STRATIGRAPHY AND URANIUM DEPOSITS
OF THE LISBON VALLEY DISTRICT,
SAN JUAN COUNTY, UTAH

by
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ABSTRACT

Uranium mineralization occurs scattered throughout southeastern Utah in the lower sandstones of the Triassic Chinle Formation. The Lisbon Valley district, however, is the only area with uranium deposits of substantial size. The stratigraphy of the Lisbon Valley district was investigated in order to determine the nature of the relationship between the mineralization and the lower Chinle sandstones.

A study of the outcrop along Lisbon Valley indicates that two separate fluvial channel systems, and possibly a third, are present within lower Chinle strata. These sandstone bodies are defined separately by their sequence of primary sedimentary structures, cross-bedding directions, and lateral facies relationships. The channel system which hosts the uranium mineralization appears to have a more southwesterly transport direction than the overlying system. A study of the facies present along the outcrop indicates that a high percentage of the sediments in the mineralized fluvial system is fine-grained, vertical accretion deposits. The sandstones were deposited by a westerly-trending river system. Sediments to the north in the vicinity of the Rio Algoma mine were the product of crevasse-splay and overbank deposition.
Subsurface control west of Lisbon Valley indicates that a separate fluvial system trended northwest and joined the Lisbon Valley fluvial system southwest of La Sal Junction. The Hatch Rock syncline and a small anticline near the confluence of the two stream systems appear to have influenced sedimentation. Contemporaneous salt anticline growth influenced sedimentation by deflecting the streams away from the active salt cells into the structural and topographically low areas.

Subsurface control from Amstrat lithologic logs and field observations of the Chinle outcrops throughout the Paradox Basin show that the Lisbon Valley uranium district is located near a regional color change within the lower Chinle strata. The mineralization occurs in an area of transition between red sediments to the east and greenish-gray sediments to the west.

The geochemistry of the Lisbon Valley uranium mineralization indicates a possible district-wide zoning. The uranium mineralization is oriented perpendicular to the channel system and appears to extend across the system as several large amoeba-shaped masses. Interpretation of the elemental zoning associated with individual ore bodies suggests that humates overtaken by a geochemical oxidation-reduction interface may have led to formation of the uranium deposits.
A regional exploration model based on the Lisbon Valley district includes the following favorable characteristics and their suggested relationship to uranium mineralization:

1. Fluvial deposition into a basin adjacent to a highland where the exposed granitic rock provided a possible source of uranium as well as clastic detritus;

2. Potential host sandstones containing a high percentage of overbank facies which tended to constrict later ground water flow;

3. Abundant organic debris preserved in the channel system by rapid deposition helped establish and preserve a reducing environment;

4. Volcanic debris in and above the sandstones provided a second possible source of uranium and preservation of the fluvial sediments by covering their upper surfaces;

5. Uplift of a portion of these sediments which permitted introduction of oxidizing ground water into the sediments initiating a geochemical cell; and

6. A continued supply of oxidizing water which moved the dissolved uranium to the edge of the tectonically active area.
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INTRODUCTION

The current demand for uranium (1979) is at an all-time high. Based on forecasts by Cameron (1978), the world's uranium requirements can be expected to undergo at least a four-to-five-fold annual increase by 1990. In order to satisfy this world-wide demand, approximately five times the present number of mines will have to be developed and in production by 1990. The current price of uranium, approximately $43.00 per pound of $U_3O_8$, has provided ample incentive for the search for new uranium ore bodies. During 1977, over 45,600,000 feet of exploration drilling were conducted within the United States alone (Chenoweth, 1978). Exploration expenditures during 1977 for 147 companies equalled about $258,080,000.

Hundreds of mines have produced uranium from the Triassic lower Chinle sandstones within the boundary of the Paradox Basin in southeastern Utah. However, the most significant production has come from a narrow belt about one mile wide (1.5 km) and fifteen miles (25 km) long called the Lisbon Valley uranium district or the Big Indian uranium district. This district is located in the east-central portion of the Colorado Plateau (fig. 1). The presence of this significant uranium district in the Chinle strata suggests that there
Figure 1. Index map of Lisbon Valley study area.
should be others, heretofore undiscovered, in the thousands of square miles of similar strata of Late Triassic age.

The exploration genetic model presented in this study has been developed in the hope that such understanding of the genesis of significant uranium deposits, such as those of the Lisbon Valley district, will make exploration efforts more efficient so less drilling is required for discoveries. The techniques and methodology described in this thesis can be applied to other areas where a basin analysis would be helpful in generating exploration drilling targets and their subsequent evaluation. The Lisbon Valley uranium deposits are ideally suited for this type of study because of good outcrop exposures, a long history of uranium production, nearby and regional subsurface borehole data, and available geochemical sampling of the individual mines located within the district.

Purpose of Investigation

The purpose of this study is to explain the genesis of the Lisbon Valley uranium deposits so that subsequent exploration efforts for similar occurrences may be more fruitful. The objectives to achieve this purpose are:

(1) Describe and interpret the stratigraphy and sedimentology of the lower Chinle depositional systems;
(2) Describe and interpret the geochemical changes within host strata that are related to the uranium mineralization;

(3) Develop and integrate a genetic model of the origin of the Lisbon Valley uranium deposits.

The use of the exploration model developed in this study should be helpful in locating favorable targets where drilling may lead to discovery of uranium mineralization.

Method of Study

This investigation was initiated with an outcrop analysis of the lower Chinle sandstones in the Lisbon Valley area. Fifteen stratigraphic sections were measured along the narrow outcrop belt of Chinle sediments in the district. The areas between the measured sections were "walked out" where the topography allowed. Projecting the outcrop interpretation into the subsurface to the west and north was accomplished by the use of drill hole data and mine mapping. The local subsurface work was conducted with the use of nearby drill hole information which was provided by Energy Reserves Group, Inc. and AMAX, Inc. Regional subsurface interpretations were based on lithologic logs of existing oil drill holes.

During the time this study was conducted, most of the mines in the Lisbon Valley district were inaccessible. However,
previous studies supplied information on the geochemical nature of the individual ore bodies. This information, coupled with some previously unreported analyses discussed in the section on geochemistry of the district provided ample information to suggest a possible geochemical model for the Lisbon Valley district.

Location and Geography

The Lisbon Valley uranium district is located about thirty miles (50 km) southeast of Moab, Utah, approximately in the central portion of the Colorado Plateau (fig. 1 and 2). Three separate paved roads enter the Lisbon Valley district and numerous unimproved dirt roads afford access to the remote parts of the study area. Canyonlands National Park lies to the west of Lisbon Valley and Arches National Monument is north of Moab. Segments of Manti-La Sal National Forest lands are to the east of Moab and to the west of Monticello. The detailed surface work was carried out along Big Indian Valley and the subsurface data were to the west of this outcrop (fig. 3).

Climate

The climate in most of the study area can be classified as arid since it receives an average of less than ten inches of rainfall per year. The annual temperature fluctuation
Figure 2. Location map of surrounding area.
Area of subsurface data

Area of outcrops of Chinle strata in Lisbon Valley district

Figure 3. Location map of surface and subsurface work.
for San Juan County is from -29° to 115° for a total range of 144° F; daily variation of about 50° is not uncommon (Doolittle, 1974). During the winter months, an occasional snowfall will blanket the study area, however, the ground is usually dry within a couple of days.
Acknowledgements

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GEOLOGIC SETTING

The study area is in the east-central portion of the Colorado Plateau. Sedimentary rocks in the vicinity range in age from Precambrian to Cretaceous. The upper Paleozoic and Mesozoic rocks are exposed in the region but the lower and middle Paleozoic formations are found only in the subsurface. The area was part of the Cordilleran geosyncline from Cambrian to Pennsylvanian time. The thin blanket of dominantly marine sediments that were deposited during this time interval indicates a period of relative crustal stability (Kelly, 1958). At the start of Pennsylvanian time, crustal movement modified the tectonic setting to create a subsiding intracratonic basin adjacent to a vertically faulted uplift.

This highland, known as the Uncompahgre uplift (fig. 4), was a major source of sediments from Pennsylvanian through Triassic time. The Paradox Basin, which was to the west, filled with evaporite sediments and shelf carbonates during Pennsylvanian time. At the beginning of Permian deposition, the Paradox Basin was almost filled, but the Uncompahgre uplift continued to provide abundant clastics which were deposited by westward-flowing streams. In the vicinity of the study area, the coarse-grained clastics from the eastern source area interfinger with finer-grained detrital sediments which were deposited in a marine environment (Baars, 1971).
Figure 4. Location of Paradox Basin of Pennsylvanian age. (Modified from Wengard, 1958).
From Early Triassic to Late Jurassic time, the general paleogeographic setting was of a seaway to the west and northwest with a fluvial source terrain to the east and southeast. The sediments of the Chinle Formation of Late Triassic age were derived from these source areas. Regionally, the deposition during this time occurred under relatively stable tectonic conditions except in the area of the eastern Paradox Basin where sediment loading caused diapiric movement of the Pennsylvanian evaporites (Molenaar, 1971).

The creation of the Mesocordilleran highland west of the Colorado Plateau in Late Jurassic time greatly changed sedimentation in the region. Clastics were now derived from the west and southwest and deposition was mainly by fluvial processes until Late Cretaceous time. Marine, shoreline, and delta plain deposition then prevailed with the creation of the Rocky Mountain geosyncline as the seas transgressed from the northeast to the southwest.

At the present time, the central part of the Colorado Plateau in southeastern Utah is undergoing intense erosion. Most of the Cretaceous and all of the Tertiary sediments have been removed from the area. To the west, in the Canyonlands area, erosion has removed all of the Mesozoic strata to expose Pennsylvanian and Permian rocks.
Stratigraphy

Regional

Pre-Chinle Stratigraphy

The clastic units of the transgressive Cambrian sea and the limestones and clastics from the Devonian and Mississippian marine inundation are believed to be the oldest sedimentary rocks in the subsurface of the study area. The Devonian and Mississippian units are the reservoir rocks for the Lisbon Valley oil field (Budd, 1960). Rocks of Ordovician and Silurian age are believed to be absent in the subsurface due to nondeposition or erosion (Cooper, 1960).

The formations of the Pennsylvanian Hermosa Group, in ascending order, are: the Pinkerton Trail Formation, the Paradox Formation, and the Honaker Trail Formation (Wengerd, 1958). The cyclic evaporites of the Paradox Formation are the oldest exposed rocks in the study area and are thought to have an original thickness of about 5,000 to 6,000 feet (1500 to 1800 m) in the deepest part of the Paradox Basin (fig. 4) (Hite, 1972). These easily deformable evaporites influenced sedimentation from the Permian to at least the Cretaceous. Fluvial, coarse-grained clastics, derived from the Uncompahgre highland to the east and northeast, covered the eastern part of the study area and interfingered with finer-grained sands and silts to the west which were predominantly
of marine origin (Baars, 1975). As the thick Permian arkoses of the Cutler Formation (fig. 5) covered the Pennsylvanian units, the evaporites of the Paradox Formation were already moving to form early diapiric structures which affected the topography, thereby deflecting the Permian drainages (Shoemaker and others, 1958).

Sedimentation during the Mesozoic followed a period of erosion, as indicated by unconformable relationships between the Cutler strata and the overlying beds of Triassic age (Stewart, 1972). Siltstones and minor sandstones of the Moenkopi Formation are widespread and represent the earliest Mesozoic sedimentation in the region; however, there are several areas where the Moenkopi is absent due to nondeposition or pre-Chinle erosion such as in the Lisbon Valley area (Shoemaker and Newman, 1959).

Chinle Stratigraphy

The Chinle Formation was first described in the literature by H. E. Gregory in 1915 (Molenaar, 1975a). The type locality for this Upper Triassic formation is the Chinle Valley in northeast Arizona where the formation consists of variegated shale, minor siltstones and sandstones, and thin limestone and conglomerate lenses. The areal distribution of this unit includes portions of five states:
Figure 5. Generalized stratigraphic section in the Lisbon Valley area.
northern Arizona, southern Utah, northern New Mexico, southwestern Colorado, and southeastern Nevada. In southwestern Colorado, the lithologic equivalent of the Chinle Formation is the Dolores Formation.

The Chinle Formation originally covered the entire region. Figure 6 shows the outcrops of the Chinle Formation in southeastern Utah and adjacent areas. This formation of Late Triassic age has been informally subdivided (fig. 7) into two parts: a lower bentonitic sequence and upper red-bed sequence (Stewart and others, 1972). The bentonitic sequence, predominantly gray in color, is composed of claystone, clayey sandstone, and widespread sandstone and conglomerate ledge formers. Montmorillonitic clay, which is thought to have been derived from volcanic ash, comprises the claystones of this sequence. The continental deposits of the bentonitic sequence formed in rivers, flood plains, and associated lakes.

The red-bed sequence is composed of reddish-brown or reddish-orange siltstones with sparse sandstones and limestones (Stewart, 1969). The rocks which comprise this sequence are thought to have formed mainly in a large, shallow lake. However, part of this sequence in east-central Utah may have formed in a somewhat different environment as indicated by the larger percentage of sandstone in the section.

Regionally, the Chinle Formation is composed of seven formal members and several informal members which are generally
Figure 6. Outcrop map of Chinle strata of southeastern areas.
(modified from Stewart, 1957)
<table>
<thead>
<tr>
<th>Stewart and others, 1972 and others, 1972</th>
<th>Stewart and others, 1972</th>
<th>O'Sullivan and MacLachlan, 1975</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Red Bed Part</strong></td>
<td><strong>Church Rock Member</strong></td>
<td><strong>Hite Bed</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Owl Rock Member</strong></td>
<td><strong>Siltstone Member</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Licy Member</strong></td>
</tr>
<tr>
<td><strong>Lower Bentonitic Part</strong></td>
<td><strong>Petrified Forest Member</strong></td>
<td><strong>Claystone Member</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Moss Back Member</strong></td>
<td><strong>Moss Back Member</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Monitor Butte Member</strong></td>
<td><strong>Mudstone Member</strong></td>
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<tr>
<td></td>
<td><strong>Shinarump Member</strong></td>
<td><strong>Shinarump Member</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Temple Mountain Member</strong></td>
<td><strong>Temple Mountain Member</strong></td>
</tr>
</tbody>
</table>

**Figure 7.** Correlation chart showing members of the Chinle Formation in southeastern Utah.
equivalent to the named members. The seven units (fig. 8) in ascending order are: Temple Mountain Member, Shinarump Member, Monitor Butte Member, Moss Back Member, Petrified Forest Member, Owl Rock Member, and Church Rock Member. Because the Temple Mountain Member is present only northwest of the study area, it is not included in the discussion of the formal members. O'Sullivan and MacLachan (1975) do not recognize the formal member names of the Chinle Formation in southeastern Utah. They prefer to use informal names (fig. 7) for the members because of facies changes that occur immediately north of the Arizona state line along Comb Ridge. Figure 9 is a generalized north-south cross section across southeastern Utah which shows the relationship between the formal and informal members of the Chinle Formation.

