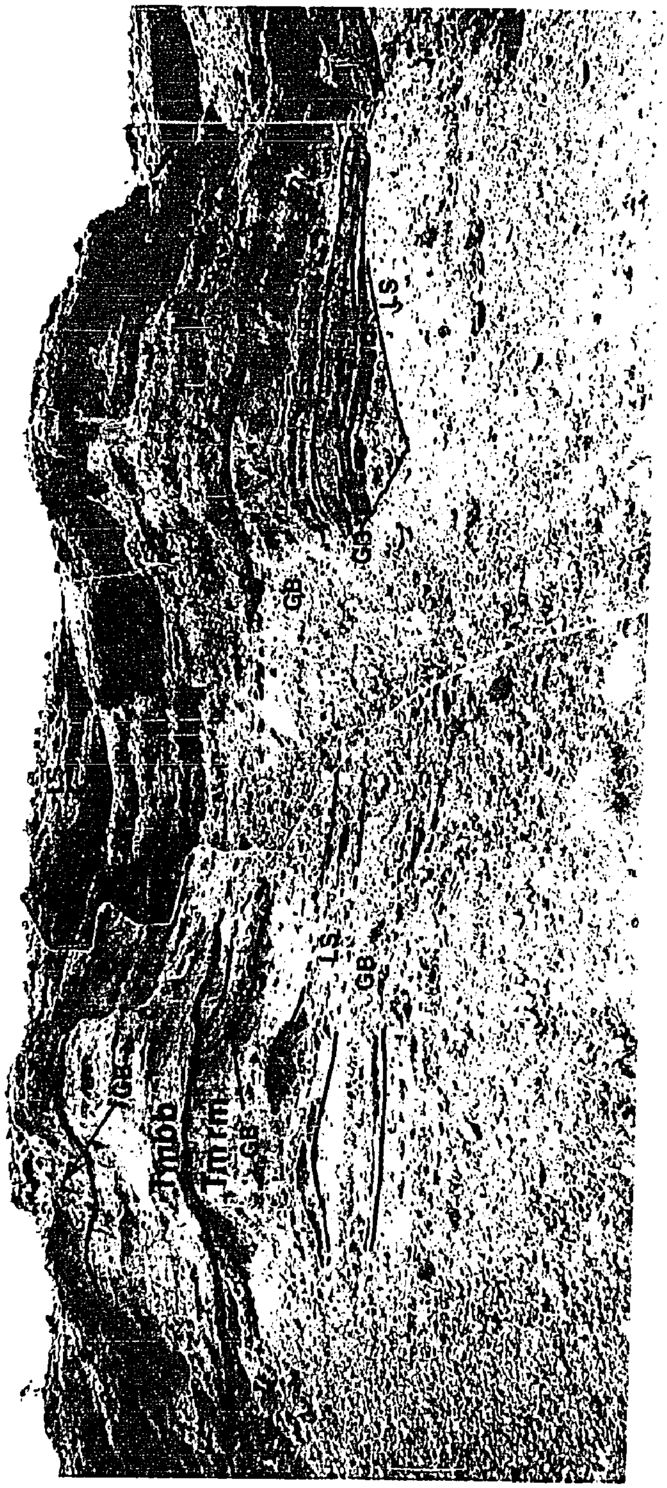


Figure 6. Plan view of the outcrop used for the Architectural analysis showing the locations of the individual mosaic photographs that make up Figure 7. (See Fig. 2. for location of the outcrop in the field area).

Figure 7. Architectural element analysis for the Boulder Basin conglomerate (Tmbb) and the River Mountain conglomerate (Tmrm) of the Muddy Creek Formation. The black and white arrows point to a hat used for scale.


GB
SG
GB
LS
GB
LS
GB
GB
LS
SB
SB
GB
CH
GB
LS


GB
GB
LS
LS
CH
LS
GB
GB
LS
GB
LS
GB


LS
GB
GB
GB
LS
GB
Tmbb

The Lakeshore and Cliffs members can not be analyzed using architectural elements because they are not considered fluvial deposits. However, their lithofacies are described, including possible modes of formation, and depositional environments are discussed based on the interpretations of the lithofacies.

River Mountain Conglomerate

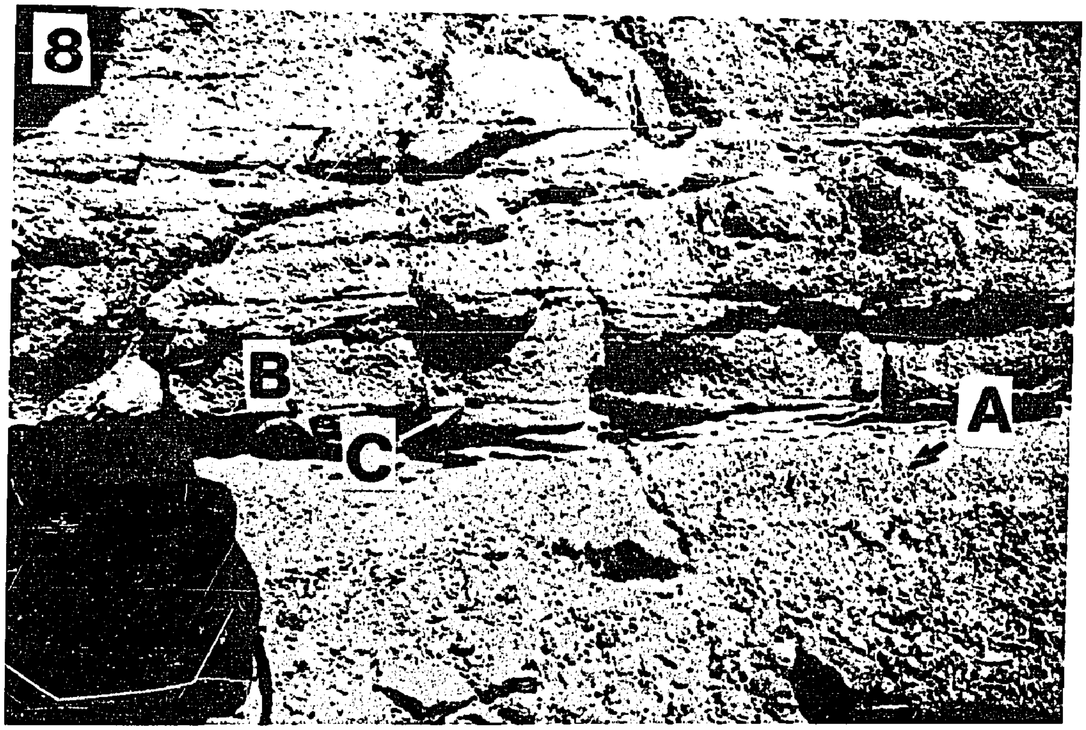
Architectural elements

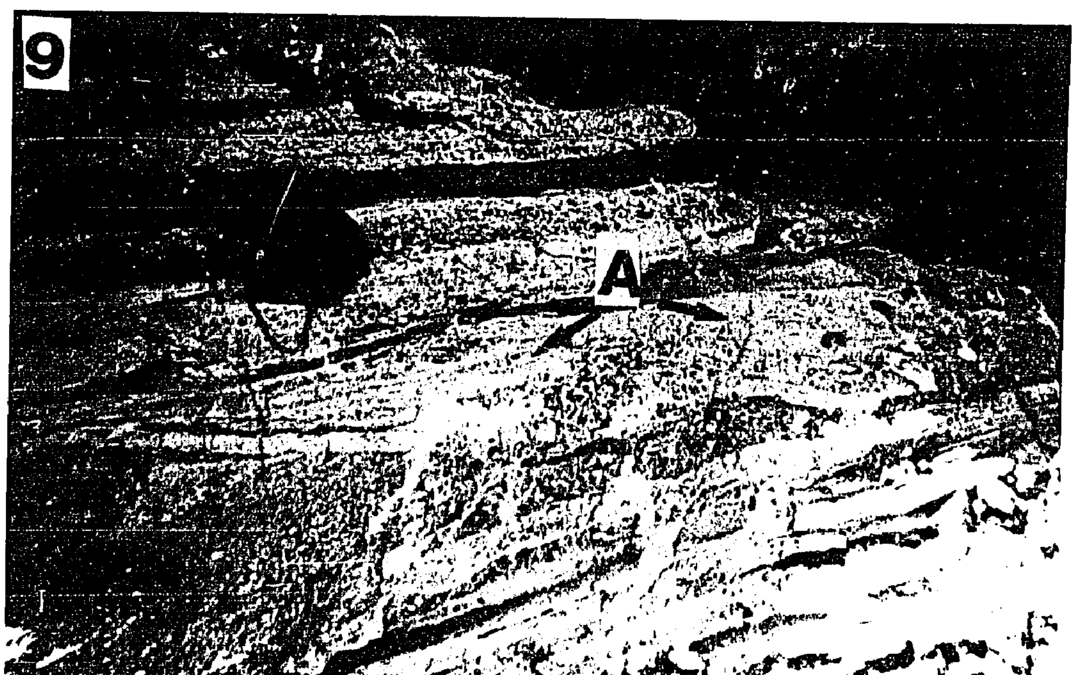
The River Mountain conglomerate contains the following architectural elements: gravel bars and bedforms (GB), channel deposits (CH), sandy bedforms (SB), and laminated sands (LS) (Fig. 7).

Gravel bars and bedforms (GB) in the River Mountain conglomerate are composed of pebble-sized clasts and sand-sized matrix. The conglomerates are clast supported and moderately to well imbricated. The internal sequence consists predominantly of massive or planar-bedded gravels (lithofacies Gm, Table 2), with minor trough cross-bedded gravel beds (lithofacies Gt). The massive and planar-bedded gravels average 40 cm thick and are laterally extensive in outcrop. The trough cross-beds are poorly to moderately developed and consist of sets 30 to 60 cm thick. The trough cross-bedded gravels are commonly laterally associated with the sandy bedform architectural element. The gravel bars and bedforms are tabular or wedge shaped with planar erosional bases (Fig. 8).

Figure 8. Gravel Bars and Bedforms (A) and Laminated Sand (B) Architectural Elements in the River Mountain conglomerate. Gravel beds are massive; laminated sand beds are planar bedded. Note tabular shape of beds and planar contacts (C). Photograph taken at station 4 (Fig. 2).

Figure 9. Sandy Bedform Architectural Element in River Mountain conglomerate. Trough cross-stratified beds (A) are in center of photograph. Photograph taken at station 4 (Fig. 2).


8
B
C
A


9
A

The planar bedded gravel deposits (lithofacies Gm) in the gravel bar and bedform architectural element may be a result of sheetflooding or hyperconcentrated flow (Smith, 1986; Blair, 1987; DeCelles et al., 1987). These types of sediments typically are deposited by shallow unconfined flow as planar beds in a high-flow regime (Steidtmann et al., 1986). The mode of transport can be a predominantly tractive process (sheetflooding) or may involve both traction and suspension (hyperconcentrated flow). The associated trough cross-stratified deposits (lithofacies Gt) can result from transport and deposition in small channels by normal stream flow (Elmore, 1984). The small size of the cross-bed sets suggest deposition in relatively shallow channels (probably less than 100 cm in depth) whereas the poor to moderate development of the cross-beds and the coarse-grained nature of the sediment suggests transport and deposition in high-velocity flow.

Channel deposits (CH) found in the River Mountain conglomerate are clast-supported conglomerates with a sand matrix. Clasts are mostly pebble sized. The conglomerates are massive gravel deposits (lithofacies Gm). Some fine upward from clasts about 2 cm to less than 1 cm in maximum diameter. Channel deposits are lense-shaped, averaging 1 m in width and 25 cm in height. They have concave-up erosional bases and nearly planar erosional upper surfaces (Fig. 7).

Channel deposit architectural elements typically represent deposition in shallow braided-stream channels (Bull, 1972; Pridemore and Craig, 1982). Clasts were transported and deposited by traction during high-velocity flow, resulting in massive, clast-supported deposits (Arguden and Rodolfo, 1986; Steidtmann et al., 1986). The sand matrix may have been deposited with the clasts, or may have infiltrated later. The lense shape of the deposit can be attributed to the original shape of the channel. The depth of the water was probably close to the thickness of the channel deposit although this is a minimum estimate because the upper surface is eroded. The coarse grain size of the infilling sediments suggests the currents were probably high-velocity.

The sandy bedform architectural element (SB) in the River Mountain conglomerate contains mostly sand-sized particles. Sandy bedforms contain both planar and trough cross-stratification (lithofacies St and Sp) (Fig. 9), although the planar cross-beds may actually represent a different view of the trough cross-stratification. The cross-bed sets are well developed, 30 to 40 cm thick, lense shaped or tabular, and have undulatory or planar contacts. Cross-stratification is about 5 to 20 mm thick. Often the planar and trough cross-stratified deposits occur together, laterally in the same bed.

The cross-bedded sandstones that make up the sandy bedform architectural element suggest deposition and

transport in a low flow regime, probably during the waning stages of flooding events (Steidtmann et al., 1986). The duration of the low-energy flow may be more sustained, allowing equilibrium conditions to be established, resulting in better sorting and the formation of well-developed cross-bedding. Planar cross-bedded sand deposits (lithofacies Sp) may result from the slip-face migration of longitudinal or transverse bars or migrating sand waves (Elmore, 1984; Steidtmann et al., 1986). Trough cross-bedding (lithofacies St) may represent transverse bar deposits, but can also be formed by migrating dunes or sand waves (Steidtmann et al., 1986).

The laminated sand architectural element (LS) in the River Mountain conglomerate is composed of thin (10 cm), sheetlike beds with sand-sized particles and contains planar bedding (lithofacies Sh), 5 to 30 mm thick with planar, erosional contacts (Fig. 8).

The planar-bedded sandstones that make up the laminated sand architectural element may have been deposited as planar beds in the upper-flow regime. The sediments were probably transported and deposited by sheetflooding or hyperconcentrated flooding (Miall, 1985; Smith, 1986, 1987; Blair, 1987; DeCelles et al., 1987).

Some of the fine-grained beds are cut by vertical wedge-shaped structures, 5 to 25 cm long and 1 to 4 cm wide, that appear to be filled with fine-grained sediments from the overlying beds. These structure are spaced 5 to 20 cm

apart within the beds. In a three-dimensional view, these structures form a network of irregular polygons (Fig. 10).

The vertical wedge-shaped structures in some of the beds are interpreted to be desiccation cracks similar to the structures photographed by Nilsen (1982, Fig. 45b). These features are produced in fine-grained sediment shortly after deposition due to drying of the sediments by evaporation. In order for desiccation cracks to develop, sediments must contain a large amount of silt and clay, which is not usually deposited in the high flow regime. Possibly the silt and clay was trapped and deposited with the sand during hyperconcentrated flow. Desiccation cracks are also indicative of subaerial deposition (Teel and Frost, 1982; Smoot, 1983).

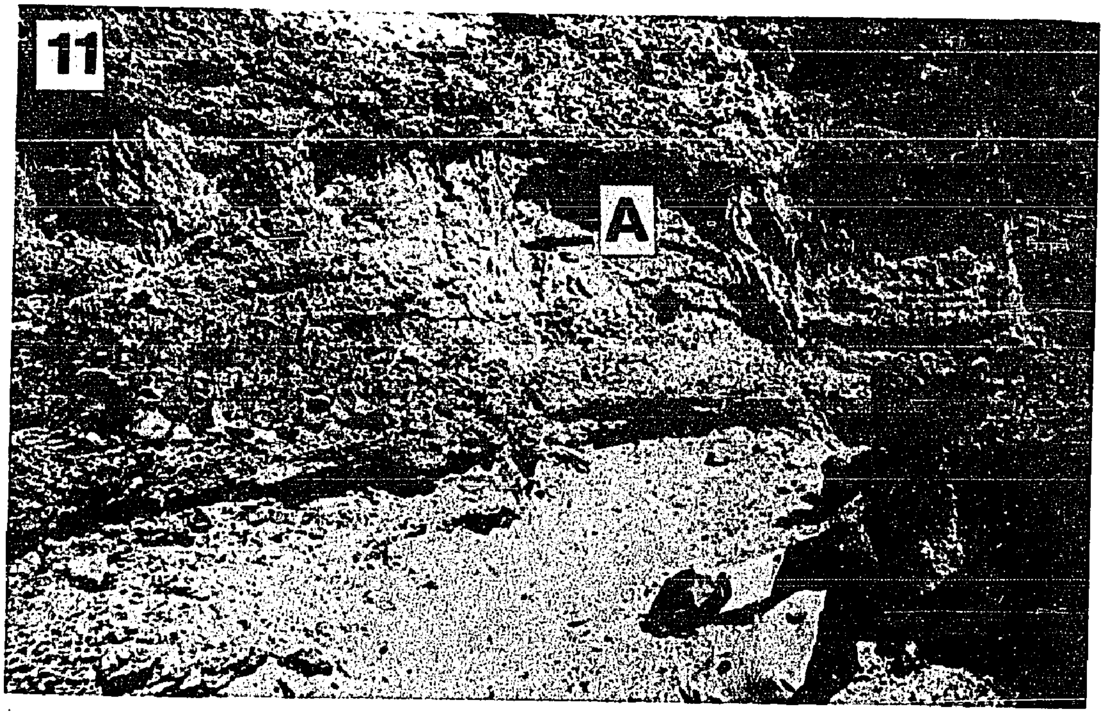
Structures seemingly produced by soft-sediment deformation are also present in the River Mountain conglomerate (Figs. 11 and 12). Soft-sediment deformation features are not common on alluvial fans, although they have been described by Teel and Frost (1982), Mills (1983), and Allen (1986). The soft-sediment deformation resulted in the convolution of many of the fine-grained beds. The convoluted beds are massive sandy-siltstones that contain matrix supported pebbles. Some of the deformed fine-grained sediments cut the coarser grained conglomerate beds, frequently along faults or fractures, and appear in some places to overlie the conglomerates as low concave mounds (Fig. 11). Overlying conglomerate beds appear to sag into

Figure 10. Desiccation cracks in the River Mountain conglomerate (arrows). Note polygonal shape of structures in lower beds. Photograph taken at station 4. (Fig. 2).


10

Figure 11. Soft-sediment deformation in the River Mountain conglomerate. Deformation occurs in the fine-grained beds (A). Note vertical fine-grained structures cutting coarser beds. Photograph taken at station 3 (Fig. 2).

Figure 12. Soft-sediment deformation in the River Mountain conglomerate showing cuspate sag structures (A). Photograph taken at station 3 (Fig. 2).


11
A


12
A

the convoluted fine-grained beds, forming cuspate, concave-up structures about 10 m across (Fig. 12). The dips of the beds vary locally, and range from 30 degrees to horizontal.

The deformation probably resulted from post or syndepositional dewatering of the fine-grained beds. The dewatering of the sediments may have been triggered seismically by earthquakes active during the depositional period. Seismic activity can recompact the sediments through liquifaction, forcing water and sand up through the overlying coarser-grained beds along fractures and faults, eventually erupting on the surface as sand volcanoes. Recompaction allows the overlying coarser sediments to sag and penetrate the underlying finer-grained beds. Similar processes and structures have been observed following modern seismic events, such as the Alaska earthquake of 1964 (Hansen, 1966; Tuthill and Laird, 1966), the 1979 Imperial Valley earthquake (Housner, 1985), and the 1886 earthquake at Charleston, South Carolina (Obermeier et al., 1985). These structures have also been recorded in the geologic record (Sieh, 1978; Allen, 1986; Mills, 1983).

Facies association

Laminated sands and gravel bars and bedforms are the most common architectural elements in the River Mountain conglomerate; often forming an alternating vertical sequence (Figs. 7 and 8). A gravel bed overlain by a laminated sand bed may represent a single depositional event. Initially

the unconfined, hyperconcentrated flood may be competent enough to transport and deposit gravels and cobbles, forming the tabular, massive or planar bedded gravels. Subsequently, the flood loses energy and water depth decreases resulting in the inability to carry the coarse-grained material and deposition of the planar bedded sands. During the beginning of the next depositional event, some of the sand beds may be eroded away while others are trapped by deposition of the next layer of gravel. Locally where all the laminated sand is eroded away amalgamated gravel deposits result. This process continues, resulting in alternating beds of massive or planar bedded gravel and planar bedded sand (Fig. 8).

Channel deposits are rare and randomly dispersed. This may indicate that braided streams were not dominant in the formation of these sediments. Hyperconcentrated debris flows normally are not very erosive and do not cut channels. Their deposits commonly are tabular-shaped; not the lenticular-shaped deposits that commonly result from braided-stream deposition. Sandy bedforms also common in braided-stream deposits are rare in the River Mountain conglomerate.

The River Mountain conglomerate lacks debris flow deposits that commonly are associated with alluvial fans. This paucity may be due primarily to a combination of the composition of the sediment supplied by the source area and

the climate. Possibly there is not enough clay or water available to induce viscous, cohesive flow.

Environment of deposition

The architectural elements and the other sedimentary structures observed in the River Mountain conglomerate indicate a distal alluvial fan deposit or alluvial plain deposit. Unsorted, oxidized, immature sediments are characteristic of alluvial fans; fine-grained beds and small grain size in the conglomerate beds indicate that the sediments were transported relatively far from the source area. Unchannelized flow is more common on the middle and distal portions of alluvial fans than in the proximal portions (Bull, 1972; Nilsen, 1982). Examples of this unchannelized flow would be sheetflooding and hyperconcentrated flooding. Channel deposits in the River Mountain conglomerate are rare and small and do not reflect the large, well established network of channels commonly found in proximal alluvial fan facies. The presence of low-flow regime features (observed in the sandy bedforms) may indicate deposition on the lower portions of the alluvial fan or on an alluvial plain where the slope of the fan and energy of transport are lower.

The depositional model for the River Mountain conglomerate does not fit with any of the models proposed by Miall (1977, 1978, 1985) or Rust (1978). Their models generally address environments that are dominated by braided

stream or debris flow deposition. The importance of hyperconcentrated flooding, a process that is intermediate between fluid stream flow and debris flow, has only recently been recognized in geology (Smith, 1986; 1987) and consequently was not integrated into the earlier models.

Boulder Basin Conglomerate

Architectural elements

Gravel bars and bedforms, channel deposits, laminated sand, and sediment gravity flows are the architectural elements that comprise the Boulder Basin conglomerate (Figs. 7 and 13).

The composition of the gravel bar and bedform architectural element (GB) is similar in the Boulder Basin conglomerate and the River Mountain conglomerate. The gravels are clast supported, moderately imbricated, and consist of massive or planar-bedded gravels (lithofacies Gm). Clast size however is larger in the Boulder Basin conglomerate (about 10 cm) and beds are thicker (about 1 m). Beds are tabular shaped with planar contacts and are laterally extensive (Fig. 14). Planar bedding ranges from 5 to 15 cm thick. The massive or planar bedding is consistent laterally and does not grade into other lithofacies (Fig. 14). No consistent lithofacies sequences were observed.

