AN ABSTRACT OF THE THESIS OF

John L. Kuiper for the degree of MASTER OF SCIENCE in GEOLOGY

presented on February 12, 1988 .

Title: THE STRATIGRAPHY AND SEDIMENTARY PETROLOGY OF THE MASCALL FORMATION, EASTERN OREGON

Abstract approved: Redacted for privacy

Dr. Robert D. Lawrence

The type section of the Mascall Formation, which is located in the John Day Valley, is interpreted to represent a sequence of paleosols. These fossil soils were formed on a floodplain during the middle Miocene. The measured thickness of this section is 1340 feet, and although the top of the section is truncated by an erosion surface, the original thickness was probably not much more than 2000 feet. Sediment accumulation rates were high in the vicinity of the type section with deposits being predominantly of the overbank type. Minimum sediment accumulation time at the type section is thought to have been several hundred thousand years.

A concretionary horizon, which occurs within the type section is determined to represent a significant temporal hiatus. Because of the absence of caliche in this layer and elsewhere in the type section, and because of the occurrence of moisture-loving plants, a wet, temperate climate is envisioned for the type section during the middle Miocene (Barstovian).

The floodplain sediments of the type section are predominantly composed of ash which was produced by nearby silicic volcanism. This ash was mostly washed in from the surrounding highlands, but on

occasion the floodplain was blanketed by air fall debris. Scanning electron microscopy demonstrates that this ash is of the type erupted by plinian and pelean type volcanoes. The ash has been mostly altered to clay minerals, and SEM, TEM, and XRD analyses, show these clays to consist principally of smectite (Ca, Mg), with lesser amounts of kaolin and tubular halloysite.

Deposits west of Picture Gorge are predominantly of floodplain origin; however, a limited lacustrine sequence also occurs. East of the type section the floodplain deposits tend to become coarser and reflect main channel deposition.

Farther to the east, near the mouth of Fields Creek a 300 foot thick lacustrine sequence occurs, representing a shallow eutrophic lake which was at least 3.5 miles in east-west dimension.

Mascall deposits of the Paulina Basin also were formed in a floodplain environment. The area was characterized by slow sediment accumulation rates, and river meandering resulted in deposition of large tabular sandstone bodies. Meander loop cut-off probably occurred often, and as a result the floodplain was probably dotted with oxbow lakes. Volcanoes were active nearby, and on occasion covered the floodplain with pyroclastic debris.

The Mascall Formation is believed to have been deposited only in the structural and topographic lows of the time. Present occurrences of Mascall rocks in the John Day Valley, Paulina Basin, Fox Basin, and Miocene rocks which may or may not be Mascall in the Bear Valley and Unity Basin, are not the remnants of a huge alluvial fan. Rather each of these structurally lows was filled in by sediment and pyroclastic material from their respective adjacent highlands.

Pumices ranging from white to black in color, representing a zoned eruption, were collected from Mascall deposits in the John Day Valley. Chemical analysis of these pumices precludes magma mixing as a means for producing the zoned eruption. It is not known whether crystal fractionation or assimilation of wall rock material represented the mechanism involved. High K_2O values in the Mascall pumice show that the magma had a continental source.

Stratigraphy and Sedimentary Petrology of the Mascall Formation, Eastern Oregon

by

John L. Kuiper

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the degree of

Master of Science

February 12, 1988

Commencement June 1988

APPROVED:

Redacted for privacy

Robert D. Lawrence, Professor of Geology in charge of major

J. G. Johnson, Chairman of Department of Geology

Redacted for privacy

Dean of Graduate School

Date thesis is presented February 12,1988

ACKNOWLEDGEMENTS

Most sincere appreciation is extended to Dr. Robert D. Lawrence, Associate Professor of Geology, Oregon State University, for suggesting the Mascall as a formation of interest, for his guidence throughout the project, and for his editorial supervision and critical review of the manuscript.

Sincere appreciation is also extended to Drs. Edward M. Taylor and Keith F. Oles, both of Oregon State University, for entertaining my many questions and for their critical review of the manuscript.

I also would like to thank the owners of the Mascall Ranch as well as the numerous other ranch owners who kindly allowed me to work on their property.

Finally I would like to thank my parents for their continued support throughout my academic career.

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THE STRATIGRAPHY AND SEDIMENTARY PETROLOGY OF THE MASCALL FORMATION, EASTERN OREGON

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Mascall Formation occurs within several of the Tertiary basins and valleys of the Canyon City Quadrangle, eastern Oregon. Areas which were studied by the author include the John Day Valley, Paulina Basin, Fox Valley, Unity Basin, and Bear Valley (see Fig. 1). These areas are readily accessible by both dirt and improved roads. Highway U.S. 26 runs the length of the John Day Valley and over to the Unity Basin. Highway U.S. 395 passes through the Fox Valley and down into Bear Valley. Access to the Paulina Basin is provided by several smaller roads.

PURPOSE OF INVESTIGATION

The purpose of this study was to examine the Mascall Formation regionally, and by so doing, resolve the major discrepancies which exist in the literature with regard to the modes and environments of deposition, and the thicknesses of the deposits. In addition it was the author's intent to 1) describe the mineralogy of the various deposits, 2) characterize the magma which produced the clastic material, 3) determine if any post-Mascall structural events could be specified, and 4) determine if the Mascall was only deposited in the structural lows of the time, or if the Mascall deposits are

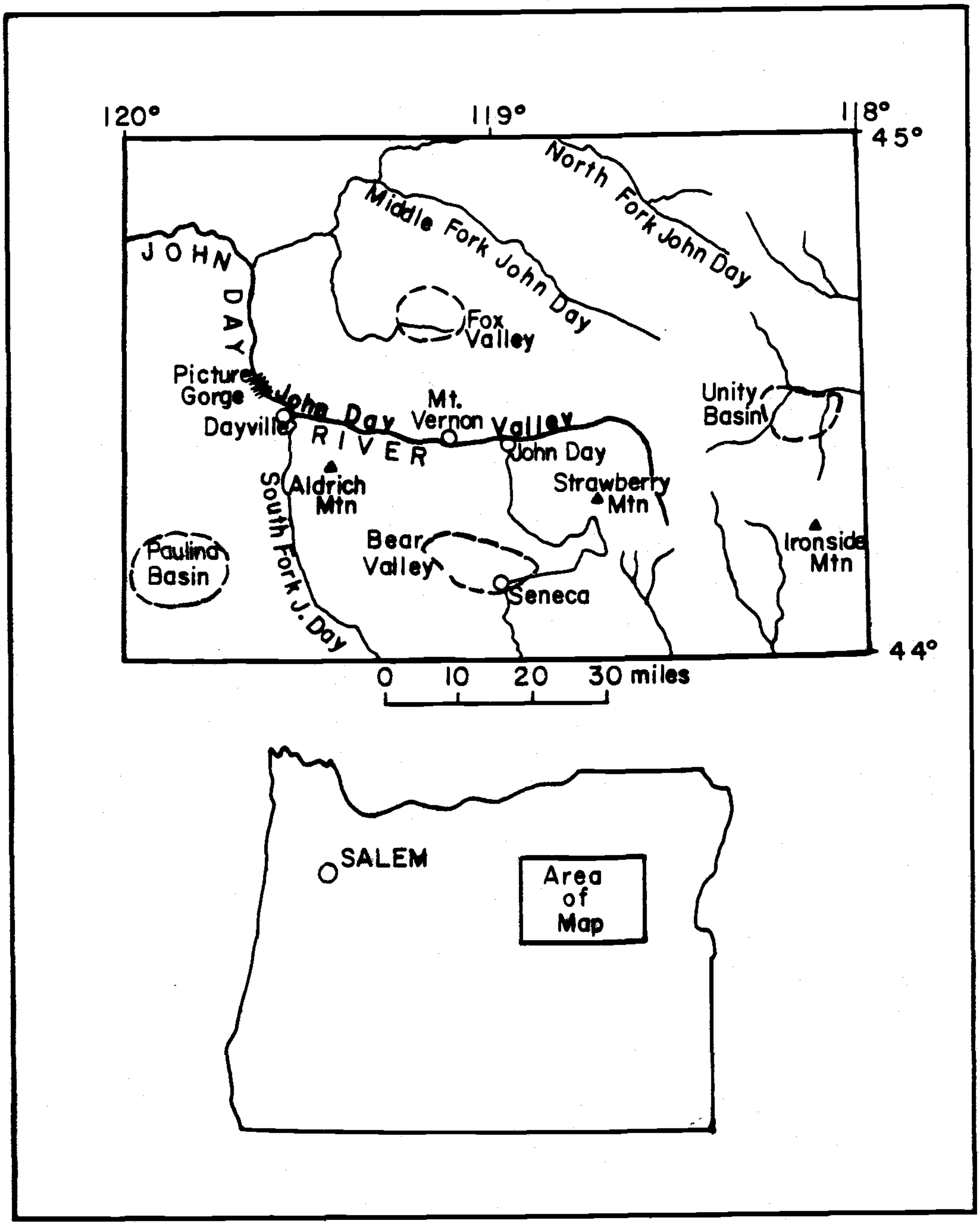


Fig. 1. Index map of the Canyon City Quadrangle. Modified from Thayer and Brown (1965).

only the remnants of a vast piedmont apron or alluvial fan.

CLIMATE AND VEGETATION

The climate of the John Day Valley, Paulina Basin, and Unity Basin is semi-arid, with the dominant vegetation consisting of grasses, sagebrush, and junipers. The Beach Creek graben, Fox Valley, and Bear Valley lie at higher elevations and consequently receive much more rainfall, with pines and firs being quite common.

EXPOSURES

Exposures of the Mascall Formation are generally poor. Because the Mascall deposits are soft and tend to form gentle vegetated slopes, some of the best exposures occur in roadcuts. Good natural exposures only occur in areas where there is little rainfall and thus little or no vegetation. It is in these areas that the erosional processes sometimes produce a "badlands" topography. The largest of these "badland" type of exposures occurs in the John Day Valley, approximately 4 miles west of Dayville, and represents the type locality (Merriam et al., 1925). However, even in these semi-arid areas, good exposures are rare and localized, a fact which makes detailed surface mapping difficult. Fair exposures occur in the Paulina Basin and the Unity Basin. However in the Beech Creek graben, Fox Valley, and Bear Valley, the surface is too heavily vegetated and the soil too deep to allow interpretation of the Mascall sediments by surface methods. Because of this, the author decided to eliminate Bear Valley from the study. Fortunately, road cuts, stream channels, and quarries permitted the author to do some geological work on the

Mascall in Fox Valley and the Beech Creek graben.

GEOLOGICAL SETTING

The Mascall is exposed in low-lying areas of eastern Oregon, with most of the deposits occurring within the Blue Mountains province (Brown & Thayer, 1966a; Ehret, 1981). The Mascall Formation appears to be best preserved in the John Day Valley structural trough where the east-west-trending John Day Fault runs along the axis. Immediately to the south, the east-west-trending Aldrich Mountain anticline separates the Mascall deposits of the John Day Valley, from similar deposits in Bear Valley and Paulina Basin. To the east, younger but similar deposits are preserved in the Unity Basin. Farther to the south and east lies the Basin and Range province. To the north of the John Day Valley, Mascall deposits are preserved in Fox Valley and in the much smaller Beech Creek graben. (Brown & Thayer, 1966a; Thayer & Brown, 1966a; Ehret, 1981).

Although the Mascall is predominantly sedimentary in nature, an ignimbrite or ash flow unit does occur within the Mascall section of the Paulina Basin (Forth, 1965; Davenport, 1971). Ash flow deposits also occur within the Mascall Formation in the Fox Basin and to a much lesser extent in the John Day Valley. Where the base of the Mascall is exposed it overlies Columbia River Basalt. In the John Day Valley and Paulina Basin, the Mascall Formation is in turn overlain, and protected by, the ignimbrite member of the Rattlesnake Formation.

During Miocene time, the Picture Gorge Basalts (part of the Columbia River Basalts) were erupting and flooding much of the western part of the Canyon City Quadrangle. While this was happening, several volcanoes in the vicinity of Strawberry Mountain were erupting andesitic to rhyolitic lava and ash and building up cones which were similar to the present-day high Cascades (Thayer, 1977). The remnants of these cones are known as the Strawberry Volcanics. Because these volcanoes rose thousands of feet above the top of the Picture Gorge Basalts, erosional debris (Thayer, 1977) and pyroclastic airfall material were locally deposited on the basalts, forming the Mascall Formation.

After the eruption of the Columbia River Basalts (of which the Picture Gorge Basalts are a part), and deposition of the Mascall Fm., there was strong north-south compression in this area. One of the major faults that formed is the John Day Fault, which trends roughly east-west and can be traced for approximately 80 miles (Thayer, 1977; Ehret, 1981). The north-south compressional forces also were responsible for producing the Strawberry-Aldrich Mountain anticline which parallels the John Day Fault. Uplift of these mountains during the Pliocene resulted in rapid erosion, producing the gravels of the Rattlesnake Formation. While these gravels were being deposited, a great volcanic eruption spread an ash flow (ignimbrite) more than 100 feet thick over much of the area, including the entire John Day Valley floor and down into the Paulina Basin (Brown & Thayer, 1966 a,b; Thayer & Brown, 1966b; Davenport, 1971; Thayer, 1977).

AGE DATING

The Mascall Formation is middle Miocene (Barstovian) in age based on: 1) Mascall deposits of the John Day Valley and the Paulina Basin contain a mammalian fauna which has been dated as Barstovian

(Merriam *et al.*, 1925, Downs, 1956); 2) the lowermost part of the formation in the John Day Valley is locally intercalated with basalt flows that have been dated by potassium-argon as 15.4 million years (Davenport, 1971); and 3) a potassium-argon analysis on an ignimbrite, which occurs within the Mascall section of the Paulina Basin, yielded an age of 15.8 (± 1.4) million years (Davenport, 1971).

STRATIGRAPHY OF THE MASCALL DEPOSITS OF EASTERN OREGON

INTRODUCTION

Mascall Formation stratigraphic sections were measured by the author in the John Day Valley and the Paulina Basin. In addition, a partial stratigraphic section was measured of what have been informally termed the Unity Deposits (Farooqui et al., 1981), which are located in the Unity Basin. Although the Unity Basin deposits are younger than those in the John Day Valley and Paulina Basin (Thayer & Brown 1966a, 1973; Ehret, 1981), Thayer and Brown (1966a) state that the Unity deposits represent the uppermost part of an extensive, 6000+ foot thick Mascall alluvial fan which encompassed these basins as well as Fox Valley and Bear Valley. This fan is now preserved only in the present-day structural lows. For this reason the author feels that it is worthwhile to include a stratigraphic section from the Unity Basin, even though he disagrees with Thayer and Brown's interpretation, and believes instead that the Mascall was only deposited in the existing structural lows of the time. Evidence in support of the author's conclusion includes: Stratigraphic units are not traceable from one basin to another; the basins differ from one another lithologically; much of the clastic material has been eroded from local sources; and pronounced facies changes occur within the Mascall deposits of the John Day Valley.

In identifying the deposits from the different stratigraphic sections and compiling evidence in support of the author`s interpretation, numerous criteria were derived from the literature. Several authors have compiled criteria for the recognition of fluvial or floodplain deposits. Authors used include: Krumbein and Sloss (1963), Visher (1972), Pettijohn et al. (1973), Reineck and Singh (1980), Monroe (1981), and Walker (1984). Likewise, several authors have listed criteria for the recognition of ancient soils or paleosols. Authors for these criteria include: Bown and Kraus (1981), Retallack (1983a, 1983b), and Bown (1985). Ash flow deposits were identified using criteria provided by Enlows (1984) and Taylor (1986). When classifying the clastic deposits according to constituent grain sizes the Wentworth classification system was used.

STRATIGRAPHY OF THE MASCALL TYPE LOCALITY (JOHN DAY VALLEY)

INTRODUCTION

The Mascall type section is located along Rattlesnake Creek near highway U.S. 26 about 4 miles west of Dayville (Sections 19, 29, & 30, T.12 S., R.26 E.) (Figs. 2 & 3). It was here in 1901 that Merriam first applied the name "Mascall" to a sequence of light colored sediments located on the "Mascall Ranch" (Merriam, 1901; Merriam *et al.*, 1925). At the type section the basal Mascall sediments rest conformably on the Picture Gorge Basalt, with both sediments and basalt flows dipping south at about 14 degrees. The Mascall sediments are in turn overlain (with pronounced angular unconformity) by the more nearly horizontal Rattlesnake Formation of which the Rattlesnake Ignimbrite is a part.

Merriam briefly described the sediments of the type locality and determined their stratigraphic thickness to be 2,090 feet (Merriam, 1901; Merriam *et al.*, 1925). Since the early nineteen hundreds, a few other workers have also briefly mentioned these sediments and attempted to measure their stratigraphic thickness. Downs (1956) erroneously measured the type section to be only 390 feet thick. Likewise Coleman reported only 435 feet (in White, 1964). Dawson (1951), gave a much more reasonable estimate of the sediment thickness and stated that it was approximately 1,500 feet (Dawson 1951). After careful measurement of the type section, using a Brunton compass and Abney level, and offsetting along strike in order to obtain better exposures, the author concluded the thickness of the type section to be 1,340 feet $\pm$ 20 feet (408 meters $\pm$ 6 meters).

For several miles east and west of Dayville, erosion of the Rattlesnake Formation has exposed the underlying Mascall sediments. The Mascall sediments, being much softer than either the basalt or the Rattlesnake Formation, tend to erode rapidly and produce gentle slopes and low, rounded hills. Generally these slopes are covered with grass and sage; however at the type section mass-wasting is occurring too fast for vegetation to establish a firm foothold, and the result is a rather scenic, badlands terrain (Figs. 2 & 3). These mass-wasting processes are accentuated by the large proportion of water-expansive clays that are present in the type section sediments. During dry weather the ground is covered by a loose, crumbly, "popcorn" soil. However, once it rains, the clays expand and the slopes are soon covered by a slick, gummy mud, which is prone to downslope movement. These clays probably also produce the slide surfaces for some of the Rattlesnake slump blocks which occur in places along the John Day Valley.

Fig. 2. Mascall Type Locality. Hill on right side of photo is capped by Rattlesnake gravels and hills in background are capped by Rattlesnake Ignimbrite.

Fig. 3. Mascall Type Locality. Mascall beds (foreground) overlie Picture Gorge Basalt (background).

During the course of this century, interpretations of the Mascall deposits of the John Day Valley have yielded numerous hypotheses and theories concerning the original environment(s) of deposition. The Mascall type section is believed by the author to represent a series of paleosols that were developed on an ancient floodplain in Miocene time, the source of these sediments having been explosive silicic volcanism in the surrounding area. Previous workers have considered the type section to represent a number of different environments. In 1925 Merriam wrote that the type section deposits were "lake beds" (Merriam et al., 1925). Later Taubeneck (1950) wrote that these deposits were mostly lacustrine with some aeolian, and Dawson stated that the Mascall sediments accumulated in playa lakes similar to those now existing in eastern Oregon (Taubeneck, 1950; Dawson, 1951). Downs, in his description of the type section stratigraphy, labeled various units as aeolian (wind blown), lacustrine, and fluvial (Downs, 1956), and White believed the type section sediments to represent ash falls onto a paludal or lacustrine setting (White, 1964). Thayer and Brown thought the Mascall represented a fluviatile basin facies (Thayer & Brown, 1965), and one year later wrote that the Mascall might represent a piedmont apron (Thayer & Brown, 1966). Finally, in 1981, Ehret stated that "The Mascall is believed to have been deposited primarily as air-fall debris from violent rhyolitic eruptions,..." (Ehret, 1981).

Careful examination of the type section sediments by the author in 1985 and 1986 revealed several lines of evidence (listed below) which indicate that the area was a floodplain with active paleosol development. The majority of the clastic material deposited on this floodplain had its origin as explosive pyroclastic ejecta from nearby silicic volcanoes. Direct air fall deposits on the ancient floodplain are considered to have been minor, the vast majority of the sediment having been washed in from the surrounding highlands. Any lakes which might have existed at the type section would have been shallow, short-lived features.

EVIDENCE

EVIDENCE FOR DEPOSITION IN A FLOODPLAIN ENVIRONMENT:

1) Presence of numerous vertebrate (mammalian) fossils, representing the animals which lived on the floodplain.
2) Absence of diatom and fish fossils (evidence against lacustrine).
3) Presence of hackberry endocarps (pits) throughout the section. Today hackberry (*Celtis*) frequents stream borders (Downs, 1956).
4) Cross bedding, cross lamination, and scour & fill structures, all of which are indicative of fluvial processes.
5) Lateral accretion (point bar) deposits, which demonstrate a meandering river traversed the area.
6) Fine-grained sediments (mostly silt & clay), which were deposited in low flow regime conditions (i.e., away from the main channel).
7) Normally graded (fining upward) sequences; indicating fluvial processes.
8) Swamp deposits; today these are common in low-lying areas of floodplains.
9) Presence of ribbon sandstones; indicating stream or river channels.

10) Tabular nature of certain mudstones, suggesting deposition on a relatively flat surface.

EVIDENCE FOR PALEOSOL DEVELOPMENT:

1) Gradational contacts between beds, suggesting soil horizon development rather than depositional contacts.
2) Presence of hackberry endocarps in horizons lacking other plant debris, the endocarps being more resistant to oxidizing conditions on the ground surface.
3) Fossil root traces (both grass and trees).
4) Presence of soil horizons (i.e., horizons rich in clay, carbon, vertebrate fossils, animal burrows, etc.).
5) Coloration of the Mascall beds (yellow indicative of A horizon; red & brown indicative of B horizon). Also coloration changes commonly show little regard to lithologic or mineralogic changes.
6) Tabular nature of individual beds (mostly mudstones), suggesting mineralogic and coloration changes occurred over a large near-horizontal area.
7) Illuviation cutans (clay skins) on framework grains (due to clay infiltration).
9) Absence of significant alteration of the iron-rich heavy minerals (magnetite & ilmenite) which indicates that the alluvial soils formed rapidly and that the coloration was not the result of alteration of the iron-rich minerals (Brown & Kraus, 1981).
10) Absence of primary sedimentary structures in mudstones and the occurrence of blocky fracture and slickensides in some mudstones; indicating chemical and lithological change in the sediments after

deposition.

DESCRIPTION OF THE MASCALL TYPE SECTION

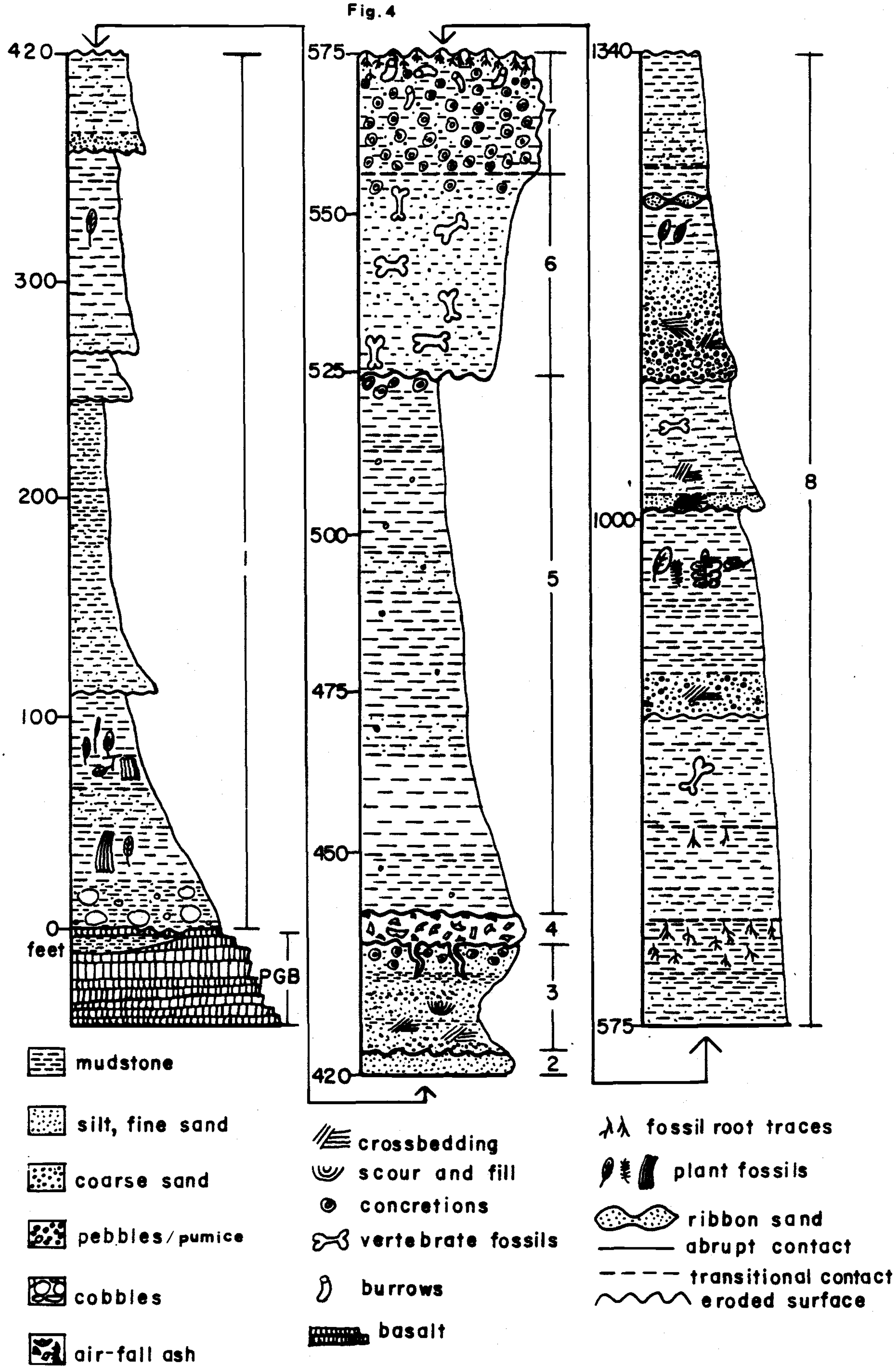
The Mascall type section was divided by the author into 8 separate units based on lithologic changes, traceability, and environmental significance. Figure 4 is a simplified sketch of the Mascal type section.

Unit #1

Unit #1 consists of a 420 ft (128 m) thick sequence of alternating yellow and gray siltstones, mudstones, and subordinate, fine grained sandstones. For convenience, the base of this unit (and thus the base of the Mascall type sediments) is considered to be the top of the uppermost Picture Gorge Basalt flow. Immediately beneath this uppermost flow is a bed of silty clay that looks much like Unit #1 and therefore it is the author's opinion that the Mascall deposits interfinger with the Picture Gorge Basalt flows in the vicinity of the type section. The very base of unit #1 contains a basalt cobble lag. These basalt cobbles are well rounded and range in diameter from 2-10 inches, and are indistinguishable from the basalt flow upon which the unit rests. These cobbles and boulders are only found as float along the very base of the unit and could not have been deposited under the same fluvial regime as the silt and clay which make up the bulk of Unit #1. It is therefore evident that although the Mascall and Picture Gorge do interfinger to a limited

Fig. 4 (following page). Mascall Type Section (measured section at Mascall type locality). Scale is consistant within columns, but not between columns.

Fig. 4



420
300
200
100
0
feet
PGB
575
550
525
500
475
450
420
7
6
5
4
3
2
1340
1000
575
8
mudstone
silt, fine sand
coarse sand
pebbles/pumice
cobbles
air-fall ash
crossbedding
scour and fill
concretions
vertebrate fossils
burrows
basalt
fossil root traces
plant fossils
ribbon sand
abrupt contact
transitional contact
eroded surface

extent, there was an interval of at least local erosion between the time of the extrusion of the uppermost basalt flow and the deposition of the base of Unit #1.

Unit #1 beds are very friable and do not crop out well at all. Instead they weather to form a soil which displays a popcorn texture in some horizons, and is nearly always covered by sage or grass. Colors of Unit #1 beds include: Dusky yellow (5Y 6/4), yellowish gray (5Y 8/2), pale grayish brown (10YR 7/2), and white. Contacts between adjacent beds are generally obscured but in the few places were they are exposed the contacts are gradational. Most of the unit consists of poorly sorted, tuffaceous siltstones and mudstones. In places these mudstones are fissle and contain numerous grass blade and leaf impressions. Under the binocular microscope it is evident that secondary clay mineral growth has taken place. This secondary clay mineral is generally yellow, often botryoidal, forms clay cutins and is almost certainly derived from the alteration of the volcanic ash (glass shards). While many beds contain only altered or relict glass shards, most of the beds still contain some glass which is at least moderately fresh.