The Shinarump Member of the Chinle Formation overlies the Moenkopi Formation and underlies the Monitor Butte Member. This fluvial member is mainly a coarse-to medium-grained sandstone with conglomerates containing granules and pebbles of quartz, quartzite, and chert (Stewart, 1957). The sandstones of this member do not have great lateral continuity; generally, they are preserved as local channel-fill deposits. The average thickness of the Shinarump Member is less than 50 feet (15 m). This member is generally restricted to the southern half of San Juan County, Utah (fig. 10). However, a cross section by Young (1964) shows Shinarump channels extending to the Moab area. Stokes (1950) discussed a possible source for the Shinarump clastics as being the Uncompahgre
Figure 8. Stratigraphic section of the Chinle Formation in southeastern Utah.
highland to the east (fig. 4). This structural feature was positive during the Triassic and undoubtedly was a significant contributor of detritus to the Shinarump streams.

The Monitor Butte Member overlies the Shinarump Member and underlies the Moss Back Member. Greenish-gray claystones, clayey sandstones, and fine-grained sandstones interstratified with claystones make up this unit. Slump features composed of tilted, warped, and intricately folded blocks are common in this member (Stewart, and others, 1972). The Monitor Butte Member is 100 to 150 feet (30 - 45 m) thick and extends a little farther north to a pinchout past the edge of the Shinarump Member (fig. 10) (Stewart, 1957).

The Moss Back Member in turn overlies the Monitor Butte Member and underlies the Petrified Forest Member. The fluvial sandstones of this unit are fine-to medium-grained with conglomeratic units locally present. The transport directions of the rivers which deposited the sandstones in the Moss Back Member were generally to the northwest (Poole, 1961). The pebbles in the Moss Back are of a different compositional ratio than those of the Shinarump Member. Analysis of pebble composition in the White Canyon area showed that for the Shinarump Member the ratio of quartz, quartzite, and chert was 82:16:2. For the Moss Back Member, the ratio was 12:37:51 (Stewart, and others, 1972). Limestone and siltstone
Figure 10. Distribution of lower members of the Chinle in southeastern Utah. (Modified from Stewart, 1957)
pebbles are rarely found in the Shinarump sandstones but commonly occur in the Moss Back sandstones (Albee, 1957). The average thickness of this unit is about 55 feet (16.5 m) but locally, it is up to 150 feet (45 m). The lower contact is erosional and the upper contact is gradational (O'Sullivan and MacLachlan, 1975).

The Petrified Forest Member is composed of variegated red, purple, green, and yellow claystones and clayey sandstones. This unit is believed to have been derived mainly from volcanic detritus. Samples from the Petrified Forest Member which were analyzed by Cadigan (1963) indicate that the source terrane of the unit contained intrusive and extrusive latitic to rhyolitic rocks. These igneous fragments were subsequently altered to montmorillonite clay. The volcanic material is believed to have been introduced into the region by stream transport and not as an ash-fall tuff. This member thins northward in the study area and grades into other members (Stewart and others, 1972).

The Owl Rock Member is composed of pale red and pale reddish-brown siltstone layers which rest upon the Petrified Forest Member and below the Church Rock Member. Both contacts are generally gradational in character. Sparse limestones occur in this member and the uppermost limestone in the Chinle Formation is usually picked as the top of the Owl Rock Member.
The Church Rock Member is the uppermost unit of the Chinle Formation. It is mainly pale reddish-brown, reddish-orange, and light brown fine-to coarse-grained siltstone. Two sandstone units are present in the Church Rock Member in southeastern Utah: a lower sandstone informally called the "Black Ledge" and an upper sandstone called the "Hite bed" (Stewart, and others, 1972). O'Sullivan and MacLachlan (1975) do not recognize the reddish-brown siltstones which occur in the uppermost part of the Chinle outcrop in the Canyonlands area as the Church Rock Member. They believe these siltstones are actually younger than the Church Rock Member at the type locality.

Fourteen species of plant megafossils have been found in the Chinle Formation of southeast Utah (Ash, 1975). Most of the megafossils occur in the Shinarump, Monitor Butte, Moss Back, and Petrified Forest Members. The type of plant fossils found in this area indicates that the sediments of the lower Chinle Formation were deposited in a climate which was warm and humid. The Chinle flora found in southeastern Utah dates the formation as Late Triassic in age.

The geologic history of Chinle sedimentation in southeast Utah contains episodes of erosion, subsidence, deposition, and volcanism (Stewart, and others, 1959). For convenience, the following sequence of events is discussed in terms of the generally recognized members of the Chinle Formation even
though not all authors recognize these members in the area.

(1) The initial event in the Chinle history was the erosion and stream cutting on the Moenkopi surface. These streams flowed in a westerly direction and in part from the Uncompahgre highland.

(2) Subsidence which occurred in the area caused the total abandonment of segments of the Shinarump streams and subsequent preservation as valley-fill deposits or blanket-type deposits. The source areas were probably restricted to the highlands to the east and south of the study area. Some volcanic material was being contributed to these fluvial sediments. Plant life flourished along the flood plains and channel margin areas. Reducing conditions were created and maintained in areas with a high ground water table which underwent rapid sedimentation.

(3) As the area continued to subside, the stream gradients during Monitor Butte deposition were less steep than before resulting in a finer-grained sediment fraction being transported. Volcanic material was also transported in the streams. Plant life thrived in these conditions and their remains were commonly preserved.

(4) Prior to and during initial Moss Back deposition, the general subsidence was interrupted and erosion again occurred over the area. The coarser-grained sediments of this event not only came from highlands, but also were derived from the Chinle itself and older formations as indicated
by the abundance of siltstone and limestone pebbles. This may indicate that the salt anticlines underwent a period of rapid growth prior to deposition of the Moss Back sands. Volcanic debris was available to the fluvial systems during this time. The abundant carbonaceous debris found in the channel systems and associated overbank deposits indicates that the plant life was prolific and preserved in a reducing environment. Humic acids were probably formed from the plant debris contained in the sandstones.

(5) A period of intense volcanism occurred during deposition of the Petrified Forest Member. This montmorillonitic unit contains rounded pumice fragments which are altered to clay. The subsiding area probably was dominated by quiet-water deposition in sluggish streams with large areas covered by lakes and flood plains. This is the uppermost member of the Chinle Formation in which plant life appears to have been preserved in large amounts.

(6) Environmental conditions appear to have changed during Owl Rock and Church Rock deposition. The climate may have become more arid as shown by the highly oxidized sediments in the upper Chinle Formation. Flood basin and lacustrine sedimentation with several large fluvial systems (e.g. Black Ledge member) and numerous smaller stream systems dominated the terrain. These smaller streams probably covered
most of the area at one time or another and may be represented by isolated sand bodies which occur throughout the Owl Rock and Church Rock section.

(7) At the close of Chinle sedimentation, widespread erosion preceded the deposition of the Wingate Sandstone.

Post-Chinle stratigraphy

The next sedimentary unit to be deposited in southeastern Utah was the sandstones of the Glen Canyon Group. In ascending order, the formations are: the Wingate Sandstone of eolian origin, the Kayenta Formation of fluvial origin, and the Navajo Sandstone of eolian origin. The San Rafael Group overlies the Glen Canyon Group and is composed of four formations. In ascending order, they are: the Carmel Formation of shallow marine origin, the Entrada Sandstone of eolian origin, the Curtis Formation of marine origin, and the Summerville Formation of tidal flat origin. Overlying the Summerville Formation is the Late Jurassic age Morrison Formation of fluvial origin. A thick sequence of sandstones, siltstones, and shales were deposited with the Cretaceous marine transgression.

Lisbon Valley Area

The oldest rocks which outcrop in the Lisbon Valley area are the Pennsylvanian age Hermosa Group (fig. 5). The limestones and sandstones of the formation are overlain by the
Cutler Formation of Permian age. At this location, the Cutler is composed of red sandstones, siltstones, and minor limestones which were apparently deposited in environments which alternated between westward-flowing streams and eastward marine transgressions. The sedimentology of this formation is being reconstructed by Campbell (1978, personal communication) in an effort to relate the depositional environments to the occurrence of uranium in the Cutler Formation.

The upper contact of the Cutler Formation is an unconformity (fig. 11). The entire Moenkopi Formation is missing at Lisbon Valley due to erosion or nondeposition. Therefore, the Chinle Formation rests directly upon the Cutler Formation. The amount of angularity between the two formations varies but generally is under 5 degrees.

Several opinions exist as to what members of the Chinle Formation are actually present in the Lisbon Valley area. The Shinarump Member and the Monitor Butte Member are generally believed to be absent at the Lisbon Valley section (Stewart, 1969). The basal sandstone interval which rests unconformably on the Cutler Formation is generally called the Moss Back Member and the remaining portion of the Chinle is called Church Rock Member. Stewart, and others (1972), suggested that the lower sandstones of the Chinle in this area may not, in fact, be the Moss Back Member but rather a younger sandstone. Young (1978, personal communication), however,
Figure 11. Exposures of Wingate (Rw), Chinle (Rc), and Cutler (Pc) strata on west flank of Lisbon Valley anticline looking southwest.
suggested the lowermost sandstones of the area may be in fact the Shinarump Member. O'Sullivan and MacLachlan (1975) preferred not to use the traditional member names for the Upper Chinle; instead, they adopted an informal lithologic breakdown of the Chinle Formation as claystone member, limy member, and siltstone member.

The Wingate Sandstone of Triassic age occurs directly above the Chinle. This sandstone formation is the basal formation of the Glen Canyon Group which comprises the youngest rocks in the area west of the Lisbon Valley fault. To the east of the Lisbon Valley fault (Plate I), the stratigraphic section continues up through the Jurassic and into the Cretaceous Dakota Sandstone.

**Structural Geology**

**Regional**

The study area lies on the stable crustal block of the Colorado Plateau (fig. 1). Two types of geologic structures occur in this region: those which formed due to salt flowage and those which formed by other processes. The timing and nature of movement of both of these types of structures influenced sedimentation. It is therefore important to understand these structures when attempting to reconstruct the depositional history of the strata in the area.
During late Mississippian time, the Paradox Basin formed with associated uplift of the Uncompahgre portion of the Ancestral Rocky Mountains (fig. 4). Accompanying this uplift was the associated sinking of the trough portion of the basin. Elston and Shoemaker (1960) suggested that the basin subsided a greater amount relative to the uplifting portion of the Uncompahgre. Gorham (1975) described this area as a aulacogen which influenced sedimentation throughout the entire Phanerozoic. The formation of the basin in Pennsylvanian time appears to have been by "stair-step" faulting towards the highland. When the salts that filled this basin were covered by detritus from the Uncompahgre highland, they deformed plastically and started to flow southwesterly away from the thick clastic accumulation. These evaporites probably flowed horizontally until encountering the upthrown side of the faults where movement of the salts was deflected upwards (fig. 12). With the addition of more Permian, Triassic, and Jurassic sediments, the evaporites continued to move upwards to produce positive features which in turn created small-scale deposition troughs between these salt anticlines. In some locations, the salts were diapiric and in other areas there appears to be little piercement of the overlying strata.

The largest structure in the region not directly related to the salt anticlines is the Monument upwarp (fig. 12). This structure may have been a positive feature which also
Monocline

Anticline

Syncline

Salt anticline in which salt is near surface

Fault

Figure 12. Main structural elements of southeastern Utah and adjacent areas (Modified from Meisner, 1973).
influenced sedimentation of the Chinle Formation. The lower Chinle sandstones are not present along the Comb Ridge portion of this asymmetrical uplift indicating either non-deposition of the unit or pre-Church Rock erosion. Almost all of the obvious structural features trend northwest in the salt anticline area. However, a northeast trend of strike-slip faults has been identified. Ten northeast-trending lineaments which may be related to basement strike-slip faulting have been mapped in the region. Hite (1975) stated that these basement faults are shear zones, wrench faults, or possibly en echelon strike-slip faults which have apparent displacements of 3-5 miles (5-9 km).

**Lisbon Valley Anticline**

The Lisbon Valley anticline is one of the main salt anticlines of the Paradox Basin (fig. 12). However, this anticline is different from the majority of the others as the Pennsylvanian salts did not penetrate to the surface. The northeastern side of the anticline has been faulted down along the Lisbon fault approximately 4,000 feet (1,200 m) (606 m) near the North Alice and Rio Algom mines (Wood, 1968). Coyote Wash syncline is about four miles (6.5 m) northeast of Lisbon Valley and the Hatch Rock syncline is about 8 miles (13 km) west of the district.
It appears that the anticline was positive and an active feature at the beginning of the Triassic Period. This is indicated by the absence of the Moenkopi Formation in the Lisbon Valley area and its presence between the Chinle and Cutler strata in adjacent synclinal areas (Wood, 1968, and Budd, 1960). Butler and Fisher (1978) suggest that small variations of Chinle thickness along the outcrop of the southwestern flank of the Lisbon Valley anticline indicate that minor uplift of parts of the anticline may have occurred during Chinle sedimentation. Tectonic activity during Laramide time or later faulted the anticline along the axis and displaced the northeast block downwards along the Lisbon fault. Figure 13 shows a diastem within the lower Chinle strata which may have been formed by movement of the salt anticline. However, such features are also commonly formed along the edge of rivers where large blocks slump into the channel (Weimer, 1979, personal communication).
Figure 13. Local diastem within the Chinle Formation.
STRATIGRAPHY AND SEDIMENTOLOGY OF
MOSS Back MEMBER

The lower Chinle sandstones of the Lisbon Valley area were investigated in a three-fold stratigraphic analysis: initially along the outcrop, then briefly in the Rio Algom mine, and finally, to the west of Lisbon Valley into the subsurface with electric logs and cuttings from a drilling program.

Outcrop Investigation

Method of Study

The outcrop of Triassic rocks at Lisbon Valley extends approximately 15 miles (25 km) in a northwest-southeast direction. Fifteen stratigraphic sections were measured along this exposure utilizing a Jacob staff. The unit of investigation was the lower Chinle sandstones, however, several of the measured sections were extended to the base of the overlying Wingate Sandstone in order to provide a datum horizon along the outcrop. The area in between the measured sections was walked out where the terrain allowed, so that correlations in between the sections could be made with a degree of confidence. During this phase of stratigraphic analysis, sketches of the different types of sedimentary structures
were made and cross-bedding directions were recorded. After the sections were measured and tentatively correlated, it became apparent that deposits of two separate stream systems, one above the other, may exist at the Lisbon Valley area. The outcrop was again investigated in selected areas to obtain cross-bedding directions from the deposits of each of the possibly different systems. Hand samples collected from both the measured sections and at intermediate localities along the outcrop were examined under the binocular microscope and thin sections were made of selected samples.