The planar bedded conglomerates (lithofacies Gm) of the gravel bar and bedform architectural element were probably deposited by shallow, unconfined flow in the upper flow

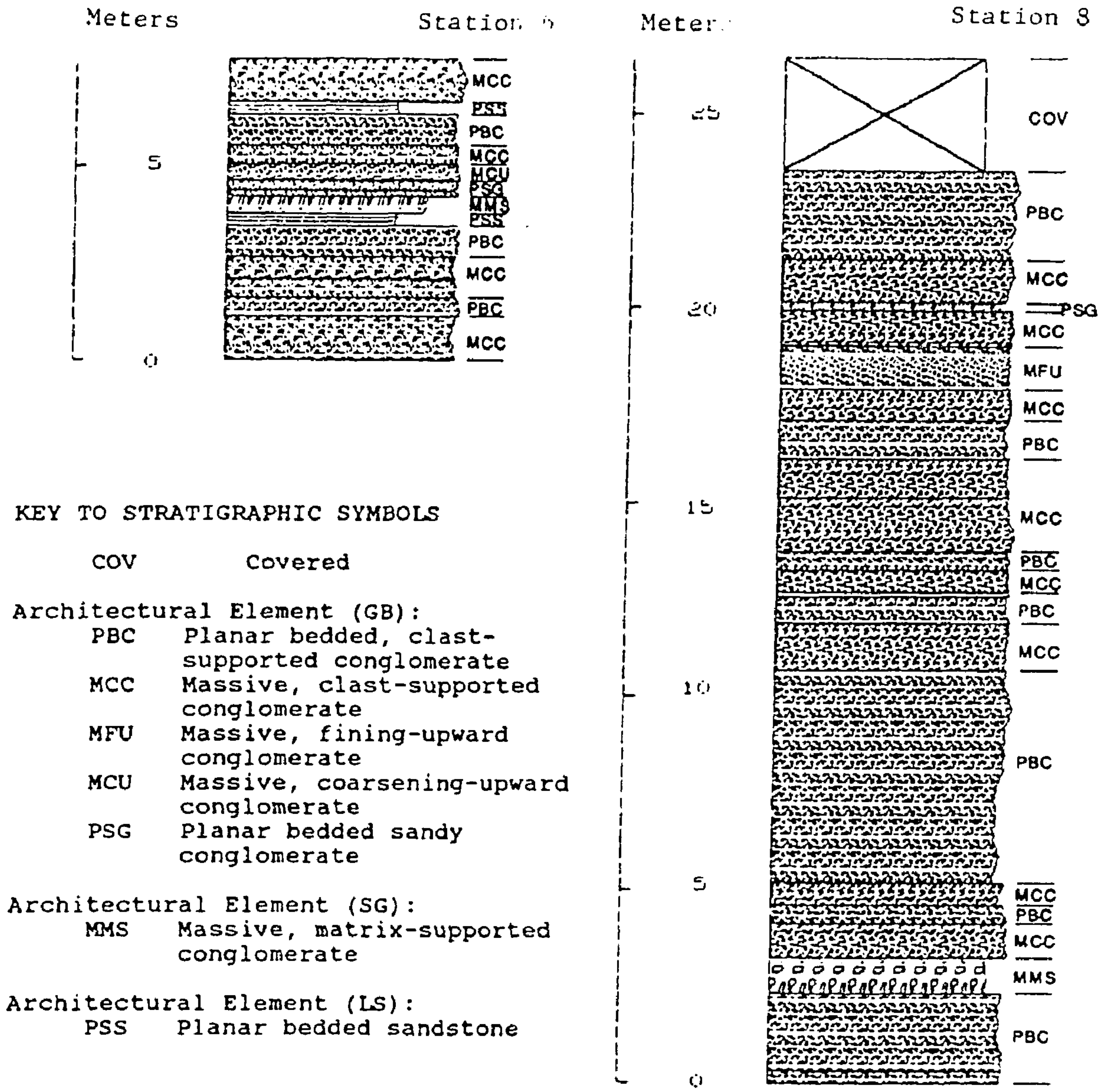
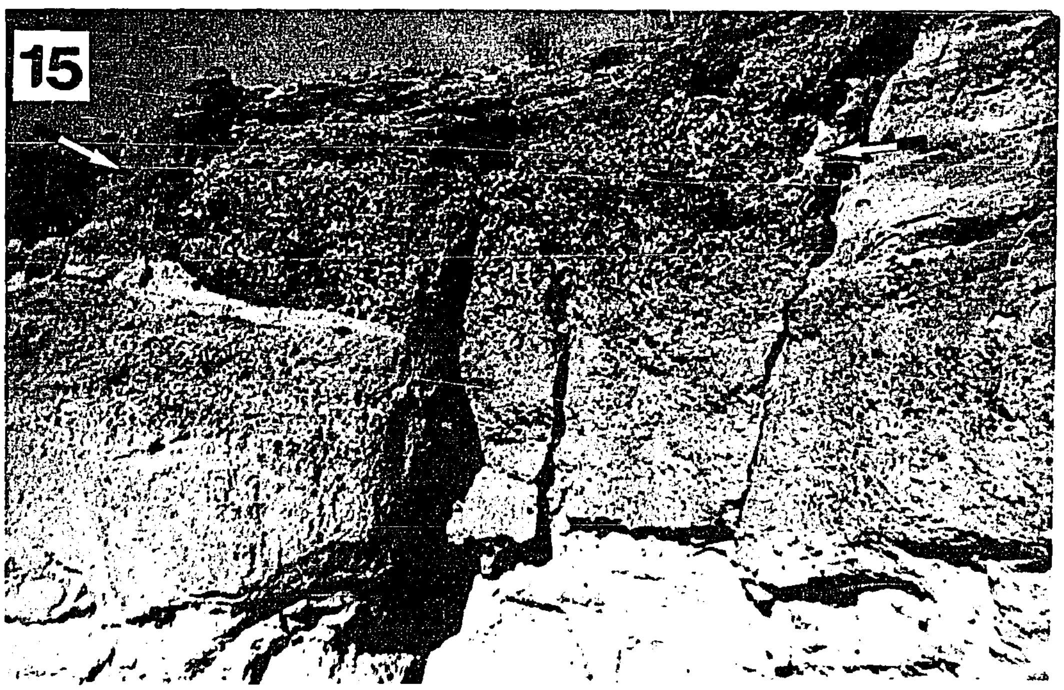


Figure 13 Vertical sections of the Boulder Basin conglomerate measured in the field area (stations 6 and 8, Fig. 2) for use as a comparison with the architectural element analysis.

Figure 14. Planar-bedded lithofacies of the Gravel Bar and Bedforms Architectural Element in the Boulder Basin conglomerate (A). Beds are tabular shaped with planar contacts. Photograph taken at station 5 (Fig. 2).

Figure 15. Channel deposit Architectural Element in the Boulder Basin conglomerate (arrows). Channel is 10 m wide and 3 m high. Photograph taken at station 7 (Fig. 2).


14
A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regime. The unsorted, clast-supported, massive or planar-bedded conglomerates may have been deposited by sheetflooding or hyperconcentrated flood flow (Smith, 1986; Blair, 1987; DeCelles et al., 1987). The large grain size and thick bedding suggest that the water transporting these sediments in the Boulder Basin conglomerate was deeper and swifter than the water transporting the gravel bars and bedforms in the River Mountain conglomerate. The lack of fining or coarsening upward sequences may suggest continuous tectonism or a large supply of sediment.

The channel deposit architectural elements in the Boulder Basin conglomerate are much larger and more common than those of the River Mountain conglomerate. The channel deposits are lenticular shaped and can exceed 10 m in diameter, and 3 m in height (Fig. 15). These deposits have erosional, concave-up bases and planar upper contacts. Clasts are predominantly cobble-sized. The sediments are clast supported and massive.

The sediments in the channel deposit architectural element reflect deposition in braided-stream channels (Bull, 1972; Pridemore and Craig, 1982). These deposits were transported and deposited by traction in a high flow regime (Howell and Link, 1979; Arguden and Rodolfo, 1986). The massive coarse-grained sediment suggests rapid deposition precluding the formation of internal structures.

The laminated sand architectural element (LS) in the Boulder Basin conglomerate is composed of sand-sized

particles. These are laterally extensive sheet-like deposits with planar contacts. Beds average about 10 cm thick, and are planar-bedded. The planar beds range from 5 to 20 mm thick (Figs. 7 and 13).

The planar-bedded sandstone also implies deposition in a high-flow regime (Arguden and Rodolfo, 1986). Because of the sheet-like nature of the beds, deposition was probably unconfined, and resulted from shallow sheetflooding or hyperconcentrated flood flow (Miall, 1985; Smith, 1986, 1987; Blair, 1987; DeCelles et al., 1987). These beds may be deposited when the flow velocity of the transporting medium becomes too low to transport gravel-sized sediment but still high enough to produce upper flow regime structures in sand.

Deposits of the sediment gravity flow architectural element (SG) in the Boulder Basin conglomerate contain mostly silt- to sand-sized particles, although some reach cobble size. The larger clasts are rare in most deposits. The sediments of the sediment-gravity flow are massive, unsorted, and matrix supported. The deposits are wedge shaped, average 50 cm thick, have undulatory, nonerosive basal contacts, and undulatory or planar upper contacts (Fig. 7 and 13).

The massive, unsorted, matrix-supported conglomerates that make up the sediment gravity flow architectural element result from deposition by viscous, debris flows (Bull, 1972; Nilsen, 1982, Smith, 1986). Such debris flows behave as

non-Newtonian fluids and transport sediments in suspension, by laminar flow (Arguden and Rodolfo, 1986). Debris flows can support very large clasts and the resulting deposits are massive or poorly stratified and matrix supported (Nilsen, 1982).

Facies association

The architectural analysis in horizontal exposures (Figure 7) and in vertical exposures (Fig. 13) indicate that the most common architectural elements in the Boulder Basin conglomerate are the amalgamated gravel bars and bedforms with laminated sands occurring infrequently between them. The infrequent occurrence of sand deposits suggests that a higher energy flow deposited the Boulder Basin conglomerate than deposited the River Mountain conglomerate in which planar bedded sand is common. The paucity of sand beds in the Boulder Basin conglomerate indicate non-deposition of sand or complete erosion prior to deposition of the next gravel layer.

Channel deposits are more common in the Boulder Basin conglomerate than in the River Mountain conglomerate, but are not as common as the gravel bars and bedforms. These depostis suggest a more proximal fan position because generally, channels are larger, deeper, and more substantial on the medial and proximal parts of alluvial fans, and have a greater preservation potential because of their size.

Debris flow deposits were rarely observed in the Boulder Basin conglomerate (Fig. 13), but are more common than in the River Mountain conglomerate. These deposits also occur between beds of gravel bars and bedforms.

Environment of deposition

The Boulder Basin conglomerate is interpreted to be a proximal or medial alluvial fan deposit. The conglomerate contains large, angular clasts, thick beds, large channel deposits, and relatively little fine-grained sediments; all indicative of deposition on the upper or middle portions of an alluvial fan (Elmore, 1984). The deposits do not appear coarse grained enough and the channels are not large enough to indicate deposition at the apex of a fan. In addition, debris flow deposits, which are rare in the Boulder Basin conglomerate, are also more common on proximal portions of alluvial fans (DeCelles et al., 1987). All the architectural elements indicate high transport velocities that would be common on the upper and middle reaches of an alluvial fan.

The depositional model proposed for the Boulder Basin conglomerate is similar to model 2 proposed by Miall (1985), because of the abundance of the gravel bars and bedforms architectural element. In Miall's model, the gravel bars and bedforms are primarily deposited by braided stream. In the Boulder Basin conglomerate model, however, the gravel bars and bedforms are attributed to deposition by

hyperconcentrated flood flows because of the lack of basal scour, tabular nature of the beds and polymodal distribution of clast size.

Lakeshore Member

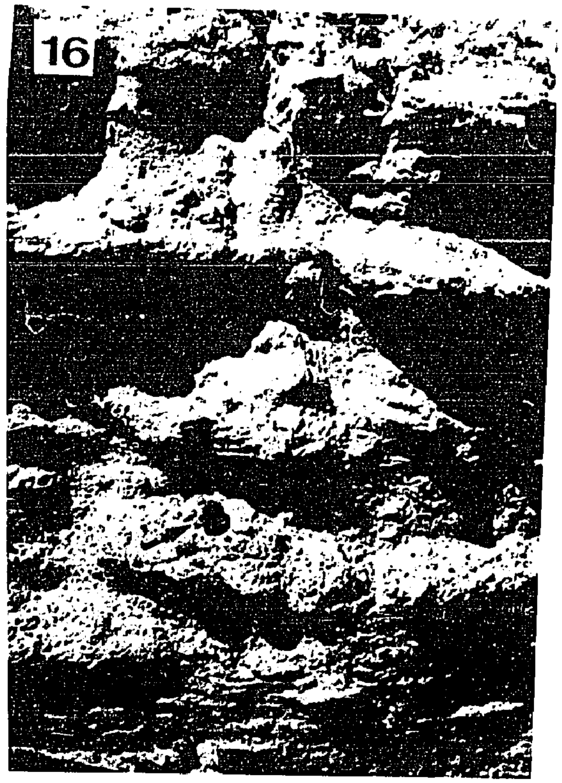
The Lakeshore member laterally interfingers with the Boulder Basin conglomerate but was not analyzed using Miall's architectural element analysis because it is a lacustrine rather than a fluvial deposit. A lithofacies description, interpretation and deposition environment analysis follows.

The Lakeshore member is predominantly a silty sandstone containing a few small pebble-sized conglomerate lenses and beds. Beds are sheet like, about 10 cm thick and have planar contacts (Fig. 16). Internally the beds are massive with no other sedimentary structures. The Lakeshore member also contains at least five 10-cm-thick structureless ash layers that have planar contacts.

Thin, massive, sheet-like silty-sandstone beds of the Lakeshore member were probably deposited under low energy conditions by slow, incompetent currents in a manner similar to that described by Picard and High (1981). The energy of the transporting medium was probably insufficient to produce traction bedform structures. The sediments introduced intermittently from flooding events, dropped out of

Figure 16. The Lakeshore member showing thin, massive, tabular nature of beds. The arrow is pointing at car keys used for scale. Photograph taken at station 2. (Fig. 2).

Figure 17. The Cliffs member. The fine-grained red deposits are siltstone (A) and the white deposits are gypsum (B). Photograph taken at station 1 (Fig. 2).


16


17
B
A

suspension or flow along the bottom, forming thin sheets of massive silty sand.

Sediments of the Lakeshore member were most likely deposited in a lacustrine environment. Thin, massive, laterally persistent beds similar to those of the Lakeshore member have been documented in lacustrine environments (Picard and High, 1981; Hardie et al., 1978). Fossils were not observed in hand specimen, although the sediments were not studied to determine the presence of microfossils. The lack of large fossils may suggest saline or brackish conditions. Alternatively, fossils may not have been preserved. The Lakeshore sediments may have been deposited close to the shore because they interfinger with the Boulder Basin conglomerate, a fluvial deposit.

The Cliffs Member

The Cliffs member is interpreted as a playa deposit and therefore was not analyzed using Miall's architectural analysis. The lithofacies, depositional mechanism and depositional environment are discussed here.

The Cliffs member is composed of siltstone and gypsum. The siltstone beds are thin, about 3 to 5 cm thick, laterally extensive, and massive (Fig. 17). No other sedimentary structures were observed in the siltstone. The gypsum occurs as a series of tabular beds, 5 to 10 cm thick.

In some places the gypsum beds are folded or deformed (Fig. 17).

The lack of fluvial sedimentary structures and the fine-grained and thin-bedded nature of the sediment suggest that the sediments were deposited in a very low energy environment (Picard and High, 1981). The fine-grained nature of the beds implies that the transport medium was not very competent. The thin beds are probably the result of intermittent supply and low capacity currents to transport the sediment (Arguden and Rodolfo, 1986). The sediment may have been supplied intermittently by flooding during storm events. The gypsum beds are a result of evaporation and precipitation. As the body of water evaporated, the gypsum precipitated out of solution, forming thin sheet-like beds (Smoot, 1983).

The presence of gypsum beds and thin, massive siltstone beds suggest deposition on a playa. Initially lake levels may have been sufficient to prevent the precipitation of evaporites. Later the lake intermittently evaporated to the point where gypsum could precipitate. Gypsum is present in many of the older formations in the Lake Mead area and may have been the source for the gypsum beds in The Cliffs member. This gypsum would have been introduced into the basin as detritus or in solution and late precipitated out to form the bedded gypsum.

STRUCTURE

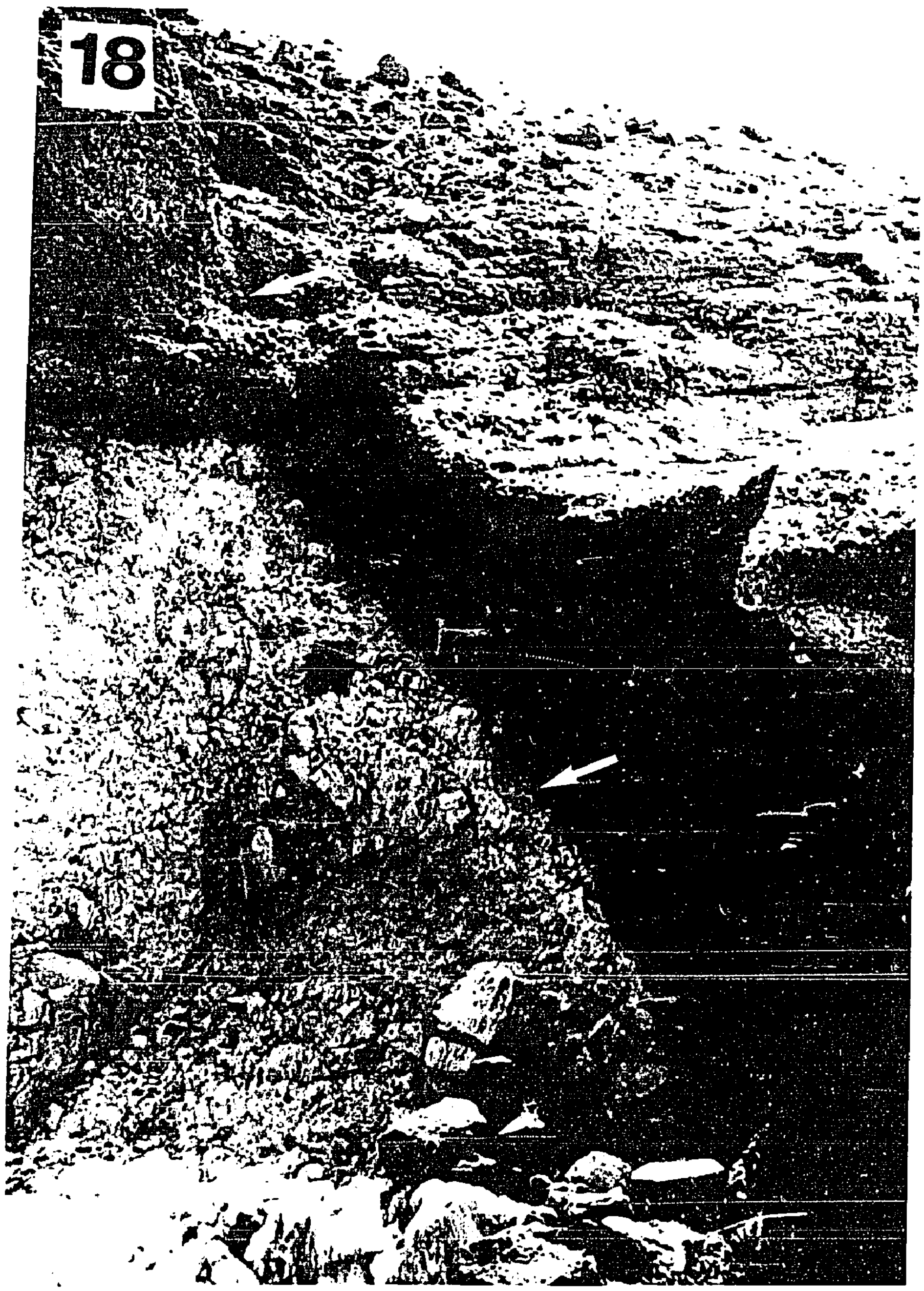
The River Mountains area was extended during the mid-Tertiary producing mostly high-angle normal faults that strike between N20W and N20E. Most normal faults in the eastern River Mountains show down-to-the-east displacement however, down-to-the-west displacement is also present. No low-angle faults were observed in the thesis area, but they are exposed in the volcanic section at Fault Basin, about 3 km south (Smith, 1982), and on Saddle Island, near the southeast corner of the thesis area (Choukroune and Smith, 1985; Dubendorfer, et al., 1988).

Most of the faults that cut the Muddy Creek Formation were active during the deposition of the Muddy Creek Formation and are classified as growth faults (Crans et al., 1980; Pridemore and Craig, 1982). The basal parts of the Muddy Creek Formation are offset and tilted more than the upper parts along the same fault (Fig. 18). Some faults cut the lower part of the Boulder Basin conglomerate but die out upsection. Offsets on most of the faults appear to be less than 10 m, although correlation of bedding across the faults is often difficult. Similar growth faulting has been described in Tertiary sediments the southern Great Basin by Proffett (1977), Frost (1979), Pridemore and Craig (1982), and Teel and Frost (1982).

Faults that exhibit larger offsets (>10 m) occur in the northwestern part of the River Mountains field area. The offset on these faults is hard to measure quantitatively,

however they have sufficient offset to omit members of the Muddy Creek Formation. One fault places the Lakeshore member in the hangingwall against the River Mountain volcanic rocks in the footwall. These faults may be basin margin structures and may have influenced local sedimentation rates throughout the depostional period of the Muddy Creek Formation.

Figure 18. A typical growth fault in the Muddy Creek Formation (arrows).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PROVENANCE STUDIES

To better understand the evolution and development of the Muddy Creek Formation, source areas for sediments must be located. The results of the provenance studies indicate sediment transport direction, the area of denudation, and the general location of the local basin margins. This information helps to further our understanding of the tectonic and depositional history of the area.

Three different techniques were used to determine the provenance of the clasts of the Muddy Creek Formation. These are: (1) measurement of paleocurrent direction indicators such as clast imbrication, (2) distribution and density of granite clasts within the sediments of the Muddy Creek Formation, and (3) chemically fingerprinting the igneous clasts in the Muddy Creek Formation and comparing the results to an existing regional geochemical database.

Paleocurrent Measurements

Paleocurrent direction was determined by measuring clast imbrications. Orientations of the A (long) and B (short) axes in the plane of imbrication in the clasts were measured using a Brunton compass and the true dip of the plane was determined with a stereonet (Potter and Pettijohn 1977, and Miall 1984). Since most of the conglomerate beds are structurally rotated about a horizontal axis, clast imbrication measurements were corrected for tilt by rotating the beds to horizontal using stereonet techniques described

by Billings (1972). The conglomerates also display cross-bedding and channel deposits.

The paleocurrent measurements are plotted on rose diagrams in Appendix A, and Figure 19. Ninety percent of the data are clast imbrication measurements, although some channel axis orientations and cross-bedding measurements are included. All of the measurements for both the River Mountain conglomerate and Boulder Basin conglomerate are plotted on a topographic map of the River Mountain area (Appendix C). The clast imbrications show a wide dispersal pattern (Fig. 19), but generally range from east to northeast for the Boulder Basin conglomerate and to the southeast for the River Mountain conglomerate. Cross-bedding measurements and channel orientation data generally support these data. The Boulder Basin conglomerate interfingers with the fine-grained Lakeshore member to the northeast, also suggesting a northeast direction of transport.

The paleocurrent direction for the Boulder Basin conglomerate is roughly to the east, with the overall grand vector mean oriented N62E. The mean vectors vary considerably as would be expected on alluvial fans where flow is distributed radially away from the apex of the fans. The vector means for the River Mountain conglomerate show an overall trend to the southeast, and have a mean orientation of S18E.