The Unit #1 siltstones and mudstones appear to have an overall average of about 50% silt and 50% clay with <1% fine sand. Composition of the coarse silt and fine sand fractions as determined by the binocular microscope are: 90% glass shards (bubble shards which range from clear to black in color), 5% plagioclase, 5% misc. (varicolored chert, quartz X-tals, magnetite, and hornblende). X-ray diffraction of the medium-fine silt and clay fractions of a representative sample of unit #1, revealed large amounts of smectite (Mg,Ca dioctahedral),

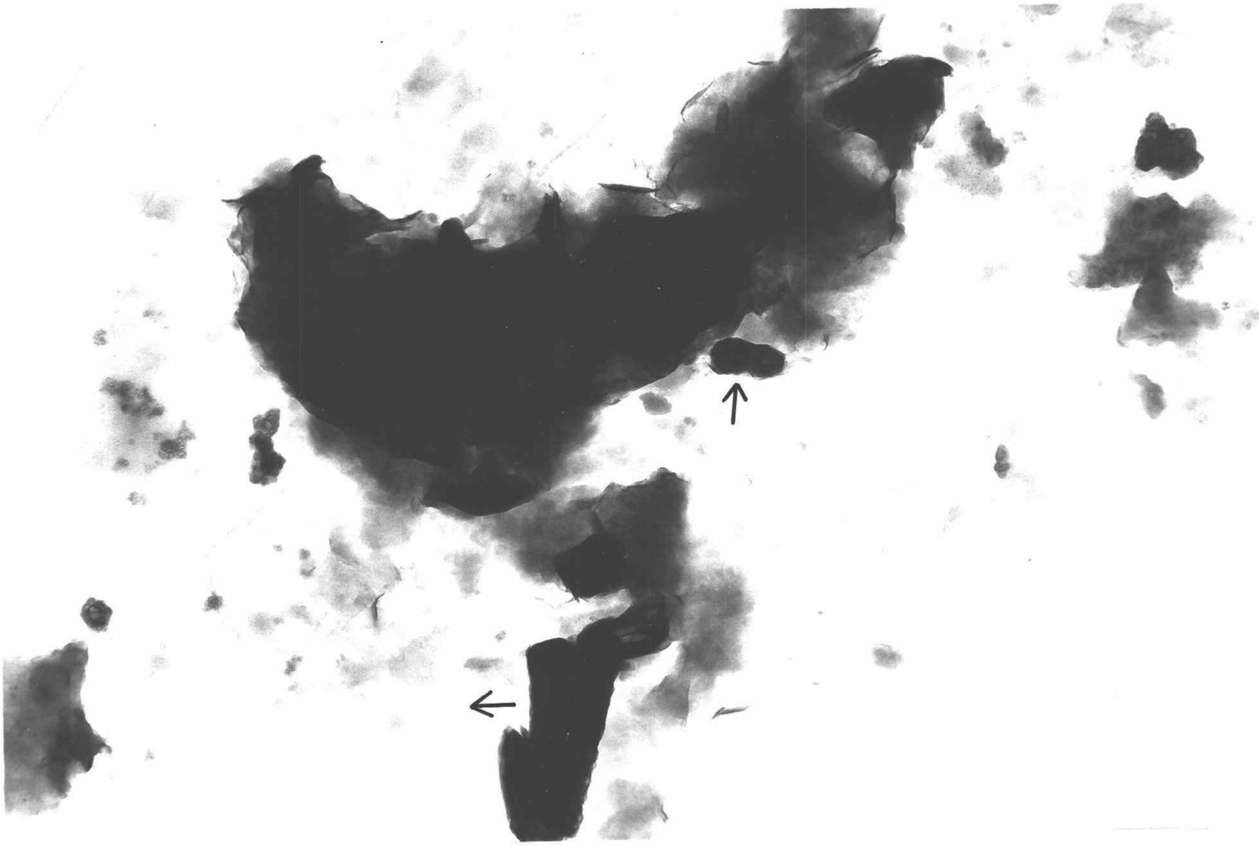


Fig. 5. Transmission electron micrograph of clay particles from unit #1. Hexagonal plates near center (arrow) are probably kaolin, and structure near bottom (arrow) is most likely tubular halloysite. Magnification is 40,000 times.

quartz, and plagioclase, and small amounts of montmorilonite (group) and magnetite-maghemite series (appendix A). Transmission electron microscopy (TEM) of this same sample revealed the additional presence of kaolin and tubular halloysite (Fig. 5). Scanning electron microscopy (SEM) of another sample (Fig. 6), shows the typical clay texture and structures of unit #1. Energy dispersive spectral analysis (EDS) of this sample showed it to contain large amounts of Si, Al, Fe, and only small amounts of Na, Mg, Ti, & Ca. The unexpectedly large amounts of Fe may be the result of precipitation in a paleosol "B horizon".

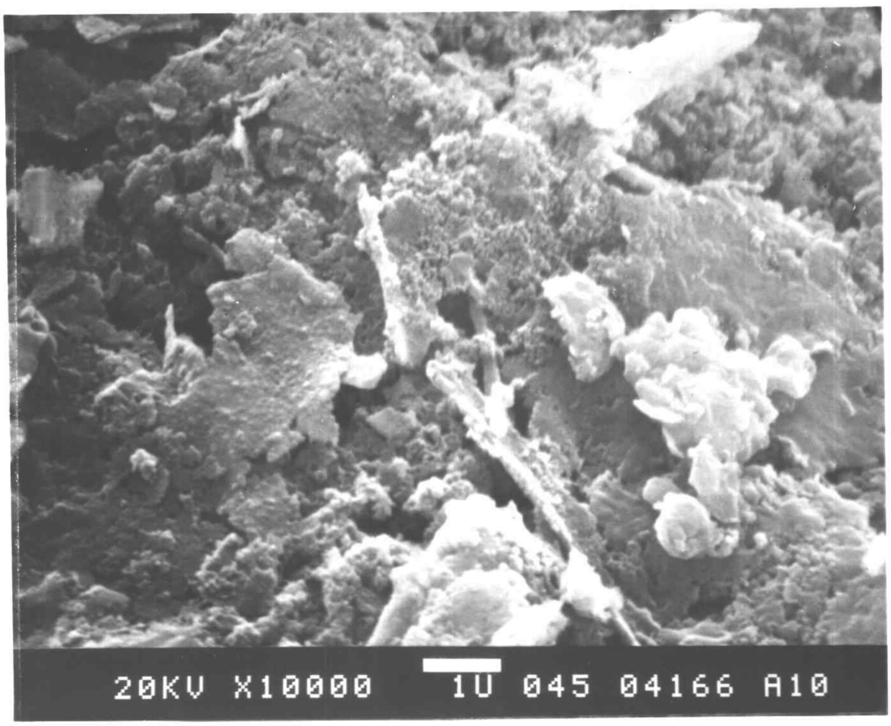


Fig. 6. Scanning electron micrograph showing the texture of unit #1. Volcanic glass has been completely altered to clay, nearly all of which is smectite. Note however the presence of a lone tubular haloysite in the upper right-hand corner.

A single, thin sandstone bed occurs near the top of Unit #1. This bed is very friable, well sorted, and composed of angular to subrounded clasts which range in size from fine to medium sand. The composition for this sandstone is 40% chert (green, gray, purple, & red), 32% glass shards (95% brown, 5% clear), 5% plagioclase, 3% magnetite, and 20% secondary clay cement derived from alteration of the glass. Although primary sedimentary structures are no longer preserved in this bed, the isolated occurrence of this bed suggests that it might be a crevasse splay.

Unit #1 represents overbank floodplain deposits. Overbank marshes are also represented along with possible crevasse splays. The lack of outcrops and poor exposure of this unit make it difficult to determine the amount of paleosol development; however it seems certain that at least incipient paleosol development did occur.

Unit #2

Unit #2 consists of a single bed of siltstone. This bed is 2-3 ft (0.6-0.9 m) thick, is well indurated, and is well exposed. The basal contact is slightly undulatory (suggesting deposition on a land surface), and the bed displays internal cross lamination. Individual laminae are generally traceable for several feet. The color of this siltstone is a light olive gray (5Y 6/1). It is moderately sorted and consists of approximately 90% coarse silt and 10% finer silt and clay. The glass shards are subangular and have been moderately altered to clay minerals. Alteration of these glass shards is highly evident in the SEM micrograph (fig. 7.). The composition of the coarse silt fraction as determined by the binocular microscope is 60% glass shards (clear), 20% plagioclase, 10% chert, 10% quartz, and <1%

magnetite.

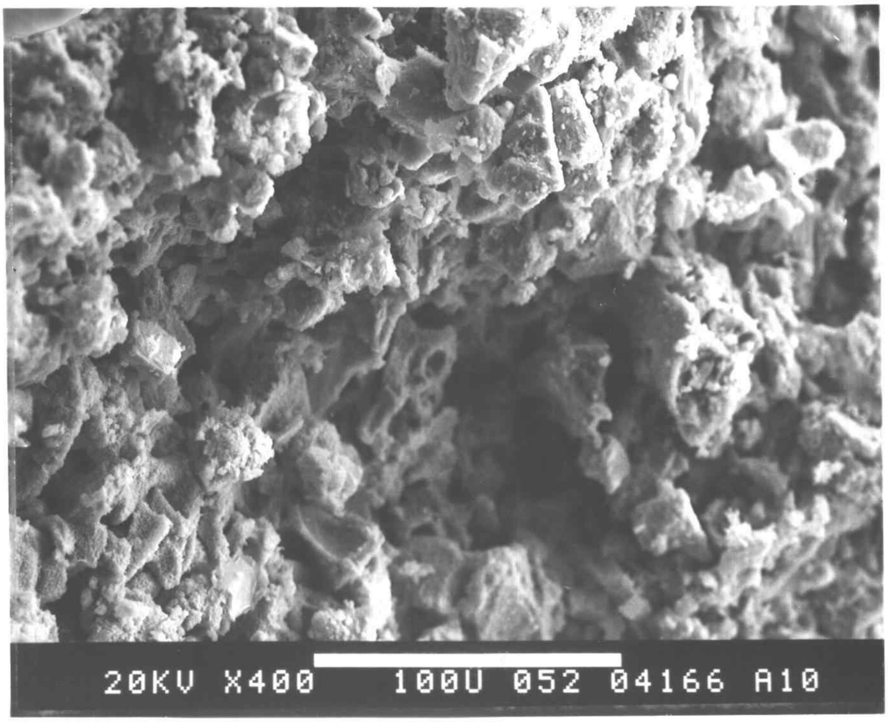


Fig. #7. Scanning electron micrograph showing the typical texture and features of unit #2. Note that the glass, which consists primarily of bubble walls, has been partially altered to clay; and that the clay serves to help cement the grains together.

Some unidentified organics are also present in this unit (see Appendix B).

Unit #2 represents a fluvial, near-channel deposit. This siltstone was deposited during a single flood event and may represent a crevasse splay. There is no evidence of any paleosol developement in this unit, and according to Retallack, 1983, the deposition of 1 meter or more of sediment is enough to arrest soil development in the underlying sediment. Presumably a new soil began forming on top of unit #2 but subsequent deposition of the overlying mudstones prevented it from developing to the point where it could be recognized. The fact that the upper contact of unit #2 seems to grade into unit #3 supports this hypothesis.

Unit #3

Unit #3 consists of a 17 ft (5 m) section of poor to moderately sorted sandstones and mudstones. Although the unit as a whole is very friable, it is indurated in a few places and forms some outcrops. The basal contact is erosional, as is the upper contact. The upper contact also displays large cracks which will be discussed in unit #4. The color ranges from a yellowish gray (5Y 7/3) to a light olive gray (5Y 6/1). The lower 2/3 of this unit displays both horizontal and cross lamination. Certain laminations are defined by heavy mineral segregations with individual laminae containing up to 20% magnetite as opposed to 1-3% for the unit as a whole. In contrast the upper 1/3 of the unit is concretionary and massive, with no hint of laminations or bedding. Upon close examination it is seen that the concretions are formed by filling in tiny burrows. This bioturbation is responsible for the elimination of the primary sedimentary features (i.e. cross bedding) and is also a feature commonly observed in fossil soils (Retallack, 1983). The contact between the upper bioturbated, concretionary part of the unit, and the lower cross bedded part of the unit is very gradational, occurring over a vertical distance of 1-3 feet.

Overall the unit consists of approximately 50% sand, 25% silt, and 25% clay. Examination of the sand sized fraction of the unit shows the composition to be: 35% glass shards (black, brown and clear, often subrounded and very altered), 25% plagioclase, 25% chert (all colors and well rounded), 5% misc. (magnetite, hypersthene, hornblende, manganese crust). The black glass is interesting in that it contains no bubbles, often displays nearly straight borders, and is silicic in composition. SEM examination (presumably of the clear glass) shows the glass to be highly vesicular and to have relatively thin bubble walls (fig. 8). These characteristics are thought to be representative of ash extruded by Plinian or Pelean types of eruptions (Heiken & Wohlentz, 1985).

Unit #3 consists of channel deposits near the base and grades into levee deposits and near-channel overbank deposits near the top. Although large scale features are poorly preserved, it is probable that this unit represents a lateral accretion sequence with the development of a paleosol in the upper 1/3 of the sequence.

According to the U.S. Department of Agriculture Classification; the "A horizon" is usually quartz-rich, sandy, and light-colored, due to being leached of humus, iron, and aluminum (Retallack, 1983). Because the upper part of unit #3 has lost its primary

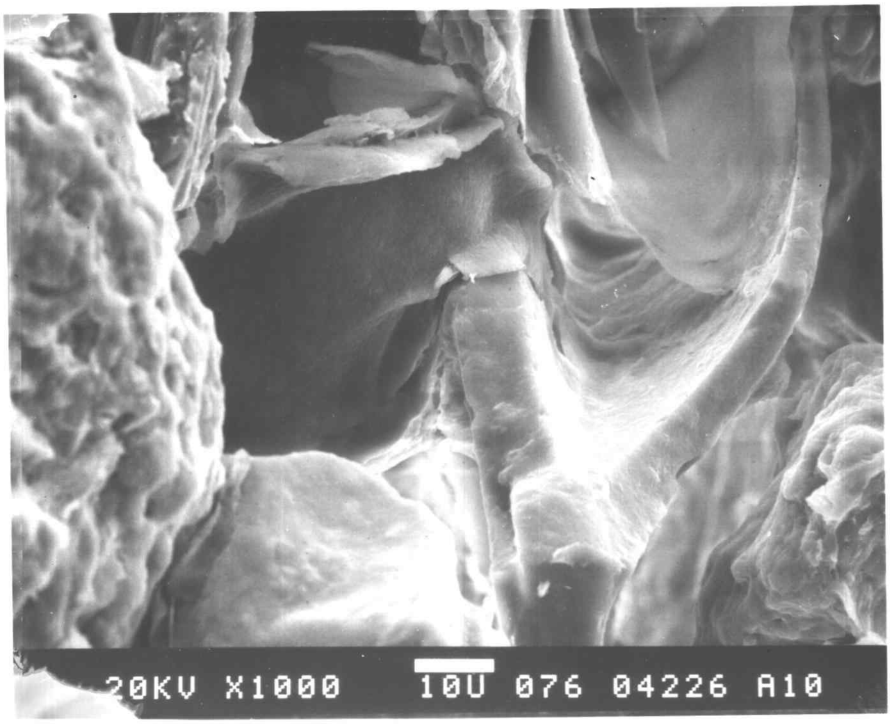


Fig. 8. Scannning electron micrograph of unit #3 showing vesicular nature of included glass (note thin bubble walls). Also note the freshness and unaltered appearence of this sample.

sedimentary structures, and because it fits the profile given by the Department of Agriculture, the author believes unit #3 to represent an "A horizon" of soil profile developement.

Unit #4

Unit #4 consists of a 4 ft (1.2 m) bed of vitroclastic air-fall tuff. The color is light gray (value of 7), and although the unit is very friable, it does form an outcrop. The basal contact is very undulatory and suggests that the unit was deposited on a land surface.

Large cracks or fissures occur at the top of unit #3 and these are filled by the ash of unit #4. The appearance is that unit #4 was injected down into unit #3, producing a series of clastic dikes. These "clastic dikes" are laterally separated by a distance of 10-20 ft (3-6 m), extend roughly 1-2 ft (0.3-0.6 m) down into unit #3, are 1-2 inches (2-5 cm) wide at the top (tapering with depth), and appear to extend in the third dimension. Similar "clastic dikes", which cut down 2-4 ft (0.6-1.2 m), occur on the north side of the John Day River where a Mascall fluvial sandstone overlys a mudstone (see fig. 32). It is highly doubtful that these could represent simple mudcracks as no smaller ones are seen. Shrock (1948) lists numerous ancient and modern examples of these features and attributes their formation to either earthquakes or subsoil creep. In the process of subsoil creep, the lower unit (unit #3 in this case) would form surface fissures or cracks which would then be filled by material that was either blown or washed in. If earthquakes were responsible they could produce the cracks before or after the deposition of the overlying strata, with the overlying strata (unit #4) either being washed in or injected in from above. The author is uncertain which one of these processes was responsible for the features observed, and can only say that these might represent ancient earthquake activity in the area.

Unit #4 is generally massive; however rare, small-scale cross bedding does occur. Small channel scours and fills with normally graded sequences also occur in a single section of the outcrop. These channels only extend a few inches in vertical dimension, a couple of feet in horizontal dimension, and are sometimes only separated by a few inches to a few feet. It seems very likely that these channels represent minor reworking of the newly deposited ash blanket by a small creek which was traversing the area.

The pyroclastic material of unit #4 is composed entirely of angular glass shards, which are incredibly fresh. Nearly 100% of this glass is of a clear, highly vesicular variety, with the remaining glass (<<1%) being black in color and displays a blocky morphology. This unit undoubtedly represents air fall from a single volcanic eruption, and as the unit is some 4 feet (1.2 meters) thick; the eruption was either very close, very large, or both. This unit also represents the only direct airfall material observed in the type section. The unit is generally well sorted with most of the pyroclasts being less than 1 mm in diameter. Figures 9 and 10 are SEM micrographs of unit #4. These photos show that the ash is composed of bubble wall shards and drawn out vesicles. According to Heiken and Wohlentz (1985), ash of this sort is a very common product of Plinian and Pelean eruptions. By comparing this ash to the ash of a fluvial deposit (Fig. 23), one can clearly see the differences in texture. The air fall ash of unit #4 shows absolutely no rounding whatsoever, and the cavities and vesicles are devoid of smaller grains which would have been picked up had the ash been transported any significant distance downstream. The fluvial ash, on the other hand, shows significant rounding and several of the vesicles have smaller clasts shoved into them.

As previously mentioned, the deposition of more than 1 meter of material is sufficient to arrest soil development and cause a new soil to begin to form on the higher land surface (Retallack, 1983). Thus it is not suprising that no soil development is recognizable by the author in unit #4.

Fig. 9.

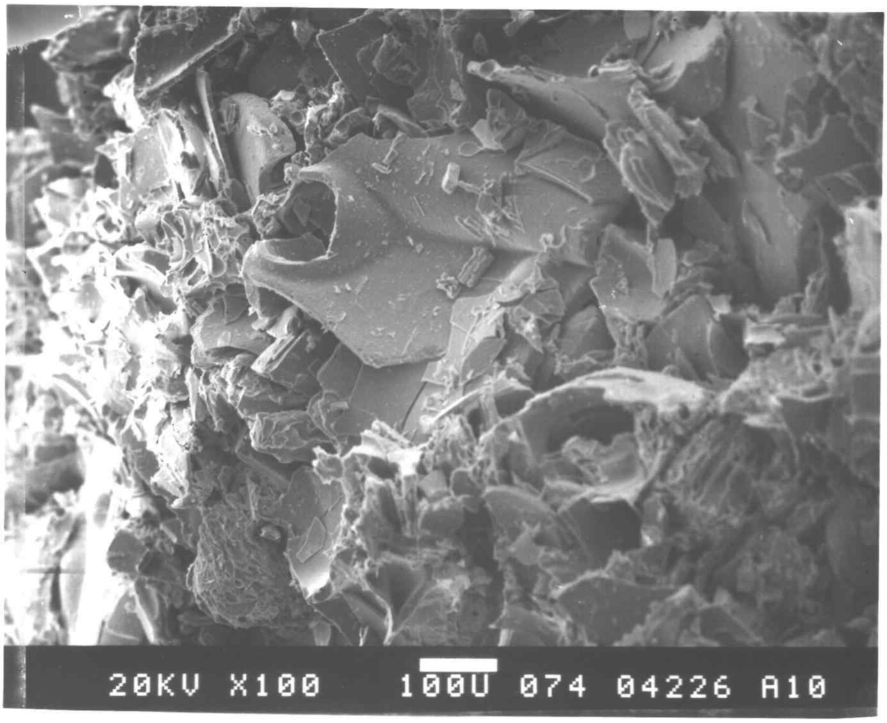
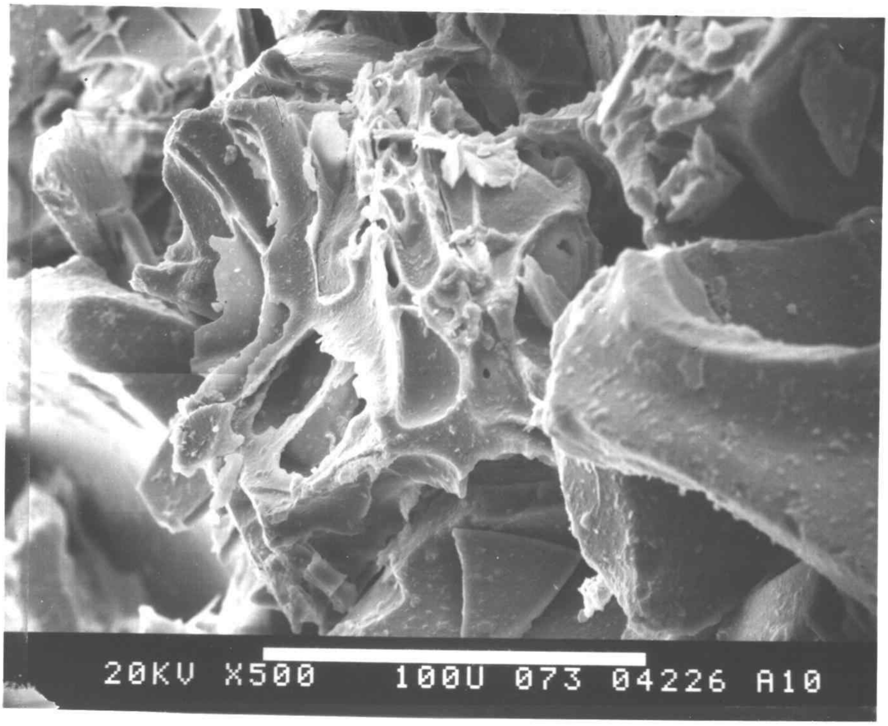


Fig. 10.



Figs. 9 and 10. Scanning electron micrographs of air fall ash (unit #4). Fig. 10 is an enlargement of the upper left-hand area of Fig. 9. Notice the high angularity of the shards, absence of cavity-filling detritus, and presence of adhering volcanic dust (all indicative of air fall material). Also note highly vesicular nature.

It should be noted that although unit #4 represents the only air fall material recognized by the author in the type section, this does not mean that air fall is non-existant in the remainder of the section. Instead, unit #4 probably represents the only time (or one of a very few times) that the air fall from an eruption exceeded 1 meter in thickness at the type section. Other air falls undoubtedly occurred over the type section, but must have been of a lesser magnitude and were incorporated into the soil which was forming on the floodplain at that time.

Unit #5

Unit #5 is an 80 ft (24 m) thick sequence of alternating yellow-gray, brown and pinkish tuffaceous siltstones and mudstones. None of the beds form outcrops, and the entire unit forms a gentle slope devoid of any detail except for gradual changes in color. Individual beds are not traceable for more than 150 feet. Some beds contain pumice clasts <1 inch in diameter which are found as float. A representative sample was collected from the middle of the unit. It is yellowish gray (5Y 7/1), composed of 90% clay and fine silt, 10% medium to coarse silt, and <1% very fine sand. Mineralogy was determined by X-ray diffraction to be mostly smectite (Mg, Ca) with large amounts of plagioclase, and small amounts of quartz, montmorilonite, and magnetite-maghemite, and a trace of clinoptilolite. SEM revealed no traces of glass shards, indicating that they have been entirely altered to clay minerals. A typical SEM view of this sample is shown in fig. 11.

Unit #5 represents overbank floodplain deposits. Paleosol development is inferred from alternating colors and the gradational

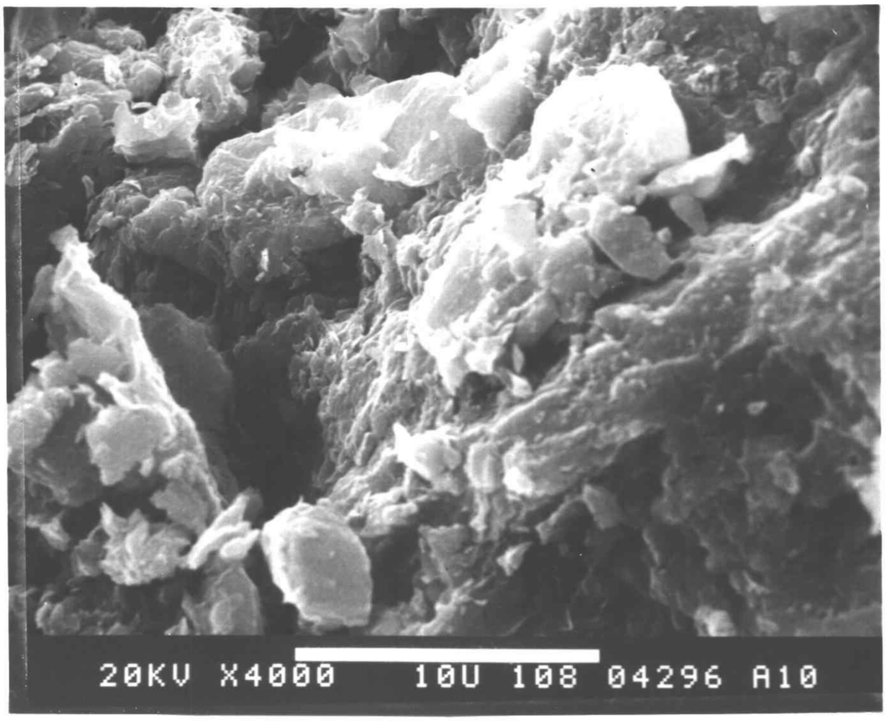


Fig. 11. Scanning electron micrograph showing typical texture of unit #5, which is dominantly composed of smectitic clay.

contacts between beds. Soil profile development includes both the A horizons and probably at least the upper B horizons, with the A horizons corresponding to the yellow beds, and the upper B horizons corresponding to the brown and pinkish beds.

Unit #6 (Mammal Horizon)

Unit #6 is 30 ft (9 m) thick, massive, tuffaceous mudstone with no trace of bedding planes. The unit overlys unit #5 with a sharp, slightly undulatory contact. This is the most famous and most studied bed of all the Mascall deposits in the John Day Valley; because it contains the bulk of the mammal fossils. This bed is so rich in mammal fossils compared to the rest of the Mascall deposits that Merriam termed this bed the "Mammal Horizon" (Merriam et al., 1925).

The "mammal horizon" is well known to the local population, and although Merriam and subsequent workers have collected most of the fossil material, each new rain brings the possibility of exposing something new. The mammalian remains are not so well preserved as those in the John Day Fm., and teeth and single bones comprise the bulk of the fossil material (Merriam, 1901). This mammalian faunal assemblage has been dated as middle Miocene (Barstovian) in age, and it is from this faunal assemblage that the Mascall deposits as a whole are dated (Merriam et al., 1925). Several fossils were found by the author as float along the slopes of the mammal horizon. These were identified by Ruben (1985), and include teeth and ankle bones of Merrychippus (horse), two artiodactyl lower jaws, and an Oreodont lower jaw (fig. 12). Dentition shows that both young and old individuals are represented. Generally the fossil material showed little or no water abrasion and no gnaw marks, an observation also noted by Downs (1956). This indicates that the animals died on the floodplain and were quickly buried.

In addition to the mammal fossils, numerous hackbery (Celtis) endocarps (pits) were found inside the unit. In a few instances large clusters of seeds, representing entire bushes, were found. The presence of hackberry endocarps is significant because today hackberry plants often frequent stream borders (Downs, 1956). Perhaps during major floods these bushes were either buried, or else bank erosion caused them to be torn loose and later deposited along with the silt.

Although hackberry endocarps occur throughout the Mascall type section as float, it is only in the mammal horizon and unit #7 that they seem to be a significant constituent of the sediment. Both the mammalian and hackberry fossils were found at all levels in the mammal horizon with no evidence to show concentration of material at the base (Downs, 1956). This observation eliminates the possibility of the unit being airfall, because if that were the case, then all the fossil material should be located at the base. In addition, the fact that only teeth, bones and hackberry endocarps were preserved (endocarps contain substantial biogenic calcium carbonate and silica), and other fossils such as leaves, branches, etc. were not, indicates oxidizing conditions such as are found in the upper soil or on the ground surface (Retallack, 1983).

The mammal horizon (unit #6) is traceable for approximately 10 miles. Wherever it crops out it is capped by the same concretionary horizon (unit 7). Because the overlying concretionary horizon is highly indurated, the mammal horizon tends to form shear cliffs 20-40 ft (6-12 m) high (fig. 13). Periodically large blocks of the mammal horizon (several feet across) break loose from the cliff and tumble down the slope. As the mammal horizon is very soft these blocks disintegrate quite rapidly.

The color of the mammal horizon is a yellowish gray (5Y 8/1), and it is composed of approximately 10% fine sand, 25% silt, and 65% clay. Framework grains are often covered by clay cutins. Most of the clay was probably formed secondarily as an alteration product of the ash. Constituents of the sand sized fraction include: Plagioclase, glass shards (clear), hackbery fragments, chert, magnetite, ilmenite,

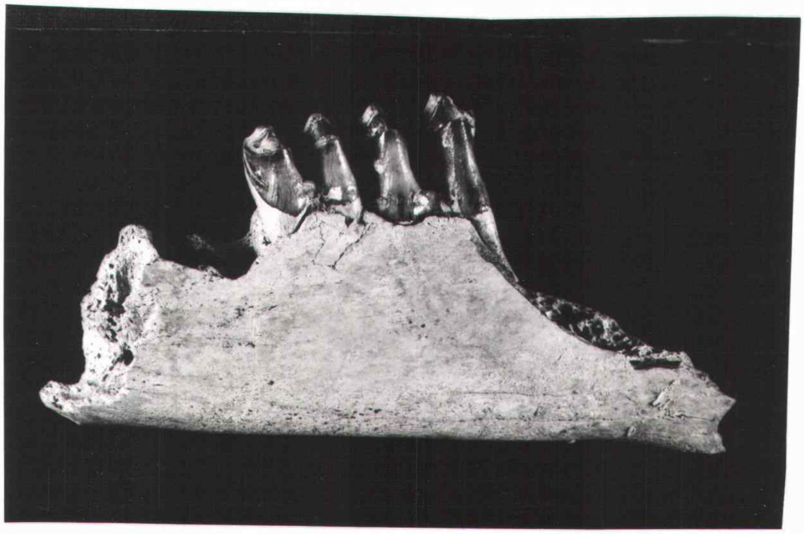


Fig. 12. Oreodont lower jaw collected from slope of mammal horizon. Notice the unabraded nature of the fossil.

Fig. 13. Photo of mammal horizon displaying cliff-like outcrop. Large blocks periodically break free and tumble down the slopes.

orthopyroxene, and very small amounts of quartz. This composition is rather unusual in that the combined magnetite and ilmenite comprise approximately 4% of the sediment. A very few pumice clasts (up to one inch in diameter) are also found in the unit. X-ray diffraction shows the composition of the clay and fine silt to be mostly plagioclase, with lesser amounts of smectite, magnetite-maghemite, quartz, montmorilonite, and possibly olivine. Transmission electron microscopy reveals the additional presence of spheroidal haloysite, (fig. 14). The microscopic appearence of the mammal horizon is well displayed in fig. 15.