**Stratigraphy and Sedimentology**

The locations of the fifteen measured sections are shown on Plate I. A stratigraphic cross section showing the measured sections along the strike of the Chinle outcrop is shown on Plate II. All fifteen of the sections included the contact of the Chinle strata with the underlying Cutler Formation and seven included the entire Chinle Formation to its contact with the overlying Wingate Sandstone. The remaining sections included only the lower sandstones of the Chinle Formation. The thickness of the total Chinle Formation at Lisbon Valley ranges from 385.5 feet (116.5 m) to 488.5 feet (148 m). The lower Chinle sandstones (Moss Back Member), which host the uranium deposits, range in thickness from 7 feet (2 m) to 57.5 feet (17.5 m). As shown on Plate II, there are three
principal sandstone units (A, B, C) at the northwestern part of the Lisbon Valley anticline where the main uranium deposits occur. The original basis for this three-fold distinction is the sequence of sedimentary structures.

Unit A

The sandstones of the Moss Back Member in the area of Spiller Canyon comprise unit A. This unit extends for about 1.2 miles (2 km) along the outcrop and obtains a maximum thickness of about 60 feet (18 m) at measured section 1 (Plate II). The sandstones are generally composed of: 95% quartz, 3% feldspars, and 2% accessory minerals. Grain size throughout unit A is variable but a general fining-upward sequence was observed along the outcrop. A basal quartz pebble conglomerate is present from measured section 1 northward to measured section 3. The sandstones overlying this conglomerate are generally fine-to medium-grained, well to poorly sorted, and subrounded. At measured section 3, the sandstones vary from very coarse-grained at the base to medium-grained in the middle part of the outcrop, and finally to fine-grained at the top of the unit. Throughout the rest of unit A, the fining-upward trend was found not to be as well developed as at measured section 3. Lenses of conglomerate and siltstone are interbedded with the sandstones and appear to occur commonly where sandstones are poorly sorted.
Clay clasts and fossil plant material were commonly observed within the conglomerate lenses. North of measured section 3, such a conglomerate lens was found cutting into a large-scale cross-bedded sandstone (fig. 14).

The basal conglomerate of unit A is generally parallel bedded to low-angle cross-stratified. The sandstones are dominantly trough cross-bedded but tabular cross-bedding was observed. The direction of sediment transport was taken from cross-bedding measurements. Care was taken to insure that only one cross-bed reading was obtained from each set. The structural dip was then rotated out using standard stereonet procedures (Pettijohn and Potter, 1963). Figure 15 shows the westerly transport direction for the sandstones of unit A. To the north and south of unit A the sandstones grade laterally into thick siltstone layers. These siltstones contain thin lenticular sandstone beds. Similar siltstones are found overlying the entire length of the unit. The overall relationship between unit A and the other sandstone units shown on Plate II indicate that unit A may have scoured at least 50 feet (15 m) into the underlying Cutler Formation.

Unit B

Unit B extends along the outcrop from measured section 4 northward past measured section 7 for a distance of approximately 4 miles (6.5 km) (Plate II). The thickness
Figure 14. Sketch of sedimentary structures in unit A. Location shown on Plate II.
Figure 15. Transport directions for unit A (n = 28).
of the unit is variable -- at measured section 4 approximately 20 feet (6 m) of unit B was observed. Northward to measured section 5, near the Mi Vida mine, the unit is over 40 feet (12 m) thick. The mineralogy of the sandstones in unit B is the same as the sandstones of unit A.

At measured section 7, unit B is composed of greenish-gray siltstones and sandstones. The sandstones are fine-grained, subrounded, and moderately well sorted. Clay clasts were observed in several of the sandy siltstones. Approximately 500 feet (150 m) south of measured section 7, the unit contains a coarse-grained sandstone which is about 15 feet (4.5 m) thick. Southward, approximately another 500 feet (150 m), unit B contains a light gray conglomerate averaging about 20 feet (6 m) thick. Pebbles composed of both quartz and siltstone rock fragments are present in this conglomerate. Small-scale trough cross-bedding and tabular cross-bedding was observed, however, these conglomerates were dominantly parallel-bedded. This conglomerate unit thins both north and south along a distance of about 200 feet (60 m). Dip directions from trough cross-beds in this area indicate a sediment transport of N11W to N50W. About 1,600 feet (485 m) south of measured section 7, most of unit B is covered. Only a 5-foot (1.5 m) thick sandstone is exposed at the outcrop.
Progressing about 2,200 feet (667 m) south of measured section 7, a 15-foot (4.5 m) thick coarse-grained sandstone is present. The next exposure along the outcrop, about 200 feet (60 m) southward, shows the unit to be at least 20 feet (6 m) thick and composed of siltstones interbedded with fine-grained sandstones. Lenses of mudstone-pebble conglomerates are present in this area. Approximately 3,500 feet (1060 m) south of measured section 7, four small adits are present within unit B. Plate III illustrates several cross sections that were made by mapping the walls of the four adits. These sections show the relationship between the various sedimentary units that are present in the area. Figure 16 shows a fossil twig that was preserved from the effects of oxidation located near one of the adits. Southward from this locality to measured section 8, the sandstone bodies are principally trough cross-bedded, however, ripple-marked sandstones were observed.

At measured section 8, unit B is composed of a 2-foot (.6 m) thick quartz-pebble conglomerate which is parallel bedded. Above this conglomerate is a 19-foot (6 m) thick interval which is partially covered, however, limited exposures indicate the interval is composed of interbedded siltstones and sandstones. Overlying this is a trough cross-bedded sandstone which is about 16 feet (5 m) thick. This sandstone is very fine-to fine-grained and subangular to subrounded,
Figure 16. Fossil twig preserved from oxidation in unit B. Location shown on Plate II and III.
About 100 feet (30 m) south of measured section 8, the unit is mostly covered. Where the rocks outcrop, the lithology is conglomerate, commonly containing red siltstone pebbles. Southward about 400 feet (120 m), a sandstone interval is exposed. At this locality, the sandstone is at least 15 feet (4.5 m) thick with a basal zone composed of interbedded quartz-pebble conglomerates and siltstones. One of the conglomerate beds contained pebbles composed of limestone clasts.

About 2,000 feet (600 m) south of measured section 8, unit B is composed of a 2-foot (.6 m) thick basal conglomerate overlain by a 10-foot (3 m) thick sandstone which contains both trough and tabular cross-bedding. This sandstone is overlain by a 15-foot (4.5m) thick siltstone interval (fig. 17). At this locality, the upper 2 feet (.6 m) of the Cutler Formation has been bleached white. Southward from this outcrop to a point about 3,800 feet (1,150 m) from measured section 8, the unit is mainly covered. Available exposures indicate the principal lithology may be siltstone. About 4,000 feet (1,212 m) south of measured section 8, a 24-foot (7.5 m) thick sandstone outcrops. Exposures of the unit for the rest of the distance to measured section 6 occur between large covered areas. However, it appears that sandstone may be the main lithology along this part of the outcrop.

At measured section 6, a 2-foot (.6 m) conglomerate containing clay clasts is overlain by about 20 feet (6 m) of sandstone. The sandstones fine upward from very coarse-
Figure 17. Sedimentary sequence of unit B. Location shown on Plate II.
grained at the base to fine-grained at the top of the interval. This sandstone is mainly trough cross-bedded. Most of the interval from measured section 6 to measured section 5 forms a vertical cliff which greatly limits access to the sandstones. About 1,000 feet (303 m) south of measured section 6, the unit locally contains a basal conglomerate. At this locality, the main type of sedimentary structure in the lower portion of the unit is trough cross-bedding. Upward, a larger percentage of the cross-bedding is composed of tabular cross-beds. About halfway between measured sections 6 and 5, a typical sequence is shown in figure 18. Here a parallel-bedded quartz-pebble conglomerate is overlain by plane to tabular cross-bedded sandstones. Overlying this is an interval which is composed of small-scale trough cross-bedding. This sequence is capped by a conglomerate bed. Southward, about 500 feet (150 m), a lenticular sandstone is truncated by a conglomerate layer (fig. 19). The lenticular sandstone has a basal conglomerate which contains abundant clay clasts. The main sandstone interval which overlies this conglomerate is principally trough cross-beded. Continuing southward for a distance of about 500 feet (150 m), a thin conglomerate containing abundant chert pebbles is present at the base of the section. This conglomerate is overlain by a thin, sheet-type conglomerate and capped by a coarse-grained,
Figure 18. Sketch of a sedimentary sequence northwest of measured section 5. Location shown on Plate II.

Figure 19. Generalized section showing nature of a channel-fill deposit northwest of measured section 5. Location shown on Plate II.
tabular cross-bedded sandstone. Abundant fossil plant material is found in this area.

At measured section 5, the lower 16 feet (5 m) of unit B is a conglomerate composed of quartz and chert pebbles. The conglomerate is light gray in color and parallel bedded. Above this is a poorly exposed interval which is believed to be siltstone. About 1,000 feet (300 m) south of measured section 5, approximately 15 feet (4.5 m) of sandstone is exposed and the basal conglomerate is only locally present. The rest of the distance to measured section 4 is generally a vertical cliff which prohibited direct examination. At measured section 4, the unit is composed of greenish-gray siltstones interbedded with sandstones. The sandstones are very fine-grained, moderately sorted, and subangular. Locally, a basal conglomerate which is about 1-foot (.3 m) thick is present.

Because of poor exposures and vertical outcrop, the system to which an accessible cross-bedding set belongs cannot always be determined with absolute accuracy. Figure 20 illustrates the combined current directions for unit B and the overlying unit C. Additional cross-bedding measurements were taken from sets which could be readily placed in unit B. These measurements were recorded after it was recognized that two separate units may exist along the outcrop. The paleocurrent directions were generally obtained
from measuring the axes of trough cross-bedded sets. This type of cross-bedding is reported to give reliable results with fewer measurements than if other types of cross-bedding are used (Dott, 1973). The number of measurements used in figure 21 is small, but the values are believed to be representative of unit B.

The Rio Algom mine (Lisbon mine) is located on the north end (fig. 39) of the district on the downthrown side of the Lisbon Valley fault (Plate I). The uranium-producing sandstones of the mine, tentatively placed in unit B, are about 2,550 feet (770 m) below the surface (Purvavec, 1978). A brief study of the mine workings was conducted in order to see what, if any, relationship existed between the sedimentation of the Rio Algom area and the outcropping sands of the district to the south. Selected ribs were measured and described in a portion of the mine that was accessible in 1975; the location of these ribs is shown on Plate IV. The geologic features shown on this Plate are projected between the measured ribs and do not represent actual detailed mapping. However, this approach is adequate for establishing the general relationship between the mine and the rest of the district. Two cross sections which are approximately perpendicular to each other are shown on Plate IV. The mine floor is the base of these two cross sections and is believed to be at or near the Cutler-Chinle contact. The longest of the two
Figure 20. Transport directions for units B & C \((n = 28)\).

Figure 21. Additional transport directions limited to unit B \((n = 7)\).
sections extends about 2,500 feet (757 m) in a northwesterly direction and the shorter section extends about 700 feet (212 m) in a northeasterly direction.

The general sedimentary sequence of the longest section for about 500 feet (150 m) from location A-1 to D (Plate IV) is dominantly a siltstone unit which generally overlies a fine-grained sandstone with conglomerate lenses containing mudstone clasts. The upper part of the section along this interval is principally a mudstone-pebble conglomerate with fine-to medium-grained sand matrix. The sequence from location D to H, over a distance of about 500 feet (150 m), is dominantly a mudstone-pebble conglomerate with a siltstone layer near the base of the sequence. Northward for about 600 feet (180 m), the dominant lithology is a sandstone which commonly contains abundant clay clasts. At locality K, this sandstone comprises over 1/2 of the lower section (3 ft., 1 m) and at locality M, it is about 3/4 of the section (5 ft., 1.5 m) where abundant clay clasts are present. The rest of the interval over a distance of about 700 feet (212 m) is principally siltstone with mudstone-pebble conglomerates near the top of the section. The shorter cross-section which trends northeasterly is principally one sandstone body about 400 feet (120 m) wide and 4 feet (1.2 m) thick. This sandstone body is generally surrounded by siltstones and siltstones
interbedded with fine-grained sandstones. Two exceptions occur at both upper edges in the vicinity of localities X and U where the overlying units are a sandstone and a conglomerate composed of siltstone pebbles, respectively.

About 15 miles (25 km) south of the Rio Algom area in the southern portion of the district, the sandstones of the Moss Back Member are generally less than 15 feet (4.5 m) thick and lenticular in character. It is not possible to determine from the field relationships along the outcrop if these sandstones are actually correlative with those of unit B to the north. Plate II shows that this area extends from measured section 9 southward to measured section 15 over a distance of about 6 miles (10 km). The principal lithology throughout this portion of the outcrop is greenish-gray silstones with minor sandstone lenses. Discontinuous basal conglomerates are generally present at the base of the Chinle outcrop. These conglomerates commonly contain abundant clay clasts and usually do not exceed 5 feet (1.5 m) in thickness. Above these conglomerates are generally fine-grained sandstones which are moderately to poorly sorted and subrounded. The sandstones are commonly parallel bedded, contain ripple-marked zones, and show trough cross-bedding. The sandstones contain abundant fossil plant material. Figure 22 illustrates a sequence of lower sandstones north of measured section 15. The conglomerate lens at the base of this figure contains clay clasts up to 4 cm in diameter.
Figure 22. Sedimentary sequence found in Lower Lisbon Valley. Location shown on Plate II.
Unit C

Unit C extends along the outcrop from measured section 4 northward past measured section 7. This unit directly overlies unit B and has an average thickness of over 30 feet (9 m). Along most of the outcrop of unit C, the exposures are generally difficult to examine because they are either covered or they form vertical cliffs which are inaccessible. The mineralogy of this unit is the same as both unit A and unit B.