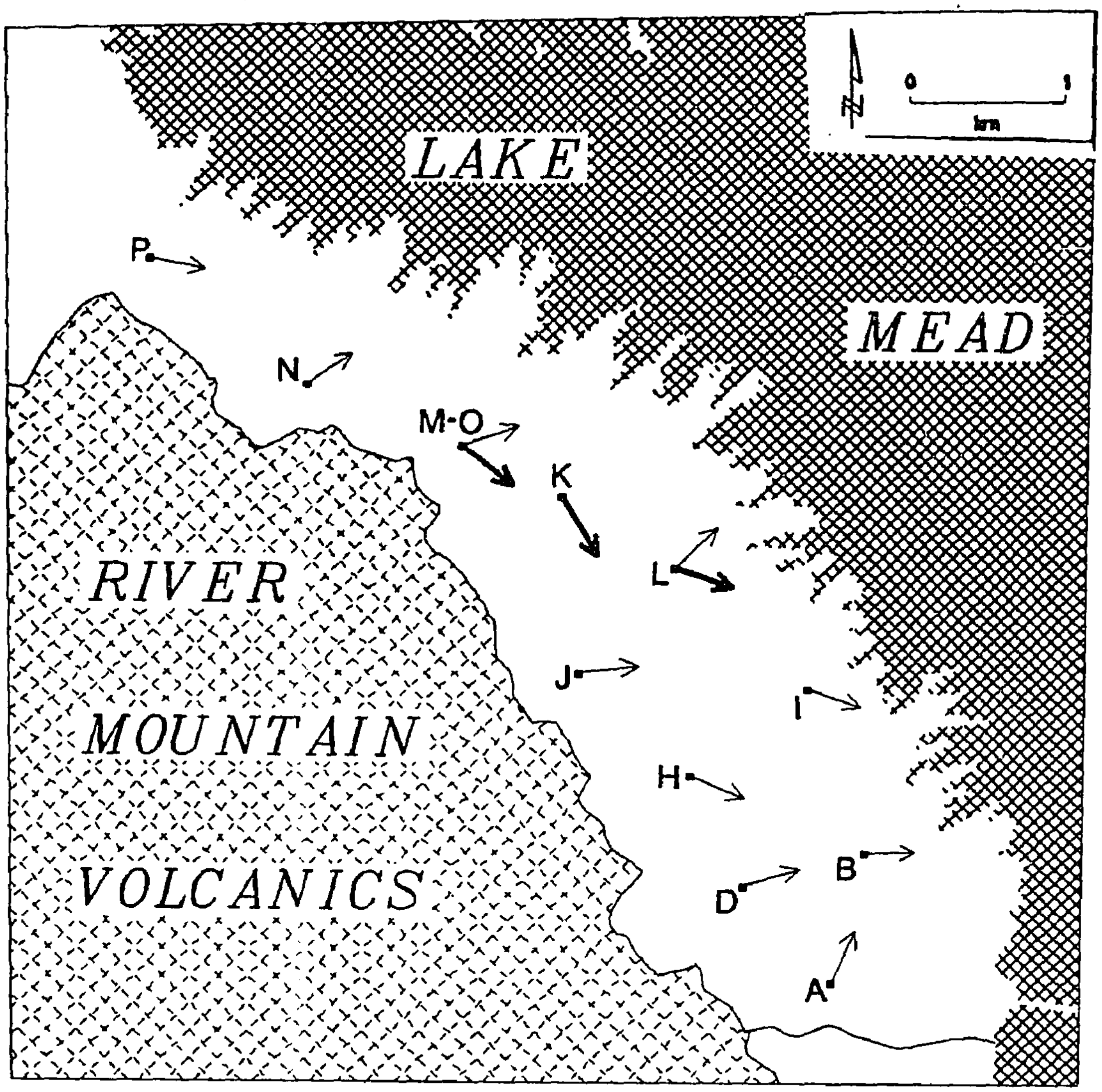


Figure 19. Map of field area showing vector means for the paleocurrent measurements for the Boulder Basin conglomerate (thin arrows) and the River Mountain conglomerate (bold arrows). The actual rose diagrams are in Appendix A.

Granite Clast Density

Source areas can also be located by mapping the distribution of distinctive clast types (Miall, 1970). This method was possible because granite clasts in the Muddy Creek Formation were found in a geographically limited area and were unique to the Boulder Basin conglomerate. Clasts counts were obtained at various stations in the field area (Fig. 20). An isopleth map (Fig. 20), representing the number of plutonic clasts counted in a square meter of outcrop, shows that the density of granite clasts is greatest in the southwestern part of the area decreasing to zero to the northeast. This distribution suggests that the source of the granite clasts was to the southwest. The area with the highest density of granite clasts appears to be spatially restricted, suggesting that it is close to a fan apex near to the basin margin. The most probable source for the granite clasts was the River Mountain stock; about 8 km to the southwest. The data obtained from this method supports the data obtained from paleocurrent measurements (Fig. 19).

Geochemical Data

Geochemical fingerprinting of the Muddy Creek clasts is a unique way to identify source areas. Geochemical fingerprinting is commonly used in other fields of geology, but has never been utilized to identify source areas for conglomerate clasts. Trace and rare-earth elements are used

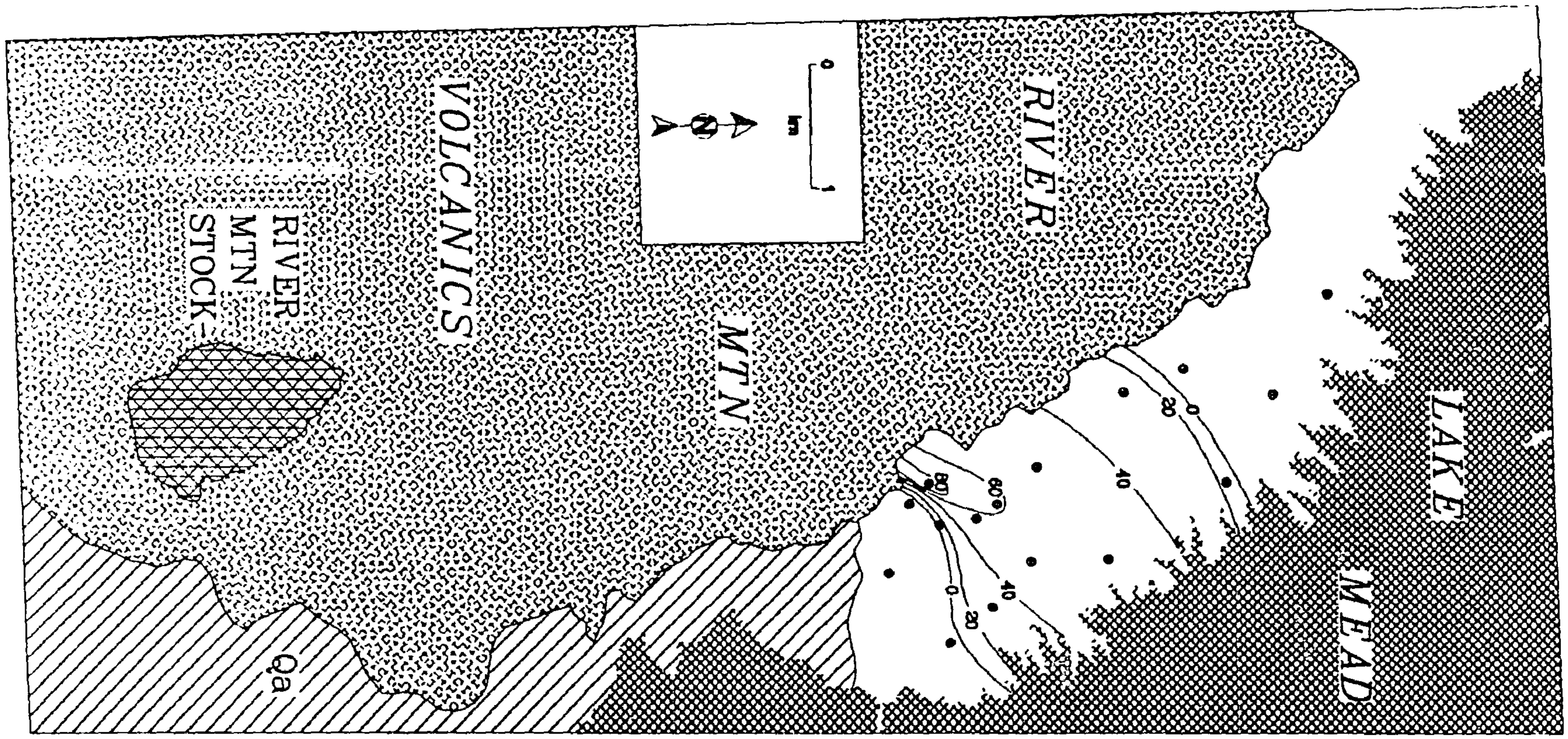


Figure 20. Isopleth map of field area showing the distribution of the granite clasts in the field area. Dots are individual stations where measurements were taken. Note the River Mountain stock at the bottom of the figure.

frequently in igneous petrology to correlate ash-flow and ash-fall tuffs (Hildreth and Mahood, 1985; Sarna-Wojcicki et al., 1984; Izett, 1981), classify volcanic rocks (Bacon et al., 1981; Mahood, 1981) and model magmatic evolution (Mahood, 1981; Hildreth, 1981; Cullers et al., 1981). Geochemical fingerprinting techniques have been used in archeology for correlating obsidian flakes to their quarries (Rapp, 1985). Sedimentary petrologists have used trace and rare-earth element geochemistry to determine tectonic environments and provenance of deep sea clays, shales and sandstones (Robertson, 1986; McLennan and Taylor, 1984). The geochemical analysis in this study is a pioneering effort to use trace and rare-earth elements to determine the source for conglomerate clasts.

Trace and rare-earth element analysis of the igneous clasts were obtained by instrumental neutron activation analysis (INAA) at the Phoenix Memorial Laboratory at the University of Michigan. The geochemical data was compared with similar data in rocks from the various volcanic and plutonic centers in the Lake Mead-Eldorado Valley area (Smith, 1982; Smith et al., 1988). The rare-earth elements (lanthanum (La), cerium (Ce), neodymium (Nd), samarium (Sm), europium (Eu), terbium (Tb), ytterbium (Yb) and lutetium (Lu)) and trace elements hafnium (Hf), thorium (Th), and tantalum (Ta) were used because they are the most immobile elements in strongly altered volcanic rocks (Hildreth and Mahood, 1985; Sarna-Wojcicki et al., 1984) and therefore

would be the most diagnostic in the highly weathered conglomerate clasts. Weber and Smith (1987) have demonstrated that the igneous rocks of the different volcanic centers in the Lake Mead area have unique geochemical signatures. Therefore similarities in abundances of rare-earth and trace elements between the Muddy Creek clasts and the igneous rocks in the Lake Mead area are indicative of possible source areas for the Muddy Creek sediments.

Two graphical methods were used to plot and compare data. Rare-earth element abundances were first normalized to the chondrite values of Haskin et al., (1968) and plotted in order of increasing atomic number (Figs. 21 and 22). Possible volcanic source areas for the clasts in the Muddy Creek Formation are the River Mountains, McCullough Mountains, Eldorado Mountains, and Hoover Dam Volcanics (Fig. 23). All four possible areas consist primarily of andesites and dacites extruded between 12 and 15 Ma. The Muddy Creek volcanic clasts closely correlate with the volcanic rocks of the River Mountains volcanic pile (Fig. 21). Both the Muddy Creek volcanic clasts and the River Mountains volcanic rocks have higher overall rare-earth-element abundances than do the rocks from the other volcanic areas in the Lake Mead area. Granite clasts in the Boulder Basin conglomerate are chemically similar to the Wilson Ridge pluton and the River Mountain stock (Fig. 21). Samples from the Muddy Creek Formation, Wilson Ridge pluton,

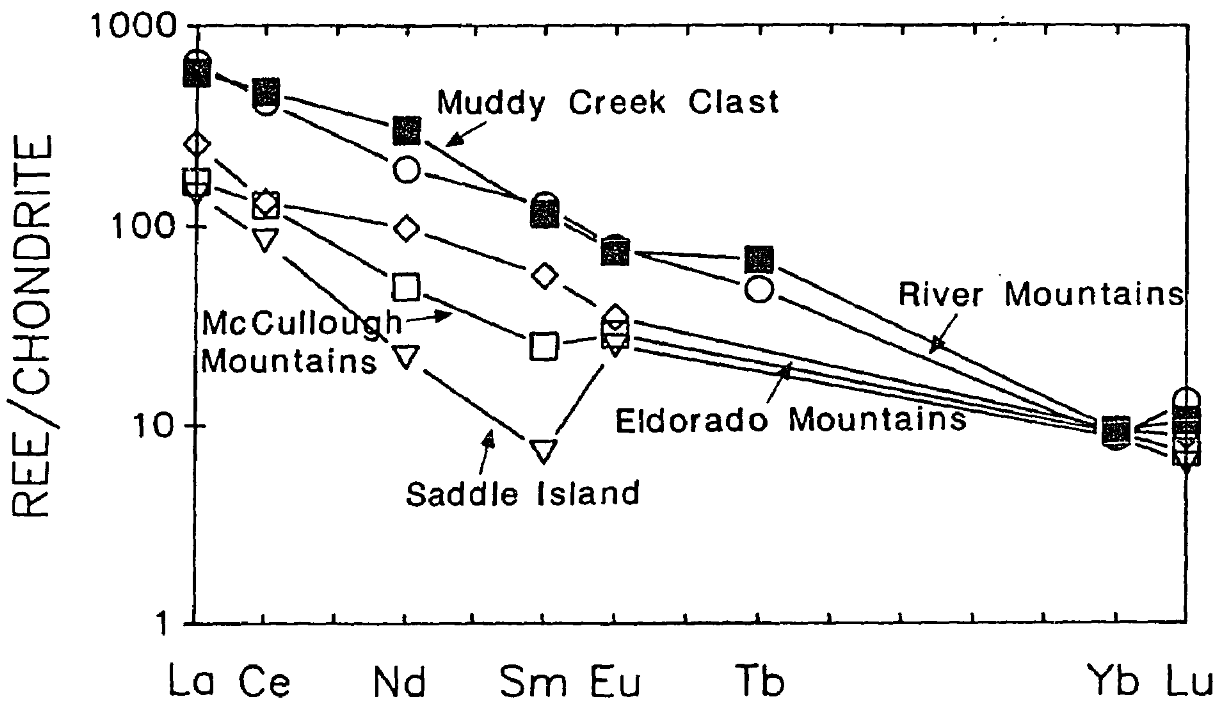


Figure 21. Normalized REE plot for basalt from the volcanic centers in the western Lake Mead area and the Muddy Creek Formation.

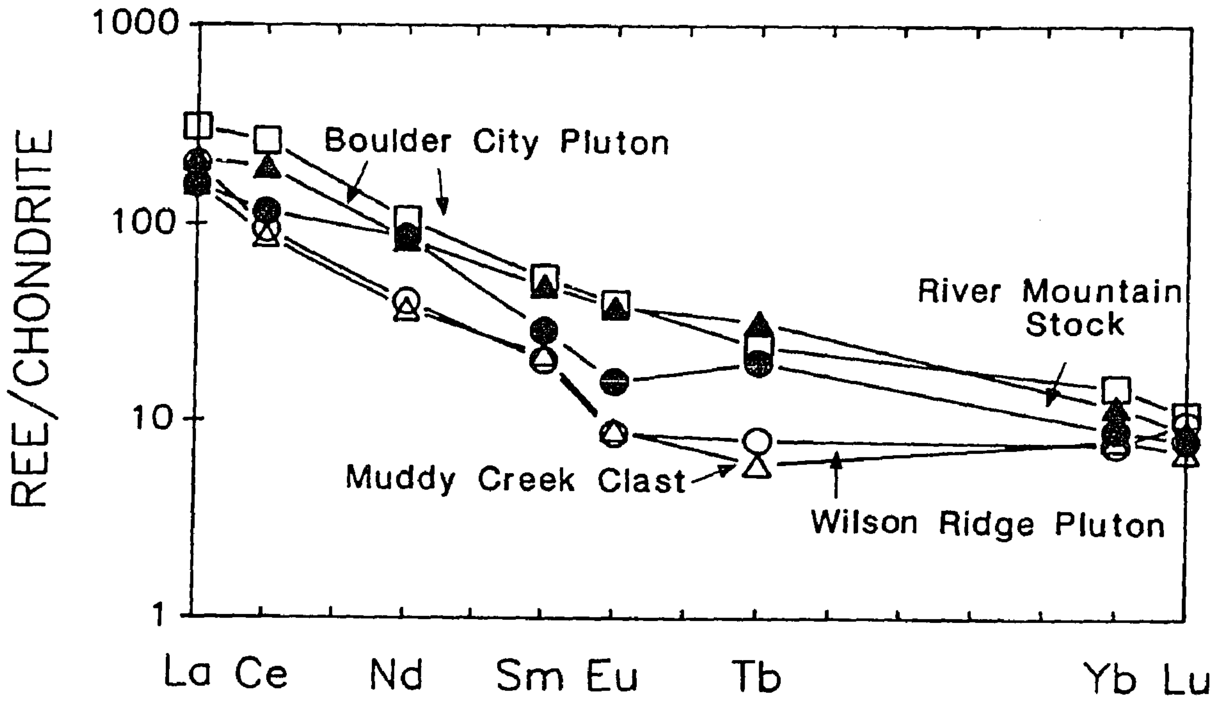
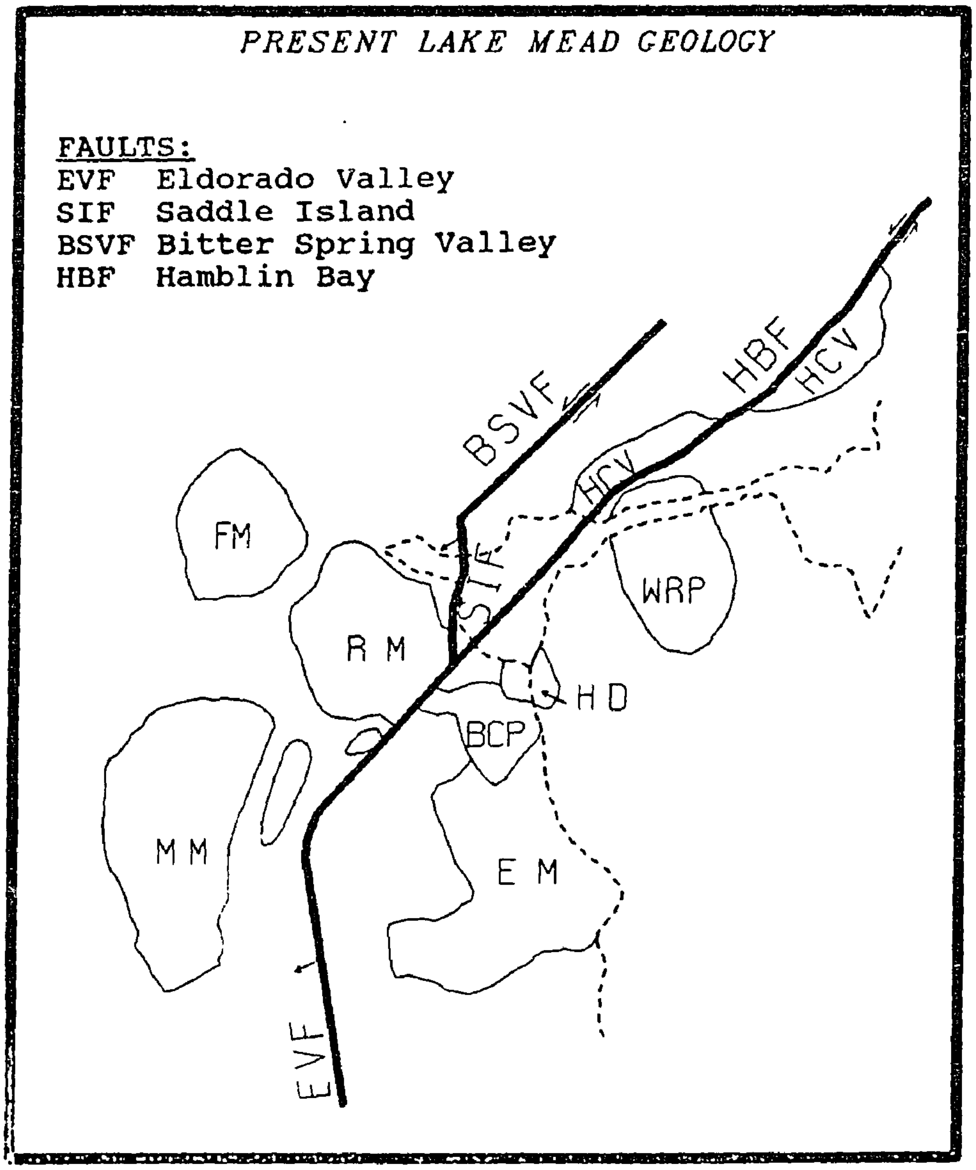


Figure 22. Normalized REE plot for granite from the plutonic exposures in the western Lake Mead area and the Muddy Creek Formation.



ROCK UNITS:
FM Frenchman Mtn
RM River Mtns
MM McCullough Mtns
EM Eldorado Mtns
BCP Boulder City Pluton
HD Hoover Dam Volcs.
WRP Wilson Ridge Pluton
HCV Hamblin Cleopatra
Volcano

Figure 23. Regional map showing possible sources for the volcanic and plutonic clasts found in the Muddy Creek Formation.

and River Mountain stock all have lower light rare-earth element contents than the Boulder City pluton (Fig. 21). The River Mountain stock is thought to be a part of the Wilson Ridge pluton that was displaced westward, along with the River Mountain volcanics by the Saddle Island detachment fault (Weber and Smith, 1987).

The trace elements hafnium (Hf), tantalum (Ta), and thorium (Th) were used previously to distinguish different volcanic and plutonic suites in the Lake Mead-Eldorado Valley area (Weber and Smith, 1987)(Fig. 24). The Hf-Ta-Th plot shows two groups; a high Ta group representative of volcanic rocks of the northern McCullough Mountains, Eldorado Mountains and the Boulder City Pluton, and a low Ta group representing volcanic rocks from the River Mountains, Hoover Dam area and Wilson Ridge pluton-River Mountain stock. The Muddy Creek igneous clasts plot in the low Ta group (Fig. 24).

The geochemical fingerprinting of the igneous clasts of the Muddy Creek Formation suggests that both the plutonic and volcanic clasts in the Muddy Creek Formation originated in the River Mountains-Hoover Dam area and the Wilson Ridge pluton/River Mountain stock.

Conclusion and discussion

All available evidence supports a source for the Muddy Creek sediments in the central or southern River Mountains.

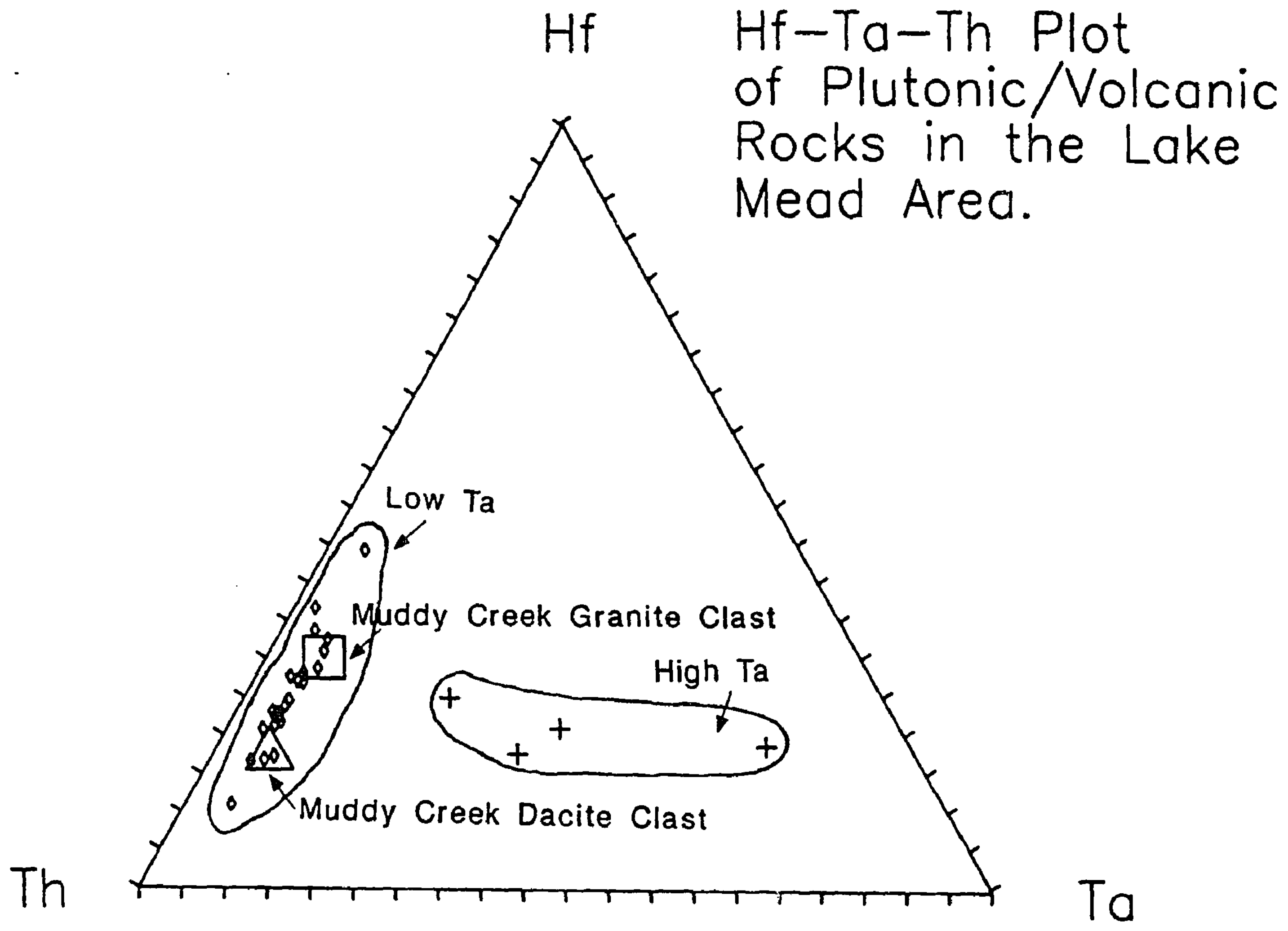


Figure 24. Hf-Th-Ta plot comparing the Tertiary volcanic rocks in the Lake Mead area (Weber and Smith, 1987). The Muddy Creek clasts plot in the low Ta group.