Fig. 14. Transmission electron micrograph depicting clay mineralogy and structures of the mammal horizon. Clay is nearly all smectite except for some spherical halloysite (arrow). Magnification 40,000X.

Fig. 15.

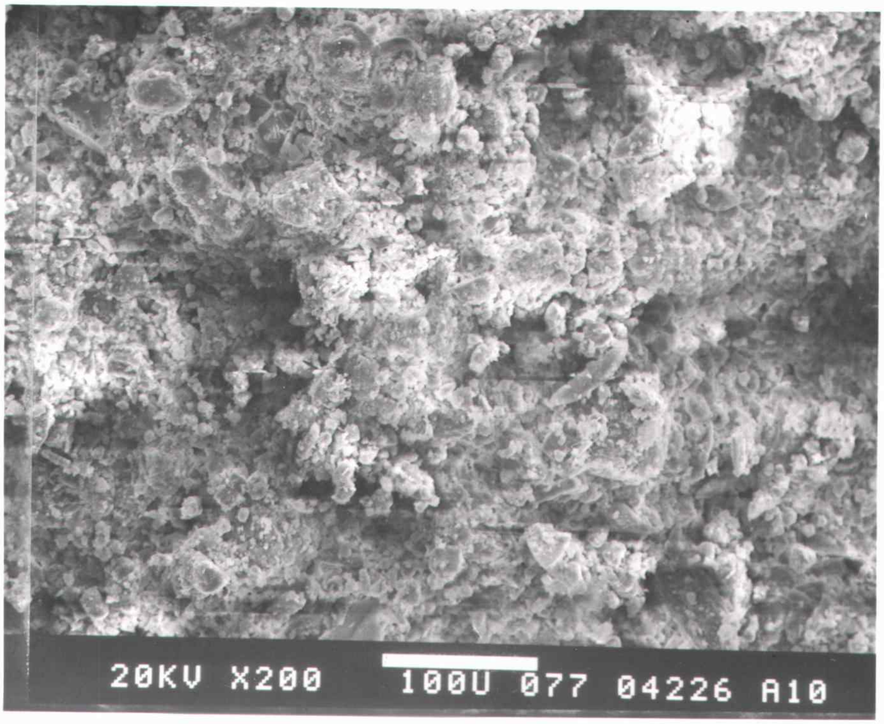


Fig. 16.

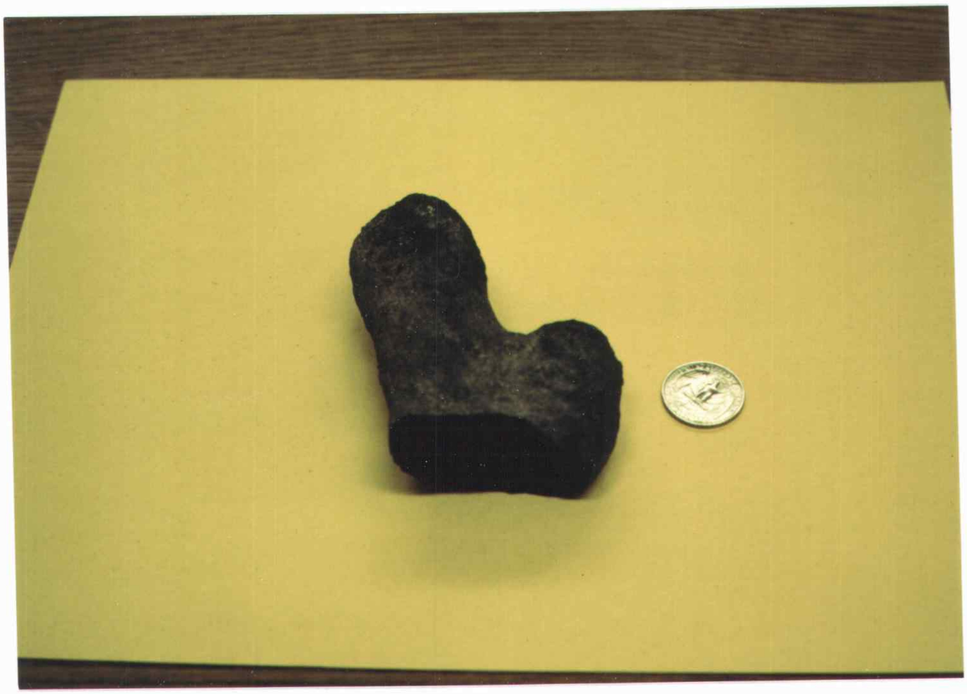


Fig. 15 & 16. Fig. 15 is a SEM micrograph of the mammal horizon. Note the poorly sorted and badly altered nature of the unit, as well as the clay skins (cutins) which have precipitated around many of the grains. Fig. 16 is of a sample of the manganeese crust which may form at the base of the mammal horizon.

The most noticeable feature in the outcrop is the tendency for thick (1-4 inch/2-10 cm) manganese crusts to form near the base of the unit. These crusts have a very unusual shape and commonly form projections which are rounded at the ends. Sheets of these crusts are generally horizontal and may reach 10`s of feet in length. Occasionally the manganese crusts also fill fractures in the unit (fig. 16). The manganese crusts are composed of roughly 40% clastics (including glass, quartz, plagioclase, and fossil bone), and 60% cement, which EDS reveals to be predominantly manganese oxide with lesser amounts of iron oxide. It appears that the manganese is probably leached from the upper 25 ft (8 m) of the unit and precipitated in the basal 5 ft (1.5 m), with this leaching being a recent phenomenon and not indicative of the soil forming conditions which occured in Miocene time.

The lack of primary sedimentary features in unit #6 along with the richness in mammal material strongly suggests that this was part of a floodplain undergoing soil formation. The fine grained nature of the sediment, and more importantly the lack of any noticeable abrasion of the fossil bones, indicates that this was an overbank area far removed from the main channel.

Unit #7 (Concretionary Horizon)

Unit #7 is a highly concretionary horizon which averages about 18 ft (5.5 m) in thickness. This horizon is very well indurated, is a ridge former, and weathers to form rugged outcrops which are often covered by lichen. It is traceable for approximately 14 miles (23 km) and with the exception of the most easterly and most westerly outcrops, it always immediately overlies the mammal horizon. Although

Fig. 17. Concretionary layer overlying the mammal horizon with gradational contact. Photo is from north side of John Day River.

the concretionary horizon displays only crude internal bedding at the type section, a few miles to the northeast it contains several thin (2-4 inch/5-10 cm) interbeds of soft, earthy-looking mudstone. The contacts between the concretionary horizon and the softer earthy beds are slightly undulatory, suggesting a land (floodplain) surface. The basal contact with the mammal horizon is very gradational (see Fig. 17), with concretions also occurring in the upper 1-2 ft (0.3-0.6 m) of the mammal horizon. This gradational contact, the fact that wherever the mammal horizon occurs the concretionary horizon overlies it, plus the fact that both units share nearly identical mineralogy; conclusivly demonstrates that unit #7 is derived by alteration of material identical to unit #6, that is, units #6 and #7 were originally a single depositional body. Because previous workers have separated these units, and because they appear radically different in the field, the author has continued to number them separately.

Unit #7 is a light olive gray (5Y 6/1) in color. The unit is generally composed of >50% concretions, 25% silt, 25% clay, and <1% sand (excluding concretions). The sand fraction is essentially identical to that of the mammal horizon; containing plagioclase, magnetite, ilmenite, hackberry fragments, glass shards, orthopyroxene, and quartz. The fine silt and clay fraction as determined by XRD (figure 18), is mostly plagioclase, with lesser amounts of smectite, magnetite-maghemnite, and halloysite (dehydrated).

Examination of the XRD pattern in fig. 18 immediately reveals the striking similarity between the mammal and concretionary horizons. Nearly all mineral peaks present in the mammal horizon sample, are present as well in the sample of the concretionary horizon. The reason for the mineral peaks being higher in the mammal horizon sample is two-fold. The main reason is that instrument sensitivity was higher on the mammal horizon run; however, the increased weathering and alteration of the concretionary horizon also contributes to this effect. Had the instrument sensitivity been the same for both samples, then the smectite peak of the concretionary horizon would have been significantly higher than that of the mammal horizon; a factor which is also the result of the increased weathering and alteration of the concretionary horizon.

The concretions in the concretionary horizon range in size from 0.5 mm to 3 cm in intermediate diameter. However, nearly all the concretions fall in the 0.5 mm to 3 mm size range and these

Fig. 18 (following page). X-ray diffraction pattern of selected units from the type section. Note similarity of mammal horizon and concretionary horizon. P-plagioclase, q-quartz, s-smectite, c-clinoptilolite, k-kaolinite, m-m-magnetite-maghemite.

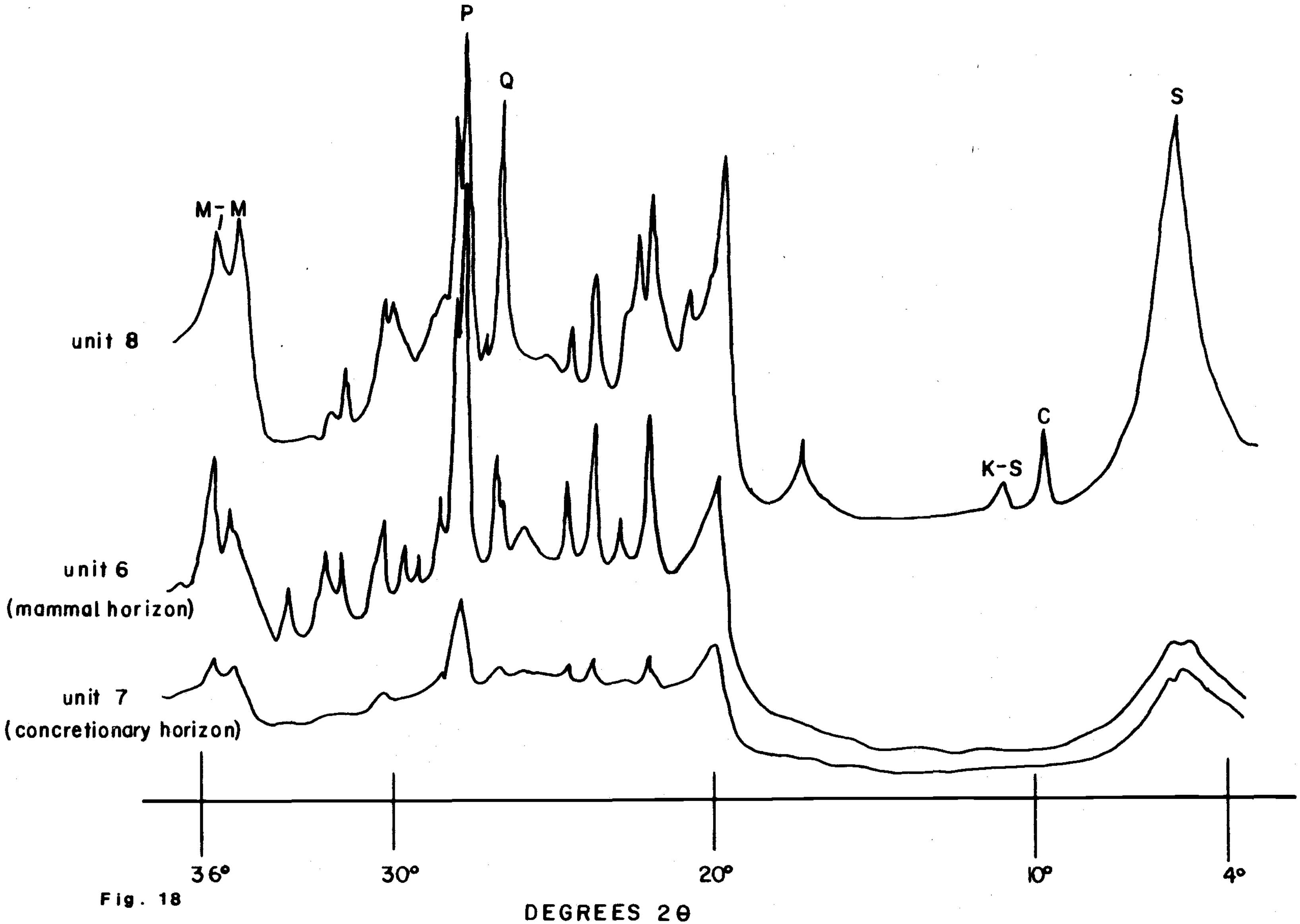

P
Q
S
M-M
unit 8
C
K-S
unit 6
(mammal horizon)
unit 7
(concretionary horizon)
36°
30°
20°
10°
4°
DEGREES 2θ

Fig. 18

are usually spherical mudballs which often contain a mudclast of different color in their center. These mudballs become somewhat larger at the westernmost exposure of the unit (radio tower), where they are commonly up to 5 mm in diameter. Nearly all the concretions larger than 5 mm were found to be formed either from pumice clasts, or more commonly from animal burrows (figure 19).

In the field, evidence abounds to support that unit #7 is a paleosol and probably represents a significant temporal hiatus. Bioturbation is very common with dozens of burrows per square meter. These burrows are commonly about 2 centimeters in diameter and and >10 centimeters long, with the terminations generally not exposed. Figure 19 is of a portion of one of these animal burrows. Root traces are also very common and are concidered to be definitive evidence of paleosol development (Retallack, 1983). In the type section the root traces are dense and only about 1-2 mm in diameter and 2-5 cm long. These probably represent grass roots, and along with the hackberry bushes suggest a typical floodplain flora. Across the John Day river, some much larger plants must have been growing. Here dozens of fossilized root fragments were found as float on the concretionary layer and mammal horizon. Some of these roots are shown in figure 20. One root fragment had a diameter of 8 cm and a length of over 1/2 m. This would seem to represent a tree of some sort.

Unit #7 (concretionary horizon) represents a significant temporal hiatus. The multitude of root traces and animal burrows, the exceptional lateral continuity (21 km as opposed to <100 meters for the rest of the Mascall), the high induration and massive nature, as well as the mineralogical similarity to the underlying mammal horizon;

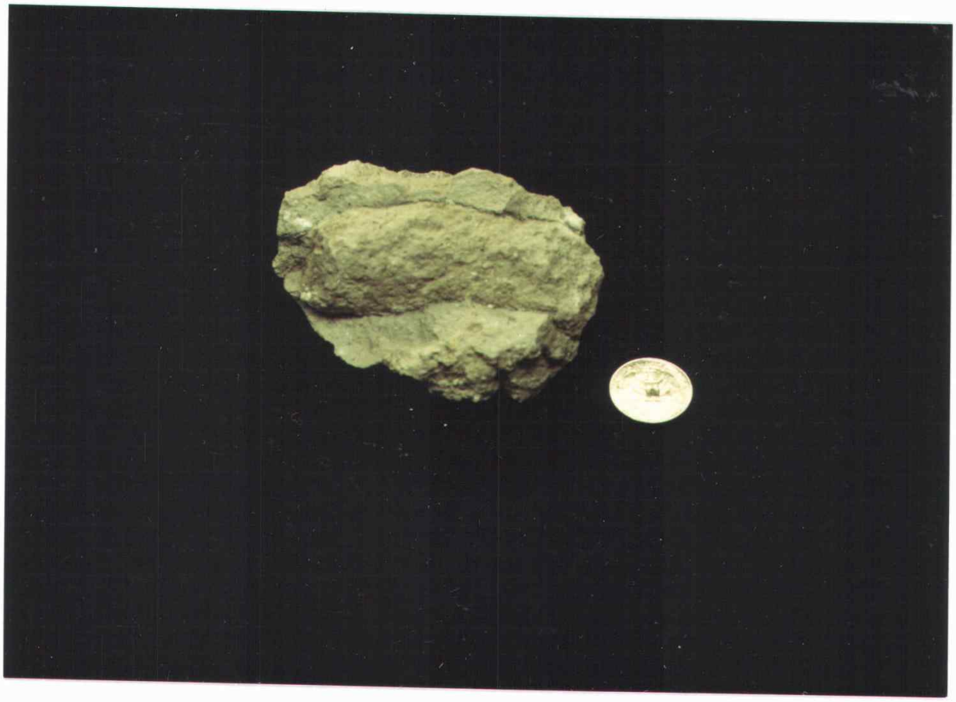


Fig. 19. Fossilized burrow from within the concretionary horizon.

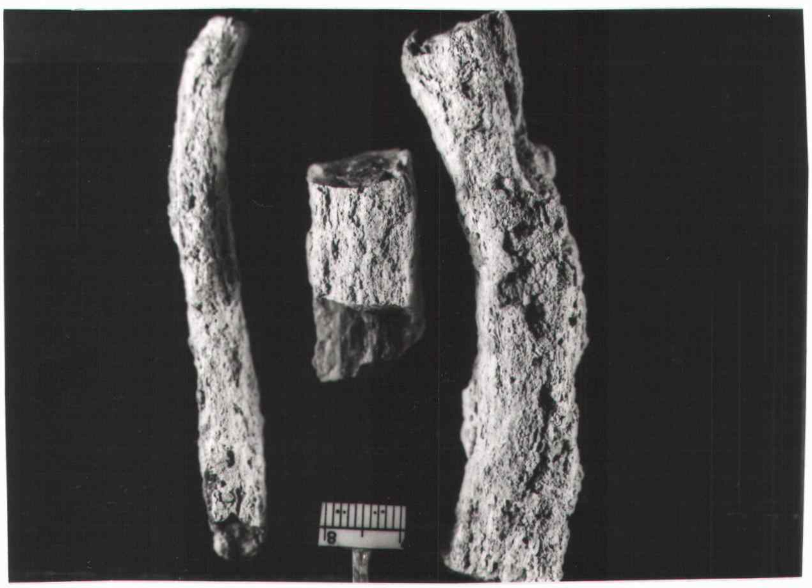


Fig. 20. Fossilized roots from the concretionary horizon.

demonstrate conclusively that this unit represents a long interval of little or no deposition, with the contemporaneous formation of a deep, aerialy extensive paleosol.

Several factors may have been responsible for this lengthy lack of sedimentation which permitted the soft mammal horizon to have its upper 18 feet (5.5 meters) transformed into a tough concretionary horizon. Probably the most likely is that unit #7 represents the formation of large alluvial terrace. Other possible reasons include a temporarily dryer climate, or a lull in volcanic activity. It should be noted, however, that no calcite or caliche occurs in this concretionary horizon (or anywhere else in the section for that matter). Reinek & Singh (1980) state that in a semi-arid climate a hiatus of 1000 years is sufficient for incipient caliche formation. Therefore, if the climate were semi-arid, the duration of the hiatus probably could not have been longer than 1000 years. If, however, the climate were wetter, as organic rich beds elsewhere in the Mascall and lack of any calcite would suggest; then no real constraints can be put on the length of the hiatus.

Unit #8

Unit #8 is 765 ft (233 m) thick section of tuffaceous siltstones and mudstones (overbank deposits), and subordinate sandstones (channel deposits). The section begins with a sharp, irregular contact at its base (suggesting deposition on a land surface) and is truncated with pronounced angular unconformity by Rattlesnake gravels at its top. Colors of the beds, although rather dull in appearance, are highly variable and include: White, olive gray, yellowish gray, yellowish brown, and dark reddish brown; with the reddish brown beds being mostly confined to the lower half of the unit. Individual beds range in thickness from 2-15 ft (0.5-5 m) and are traceable for as much as 100 feet (30 meters). The beds are generally friable and nearly always form smooth slopes. Contacts between adjoining beds are gradational. Popcorn soil is fairly well developed in some horizons, and manganesse crusts tend to form where particular beds crop out. A few fossil bone fragments and hackberry endocarps occur as float throughout the unit. Lateral accretion deposits are identified in this unit, and although they are poorly defined, they appear to have been formed by a channel on the order of 10 ft (3 m) in depth. Swamp deposits, pebble lenses, and a ribbon sandstone are also identified in this unit.

Many beds of unit #8 are particularly important in describing the characteristics of the type section. For this reason samples from five differet beds were collected for laboratory study. These samples are discussed below.

Sample H (I) is of a poorly sorted sandstone which is located approximately 1/3 of the way up into the unit. This bed is very coarse in comparison with the rest of the type section sediments, and represents a channel deposit. Grain size analysis (Appendix C) shows the unit to be positively skewed with a mean size of 0.98 phi. This sandstone consists of approximately 65% ash flow clasts, 20% chert (varicolored), 10% basalt, 5% misc. (quartz, magnetite, plagioclase, and hornblende). The ash flow constituent becomes increasingly important in the coarser size fractions and makes up over 90% of the rock in the granule size.

Sample H (II) is of a poorly sorted pebbly sandstone. This sandstone occurs roughly 2/3 of the way up in the unit. It is lenticular in nature and is the coarsest bed to be found anywhere in the type section (excluding the basalt cobble lag at the base of unit #1). Grain size analysis shows the sample to have a skewness of zero and a mean grain size of -0.25 phi. Like the previous sandstone, this one is also dominately composed of ash flow clasts with the ash flow contribution equaling 100% of the clasts in the -2 phi to -4 phi (pebble) size fraction. The statistical sample contained a single cobble of scoria, however examination of a larger sample revealed that scoria cobbles were very rare. Overall the composition of the pebbly sandstone is 90% ash flow clasts, 5% sandstone clasts, 5% misc. (basalt, chert, quartz, clay balls & disks, and monzonite).

Sample H (III) is of a well indurated, reddish brown, tuffaceous mudstone. This mudstone tends to break into blocky fragments which display slickensides and black precipitates on their surfaces. Root traces are very common and are approximately 1-2 mm in diameter and 2-4 cm in length. This bed is approximately 10% silt and 90% clay. X-ray diffraction shows the fine silt and clay fraction to be mostly smectite ((Mg, Ca) dioctahedral), plagioclase, and quartz, with lesser amounts of montmorilonite, magnetite-maghemite, clinoptilolite, and a trace of what is probably mixed layer kaolinite-smectite (Mg, Ca). Figure 21 is an TEM micrograph, displaying the clay mineralogy and structure of the sample. A few scattered halloysites are seen to occur in addition to those clays previously mentioned. A line drawing of the X-ray diffraction pattern of this sample is displayed in fig. 18.

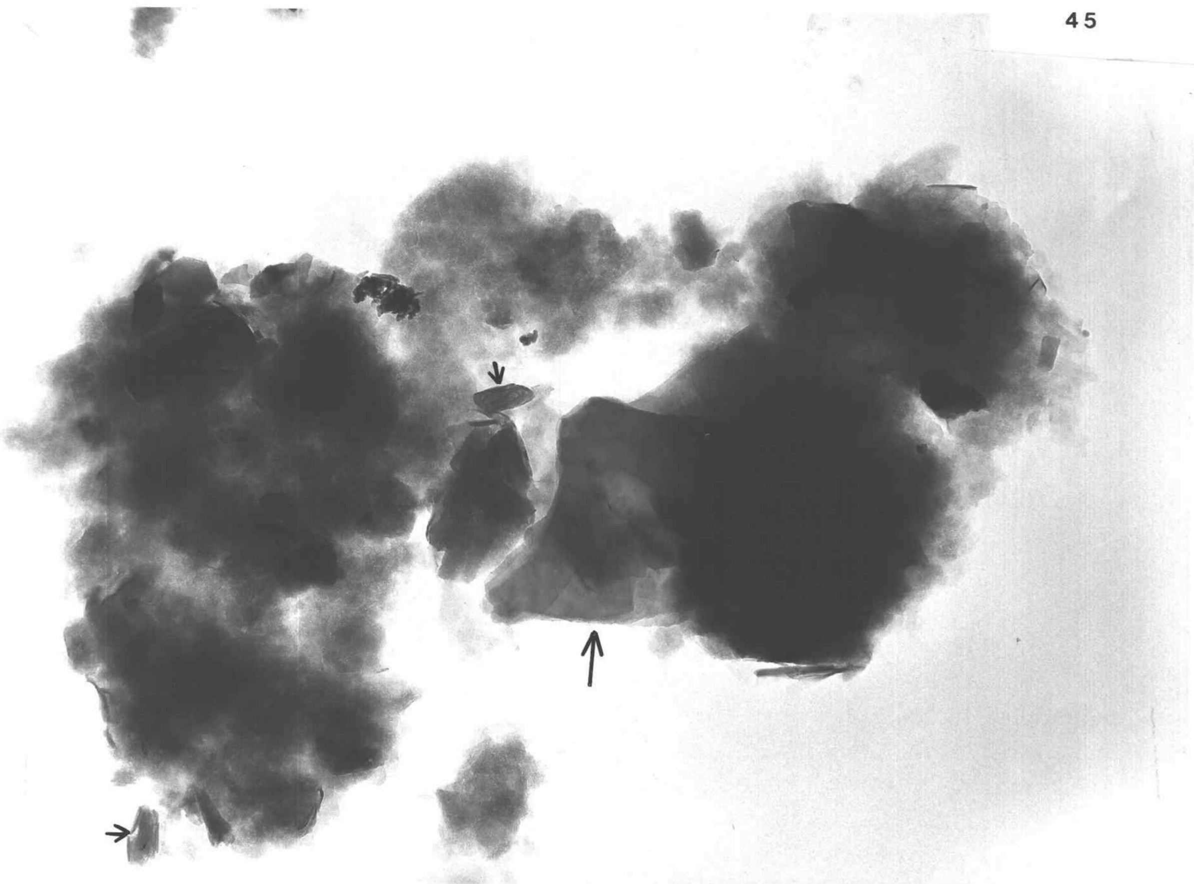


Fig. 21. Transmission electron micrograph of clay particles from a bed within unit #8. The bulk of the clay particles are smectite. The large plate (arrow) is probably mixed layer kaolinite-smectite, and smaller arrows point to spheroidal halloysite. Mag. 40,000X.

Sample H (IV) is of a swamp deposit. The bed is a light brown and does not contain any lignitic material; therefore soil conditions must have remained fairly oxidizing. The bed is very well indurated and consists of approximatly 0-5% fine sand, 40% silt, and 55% clay. Ferns, Metasequoia glyptostroboides(?), and broad-leaf deciduous plants (possibly Alnus), all occur as impressions in this deposit. Animal burrows (0.5-2.0 cm in diameter) are also quite common in this deposit. The bed is pervaded by a myriad of tiny spherical bubbles ranging from a pin-point to 3 mm in diameter. Presumably these bubbles represent swamp gases formed by decomposition of vegetable matter.

Sample H (V) is of a vitroclastic ribbon sandstone. Unlike the other sandstones of the type section, this channel sandstone is composed of nearly pure volcanic ash (impurities being <<1%). The ash is very fresh, is snow-white in color, and contains black specks which are scattered throughout. This ribbon sandstone is a simple sandstone body (one story), and contains no adjoining wings. For a description of ribbon sand geometry see Friend et al. (1979). This sandbody represents a single volcanic eruption in which a stream channel became partially filled with ash. The channel is highly sinuous and highly lenticular. As the sand body is 20 ft (6 m) wide by 6 ft (1.8 m) high; the channel has an apparent width/height ratio of 3.3. Because the stream channel was not completely filled by the ash (there are no wings or overbank ash); the depth of the channel must have been somewhat greater than 6 ft (1.8 m). It is difficult to say just how wide the channel actually was for two reasons: First the outcrop probably represents a somewhat oblique section across the channel (making the true channel less than 20 ft) and secondly the ash did not completely fill the channel (channel boundries are only visible where the white ash is in contact with the adjacent gray mudstone,thus implying that the true channel width may be much larger than 20 ft). A good guess is that the channel width was probably on the order of 30-40 ft (9-12 m). The channel sandstone ranges from very friable to moderately indurated, is crosslaminated, and is well sorted (clasts range in size from very fine sand to coarse silt). The ash consists of 99% glass (clear and extremely fresh), 1% biotite, and a trace of magnetite. The presence of biotite is in itself important in determining provinance of the Mascall Formation ash. Because the mineral biotite is highly uncharacteristic of the Cascade volcanoes (Taylor, 1986), this may suggest that the Cascades were not the source of the Mascall ash. Scanning electron microscopy (fig. 23) reveals the ash to be somewhat rounded and in some cases cemented together to form aggregates. The highly vesicular nature of some of the pyroclasts suggests that the eruption was probably of a Plinean or Pelean nature (Heiken, 1985).

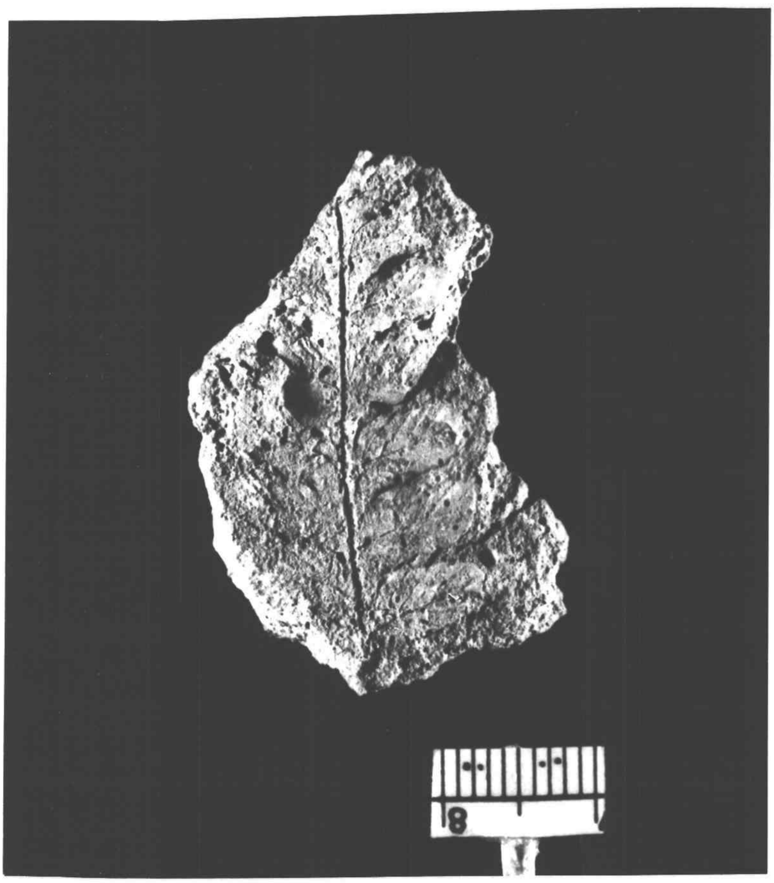


Fig. 22. Fern impression in what are believed to be swamp deposits. Note the vesicles which pervade the rock.