The general vertical sequence of unit C contains a basal conglomerate which is parallel bedded. This in turn is overlain by a sandstone with plane or massive bedding which grades upward into a trough cross-bedded sandstone which is generally capped by plane-bedded or ripple-marked sandstone. In all cases where the upper sandstones of unit C were exposed, they were overlain by greenish-gray siltstones. Along portions of the outcrop which are poorly exposed or where the general vertical sequence of the unit is not preserved, it is extremely difficult, if not impossible, to distinguish unit C from the underlying unit B. The best location for picking this contact is where a sandstone sequence of about 10 to 15 feet (3 to 4.5 m) thick is cut into by a basal conglomerate overlain by finer-grained sandstones representing unit C.
At measured section 7, unit C is 28 feet (8.5 m) thick, fine-to very fine-grained, moderately sorted, and subangular. The basal 3 feet (.9 m) is a quartz-pebble conglomerate which is overlain by plane-bedded sandstone with some low-angle trough cross-bedding. The upper part of the sequence is ripple marked. Southward to measured section 8, the unit is 37 feet (11 m) thick. At this location, the lower part of the sequence contains parallel-bedded conglomerates and coarse-grained sandstones overlain by a zone of trough cross-bedding. The remaining part of the sequence is principally plane-bedded and ripple-marked sandstones. Southward to measured section 6, the upper part of unit C is covered. The 17 feet of quartz-pebble conglomerate which are exposed at measured section 6 contain large-scale trough cross-bedding and exhibit graded bedding. The upper contact of the unit was not observed at this locality. At measured section 5, unit C again shows a fining-upward sequence with a basal conglomerate overlain by tabular cross-bedded sandstones which in turn is overlain by trough cross-bedded sandstones. At measured section 4, the vertical sequence of sedimentary structures is: a lower interval of trough cross-bedding, a middle interval of low-angle tabular cross-bedding, to parallel bedding, and an upper interval of trough cross-bedding.
Current directions obtained from cross-bedding in unit C are included in figure 20. After it was recognized that two separate units may exist along the outcrop, additional cross-bedding measurements were obtained. These additional measurements are shown on figure 23 where the small amount of cross-bed readings indicate a northwesterly transport direction. Figure 24 shows the general sedimentary transport for units A, B, and C to be in a westerly direction.

Upper Chinle sediments

The sediments of the Chinle Formation which overlie the Moss Back Member and extend upward to the base of the Wingate Sandstone have been called the Church Rock Member (Stewart, 1972, Pl. 5). The general vertical sequence of this unit in the northern part of Lisbon Valley consists of a lower greenish-gray siltstone, a middle reddish-brown to pale red sandstone, and an upper reddish-brown siltstone. Both siltstone intervals are usually partially covered, however, small lenticular sandstones are believed to be present in the siltstones beneath the covered slopes. The middle sandstone interval is usually very fine-to fine-grained, well to moderately sorted, and subrounded. Locally, the basal part of the sandstones contain conglomerates composed of quartz pebbles. Stratification types include plane bedding, large-scale trough cross-bedding, some tabular cross-bedding, and ripple-marked zones. The upper sediments of the Chinle Formation along
Figure 23. Additional transport directions limited to unit C (n = 5).
Figure 24. Transport directions for units A, B, and C combined (n = 56).
the south part of the district are also principally siltstones. The sandstones appear to be more discontinuous than those to the north, especially in the area between measured sections 9 and 13.

Depositional Environments

The environment of deposition for the lower Chinle sandstones on the Colorado Plateau has been interpreted by several workers. Stokes (1961) described the Chinle sandstones as a degrading fluvial system as opposed to an aggrading system (e.g., Morrison Formation). This is shown by the channeling of the Shinarump Member to the southwest but it is not obvious for the sandstones at Lisbon Valley. Stewart and others (1972) compared features they have observed during the many years they have worked in the region with characteristics common to modern sedimentary deposits. Features like clay drapes, lag deposits, and continuity of the sandstones led them to suggest that the deposits formed in a meandering stream. Lupe (1976, 1977, 1978) measured sections and mapped the Chinle Formation from the White Canyon area to Moab and up to the San Rafael Swell area. During these investigations, he identified sedimentary sequences which he interpreted as being proximal and distal bars of a braided stream system. In order to interpret the depositional environment of the lower Chinle sandstones at Lisbon Valley, a brief discussion
of fluvial models for both meandering rivers and braided rivers is presented below.

The sedimentary deposits from meandering rivers have been described in greater detail than the deposits from braided rivers. The main depositional facies related to the channel deposits of meandering rivers include: channel lag, point bar, chute and chute bar, and channel plug (Galloway, and others, 1978). Channel margin facies include natural levee, crevasse-splay, and flood basin deposits. Most of the sediments in meandering streams are transported as both suspended load and bed load material. The overall shape of a sand body formed in streams which meander is elongate and tabular (Moody-Stuart, 1966).

Channel lag deposits (fig. 25) form on the channel floor and contain the coarsest material transported by the river. Blocks of undercut bank material and mud clasts which were locally derived can be found in these deposits. The main sedimentary deposit formed in the channel of a meandering river is the point bar. A general decrease in grain size from the base of the point bar upward to the top portion of the bar is well documented. The generalized sedimentary structures which occur in the point bar have been described by several workers including Allen (1965), LeBlanc (1972), and Schumm and others (1978). The sequence from the base upward is: basal conglomerate (channel lag), large-scale trough cross-
Figure 25. Depositional environments of a meandering river. (Modified from Galloway and others, 1978)
bedding, parallel stratification, small-scale current ripples and ripple drift cross-bedding. LeBlanc (1972) reported that at least 75% of the sand that is deposited in a meandering stream will be by point bar sedimentation. Chute and chute bar deposits form during flood stages when the river cuts a channel across the top part of the point bar. Coarse-grained material from the main channel can then be transported into the smaller chute channel where the sediment is deposited in the chute or at the downstream portion of the channel as chute bars. Channel plug deposits (abandoned channel fill) form where a segment of a channel is abandoned and the only source of sediments is the suspended load material which washes over the natural levees. These deposits generally contain abundant plant material with the finer-grained sediments.

The channel deposits of a meandering river have been subdivided into two separate depositional models by McGowen and Garner (1970), Brown and others (1973), and Galloway and others (1978). These two models can be referred to as fine-grained, point bar, meander-belt model and coarse-grained, point bar, meander-belt model. The sandstones of the fine-grained, point bar, meander-belt model are commonly poorly to well sorted, very fine-to medium-grained with gravel and mudstone layers present in the complete sequence. Plant debris and mudstone clasts are found in the basal part of the sandstone unit. The sandstones form dip-oriented belts
which are lenticular bodies with scour bases. The sandstone belts commonly form tributary and distributary patterns and contain local areas of sandstone thickening within the belts which give a "beaded" appearance on the isopach maps. The sandstone bodies are generally multistory and have width/thickness ratios of moderate to high. The generalized vertical sequence of sedimentary structures is shown in figure 26. The basal conglomerate is overlain by medium-to large-scale trough cross-bedding which is followed by parallel-bedded sandstones and parallel-laminated mudstones. Generally, the grain size decreases upward but may be locally erratic. Current directions measured from cross-bedding are parallel to the trend of the sandstone body but locally show wide variation (Reineck and Singh, 1975).

The sandstones of the coarse-grained, point bar, meander-belt model are composed of fine-to coarse-grained sandstones containing gravel zones. The vertical distribution of grain size generally does not show good upward fining. Mud clasts and plant debris are common constituents. Sorting characteristic of both modern and ancient examples is from poorly to well sorted (McGowen and Garner, 1970, fig. 22). The sandstone bodies are dip oriented, multilateral, and have moderate to high width/thickness ratios (Galloway and others, 1978). The generalized vertical sequence of sedimentary structures is shown on figure 27. The lower portion of the
Clay layer
Ripple cross-bedding
Horizontal lamination
Trough cross-bedding
Channel lag deposit

Figure 26. Generalized sequence of fine-grained, point bar, meander-belt model (modified from Reineck and Singh, 1975).

Horizontal to small tabular cross-bedding
Large foreset cross-bedding
Small trough cross-bedding
Large trough cross-bedding

Figure 27. Generalized sequence of coarse-grained, point bar, meander-belt model (modified from Reineck and Singh, 1975).
sequence is principally large-to small-scale trough cross-bedded sandstone. The upper portion of the sequence is dominated by chute and chute bar deposits which are characterized by large-scale foreset cross-bedding, trough cross-bedding, gravel lenses, and parallel and ripple-laminated sandstones. Current directions measured from cross-bedding are parallel to the trend of the sandstone body but locally show wide variation. Table 1 compares characteristic features between the fine-grained, point bar, meander-belt model and the coarse-grained, point bar, meander-belt model.

Finer-grained overbank sediments commonly comprise from 10 to 30 percent of the total deposits associated with meandering rivers (Miall, 1977b). Most of this channel margin sedimentation occurs during floods when the river water washes over the natural levee or cuts a small channel (crevasse) through the levee. Sediments deposited on the natural levee are dominantly fine-grained sandstone, siltstone, and some clay layers. Sedimentary structures common to levee deposits include ripple marks, climbing ripples, parallel bedding, and laminated mud layers (Reineck and Singh, 1975). Root zones, scour and fill sandstone lenses, and penecontemporaneous deformation of the sediments are also characteristic of natural levee deposits. Because levees undergo cycles of flooding and drying, the sediments on the upper part of the levee are usually oxidized. Along the lower part of the
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Fine-grained point bar</th>
<th>Coarse-grained point bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel stability</td>
<td>high</td>
<td>slight</td>
</tr>
<tr>
<td>Channel cross-section</td>
<td>relatively narrow asymmetrical</td>
<td>broad, shallow symmetrical or asymmetrical</td>
</tr>
<tr>
<td>Sinuosity</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Sand facies geometry</td>
<td>multistory low sand/mud</td>
<td>multilateral high sand/mud</td>
</tr>
<tr>
<td>Vertical sequence of</td>
<td>climbing ripple laminae small trough sets</td>
<td>parallel laminae and thin foreset cross-</td>
</tr>
<tr>
<td>sedimentary</td>
<td>parallel laminae</td>
<td>stratification</td>
</tr>
<tr>
<td>structure</td>
<td>trough-fill cross-stratification and thin</td>
<td>thick foreset cross-stratification</td>
</tr>
<tr>
<td></td>
<td>foreset cross-stratification and large</td>
<td>thin foreset cross-stratification and small</td>
</tr>
<tr>
<td></td>
<td>trough-fill cross-stratification</td>
<td>trough-fill cross-stratification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>large trough-fill cross-stratification or</td>
</tr>
<tr>
<td>Grain-size</td>
<td>upward fining</td>
<td>homogeneous sediment</td>
</tr>
<tr>
<td>trend</td>
<td></td>
<td></td>
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</tbody>
</table>
levee, which is commonly poorly drained, the sediments are generally reduced and darker in color.

Crevasse-splay deposits occur where the natural levee is breached during floods. Suspended and bed load material is transported into the channel margin area towards the flood basin. Splays of sand prograde into the lower topographic areas depositing a fan-shaped body. During flood stages, the splays build into standing bodies of water which can produce a deposit similar to a small lacustrine delta. Rivers which frequently flood can build splay deposits that form broad aprons parallel to the main channel and cover several square miles in area. Galloway and others (1978) provide a good description of the nature of a crevasse-splay deposit:

Ripple, climbing ripple, planar, wavy, and medium-scale trough cross-lamination, mud drapes, graded beds, and local scour and fill structures are common. In addition, the splays are sedimentary garbage piles, accumulating large amounts of plant debris and mud clasts. Grain sizes and unit thickness are generally less than that of the associated channel sequences but otherwise can be quite variable, depending on magnitude of flooding, effectiveness of the confining levees and water depths in the flood basin.

Fine-grained sedimentation in flood basins occurs during periods of high water when the channel margin is breached and the coarser sediments are deposited in the nearby crevasse splays. Flood basin deposits contain the finest grained
sediments that are deposited in the fluvial system. These deposits are elongate bodies parallel to the main channel and occasionally contain thin, sandy stringers which are extensions of the crevasse-splay deposits. Continued flooding of the basin produces a high water table which preserves the buried plant material by maintaining a reducing environment.

Until recently, the sediments in a braided stream environment received relatively little attention. Early workers who noted the various sedimentary structures and facies from braided rivers include Doeglas (1962) and Williams and Rust (1969). A recent paper by Miall (1977a) provides an excellent reference on braided river deposits. The main sediment-forming processes include: overbank sedimentation, low water accretion, channel-floor dune migration, and bar formation. The bars constitute the main deposits which are preserved in the rock record. There are three basic types of bars: longitudinal, which are parallel-bedded gravel or sand sheets; transverse to linguoid, which are formed by avalanche-face progradation (tabular cross-bedding) and consist of sand or gravel; and point or side bars which form in areas of lower energy. Ten separate facies which can occur within this environment have been identified. Vertical sequences indicate several types of depositional environments, including: flood-, channel fill-, valley fill-, channel reoccupation-, and point bar-cycles. Some of the sequences have been found to become increasingly finer-grained upwards which could
result in confusion with meandering stream deposits. Galloway and others (1978) provide a generalized summary for the braided river model. The channel deposits from braided rivers are composed dominantly of sand but commonly contain conglomerate layers. The sorting is poor to good and mud and clay are minor constituents of the deposit. The sandstones form dip-oriented, multilateral bodies which are broad and tabular with high width/thickness ratios. The scour surface at the base of the channel sandstones is commonly low relief. Braided river deposits are dominated by tabular cross-bedding with trough cross-bedding being rare to common. Current directions from cross-bedded sandstones show minor deviations from the trend of the sand body (Reinech and Singh, 1975). Pebble sheets, lenticular gravels, and numerous local scour surfaces are found throughout the channel deposits. Channel margin sedimentation, which is usually of minor importance, includes natural levee, crevasse-splay and flood basin facies. These overbank deposits are described in the discussion on meander-belt sedimentation. In an excellent description of braided systems, Miall (1977a) suggested that braided fluvial deposits fall into one of four main types which are listed below:

1. Scott type: Consists mainly of longitudinal bar gravels with sand lenses formed by infill of channels and scour hollows during low water (see figure 28a).
2. Donjek type: May be dominated by sand or gravel distinguished by fining-upward cycles caused by lateral point-bar accretion or vertical channel aggradation. Cycles commonly are less than 3 m thick, but cycles up to 60 m may be present, representing valley fill sequences. Longitudinal and linguoid-bar deposits, channel-floor dune deposits, bar-top and overbank deposits all may be important (see figure 28b).

3. Platte type: Characterized by an abundance of linguoid bar and dune deposits (planar and trough cross bedding). No well developed cyclicity, probably owing to a lack of topographic differentiation in the river (no evidence of deep, primary channels, abandoned areas or overbank areas) (see figure 28c).

4. Bijou Creek type: Consists of horizontally laminated sand plus subordinate amounts of sand showing planar cross-bedding and ripple marks. Formed during flash floods and may be most typical of ephemeral streams (see figure 28d).

Table 2 compares characteristic features between braided river deposits and meander river deposits.