The River Mountain stock may have supplied the plutonic clasts to the Boulder Basin conglomerate.

At the time of deposition, a major stratovolcano occupied the southeastern River Mountains. The River Mountain Stock formed the core of this mid-Miocene stratovolcano (Smith 1979, 1981, 1982; Bell and Smith, 1980). The River Mountain Stock may have formed topographically high exposures during Muddy Creek time, and sediments derived from this high may have been shed as a thick clastic wedge to the northeast into the thesis area. If this model is correct then the Muddy Creek Formation may have covered much of the northeastern part of the River Mountains.

It is also possible that transport of plutonic clasts was constrained by northeast-trending, fault-bounded valleys that formed soon after the construction of the stratovolcano (Smith, 1982)(Fig. 25). These valleys may have channeled sediments to the north. Since there is no Muddy Creek sediment exposed between the thesis area and the stock, a unique transportation path cannot be determined.

Figure 25. Map of the field area showing geometry of the faults and valleys in the River Mountains today and the distribution of the granite clasts.

DEPOSITIONAL MODEL

Based on the data gathered for this study, a four phase depositional model is proposed for the Muddy Creek Formation in the northwestern Lake Mead area (Fig. 26). Phase I represents the depositional period of the River Mountain conglomerate (Fig. 26). Alluvial fans were shed from the west and northwest, forming the River Mountain conglomerate along the basin margin. The primary mechanism of transport was hyperconcentrated flood flow or sheetflooding. Growth faults in the River Mountain conglomerate suggests that during this depositional period, the area was undergoing active extension along east-dipping, high-angle normal faults that trend northwest-southeast. These faults cut the River Mountain volcanics and the River Mountain sediments and rotate beds to the west. Rotation of the bedrock by these faults resulted in the formation of half-grabens that controlled the location of basin margins. As shown by the paleocurrent indicators in the River Mountain conglomerate (page 69), sediment was transported southeast along the axes of the half-grabens instead of eastward into the basin. This phase may also coincide with the deposition of The Cliffs member in the central part of the basin.

In Phase II extension remained active, however the area was undergoing erosion instead of deposition (Fig. 26). Uplift occurring simultaneously with the extension may have lifted the area above base level causing erosion of the volcanic pile and cannibalization of the River Mountain

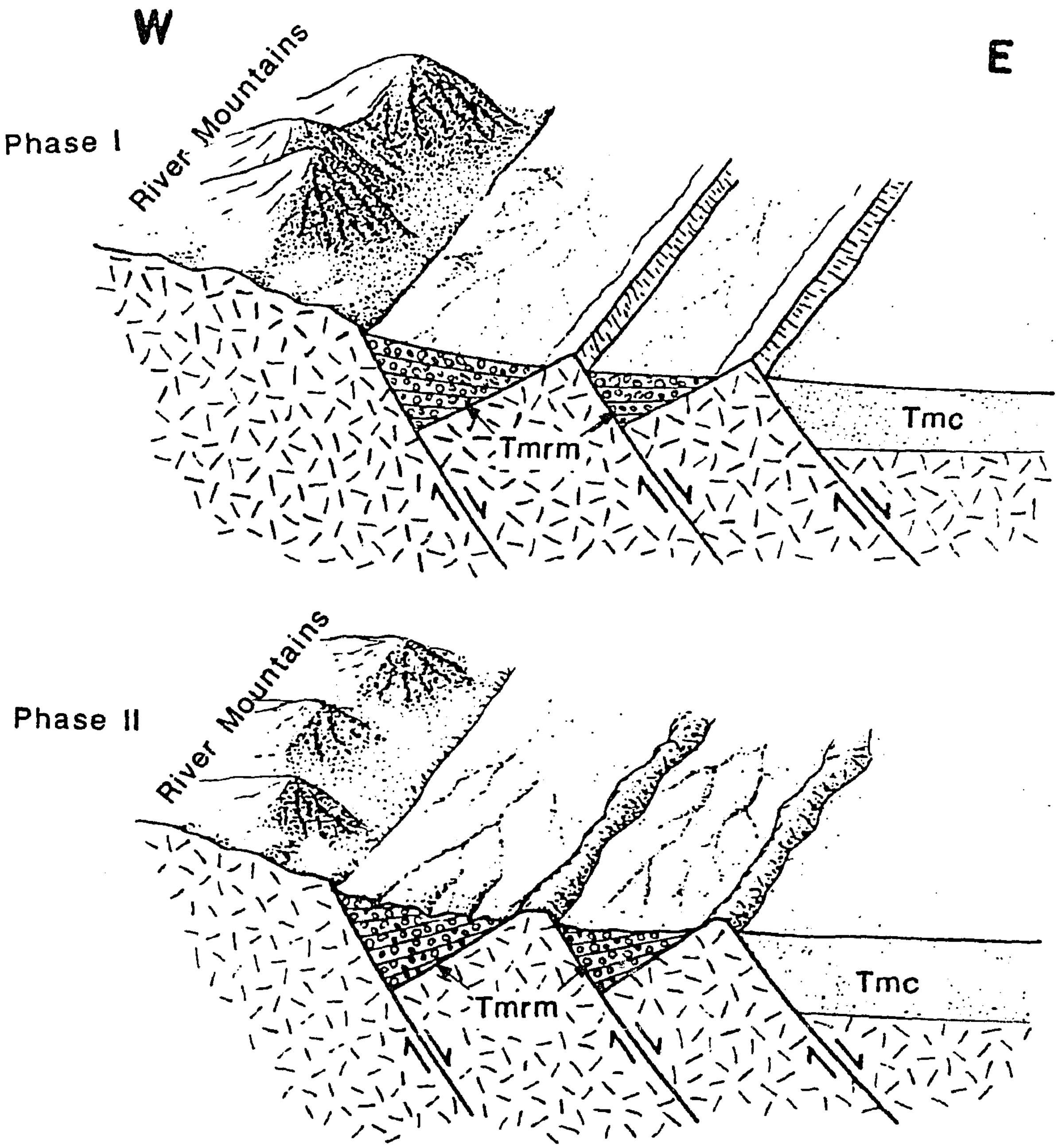
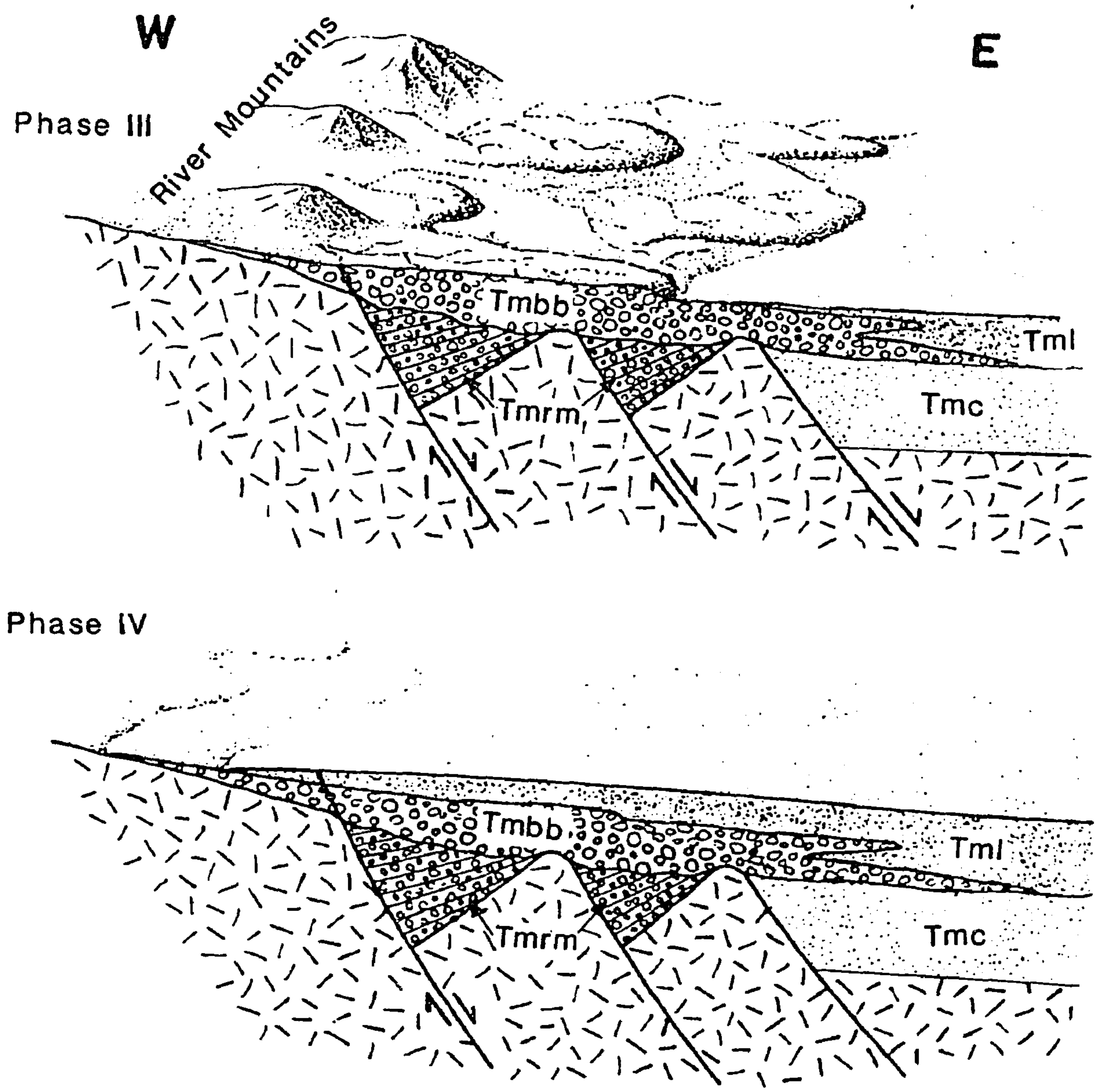


Figure 26. Depositional model for the Muddy Creek Formation. Phase I. Depositional period of the River Mountain conglomerate (Tmrm) and The Cliffs (?)(Tmc) member in an east-west extensional regime. Phase II. Erosion and continued extension and rotation of the River Mountain conglomerate beds.



Phase III. Deposition of the Boulder Basin conglomerate (Tmbb) and the Lakeshore (Tml) member during at the end of extension. Phase IV. Continued deposition of the Lakeshore member.

conglomerate. Continued activity along the high-angle normal faults rotated the River Mountain conglomerate beds further to the west, truncating the beds by erosion at the surface.

Phase III represents the depositional period of the Boulder Basin conglomerate (Fig. 26). The Boulder Basin conglomerate was unconformably deposited on the volcanic rocks of the River Mountains, and the River Mountain conglomerate. This phase coincided with the end of tectonic extension because most faults die out in the lower parts of the Boulder Basin conglomerate (page 63). The coarse-grained sediments were no longer restricted to half-grabens at the basin margins and were able to prograde eastward into the basin. This eastward movement is demonstrated by the paleocurrent indicators, the distribution of the granite clasts in the Boulder Basin conglomerate, and the distribution of the sediment sizes in the Boulder Basin conglomerate and the Lakeshore member (pages 69 and 71). These sediments were transported as sheetfloods and hyperconcentrated floods on alluvial fans. The interfingering and transitional nature of the contact between the Boulder Basin conglomerate and the Lakeshore member suggests that deposition of the Lakeshore member as lacustrine sediments in the central part of the basin was coeval with the deposition of the Boulder Basin conglomerate.

Deposition continued during Phase IV, however the volcanic highlands may have been considerably denuded by this time (Fig. 26). As the River Mountain volcanics were eroded closer to base level, sediment transport rates and production of coarse-grained sediments were decreased; thus fine-grained sediments (the Lakeshore member) were deposited adjacent to basin margins and prograded westward to cover the Boulder Basin conglomerates.

CONCLUSIONS

(1) Clasts in the Muddy Creek conglomerates on the west shore of Lake Mead are volcanic and plutonic rocks that were derived from the River Mountains to the southwest and west. Clasts of granite and quartz monzonite were derived from the River Mountain Stock southwest of the thesis area.

(2) The Muddy Creek Formation consists of alluvial fan and lacustrine sediments that were deposited in internally drained closed basins. The River Mountain conglomerate was deposited as a series of distal alluvial fan deposits by sheetflooding and hyperconcentrated flooding during active extension. The Cliffs member may have been deposited as a section of playa sediments at the same time. The Boulder Basin conglomerate was deposited by hyperconcentrated flood flow and sheetflooding after extension ceased. The Lakeshore member was deposited as lacustrine deposits coevally with the Boulder Basin conglomerate.

(3) The Muddy Creek Formation was deposited during the waning stages of mid-Tertiary structural deformation expressed by extensional features in the River Mountains. The Muddy Creek sediments reflect this extension by growth faulting and decreased rotation of tilted strata upsection.

MALPAIS FLATTOP-GALE HILLS

In order to gain a regional overview of the Muddy Creek Formation, sedimentologic studies were conducted at Malpais Flattop and in the Gale Hills (Figs. 27 and 28). These areas were studied in order to locate basin margins, and to compare depositional environments for the Muddy Creek Formation over a wider area than is exposed in the River Mountain area

Malpais Flattop

The Malpais Flattop section of the Muddy Creek Formation is located between Malpais Flattop and the Colorado River (Fig. 27). Here, the Muddy Creek Formation lies unconformably on Mount Davis volcanics (12-15 Ma) and is overlain by and interbedded with Fortification Hill Basalt (6 Ma)(Fig 28). The section is about 762 m thick and appears to lack major unconformities. Beds in the lower part of the section dip between 35 and 25 degrees east and decrease to between 10 and 15 degrees east at the top of the section.

The Muddy Creek conglomerate at Malpais Flattop contains Precambrian metamorphic and Tertiary volcanic clasts. Clasts of Precambrian rock are mainly gneiss and schist; phyllite and pegmatite are subordinate. Volcanic clasts are mainly andesite of probable Mount Davis age.

A measured section of the Muddy Creek Formation at Malpais Flattop is shown in Figure 28. Conglomerates are

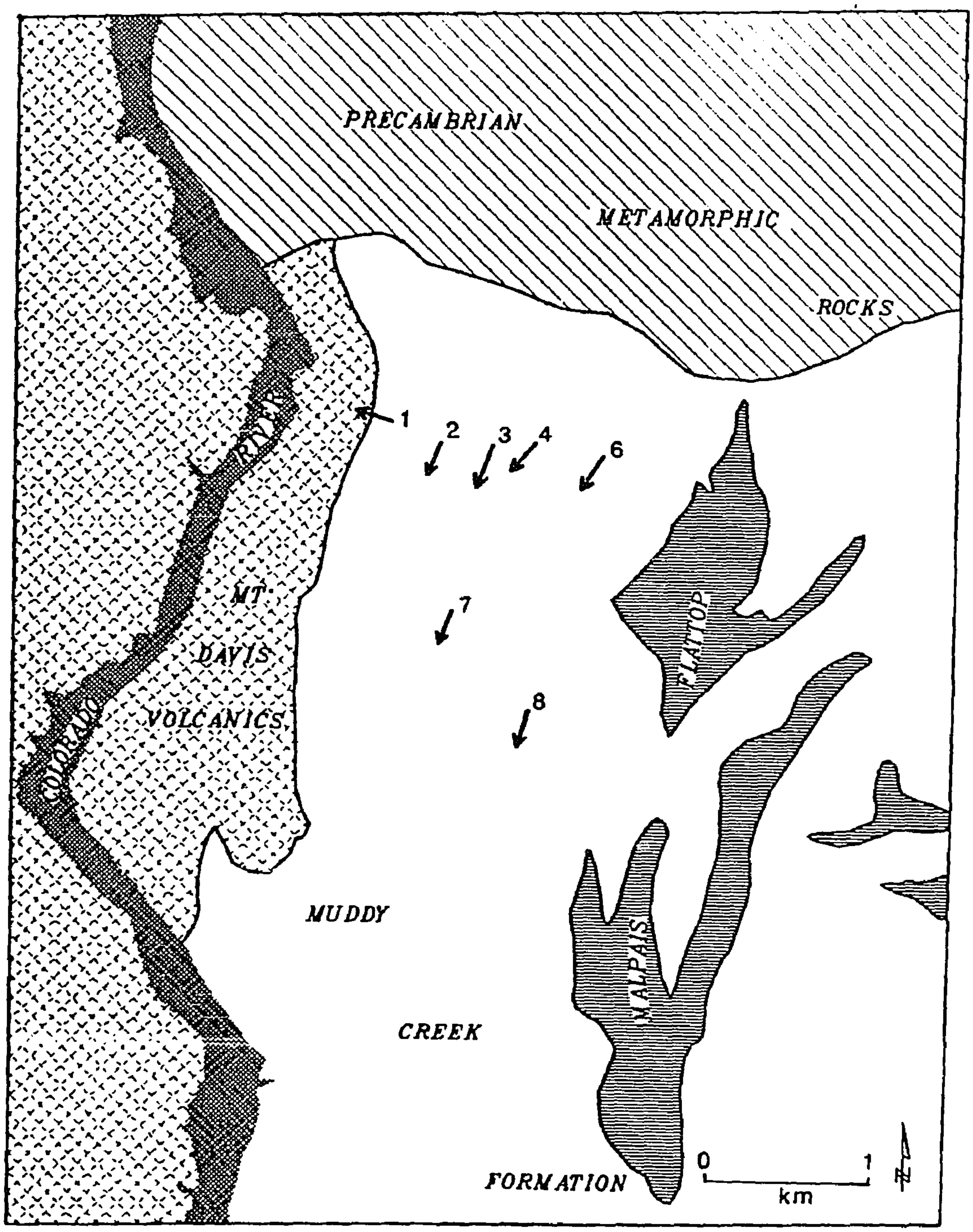


Figure 27. Location map of Malpais Flattop and paleocurrent data (see Fig. 1 for regional location). The actual rose diagrams are in Appendix A. ▤ is basalt.

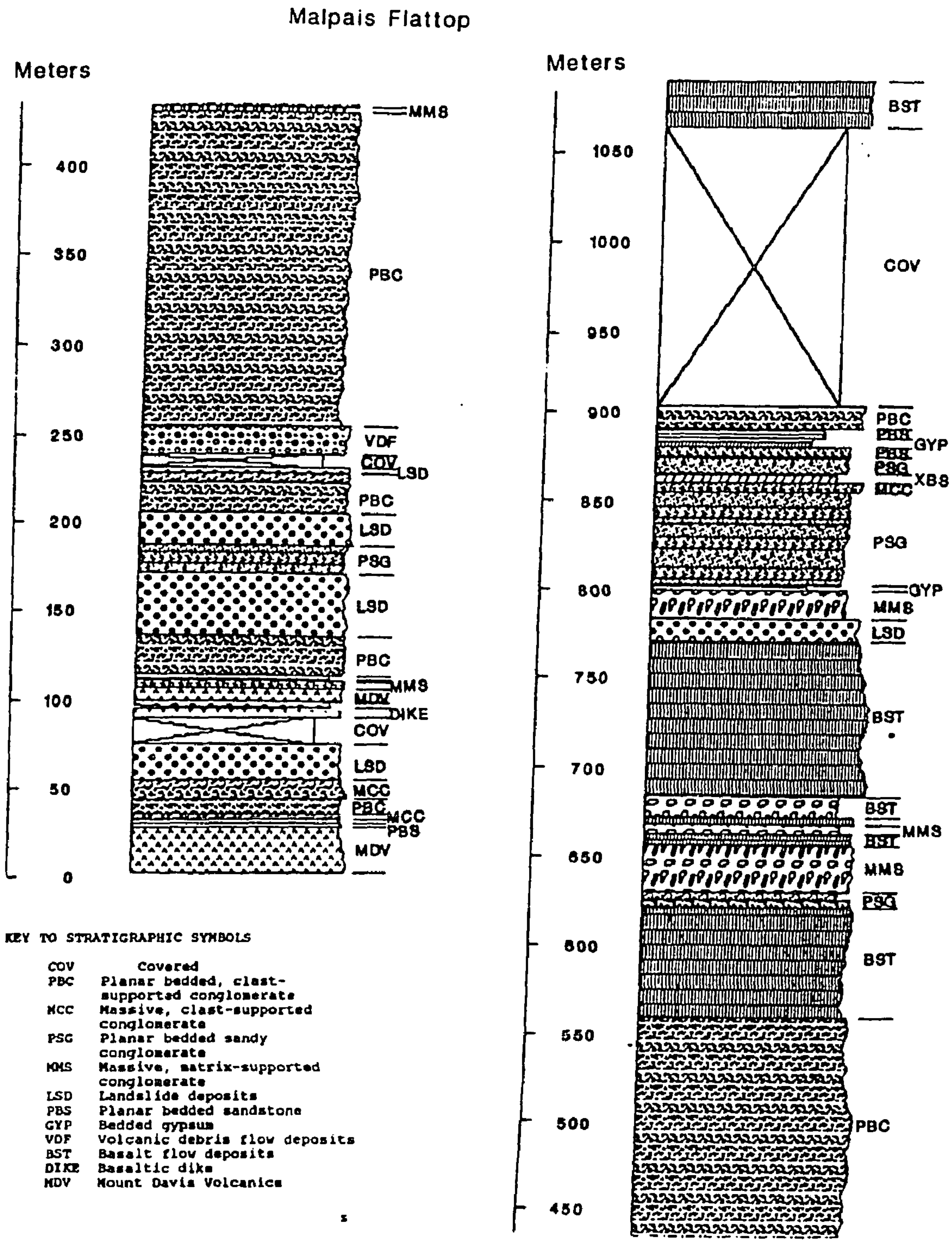


Figure 28. Stratigraphic section of the Muddy Creek Formation measured at Malpais Flattop.

predominantly clast-supported, massive, or planar-bedded and interbedded with megabreccia. Matrix-supported conglomerates are common, but not dominant. Tabular or wedge-shaped bedding is common. Megabreccia is monolithologic, consisting of Precambrian gneissic clasts and rarely volcanic clasts. Longwell (1963), and Anderson (1978a) interpreted the megabreccia as a landslide deposit.

The upper part of the Muddy Creek section is interbedded with three basalt flows that range in thickness from 25 to 100 m and exhibit baked contacts with the underlying sedimentary units. The lower part of the Muddy Creek section is cut by a dike that trends N35W and varies in width from about 2 to 10 m. This dike may be a feeder for basalt on Malpais Flattop Mesa (Feuerbach, 1987, personal communication).

Near the top of the section is sandstone interbedded with a few thin (10 cm) beds of gypsum. Sandstone is primarily massive, thinly bedded (10-30 cm thick), and frequently contains lenses of gravel with boulders greater than 50 cm.

Comparison of Malpais Flattop section with the River Mountain section

The major differences between Muddy Creek deposits at Malpais Flattop and the River Mountain area are: (1) lack of ash beds in the section at Malpais Flattop, (2) the presence of landslide deposits at Malpais Flattop, and (3) differences in depositional models (see below).