Fig. 23. Scanning electron micrograph of the channel ash in unit #8. Note rounding and aggregation of pyroclastics, and the washing of detritus into the vesicles.

PALEOENVIRONMENTAL CONCLUSIONS

All the observations of the Mascall Type section are consistent with the flood plain model. Nearly all of the type section sediments represent overbank deposits; however, some channel sands and air fall material also are present. Channel sands and lateral accretion deposits suggest that the stream or river which traversed this floodplain was probably at least 10 feet (3 meters) deep and on the order of 30-40 feet (9-12 meters) wide. The floodplain was heavily vegetated as evidenced by the numerous fossil roots. Isolated swamp deposits represent the marshy environments commonly observed on modern floodplains. Although the swamp deposits of the type section are minor, elsewhere in the John Day Valley (both east and west of the type section) lignitic beds occur, showing that large swamps or marshes did occur in certain areas of the floodplain. No lacustrine sediments were identified in the type section deposits. However, about 14 miles (23 km) to the east lacustrine sediments were identified by the author and previous workers. Although these lacustrine sediments also directly overlie CRB, the author is unsure as to whether or not they are equivalent in age to the type section sediments.

According to Reineck & Singh (1980), two types of flood plain soil formation can be distinguished: One operative in a wet, cold climate (humid); the other in a dry, hot climate (semi-arid). The soils in the humid climate are characterized by the preservation of large amounts of organic matter, and the soils of the semi-arid climate are characterized by negligible organic content and the presence of $CaCO_3$ concretions (caliche). The type section soils contain neither large amounts of organic matter, nor calcite of any sort, and thus would seem to have been formed in an intermediate climate. Both A and B horizons of paleosols are preserved at the type section; however, these are mostly immature. Brown and Kraus (1981) state that brown to orange brown colors are normally found in alluvial soils of temperate regions, whereas yellowish brown and reddish colors are more common in the tropics. Because the Mascall soils are dominantly yellowish gray in color, and contain both brown and reddish colors, they are of little help in pinning down a climate.

The best climatic evidence comes from the plants which were found within the type section, namely: *Metasequoia*, *Celtis* (hackbery), *Alnus*(?), ferns, and grasses. With the exception of hackbery, which today frequents stream boarders in the southwestern United States, this association of plants would seem to reflect a climate in which extremes of temperature were lacking and in which rainfall was abundant (Axelrod, 1940). Ferns in particular are known to require moist environments, and today *Metasequoia glyptostroboides* only survives in Hupeh and Szechuan provinces of China where it occupies moist valleys and ravines at moderate elevations (Chaney, 1949; Hora, 1981). It is possible that while the ferns actually grew within the immediate vicinity of the swamp, hackberry grew on dryer areas of the floodplain, and the *Metasequoia* and *Alnus* may have grown in the surrounding hills or mountains and been washed in. It is believed that a cool temperate climate persisted in the conterminous United States throughout the Miocene, and that sometime during the middle Miocene the Cascades became enough of a barrier to bring about a change from summer-wet to summer-dry climates (Wolfe & Hopkins, 1967). Because of the moisture-loving vegetation which was preserved in the type section, and the lignitic mudstones which occur sporadically throughout the John Day Valley, it seems that a summer-wet climate was still in effect when the Mascall Formation of the John Day Valley was deposited.

The sandstone to mudstone ratio in the type section is approximately 1:25 with the ratio fairly constant from the bottom of the section to the top. It should be noted, however, that the original ratio was almost certainly somewhat higher (perhaps 1:20) due to the fact that much of the original glass shard material (fine sand to coarse silt in size) has since been altered to clay. This ratio is also greatly influenced by the sediment available (mostly ash), and this would tend to bring about a low sandstone to mudstone ratio. Low sandstone/mudstone ratios may indicate high vertical accretion rates; in other words fine-grained overbank deposits accumulate too rapidly for channel belt meandering to produce large tabular sandstone bodies. It is thought that low sandstone/mudstone ratios may also indicate rapid basin subsidence (Brown & Kraus, 1981). If this is indeed so, then perhaps the Mascall type section represents a time of major Plinian-Pelean eruptive activity, possibly combined with basin subsidence.

STRATIGRAPHY OF THE MASCALL DEPOSITS OF GRINDSTONE CANYON (PAULINA BASIN)

INTRODUCTION

The Mascall deposits which occur in the Paulina basin are believed to be contemporaneous with the Mascall Deposits of the John Day Valley, in that like the deposits of the John Day Valley, the Paulina deposits also contain the fossilized remains of a Barstovian mammalian fauna (Downs, 1956; Forth, 1965). Several mammal fossils were collected along the Mascall slopes as float by the author, including teeth and toe bones from the horse, Merychippus, and a partial tooth and ankle bones from what was probably a Rhinoceros (Ruben, 1986).

The Mascall deposits overlay Columbia River Basalt with pronounced unconformity and are in turn overlain nearly conformably by the Rattlesnake Ignimbrite. The Mascall deposits of Grindstone Canyon are nearly horizontal, dipping to the north at a modest 1/2-2 degrees, whereas the underlying Columbia River Basalt dips northward at a much steeper 11 degrees.

With the exception of a poorly welded ash flow that occurs within the Mascall section, the deposits are all easily eroded and form gentle slopes which are usually covered by grasses and sage. Good exposures are very rare with the best exposures occurring in Grindstone Canyon (SE 1/4 of NW 1/4 of NE 1/4 of Sec 16, T. 18 S., R. 24 E.). Forth (1964) very briefly described the Mascall stratigraphic section of Grindstone Canyon, however, the description was largely incomplete and for this reason the author feels that a more in depth description is appropriate here.

The Mascall deposits of the Grindstone Canyon are believed by the author to represent deposition in a floodplain environment. Channel deposits are much more important than in the type locality (John Day Valley), and make up roughly 1/3 of the stratigraphic section. Also the deposits are generally much coarser than those of the type locality. Air fall and lacustrine deposits were also recognized by the author in the Grindstone Canyon section, however these were very subordinate to the alluvial deposits. Only one paleosol of minor thickness was recognized and this probably indicates that the river or stream(s) which deposited the sediments meandered too rapidly for extensive soils to develop and be preserved.

EVIDENCE

EVIDENCE SUPPORTING DEPOSITION IN A FLOODPLAIN ENVIRONMENT:

1) Crossbedding (large and small scale).
2) Scour and fill structures.
3) Irregular contacts and undulatory contacts between beds (suggests deposition on a land surface).
4) Thin lacustrine deposits (small lakes are common on floodplains).
5) Tabular nature of mudstone and sandstone units.
6) Occurrence of thick, coarse sandstones (channel deposits).
7) Occurrence of normally graded (fining upward) sequenses.
8) Fumerolic structures at the base of the ash flow and soft sediment deformation features in the overbank and air fall deposits immediately beneath the ash flow (indicating deposition of a hot ash flow onto a wet, somewhat soupy ground surface).

9) Abraded nature of fossil bones; implying river transport.

10) Gnaw marks on fossil bones; indicating that they were lying about on the ground surface.

11) Presence of Hackberry endocarps (today hackberry bushes frequent stream borders (Downs, 1956)).

DESCRIPTION OF THE GRINDSTONE CANYON SECTION:

The Mascall deposits of Grindstone Canyon were divided by the author into 10 units based on lateral continuity, lithologic contrast, and environmental significance. The entire section was measured using a Jacobs staff and Abney level and found to be 471 ft (144 m) thick. As the base of the section is not exposed, the Mascall section is somewhat thicker than the measured 471 feet. Figure 24 is a simplified sketch of the Grindstone Canyon stratigraphic section.

Unit #1

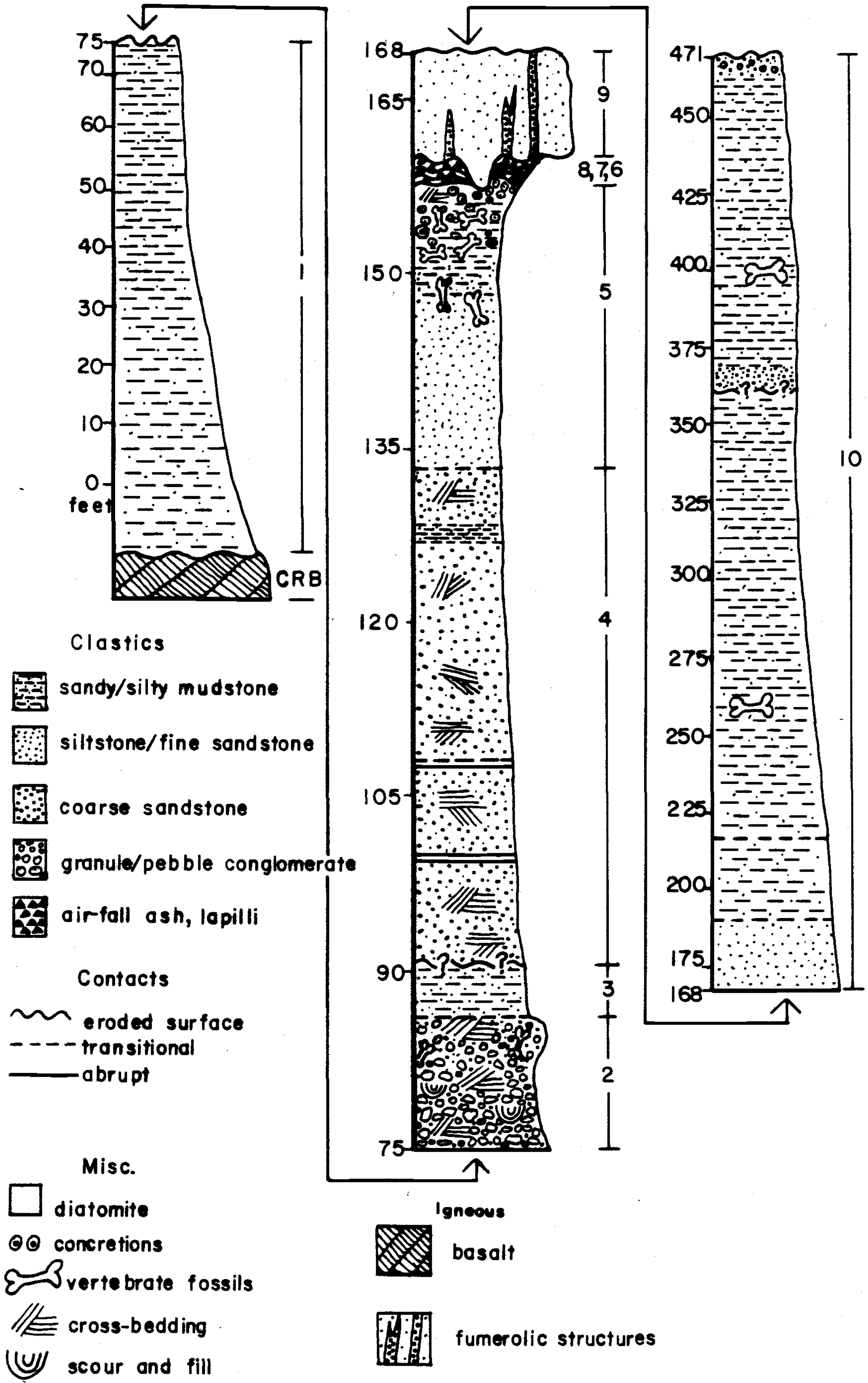
Unit #1 is a 75 ft (23 m) thick section of silt, clay and mudstone. The unit is entirely covered and weathers to form a brownish gray soil. An excavated sample was a very pale orange (10 YR 7/2) in color. The sample tended to break into irregular blocks and was composed mostly of altered glass shards. Examination of this sample by XRD revealed mostly smectite (Mg, Ca), with large amounts of plagioclase, small amounts of magnetite-maghemite series, and traces of olivine (fayalite) and quartz. Unit #1 is considered to represent alluvial overbank deposits.

Unit #2

Unit #2 is a poorly sorted pebble conglomerate measuring roughly 11 ft (3.4 m) in thickness. Although friable, the unit does

Fig. 24 (following page). Measured section of the Mascall deposits at Grindstone Canyon. Scale is consistant within columns, but not between columns.

Fig. 24


75
70
60
50
40
30
20
10
0
feet
CRB
168
165
150
135
120
105
90
75
9
8,7,6
5
4
3
2
471
450
425
400
375
350
325
300
275
250
225
200
175
168
10
Clastics
sandy/silty mudstone
siltstone/fine sandstone
coarse sandstone
granule/pebble conglomerate
air-fall ash, lapilli
Contacts
eroded surface
transitional
abrupt
Misc.
diatomite
concretions
vertebrate fossils
cross-bedding
scour and fill
Igneous
basalt
fumerolic structures

form infrequent outcrops. The unit displays a tabular geometry and is traceable for over 1 mile (1.6 km). Clasts are moderately rounded and the clast sizes range up to 3-4 cm in long diameter. The basal contact is erosional with approximately 5 feet of relief. Cut and fill structures, crossbedding, and normally graded sequences are all very common in this unit. The color of this unit is variable depending on the concentration of bluish gray basalt pebbles (these seem to owe their color to a surface precipitate or film of some sort). Near the base, where basalt clasts (mostly vesicular) make up 80% of the volume of the rock, the color is a distictive blue gray. In the middle of the unit the color is more yellowish (due to the presence of a yellow silty matrix), and the top of the unit is an olive gray (5Y 4/1) (owing to the presence of a large percentage of sand sized grains). As a whole, the unit is predominantly composed of basalt clasts (with included plagioclase), glass (black & clear, shards & spheres), pumice, plagioclase, quartz, and magnetite. A few vertebrate fossils occur within this unit and as float along the slopes. Unit #2 is interpreted to represent channel deposits of a meandering stream or river.

Unit #3

Unit #3 is a 5 ft (1.5 m) thick mudstone bed which does not crop out, but instead forms a yellowish brown soil. The mudstone is yellowish gray in color (5Y 7/2) and consists of approximately 20% sand and 80% finer material. The sand fraction is composed of roughly 50% white pumice clasts, 25% black, vessicular glass (with included plagioclase), 15% plagioclase, 5% clear, vesicular glass, and 5% quartz. This unit is conformable on top of unit #2 and is believed to represent near-channel, overbank deposits. Together, units #2 and #3 represent a normally graded (fining upward) sequence.

Unit #4

Unit #4 is a 42 ft (12.8 m) thick bluish gray sandstone. The unit is moderately to well sorted with clast sizes generally ranging from fine to coarse sand. Although this unit is very friable, its distinctive blue color (5 B 5/2) and intense crossbedding make it very easy to recognise (Fig. 25). The unit is tabular in nature and can be traced for over 1 mile (1.6 km). Dips of the crossbed sets appear to vary by nearly 180 degrees, suggesting a highly sinuous river. The basal contact is not exposed, and the upper contact is very gradational.

Fig. 25. Blue crossbedded sandstoned. Sand is composed of basalt clasts and plagioclase crystals. Abney level for scale.

Upon closer examination the rock takes on a speckled appearence (blue and white speckles), with the blue (glassy basalt) comprising approximately 70% of the rock and the white (plagioclase) making up most of the remaining 30%. A few clay balls also occur, but don`t constitute more than 1%. The plagioclase (An 65%) is labradorite. The basalt clasts also contain phenocrysts of plagioclase, hypersthene and olivine. Like unit #2 the basalt clasts are tinged blue by a thin surface film or precipitate.

Eight feet above the base of unit #4 there is an interbedded lacustrine deposit. This lacustrine bed is only 2-3 inches (5-8 cm) thick, is composed of silt and clay, and although well indurated, does not outcrop. Because the lacustrine deposit is very thin, it is evident that it only persisted for a very short time, and represents a temporary feature of the floodplain. Although the bed does not outcrop, its very light gray color facilitates its being traced by inspection of tailings from animal burrows. Examination with the binocular microscope shows this bed to be composed of tubular diatoms (mostly in-situ), fish vertabrae, plant stem molds, and grass blade impressions. The diatoms commonly reach 2 mm in length and are exceptionally well preserved. X-ray diffraction of the fine silt and clay fraction, reveals the additional presence of plagioclase, smectite (Mg, Ca), magnetite-maghemite, pyrolusite, olivine (forsterite & fayalite), and quartz. This thin lacustrine deposit either represents meander loop cut-off, and formation of an oxbow lake; or temporary damming of the river, probably by volcanic debris. The former mechanism is preferred by the author. From the high amount of biotics present, it can be inferred that this lake was probably eutrophic in nature (Hakanson & Jansson, 1983). Fifteen feet up into unit #4 another of these thin lacustrine deposits occurs, and 30 feet up into unit #4 there is a very thin overbank deposit.

Unit #4 represents fluvial channel deposits. The existance of widely diverging crossbeds, and the occurrence of short-lived lakes, strongly suggest that the river which traversed this area was a highly sinuous one.

Unit #5

Unit #5 is a 25 ft (8 m) thick, fining-upward sequence which only outcrops near the top. The basal contact is very gradational with blue sand percentage slowly disappearing over a vertical distance of about 4 feet. Near the top the unit contains impressions of plant stems, and becomes silty and clayey, probably as the result of increasing distance from the main channel. The upper few feet are somewhat concretionary, evidence that soil forming processes were occurring on areas of the floodplain which were distal from the main channel. However, because the concretionary horizon still contains remnants of primary sedimentary structures (ie. horizontal lamination and trough crossbedding), paleosol development was evidently arrested in its incipient stages. Numerous mammalian fossils occur as float along the slopes of this unit, and therefore this unit constitutes a fossil-rich horizon, a characteristic which is indicative of soil formation (Bown, 1985). The upper contact displays soft sediment deformation which is believed by the author to result from the overlying ash flow (unit #9). Unit #5 is very poorly sorted with clast sizes ranging from granules to clay. The larger clasts include black glass (vesicular, with included plagioclase), pumice, basalt, plagioclase, quartz, and clinopyroxene.

Unit #5 contains channel deposits near the base, with a transition to overbank deposits and active soil development at the top. This unit is the only unit in the Grindstone Canyon section in which a paleosol was recognised. Together unit #4 and #5 represent a 67 ft (20 m) thick, fining upward sequence.

Unit #6

Unit #6 is a very thin (0-8 cm) air-fall tuff, which is light olive gray (5Y 6/1) in color, and which can be traced for nearly 2 miles (3 km). Generally the thickness of this bed is very constant (4-6 cm), and thickness variations are mostly the result of soft sediment deformation caused by unit #9. Pyroclastics range in size from ash to lapilli, with the ash component being dominant. The lapilli fraction is composed entirely of angular pumice, much of which is in fairly good condition. The ash on the other hand is rather altered. Constituents of the ash fraction include glass shards, plagioclase, quartz, and magnetite.

This is a pyroclastic air fall unit which was produced by the eruption of some not too distant volcano, the resultant ash and lapilli blanketing the floodplain with an even layer.

Unit #7

Unit #7 is a very thin (0-10 cm), well sorted, vitroclastic, lapilli tuff. Over 95% of the clasts are altered pumice (almost certainly from a single eruption), with the remainder being plagioclase and quartz. Like unit #6, this unit can be traced for nearly 2 miles (3 km) and is generally of a very constant thickness (5-8 cm). Soft sediment deformation (produced by unit #9) is common and in places unit #7 contains ripups of unit #6. Like #6, this unit represents a pyroclastic air fall event on the ancient floodplain.

Unit #8

Unit #8 is a 0-1 ft (0-30 cm) thick bed of vitroclastic air fall ash. This air fall tuff is horizontally laminated, and thickens and thins rapidly in response to the sudden deposition of the overlying ash flow (unit #9). The unit is yellowish gray (5Y 8/1) in color, very friable, and consists of nearly 100%, clear, angular glass shards, with traces of magnetite. The ash is moderately sorted with the largest pyroclasts being 0.5 mm in intermediate diameter. As the glass is highly vesicular with thin bubble walls, this ash was probably produced by an eruption of the Plinean-Pelean type (Heiken, 1985). This ash represents air fall (from a single volcanic eruption) onto the floodplain.

Unit #9

Unit #9 is a 9 ft (2.7 m) thick, poorly welded ash flow (ignimbrite), which forms a topographic bench. For a detailed description of this ignimbrite see Davenport (1971). The age of this ignimbrite (and thus the relative age of the encompasing sediments), was determined by potassium-argon analysis (Davenport, 1971), and found to be 15.8 ($\pm$ 1.4) million years.

The basal contact of this unit is highly irregular, and in places it cuts down through unit #'s 8, 7, 6, and into the top of unit #5. The emplacement of this ash flow onto the floodplain also caused significant soft sediment deformation in the underlying units which must still have been soft at the time of deposition. The base of this ash flow also contains numerous fumerolic structures (Fig. 26).

Fig. 26. Small fumerolic structure at the base of an ash flow unit which occurs within the Mascall section of Grindstone Canyon. Rock hammer is for scale.

These structures are depleted in fine material and generally are comprised of granule-sized clasts. The fumerolic structures are commonly 2-3 ft (0.5-1 m) in vertical dimension, however some extend through to the top of the unit, a vertical distance of 9 feet. These fumerolic structures are significant because they demonstrate that the ash flow was still hot when it was deposited on the wet floodplain. The ash flow is pale, yellowish gray in color (10 YR 6/1), and is very poorly sorted. Coarse clastic material is concentrated near the base of the unit and decreases upward. In some exposures the ash flow is seen to contain crossbedding and scour and fill structures in its middle and upper portions, presumably the result of drainage networks re-establishing themselves. Constituents of the ash flow include:

glass (clear shards & black spheres), plagioclase, country rock, magnetite, ilmenite, quartz, hornblende, clinopyroxene, and orthopyroxene.

Because the pumice and ash of air fall units #6, #7, and #8 show no evidence of having been incorporated into the existing soil or sediment of the floodplain, it is highly likely that unit #9 was deposited very soon after units #6, #7, and #8 (probably within a year). It is also likely that all four of these units are genetically related and were probably erupted by the same volcano, probably during a single eruption cycle.

According to Retallack (1983), deposition of approximately one meter of sediment is sufficient to arrest soil forming processes, and thus it is clear that deposition of a 9 foot thick ash flow was much more than sufficient to arrest the soil development which had been occuring in the upper part of unit #5.

Unit #10

Unit #10 is a 303 ft (92 m) thick section of alternating olive gray, brownish gray, and yellowish brown, mudstones, siltstones and subordinate sandstones. A few pebble lenses also occur. The basal contact is undulatory, and limited erosion probably occurred on the surface of the underlying ash flow. Individual beds do not crop out and are not easily tracable. A few fossil fragments (mammalian bones and hackberry endocarps) occur as float along the slopes. Mudstones commonly contain molds of plant stems and twigs. Mineralogy of unit #10 includes: Glass (clear shards), Pumice (white), rhyolite clasts, plagioclase, quartz, chert, orthoclase, basalt, schist and phyllite, magnetite, and epidote. The glass is highly vesicular with thin bubble walls, which suggests that it was produced in a Plinean-Pelean type of eruption (Heiken, 1985).

Unit #10 represents alluvial deposits; including floodplain overbank deposits (both proximal and distal to the channel), as well as channel deposits.

PALEOENVIRONMENTAL CONCLUSIONS

Mascall deposits in the Grindstone Canyon area are predominantly alluvial and were deposited in a floodplain environment. The river or stream(s) which traversed the floodplain were characterized by a highly sinuous and meandering morphology. The sandstone to mudstone ratio is roughly 1:3, and according to Bown and Kraus (1981), this would indicate a rather low rate of sediment accumulation and/or a low rate of basin subsidence. The low sediment accumulation rates not only permitted the reworking of overbank deposits and the formation of tabular sandstones, but also prevented paleosols from being preserved except in rare instances. The presense of thin lake deposits probably reflect the existance of cut-off meander loops or ox-bow lakes. The incidence of hackberry (a plant which today occurs in semi-arid regions of the southwestern United States), combined with the absence of swamp deposits and seeming rarity of trees, may indicate semi-arid conditions (Axelrod, 1940). The surrounding terrane probably consisted of low hills composed of basalt and some low-grade metamorphics. Active stratovolcanoes of Plinean or Pelean type were situated nearby, and probably erupted frequently.

STRATIGRAPHY OF THE UNITY DEPOSITS (UNITY BASIN)

INTRODUCTION

As previously stated the literature leaves some question as to whether or not the Unity Basin sediments should be considered a part of the Mascall Formation. They are certainly younger than the deposits of the John Day Valley and Paulina basin. However, there appears to be some disagreement as to just how much younger they actually are, partly as a result of recent revision of the age of the Pliocene-Miocene boundry. Thayer and Brown (1966a, 1973) and Ehret (1981) believed the Unity Deposits to be early Pliocene in age as opposed to middle Miocene (Barstovian) for the John Day and Paulina deposits (Downs, 1956). However in 1968 Lowry reported Clarendonian vertebrates in the Unity deposits (Farooqui, et al., 1981) which would place the deposits as middle to late Miocene in age (Berggren, et al., 1985). Because the Unity Deposits are younger than the traditional Mascall deposits (probably by at least 2 million years), it is the author's opinion that they should be considered separately. However, because Brown and Thayer (and possibly others) consider the Unity Basin sediments to be a part of the Mascall Formation; the author includes here a brief stratigraphic section and description of the Unity Basin sediments. It is stressed however that this description is by no means complete, nor is it as detailed as the descriptions of the Grindstone Canyon and type sections.

The Unity Basin sediments consist primarily of poorly sorted alluvial sandstones, siltstones, and mudstones, which according to Thayer and Brown (1973), directly overlie and are locally intercalated with flows of the Strawberry Volcanics. Minor lacustrine deposits also occur, and these are characterized by chert, diatomite, and gypsiferous beds (Farooqui, et al., 1981). Fossil bones collected by the author display both abrasion and gnaw marks, implying fluvial transport and exposure on the ground surface, respectively.

Three miles northeast of the town of Unity (SW 1/4 of NE 1/4 of T. 13 S., R. 37 E.) a partial stratigraphic section was measured of the Unity Basin sediments. Measurement of section was difficult because the Unity Deposits are highly faulted (Farooqui, et al., 1981). In addition the base of the section is covered, and so measuring was started where the sediments first crop out. A total of 530 feet of section was measured at which point the sediments are truncated by a fault. Across this fault sediments of a similar nature continue to the north, unfortunatly no marker bed could be confidently traced across this fault, and thus only the 530 ft of section was measured. The total thickness of the sediments in the Unity Basin is certainly much greater than the 530 ft measured and probably exceedes 1500 ft in thickness.

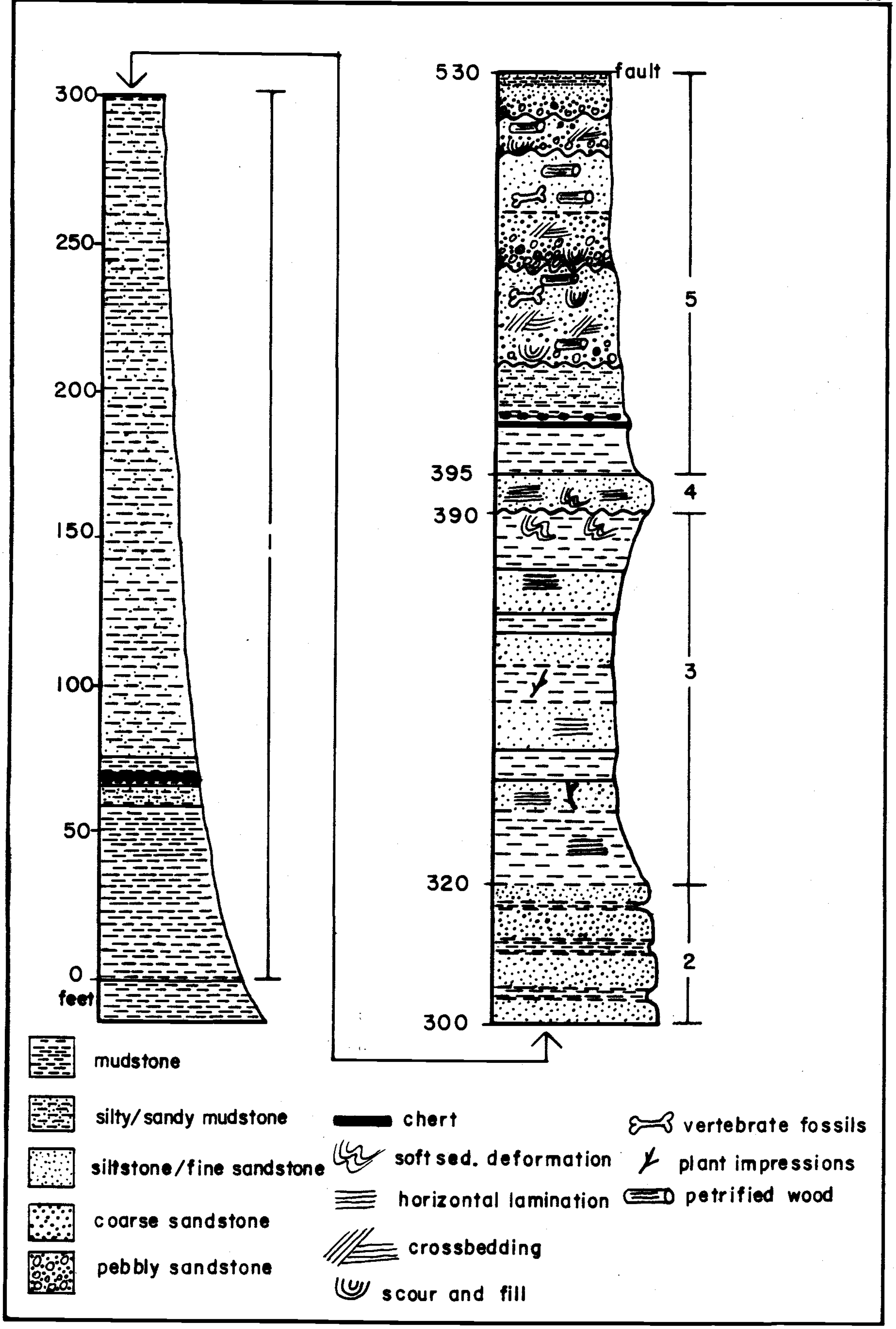
DESCRIPTION OF THE UNITY BASIN SECTION

The measured section was divided by the author into 5 units based on distinctive characteristics in the field, and environmental significance. Figure 27 is a sketch of the measured section.