Unit A

The sandstone body of unit A has a width/thickness ratio of approximately 100. This ratio does not represent an individual channel but rather several channel deposits which coalesced over the outcrop distance of about 1 mile (1.5 km). The apparent deep scouring of unit A and increased thickness of sandstone at measured section 1 indicates this unit may be a small valley-fill deposit. Brown and others (1973) discuss four features which are characteristic of valley fill deposits. First, the basal part of the
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Braided Rivers</th>
<th>Meandering Rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral accretion deposits</td>
<td>point bars, linguoid bars, low-water bar accretion</td>
<td>fining-upwards point bars (including epsilon crossbeds)</td>
</tr>
<tr>
<td>Vertical accretion deposits</td>
<td>channel-floor bedforms, sheet-flood deposits, bar-top deposits, minor overbank deposits</td>
<td>overbank deposits, channel lag deposits</td>
</tr>
<tr>
<td>Type of scour surface</td>
<td>channel erosion</td>
<td>meander widening</td>
</tr>
<tr>
<td>Channel abandonment behavior</td>
<td>progressive, as a result of aggradation fill</td>
<td>sudden, as a result of meander neck cut-off</td>
</tr>
<tr>
<td>Channel abandonment deposit</td>
<td>fining-upward cycle</td>
<td>fine-grained fill</td>
</tr>
<tr>
<td>Facies occurrence:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>massive or crudely bedded gravel</td>
<td>common (longitudinal bar deposit)</td>
<td>rare to common (generally as a thin lag deposit)</td>
</tr>
<tr>
<td>trough-cross bedded gravel</td>
<td>rare to common</td>
<td>absent</td>
</tr>
<tr>
<td>planar-cross bedded gravel</td>
<td>rare to common</td>
<td>absent</td>
</tr>
<tr>
<td>trough-cross bedded sand</td>
<td>common</td>
<td>common</td>
</tr>
<tr>
<td>planar-cross bedded sand</td>
<td>common</td>
<td>generally rare</td>
</tr>
<tr>
<td>horizontally bedded sand</td>
<td>common</td>
<td>common</td>
</tr>
<tr>
<td>ripple cross-laminated sand</td>
<td>common</td>
<td>common</td>
</tr>
<tr>
<td>scour-fill sand</td>
<td>rare to common</td>
<td>absent</td>
</tr>
<tr>
<td>laminated sand, silt, and mud</td>
<td>rare to common</td>
<td>common</td>
</tr>
<tr>
<td>mud or silt drape</td>
<td>rare to common</td>
<td>common</td>
</tr>
<tr>
<td>channel-fill sequences</td>
<td>rarely greater than 3 m.</td>
<td>commonly greater than 3 m.</td>
</tr>
</tbody>
</table>
Figure 28. Generalized vertical sequence of the deposits of four types of braided rivers. (Modified from Miall, 1977a)
fill contains gravel bar which may be up to several feet high due to the confined flow of the river water. In the vicinity of measured sections 1 and 3, the basal part of the sequence contains gravel zones which are over 5 feet thick. However, to the south at measured section 2, a conglomerate was not observed in the basal portion of the unit. A second feature of valley-fill deposits is the poorly developed upward fining of the sediments. Most of the sandstones of unit A are very fine-grained except at measured section 3 where the grain size ranges upward from very coarse-grained to medium-grained and finally to fine-grained at the top. A third feature is the dominance of large-to moderate-scale trough cross-beds within the valley fill. The principal cross-bedding type at all three measured sections of unit A is trough cross-bedding. Tabular cross-bedding and plane bedded sandstones are also present in minor amounts at the locations of the measured sections. The fourth feature common to valley-fill deposits is the occurrence of finer-grained sediments, overlying the channel sandstones, which represent abandonment of the valley. Directly above sandstone unit A is an interval containing siltstones interbedded with several thin sandstones which may represent abandonment of the valley.

The fluvial system which formed the valley-fill deposit would have been modified by the confining nature of the
valley. The general vertical sequence of the valley fill is a channel lag conglomerate overlain by a trough cross-bedded sandstone which is capped by a thick siltstone interval. This depositional sequence is similar to the Donjek type braided river model except that the quantity of siltstone occurring laterally to the sandstones is too high for a braided river model. The amount of finer-grained sediments associated with the sandstones in the sequence is similar to the fine-grained, point bar, meander-belt model except for the absence of the upper point bar facies of plane lamination and ripple cross-stratification. North of measured section 3, the conglomerate lens which cuts into the underlying sandstone (fig. 14) may represent a chute fill of a coarse-grained, point bar, meander-belt model. Brown and others (1973) suggest that neither braided nor meandering rivers are responsible for valley-fill deposition but that the confined nature of the valley suggests the channels were straight. Maill (1977b) describes deposits of straight channels to be similar to those of the Donjek type braided river model. He also noted that a general absence of tabular cross-bedding, as in unit A, may indicate deposition by straight channels.

Unit B

The sandstone belt of unit B outcrops over a distance of 4 miles (6.5 km) and has an average thickness of about
20 feet (6 m). The unit is composed of coalesced channel sandstones that are multilateral bodies giving the belt a tabular shape. The width and thickness of this belt is common to both braided streams and laterally-accreting meandering streams. One of the best approaches to interpreting the depositional environment of a channel sandstone is to use facies analysis to suggest a generalized depositional model. The vertical sequence of facies at measured section 4, located at the southern end of the sandstone belt (Plate II), starts with a thin, parallel-bedded conglomerate facies overlain by a siltstone interbedded with sandstone facies. This thick sequence of siltstones and very fine-grained sandstones is believed to have been deposited in the channel margin environment. The presence of the interbedded sandstones and close proximity to the thicker channel sandstones to the north indicate the depositional environment in this area might have been a natural levee.

The vertical sequence at measured section 5 is of a parallel-bedded conglomerate facies overlain by a partially covered interval which is believed to be mainly a siltstone facies. The depositional history at this locality appears to be channel formation and accumulation of a thick channel lag deposit which was then followed by abandonment and in-filling of the channel by fine-grained sedimentation. This type of deposit is common to both braided and meandering river systems.
Northward, towards measured section 6, the general vertical sequence of facies is a basal lag deposit overlain by a sandstone that is trough cross-bedded or locally tabular cross-bedded. This sequence of sedimentary structures is similar to those found in the lower portion of a point bar. The occurrence of clay clasts in the basal lag deposits is common to meandering streams.

The facies at measured section 6 indicate the sandstone was deposited on the lower part of a point bar. The channel lag deposit is overlain by a very coarse-grained, trough cross-bedded unit which is overlain by a fine-grained, trough cross-bedded to parallel-bedded sandstone. This sequence of cross-bedding is not similar to transverse bars (distal bars) because of lack of tabular cross-bedding or longitudinal bars (proximal bars) because the beds are not solely parallel-bedded. However, Smith (1970) stated that trough cross-stratified to planar cross-stratification is associated with some longitudinal bars. The origin of this sequence could be a longitudinal bar or possibly the lower part of a point bar where the very coarse-grained trough cross-bedding represents scour fill sediments.

A basal conglomerate indicating a channel lag deposit is present at measured section 8. This is overlain by a facies of interbedded siltstones and sandstones which is believed to indicate a period of abandonment soon after the
channel was cut and the channel lag facies was deposited. The trough cross-bedded sandstone which caps the sequence may indicate channel reoccupation of the area. This sequence of facies is common to both braided and meandering streams.

Along the northern edge of the sandstone belt at measured section 7, the unit is composed of siltstones interbedded with sandstones. This area is believed to have been dominated by channel margin sedimentation. The nearness of channel sandstones to the south and the abundance of fossil plant material and clay clasts in the interbedded sandstones suggest this may have been an area of crevasse-splay deposition.

The main facies observed along the outcrop and their percentage of the total sequence as calculated from the measured sections include: 15% parallel-bedded conglomerate, 15% trough cross-bedded sandstone, 66% interbedded siltstone and sandstone, and 4% other facies. Wood (1968) reported that the depth of scouring by the Chinle sandstones into the Cutler Formation along the area covered by unit B ranges from 5 to 30 feet (1.5 to 9 m). The generalized depositional model for unit B starts with a scour surface upon which channel lag conglomerates were deposited. This facies is overlain by trough cross-bedded sandstone indicating channel filling and finally capped by interbedded siltstones and sandstones at the top of the sequence indicating overbank deposition. The large amount of fine-grained sediments (siltstones),
the depth of scouring, abundant mudstone clasts in the conglomerate, and a poorly defined fining-upward sequence suggests deposition by a meandering stream. However, the lack of the upper point bar facies of parallel lamination and ripple-marked sandstones presents a problem. It is possible that the reason for this apparent absence of upper point bar sediments is that the river which deposited these sediments belonged to the coarse-grained, point bar, meander-belt model. In this type of river, the sediments of the upper point bar are removed by chute erosion. Conglomerate lenses overlain by trough cross-bedded sandstones were occasionally observed in between the measured sections in the upper part of the unit and may represent chute fill. This model is not wholly satisfactory because large foreset bedding characteristic of chute bars was not observed along the outcrop. The Donjek type braided river model commonly contains point bar deposits similar to those described along the outcrop. However, the large amount of fine-grained overbank material associated with unit B is not common to the braided river model.

The host rock of the Rio Algom mine (Lisbon mine) is believed to be equivalent to unit B because the interval rests directly above the Cutler Formation. The dominant lithologies within the mine area are siltstones, fine-grained sandstones, and mudstone-pebble conglomerates. The NW-SE
cross section extends down the middle of the studied area in the mine workings shown on Plate IV. This cross section shows extensive cutting of the siltstones by mudstone-pebble conglomerate layers. These mudstone-pebble conglomerates are contained in a sandstone matrix which is fine-to medium-grained. The large amount of siltstones, flat-pebble conglomerates and thin sandstone beds in this area suggests sedimentation in an environment different from the rest of the district to the south. This area lies to the north of the projected transport direction of the main fluvial system which hosts uranium mines to the south. The mine is interpreted as being in an area that was marginal to the main channel system where the dominant sedimentation was in an overbank environment of crevasse-splay deposits into a flood basin. This is supported by the abundance of mudstone clasts and generally finer-grained sediments in the vicinity of the mine. The mudstone clasts are composed of both reddish-brown and greenish-gray colored fragments. The reddish-brown clasts may have been derived from the higher oxidized portion of the natural levee and the greenish-gray clasts may have come from the lower and more reduced portion of the levee.

The SW-NE cross section (Plate IV) is principally composed of a thin lenticular sandstone surrounded by siltstones. This sandstone may be a crevasse-splay channel deposit which extends roughly perpendicular to the line of the
cross section. Recent detailed work by Purvance (1978, personal communication) indicates that the transport directions of the channel sandstones in the Rio Algom mine are in a northerly direction. Figure 29 is a sketch which shows the geometry of crevasse-splay deposits associated with the Brahmaputra River. It is not unreasonable to expect that the sedimentary deposits in the mine area formed in an environment similar to that shown on the sketch. The descriptions of cores from a drilling program which tested the lower Chinle sandstones to the northwest and southeast of the mine provides information which is in agreement with the crevasse-splay interpretation. This line of drill holes extends from about 4 miles (6.5 km) southeast of the mine to about 2 miles (3 km) northwest of the Rio Algom mine as shown on figure 31. Bohn (1977) conducted a detailed petrographic study of the cores in which he noted abundant mudstone conglomerate layers directly northwest and southeast of the mine. Figure 30 is a generalized fence diagram which shows the lithologic relationship between the cored intervals. The area of the section along line E-F-G contains a higher percentage of sandstone than does the northern part of the section. The increased thickness of sandstone to the southeast indicates this segment might have been at the channel margin during sedimentation. This area is believed to have been upstream from the main channel sandstones that are exposed
Figure 29. Drawing from photo of crevasse-splay depositional environment. (Modified from Reineck and Singh, 1975)
Figure 30. Generalized fence diagram of the lower Chinle Fm. across Rio Algom mine area. Figure 31 gives location of core holes (modified from Bohn, 1977).
along the outcrop. Westward along the line from corehole E to the vicinity of the Rio Algom mine the amount of mudstone-pebble conglomerates increases, and from the mine area to holes C-B-A the amount of mudstone conglomerate decreases. Galloway and others (1978) state that accumulations of large amounts of clay clasts are common to crevasse-splay deposits. This thickening of mudstone conglomerates suggests that the depositional environment in the vicinity of the mine was dominated by crevasse-splays.

The lower Chinle sandstones along the southern part of the outcrop from Big Indian Rock to Woods Ranch (Plate I) are also believed to have been deposited in a channel margin environment. This interpretation is based on the features which are believed to indicate overbank sedimentation: first, the principal lithology throughout this part of the outcrop is a thick siltstone (Plate II) which is indicative of channel margin sedimentation. Second, the lenticular sandstones are generally fine-grained, parallel-bedded or ripple-laminated, and the thin conglomerate beds contain abundant clay clasts and plant debris. These features indicate lower energy deposition common to the channel margin environments of natural levee and crevasse channel deposition. If this interpretation is correct, then the depositional environment that prevailed behind the outcrop to the southwest would be of crevasse-splays and flood basin sedimentation as described in the text on depositional models.
Unit C

The sandstone belt of unit C directly overlies unit B and has an average thickness of over 30 feet (9 m). The channel sandstones in this unit appear to be multilateral bodies giving the belt a tabular shape. At measured section 4, three main facies were observed: a lower trough cross-bedded interval, a middle parallel-bedded interval, and an upper trough cross-bedded interval. This vertical sequence indicates higher energy deposition near the base, lower energy deposition for the middle interval, and higher energy deposition at the top. The lower trough cross-bedded interval could have been deposited as a subaqueous sand dune and the middle parallel-bedded interval might have been a longitudinal bar. However, the sequence might also represent a point bar which was truncated above the parallel-bedded interval by a chute channel. The coarse-grained, poorly sorted, trough cross-bedded interval at the top of the sequence may be a chute channel-fill deposit.

At measured sections 5 and 8, the general vertical sequence contains a basal conglomerate interval which is generally overlain by facies common to point bar deposition. Measured section 5 contains a tabular cross-bedded interval which is occasionally found in point bars. Measured section 8 contains a parallel-bedded sandstone above the conglomerate and below the trough cross-bedding interval. Parallel-bedded
sandstones form in both the upper flow regime deposition- 
al environment as on the lower point bar and in the lower 
flow regime depositional environment as on the top of the 
point bar (Reineck and Singh, 1975). The position of this 
parallel-bedded sandstone in the lower part of the sequence 
is consistent with a point bar model. The lithology which 
directly overlies these channel sandstones is an interval 
of siltstones believed to be of overbank origin.

At measured section 5, the only exposure of unit C is 
believed to be a 17-foot (5 m) thick conglomerate which is 
trough cross-bedded and contains intervals of graded bedding. 
The interval above this conglomerate is partially covered 
but the main lithology may be siltstones. The lower conglomer-
ate was probably deposited during the waning stages of a 
flood. Reineck and Singh (1975) stated that graded beds in 
fluvial environments do not form thick sequences and are 
deposited in the last stages of a heavy flood. The sedi-
mentary sequence of unit C at measured section 6 may represent 
a time of heavy flooding when a thick conglomerate formed 
in a channel of a meander loop. Abandoned river segments 
are formed by neck cut-off of meander loops which commonly 
occur during periods of heavy flooding. The absence of a 
sandstone facies above this conglomerate indicates the area
was abandoned during the flood and later filled by siltstones in an overbank depositional environment. The sequence at measured section 7 is dominated by very fine-to fine-grained, parallel-bedded and rippled-marked sandstones. The depositional environment which created these lower energy bed forms could have been a natural levee.