The vertical section in the River Mountains displays a change from a basal, distal alluvial fan facies (River Mountain conglomerate) to a proximal facies (Boulder Basin conglomerate) overlain by a playa facies (Lakeshore member). This sequence suggests a period of tectonic disturbance followed by a period of quiescence. The sequence in the Malpais field area gradually fines upward, from a proximal facies to a distal facies (both with interbedded basalt flows) and finally to a playa facies. This sequence is overlain by a coarsening upward sequence that is capped by basalt flows. Beds in the lower section are rotated more than beds in the upper section. Applying a model similar to the one used in the River Mountains area would suggest that during the most active structural period, coarse-grained material is deposited along basin margins and fine-grained sediments are deposited in the interior of the basin. As tectonic activity ceased, coarser sediments are no longer constrained to the basin margins and prograded into the basin, depositing coarse alluvial sediments on top of the fine-grained sediments of the basin interior.

Gale Hills Area

The Gale Hills are north of Lake Mead about 8 km north of Callville Bay Marina (Fig. 29). The Muddy Creek Formation in this area which is at least 40 m thick, unconformably overlies the Thumb Member of the Horse Spring Formation (Bohannon, 1984).

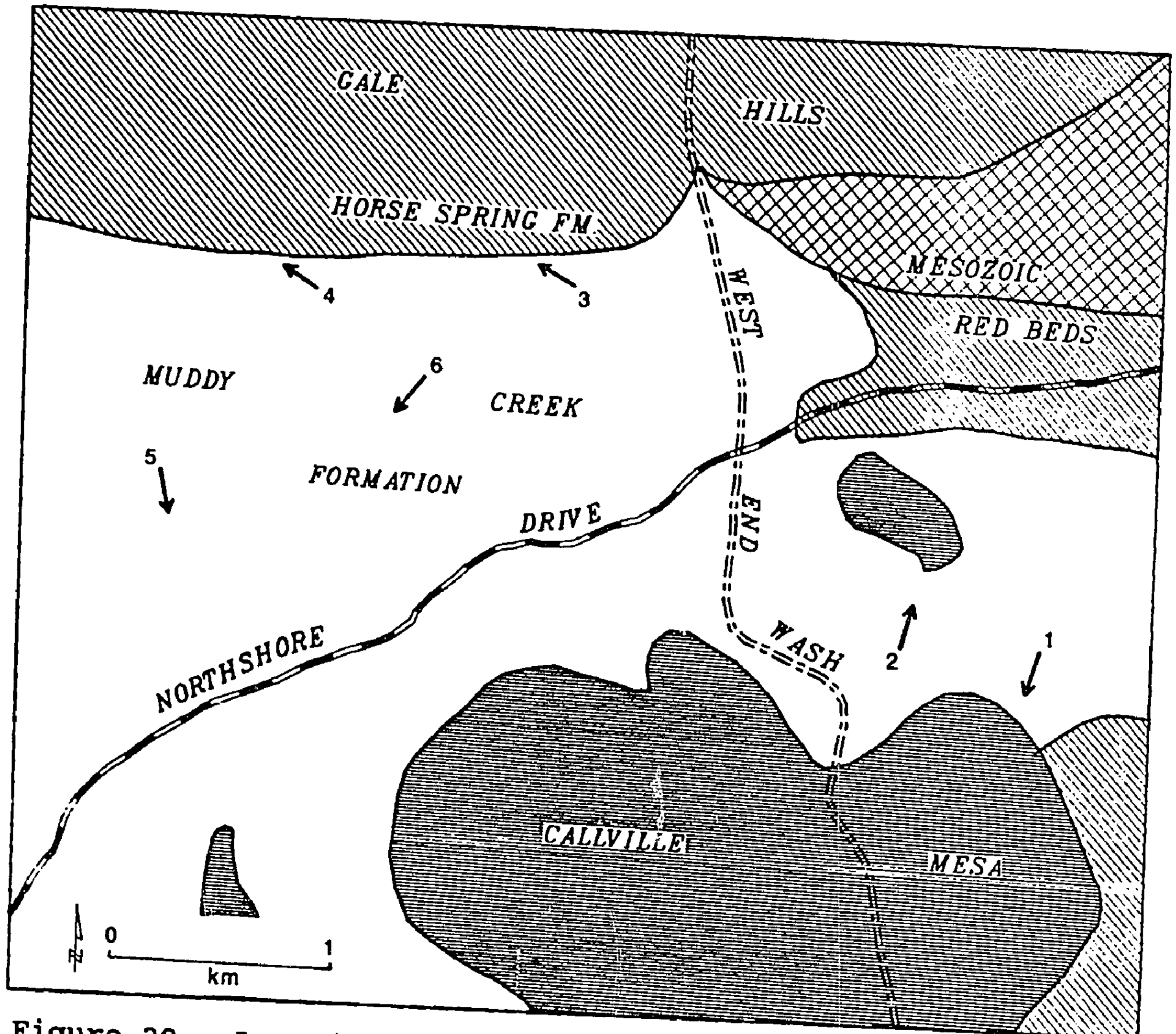
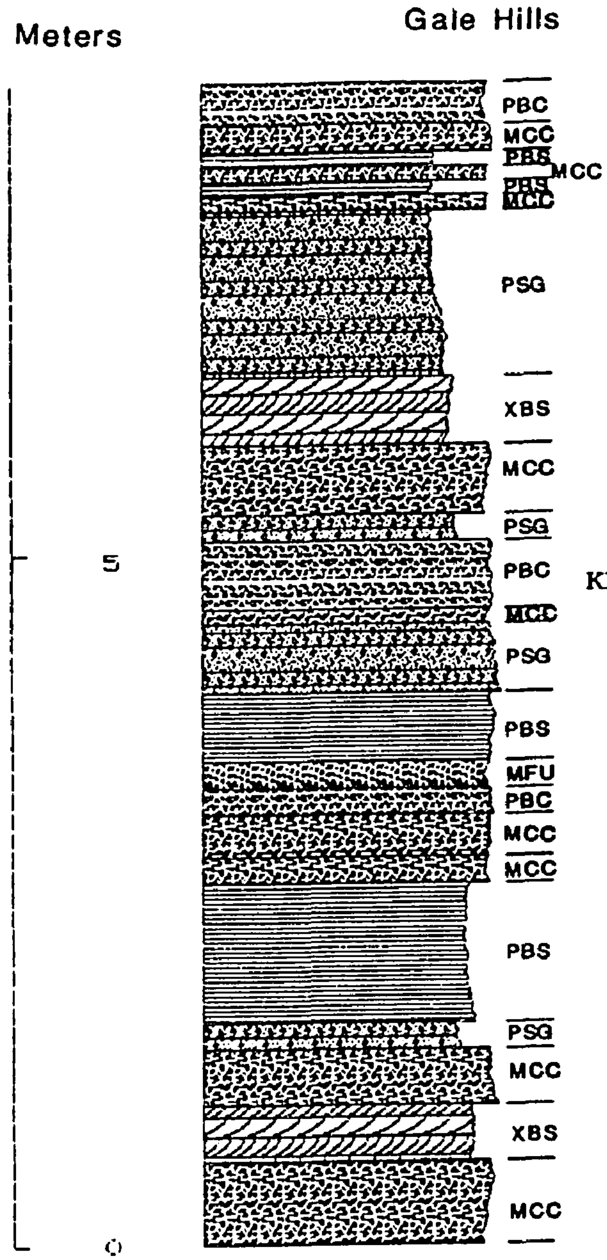


Figure 29. Location map for the Gale Hills and paleocurrent data (see Fig. 1 for regional location). The actual rose diagrams are in Appendix A. [basalt pattern] is basalt.

Clasts in the Gale Hills area are subrounded to subangular. They average 3 cm in diameter but are as large as 30 cm. Clasts are about 45 percent Paleozoic and Tertiary carbonate, 25 percent volcanics (andesites and dacites, with some basalt), 25 percent sandstone resembling Tertiary redbeds or possibly Jurassic Aztec Sandstone, and 5 percent Precambrian metamorphic clasts.

A measured stratigraphic section is shown in Figure 30. Conglomerates are well lithified, moderately sorted, clast supported, and massive. Clasts are small, (2-4 cm) and sub-rounded to sub-angular. Beds are 10-20 cm thick, tabular or wedge shaped in outcrop, and are interbedded with thin beds of silty sandstone. Sandstone beds are massive or planar bedded. Desiccation cracks and channel deposits are rare.

The Muddy Creek sediments at Gale Hills are very similar to the sediments of the River Mountain conglomerate member of the Muddy Creek Formation in the River Mountain field area. These sediments are also interpreted as mid- to distal- alluvial fan sediments. Sheet floods and hyperconcentrated floods were probably the main mode of sediment transport as is evidenced by the thin, tabular, unchannelized nature of the beds; massive, moderately sorted, clast supported conglomerates; and the planar sandstone beds.



KEY TO STRATIGRAPHIC SYMBOLS

PBC	Planar bedded, clast-supported conglomerate
MCC	Massive, clast-supported conglomerate
MFU	Massive, fining-upward conglomerate
PSG	Planar bedded sandy conglomerate
PBS	Planar bedded sandstone
XBS	Cross-bedded sandstone

Figure 30. Stratigraphic section of the Muddy Creek Formation measured in the Gale Hills.

Comparison of the Gale Hills section with the River Mountain section.

The major differences between the Muddy Creek conglomerate in Gale Hills and River Mountains are: (1) Ash layers are lacking in the Muddy Creek conglomerates in Gale Hills. (2) Matrix supported debris flow deposits are not present in the Gale Hills. (3) The clasts in the Muddy Creek Formation in the Gale Hills are more rounded than the clasts in the River Mountains. (4) Generally, there are no upsection lithological changes recorded in the Gale Hills section. Conglomerates in the Gale Hills field area record the formation of sheet-flood deposits on the distal portions of alluvial fans. (5) No unconformities were observed within the Muddy Creek Formation itself. There is no evidence of syndepositional tectonism and no large displacement faults cut the conglomerates.

Sediment Transport Direction

Clast imbrication measurements were made at seven stations at Malpais Flattop and at six stations in the Gale Hills. Clast imbrication measurements are shown in Figures 27 and 29.

In the Malpais Flattop area the vector means of the clast imbrication range from N80W to due south, with a grand vector mean of S28W. Although the measurements are widely dispersed they indicate that the source area for the sediments was generally to the northeast.

In the Gale Hills the vector means for the sediment transport range from S11E to N58W. The vector means for the paleocurrent data in the Gale Hills is more dispersed than the vector means for the paleocurrent data at Malpais Flattop. The grand vector mean of all stations is S47W, suggesting a possible source to the northeast.

Interpretation of sediment transport data

The transport vectors in the Gale Hills and the River Mountains point in opposite directions (Fig. 31). This pattern may suggest that a single basin, 20 km wide, or several smaller basins may have existed between the River Mountains and the Muddy Mountains. The Callville Mesa volcano, a 10 Ma basaltic center (Feuerbach, 1988, personal communication), lies lies between the Gale Hills and the River Mountains and may have affected sediment dispersal of the Muddy Creek Formation.

Tectonic Implications

The two models presented here represent endpoints of a continuum of tectonic models that are supported by the data above. A more accurate depiction of the tectonic regime would probably combine elements of both models.

Model 1 is based on the assumption that the sediments in each area represent the same depositional period (Fig. 32). During this period, a variety of depositional styles is recorded in the three areas. Sedimentation in each of

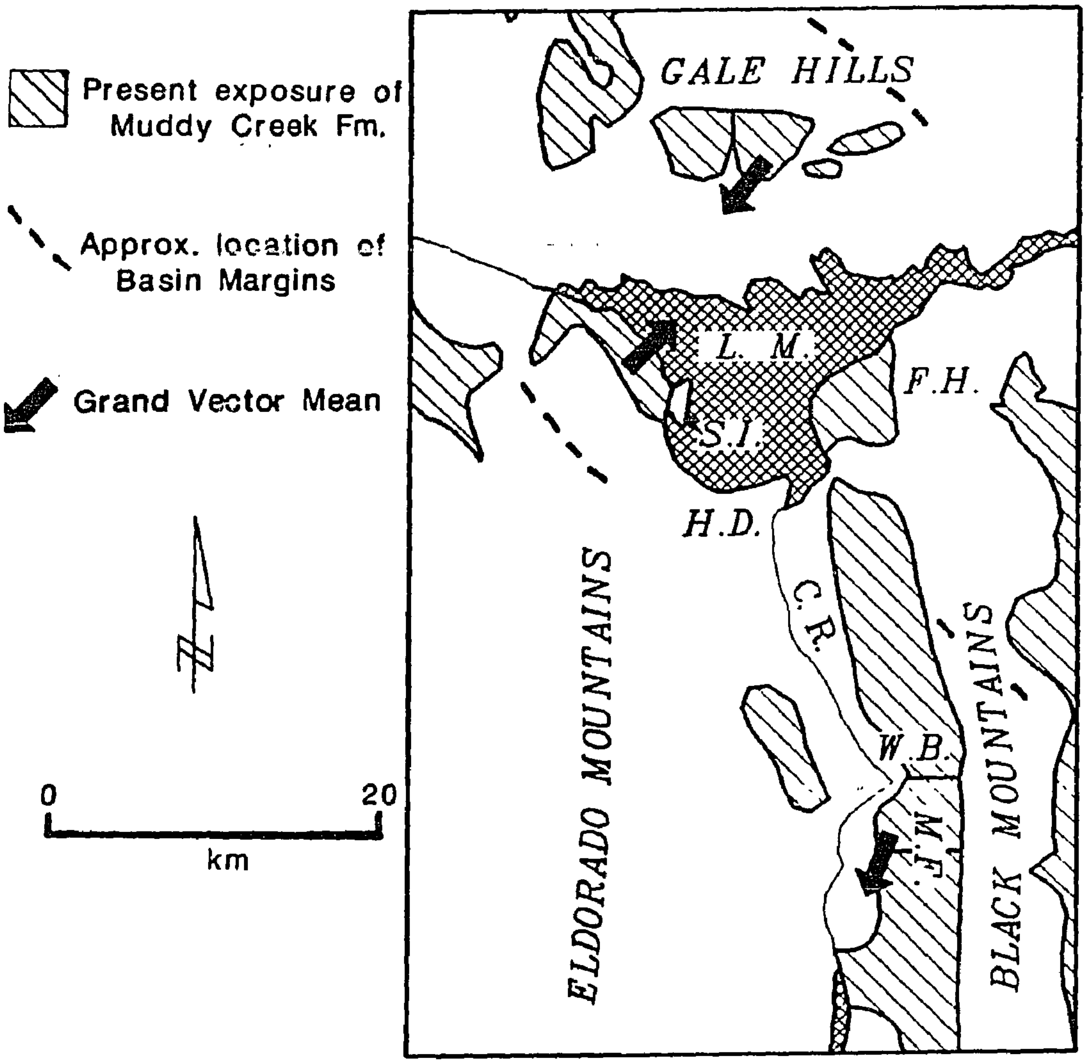


Figure 31. Regional map showing grand vector means for the paleocurrent data for the three field areas and the approximate location of possible basin margins.

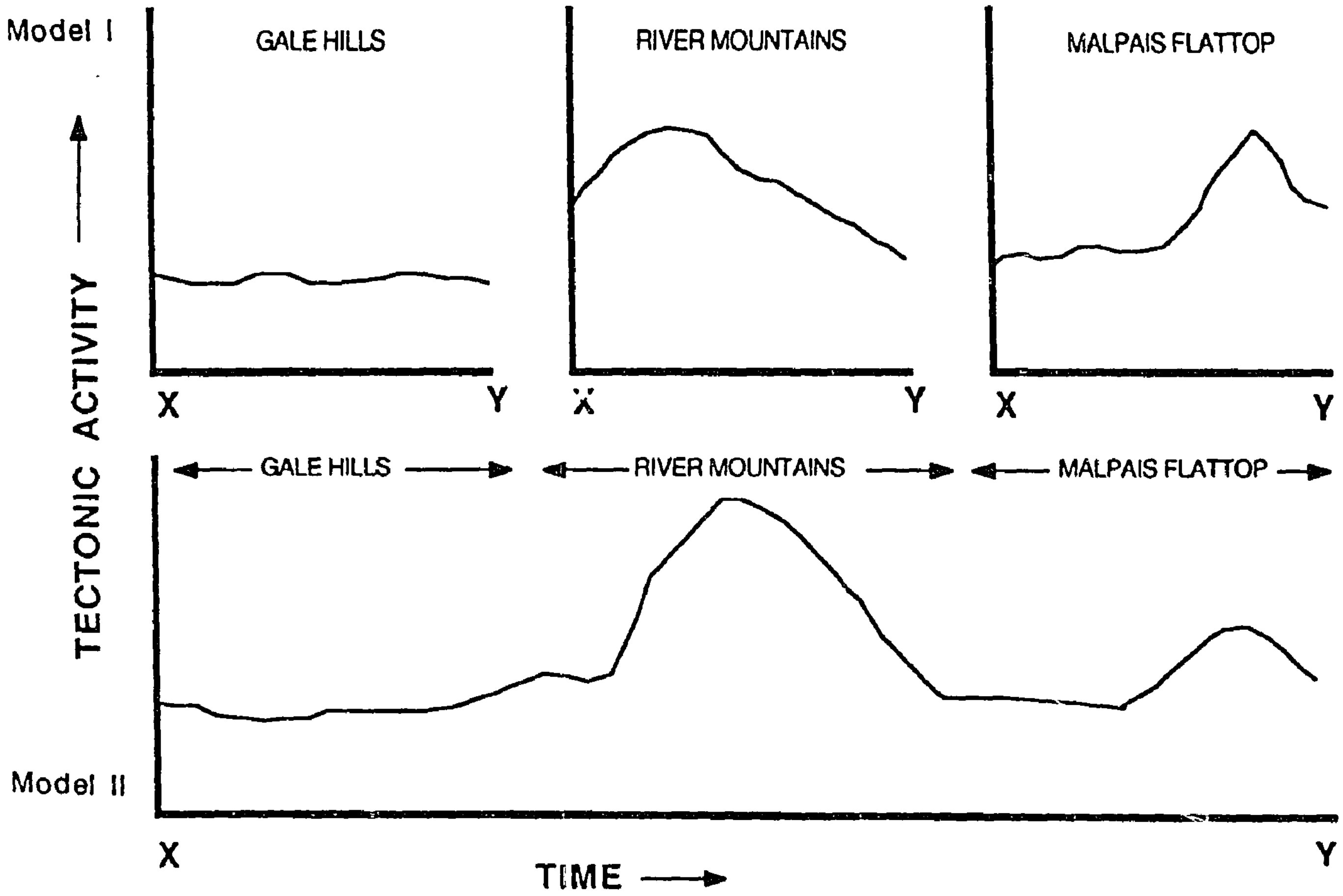


Figure 32. Graphical representation of the two models discussed. Model I shows the tectonic "intensity" in each area if all the sediments represented the same time period. Model II shows how the intensity of regional tectonic activity could influence depostion in each area if deposition in the three areas was not coeveal. X and Y represent equal ammounts of time in each model.

the areas was locally controlled. Regional structures were inactive; tectonism was sporadic and locally influenced Muddy Creek deposition in each of the areas.

Model 2 would represent the opposite situation. Sediments in each of the areas represent distinctly different periods of time during the deposition of the Muddy Creek Formation (Fig. 32). The depositional history recorded in the sediments in each area represent a "snapshot" of time. Faults may be of regional significance yet evidence of faulting may not be recorded in the sediments of each basin.

FUTURE WORK

Further work on the Muddy Creek Formation should include the following:

(1) Age-dating of the ash horizons in the Muddy Creek Formation. This study will help to determine the timing of the termination of Tertiary extension.

(2) Additional sedimentological and provenance data should be collected from other areas where the Muddy Creek Formation is exposed. This data may provide a clearer picture of the paleogeography and tectonic history during the deposition of the Muddy Creek Formation.

(3) Faults in the Muddy Creek Formation could be studied in detail to determine the influence regional structures (such as the Lake Mead Fault Zone and the Las Vegas Valley Shear Zone) had on the deposition of the Muddy Creek Formation and, because the Muddy Creek Formation can be precisely dated, to determine the time of movement on these major regional geologic structures.

REFERENCES:

Allen, J. R. L., 1986, Earthquake magnitude-frequency, epicentral distance, and soft-sediment deformation in sedimentary basins: Sedimentary Geology, v. 46, p. 67-75.

Anderson, R. E., 1978a, Geologic map of the Black Canyon 15-minute quadrangle, Clark County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1395.

______, 1978b, Chemistry of Tertiary volcanic rocks in the Eldorado Mountains, Clark County, Nevada, and comparisons with rocks from some nearby areas: U. S. Geological Survey Journal of Research, v.6 p. 409-424.

Anderson, R. E., Longwell, C. R., Armstrong, R. L., and Marvin, R. F., 1972, Significance of K-Ar ages of Tertiary rocks from the Lake Mead region, Nevada-Arizona: Geological Society of America Bulletin, v. 83, p. 273-288.

Arguden, A. T., and Rodolfo, K. S., 1986, Sedimentary facies and tectonic implications of Lower Mesozoic alluvial-fan conglomerates of the Newark Basin, Northeastern United States: Sedimentary Geology, v. 51, p. 97-118, .

Bacon, C. R., MacDonald, R., Smith, R. L., and Baedecker, P. A., 1982, Pleistocene high-silica rhyolites of the Coso volcanic field, Inyo County, California: Journal of Geophysical Research, v. 87, p. 2045-2056.

Bell, J. W., and Smith, E. I., 1980, Geological map of the Henderson Quadrangle, Clark County, Nevada: Nevada Bureau of Mines and Geology Map 67.

Billings, M. P., 1972, Structural Geology: Englewood Cliffs, New Jersey, Prentice-Hall, 606 p.

Blair, T. C., 1987, Sedimentary processes, vertical stratification sequences, and geomorphology of the Roaring River alluvial fan, Rocky Mountain National Park, Colorado: Journal of Sedimentary Petrology, v. 57, p. 1-18

Blair, W. N., 1978, Gulf of California in the Lake Mead area of Arizona and Nevada during late Miocene time: American Association of Petroleum Geologists Bulletin, v. 62, p. 1159-1170.

Blair, W. N., Bradbury, J. P., and Oscarson, R. L., 1979, Upper Miocene Hualapai Limestone member from the proto-Gulf of California at Lake Mead, Arizona, in Newman, G. W., and Goode, H. D., eds., Basin and Range symposium and Great Basin field conference: Rocky Mountain Association of Geologists Guidebook 1979, p. 285-292.

Blair, W. N., McKee, E. H., and Armstrong, A. K., 1977, Age and environment of deposition--Hualapai Limestone Member of the Muddy Creek Formation (abs.): Geological Society of America Abstracts with Programs, v. 9, p. 390-391.

Bohannon, R. G., 1984, Nonmarine sedimentary rocks of Tertiary age in the Lake Mead region, southeastern Nevada and northwestern Arizona: U.S. Geological Survey Professional Paper 1259, 72p.

Bradbury, J. P., and Blair, W. N., 1979, Paleoecology of the Upper Miocene Hualapai Limestone member of the Muddy Creek Formation, north western Arizona, in Mewman, G. W., and Goode. H. D, eds., Basin and Range symposium and Great Basin field conference: Denver Rocky Mountain Association of Geologists Guidebook 1979, p. 293-303.

Bull, W. B., 1972, Recognition of alluvial-fan deposits in the stratigraphic record, in Rigby, K. J., and Hamblin, W. K., eds., Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralolgists Special Publication 16, P. 63-83.

Choukroune, P., and Smith, E. I., 1985, Detachment faulting and its relationship to older structural events on Saddle Island, River Mountains, Clark County, Nevada: Geology, V. 13, p. 421-424.

Crans, W., Mandl, G., Harembourne, J., 1980, On the theory of growth faulting: A geomechanical delta model based on gravity sliding: Journal of Petroleum Geology, v. 2, p. 265-307.

Cullers, R. L., Koch, R. J., and Bickford, M. C., 1981, Chemical evolution of magmas in the Proterozoic terrane of the St. Francois Mountains, southeastern Missouri 2. Trace element data: Journal of Geophysical Research, v. 86, p. 10388-10401.

Damon P. E., Shafiquillah, M., and Scarborough, R. B., 1978, Revised chronology for critical stages in the evolution of the lower Colorado River: Geological Society of America Abstracts with Programs, v. 10, p. 101-102.