Unit #1

Unit #1 is a 300 ft section of bedded mudstones. The mudstone is often fissile, parting parallel to bedding. Beds are generally very light gray and very pale orange (10 YR 8/2) in color Beds are

Fig. 27 (following page). Measured section of the Unity Basin deposits. Columns are not to scale.


300
250
200
150
100
50
0
feet
530
fault
395
390
320
300
5
4
3
2
mudstone
silty/sandy mudstone
siltstone/fine sandstone
coarse sandstone
pebbly sandstone
chert
soft sed. deformation
horizontal lamination
crossbedding
scour and fill
vertebrate fossils
plant impressions
petrified wood

sometimes thin and tabular, with sharp contacts, and traceable for substantial distances suggesting deposition in a lacustrine environment (Yuretich, et al., 1984). Other beds have gradational contacts and are almost certainly overbank (floodplain) muds which have undergone limited soil formation. Clast size is too small to be studied by optical means, however x-ray diffraction shows the mineralogy to consist mostly of quartz and plagioclase, with lesser amounts of K-feldspar, smectite (Mg, Ca), and halloysite. Unit #1 most likely represents floodplain deposits and deposits associated with temporary lacustrine conditions.

Unit #2

Unit #2 is a 20 ft thick, poorly sorted siltstone. The siltstone is light gray (value of 7) in color, is well indurated, and contains interbeds of very light gray (value of 9) tuffaceous mudstone. Mineralogy of the siltstone consists of basalt clasts, minor quartz, and altered glass shards. Unit #2 probably represents near-channel overbank deposits.

Unit #3

Unit #3 is a 70 ft thick sequence of light to medium gray, poorly sorted siltstones and interbedded mudstones. Some of the mudstones are very fissile, and several of the mudstones and siltstone beds contain plant stem casts. Horizontal lamination is common, and near the top of the section a thin lignite occurs. The presence of this thin lignite, as well as the occurrence of the fissile mudstones and horizontal lamination, provides supporting evidence for the existence of a small lake during this time (Monroe, 1981; Yuretich, et al., 1984). Composition of the larger silt grains includes basalt, glass shards, rhyolite, plagioclase, and magnetite. X-ray diffraction of the fine silt and clay fraction reveals large amounts of smectite (Mg, Ca) and plagioclase, small amounts of magnetite-maghemite, and the presence of what may be graphite. Unit #3 sediments were formed in areas of the floodplain which were distal to the main channel and contained swampy environments as well as intermittent ponds or lakes.

Unit #4

Unit #4 consists of a 5 ft thick, very resistant siltstone, which displays an undulatory basal contact. The siltstone is light gray in color (value of 6.5), and displays both horizontal lamination and soft sediment deformation. Clasts are predominantly of basalt, glass (clear & black), and plagioclase. This unit probably represents near-channel overbank deposits.

Unit #5

Unit #5 consists of a 135 ft section of generally friable sediments of wide ranging lithology. The basal contact is abrupt, but conformable, and several minor erosion surfaces occur within the unit. Some horizons are very bentonitic, while others are very sandy and even pebbly. Colors are mostly grays, yellowish grays, and yellowish browns. Although fine grained tuffaceous sediments occur throughout the unit, unit #5 represents a coarsening upward sequence, and nearly all sandstones and pebble lenses occurring in the upper half. X-ray diffraction of a typical mudstone revealed large amounts of smectite (Mg, Ca) and plagioclase, small amounts of magnetite-maghemite, and what may be graphite. The coarse grained horizons are usually very poorly sorted, display crossbedding and cut and fill structures, and are definitely fluvial in nature. Fossil bones and wood in various stages of petrification are very common in these coarse grained sediments. Other constituents include: basalt, glass shards (mostly altered), pumice, rhyolite, and magnetite.

Chert

Near the base of unit #5 there occurs a tuffaceous mudstone within which is a 6 inch bed of varicolored chert. Contacts both above and below the chert are sharp and conformable; however, the mudstone immediately above the chert (within 6 inches of the chert) contains a few small nodules of chert. According to Friedman & Sanders (1978), there are three possible explanations for the formation of this chert. The chert may be 1) an alteration product of volcanic rock (montmorillonite or volcanic glass), or 2) a precipitate derived from the dissolution of tests of siliceous organisms, or 3) an inorganic precipitate. Because of the sharp, conformable contacts above & below the chert, it seems unlikely that this particular chert bed is a result of alteration of pre-existing sediment. Scanning electron microscopy revealed no structures whatsoever and thus a biogenic origon also seems unlikely. The third explanation is the one preferred by the author. It is known that inorganic precipitation of hydrated sodium silicate periodically occurs in some modern lakes in which the waters are sodium-carbonate brines. Lake Magadi, a modern lake in Kenya which is surrounded by volcanic rocks, may be somewhat annalogous to temporary conditions that occured in the Pliocene "Unity Basin". During dry spells, the concentration of silica in Lake Magadi attains values as high as 2700 ppm, and the pH may exceed 10. Flood discharges of freshwater lower the pH, causing silica to precipitate as hydrous sodium silicate. Presumably this hydrous sodium silicate will eventually be converted to chert (Friedman & Sanders, 1978).

Unit #5 is thought to contain floodplain overbank deposits and lacustrine deposits near the base, with a transition to channel deposits and subordinate overbank deposits near the top.

CONCLUSIONS

Although the 530 feet of section which were measured showed little or no evidence of paleosols; northward across the fault, several of the sedimentary horizons are distinctly red in color, appear to have gradational contacts, and probably reflect ancient soil development on areas of the floodplain which were more distal to the channel. Lakes that formed on this floodplain back in early Pliocene time were probably short-lived features, which resulted either from meander loop cut-off, or blockage of the drainage system by lava flows. The postulated paleoenvironment of the Unity Basin deposits is one of broad floodplains covered in places by shallow lakes.

SEDIMENTARY PETROLOGY OF THE MASCALL FORMATION OF EASTERN OREGON

INTRODUCTION

Although the Mascall Formation was named nearly a century ago, very little work has been done in its sedimentary petrology. Primary interest in the Mascall has been by paleontolgists (Merriam, 1901; Merriam et al., 1925; Downs, 1956) and paleobotanists (Axelrod, 1940; Gray, 1956; Chaney 1949, 1967), and has centered mostly around the collection of the mammal bones and teeth which represent a Barstovian (middle Miocene) mammalian fauna (Merriam, et al., 1925; Downs, 1956, Baldwin, 1981).

A quick glance at the limited literature on the Mascall, shows that agreement does not even exist regarding the thickness of the type section; much less the environment(s) of deposition and the original aerial extent of the formation (Merriam, 1901; Merriam et al., 1925; Taubeneck, 1950; Dawson, 1951; Downs, 1956; White, 1964; Thayer & Brown, 1965; and Thayer & Brown, 1966a, 1966b). Thus it was the author's intention to perform a regional study of the Mascall Formation and to: 1) measure and describe stratigraphic sections from each of the basins (John Day, Paulina, and Unity), 2) describe the lithology and mineralogy from each of the basins, 3) determine the environments of deposition, 4) Determine the original extent of the Mascall, and 5) characterize the magma which produced the deposits of the John Day Valley.

In identifying the deposits, numerous criteria were used which have been compiled by other workers. Several authors have listed criteria which are useful in the recognition of fluvial or floodplain deposits. Authors whose criteria were used include: Krumbein and Sloss (1963), Visher (1972), Pettijohn _et al_. (1973), Bridge and Leeder (1979), Reineck and Singh (1980), Monroe (1981), and Walker (1984). Criteria which were used in the identification of paleosols are published in recent articles by Bown and Kraus (1981), Retallack (1983a, 1983b), and Bown (1985). Criteria for the recognition of ash flows was provided by Enlows (1984) and Taylor (1986).

MASCALL DEPOSITS OF THE JOHN DAY VALLEY

INTRODUCTION

Approximately 30 miles of Mascall sediments are exposed along the length of the John Day Valley, and just west of Picture Gorge. Although the sediments are usually covered by grasses and soil, outcrops occur sporadically from about 5 miles west of Picture Gorge, to within a couple of miles of the town of Mount Vernon. As one travels along the length of the valley, a distinct lithological change occurs in the Mascall sediments: The deposits in the western part of the John Day Valley, and those which are just west of Picture Gorge, are almost entirely composed of mudstones; the deposits located along the middle portion of the John Day Valley tend to be somewhat coarser, although mudstones are still the dominant lithology; and the eastern deposits consist of diatomite.

FINE-GRAINED ALLUVIUM (TYPE LOCALITY DEPOSITS)

Introduction

The type locality of the Mascall Formation occurs approximately 4 miles west of Dayville and includes portions of sections 19, 29, and 30, of T. 12 S. and R. 26 E. It was here that in 1901 Merriam first applied the name "Mascall" to a sequence of light colored sediments which were located on the "Mascall Ranch" (Merriam, 1901). Since that time, much fossil material has been collected from the exposed slopes, however very little interpretive work has been done. Figure 28 is of the type locality and clearly displays the "badlands" type of topography which is present in the area.

Fig. 28. Photo of the Mascall type locality, approximately 4 miles west of dayville. Note the "badlands" type of topography and the gradational contacts between beds.

The deposits of the type locality (fig. 28) have a stratigraphic thickness of 1340 feet $\pm$ 20 feet (408 meters $\pm$ 6 meters) and were produced in an ancient floodplain environment. Deposits are mostly of the overbank type, as evidenced by fine grain size, and a sand to mudstone ratio of approximately 1:30. These sediments were most likely deposited well away from the main channel belt of the ancient river. Floodplain deposition is primarily by major seasonal floods, and the average annual sediment thickness deposited on modern floodplains is only on the order of millimeters (McGowen & Garner, 1970; Bridge & Leeder, 1979). As the predominantly floodplain sediments of the type section are on the order of 400 meters thick, probably a minimum of several hundred thousand years would have been required for the accumulation of the type section sediments.

In addition to the overbank floodplain deposits, channel sands, lateral accretion deposits, pyroclastic airfall material, and swamp deposits also occur; but these are of relatively minor importance. Extensive paleosols are preserved in this floodplain sequence, and by looking at Figs. 2,3, and 28, the reader can see that many of the contacts are gradational in nature; evidence that soil forming processes were in effect on the ancient floodplain. The paloesols of the Mascall type locality are generally yellowish gray, olive gray, pinkish, and dark reddish brown. The yellowish gray and olive gray sediments probably represent ancient A horizons, and the pinkish and dark reddish brown sediments probably represent ancient upper B horizons (Retallack, 1983; Bown, 1985). A sketch of the Mascall type section is given in Fig. 4.

Evidence

Evidence abounds in the type locality to support the interpretation that these sediments were indeed deposited on a floodplain characterized by active soil development. The major lines of evidence which were observed by the author are summarized below.

EVIDENCE SUPPORTING AN ANCIENT FLOODPLAIN ENVIRONMENT:

1) Presence of numerous vertebrate (mammalian) fossils.

2) Absence of diatom and fish fossils.

3) Presence of hackberry endocarps (pits) throughout the section.

4) Cross bedding, cross lamination, and scour & fill structures.

5) Lateral accretion deposits.

6) Fine-grained nature of the sediments (mostly silt & clay).

7) Normally graded (fining upward) sequences.

8) Swamp deposits.

9) Tabular nature of stratigraphic units.

10) Presence of ribbon sandstones.

EVIDENCE OF PALEOSOL DEVELOPMENT

1) Gradational contacts between beds.

2) Presence of hackberry endocarps in horizons lacking other plant debris.

3) Fossil root traces (both grass and trees).

4) Presence of soil horizons (ie. horizons rich in clay, carbon, mammal fossils, animal burrows, etc.).

5) Coloration of the Mascall beds.

6) Tabular nature of individual beds (mostly mudstones).

7) Illuviation cutans (clay skins) on framework grains due to clay infiltration.

8) Absence of significant alteration of the iron-rich heavy minerals (magnetite & illmenite) which indicates that the alluvial soils formed rapidly and that the coloration was not the result of alteration of the iron-rich minerals (Brown & Kraus, 1981).

9) Absence of primary sedimentary structures in mudstones and the occurrence of blocky fracture and slickensides in some mudstones.

Description of Deposits

The basal Mascall sediments consist mostly of tuffaceous mudstones which conformably overlay, and are interfingered with, the uppermost flows of the Picture Gorge Basalts (the Picture Gorge

Basalts are a part of the Columbia River Basalts). The lowermost mudstone contains a basalt cobble lag at its base. These basalt cobbles are well rounded, range in diameter from 2-10 inches (5-25 cm), and are indistinguishable from the basalt flow upon which the unit rests. Thus at least temporary periods of erosion occurred between the eruption of the uppermost basalts and the deposition of the lowermost Mascall at the type locality.

The lower third of the Mascall is composed of tuffaceous mudstones along with subordinate siltstones and sandstones. These are generally gray, olive gray, and yellowish gray in color and are very friable. Composition of these sediments is mostly volcanic ash (glass shards), with relatively small amounts of plagioclase, quartz, magnetite, hornblende, and chert. The glass shards are usually quite altered, the primary alteration product being a Mg, Ca, dioctahedral smectite, as determined by X-ray diffraction. Scanning electron microscopy along with optical microscopy shows these sediments to be devoid of diatoms and fish fossils.

Hackberry (*Celtis*) endocarps (pits) do occur throughout the type locality, and present day hackberry is known to frequent stream borders (Downs, 1956). Glass blade and leaf impressions also occur in this lower third of the Mascall section; and thus the surrounding area probably had significant vegetation.

Although fining upward sequences along with minor crossbedding and scour and fill do occur in a few horizons, it is the author's interpretation that these lower Mascall sediments for the most part constitute overbank deposits which were deposited a significant distance from the main channel. General absence of primary sedimentary structures, gradational contacts between beds, and the presence of a concretionary, bioturbated horizon attest to the fact that soil forming processes were occurring.

About a third of the way up into the Mascall section, a single bed of air fall ash occurs, which averages 4 ft (1.2 m) in thickness. This pyroclastic material is composed of nearly 100% angular glass shards, which are incredibly fresh. The glass is mostly clear, and of a highly vesicular nature. Figures 9 and 10 are SEM micrographs of this ash, which was certainly produced in a single volcanic eruption, probably of the Plinian or Pelean type (Heiken & Wohlentz, 1985). No soil developement occurs in unit 4, however this is to be expected, because deposition of more than 1 meter of material is sufficient to arrest soil development and cause a new soil to form on the higher land surface (Retallack, 1983). Localized crossbedding, scour and fills, and fining upward sequences, indicate that small creeks on the floodplain re-sorted some of this ash before it became burried by other sediment.

The basal contact of this air fall unit is especially interesting. Not only is the contact sharp and slightly undulatory, suggesting deposition on a land surface; but "clastic dikes" of this ash extend down through fissures into the underlying concretionary mudstone. A nearly identical relationship occurs in Fig. 32, which is a photo of Mascall sandstone and mudstone on the north side of the John Day River. These ash dikes are 1-2 inches (2-5 cm) wide at the top (tapering with depth), and extend 1-2 ft (0.3-0.6 m) down. Shrock (1948) describes several ancient and modern examples of these clastic dikes from around the United States, and attributes their formation to either earthquakes or subsoil creep. As the author is unaware of any definitive criteria which can be used to determine which of these possible mechanisms was involved; he can only say that these clastic dikes might represent earthquake activity in the John Day Valley during the time that the Mascall was being deposited.

Above this airfall bed, the section once again is characterized by overbank floodplain mudstones. These mudstones are tuffaceous in nature, and XRD reveals the presence of large amounts of Mg, Ca, dioctahedral smectite, as well as plagioclase, quartz, magnetite-maghemite, and clinoptilolite. Like the lower deposits, the contacts are mostly gradational, and primary sedimentary structures are hard to identify. In addition to the yellowish and gray colored beds observed lower in the section, brown and pinkish beds also occur, suggesting significant paleosol development with the A horizons and upper B horizons being preserved.

At approximately the middle of the section a 30 ft (9 m) thick, massive, tuffaceous, mudstone occurs, which is capped by an 18 ft (5.5 m) thick concretionary horizon. The lower part of this unit is very rich in mammal fossils (see figs. 29 & 30), so much so that Merriam termed it the "mammal horizon", and it is from this faunal assemblage that the Mascall deposits as a whole have been dated as middle Miocene or Barstovian in age (Merriam _et_ _al_., 1925). Although the mammal horizon and the concretionary layer appear very different in the field, and have been treated separately by previous workers (Merriam et al., 1925; Downs, 1956); the author has interpreted them to be genetically related and to in fact be the upper and lower parts of a single unit. Three lines of evidence support this

Fig. 29.

Fig. 30.

Figs. 29 & 30. Sample of mammal bones and teeth which litter some of the mammal horizon slopes in the area.

interpretation: 1) wherever the mammal horizon occurs it is seen to be overlain (gradationally) by the concretionary layer; 2) with the exception of the mammal fossils in the mammal horizon, the mineralogical compositions of the mammal horizon and the contretionary layer are nearly identical to one another, yet differ significantly from the sediments both above and below; and 3) the mammal horizon is traceable for approximately 10 miles, with the overlying concretionary layer being traceable for an additional 4 miles (this is in marked contrast to the other Mascall beds which are only traceable for 50 m or so).

As the mammal horizon and concretionary layer have been described in detail above, only a brief overview is presented here. The concretionary layer is by far the most resistant of all the Mascall deposits of the type section, typically forming rough outcrops, and displaying a gradational contact with the softer, underlying mammal horizon at its base. This unit is very important in that it is traceable in an east-west direction for 14 miles (23 km). A major compositional differance between the mammal horizon/concretionary layer, and the rest of the type section sediments, is the occurrence of numerous hackberry endocarps (as much as 1% of material) and the addition of large amounts of ilmenite (ilmenite comprising approximately 2% of samples analyzed). Clusters of endocarps representing entire hackberry bushes occur throughout this unit, and the mammal fossils which occur in mammal horizon, show no evidence of concentration near the base (Downs, 1956). Thus the unit could not be the result of a single major airfall (in which case the hackberries and mammal fossils would be concentrated at the base). Likewise the fossils could not have been washed into a lake, because most of the fossils show little or no transport abbrasion (an observation also noted by Downs, 1956). Animal burrows and root casts (figs. 19 & 20) are very common in the concretionary horizon, and provide definitive evidence of paleosol development (Retallack, 1983).

The concretionary horizon is probably the result of a significant temporal hiatus. During this time the sediments of the mammal horizon were extensively weathered, bioturbated, and vegetated during soil formation, transforming the uppermost 18 ft of the unit into a well indurated, concretionary horizon. Most probably this unit was part of an alluvial terrace, and hence not subject to the flood related deposition which was occurring elsewhere on the floodplain. Like the rest of the type section sediments, the concretionary layer contains no calcite or caliche. According to Reinek and Singh (1980), in semi-arid climates incipient caliche formation occurs in as little as 1000 years. Thus the complete lack of any caliche formation, even during a temporal hiatus, would seem to rule out a semi-arid or summer-dry climate for the area during Barstovian time.

The Mascall beds which overly the concretionary layer and mammal horizon are much the same as the beds in the lower part of the section, except that the reddish beds are slightly more common (these reddish beds probably represent the upper part of B horizons). A few minor swamp deposits occur, within which were found fossil debris of ferns and Metasequoia. As ferns are known to inhabit moist areas, and present day Metasequoia only occurs in a limited area of central China where it inhabits valleys characterized by moist summers and mild winters (Chaney, 1949); the occurrence of these plants along with the previously noted absence of any caliche, would seem to suggest a moderate, moist climate for the area during the Barstovian.

Conclusions

The data gathered above allows limited inferences regarding the river system that traversed the area during the middle Miocene. Lateral accretion deposits, as well as a ribbon sandstone (channel sandstone) deposit, demonstrate that meandering did occur. Also the height of the lateral accretion sequence, as well as the thickness of the ribbon sandstone (both of which are discussed at length in the stratigraphic description), demonstrate that the river(s) or stream(s) which traversed this part of the ancient floodplain, was at least 10 ft deep and on the order of 30 -40 ft wide.

The average grain diameter of the clastic material which was transported to the Mascall type locality was probably in large part determined by the size of the available pyroclastic material which was blanketing the landscape at the time. The largest volume of material was in the form of volcanic ash. This is evidenced by the fact that the single largest constituent of the sedimentary material in the type section is volcanic ash, or its alteration product, Mg-Ca smectite. Even the preserved channel deposits are predominantly ash; and where coarse pebble lenses do rarely occur, they are comprised of ash flow clasts. Thus even though vast amounts of Columbia River Basalt must have been exposed in the area, the tremendous volumes of easily eroded air fall ash, and poorly welded ash flow tuffs, provided the bulk of the sediment which was carried by the rivers into the John Day Basin.

Ash fall on the floodplain itself was limited to small amounts at any given time. Probably ash falls of up to several 10's of centimeters occurred commonly and were simply incorporated into the floodplain soil. However, a major air fall exceeding one meter in depth, and capable of arresting soil development (Retallack, 1983) and thus capable of being preserved as such, was a very rare event indeed. The rarity of such an occurrence is demonstrated by the fact that only one such ash bed was recognized in the entire 1340 foot thick sequence of sediments at the type locality.

FINE-GRAINED ALLUVIUM (DEPOSITS WEST OF PICTURE GORGE)

Introduction

Like the deposits of the type section, the Mascall deposits west of Picture Gorge (fig. 31) are also believed by the author to be representative of an ancient floodplain environment. This area was probably distal to the main river channel, and evidently a small pond or lake existed in the area.

Basal Contact

The Mascall deposits west of Picture Gorge rest on Picture Gorge Basalt. This basalt has been broken into several fault blocks, all of which seem to dip to the south at varying degrees. The Mascall is seen to overly the basalt with angular unconformity. In one fault block the basalt dips 24 degress to the south, and the overlying Mascall Formation dips only 16 degress to the south, leaving an angular discordance of 8 degrees.

Fig. 31. Mascall deposits west of Picture Gorge. Both the Mascall beds and the underlying Picture Gorge Basalt are dipping south. Rattlesnake Ignimbrite caps the hills in the background.

A few scattered rounded basalt cobbles and boulders occur at the basal contact. Because these occur regardless of whether or not there is an observable unconformity, it is evident that at least a short period of erosion must have elapsed between the eruption of the basalt and the deposition of the Mascall.

Description of Deposits

A 30 foot thick, massive, very coarse sandstone is exposed at the westernmost Mascall outcrop (SE 1/4 of Sec. 16, T. 12 S., R. 25 E.). This sand contains numerous rip-ups of tuffaceous mudstone which may reach 3 feet in long diameter. Constituents of the sandstone, in decreasing order of abundance, include: Pumice (up to 5 mm), ash (glass shards), plagioclase, quartz, chert, and hypersthene. The sandstone is overlain by tuffaceous mudstone which may represent a paleosol, and is at least 20 feet thick.

About a half mile to the northeast a concretionary layer crops out along the hillside. This concretionary layer is about 5 feet thick and although neither the upper or lower contacts are exposed, this unit appears to be identical to the concretionary horizon described in the type section. Like the horizon from the type section, this concretionary layer is believed to represent a paleosol.

Nearby to the east (Sec. 15, T. 12 S., R. 25 E.), there occurs a very thick (20 ft) lignitic mudstone. This lignitic mudstone is traceable for several hundred feet, and is usually very fissile. In places the mudstone is very dark brown and breaks into paper-thin sheets which contain many well preserved leaf and plant stem impressions. The lignitic mudstone is cut by secondary gypsum viens, interpretation of which is not entirely clear to the author. The gypsum is commonly of the satin-spar variety, and cuts across bedding by means of thin (1/4 inch) gypsum veins, or forms thin (1/4-1/2 inch) lenses which resemble volcanic sills. The veins commonly contain fragments of the surrounding lignitic mudstone which float in the gypsum. These fragments are characteristically angular, and it is often possible to locate the place in the adjacent mudstone from which they were detached. According to Shreerman, et al. (1972), hydrolic fracture is probably the mechanism for the implacement of the gypsum into the lignitic mudstone. Hydration of anhydrite results in a volume increase provided that all the calcium sulphate is retained within the system. This excess calcium sulphate (gypsum) is present as veins which cut the country rock, which in this case is the lignitic mudstone (Shreerman, et al., 1972). The original source of the gypsum however is unclear, and the author cannot say with certainty if the gypsum comes from beds stratigraphically above or below the lignitic mudstone. As no gypsum or limestone beds crop out in the area, it seems most likely that the gypsum source rocks must be present below the lignite and almost certainly are minor in extent.

The lignitic unit is overlain by a thin white tuffaceous mudstone, which is in turn overlain by two thick (on the order of 30 ft) reddish brown and yellowish, silty mudstones, which may reflect paleosol development on a floodplain. Capping the mudstone horizons are a series of thin sandstones (2-4 ft) and gravel lenses. This sequence of deposits is very similar to the ideal lacustrine facies sequence described by Picard and High (1972), where basal mudstones are overlain by silty mudstones, which are in turn overlain by sandstones, and ultimatly overlain by conglomeratic sandstones.

Conclusions

The presence of such a thick lignitic mudstone (20 ft), suggests that an extensive and long lived swamp was present. This was probably not a back-swamp, such as commonly exist on areas of a floodplain distal to the main channel, but rather the kind of swamp which occurs along the margins of a small lake or large pond. The presence of mudstones which display paper-thin fissility also lends support to the existence of a lake. Finally the presence of gypsum, although minor, strongly suggests that a small lake or large pond existed in the area, which in times of drought had no outlet. A probable mechanism for the formation of the lake would be the damming of a small river or stream by lava or other voluminous eruptive material. The resulting lake would then slowly infill along its margins, with carbonaceous and clastic detritus; sulfates and carbonates may have been precipitated during periods of drought. Eventual filling in of the small lake, or overtopping, or breaching of the "lava" dam, would have resulted in a return to fluvial depositional processes, with subsequent deposits no different than elsewhere on the surrounding floodplain.

COARSER ALLUVIUM (DEPOSITS NEAR RADIO TOWER)

Introduction

The Mascall deposits near the radio tower (NE 1/4 of Sec 10, T. 13 S, R. 27 E.), as well as those occurring for approximately 5 miles to the east and west, constitute the coarse-grained facies of the Mascall Formation in the John Day Valley. Sandstones, and conglomerates are very common, and although mudstones and siltstones still form the bulk of the deposits in this area, the sandstones and conglomerates make up at least 25% of the deposits as opposed to less than 4% in the type section. It is inferred that this area represents the main channel belt of the ancient river.

Both silicified and opalized wood are fairly common in the area. Thus the surrounding area must have been well vegetated. Vertebrate fossils however are scarce, and this probably reflects the increased reworking of the deposits by the meandering river.

Description of Selected Exposures

A nearly 200 foot sequence of conglomerates and coarse sandstones occurs south of the John Day River near the eastern margin of the coarse-grained facies (Sec. 16 and 17, T. 13 S, R. 28 E.). A few interbedded mudstones occur, and these are sometimes reversly graded. Both trough and planar crossbedding are prevelent in all lithologies, with large scale crossbedding occurring in the conglomerates. Normally graded sequences and scour and fill structures are common, and in addition, the conglomerates contain rip-ups of mudstone which may be as much as 2 feet in diameter. The conglomerates are predominatly composed of well rounded basalt clasts which range up to 2 inches in long diameter. These basalt clasts are porphyritic with subhedral phenocrysts of labradorite, olivine, and hypersthene in a hyalopilitic groundmass of plagioclase microlites and glass. The conglomerates are well cemented and often weather to form crags and pinnacles. The conglomerates have a rusty stain to them which is probably caused by oxidation of the iron in the basalt, and this suggests that the cementing material may be predominantly hematite.

North of the John Day River, near the western-most exposures of the coarse-grained facies (Sec 26, T. 12 S., R. 26 E.), the deposits tend to consist of coarse sandstones near the base, which grade into siltstones and mudstones higher in the section. The basal sandstones are usually planar crossbedded, contain scour and fill structures, and often part readily parallel to bedding.

South of the radio tower (Sec 10, T. 13 S., R. 27 E.), there occurs a conglomerate from which numerous pebbles were collected for petrographic study. These pebbles include: siltstones and cherts (some of which have undergone metamorphism), basalt (vesicular with a hyalopilitic groundmass containing plagioclase microlites), sandstone (graywacke, locally, and containing clasts of meta quartzite), and andesites containing labradorite, (probably from the Clarno

Formation, Taylor, personal communication 1987).

North of the radio tower (border of sections 3 & 4, T. 13 S., R. 27 E.), occurs a large channel deposit. It consists of a pebble conglomerate at the bottom and grades upward and laterally into sandstone. Some crossbedding is discernable and the unit is generally well indurated. This unit is 15 feet thick and appears to have been deposited in a single event. The unit overlies marshy mudstone deposits with an erosional contact, and along the flanks the sandstone cuts into the underlying mudstone in a series of clastic dikes. Figure 32 is a photo showing the clastic dikes at the base of this deposit. Similar clastic dikes and their mechanism of formation, have been previously mentioned in the discussion on the type section. This channel unit consists mostly of volcanic ash near its top, but contains considerable amounts of quartz, chert, clay balls, breccia clasts, meta-quartzite, quartz gneiss, orthoclase, and fossil bones and teeth near its base.

Near the radio tower (NE 1/4 of Sec. 10, T. 13 S, R. 27 E.) a sequence of interbedded mudstones and siltstones crops out (see Fig. 33) in which a channel is scoured and filled by a pumice conglomerate. This is in turn overlain by a concretionary horizon (probably the same as the one previously described from the type section). The interbedded mudstones and siltstones display excellent planar crossbedding, convolute bedding, horizontal lamination, and in some places soft sediment deformation. These beds constitute multiple fining upward sequences, commonly begining with either an erosional or abrupt basal contact upon which a siltstone or sandstone containing occasional pumice pebbles, grades up into a clay-rich mudstone.

Fig. 32. Clastic dike in sediments north of the John Day River.

Fig. 33. Sequence of interbedded siltstones and mudstones.

The concretionary bed which caps this outcrop is believed by the author to be the same as the concretionary horizon previously described. This is the most easterly exposure of this unit however, and it is much thinner, coarser-grained, and fresher in appearance than its counterparts elsewhere in the John Day Valley.