The main facies observed along the sandstone outcrop of unit C and their percent of the total sequence as calculated from the measured sections include: 22% parallel-bedded and trough cross-bedded conglomerate, 32% trough cross-bedded sandstone, 32% parallel-bedded sandstone, 10% ripple-marked sandstone, and 4% other facies. These percentages are only of the sandstones and do not include the siltstones which occur at the top of the sequence. The reason that the overlying siltstones were not incorporated into the breakdown of the facies is that it was not possible to ascertain what thickness of siltstones were deposited by the channels of unit C. The generalized depositional model of this unit starts with a channel lag conglomerate followed by channel-fill facies of trough cross-bedded and parallel-bedded sandstones. The upper part of the sequence contains ripple-marked sandstones capped by siltstones. This model is suggestive of point bar deposits. The abundance of siltstone at the top of the sandstone interval and vertical sequence of sedimentary structures suggests a fine-grained, point bar,
meander-belt model. However, the occurrence of trough cross-
bedding in the upper part of the interval (measured section 4)
and poorly defined upward fining of grain size suggests a
coarse-grained, point bar, meander-belt model.

Upper Chinle Sediments

Most of the sediments in the upper Chinle Formation in
Lisbon Valley consist of reddish-brown, parallel-bedded
siltstones containing a middle interval of dominantly paral-
lel-bedded and trough cross-bedded sandstones overlying a
basal conglomerate. Stewart and others (1972) believe that
most of this unit in southeast Utah was deposited in a large,
shallow lake. However, they also state that some of the silt-
stones may have been deposited on flood plains and the thick
trough cross-bedded sandstones may be of fluvial origin.
The trough cross-bedded sandstone interval in the upper
Chinle sediments appears to be similar in both stratigraphic
position and lithology to the informal Black Ledge member to
the north of Lisbon Valley. O'Sullivan and MacLachlan (1978)
describe the Black Ledge as generally "pale red, reddish-
brown and gray, very fine-grained, cross-bedded sandstone." The
origin of the middle sandstone interval may have been the
same as that of the Black Ledge member. Stewart and others
(1972) suggest that the sandstones of the Black Ledge represent
point bar deposits. The vertical sequence of sedimentary
structures and presence of a basal conglomerate (Plate II)
suggest the middle sandstone interval at Lisbon Valley may be of point bar origin.

**Subsurface Investigation**

**Method of Study**

The study area was enlarged to include a large land block to the west of Lisbon Valley where the results of a drilling program allowed the projection of the fluvial system into the subsurface. Over 27,000 feet (8,100 m) of drill cuttings from 22 drill holes were logged with the aid of a hand lens and about 10,000 feet (3,000 m) of the Chinle sediments were collected and again examined under a binocular microscope. Chemical analyses were run on several of the samples, the results of which are discussed in the geochemical section.

The standard exploration logs of gamma, resistivity, and spontaneous potential were run on all the holes. The drill sites were not surveyed, rather they were spotted on air photos and then transferred to an enlarged topographic map of approximately the same scale. The collar elevations which were used in the structure contour map were obtained from the topographic map and should be considered as approximate. Most of the drill holes collared in the Navajo Sandstone and bottomed in Cutler Formation; however, several are believed
to have bottomed in the Moenkopi Formation. Figure 31 shows
the location of the drill holes in relation to the measured
sections along Lisbon Valley. The drill holes are on ap-
proximately 1-mile (1.5 km) centers and range from about
2 to more than 11 miles (3 km to 18 km) from the outcrop.

Lithologic Data

The subsurface thickness of the Chinle Formation, as
picked from electric logs, showed that the formation varied
from 407 feet (123 m) in the northern part of the study area
to 540 feet (164 m) in the southern part of the study (fig.
32). The upper Chinle sediments are principally reddish-
brown siltstones containing thin sandstone beds. The Moss
Back Member, as picked from electric logs, varied from 25
feet (7.5 m) to 68 feet (20.5 m) in thickness (fig. 33).
The drill cuttings of the Moss Back Member contained greenish-
gray siltstones mixed with light-gray sandstones. The sand-
stones were found to be fine-to medium-grained and subrounded
to subangular. Because of poor sample recovery, up-hole
caving, and sample mixing as the cuttings ascended from
depths that were frequently greater than 1,500 feet (450 m),
the observed lithologic features in the cuttings can only be
taken to be representative of the sandstone unit and not of
a specific interval. It was noticed that as several of the
drill holes penetrated rocks below the Moss Back Member,
the drilling fluids turned chocolate brown, whereas at other
Figure 31.
Index map of data points in the Lisbon Valley and adjacent areas.

- Uranium mineralization
- B Cored interval (from Bohn, 1977)
- o3 Drill hole
- +7 Measured section

Legend:
- km
- miles
Figure 32.
Isopach map of Chinle Fm.

Contour line, 20 foot interval.

- Drill hole
+ Measured section

0.411 Thickness of Chinle Fm.
(in feet)
drill holes, the fluids turned reddish-brown in color. The chocolate brown color may have indicated the presence of the Moenkopi Formation and the reddish-brown color may have indicated the Cutler Formation. However, from examining the cuttings of these intervals, it was found to be impossible to distinguish the Moenkopi Formation from the Cutler Formation as both intervals were reddish-brown siltstones.

Structure

Figure 34 is a structure contour map of the base of the Chinle Formation. The Hatch Rock syncline is the dominant structure west of the Lisbon Valley anticline. In the southern part of the study area, the syncline trends northeast parallel to the Lisbon Valley anticline. A small anticline also occurs in the northwest portion of the study area. East of the drilling where the Chinle Formation outcrops, the elevations of the base of the Chinle were taken from the geologic map on Plate I and from Wood (1968, fig. 1). These elevations are given for the locations of the measured sections (fig. 34) and should be considered as approximate heights above sea level. Due to the steepness of the Lisbon Valley anticline, the contour interval was changed from 50 feet (15.5 m) to 100 feet (30 m) and finally to 500 feet (151.5 m) from the Hatch Rock syncline to the western flank of the anticline.
Stratigraphy and Geometry of the Sediments

Two maps were prepared illustrating the geometry of both the total Chinle sediments and the lower sandstones of the formation. Figure 32 is an isopach map of the Chinle Formation. The increase in total thickness in the region of the Hatch Rock syncline suggests that this structure may have been active during Chinle deposition and influenced sedimentation. In general, the formation appears to be thinning in a north and northeastern direction. It is possible that this reduction in total thickness could have been influenced by the Lisbon Valley anticline if it were a positive feature during Chinle time. Figure 33 is an isopach map of the lower Chinle sandstones in the area. Two main stream systems are indicated on this map, a northern one which apparently swings to the north past drill hole 24 and then turns to the west. The second stream system apparently flowed northwest along the Hatch Rock syncline where it joined the northern system and flowed westward. Based on the isopach map of the total lower Chinle sandstones, it appears that the small anticline in the northwest may have influenced the sedimentation as indicated by the thinness of lower sandstones found in the drill hole. A gravity low which may indicate the presence of a minor salt cell underlying this anticline has been reported by Byerly and Joesting (1959). If this area were slightly positive, then it may have acted as an intra-stream divide
and most of the sediments at that locality would be the finer-grained overbank deposits.

The trend of the thickest portion of the lower Chinle sandstones along Hatch Rock syncline also indicates the possibility of tectonic influence on sedimentation. In this area, the elongate nature of the sandstone isopach follows the synclinal axis. Plate V is a cross section running approximately parallel to the northern fluvial system which reveals the nature of the lower Chinle sandstones in that portion of the study area. Plate VI is a cross section which is approximately parallel to the suggested stream system that may have been influenced by the Hatch Rock syncline. Plate VII is a cross section that is approximately transverse to a portion of the suggested stream systems. The geometry of the lower sandstones shown on this plate is suggestive of an onlapping relationship from the southwest to the northeast. This relationship indicates that the southern stream system may be older than the system to the north. Figure 35 is a cross section of the lower Chinle sands which are considered to be perpendicular to the southern stream system.

Because the identification of the two stream systems (units B and C) is based on the outcrop study of the sequence of the sedimentary structures, the division could not be easily made on the electric logs. Bedwell (1974) showed that depositional facies can be identified in a relative sense based on textural parameters of the rocks. Several of the electric
Figure 35. Cross section transverse to southern channel system, Hatch Rock syncline area.
logs appeared to show two separate depositional systems, especially where the fine-grained sediments of the upper part of the lowest system were preserved. However, in most cases, such a breakdown could not be made.

**Summary of Moss Back Deposition**

The results of the outcrop study and the drilling program suggest that the Lisbon Valley area was the site of two main belts of fluvial sedimentation in the Moss Back Member. These northwesterly trending belts (fig. 33) averaged about 4 miles (6.6 km) in width except in the area of T.29S., R.23E. where the width may be from 6 to 10 miles (10 - 16.5 km). The nature of the vertical sequences of the sedimentary structures, the various facies of fine-grained sediments and massive conglomerates, suggest the lower Chinle sandstones at Lisbon Valley were deposited by a river belonging to a coarse-grained, point bar, meander-belt model or a Donjek type braided river model. It is interesting to note that the main Lisbon Valley uranium deposits appear to be located perpendicular to a fluvial belt that has been interpreted as characteristic of a coarse-grained, point bar, meander-belt model. This is in agreement with the observation of Rackley (1976) that most of the uranium deposits of the western United States occur in sediments deposited by coarse-grained, point bar, meander-belt rivers.
Large amounts of clay which are believed to be derived from volcanic ash are present in the lower part of the Chinle Formation (Schultz, 1963). The abundant fossil plant material also found in the lower Chinle sediments indicates that the climate provided ample water to support lush vegetation. These plants undoubtedly gave rise to humic and fulvic acids that were introduced into the ground water system. Figure 36 shows the interpreted paleogeographic setting during Moss Back deposition in the Lisbon Valley area as suggested by the outcrop and subsurface work.

In order to relate the Lisbon Valley fluvial model with the rest of the basin, Amstrat lithologic logs which were used in a Triassic study by Marchand and De Voto (1975, personal communication) provided information about the regional character of the Chinle Formation. Figure 37 illustrates the total amount of the sandstone contained within the Chinle Formation and the thickness of sediments that are inferred to be reduced because of their color as reported on the lithology logs. Even though the information shown in this figure represents only a portion of the total wells in the basin, several regional observations can be made. If the salt anticlines were positive features during Chinle deposition, then the stream systems for both the lower and upper portion of the formation would be expected to flow in the low-lying areas in between the anticlines. Several logs
Figure 16. Idealized paleogeographic setting during lower Chinle sedimentation, Lisbon Valley anticline-
Mauke Rock syncline area.
suggest that this condition may have existed, especially in the area between Dolores anticline and Gypsum Valley anticline and between Moab Valley anticline and Castle Valley anticline. Because exploration oil wells are not generally drilled in structural lows, not enough data-points are available to allow little more than speculation as to the thickness of the Chinle sands in these areas.

Another factor contributing to the understanding of the influence of tectonics during Triassic sedimentation is the color of the sediments. If the structural features were active during Chinle sedimentation and prior to lithification, then the paleohydrogeologic conditions should have been favorable for the introduction of oxygen-rich ground waters into the sands. The areas of the greatest recharge would most likely be associated with the salt cells of the anticlinal areas that had the highest structural and topographic relief. Where oxidizing conditions prevailed, the sediments which were deposited in reducing conditions would be oxidized to a reddish color. In areas where the oxidizing ground waters did not invade the Chinle sediments, they would remain a greenish-gray color. The Amstrat lithologic logs indicate that the Chinle Formation in the main portion of the salt anticline area underwent oxidation which altered the sediments to a red color. It appears as if the oxidation continued to the margins of the salt anticline area. A cored interval
(core hole G) from the lower Chinle sediments approximately one mile (1.5 km) east of the Lisbon Valley fault in section 5, T.30S., R.24E., has been described by Bohn (1977). The lower 20 feet (6 m) of the generally fine-to very fine-grained sandstones in this area are red to light gray in color. This subsurface observation is in agreement with Johnson and Thordarson (1966) who noted that greenish-gray rocks were lacking in the Chinle outcrops north of the anticlinal axes.

The study of the lower Chinle sandstones in the Lisbon Valley area lends itself to formulation of a regional model for sedimentation. The model for the Moss Back Member must take into account the source area, the types of depositional systems, the effect of salt tectonics, and the events in the depositional history which may have been favorable for the accumulation of uranium. During the Chinle depositional episode, two highlands were the dominant contributors of clastic material: the Uncompahgre uplift to the east and the Mogollon uplift to the south. The direction of transport as indicated by cross bedding in the Lisbon Valley area suggests that the source of clastics for these sands was the eastern Uncompahgre uplift. Rivers flowed from this mountain range westward across the salt anticline region. Structurally controlled valleys were formed in the areas between the salt anticlines. The river systems were probably deflected off the positive areas into the northwest-trending synclinal
troughs. In some areas, such as Lisbon Valley, the rivers may have entrenched themselves into the growing anticlines. These valley areas tended to constrict the width of the fluvial belts and subsequent ground water flow.
URANIUM OCCURRENCES IN THE CHINLE FORMATION

Hundreds of uranium mines have produced from the Chinle Formation throughout the central Colorado Plateau region. Most of these mines are clustered in districts with total uranium production of under 10 million pounds each (Hansen, 1972). The Lisbon Valley district is a notable exception; the total production plus remaining reserves have been estimated to be over 70 million pounds. General descriptions of the uranium districts in southeast Utah are given by Stokes (1967) and Thomson (1967). The uranium deposits of San Juan County, Utah, have produced more uranium than any other area in Utah. Doelling (1969) presented a good summary of the various districts of the county.

Even though the other Chinle districts are not confined to the study area, a brief summary is presented before the description of the Lisbon Valley deposits. The reason for including these other districts in the text is to compare the deposits of the anomalous Lisbon Valley area and the rest of the Chinle deposits. Such a comparison aids in the understanding of the Lisbon Valley deposits and is helpful for suggesting target areas for prospecting.
Selected Chinle Uranium Districts

The San Rafael Swell area (fig. 38) is composed of three districts: the southern belt, a central Temple Mountain belt, and a northern belt. The deposits in this area are generally small, tabular uranium deposits which occur in the Monitor Butte and the Moss Back Members of the Chinle Formation. The ore bodies seem to be localized in small scours except in the Temple Mountain area where pipe-like collapse structures seem to have modified the deposits. Hawley and others (1968) classify the deposits into the following categories: vanadium-uranium deposits, zinc-lead-uranium deposits, copper-uranium deposits, and copper-rare earth-uranium deposits. The lead and rare earth minerals are considered to be distinctive and the others are the dominant metals of the deposits. Also associated with uraninite are minor amounts of chalcopyrite, galena, sphalerite, chalcocite(?), molybdenite (?), and montroseite.