DeCelles, P. G., Tolson, R. B., Graham, S. A., Smith, G. A., Ingersoll, R. V., White, J., Schmidt, C. J., Rice, R., Moson, I., Lemke, L. Handschy, J. W., Follow, M. F., Edwards, D. P., Cavazza, W., Caldwell, M., and Bargar, E., 1987, Laramide thrust generated alluvial-fan sedimentation, Sphinx Conglomerate, southwest Montana: American Association of Petroleum Geologists Bulletin, v. 71, p. 135-155.

Dott, R. H. Jr., and Bourgeois, J., 1982, Hummocky stratification: Significance of its variable bedding sequences: Geological Society of America Bulletin, v. 93, p. 663-680.

Dubendorfer, E. M., Sewall, A. J., and Smith, E. I., 1988, Kinematic interpretation of lower-plate mylonites, Saddle Island detachment complex, Lake Mead, Nevada: Geological Society of America Abstracts with Programs, v. 20, p. 157.

Elmore, R. D., 1984, The Copper Harbor Conglomerate: a late Precambrian fining-upward alluvial fan sequence in northern Michigan: Geological Society of America Bulletin, v. 95, p. 610-617.

Frost, E. G., 1979, Growth-fault character of Tertiary detachment faulting, Whipple Mountains, southeastern California, and Buckskin Mountains, western Arizona: Geological Society of America Abstracts with Programs, v. 13, p. 57.

Hansen, W. R., 1966, Effects of the earthquake of March 27, 1964 at Anchorage, Alaska U.S. Geological Survey Professional Paper 542-A 68 p.

Hardie, L. A., Smoot, J. P., and Eugster, H. P., 1978, Saline lakes and their deposits: a sedimentological approach, in Matter, A., and Tucker, M. E., eds., Modern and Ancient Lake Sediments: International Association of Sedimentologists Special Publication 2, p. 7-42.

Haskin, L. A., Haskin, M. A., and Frey, F. A., 1968, Relative and absolute terrestrial abundances of the rare earths, in Aherns, L. H., ed., Origin and Distribution of the Elements: Oxford, Pergamon, p. 889-912.

Hildreth, w., 1981, Gradients in silicic magma chambers: implications for lithospheric magmatism: Journal of Geophysical Research, v. 85, p. 10153-10192.

Hildreth, W., and Mahood, G., 1985 Correlation of ash-flow tuffs: Geological Society of America Bulletin, v. 96, p. 968-974.

Housner, G. W., 1985, Liquefaction of Soils During Earthquakes: document prepared by Committee on earthquake engineering, Commission on engineering and technical systems, Washington, D. C., National Research Council National Academy Press, 240 p.

Howell, D. G., and Link, M. H., 1979, Eocene conglomerate sedimentology and basin analysis, San Diego and the southern California borderland: Journal of Sedimentary Petrology, v. 49, p. 517-540.

Izett, G. A., 1981, Volcanic ash beds: Recorders of upper Cenozoic silicic pyroclastic volcanos in the western United States: Journal of Geophysical Research, v. 86, p. 10200-10222.

Longwell, C. R., 1928, Geology of the Muddy Mountains, Nevada with a section through the Grand Wash Cliffs in western Arizona: American Journal of Science, 5th Series, v. 1, P. 39-62.

_____ 1936, Geology of the Boulder reservoir floor, Arizona-Nevada: Geological Society of America Bulletin, v. 47, p. 1393-1476.

_____ 1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada: U.S. Geological Survey Professional Paper 374-E, 51 p.

Longwell, C. R., Pampeyan, E. H., Bower, B., and Roberts, R. J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines Bulletin 62, 218p.

Lucchitta, I., 1972, Early history of the Colorado River in the Basin and Range Province: Geological Society of America Bulletin, v. 83, p. 1933-1948.

Mahood, G. A., 1981, Gradients in Silicic magma chambers: Implications for lithospheric magmatism: Journal of Geophysical Research, v. 86, p. 10153-10192.

McLennan, A. M., and Taylor, S. R., 1984, Archaean sedimentary rocks and their relation to the composition of the Archaean continental crust, in Kroner, A., Hanson, G. H., and Goodwin, A. M., eds., Archaean Geochemistry: Berlin, Springer-Verlag, 286 p.

Miall, A. D., 1970, Devonian alluvial fans, Prince of Wales Island, Arctic Canada: Journal of Sedimentary Petrology v. 40, p. 556-571.

_____ 1977, A review of the braided river depositional environment: Earth Science Review, v. 13, p. 1-62.

_____ 1978, Lithofacies types and vertical profile models in braided river deposits; a summary, in Miall, A. D., ed., Fluvial Sedimentology: Canadian Society of Petroleum Geologists., Memoir 5, p. 597 -604.

_____ 1984, Principles of sedimentary basin analysis: New York, Springer-Verlag, 490 p.

_____ 1985, Architectural-element analysis: a new method of facies analysis applied to fluvial deposits: Earth-Science Review, v. 22, p. 261-308.

Mills, C. P., 1983, Genesis and diagnostic value of soft-sediment deformation structures-a review: Sedimentary Geology, v.35, p. 83-104.

Nilsen, T. H., 1982, Alluvial fan deposits, in Scholle, P. A., and Spearing, Darwin eds., Sandstone Depositional Environments: Memoir of the American Association of Petroleum Geologists, v. 31, p. 49-86.

Obermeier, S. F., Gohn, G. S., Weems, R. E., Gelinas, R. L., and Rubin, M., 1985, Geologic evidence for recurrent moderate to large earthquakes near Charleston, South Carolina: Science, v. 227, p. 408-440.

Potter, P. E., and Pettijohn, F. J., 1977, Paleocurrents and Basin Analysis: New York, Springer-Verlag, 425p.

Picard, D. M., and High, L. R. Jr., 1981, Criteria for recognizing lacustrine rocks, in Ethridge, F. G., and Flores, R. M., eds., Recent and Ancient Nonmarine Depositional Environments: Models for Exploration: Society of Economic Paleontologists and Mineralogists Special Publication No 31, p. 108-145.

Pridemore, C. L., and Craig C., 1982 Upper-plate structure and sedimentation of the Baker Peaks area, Yuma County, Arizona, in Frost, E. G., and Martin, D. L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada, San Diego: Cordilleran Publishers, p. 357-375.

Proffett, J. M., 1977, Cenozoic geology of the Yerington district, Nevada and implications for the nature and origin of Basin and Range faulting: Geological Society of America Bulletin v. 88, p. 247-266.

Rapp, G., Jr., 1985, The provenance of artifactual raw materials, in, Rapp, G., Jr, and Gifford, J. A., eds., Archaeological Geology, Yale University Press, p. 353-375.

Robertson, A. H. F., 1986, Geochemical evidence for the origin of Late Triassic melange units in the Oman Mountains as a small ocean basin formed by continental rifting: Earth and Planetary Science Newsletters v. 77, p. 318-332.

Rust, B. R., 1978, Depositional models for braided alluvium, in Miall, A. D., ed., Fluvial Sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 605-626.

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russel, P. C., Woodward, J. J., McCoy, G., Rowe, J. J. jr., Baedecker, R. A., Asaro, F., and Michael, H., 1984, Chemical analyses, correlations, and ages of Upper Pliocene and Pleistocene ash layers of east-central and southern California: U.S. Geological Survey Professional Paper 1293 40 p.

Scott, A. J., and Weber, M. E., 1986, The Muddy Creek Formation--syntectonic deposition: in Journal of the Arizona-Nevada Academy of Sciences, Proceedings Supplement, p. 54.

Sieh, K. E., 1978, Prehistoric large earthquakes produced by slip on the San Andreas Fault at Pallett Creek, California: Journal of Geophysical Research, v. 83 p. 3907-3909.

Smith, E. I., 1979, Late Miocene volcanism in the River Mountains, Clark County, Nevada: Transactions of the American Geophysical Union, v. 61, p. 69.

_____ 1981, Contemporaneous volcanism, Strike-slip faulting and exotic block emplacement in the River Mountains, Clark County, southern Nevada: Geological Society of America Abstracts with Programs, v. 13, p 107.

_____ 1982, Geology and geochemistry of the volcanic rocks in the River Mountains, Clark County, Nevada, and comparisons with volcanic rocks in nearby areas: in Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, Cordilleran Publishers, p. 41-54.

_____ 1984, Geological map of the Boulder Beach Quadrangle, Nevada: Bureau of Mines and Geology Map 81.

Smith E. I., Schmidt, C. S., and Mills, J. G., 1988, Mid-Tertiary volcanoes in the Lake Mead area of southern Nevada and northwestern Arizona, in Weide, D. L. and Faber, M. L., eds., This Extended Land, Geological journeys in the southern Basin and Range: Geological Society of America, Cordilleran Section, Field Trip Guidebook: University of Nevada, Las Vegas, p. 107-122.

Smith, G. D., 1986, Coarse-grained nonmarine volcaniclastic sediment: terminology and depositional process: Geological Society of America Bulletin, v. 97, p. 1-10.

Smith, G. D., 1987, The influence of explosive volcanism on fluvial sedimentation: the Deschutes Formation (Neogene) in central Oregon: Journal of Sedimentary Petrology, v. 57, p. 613-629.

Smoot, J. P., 1983, Depositional subenvironments in an arid closed basin: the Wilkins Peak Member of the Green River Formation (Eocene), Wyoming, U.S.A.: Sedimentology, v. 30, p. 801-827.

Steidtmann, J. R., Middleton, L. T., Bottjer, R. J., Jackson, K. E., McGee, L. C., Southwell, E. H., Lieblang, S., 1986, Geometry, distribution, and provenance of tectogenic conglomerates along the southern margin of the Wind River Range, Wyoming, in Peternom, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 321-332.

Stock C. 1921, Later Cenozoic mammalian remains from the Meadow Valley region, southeastern Nevada: American Journal of Science 5th series, v. 2, p. 250-264.

Teel, D. B., and Frost, E. C., 1982, Synorogenic evolution of the Copper Basin Formation in the eastern Whipple Mountains, San Bernardino County, California: in Frost, E. G., and Martin, D. L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada, San Diego, Cordilleran Publishers, p. 275-285.

Tuthill, S. J., and Laird, W. M., 1966, Geomorphic effects of the earthquake of March 27, 1964 in the Martin-Bering Rivers area Alaska: U.S. Geological Survey Professional Paper 543-B, 29 p.

Van Houton, F. B., 1956, Reconnaissance of Cenozoic rocks of Nevada: American Association of Petroleum Geologists , v. 40 p. 2801-2825.

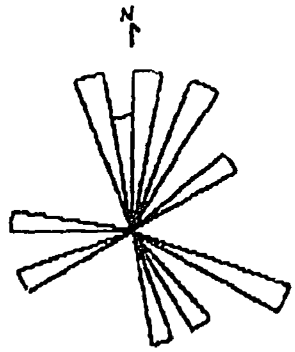
Weber M. E., and Smith E. I., 1987, Detachment terrane structures and geochemistry: constraints on the reassembly of disrupted mid-Miocene stratovolcanoes in the Lake Mead-Eldorado Valley area of southern Nevada: Geology, v. 15, p. 553-556.

APPENDIX A ROSE DIAGRAMS

River Mountains

Station

A



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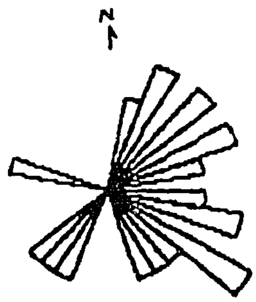
B

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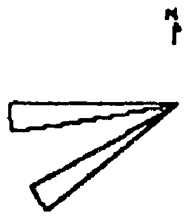
Station



D

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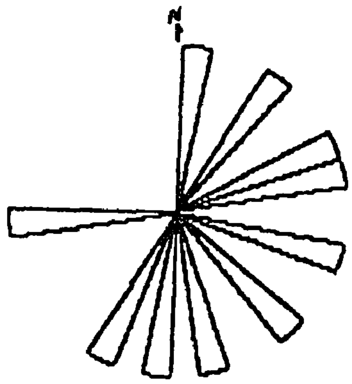

H

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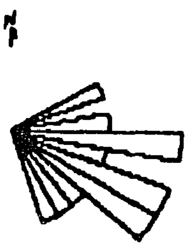

I

Tmbb

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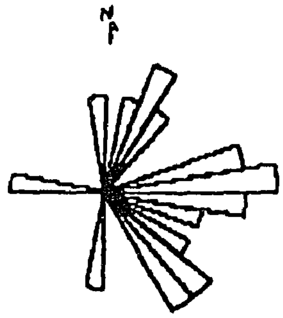
Station

J



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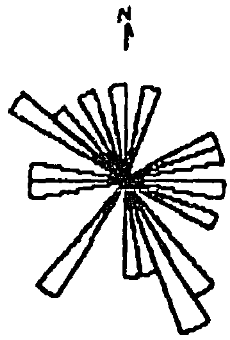
K



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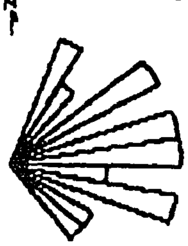
L



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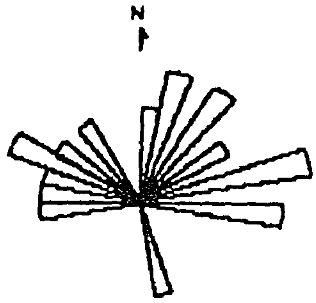
Station

L



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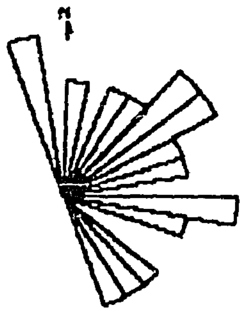
M



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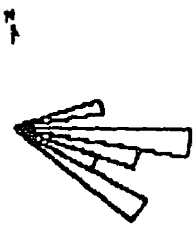
N



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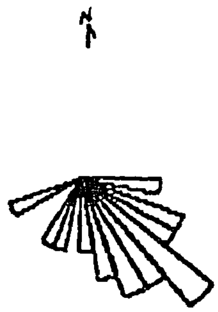
Station

O



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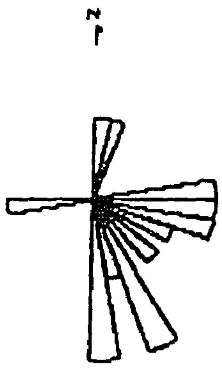
P



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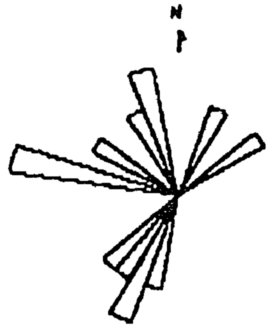
Malpais Flattop

Station

1



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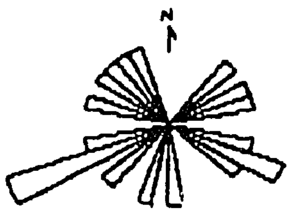
2



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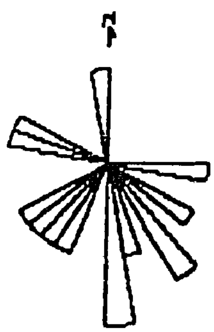
3



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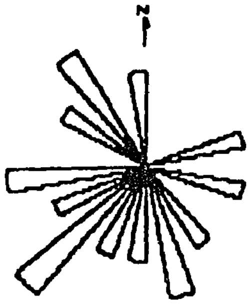
Station

4



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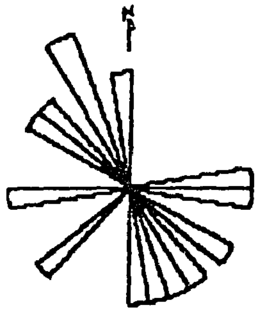
6



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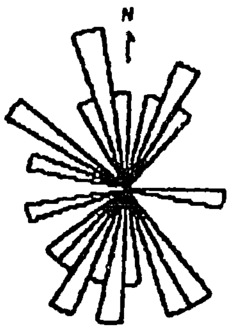
7

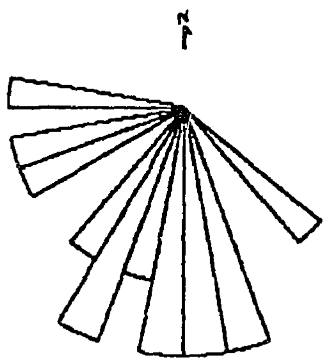


SAMPLE m-7
ORIENTATION=244.21 DEGREES
CHI-SQUARE VALUE= 0.7
VECTOR MEAN=244.21, VECTOR MAG=0.11

Gale Hills

Station

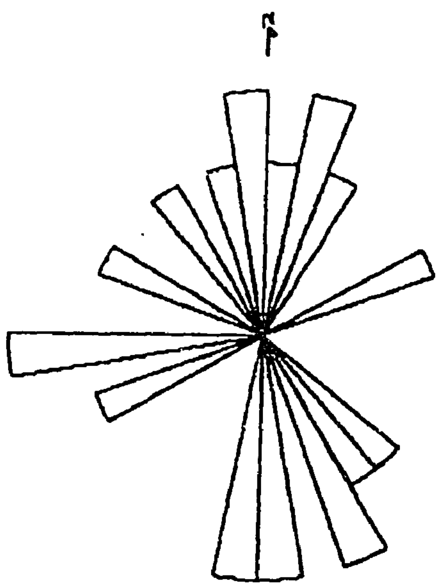
1



n = 14

SAMPLE g-1
ORIENTATION=196.10 DEGREES
CHI-SQUARE VALUE= 19.8
VECTOR MEAN=196.10, VECTOR MAG=0.82

2

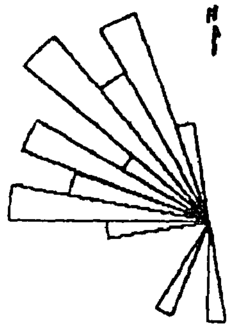


n = 21

SAMPLE g-2
ORIENTATION=207.73 DEGREES
CHI-SQUARE VALUE= 0.3
VECTOR MEAN=207.73, VECTOR MAG=0.08

Station

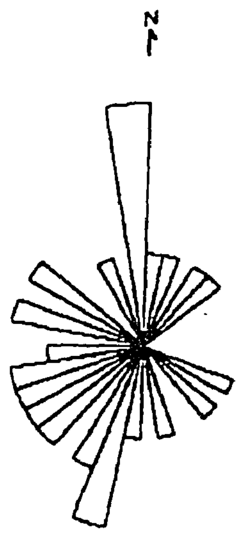
3



n = 29

SAMPLE g-3
ORIENTATION=303.93 DEGREES
CHI-SQUARE VALUE= 38.1
VECTOR MEAN=303.93, VECTOR MAG=0.82

4

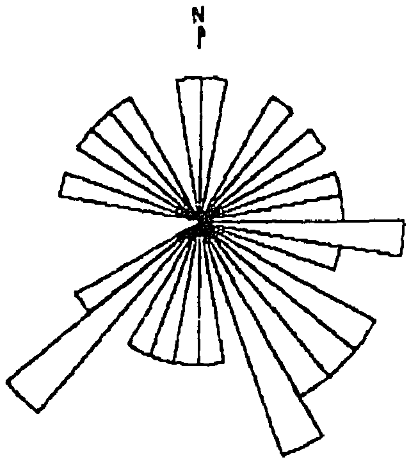


n = 35

SAMPLE g-4
ORIENTATION=241.04 DEGREES
CHI-SQUARE VALUE= 9.5
VECTOR MEAN=241.04, VECTOR MAG=0.41

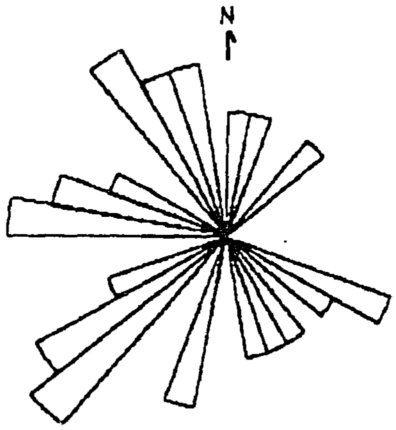
Station

5



n = 30
SAMPLE g-5
ORIENTATION=140.98 DEGREES
CHI-SQUARE VALUE= 5.5
VECTOR MEAN=140.98, VECTOR MAG=0.30

6



n = 32
SAMPLE g-6
ORIENTATION=263.90 DEGREES
CHI-SQUARE VALUE= 9.1
VECTOR MEAN=263.90, VECTOR MAG=0.39

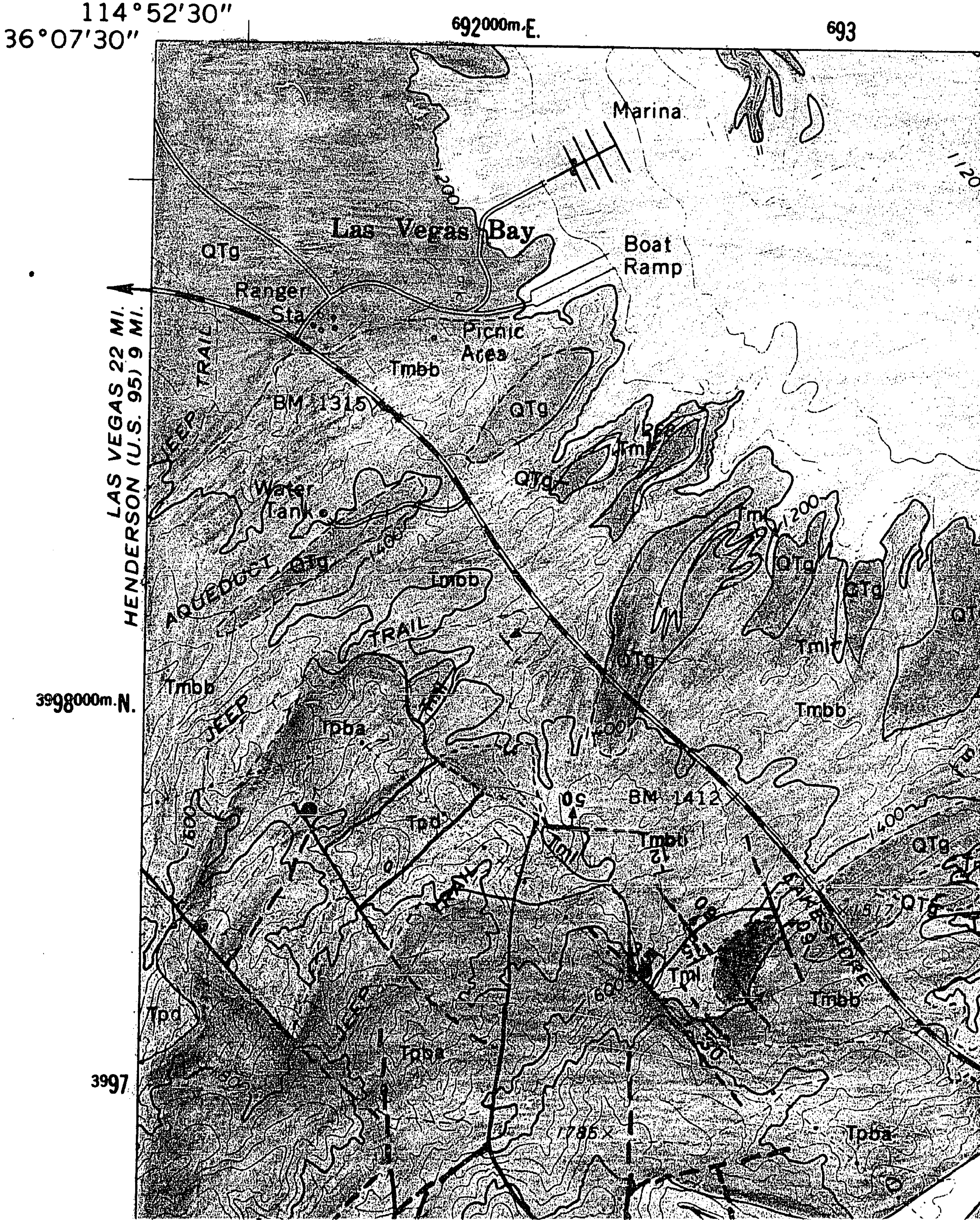
PLEASE NOTE:

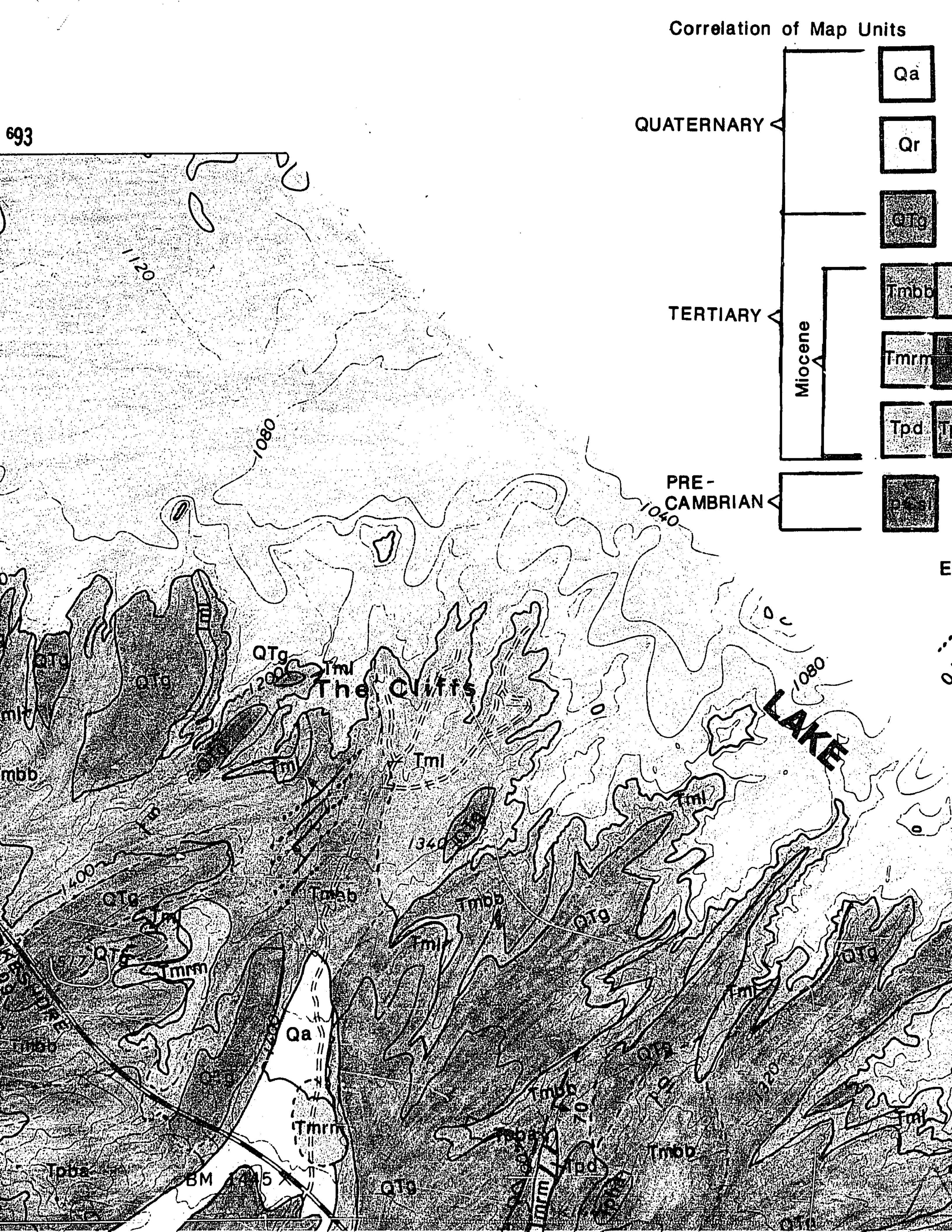
Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Standard 35mm slides or 17" x 23" black and white photographic prints are available for an additional charge.


114°52'30"
36°07'30"
692000m.E.
693
3998000m.N.
3997
LAS VEGAS 22 MI.
HENDERSON (U.S. 95) 9 MI.
Marina
Las Vegas Bay
Boat
Ramp
Ranger
Sta.
Picnic
Area
QTg
Tmbb
Tml
Tmlr
Tpba
Tpd
BM 1315
BM 1412
Water
Tank
JEEP TRAIL
AQUEDUCT
TRAIL
LAKESHORE
1200
1400
1600
1517
1785


Correlation of Map Units
QUATERNARY
TERTIARY
Miocene
PRE-CAMBRIAN
Qa
Qr
QTg
Tmbb
Tmrm
Tpd
693
1120
1080
1040
The Cliffs
LAKE
QTg
Tml
Tmbb
Tmrm
Tpba
Qa
1400
1340
BM 1445

s

Qa

Qr

QTg

Tmbb Tml

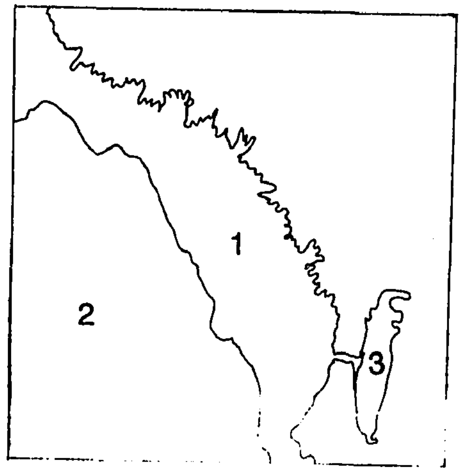
Tpd Tpba

GEO

FO

MC

C

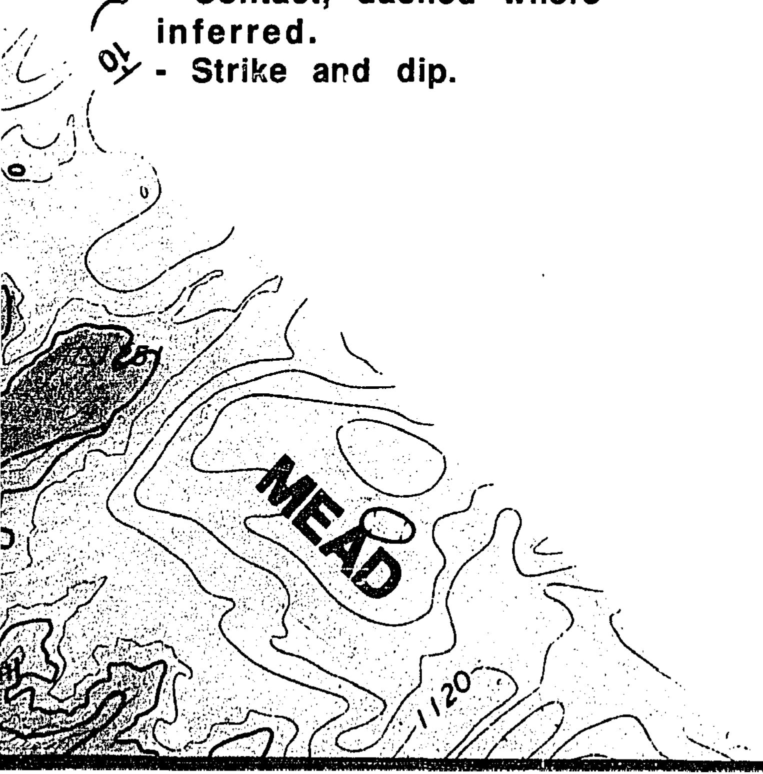


Explanation of Mapping Detail

1. Detailed Mapping
2. Smith, 1984
3. Dubendorfer et al., 1988

EXPLANATION

- Tertiary normal fault, ball is on the downthrown side. Fault is dashed where inferred, dotted where buried.
- Tertiary normal fault, arrow shows dip of the fault plane.
- Contact, dashed where inferred.
- Strike and dip.



DESCRIPTION OF MAP UNITS

QUATERNARY DEPOSITS

Qa

Qa **Modern wash deposits.** Mostly unlithified, poorly sorted, massive gravel and sand. Includes sediments that are presently being transported and deposited in most of the larger washes.

Qr

Qr **Pediment deposits of the River Mountains.** Unlithified, unsorted, massive or crudely bedded, coarse gravel deposits composed of angular volcanic clasts that commonly have thin calicum carbonate rinds. These deposits unconformably overly Tmbb and are cut by washes containing Qa. Generally < 5 m thick.

QTg

QTg **Older pediment deposits.** Thin (< 10 m) unlithified, unsorted, crudely stratified, sandy gravel deposits. Clasts are dacite, basalt, and andesite. These sediments crop out on hilltops, unconformably overlying Tmbb and Tml.

TERTIARY DEPOSITS

Muddy Creek Formation

Tml

Tml **Lakeshore member.** A fine-grained deposit composed of siltstone and sitly sandstone with local pebble lenses and beds. The unit is tan to buff, reaching 45 m in thickness. The deposit does not exhibit any sedimentary structures. Bedding averages 40 cm thick. The sediments

GEOLOGIC MAP OF THE MUDDY CREEK FORMATION, RIVER MOUNTAINS, CLARK COUNTY, NEVADA

BY

ALLAN J. SCOTT

ON OF MAP UNITS

DEPOSITS

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OSITS

Formation

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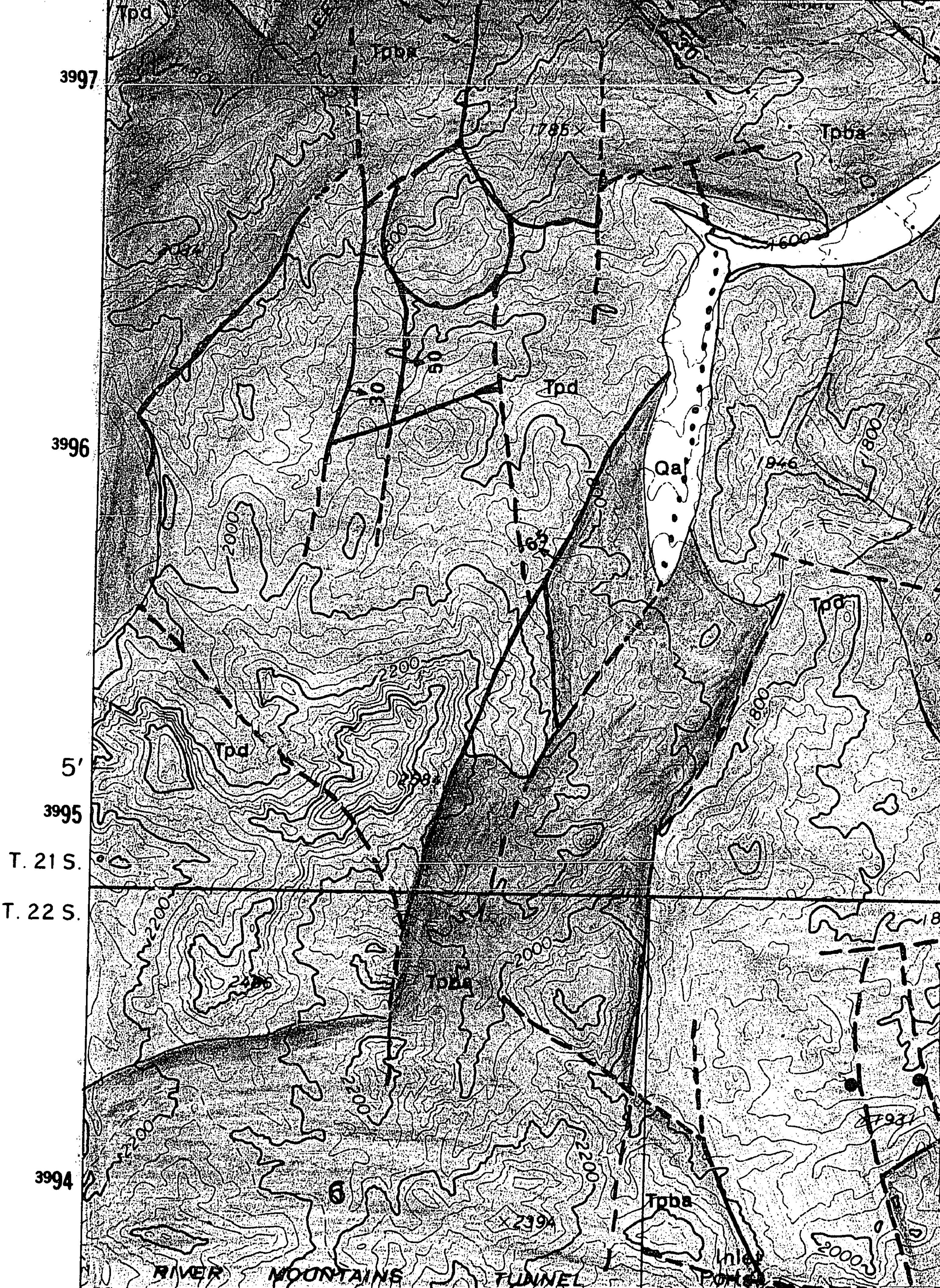
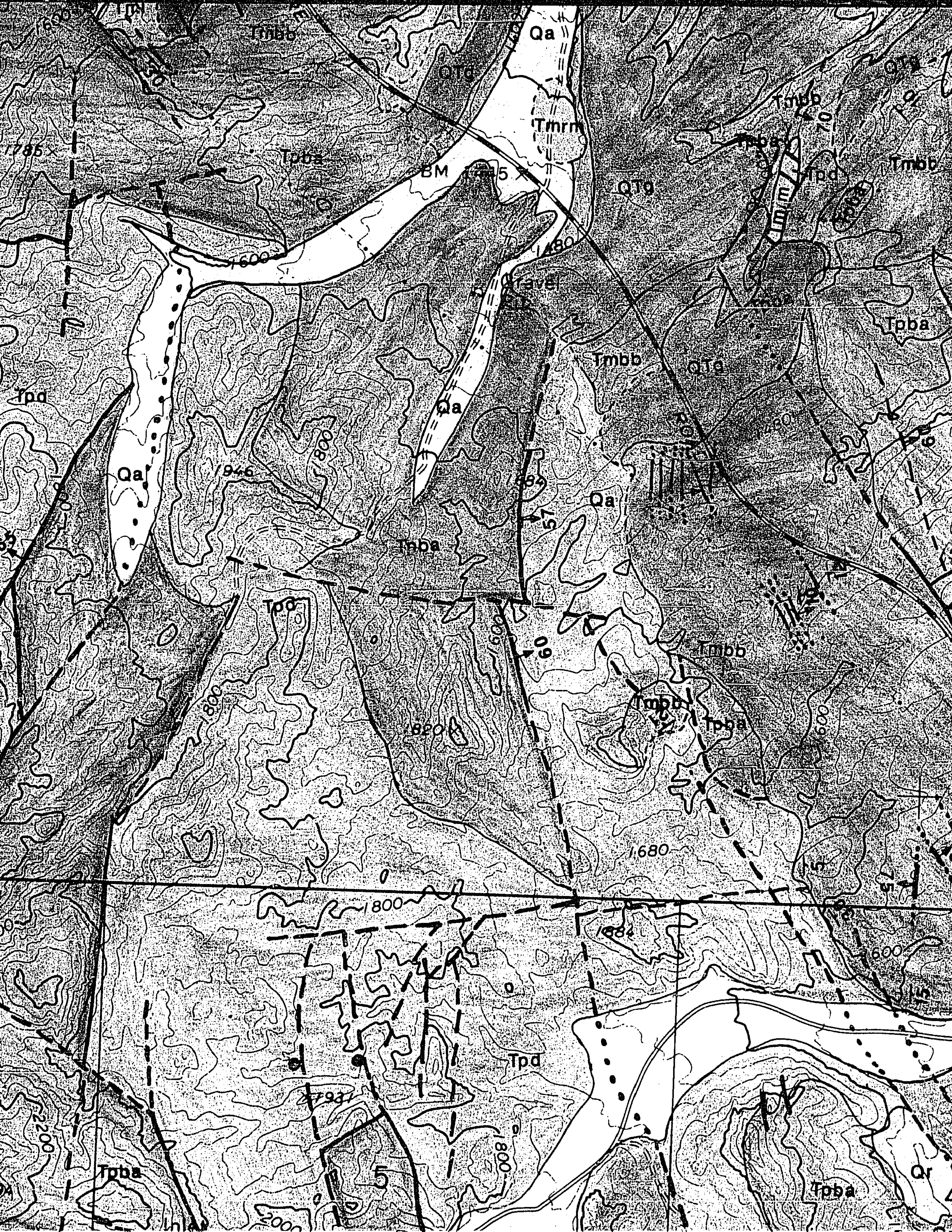
Tmbb **Boulder Basin conglomerate.** A lithified, brown to buff, clast-supported conglomerate. The unit is massive or crudely bedded and at least 25 m thick, with an average bed thickness of 0.8 m. Beds are tabular or wedge shaped, with some lens-shaped channel deposits. Clasts are volcanic and plutonic, highly weathered, and angular. Beds of Tmbb interfinger with and laterally grade into Tml. Tmbb contains at least two ash layers, but these cannot be correlated with the ash layers in Tml because of lack of continuity and exposure.

Tmc **The Cliffs member.** A dark red silty deposit that crops out in one wash about 1.25 km due west of The Cliffs. Tmc contains abundant gypsum that occurs as thin, laminated beds in the upper part of the unit, and as secondary selenite crystals throughout the deposit. The unit is at least 4.5 m thick; the lower contact is buried. Tmc is overlain by and faulted against Tmbb.

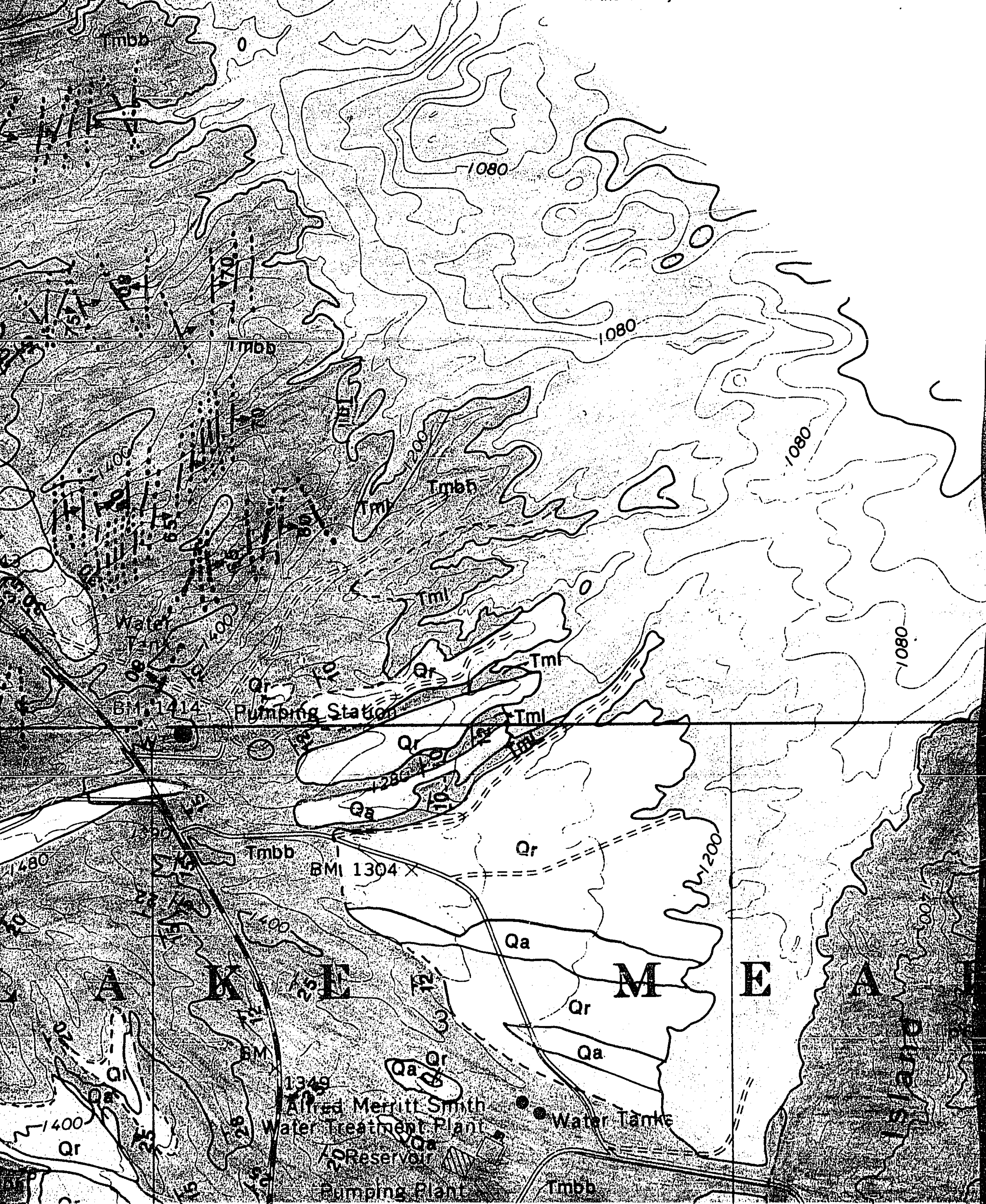
Tmrm **River Mountain conglomerate.** A red to buff, predominantly conglomeritic unit that is unconformably overlain by Tmbb. Conglomerates are primarily clast-supported and thinly bedded; beds average 30 cm thick. Clasts consist of dacite, andesite, basalt, and minor amounts of rhyolite, are modreately to highly altered, and are sub-angular to sub-rounded. Sediments are massive to crudely bedded, and are poorly sorted. Beds commonly display lateral changes in lithology and range from pebbly sandstone and siltstone to clast-supported cobble conglomerate. Its exposure is limited; it is only exposed in


3997
3996
5′
3995
T. 21 S.
T. 22 S.
3994
Tpd
Tpba
1785×
Tpba
1600
50
30
Tpd
Qal
1800
2000
62
Tpd
2200
1800
Tpd
2000
Tpba
2200
2000
×2394
Tpba
Inlet
RIVER MOUNTAINS TUNNEL


Tmbb
Qa
QTg
Tmrm
Tpba
BM
Tpd
Gravel
1600
1480
1946
1820
1680
1800
1884
Tpbd
Qr


MEAD
Qa
QTg
Tmrm
Tmbb
Tpd
Tpba
Tml
Gravel Pit
Water Tank
BM 1414
Qr
Tpbb
1680
1684
1480
564
L A K

thickness. The deposit does not exhibit any sedimentary structures. Bedding averages 40 cm thick. The sediments contain selenite and alabaster, and at least five ash layers in the vicinity of The Cliffs.