Pumice Conglomerate

Overlying these mudstones and siltstones, with a pronounced erosional contact, is a pumice conglomerate. This conglomerate contains by far, the best preserved and largest concentration of pumice, of any of the outcrops examined by the author in the John Day Valley. In addition these were also by far the largest pieces of pumice, with some clasts reaching nearly 20 cm in long diameter. In the outcrop, scour and fill structures and trough crossbedding are clearly visible. The pumice of the unit constitutes a complete color gradation from white to coal-black. Mineralogy of the different colored pumice includes: White pumice (plagioclase, quartz, magnetite, orthopyroxene, clinopyroxene, and biotite); brown pumice (plagioclase, quartz, orthopyroxene, clinopyroxene, magnetite, and illmenite); and black pumice (plagioclase, quartz, magnetite, orthopyroxene, and clinopyroxene). Although the author is unsure of the reason, the black pumice tends to weather faster on the outcrop than the lighter pumice.

Analysis of this pumice conglomerate provides some insights into interpretation of the characteristics of the magma which produced at least part of the Mascall Formation. Because the pumice in this unit consists of a complete gradation from white pumice to coal-black pumice, it is probable that all of these pumices were produced in a single, zoned eruption. Evidence to suport this hypothesis includes: 1) The conglomerate is almost entirely composed of pumice, (this is in sharp contrast to the relative paucity of pumice in the nearby sediments, both above and below the conglomerate, and throughout the John Day Valley); 2) the different colors of pumice all display similar range in size (generally 1 mm - 3 cm in long diameter with occasional clasts being much larger); 3) all colors occur throughout the conglomerate, and 4) some of the brown and black pumice are actually hybrid pumice which contain thin stringers of white pumice. Because the clasts are so large, and pumice clasts are easily abraded, the eruption must have taken place nearby. Stanley (1978) describes pumice gravels from the Riviere Claire which are well rounded and well sorted; yet have only been transported about 6 km.

Pumice was collected from this outcrop for major element chemical analysis and the results are listed in table 1. Because the pumice was not only fresh, but also large, the author was able to scrape away the outer "rinds" of the pumice and thus obtain better data by only analyzing the pumice interiors.

In addition pumice was also collected from some thick pebbly sandstone units which occur below the mammal horizon at the western extent of the coarse grained facies (Sec 26, T. 12 S., R. 26 E.). Mineralogy of this pumice includes plagioclase and very minor amounts of quartz and clinopyroxene. It should be noted however that the pumice from this outcrop was not nearly as fresh as the radio tower pumice.

Major element chemical analysis was performed by Washington State University. The very low Na_2O value reported for sample JLK42 is almost certainly due to extensive hydration of this pumice sample. It is known that excessive hydration of fresh glass leads to a preferential loss of Na+ and a gain in the K+/Na+ ratio (Stewart, 1979).

Oxide	JLK48A	JLK48B	JLK48C	JLK42
SiO_2	74.07	65.05	61.24	71.84
Al_2O_3	12.62	14.08	14.63	13.82
Fe_2O_3	1.70	3.70	3.99	2.11
FeO	1.95	4.24	4.57	2.42
MgO	0.25	1.42	2.37	2.89
CaO	0.67	3.75	5.26	2.09
Na_2O	1.75	3.20	3.29	1.24*
K_2O	6.59	2.66	2.04	3.23
TiO_2	0.23	1.16	1.58	0.22
P_2O_5	0.079	0.546	0.842	0.058
MnO	0.08	0.18	0.18	0.07

Table 1. Chemical analyses of Mascall pumice samples taken from the John Day Valley. Samples JLK48A, JLK48B and JLK48C are from the radio-tower outcrop and are of white, brown, and black pumice respectively. Sample JLK42 is from the north side of the John Day River (* denotes loss of Na_2O due to hydration).

Major element chemical analysis of the Mascall pumice was performed in order to help characterize the magma which was responsible for producing much if not most of the Mascall ash and pumice. Although a detailed study is far beyond the scope of this project, comparison of the Mascall samples with samples from two nearby volcanic provinces, the High Cascades and the Harney Basin, does provide significant insights as to possible genetic relationships. Mount Mazama is selected as the best representative of the Cascades area, since it has received the most study of any of the stratovolcanoes in the region (Williams, 1942; Randle, 1970; Lidstrom, 1972; Baldwin, 1981; Priest & Vogt, 1983; Taylor, 1987). The rocks of the Mount Mazama region, like those of all the High Cascade volcanoes, belong to the calcic igneous series as defined by Peacock (Williams, 1942). Table 2 lists the major element percentages of Mazama pumice. Data for the Harney Basin ash flows was compiled from work done by Davenport (1971), Greene (1973), and Parker (1974), and is presented in tables 3 through 6.

Oxide	Sample 29	Sample 31	Sample 32
SiO_2	66.38	68.56	69.50
Al_2O_3	15.74	14.22	15.18
Fe_2O_3	0.64	1.42	1.24
FeO	2.12	1.49	1.42
MgO	0.74	0.83	0.83
CaO	2.68	2.35	2.08
Na_2O	4.11	5.18	4.78
K_2O	2.37	2.47	2.18
H_2O	4.50	3.32	2.51
TiO	0.48	0.58	0.41
P_2O_5	0.05	0.10	0.21
MnO	Nil	0.03	0.03

Table 2. Chemical analyses of dacite lump pumice from Mount Mazama (Williams, 1942).

Oxide	DP-245L	DP-245D	G-149-5a	B-4-21-2b
SiO_2	75.0	71.3	75.3	73.05
TiO_2	0.20	0.35	0.24	0.27
Al_2O_3	11.8	13.4	12.0	13.23
FeO (total Fe)	2.7	4.5	0.76	1.04
MgO	0.15	0.41	0.10	0.08
CaO	0.6	1.9	0.31	0.29
Na_2O	3.12	3.85	3.7	3.05
K_2O	6.3	6.0	4.9	5.04

Table 3. Chemical analyses of the ash flow tuff of Devine Canyon (Greene, 1973; Parker, 1974).

Oxide	DP-290	DP-311B	DP-119	B-0-20-2a
SiO_2	76.4	74.2	73.8	74.27
TiO_2	0.13	0.15	0.13	0.18
Al_2O_3	11.7	12.1	11.7	13.73
FeO (total Fe)	2.7	3.0	3.0	0.30
MgO	0.7	0.24	0.15	0.16
CaO	0.35	0.43	1.2	0.14
Na_2O	4.4	4.6	4.45	4.02
K_2O	4.28	4.41	4.5	4.37

Table 4. Chemical analyses of the ash flow of Prater Creek (Parker, 1974).

Oxide	DP-64-2DP	DP-66-1DP	DP-66-4DP	DP-130DP	DP-66-2LP	DP-130LP
SiO_2	77.1	76.1	76.4	70.0	77.7	75.8
TiO_2	0.12	0.14	0.14	0.75	0.12	0.12
Al_2O_3	11.6	11.9	12.5	13.0	12.4	11.2
FeO (total Fe)	0.95	1.6	1.6	4.8	0.7	0.9
MgO	0.1	0.4	0.2	0.1	0.3	0.5
CaO	0.5	0.82	1.6	2.90	0.7	1.40
Na_2O	3.45	3.0	3.1	3.1	3.25	2.7
K_2O	5.22	5.5	5.1	4.5	5.05	6.11

Table 5. Chemical analyses of the Rattlesnake Ignimbrite Tongue pumice (DP=dark pummice, LP=light pumice) (Parker, 1974).

Oxide	DP-64-3DS	DP-64-3LS	Average of Dark Shards & Pumice	Average of light Shards & Pumice
SiO_2	76.7	76.7	74.8	76.7
TiO_2	0.12	0.12	0.28	0.12
Al_2O_3	11.9	11.9	12.3	11.8
FeO (total Fe)	0.80	0.70	2.2	0.8
MgO	0.3	0.05	0.25	0.28
CaO	0.80	0.5	1.5	0.87
Na_2O	3.5	3.8	3.2	3.3
K_2O	5.28	5.25	5.1	5.5

Table 6. Chemical analyses of the Rattlesnake Ignimbrite Tongue shards (DS=dark shards, LS=light shards) and average of glasses (Parker, 1974).

The presence of biotite in the Mascall pumice, and in the Mascall ash (type section), is significant. No biotite was reported in any pumice of the Harney Basin ash-flows (Devine Canyon, Prater Creek, or Rattlesnake) (Greene, 1973; Parker, 1974), and likewise, none was reported in the pumice from the culminating eruptions of Crater Lake (Williams, 1942; Lidstrom, 1972).

According to Parker (1974) the major element chemistry of the Harney Basin rocks (Rattlesnake Ignimbrite, ash-flow of Devine Canyon, and ash flow of Prater Creek), is different from that of the rhyolitic rocks surrounding the Harney Basin, such as those of Newberry Carter. The Harney Basin rocks contain, on the average less Al_2O_3 than the Newberry rhyolites, and K_2O is more abundant than Na_2O. Conversely, Na_2O is more abundant than K_2O in the Newberry rhyolites (Parker, 1974). The Mascall rhyolites seem to have K_2O in excess over Na_2O; although the low Na_2O values for the Fox Basin Mascall (table 7), and the north side of the John Day River (table 1), are partially due to pumice hydration. Although the Al_2O_3 values of the Mascall pumices are not quite as high as the Mazama pumice, the values are significantly higher than that of the Harney Basin rocks. CaO values are very high for the Mascall pumices and suggest an affinity to Cascades rocks. The moderate to high K_2O values of the Mascall pumice definitly suggest a continental source. Figure 34 shows the Mascall pumice plotted on a K_2O/SiO_2 variation diagram. Harney basin and Mazama pumice are also plotted for comparison. The pumice series from the zoned eruption is seen to form a convex upward curve, rather than a straight line, thus precluding magma mixing as the mechanism for

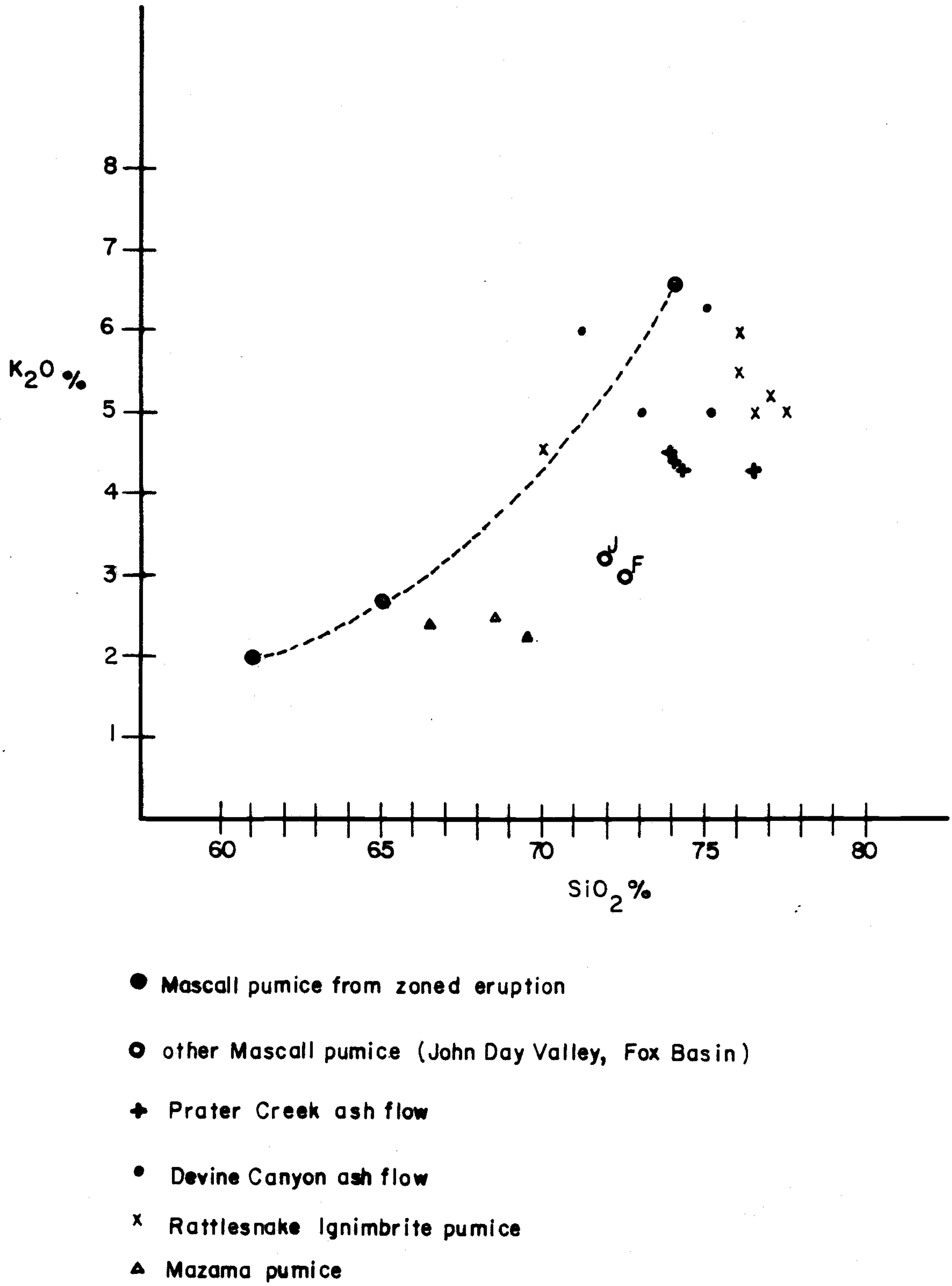


Fig. 34. Variation diagram (Mascall plotted relative to other eastern and central Oregon volcanic units).

producing the zoned eruption. It cannot be determined from the available data which of the remaining mechanisms (crystal fractionation or assimilation of wall rock material) were indeed responsible.

LACUSTRINE DIATOMITE DEPOSITS (NEAR FIELD'S CREEK TURNOFF)

Introduction

Unlike the deposits of the rest of the John Day Valley, the Mascall deposits located around the Fields Creek turnoff contain large amounts of diatomite and are certainly of a lacustrine origin. Evidence for a lacustrine depositional environment includes diatomite, fish fossils, sharp contacts between beds, abundant leaf fossils (found on the white hills across the river), and a total absence of crossbedding. Three areas where these lacustrine deposits are best exposed include: The Field`s Creek roadcut (SE 1/4 of SW 1/4 of Sec 13, T. 13 S., R. 28 E., & NE 1/4 of NW 1/4 of Sec 24, T. 13 S., R. 28 E.), the hwy 26 roadcut one mile east of the Fields Creek turnoff (SW 1/4 of SW 1/4 of SE 1/4 of Sec 18, T. 13 S., R. 29 E.) and the hwy 26 roadcut 2 miles west of the Fields Creek turnoff (NW 1/4 of NW 1/4 of SW 1/4 of Sec 15, T. 13 S., R. 28 E.). Because these deposits are all nearly identical in nature, they are believed by the author to all have formed approximately contemporaneously in the same lake. Taken together, these outcrops span an east-west distance of 3.5 miles, suggesting that at least in east-west dimension the lake was sizable. As the lacustrine deposits at the Field's Creek turnoff are at least 300 ft thick, it is inferred that the center of the ancient lake was located in the immediate vicinity. Also, for lacustrine deposits to accumulate to a thickness of 300 feet, this lake must have persisted on the Miocene landscape for quite some time. The presence of a large number of fossils suggests that this lake was eutrophic in nature (Hakanson & Jansson, 1983; Bradburry, 1986).

Basal Mascall

The base of the lake deposits is well exposed at the eastern hwy 26 roadcut, and corresponds to the base of the Mascall Formation in this area. Here the lacustrine beds are seen to unconformably overly Columbia River Basalt (fig. 35). The uppermost part of the CRB is very eroded, and shows obvious paleosol characteristics; basalt cobbles of the uppermost 2 feet are highly weathered and petrified tree roots extend as far as 15 feet down into the basalt. Because the petrified tree roots are very common, this is interpreted to have been a well forested area. Immediately above this paleosol horizon is a pebbly sandstone which is a couple of feet thick and is interpreted to represent beach deposits on the shore of the ancient lake. Above this is a thin lignitic mudstone which is in turn overlain by Mascall diatomite. The lignitic mudstone is interpreted to represent the vegetation choked, shallow water environment at the margin of an expanding lake. The diatomite probably represents a shallow lacustrine environment; an interpretation which is supported by the species identification of the diatoms (Bradbury, 1987). When deposition of the diatomite began, the lake was already of a fairly large size and had probably been in existance for quite some time. This is demonstrated by the fact that the basal diatomite contains a myriad of fish fossils (vertabrea, spines, scales, etc.) representing fairly large fish (probably at least 12-14 inches in length).

Fig. 35. Base of the Mascall exposed in highway 26 road cut. Lacustrine Mascall unconformably overlys Columbia River Basalt. Basalt is nearly verticle in this area.

Plant Identification

Numerous plant fossils also occur in the basal diatomite at the eastern hwy 26 roadcut. Several plant leaves and seeds were collected by the author from this diatomite, and were identified by James Thompson (1987). These plants include: *Cedrela trainii*, *Cyperacites* sp, *Juglans browniana*, *Metasequoia occidentalis*, *Quercus dayana*, *Quercus hannibali*, and probably *Cucurbita*, and *Alnus*. These plants are useful in helping to determine the paleoenvironment of the John Day Basin. Today *Metasequoia* only occurs in a limited area in central

China, where it occupies "... moist valleys and ravines at moderate elevations, under climatic conditions characterized by humid summers and mild winters." (Chaney, 1949). Chaney (1949) also reports the occurrence of Taxodium dubium from the Mascall deposits of the John Day Basin. Today Taxodium is a genus of three closely related species, popularly known as swamp cypresses, which are natives of southern and southeastern United States and Mexico. Likewise, modern Alnus has a high tolerance of wet soils, and is characteristic of cool, temperate regions of the northern United States (Hora, 1981). Thus the presence of these trees strongly suggests a wet temperate climate for the area during "Mascall time". Although Cedrela, Quercus, and Juglans contain in excess of 100 species apiece, and are much too widespread to be environmental indicators; these genera also have present day representatives which inhabit temperate regions (Hora, 1981).

Diatom Identification

Although the lake deposits include beds of silt, sand, and highly lignitic mudstone; by far the dominant lithology is silty diatomite. Scanning electron micrographs were taken of both the basal diatomite, and of diatomite from near the middle of the section and are presented in figs. 36, 37, 38, and 39. Identification of these diatoms was performed by Platt Bradburry (1986). Diatoms indentified include: Aulacosira ambigua (which is dominant), Aulacosira granulata (also common), Melosira teres, and a number of pennate diatoms from the genera Gomphonema, Cymbella, Fragilaria, Synedra, and Navicula. Tetracyclus ellipticus is rare, but suggests that the deposit is Miocene in age. These diatoms, with the possible exception of Tetracyclus ellipticus, are extant forms that live in freshwater (less than 2000 ppm total dissolved solids), circumneutral, eutrophic, turbulent lakes that are often comparatively shallow (Bradburry, personal communication 1986). Aulacosira ambigua, the dominant form in this Miocene lake, is also the dominant form in many present day lakes in central Minnesota (Bradburry, 1986).

Fig. 36.

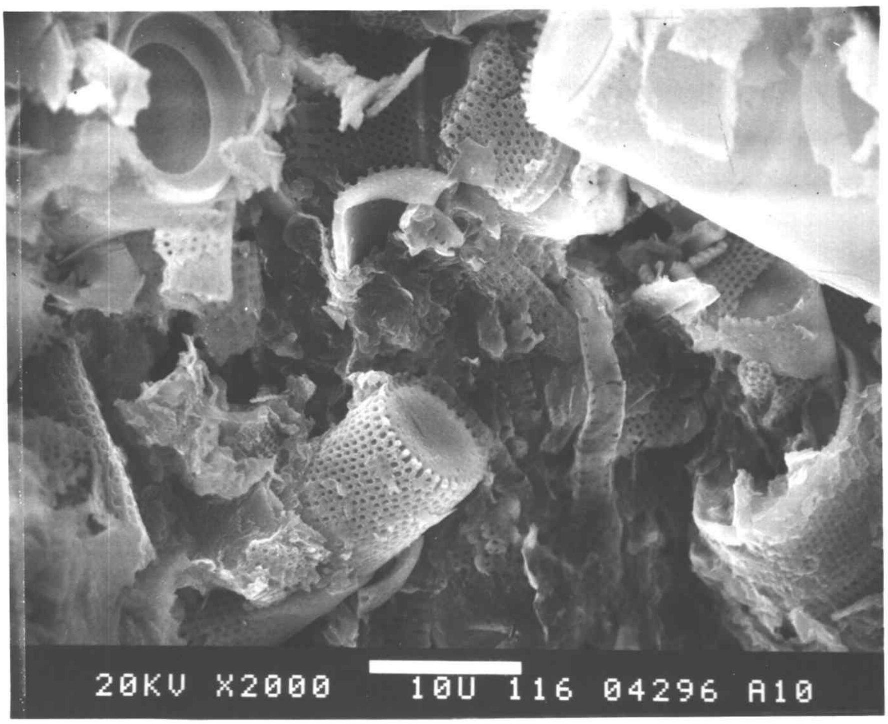
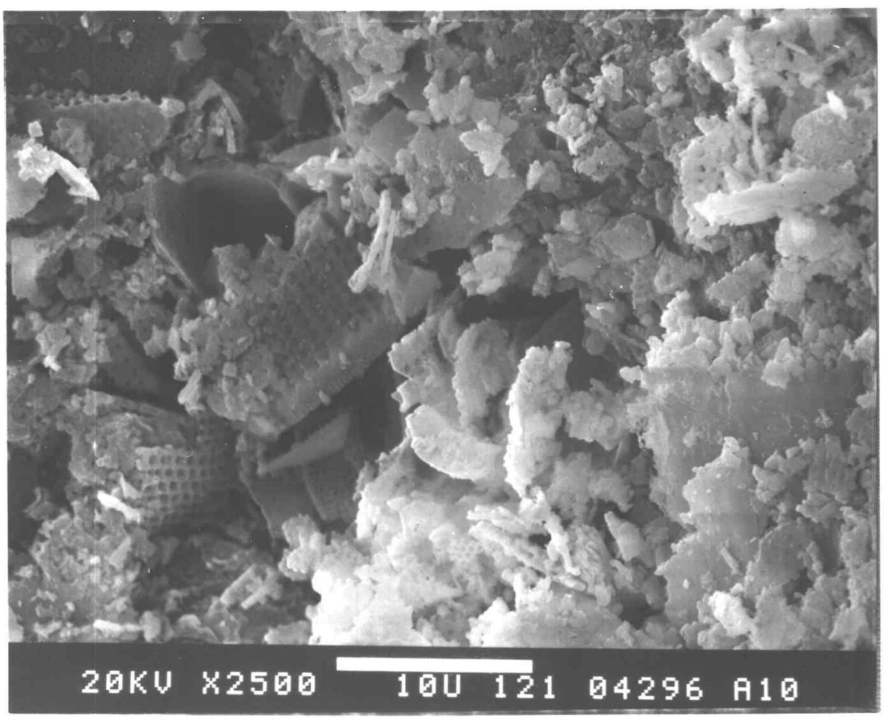


Fig. 36. Scanning electron micrograph of basal Mascall diatomite. Large cylindrical diatoms are Melosira.

Figs. 37 & 38 (following page) are SEM micrographs of diatomite from the basal and upper portions of the lacustrine deposit respectively.

Fig. 37.

Fig. 38.



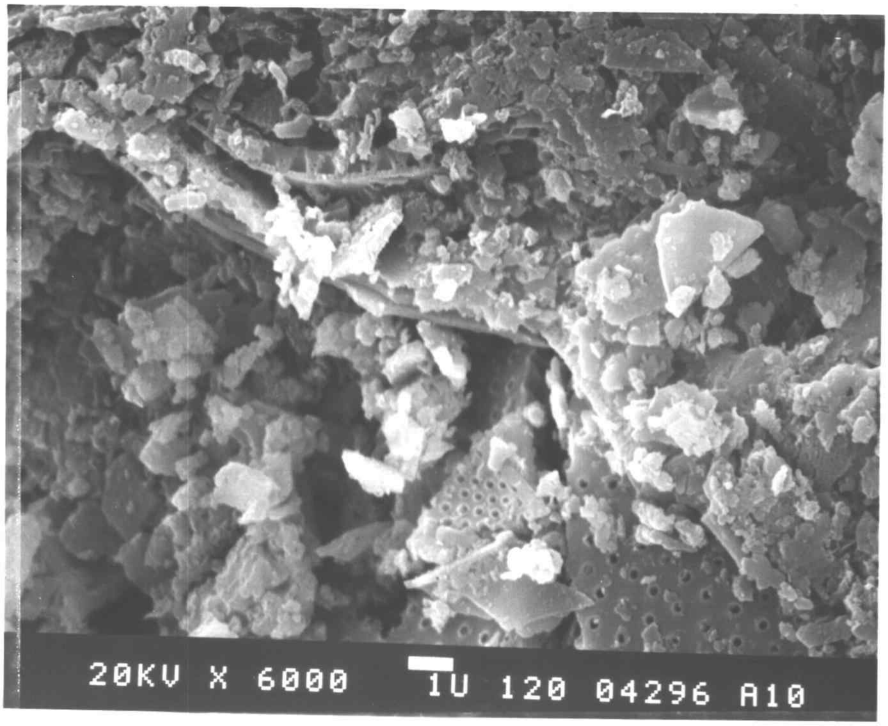


Fig. 39. Scanning electron micrograph from upper lacustrine deposits (sample taken from Fields Creek road cut).

Total thickness of the lacustrine deposits is unknown, however, they are at least 300 feet thick at the Field's Creek turnoff. Plant detritus is very common near the base of the lacustrine deposits, and presumably this is due to the proximity of the shoreline to these deposits. Farther up in the section plant detritus becomes rare. Fish fossils, although mostly concentrated near the base, are common throughout the section. Gastropods on the other hand are rare near the base, but are preserved by the thousands near the top of the section. Sandstones, mudstones, and lignitic mudstones become thicker and more common near the top of the exposed section, indicating a filling in of the shallow lake and increasing proximity to the stream(s) which fed the lake.

Gastropod Fossils

At the Field's Creek roadcut, near the top of the lacustrine section, there occurs within the diatomite an unusual stratification sequence. This sequence consists of dozens of thin (1-2 inch) interbeds of mudstone, along with slightly thicker (1-4 inch) diatomaceous beds which are composed almost entirely of gastropod fossils (in the form of molds and casts). These interbeds are separated by much thicker 4-12 inch beds of relatively featureless diatomite. The gastropods average 1-1.5 inches in long diameter, are very poorly preserved, and usually overlap one another. The interbeds of mudstone occur every few feet and are probably the result of major flooding, with swollen streams washing mud into the lake. Occurrence of these muds near the top of the lacustrine section strongly suggests that the lake was filling in by this time, and that possible delta progradation was occurring nearby.

Gastropods (snails) are known to inhabit all types of lakes, except for acid waters where their calcereous shells are destroyed. They live on different types of bottoms, but are particularly abundant in the littoral zone (Hakanson & Jansson, 1983), further evidence that the lake was filling in at this time. It is unclear, however, what processes were involved in concentrating the gastropod shells into thin beds within the diatomite. As the gastropod fossils are themselves composed of diatomite, whatever process(es) were involved did not affect the deposition of diatomite. Because the interbeds of mud and sand, which were produced by heavy runoff into the lake, are devoid of gastropods; the gastropods could not have been simply washed in from the local streams, and thus must have inhabited the shallow lake waters. Likewise, the gastropods could not have been killed by silt from flooding, or they would be found at the base of the silty layers, which is usually not the case. Also, as the gastropod horizons are commonly separated by 1-2 feet of diatomite, any annual or seasonal mechanism can also be ruled out. It should be noted that the gastropods are not confined to these specific horizons, but that a few also occur within the diatomite between them, and thus preservation conditions probably remained mostly constant throughout several cycles of gastropod "deposition". These interbeds probably represent a cyclical gastropod population explosion, which occurred every several years or decades when conditions for the snails were optimal. Probably these conditions persisted for at least a few years before the snail populations returned to normal levels.

John Day Fault

The Mascall deposits at the Fields Creek roadcut are cut by a fault which Thayer (1977) believes to be the John Day Fault. Figure 40 shows the general structural relations of the different formations in this section of the valley, as well as Thayers interpretation of the location of the John Day Fault trace (Thayer, 1977).

Although the attitude of the Picture Gorge Basalt on either side of the valley provides good evidence that the John Day Fault passes through the area, it appears to the author that the fault which cuts through the Fields Creek roadcut is probably a parallel, subsidiary, or step fault, and not the John Day Fault itself. The attitude of the lacustrine Mascall beds is certainly very different on either side of the fault in question. North of the fault the Mascall beds dip gently southward at an angle of 3 degrees, whereas south of the fault the beds dip steeply northward at an angle of 67 degrees. Thus this fault probably has at least moderate displacement. However, the main John Day fault, which has been traced about 80 miles, is thought to have a vertical displacement on the order of 1000 feet (Thayer, 1977). Because lacustrine diatomite is present on both sides of the fault trace, and the lacustrine deposits are probably not much thicker than the measured 300 feet, the maximum vertical displacement along the fault in question could not have been more than a few hundred feet. In addition, although a few of the Mascall beds immediately adjacent to the fault display shearing and deformation, with one sandstone bed having been squeezed into pod-like shapes by fault associated stresses (see Fig. 41), the deformation of the relatively soft Mascall beds does not appear to be sufficient to account for the displacement along a major fault such as the John Day. Thus it is the author's belief that in this area the John Day fault consists of two or more parallel step faults, with the larger faults cutting through the Mascall deposits to the north, along the valley floor.

In places along the Field's Creek roadcut, it appears that the Quaternary terrace gravels may have been slightly offset (2-4 feet) in a few places. If this is indeed true, then it may be that the John Day fault is still slightly active. (Lawrence, personal communication 1985).