The Inter-River area includes the Seven-Mile Canyon district and the Mineral Canyon district. The deposits in this area are generally small with only five of the deposits producing over 5,000 tons of ore (Chenoweth, 1975). The majority of these deposits occur in paleochannels of the lower Chinle sands which are scoured into the underlying Moenkopi Formation. However, the deposits in the Seven-Mile
Figure 10. Location of Triassic uranium districts, central Colorado Plateau area.
Canyon district are somewhat different in character. The host rocks of this district have been described by Chenoweth (1975) as being lenticular in nature and containing argillaceous mudstone, limestone-and mudstone-pebble conglomerate, and carbonaceous mudstone and sandstone. The description of this generally fine-grained unit with mudstone-pebble conglomerate and lenticular sandstones appears to be similar to the lower Chinle sediments in the Rio Algom area of Lisbon Valley. It is interesting to speculate that the sediments of Seven-Mile Canyon area could have formed in a depositional environment similar to that of the crevasse-splay deposits of Rio Algom.

The Natural Bridges area includes the White Canyon-Red Canyon districts, the Deer Flats district, and the Elk Ridge district. The deposits of this area differ from those discussed above because they are hosted in the Shinarump Member of the Chinle Formation. Most of the deposits in this area are linear in plan view with some deposits having a shape of curvilinear to non-linear. One of the few non-linear deposits of the area includes the Happy Jack deposit of the White Canyon district. Chenoweth (1975) describes meander loops in the Shinarump channels as being favorable sites for the formation of uranium ore deposits. The ore bodies are usually composed of lenticular mineralized pods which are subparallel to the bedding and closely spaced. Individual
mineralized bodies range from one to twelve feet high (0.3 to 3.6 m) and a few feet to a few hundred feet (0.9 to 90 m) in length. The average width is about 1/5 to 1/10 the length. Minerals associated with uraninite include: vanadium minerals, chalcopyrite, bornite, chalcocite, and covellite. Calcium carbonate is commonly a cementing agent in the sandstone host.

The deposits of the Monument Valley area were discovered in 1942 and put into production in 1948. The deposits of this area are believed to be almost identical to those of the Natural Bridges area. The uranium is found in the basal scours of the Shinarump Member. Mineralogy of the Monument No. 2 mine includes: uraninite, coffinite, montroseite, corvusite, vanadium hydromica, and sulfides of iron, copper, and lead (Malan, 1968). The uranium mineralization is generally associated with deep-scour channels which reveal some geochemical zoning. Lewis and Trimble (1959) report that higher grades of vanadium occur below and downdip from the uranium mineralization. Halos of fluorescent silica have been used as exploration guides in this district.

The Circle Cliffs area contains uranium deposits which are restricted to a zone of about 2 feet (0.6 m) thick at the Shinarump-Moenkopi contact. These uraninite deposits are small and discontinuous and take the form of high-grade ore pods that are a few square feet in cross section and up to several hundred feet long (Davidson, 1967). These deposits
contain pyrite, marcasite, sphalerite, and galena. Elemental associations include nickel, silver, molybdenum, cobalt, yttrium, and ytterbium. The uranium mineralization is again economic where the lower Chinle sandstones (Shinarump Member) have been deposited in scours or channels in the underlying formation.

Lisbon Valley Uranium District

The first reported discovery of uranium in the Lisbon Valley area was made in 1913 along the southern end of the anticline in the sandstones of the Chinle Formation (Wood, 1968). Decades later in 1948, a low-grade uranium ore body was developed in the upper Cutler sandstones. Charles A. Steen, drilling for Permian ore bodies in July of 1952, intersected 13 feet (4 m) of high-grade uranium in the Triassic sandstones of the Chinle Formation. The first ore produced from this discovery was on December 4, 1952 (Stocking, 1975) and in the following few years, the biggest single uranium district in southeast Utah was delineated. Early work in the district was confined to mineralogic studies, including those of Dix (1953), Gruner (1954), and Botinelly (1956). Later studies by Weir and others (1957) discussed geochemical zoning on a district-wide scale, and a detailed statistical study by Kock and others (1964) on the Mi Vida mine showed that the deposit was divided into a northern and southern
part based on metal distribution. This study also noted that the famed accidental discovery hole drilled by Steen could not have been better located in the ore body. The general geology of the district has been discussed by Isachsen (1964) and Lekas and Dahl (1956). A more detailed study of the northern part of the district was conducted by Loring (1958) in which he briefly discussed some of the sedimentologic features of the Moss Back sandstones.

Figure 39 shows the location and the approximate outline of the mineralized areas of the district. The Lisbon Valley district, also known as the Big Indian Valley district, can be subdivided into two areas of mineralization. The southern area, which is the smallest of the two, includes the Service Berry, Divide, and Continental mines. Atlas Minerals Corporation has recently announced the discovery of a new high-grade uranium deposit in this part of the district. The northern area contains the majority of the reserves in a narrow belt which is about 1/2 mile wide (1 km) and about 6 miles long (10 km). The mines in this area include: Louise, Mi Vida, Ike-Nixon, La Sal, Cord, Radon, Far West, North Alice, and Rio Algom. Wood (1968) describes the ore bodies as irregular, amoeba-shaped masses that are concordant to the bedding. The average thickness is about 6 feet (2 m) but ranges from a few inches up to over 45 feet (13.5 m) in thickness with an average grade of 0.39 percent $U_3O_8$. The total production
Figure 39. Uranium mineralization and mines in the Lisbon Valley district (modified from Doelling, 1968).
and the remaining reserves for the district is believed to exceed 70 million pounds of $\text{U}_3\text{O}_8$.

The uranium deposits of Lisbon Valley occur in the lowest sandstone or conglomerate of the Moss Back Member (Wood, 1968). Sedimentological controls of the uranium mineralization were not recognized along the Moss Back outcrop in Lisbon Valley. However, the isopach map of the lower Chinle sandstones (fig. 33) shows a spatial relationship between sandstone thickness and the uranium mineralization. The mineralized areas seem to occur where the thickness of lower sandstones exceed 40 feet (12 m). The thickness of the sandstones in the middle of the belt suggests that an intra-stream divide may have existed during Moss Back deposition.

Based on the stratigraphic interpretation of the lower Chinle sediments, the uranium deposits in the northern part of the district, from the Mi Vida mine to the Rio Algom mine (fig. 39), are restricted to unit B. Here, the main uranium deposits are spread out from the southern edge of the sandstone belt (unit B) all the way across the channel deposits to the northern edge, and in the case of the Rio Algom mine, the mineralization spreads past the banks into the crevasse-splay deposits.

If the interpretation of the Rio Algom mine area is correct, then the northern extent of mineralization would
be limited by the pinchout of the crevasse-splay sandstones into the flood basin deposits. The uranium deposits in the southern portion of the district are also believed to be hosted in crevasse-splay deposits. The location of the Lisbon Valley uranium district is at the edge of a regional oxidation-reduction interface as shown on figure 37. Paleo-current directions and a sandstone isopach map indicate the rivers which deposited the Moss Back sandstones flowed in a northwesterly direction. The "down dip" movement of the oxidized ground water which formed the oxidation-reduction interface was probably in a westerly direction away from the Uncompahgre uplift and the salt anticline region (fig. 12).

A comparison of the Lisbon Valley district with the other districts which were previously described indicates several points of significant contrast. The Triassic host rocks of the White Canyon area are notable rich in copper and silver and low in vanadium. The host rock in the San Rafael Swell area generally contains more vanadium and less copper than the other districts (Miesch, 1963). The Monument Valley area contains both copper-uranium type and uranium-vanadium type of deposits and the Elk Ridge and Deer Flat areas are mainly uranium-copper type (Doelling, 1969). The Lisbon Valley district contains ore bodies of large tonnage which are grouped together to form two or three very large deposits, whereas the other districts are composed of isolated linear
pods of mineralization which are not connected and are composed of small tonnage. The average grade for the other Triassic districts is from 0.20 to 0.30 percent $\text{U}_3\text{O}_8$ (Finch, 1959), whereas the average grade for the Lisbon Valley district was 0.39 percent $\text{U}_3\text{O}_8$. The location of the uranium mineralization in Lisbon Valley does not appear to be related to deep channel scours as is the case for the other uranium districts. The Lisbon Valley district contains some of the same elemental associations as the other districts; however, its geochemical signature is markedly different. The importance of this difference must be tempered with the fact that more detailed geochemical work has been undertaken on the Lisbon Valley deposits in comparison with the other districts (Kennedy, 1961, and Schmitt, 1968).

**Outcrop Radioactivity**

Whereas a blind drill hole has been given credit for the discovery of the large Triassic Lisbon Valley deposits, the outcrop was investigated to see if a radiometric survey of the lower Chinle outcrop would be of exploration value. The Mount Sopris scintillometer which was used throughout the entire traverse gave a general background reading of about 100 counts per second (cps). All of the following descriptions of outcrop radioactivity are from sandstone unit B (Plate II). Near measured section 7, the count in the basal
portion of the sandstone ranged from 130 to 170 cps. Northward along the sandstones, the readings averaged approximately 100 to 140 cps. South of measured section 7, the count in a coarse-grained sandstone was recorded at over 200 cps.

Farther south near the Small Fry mine, 3,000 cps were recorded at the Chinle-Cutler contact; the counts per seconds decreased upward as shown on figure 40. Approximately 400 feet (120 m) to the south of the Small Fry mine, another area of anomalous radioactivity was recorded. The maximum count for this site was 1,200 cps as shown on figure 41. Here, the maximum count was found in the lower portion of a small channel-fill sequence. Northwest of measured section 8, an anomalous area was found to be associated with fossil plant material.

Figure 42 shows the general nature of sedimentary structures and the location of a log which gave a count in excess of 3,000 cps. The average reading above and below this log was about 300 cps. South of measured section 8, at numerous locations on the surface, the radioactivity over a small area was in excess of 200 cps and ranged up to 1,600 cps in a conglomeratic unit. Northwest of measured section 6, a large channel-fill deposit of about 250 feet wide (75 m) showed a radioactivity increase from about 500 cps near the edge of the deposit to over 3,000 cps in the thickest portion of the channel-fill sandstones and conglomerate. Reconnaissance along the rest of the outcrop revealed that the radioactivity continued to be anomalously high and readings of 250 to 200 cps were common in the sandstones.
Figure 40. Radioactivity above the Chinle-Cutler erosional contact in counts per second, near Small Fry mine, Lisbon Valley area.

Figure 41. Radioactivity of a channel-fill deposit and overlying facies in counts per seconds, near Small Fry mine, Lisbon Valley area.
Figure 42. Radioactivity showing anomaly associated with a fossilized log northwest of measured section 8, Lisbon Valley area.
The radioactivity of the outcropping lower Chinle sandstones at Lisbon Valley ranged up to about 30 times background but the majority of the anomalous readings were from 2 to 10 times background. Not surprisingly, this survey showed that anomalous radioactivity along the outcrop is a good exploration guide for the uranium deposits. Though none of the major ore bodies outcrop, minor uranium mineralization from the migration of the uranium-bearing solutions is present along the outcrop.

Geochemistry of the District

The nature of the uranium deposits at Lisbon Valley in comparison with the other Chinle districts in the region indicates that the Lisbon Valley district might have formed by somewhat different processes. Though most of the mines were inactive during the course of this investigation, several earlier studies conducted in the area provide valuable information on the genesis of the district. Kennedy (1961) analyzed splits from ore shipments sent to the mill; several of these samples represented over 1,500 tons from each individual mine. He also analyzed samples of barren Moss Back sandstones in order to determine what elements had been concentrated along with the uranium. Apparently, vanadium, arsenic, beryllium, cobalt, copper, lead, molybdenum, ytterbium, yttrium, and probably barium, lanthanum, manganese, nickel, and zirconium were concentrated in these deposits. Figure 43 shows the
Figure 43. Concentration of vanadium in uranium ore (in ppm) in northern part of Lisbon Valley uranium district. (data from Kennedy, 1961)
distribution of vanadium, and figure 44 illustrates the distribution of molybdenum in several of the ore bodies of the district. Zoning of two elements associated with the ore bodies was found to occur over the deposits. Kennedy (1961) found that a molybdenum halo extended up to about 9 feet (2.7 m) above the uranium mineralization in the northern part of the district. Calcium was also found to be concentrated above the ore for about 2 feet (.6 m). Recent work by Brooks (1978, personal communication) provides a detailed look at the mineral zoning. Sampling on approximately six-inch spacing revealed the ore body at the Far West incline to have an upper molybdenum maximum value underlain by the uranium zone which in turn was underlain by a vanadium zone followed by a copper zone. Figure 45 is a generalized graph which shows this relation between the uranium mineralization and the element zoning. This sequence of zoning is characteristic of the upper limb, or more generally, the outer side of a geochemical cell (i.e. roll-type deposit), as described by Rackley (1976) and Harshman (1974).

The major ore minerals of the Chinle deposits are colloform uraninite, coffinite, montroseite or paramontroseite, and vanadium hydromica (Schmitt, 1968). Table 3 lists the minerals that have been identified in the Chinle ores. Uraninite coats detrital grains, forms veinlets which cut grains, penetrates along cleavages of feldspars and micas,
Figure 44. Concentration of molybdenum in uranium ore (in ppm) in northern part of Lisbon Valley uranium district (data from Kennedy, 1961).
Figure 45. Main geochemical facies of a mineralized section in the Far West Incline (Brooks, 1978, personal communication).
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<th>COPPER MINERALS</th>
<th>SULFIDE MINERALS</th>
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**TABLE 3. MINERALS IDENTIFIED IN LISBON VALLEY DISTRICT**
(from Schmitt, 1968)
and nearly completely replaces feldspar grains in some cases. Schmitt (1968) conducted an investigation into the unit cell dimensions of uraninite crystals from uranium ores of several mines in the district. His measurements of uraninite samples from eight mines indicated that the crystallinity sizes are essentially uniform throughout the district and show no spatial relation to distance from the Lisbon Valley fault. From this information, he concluded that the uranium mineralization could not have been introduced by hydrothermal solutions ascending along the fault.

The age dates for these ores by lead-uranium and lead-lead methods show a wide range of values. However, fifty percent of the samples have age dates near 200 million years ago. Schmitt (1968) believes that uranium mineralization occurred during or shortly after diagenesis of Chinle sediments or penesyn genetically and was later followed by local remobilization and crystallization of the mineralization.