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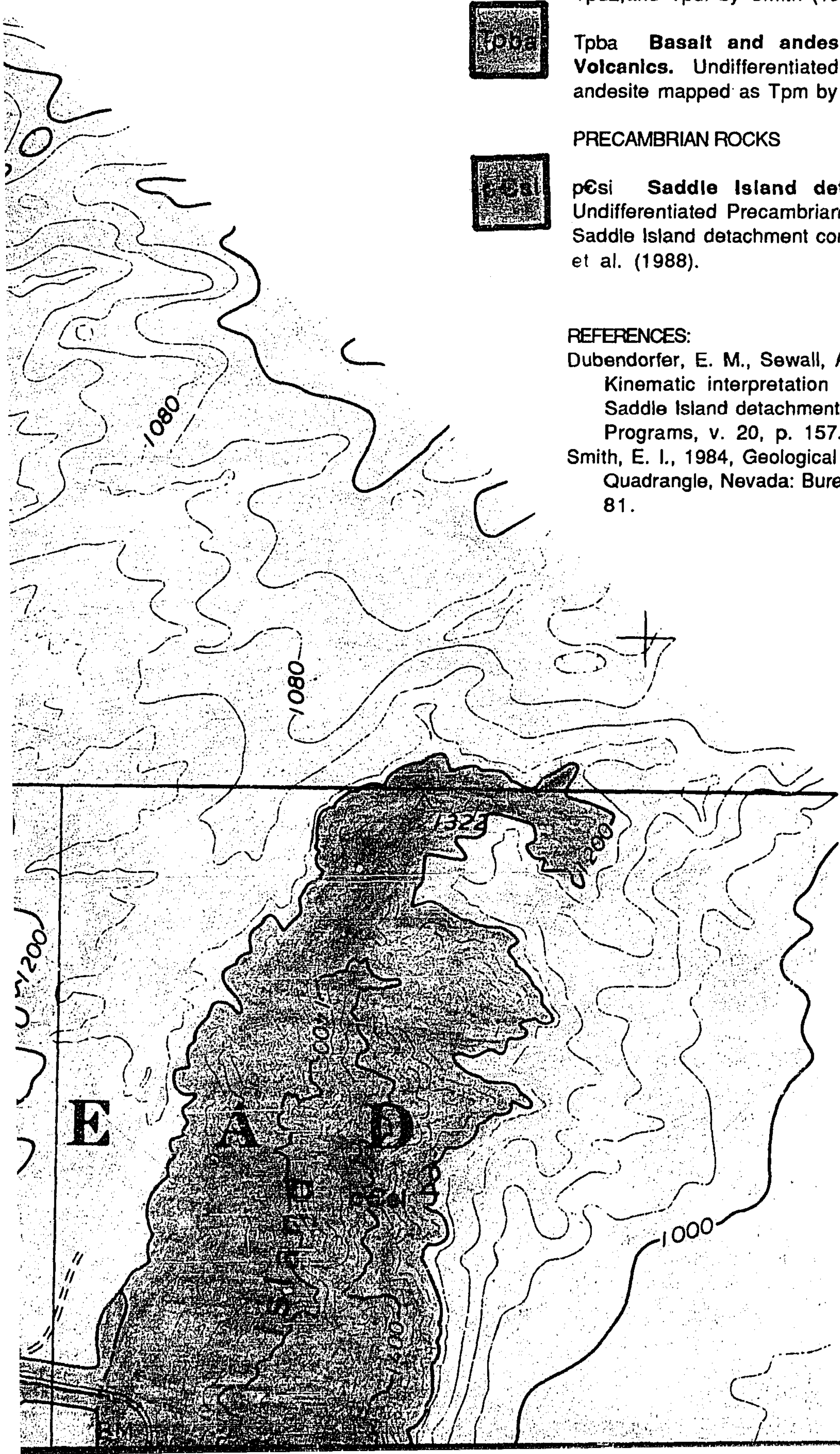
Volcanic Rocks

Tpd **Dacites of the Powerline Road Volcanics.** Undifferentiated Powerline Road dacite mapped as Tpdu, Tpd2,and Tpdl by Smith (1984).

Tpba **Basalt and andesite of the Powerline Road Volcanics.** Undifferentiated Powerline Road basalt and andesite mapped as Tpm by Smith (1984).

PRECAMBRIAN ROCKS

p€si **Saddle Island detachment complex.** Undifferentiated Precambrian and younger rocks of the Saddle Island detachment complex mapped by Dubendorfer et al. (1988).



REFERENCES:

Dubendorfer, E. M., Sewall, A. J., and Smith, E. I., 1988, Kinematic interpretation of lower-plate mulonites, Saddle Island detachment complex, Lake Mead, Programs, v. 20, p. 157.

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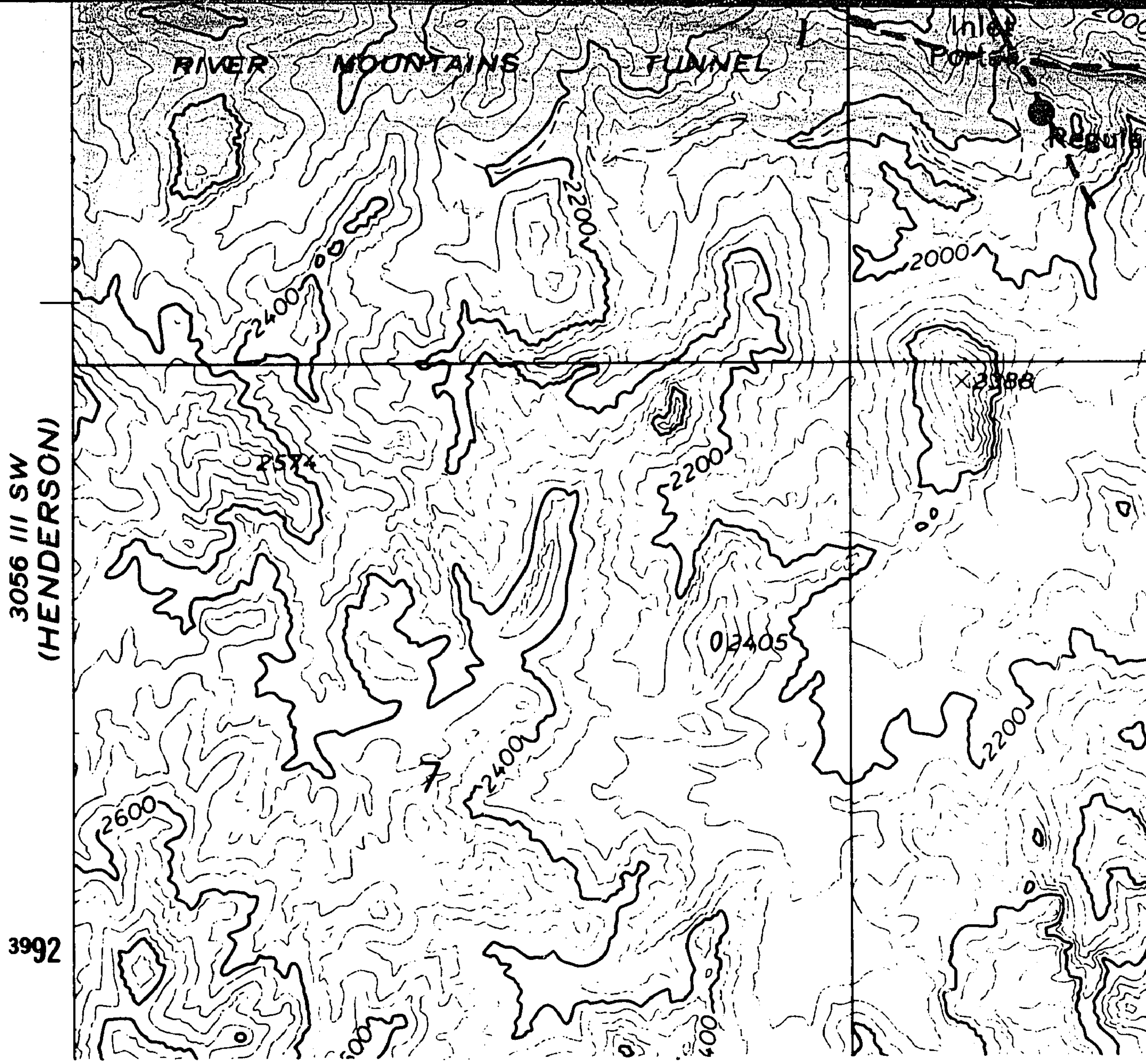
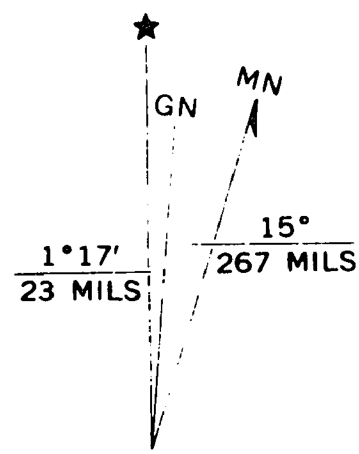
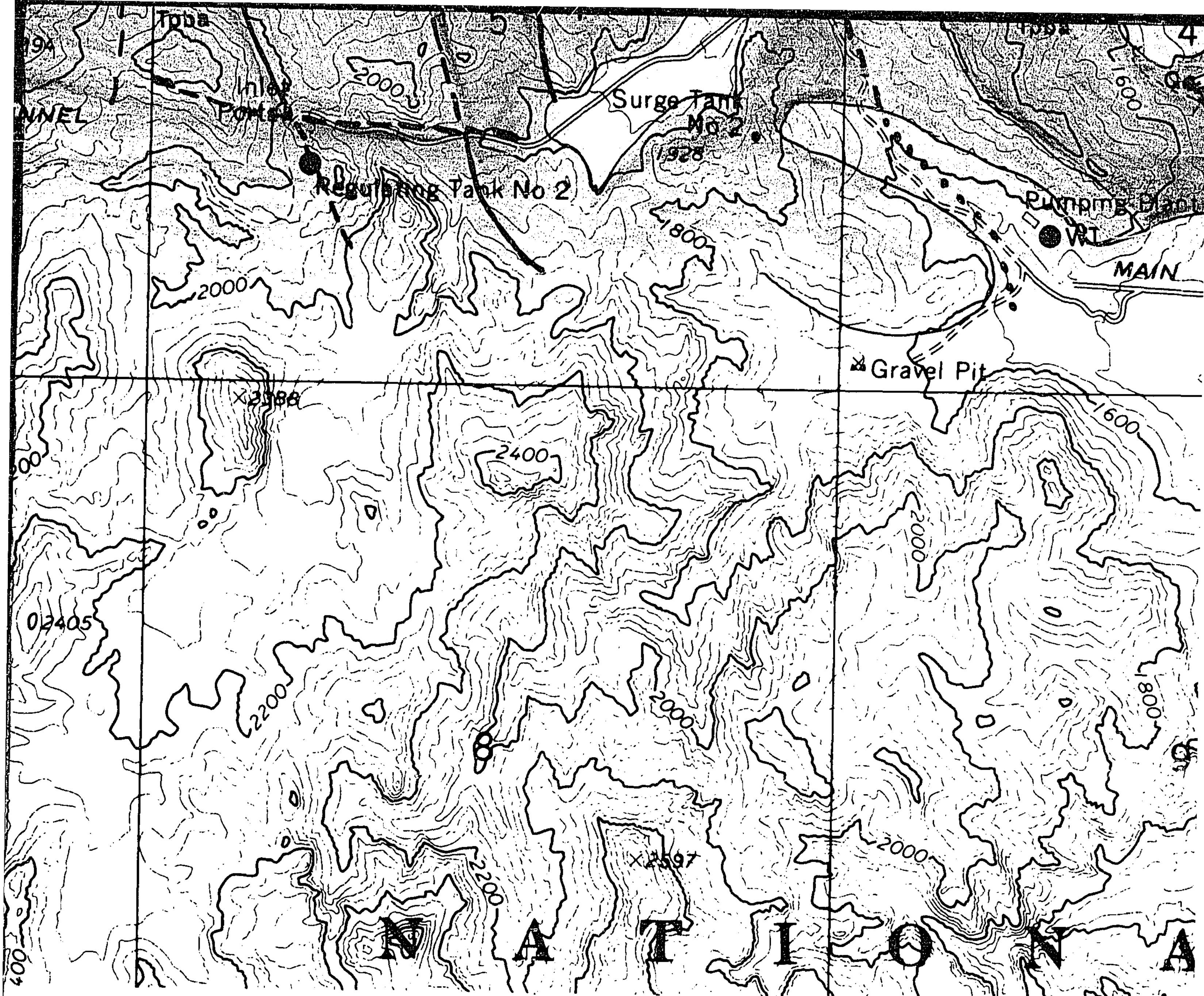
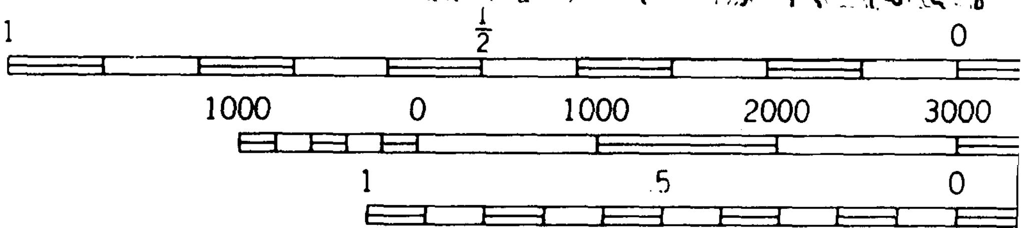
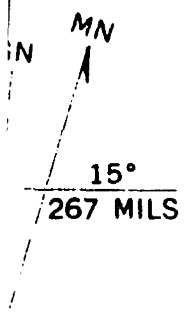




UTM GRID AND 1970 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

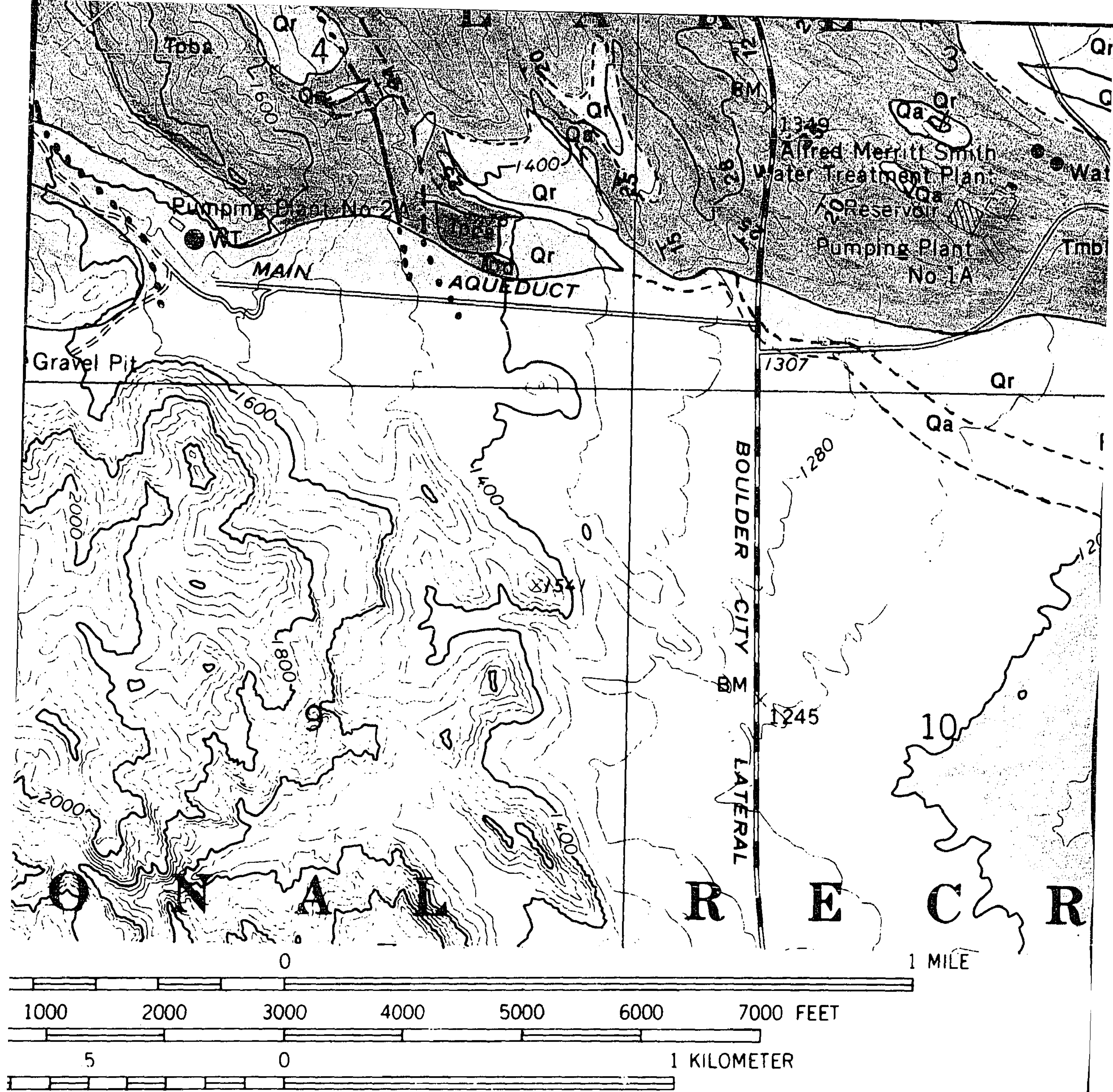






CONTOUR INTERV
DATUM IS MEAN
1:12000

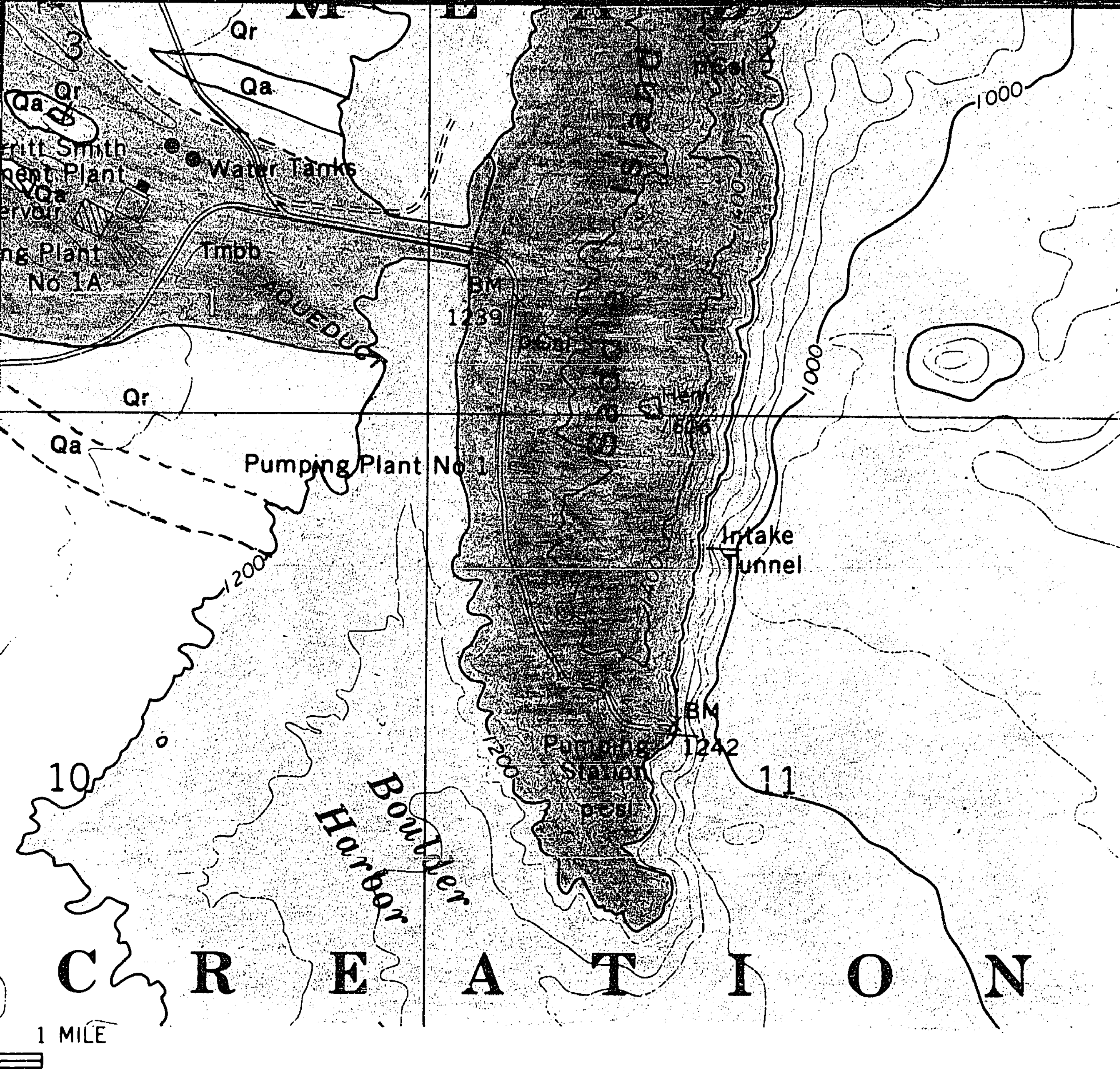
MAGNETIC NORTH
ENTER OF SHEET

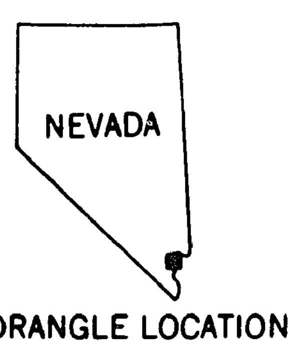


CONTOUR INTERVAL 40 FEET

DATUM IS MEAN SEA LEVEL

1:12000





QUADRANGLE LOCATION

GEOLOGIC MAP OF THE MUDDY CREEK FORMATION, RIVER MOUNTAINS, CLARK COUNTY, NEVADA

BY

ALLAN J. SCOTT

Correlation of Map Units

Qa
Qr
QUATERNARY
TERTIARY
Miocene
PRE-CAMBRIAN

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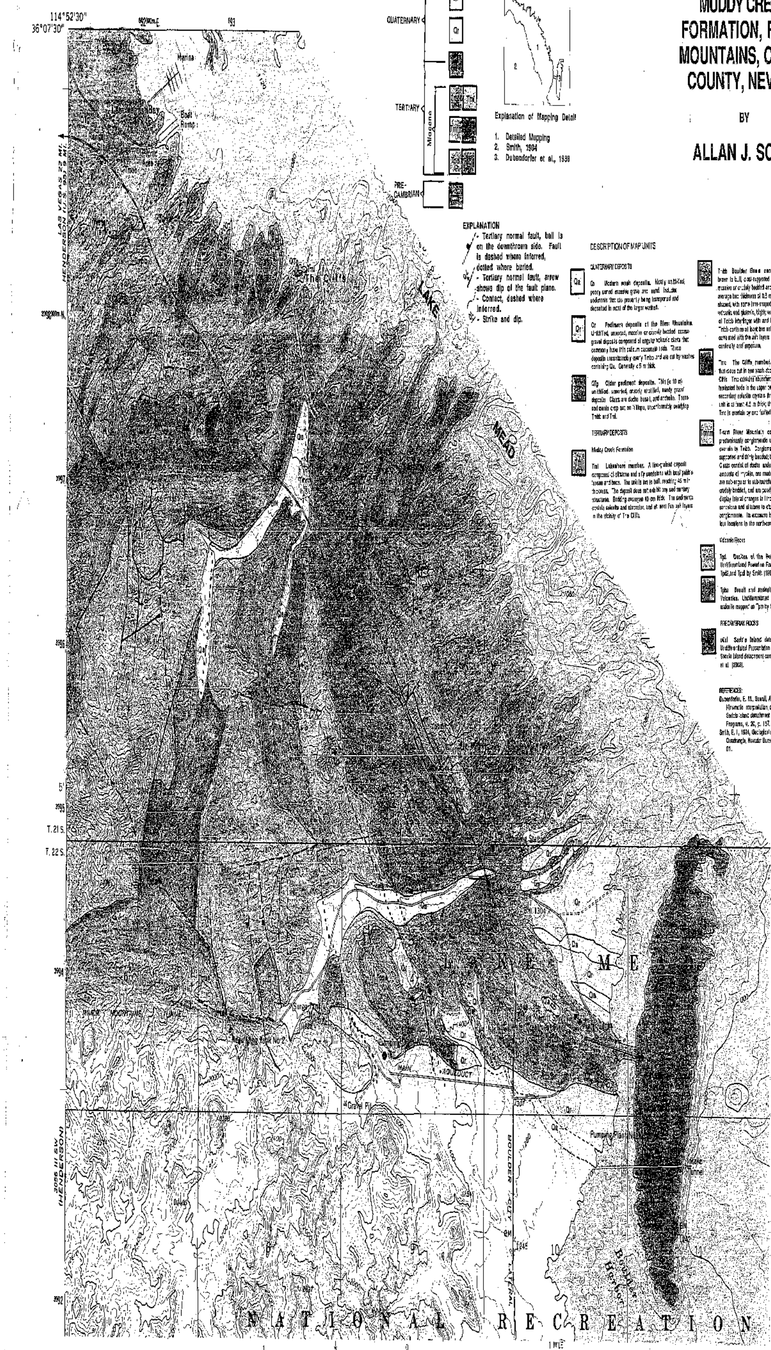

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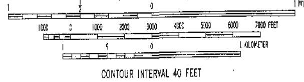
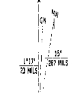
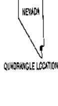


CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
1:12000



UTM GRID AND 1970 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET



QUADRANGLE LOCATION

1