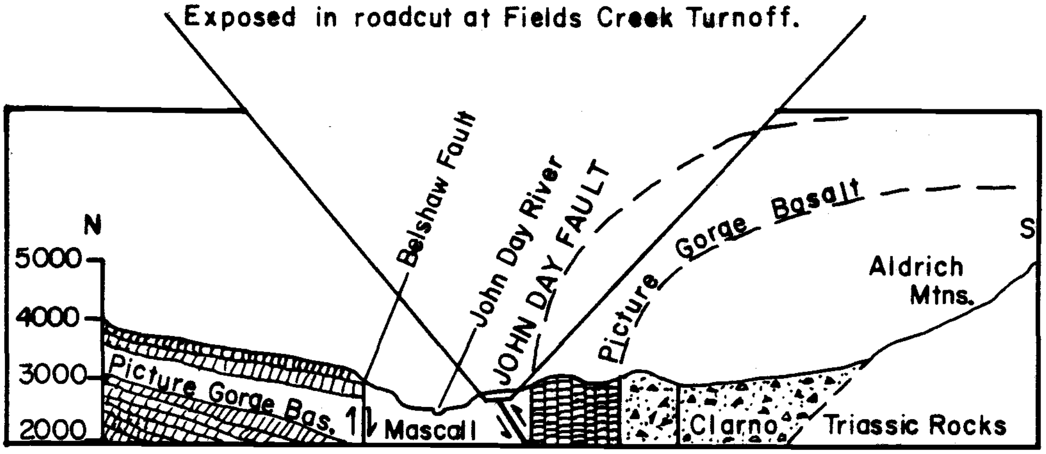


Fig. 40. Structural relations of various formations to the John Day Fault. Diagram is modified from Thayer (1977).

Fig. 41. Mascall lacustrine beds exposed at Fields Creek road cut. Beds are on the south side of the fault trace. Diatomite is sheared and a sandstone bed has been squeezed into pod-like shapes.

ASH FLOW DEPOSITS

The only ash flow deposit recognized by the author in the vicinity of the John Day Valley occurs near the Belshaw Fault, directly opposite the Field`s Creek turnoff. The only other evidence of ash flows in the area, are the previously mentioned sandstones of the type section, which are predominatly composed of ash flow clasts.

LIGNITES

Thin lignites and lignitic mudstones occur throughout the Mascall deposits of the John Day Valley. Most are only on the order of a couple inches to a couple of feet in thickness. The thickest lignites observed by the author are those previously mentioned which occur in the deposits west of Picture Gorge. According to Thayer and Brown (1966a), lignitic lenses as much as 5 feet in thickness have been exposed in roadcuts and in an old mine, approximatly 10 miles east of Dayville.

STRUCTURAL EVENTS IN THE VICINITY OF THE TYPE LOCALITY

The Mascall beds lie atop of the Picture Gorge basalt flows either conformably or with angular unconformity, depending on the exact location of the measurements. The Mascall beds are in turn overlain with angular unconformity by the Rattlesnake Formation.

The Picture Gorge Basalt is a member of the Columbia River Basalt group and is considered to be middle Miocene (10.5-16.5 m.y.) in age (Schlicker, 1954; Berggren et al., 1985). At the type locality the lowermost beds of the Mascall are intercalated with the uppermost flows of the Picture Gorge Basalt. It has been reported by Davenport (1971) that some of these intercalated basalt flows (presumably from the vicinity of the type section) have been dated at 15.4 million years. The Mascall is also concidered to be middle Miocene (Barstovian; 12-16.5 m.y.) in age because of its fossil fauna (Merriam et al., 1925; Berggren et al., 1985).

It appears that deformation in the area was a slow, ongoing process, which began before the last basalt had been erupted, and continued till well after the Rattlesnake Ignimbrite had been deposited (approximatly 6 million years ago). It should be noted, however, that the visible onset of this deformation occurs at different times in different localities. In Picture Gorge itself the basalt flows strike N 82 W and have a southerly dip of 14 degrees. The overlying beds of the Mascall type section (approximately 1/3 of the way up into the section) strike N 76 W and also have a southerly dip of 14 degrees. Thus at least at the type locality no appreciable amount of faulting or tectonic tilting is believed to have occured until after the deposition of the Mascall Formation. However, just a few miles away, block faulting of the CRB had begun before the deposition of the Mascall (probably around 15 m.y. ago). This is evidenced by the fact that a single fault block, which occurs a couple miles west of Picture Gorge, displays an angular unconformity with the overlying Mascall beds of about 7 degrees; even though adjacent fault blocks seem to have conformable or nearly conformable contacts with the Mascall which overlys them. Because the Rattlesnake Ignimbrite (which was deposited nearly horizontally) displays a small southerly dip in the vicinity of the type section, some of the tilting of the Mascall beds had to have occured after about 6.6 million years ago. In addition, the only faulting of the Mascall section recognized by the author can easily be accounted for by post-Rattlesnake faulting (Lawrence, 1986). Probably about 60-80% of the southerly tilting of the Mascall had taken place by the time that the Rattlesnake Ignimbrite was extruded.

Thus it is believed that faulting and fault block rotation in the area of the type section began shortly before the Mascall was deposited. Rotation then proceeded at a pace which was slow in comparison with the rate of sedimentation, so that no discernable difference in dip occurs between the lower and upper Mascall beds. The bulk of the fault block rotation occured between the time that the uppermost Mascall Fm. and the Rattlesnake Fm. were deposited. After extrusion of the Rattlesnake Ignimbrite, deformation continued at a slow pace, with continued rotation and the production of new faults.

MASCALL DEPOSITS OF THE FOX BASIN AND BEACH CREEK GRABEN

INTRODUCTION

North of the John Day Valley, Tertiary sediments occur which are supposedly correlative with the Mascall Formation (Brown & Thayer, 1966a; Thayer & Brown, 1966a). These sediments are located within the Fox Basin and the Beach Creek Graben. As the author is unaware of any firm age dates for these sediments, either radiometric or paleontologic, the fact that they overlie CRB does not necessarily make them correlative with the Mascall Deposits of the John Day Valley. However, they are still referred to as Mascall herein.

Fox Basin is basically a syncline in the Columbia River Basalt, which has several normal faults along its margins, and which is filled with sediments of the Mascall Formation (Brown & Thayer, 1966a). The Beach Creek Graben, as its name implys, is simply a graben which has formed, and subsequently become filled with deposits. Natural exposures of the Mascall are rare in the Fox Basin and Beach Creek Graben, and the Mascall deposits are usually obscured by soil and vegetation. Consequently, the deposits examined by the author primarily consisted of those which were exposed in road cuts and other man-made features.

LITHOLOGY

The Fox Basin deposits which were studied by the author, consist predominantly of ash flows, tuffaceous mudstones (containing pebble-sized pumice), and conglomerates. The conglomerates consist mostly of locally derived basaltic debris (Thayer & Brown, 1966a). Only ash flow deposits were observed by the author in the Beach Creek

Graben. These ash flows contain both light and dark pumice, and pumice sizes may exceed 4 inches in diameter. According to Thayer & Brown (1966a), "In the Beech Creek graben 350 to 400 feet of pumice breccia and welded tuff with Mascall-like gravel at the base overlies basalt flows and interfingers southeastward with basalt.".

ASH FLOW

A small quarry exists in the western part of the Fox Basin (T. 11 S., R. 29 E.) and the walls of this quarry expose an ash flow deposit which is overlain by tuffaceous sediment. The ash flow deposit actually consists of two ash flow units (each about 5 feet thick) which can best be distinguished by the color of the outcrop (the lower unit is gray, and the upper unit is pinkish, owing to oxidation of the rhyolite clasts). The contact between the two units is very obscure and this probably indicates that the upper unit was deposited very soon after the lower unit. Fumerolic structures are very common in the upper unit and average about 1 foot in vertical dimension and about one inch in diameter. The fumerolic structures are easy to recognize in that they are greatly depleted in the fine clastic material which is present elsewhere in the unit. Small pumices are present within this ash-flow unit and are usually white in color, however dark brown and reddish pumice also occur. Due to the paucity of easily obtainable material, only the white pumice was collected for major element chemical analysis. The analyses were performed by Washington State University and are presented in table 7. This pumice is plotted on the variation diagram (Fig. 34) where it plots very close to the white pumice collected north of the John Day River. Like the pumice from the John Day Valley, this pumice has high Al_2O_3 and may come from a magma which is compositionally like that of the Cascades.

Oxide	JLK86
SiO_2	72.60
Al_2O_3	14.49
Fe_2O_3	2.54
FeO	2.91
MgO	0.74
CaO	1.43
Na_2O	1.24*
K_2O	2.98
TiO_2	0.87
P_2O_5	0.068
MnO	0.14

Table 7. Chemical analyses of light colored Mascall pumice from the Fox Basin (* denotes low Na_2O due to hydration).

Mineralogically the upper and lower ash flow units are very similar in composition. The lower unit contains glass shards (both clear and dark brown), plagioclase, rhyolite (in various stages of alteration), basalt clasts, hornblende, magnetite, and chert. The upper unit consists of glass shards (clear, brown, and black, and commonly eutaxitic), plagioclase, rhyolite (in various stages of alteration), basalt clasts, hornblende, quartz, clinopyroxene (with vapor phase alteration), and magnetite (trace).

MASCALL DEPOSITS OF THE PAULINA BASIN

INTRODUCTION

The Mascall deposits of the Paulina Basin are very much like those of the John Day Valley in that they were laid down on an ancient floodplain. Like the John Day Valley deposits, these also contain a Barstovian mammalian fauna (Downs, 1956; Forth, 1965). Vertebrate fossils collected by the author include those of the horse, Merychippus, and of what was most likely a rhinoceros (Ruben, 1986). With the exception of a poorly welded ash flow that occurs within the Mascall section, the deposits are easily weathered and tend to be covered by soil and vegetation.

The best exposures of Mascall rocks occur within Grindstone Canyon. Here the Mascall overlies Columbia River Basalt with pronounced angular unconformity, and is in turn overlain nearly conformably by the Rattlesnake ignimbrite. The author measured the Mascall section to be 471 feet (144 m) in thickness, and the detailed description is presented in an earlier section of this paper. Exposures within Grindstone Canyon provide conclusive evidence that the Mascall sediments were indeed deposited in a floodplain environment.

EVIDENCE

EVIDENCE SUPPORTING DEPOSITION IN A FLOODPLAIN ENVIRONMENT:

1) Crossbedding (large and small scale).
2) Scour and fill structures.
3) Irregular contacts and undulatory contacts between beds (suggesting deposition on a land surface).
4) Thin lacustrine deposits.

5) Tabular nature of mudstone and sandstone units.

6) Occurance of thick sheet sandstones (channel deposits).

7) Occurance of normally graded (fining upward) sequences.

8) Fumerolic structures at the base of the ash flow and soft sediment deformation features in the overbank and air fall deposits immediately beneath the ash flow (indicating deposition of a hot ash flow onto a soft, wet ground surface).

9) Abraded nature of fossil bones, implying river transport.

10) Gnaw marks on fossil bones; indicating that they were lying about on the ground surface.

11) Presence of Hackberry (Celtis) endocarps. Today hackberry bushes frequent stream boarders (Downs, 1956).

DESCRIPTION OF DEPOSITS

The deposits of Grindstone Canyon constitute a wide-ranging lithology. Sediments include mudstone, siltstone, sandstone, conglomerate, and diatomite. In addition pyroclastics are present as well, and are represented by an ash flow and air fall ash and lapilli. Many of the units are highly tabular in nature and are traceable for nearly 2 miles. Vertebrate fossil material is reasonably abundant and occurs throughout the deposits as float. The bones are commonly abraded and some show gnaw marks.

Two very different conglomerates occur in Grindstone Canyon. The first is bluish in color and is highly tabular, being only 11 feet thick and having a lateral extent of well over one mile. This conglomerate crops out where the measured section was made (SE 1/4 of NW 1/4 of NE 1/4 of Sec 16, T. 18 S., R. 24 E.) and has been previously described. In brief, this conglomerate is predominatly composed of vesicular basalt clasts, pumice, and ash. This conglomerate probably represents the contribution of local volcanoes. The second conglomerate is lensoidal in nature and consists of a wide variety of clastic material. Clasts incude basalt and andesite (which may be ophitic, pilotaxitic, hayalopilitic, or intersertal), radiolarian chert (varicolored), argilite, phyllite, and metaquartzite. This conglomerate almost certainly reflects the clastic contribution of a local Mesozoic and Paleozoic melange terrane. A present-day melange terrane of Mesozoic and Paleozoic rocks exists in the Grindstone-Twelvemile area, and contains a nearly identical lithologic assemblage as occurs in this Mascall conglomerate (Dickinson & Thayer, 1978).

A well defined fining upward sequence occurs approximately midway up the measured section. A 42 foot (12.8 m) bluish gray sandstone occurs at the base of this sequence. This sandstone is composed of basalt and plagioclase crystals, and like the bluish conglomerate, derives its blue color from a thin film or precipitate which coats the grains. This sandstone is of a tabular nature (sheet sandstone), displays intense crossbedding, and almost certainly represents river channel deposition. Wide divergence of the cross bed sets suggests that the river which traversed the area was of the meandering type. Within this channel sand are three very thin (2-4 inch) beds of diatomite. This diatomite is highly biogenic, containing in-situ diatoms, fish vertebrae, and plant impressions. These lakes were eutrophic in nature (Hakanson & Jansson, 1983), and because they only persisted for such short periods, were probably formed either by temporary damming of the river by volcanic debris, or by meander loop cut-offs (oxbows). Overlying this sand with gradational contact is a 25 foot (8 m) thick siltstone which becomes clayey and concretionary at the top. A vertebrate fossil horizon also occurs within the upper portion of this siltstone. These vertebrate and concretionary horizons suggest the presence of paleosols within the upper part of this sequence (Retallack, 1983a). This 20 meter (67 foot) fining upward sequence is believed by the author to represent the gradual switching from river channel deposits, to levy and proximal overbank deposits, and finally to distal overbank deposits with soil development.

Immediatley overlying this fining upward sequence is a pyroclastic sequence of four beds, which reflects the onset, or at least a major increase, in the local volcanic activity. The sequence from base to top includes: Air fall tuff (5 cm), vitroclastic air fall lapilli (5 cm), vitroclastic air fall ash (15 cm), and an ash-flow (2.7 m / 9 ft). The ash flow has been previously described by Davenport (1971), and he dated it as 15.8 ($\pm$1.4) million years. As the pyroclastic contribution throughout the rest of the section is comparatively very minor, it is likely that each of these units had its origin in the same volcanic center. Because no seasonal flood deposition took place on the floodplain between any of these beds, this entire pyroclastic sequence was probably deposited within a single year.

PALEOENVIRONMENTAL CONCLUSIONS

The Mascall rocks of the Grindstone Canyon area were deposited on an extensive floodplain upon which various mammals grazed. The high sandstone to mudstone ratio (1:3) indicates a low rate of sediment accumulation (Bown & Kraus, 1981). It is likely that the floodplain was dotted by small oxbow lakes, which were inhabited by fish. The northwestern conterminous United States is believed to have changed from a summer-wet climate to a summer-dry climate sometime during the middle Miocene (Chaney, 1949; Wolfe & Hopkins, 1967). The lack of plant debris in the Mascall floodplain sediments (except around the lakes), and complete lack of lignites, suggests that the Cascades had risen sufficiently to effect this change. Occasionally nearby volcanoes blanketed the floodplain with their pyroclastic debris.

DEPOSITS OF THE UNITY BASIN

INTRODUCTION

The Unity Basin sediments directly overlie and are locally intercalated with flows of the Strawberry Volcanics (Thayer & Brown, 1973). Because the Unity Basin deposits contain Clarendonian vertebrates, rather than Barstovian vertebrates (Farooque, et al., 1981), they are probably at least a couple of million years younger than the John Day Valley and Paulina Basin deposits; and it is the author's opinion that they should not be included in the Mascall Formation. However, like the Mascall deposits of the John Day Valley and Paulina Basin, these deposits are also interpreted to represent an extensive floodplain environment. Measurement of a partial section by the author suggests that the deposits probably exceed 1500 feet in thickness.

DISCUSSION

The Unity Basin sediments consist primarilly of poorly sorted alluvial sandstones, siltstones, and mudstones, which are predominantly composed of basalt, andesite, ash, pumice, rhyolite, and magnetite. These alluvial deposits contain large amounts of fossilized wood suggesting that the surrounding area was well vegetated. Fossil bones collected by the author were found to be both abraded and gnawed upon, suggesting that the carcasses which laid on the ancient floodplain were eventually swept away by the waters and deposited farther down stream. Reddish mudstone horizons, which occur in some areas, are probably the result of ancient soil development on areas of the floodplain which were distal to the main channel.

Minor lacustrine deposits occur within the predominantly alluvial sequence, and these are represented by chert, diatomite, lignite, and gypsiferous beds (Farooqui, et al., 1981). Presence of chert and gypsum suggests that at least some of these lakes posessed no outlet. Presumably the lakes were short-lived features on the floodplain and either resulted from meander loop cut-off, or from temporary damming by volcanic debris.

ORIGINAL EXTENT OF THE MASCALL FORMATION

Although the Mascall Formation almost certainly covered a larger area at one time than it presently does, just how large an area it covered is a matter open for debate. Thayer and Brown (1966a) believe that a giant piedmont apron, up to 7000 feet thick, extended northward and westward out over the basalt plateau, from volcanoes to the south and east. Thus the deposits of the Paulina Basin, Bear Valley, Unity Basin, John Day Valley, Beach Creek Graben, and Fox Basin, would merely be the tiny remnants of this once great formation. The author on the other hand believes that the Mascall Formation was originally deposited only in the structural and topographic lows of the time, from localized sources; and that the original extent of the formation was only moderatly greater than its present-day extent.

Evidence to suport this interpretation that the Mascall was only deposited in the low-lying areas of the time include: 1) The thickest measured deposits, those of the type section, are only 1340 feet (408 m) thick; 2) deposits in the different basins and valleys are not all of the same age; 3) lithology in the different basins is not the same; 4) many of the deposits appear to be locally derived; and 5) facies changes may occur within a basin or valley.

In the type section the uppermost deposits have been eroded away and Rattlesnake gravels have been deposited in their place. Because the beds are dipping to the south it seems highly probable that the Mascall deposits also thicken to the south. However due to cover by the Rattlesnake Formation it is impossible to tell how far to the south the Mascall extends, or what thickness it achieves. It seems unlikely to the author however that the thickness to the south could be significantly greater than at the type section.

Although the Mascall deposits of the John Day Valley and Paulina Basin are nearly contemporaneous (Downs, 1956), the Unity Basin deposits are significantly younger (Thayer & Brown, 1973; Farooqui et al., 1981), and the deposits of the Bear Valley and Fox Basin have not yet been dated. Thus to conclude that the deposits from each of these areas were all a part of one extensive sheet of material, is without solid foundation.

The lithology of the different basins is not the same. As previously mentioned the Fox Basin and Beech Creek Grabens contain a high percentage of ash flow material, whereas in the nearby John Day Valley, ash flow deposits within the Mascall are virtually non-existent. The John Day Valley contains a thick sequence of floodplain deposits as well as thick lacustrine deposits, neither of which seem to be present to the north in any significant amount. The John Day floodplain deposits are not even the same as the Paulina floodplain deposits in that the latter are significantly coarser, contain an ash flow, and lack any sort of lignite deposits. Although the Mascall (?) deposits of the Bear Valley do not crop out, numerous pebbles and cobbles of locally derived obsidian occur as float; thus partially distinguishing these deposits from those of the other valleys and basins.

A four foot thick air fall ash at the type section, as well as 6 inch diameter pumice clasts from the radio tower outcrop, demonstrate that at least some of the volcanic material was comming from an source very near to the John Day Valley. Likewise, large amounts of ash flow material in the Fox Basin, Beech Creek Graben, and smaller amounts in the eastern John Day Valley, compared with the absence of ash flow material in the central and western John Day Valley, sugests a volcanic source which was close to the Beach Creek Graben (perhaps to the north or east). Thayer and Brown (1966a) themselves note that the conglomeratic material in the Fox Basin is locally derived. The basalt conglomerates which occur near the radio tower in the John Day Valley were certainly locally derived, as were the conglomerates and bluish sandstone units of the Paulina Basin.

Facies variations within the Mascall deposits of the John Day Valley, strongly suggest that these deposits were not part of a huge piedmont apron which extended across all of the previously mentioned basins, but rather were confined to areas only moderatly larger than that in which they now occur. The western exposures, type section included, contain an overwelming abundance of fine grained alluvial sediment, suggesting a broad floodplain. Farther to the east the sediments are coarser, with conglomerates becoming more commonplace. Farther east yet, the deposits of an ancient lake occur which was over 3 miles in east-west dimension. Finally, northeast of the type section (across the John Day River), the Mascall deposits thin significantly. Whereas the mammal horizon is approximatly 500 feet above the base at the type section, to the northeast it is only about 100 feet above the base. Likewise the concretionary horizon which is massive and 18 feet thick at the type section, contains interbeds of silty material to the northeast, and at its northern most exposure (near the radio tower), it has thinned to less than 10 feet. This suggests that the Mascall floodplain sediments of the John Day

Valley probably extended no more than a few miles north of the present valley walls.

CONCLUSIONS

The Mascall Formation at the type locality, consists of a 1340 foot thick sequence of sediments which were deposited on a broad floodplain during the middle Miocene. Although channel, swamp and pyroclastic air fall deposits all occur in the type section, overbank floodplain muds are dominant by far. This floodplain was characterized by soil development, and numerous A and B horizons are preserved as paleosols.

The concretionary horizon and the mammal horizon are actually the upper and lower parts, respectively, of a single stratigraphic unit. The concretionary horizon represents a temporal hiatus (interval of non-deposition) at the type locality. During this period of non-deposition the upper portion of the mammal horizon became heavily burrowed and vegetated, eventually forming a tough concretionary horizon. The most likely cause of this hiatus is the formation of an alluvial terrace.

The type section sediments are predominantly composed of volcanic ash and its alteration product, Ca-Mg smectite. This ash was supplied by nearby silicic volcanoes, probably of the Plinian or Pelean type. Although most of the ash was washed in from the surrounding drainage basin, occasionally the floodplain was blanketed by direct air fall material. Chemical analysis of Mascall pumice from the John Day Valley indicates that the magma responsible for producing at least some of the Mascall material, had a continental source.

While most of the deposits of the John Day Valley are of the overbank type, other types of deposits do occur. A few miles to the east of the type locality the deposits become significantly coarser and may reflect increasing proximity to the main channel meander belt. West of the type locality lignites, gypsum, and fissile mudstones indicate the presence of a large pond or small lake on the floodplain. Farther to the east (Fields Creek area), diatomite deposits mark the site of a shallow, eutrophic lake which was at least 3.5 miles in east-west diameter. Beds of gastropod fossils within this diatomite probably reflect periodic population explosions which occurred when conditions were optimal for the snails.

The Mascall deposits of the Paulina Basin are similar to those of the John Day Valley in that they formed on a middle Miocene (Barstovian) floodplain; however some differences occur. Channel deposits, although very rare in the Mascall type section, are common in the Grindstone Canyon measured section. Fining upward sequences are also much better displayed in the Grindstone Canyon section. The river which traversed the Grindstone Canyon area was of the meandering type, and oxbow lakes probably dotted the ancient floodplain. Also, vertical accretion rates are believed to have been significantly lower than in the John Day Valley, as evidenced by the formation of extensive lateral accretion sands (point bar deposits).

Like the deposits of the John Day Valley, the Paulina Basin deposits reflect nearby silicic volcanism. Sediments of the Paulina Basin contain a high percentage of volcaniclastic material. In addition an eruptive sequence, begining with pyroclastic air fall material, and concluding with the extrusion and deposition of an ash flow, is included within the Mascall sediments of Grindstone Canyon. Not all of the Mascall deposits of the Paulina Basin are volcanically derived however. A significant amount of the sedimentary material of the Grindstone Canyon deposits was eroded from the surrounding melange terrane.

The Unity Basin deposits are younger than those of the John Day Valley and the Paulina Basin, and probably should not be included in the Mascall Formation. However, the Unity Basin deposits are similar to the Mascall deposits in that they also represent predominantly alluvial deposition of volcanically derived material.

The John Day Valley was well vegetated during the middle Miocene (Barstovian) and the climate was moist throughout the year. To the south in the Paulina Basin, the climate was probably somewhat dryer, at least during the summer.

It is believed by the author that the Mascall Formation was only deposited in the existing low-lying areas of the time. Some of these structural lows have remained low-lying till the present day, thus allowing the Mascall deposits to have survived.

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APPENDICES

APPENDIX A (X-RAY DIFFRACTION DATA)

X-ray diffraction was performed by the author at Oregon State University. Samples were first crushed and then flushed with distilled, filtered water to create a fine silt and clay suspension. This suspension was pipeted and put in a test tube and allowed to settle for 24 hours at which time the water was drained off. The sample (still wet) was then smeared onto a slide and allowed to air dry. This ennabled the clays to settle in a semi-prefered orientation and thus made identification much easier. After a couple of weeks the samples were run in the diffractometer using Ni-filtered CuK radiation and a detection speed of 2 degrees 2 theta per minute. Certain samples were then heated to 300 degrees Celsius for 1 hour and run again to confirm the presence of smectites. The following tables give the aquired peaks, their relative intensities on a scale of 1 to 100, and the probable mineral corresponding to those peaks. Identification was done using tables published by Chen, 1977 and Brindley & Brown, 1980.

SAMPLE A (UNIT #1) TYPE SECTION

2 THETA	D-SPACING	INTENSITY	MINERAL
26.72	3.34	100	quartz
5.79	15.26	50	smectite (Mg, Ca)
27.83	3.21	44	plagioclase
19.86	4.47	35	montmorill. (group)
20.87	4.26	34	quartz
35.02	2.56	25	montmorill. (group)
35.65	2.52	23	magnetite-maghemite
36.64	2.45	23	montmorill. (group)
23.71	3.75	21	plagioclase
21.97	4.05	20	plagioclase
24.45	3.64	19	plagioclase
42.53	2.13	18	(?)
39.45	2.28	17	(?)

SAMPLE E (UNIT #5) TYPE SECTION

2 THETA	D-SPACING	INTENSITY	MINERAL
5.85	15.11	100	smectite (Mg, Ca)
27.80	3.21	95	plagioclase
22.02	4.04	50	plagioclase
26.65	3.34	50	quartz
19.78	4.49	50	smectite
35.68	2.52	43	magnetite-maghemite
34.92	2.57	43	montmorill. (group)
23.69	3.76	42	plagioclase
24.47	3.64	40	plagioclase
65.15	1.49	40	smectite (dioc.)
42.14	2.14	32	(?)
9.85	8.98	12	Clinoptilolite

SAMPLE F (UNIT #6) TYPE SECTION

2 THETA	D-SPACING	INTENSITY	MINERAL
27.83	3.21	100	plagioclase
21.98	4.04	65	plagioclase
23.68	3.76	61	plagioclase/maghemite
26.72	3.34	56	quartz
35.63	2.52	55	magnetite-maghemite
24.46	3.64	55	plagioclase
19.83	4.48	53	montmorillonite (?)
28.48	3.13	49	(?)
22.87	3.89	47	olivine (forsterite)
35.17	2.55	47	montmorill. (group)
30.23	2.96	46	maghemite
29.58	3.02	42	(?)
32.03	2.79	41	olivine (forsterite)
31.52	2.84	40	fayalite (?)
33.20	2.70	35	(?)
5.40 (broad)	16.37	31	smectite (Mg, Ca)
42.20	2.14	25	(?)

SAMPLE G (UNIT #7) TYPE SECTION

2 THETA	D-SPACING	INTENSITY	MINERAL
27.84	3.20	100	plagioclase
20.02	4.44	82	halloysite
22.02	4.04	74	plagioclase
5.50 (broad)	16.07	65	smectite (Mg, Ca)
35.62	2.52	65	magnetite-maghemite
34.00	2.64	62	plagioclase
24.50	3.63	61	plagioclase
23.78	3.74	61	plagioclase

SAMPLE H (III) (UNIT #8) TYPE SECTION

2 THETA	D-SPACING	INTENSITY	MINERAL
27.78	3.21	100	plagioclase
26.65	3.34	86	quartz
5.85 (broad)	15.11	81	smectite (Mg, Ca)
28.04	3.18	80	plagioclase
19.78	4.49	72	smectite (Mg, Ca)
22.00	4.04	64	plagioclase
34.92	2.57	57	montmorill. (group)
35.63	2.52	54	magnetite-maghemite
22.40	3.97	54	clinoptilolite
61.62	1.51	51	smectite (dioc.)
23.76	3.74	45	plagioclase
30.20	2.96	43	clinoptilolite
20.84	4.26	43	quartz
24.45	3.65	39	plagioclase
53.97	1.70	37	montmorill. (group)
55.04	1.67	35	montmorill. (group)
31.58	2.83	33	fayalite (?)
42.61	2.12	33	(?)
9.83	9.00	23	clinoptilolite
17.30	5.13	21	(?)
11.17	7.92	15	kaolinite-smectite mixed layer

SAMPLE FCD (FIELD'S CREEK DIATOMITE) JOHN DAY VALLEY

2 THETA	D-SPACING	INTENSITY	MINERAL
26.65	3.34	100	quartz
22.05	4.03	82	plagioclase
21.00	4.21	80	K-feldspars
5.79	15.26	76	smectite (Mg, Ca)
20.00	4.44	75	smectite/ halloysite
34.98	2.57	50	smectite/halloysite/ montmorill. (group)
59.91	1.54	38	quartz
62.00	1.50	37	smectite (dioc.)
12.30	7.20	32	halloysite/kaolinite

SAMPLE 127 (GRINDSTONE CANYON DIATOMITE)

2 THETA	D-SPACING	INTENSITY	MINERAL
27.90	3.20	100	plagioclase
28.02	3.18	88	plagioclase
5.80	15.24	75	smectite (Mg, Ca)
35.70	2.52	70	magnetite-maghemite
24.52	3.63	55	plagioclase
23.79	3.74	55	plagioclase
22.10	4.02	55	plagioclase
28.47	3.14	52	pyrolusite
19.98	4.44	48	smectite (dioc.)
22.89	3.89	40	olivine (forsterite)
25.78	3.46	40	(?)
26.58	3.35	40	quartz (?)
29.59	3.02	38	smectite
30.35	2.95	38	plagioclase
31.60	2.83	29	olivine (fayalite)
33.80	2.65	27	plagioclase
42.38	2.13	26	pyrolusite

SAMPLE 140 (GRINDSTONE CANYON)

2 THETA	D-SPACING	INTENSITY	MINERAL
5.78	15.29	100	smectite (Mg, Ca)
27.97	3.19	73	plagioclase
28.12	3.17	58	plagioclase
19.93	4.45	47	smectite (dioc.)
35.78	2.51	46	magnetite-maghemite
35.01	2.56	35	montmorill. (group)
62.00	1.50	31	smectite (dioc.)
28.60	3.12	30	(?)
23.82	3.74	30	plagioclase
22.10	4.02	30	plagioclase
24.59	3.62	27	plagioclase
42.20	2.14	20	(?)
31.58	2.83	20	olivine (fayalite)
30.36	2.94	20	plagioclase
29.65	3.01	20	smectite
26.60	3.35	20	quartz (?)
23.00	3.87	20	(?)

SAMPLE 154 (UNITY BASIN)

2 THETA	D-SPACING	INTENSITY	MINERAL
5.80	15.24	100	smectite (Mg, Ca)
27.82	3.21	90	plagioclase
28.05	3.18	71	plagioclase
22.09	4.02	56	plagioclase
23.78	3.74	42	plagioclase
28.46	3.14	40	(?)
35.59	2.52	38	magnetite-maghemite
19.94	4.45	34	smectite (dioc.)
24.55	3.63	33	plagioclase
20.75	4.28	32	(?)
30.32	2.95	31	plagioclase
62.09	1.49	30	smectite (dioc.)
26.55	3.36	30	graphite (?)
29.59	3.02	28	smectite (dioc.)
22.95	3.88	28	(?)
31.52	2.84	27	(?)
25.70	3.47	26	(?)
42.21	2.14	25	graphite (?)
33.78	2.65	20	plagioclase

SAMPLE 156 (UNITY BASIN)

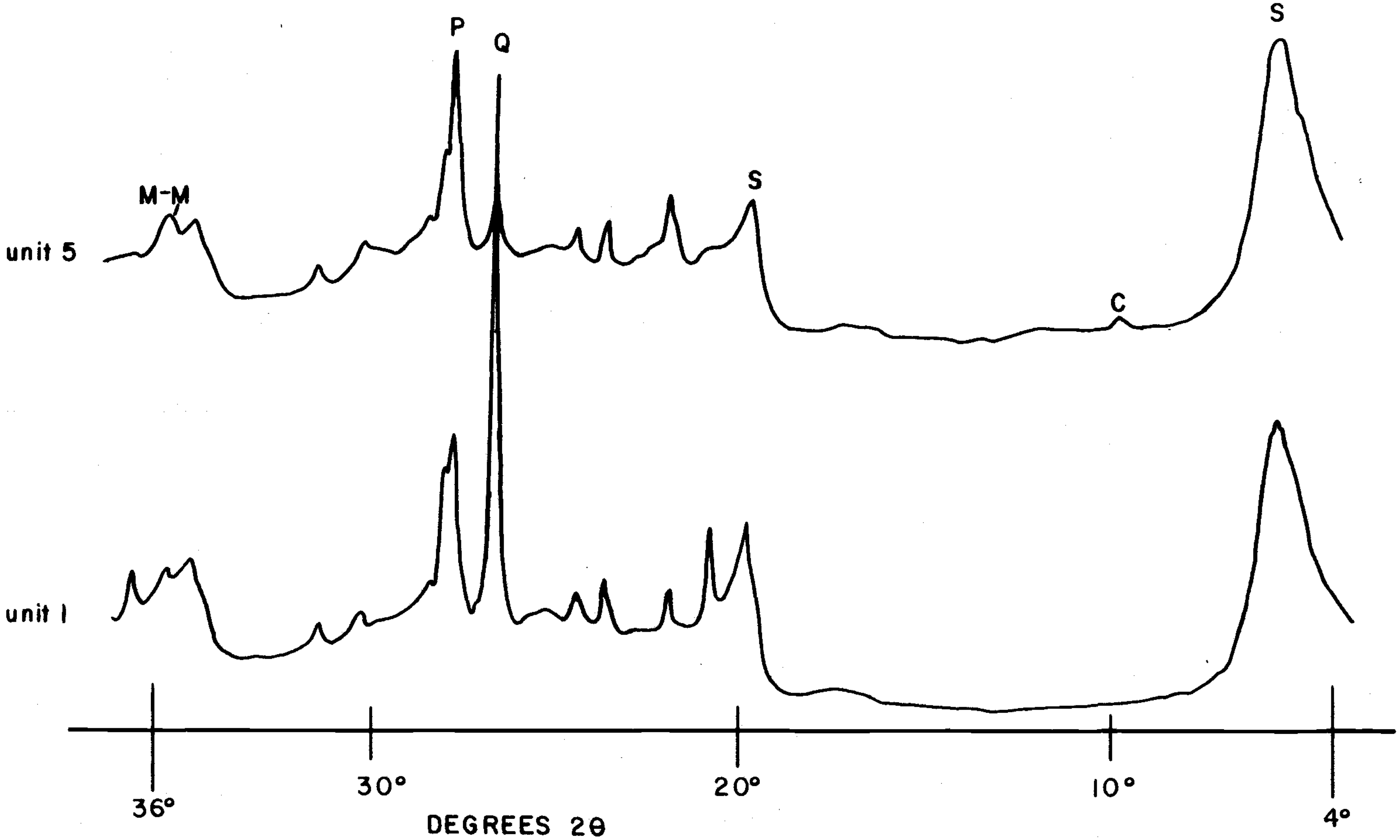
2 THETA	D-SPACING	INTENSITY	MINERAL
27.81	3.21	100	plagioclase
5.82	15.19	74	smectite (Mg, Ca)
28.05	3.18	58	plagioclase
23.73	3.75	45	plagioclase
19.95	4.45	43	smectite (dioc.)
35.70	2.52	43	magnetite-maghemite
24.45	3.64	38	plagioclase
21.99	4.04	38	plagioclase
28.46	3.14	36	(?)
30.29	2.95	35	plagioclase
42.20	2.14	28	graphite (?)
29.60	3.02	28	smectite
26.50	3.36	28	graphite (?)
31.54	2.84	25	(?)
33.78	2.65	19	plagioclase

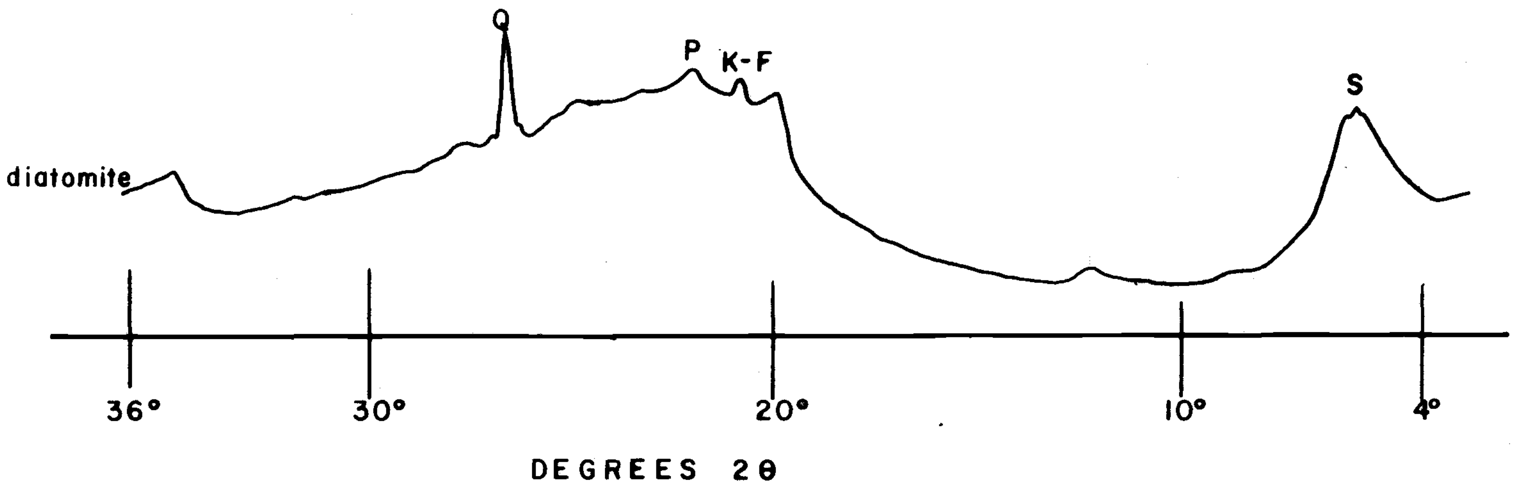
SAMPLE 160 (UNITY BASIN)

2 THETA	D-SPACING	INTENSITY	MINERAL
26.67	3.34	100	quartz
22.04	4.03	89	plagioclase
27.79	3.21	79	plagioclase
20.95	4.24	68	K-feldspars
20.05	4.43	68	halloysite
23.77	3.74	65	plagioclase
5.80	15.24	50	smectite (Mg, Ca)
35.05	2.56	50	halloysite/montmorill.
62.10	1.49	48	smectite (dioc.)
36.59	2.46	46	quartz
55.03	1.67	37	graphite (?)
60.00	1.54	35	quartz
42.51	2.13	35	graphite (?)
31.45	2.84	35	(?)
50.23	1.82	33	quartz
63.89	1.46	32	(?)
12.33	7.18	21	halloysite/kaolinite

The following diagrams are line drawings of the X-ray diffraction patterns obtained for the different samples.

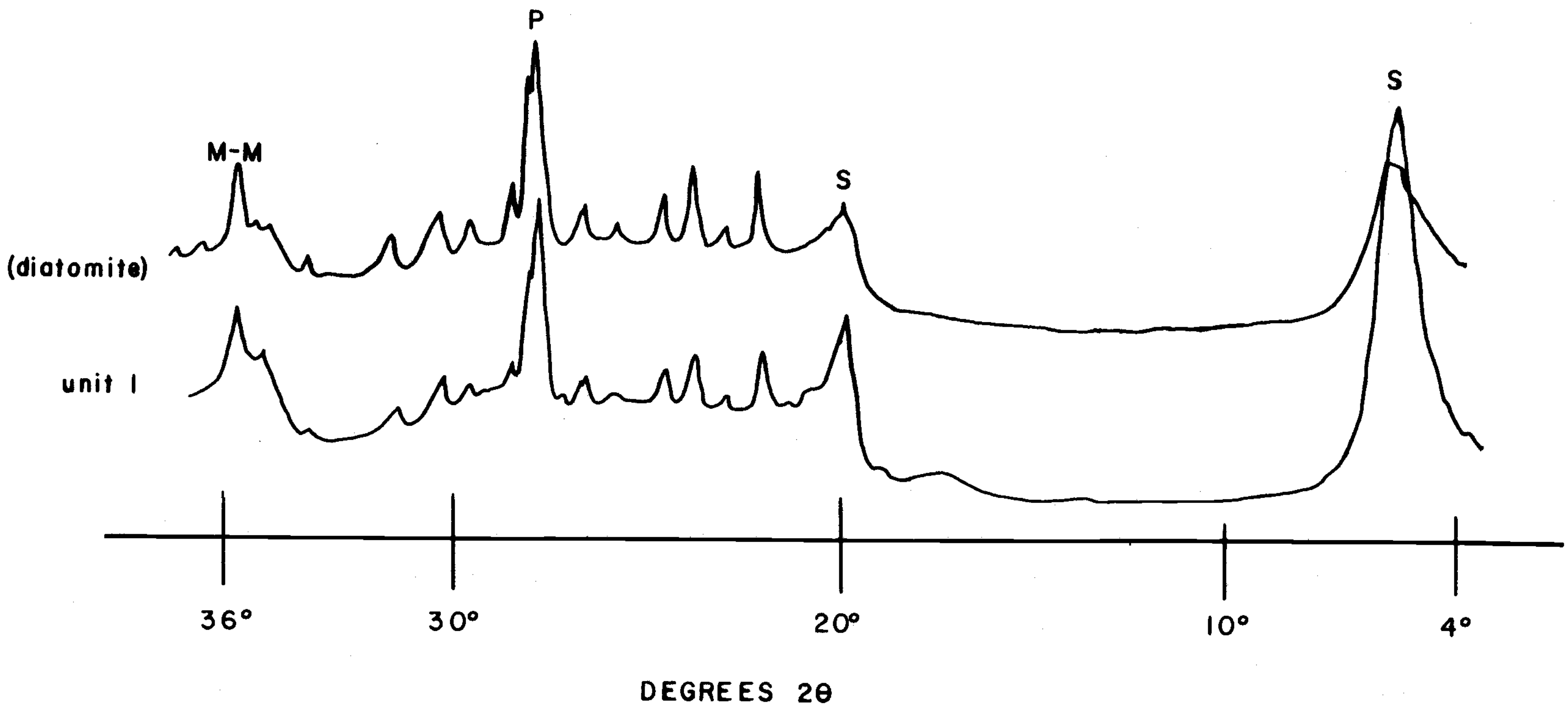
X-ray diffraction pattern of selected units from the Mascall type section.
P-plagioclase, K-F - K-feldspar, Q-quartz, M-M - magnetite-maghemite, S-smectite, K-kaolinite, C-clinoptilolite, H-haloysite.



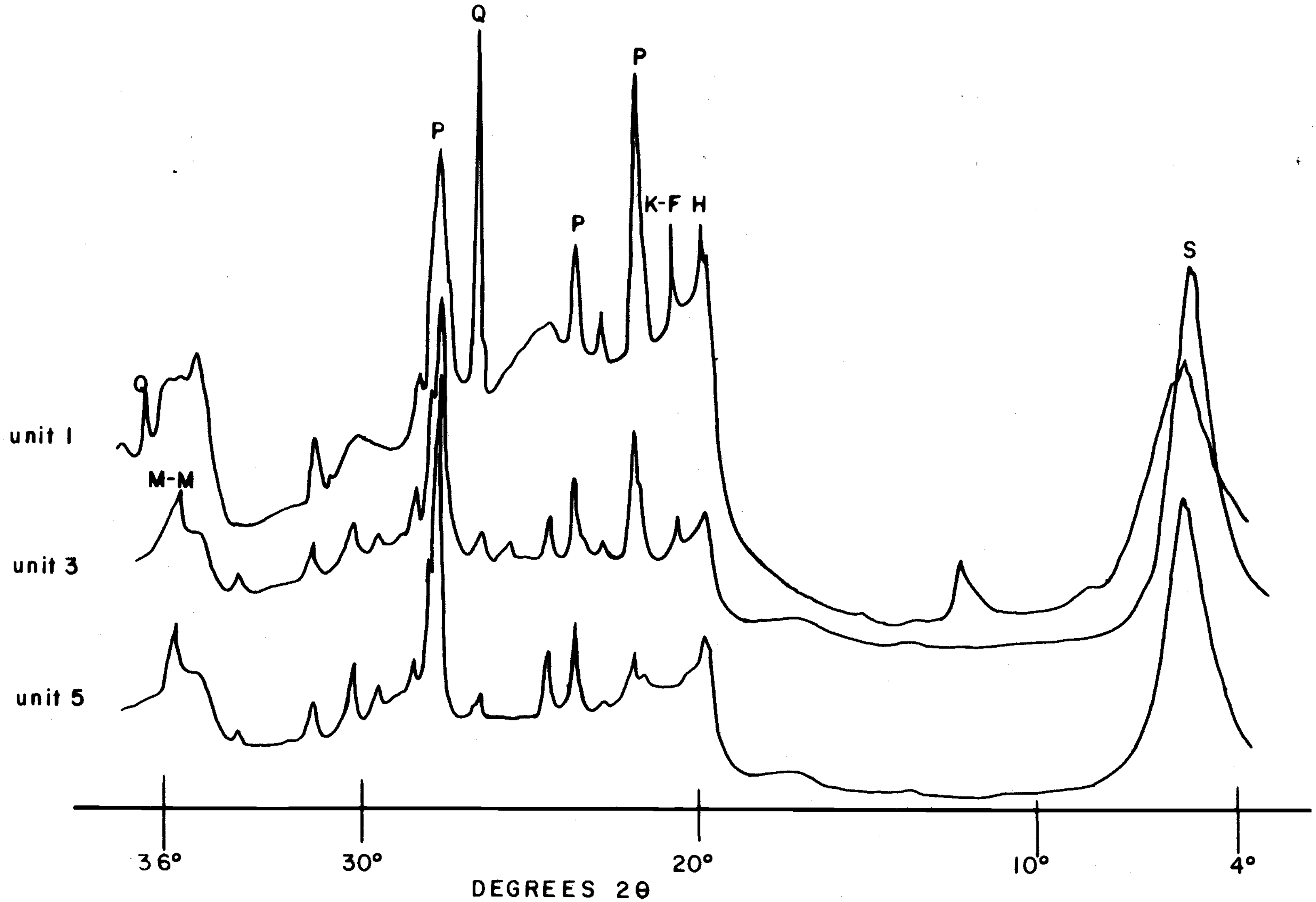


X-ray diffraction pattern (line drawing) of Fields Creek Diatomite.

X-ray diffraction patterns (line drawings) of selected units from the Paulina Basin. Diatomite is from within unit #4.

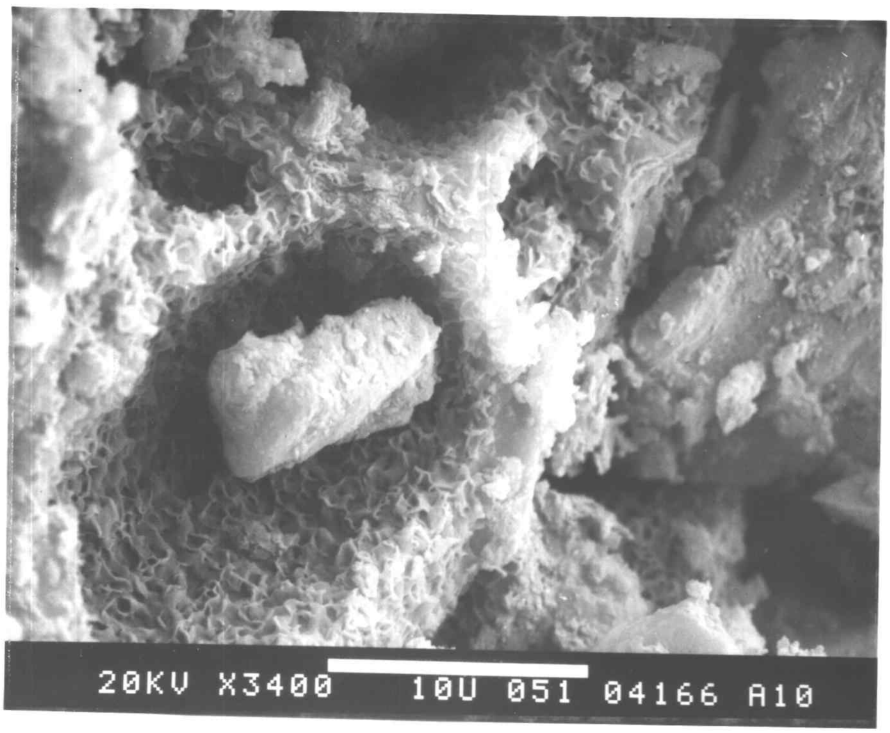


X-ray diffraction pattern (line drawing) of selected units from the Unity Basin.

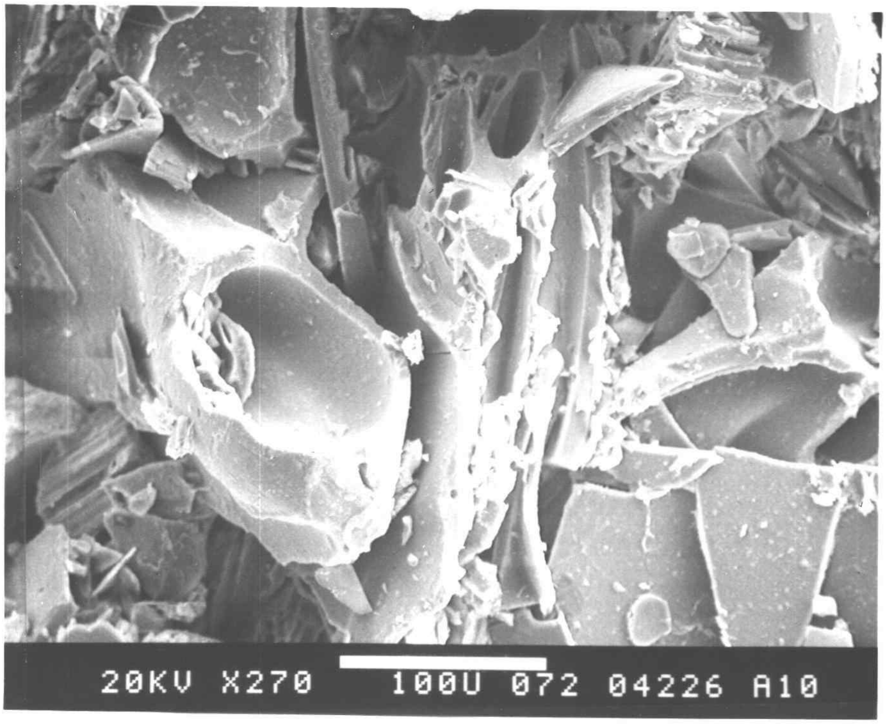


APPENDIX B (ELECTRON MICROSCOPY)

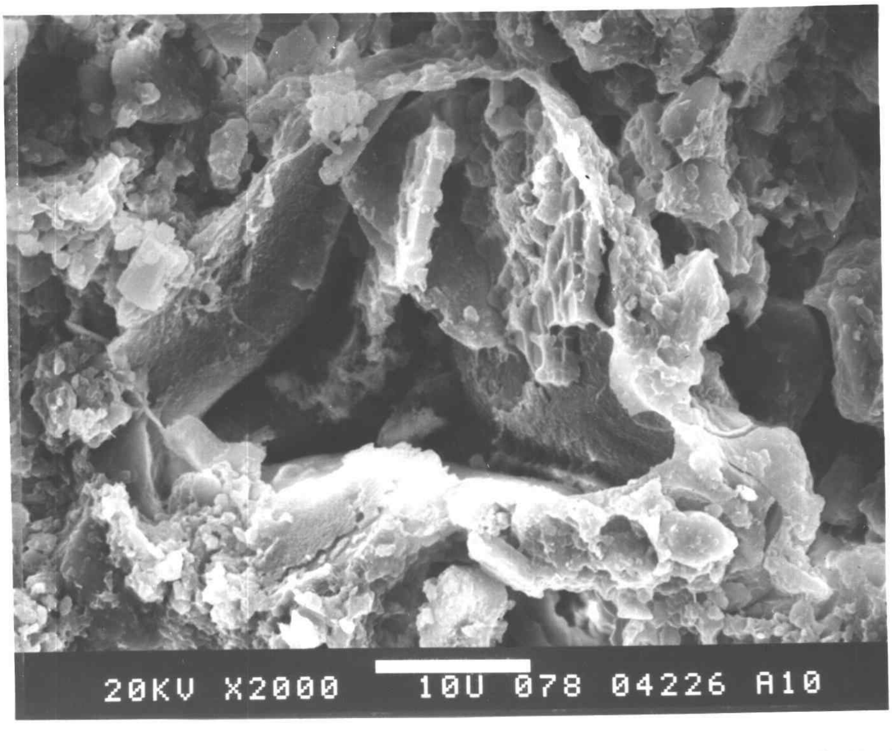
Both scanning electron and transmission electron microscopy were performed at Oregon State University. Additional scanning electron micrographs of sediments from the Mascall type section are presented here.



Unidentified organic material within unit #2 of the Mascall type section.

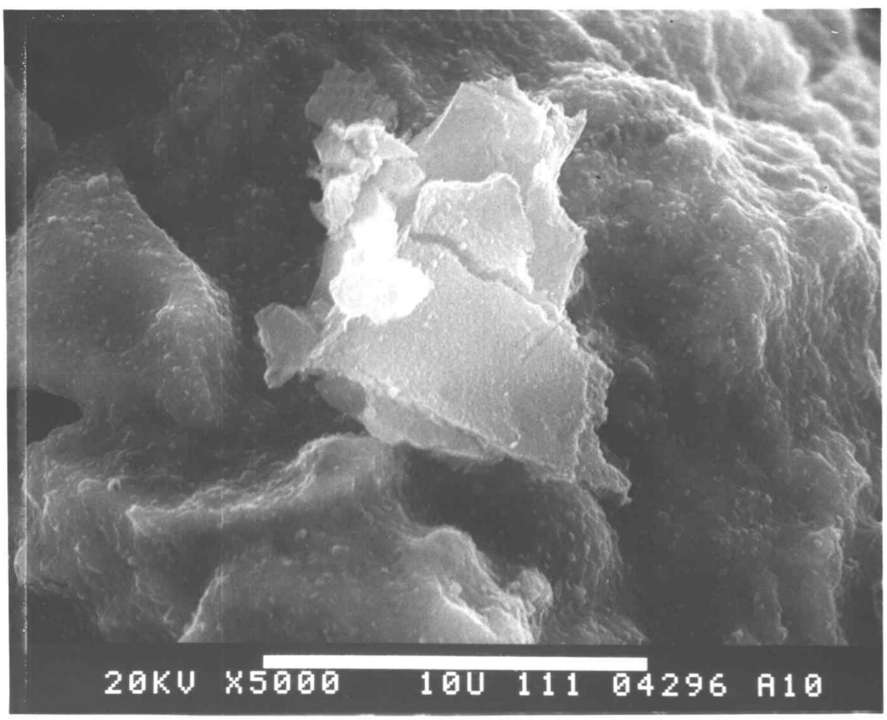


Vitroclastic air fall ash from unit #4, type section.



Organic material in mammal horizon (possibly a club moss megaspore).

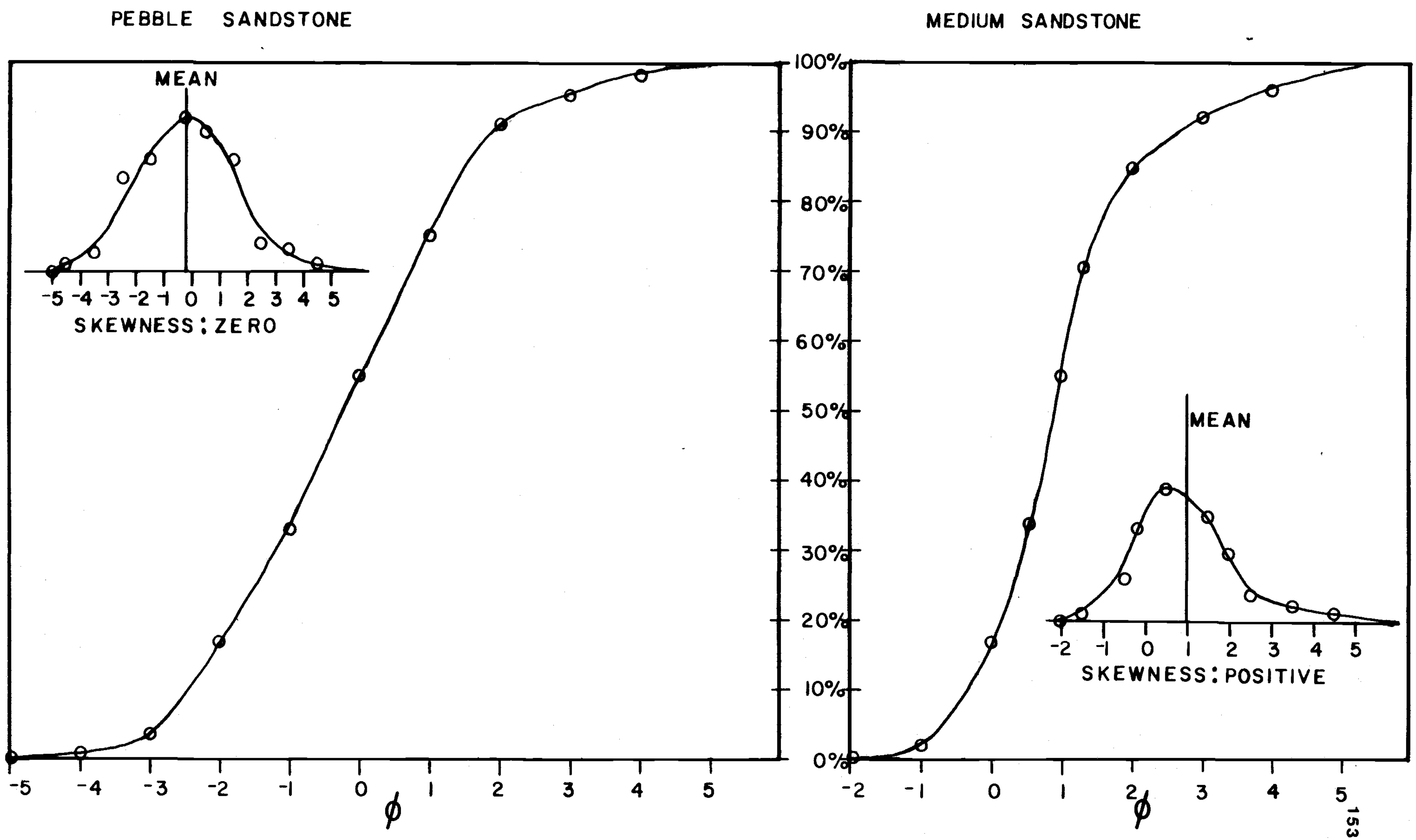
Vitroclastic channel sandstone (ash) from unit #8, type section.



Mudstone from unit #8 showing smectite and kaolin-smectite (center).

APPENDIX C (GRAIN SIZE ANALYSIS OF TYPE SECTION SANDSTONES)

Grain size analysis was performed on the two coarsest beds in the type section (excluding the basal cobble lag), using statistical techniques described by Pettijohn (1973). The following diagram is consists of two graphs whcih depict the grain size distribution of these two sandstones. Both sandstones occur within unit #8, and although separated by a vertical distance of better than 100 feet, they are both predominantly composed of similar looking ash flow clasts. The pebbly sandstone has a mean of -0.25 phi, a median of -0.22 phi, and a mode of -0.50 phi. The medium sandstone, which is stratigraphicaly below the pebbly sandstone, and is the second coarsest unit, has a mean of 0.98 phi, a median of 0.90 phi, and a mode of 0.50 phi.



PEBBLE SANDSTONE
MEDIUM SANDSTONE
MEAN
-5 -4 -3 -2 -1 0 1 2 3 4 5
SKEWNESS: ZERO
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
MEAN
-2 -1 0 1 2 3 4 5
SKEWNESS: POSITIVE
-5 -4 -3 -2 -1 0 1 2 3 4 5
ϕ
-2 -1 0 1 2 3 4 5
ϕ