The study of sulfur isotopes is helpful for unravelling the origin of the uranium mineralization. Schmitt (1968) reports that the $\text{S}^{32}/\text{S}^{34}$ ratio for the sulfides associated with the uranium ore deposits was light and variable. This condition is produced by anaerobic bacteria which metabolize sulfate to generate $\text{H}_2\text{S}$ depleted in $\text{S}^{34}$ relative to the original sulfate. Bacteria of the Desulfovibrio type produce this fractionated $\text{H}_2\text{S}$ in temperatures of less than 115$^\circ$ C.
Most of the sulfides from the Mi Vida mine have $\frac{S^{32}}{S^{34}}$ ratios greater than 23.1 indicating strong enrichment in the lighter isotope. Because pyrite composed of this lighter sulfur isotope formed at the same time as the uranium mineralization, it is probable that the biogenic environment which produced the $H_2S$ was also responsible for creating the reducing conditions which reduced and deposited the uranium. The importance of anaerobic bacteria of the Desulfovibrio type in the precipitation of uranium mineralization from the geochemical cell has been discussed by Rackley (1976).

In an effort to determine how the ore deposits of the Rio Algom mine were related to the rest of the district to the south, samples from different sedimentary facies were analyzed for their trace element content. As previously discussed, the depositional environment of the Rio Algom mine area has been interpreted as being marginal to the main channel system in a crevasse-splay facies. If uranium complexes migrated with the ground water through the main channel system and out along the crevasse channels, then analysis of the elemental content of these channel-fill facies should indicate a difference between the conduit channels and the enclosing overbank deposits. Figure 46 illustrates the location of three samples taken above a crevasse channel (A), in the channel (B), and below the channel (C). This area of the mine is rib V on Plate IV. Table 4 gives the
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Figure 46. Sketch of rib V in the Rio Algom mine indicating location of samples taken from different facies. Analyses for samples are listed in table 4.

Figure 47. Sketch of a rib of the Rio Algom mine showing location of samples taken from flat pebble channel-fill facies cut into a siltstone overbank facies. Analysis for samples are listed in table 5.
spectrographic analysis for the samples. Another area of the mine was analyzed in the same manner except that the channel-fill facies also contained flat mudstone pebbles. Figure 47 shows the location of the samples taken near rib A-1 of Plate IV and Table 5 gives the spectrographic results. A comparison of these tables indicates that the channel-fill facies are enriched in calcium, barium, and manganese, and slightly enriched in molybdenum. Kennedy (1961) showed that all of these elements were associated with the uranium ore-forming process. It is interesting to note the decrease in the amount of titanium in the channel-fill facies at both locations and the decrease of total iron in the sandstone shown in Table 4. The removal of iron from channels in which organic-rich solutions (humic) have migrated through as a precursor event to the uranium mineralization has been noted by Adams and others (1974).

A similar comparison of host rock geochemistry was made along the main channel system to see if a difference existed between the sandstone updip from the mineralization and the sandstone downdip from the ore bodies. Table 6 lists the spectrographic results from an outcrop sample, the Ike-Nixon mine, and drill hole LC-24; figure 48 shows the location of the sample points. Because the outcrop sample does not represent a statistically valid analysis of a large volume of rock and the drill hole analysis represents cuttings
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**TABLE 6. RESULTS OF SPECTROGRAPHIC ANALYSIS FOR LOCATIONS GIVEN IN FIGURE 48**

(Values are ppm except as noted.)

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>OUTCROP</th>
<th>IKE-NIXON MINE*</th>
<th>DRILL HOLE 24</th>
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</tr>
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</tr>
<tr>
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</tr>
<tr>
<td>V</td>
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<td>2,600</td>
<td>50</td>
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</table>

*Values from Kennedy (1961)
Figure 48. Location of data points listed in table 6.
over a ten-foot interval whose contamination is unknown, the interpretations are, of course, tenuous. However, the data presented are believed to be sufficient for suggesting possible trends related to the mineralization process. It appears that all the elements thought by previous authors to be concentrated with the mineralization are in fact present in greater amounts in the deposits relative to the outcrop and the drill hole with the possible exception of calcium. It is interesting to note that titanium is apparently depleted updip from the uranium ore bodies. Gross (1956) reported that magnetite (Fe$_3$O$_4$) and rutile (TiO$_2$) are minor components in the heavy mineral fractions which he analyzed from the district. The use of TiO$_2$ alteration as an exploration guide for the search of areas where organic solutions have passed has been discussed by Adams and others (1974) and Hafen and others (1976). To see if such guides were applicable for the Lisbon Valley area, the cuttings collected from the channel sandstones for all the drill holes were spread out on a sheet of paper and a strong magnet was passed over the grains. None of the magnetic minerals was detected in the cuttings by using this method. However, this does not mean they are not present in the subsurface sandstones; the method of sample collection used on the drill rig could easily allow for the heavy mineral fraction to settle out prior to recovery. If the Chinle sandstones had been cored, magnetite and ilmanite probably would have been found to be present.
Finally, a geochemical comparison between the two channel systems was made to determine whether an elemental difference existed. Table 7 gives the values for a sample from the upper system C and a sample from the lower system B. A review of this table shows that total iron and titanium is depleted and calcium, barium, lathanium, manganese, and strontium are slightly enriched in system B, assuming initial concentrations were the same. These results indicate that the mineralizing solutions and possibly the earlier migration of humates were restricted to the lower channel system. The paragenesis of the Lisbon Valley district was worked out by Gross (1956) and substantiated by Schmitt (1968) except for the addition of marcasite with pyrite. Figure 49 showing the paragenetic sequence of the Mi Vida mine is probably accurate for the entire district even though remobilization of the deposits has undoubtedly occurred.

Interpretation

The geochemical framework of the Lisbon Valley district suggests that these uranium deposits formed from a geochemical oxidation-reduction cell similar to that presented by Rackley (1976). The regional picture based on Amstrat logs indicates that a significant portion of the lower Chinle sandstones to the east of Lisbon Valley are oxidized as indicated by their red color. The alteration effect at the local
Figure 49. Paragenesis of uranium mineralization at the Mi Vida mine (after Gross, 1956 and Schmitt, 1968).
<table>
<thead>
<tr>
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(Values in ppm except as noted.)
setting is not in the form of a clear-cut color change. However, Schmitt (1968) notes that a red, pink, or salmon coloration is a characteristic feature of ore-bearing sandstone. The bleaching of the underlying Cutler Formation and the possible slight removal of iron from the Chinle sandstones indicates that humates may have migrated through the area and/or possibly remained to trap uranium in solution. The elemental zoning above and below the uranium ore bodies suggest that a tubular-like geochemical oxidation-reduction cell was present in the basal few feet of the channel and was expanding upward and outward in the direction of the ground water flow. While the geochemical cell was expanding in the direction of ground water movement, its expansion may have been checked in the upward direction by the presence of humates. If a reducing halo, possibly generated by anaerobic bacteria similar to Desulfovibrio existed around a humic body, then several reactions could be expected. The uranyl cation as it migrated upward would attach itself to the negatively charged groups in the humic body (Jennings, 1976). The ions would remain in their oxidized state until they were reduced over a period of time, the length of which would depend on the nature of the reducing environment created by the anaerobic bacteria.

This is in agreement with the observation of Schmitt (1968) that the nature of the ore deposits suggested they
formed by colloidal means. These humic bodies probably did not act as an impervious barrier to all the metals transported in the cell. As the ions migrated up through the mass, the metals precipitated in the same general sequence as described by Harshman (1974) as being characteristic of roll-type uranium deposits. The occurrence of such a humic body can account for the tabular nature of the uranium deposit. Figure 50 is a generalized sketch illustrating the tubular nature of the geochemical cell and its suggested relation to humic bodies in a confined channel system. As is common to many uranium districts, the alteration effect in the "oxidized" portion of the cell is not obvious.
Figure 50. Idealized sketch of tubular-type geochemical cell in confined channel-fill deposits. Direction of ground water flow is perpendicular to page.
EXPLORATION MODEL

The large uranium deposits of Lisbon Valley lend themselves to the establishment of a generalized exploration model based on their sedimentologic, tectonic, and geochemical characteristics. The importance of a model based on this district is several-fold: first, it offers an explanation for the difference between the large Lisbon Valley uranium district and the numerous smaller Chinle districts in the central Colorado Plateau; second, the model can be applied to the Triassic rocks of the region to see if similar favorable conditions may have prevailed elsewhere; and third, when the model is viewed solely from a genetic sense irrespective of formation names and strict geographic locations, it can provide a basis for outlining favorable geologic environments for potential uranium mineralization in other basins. The danger of suggesting a detailed geologic model for use in exploration is that no two uranium districts are exactly alike and if the model is overzealously applied, deposits could be overlooked simply because they varied from the local geologic setting.

The accumulation of the great thicknesses of Pennsylvanian evaporites in the Paradox Basin set the stage for the subsequent tectonic activity which influenced the uranium related Triassic events. The Uncompahgre portion of the Ancestral Rocky Mountains was a positive feature which
provided clastic debris that filled the basin. Early loading and compaction of the Paradox salts initiated movement westward and then upward where they were deflected by basement faults. These northwest-trending salt anticlines were in the form of individual salt cells which probably deflected the streams which deposited the lower Chinle sandstones. Where the stream systems were of a degrading nature similar to the Shinarump Member (fig. 51), they may have incised into the rising bedrock and as such, showed little influence between tectonics and sedimentation. However, where these streams were of an aggrading nature similar to the Moss Back Member (fig. 52), they were probably localized in the structurally lower areas. Thus, the Triassic inter-anticlinal areas have the greatest thickness of sandstone. The conditions produced in these fluvial sediments were ideal for creating uranium host rocks. The climate was tropical enough to support ample vegetation as evidenced by the abundance of carbonaceous detritus which occurs in the lower Chinle sediments. The type of fluvial sedimentation varied from braided channels to meandering channels. The reasons for such variations are probably several-fold: the establishment of topographic nick points due to the rising salt anticlines produced different stream gradients; abundant vegetation stabilized the bank deposits which in turn confined the channel systems; and the amount of sediment supplied from the
Individual salt cell which may have influenced sedimentation in Triassic time, (location of individual cells taken from Shoemaker and others, 1958).

Area of salt anticlines that may have influenced sedimentation to a lesser degree.

Generalized stream pattern; arrows pointing downstream.

Figure 51. Suggested paleogeographic setting during time of Shinarump deposition.
Individual salt cell which may have influenced sedimentation in Triassic time, (location of individual cells taken from Shoemaker and others, 1958).

Area of salt anticlines that may have influenced sedimentation to a lesser degree.

Generalized trend of stream systems.

Figure 52. Suggested paleogeographic setting during Moss Back deposition.
source area coupled with variable discharge rates produced
different types of sedimentary sequences.

Uranium mineralization was probably introduced soon
after deposition of the fluvial sequences. The source of
this uranium could have been volcanic ash incorporated in
the clays found in the lower Chinle sediments or from leaching
high-uranium granites in the area which supplied the clastics.
Such an area has been identified in one of the source terrains and
found to contain over 14 ppm $\text{U}_3\text{O}_8$ in surface samples from
the Trimble granite in the San Juan Mountains (Metzger, 1978,
personal communication). The uranium, either from volcanic
ash, anomalous granites, or possibly both, was transported
in the near-surface ground waters. The uranium continued
to migrate down the hydrologic gradient until it encountered
organic matter in the form of humates. Where the uranium
in solution came into contact with these organic masses, it
was taken out of solution and fixed as a colloid. Szalay
(1969) has shown that humates can remove great amounts of
uranium and vanadium from ground waters. This process was
effective all along the entire length of the river from
near its headwaters to the lower reaches -- wherever humate
bodies occurred.

After the deposition of the lower Chinle sandstones,
the climate appears to have become more arid or the paleotopo-
graphy changed with respect to the ground water table. This
is indicated by the oxidized nature and the general lack of plant debris in the upper Chinle sediments. Conditions during sedimentation of the upper Chinle rocks would have been ideal for the introduction of oxidizing waters which dissolved the uranium and transported it to an oxidation-reduction interface. The degree of oxidation and general overall nature of these geochemical cells throughout the central Colorado Plateau area are believed to be highly variable. In the salt anticline region of the Paradox Basin, these cells were probably of a "stronger" and better defined character than those in the areas to the west. The reason for this belief is that the salt anticlines were probably positive features which allowed large magnitudes of oxygenated waters to enter into the host rocks and mobilized the uranium. Initially, the salt anticline area east of Lisbon Valley may have contained numerous small deposits similar to the districts of Elk Ridge, White Canyon, and the various belts of the San Rafael Swell (fig. 53). These deposits are believed to have formed as a result of leaching uranium from the overlying volcanic ash and subsequently accumulating in small humate bodies contained in the lower Chinle sandstones. However, with continued introduction of oxidized waters in the salt anticline region, these smaller deposits may have been mobilized to form the large Lisbon Valley Uranium District (fig. 54). Where the oxidized waters were unable to invade
Individual salt cell which may have influenced sedimentation in Triassic time, (location of individual cells taken from Shoemaker and others, 1958).

Area of salt anticlines that may have influenced sedimentation to a lesser degree.

Generalized trend of stream systems and extent of small mineralized bodies.

**Figure 53.** Schematic diagram showing possible distribution of mineralization prior to geochemical cell development in southern part of Paradox Basin.
Individual salt cell which may have influenced sedimentation in Triassic time, (location of individual cells taken from Shoemaker and others, 1958).

Area of salt anticlines that may have influenced sedimentation to a lesser degree.

Generalized trend of stream systems with mineralization.

Direction and extent of movement of oxygenated ground waters.

Figure 54. Schematic diagram showing suggested direction and extent of geochemical cell migration.
areas which contained one of these small deposits because of differential ground water flow or for any other reason, the uranium deposit would remain behind as an island surrounded by the geochemical cell.

If this model for the Lisbon Valley district is generally correct, then several other target areas appear to merit further investigation. Whereas the model discusses only one segment of the salt anticline area, a similar setting is believed to have been present throughout all of the salt anticlines as shown in figure 55. During the time when oxidizing waters were mobilizing the uranium, the supply of water was probably adequate to transport these dissolved species to the fringe area of the salt anticline region. Figure 56 outlines the area where it is believed that similar conditions may have existed to those which produced the 70-million-pound Lisbon Valley uranium district.

This model can be summarized best by discussing the influence of tectonics on both sedimentation and subsequent geochemical events. Uplift initially created a gradient from a highland to a basin down which the streams flowed. The tectonic movement of small salt anticlines appears to have influenced the regional as well as the local sedimentology. An adequate source of uranium is present in the area and is believed to have been available to the host sands. Continued growth of the salt anticlines coupled with a possible but
Individual salt cell which may have influenced sedimentation in Triassic time. (Location of individual cells taken from Shoemaker and others, 1958).

Area of salt anticlines that may have influenced sedimentation to a lesser degree.

Generalized trend of stream systems and direction and distance of movement of oxygen rich ground waters.

Figure 35. Schematic diagram showing suggested extent of geochemical cell development.
not necessary change in climatic conditions established geochemical cells. These cells were active as long as tectonic and sedimentologic conditions allowed for their recharge by oxygenated water. Uranium found in the stream sediments was dissolved in the cell, transported down the hydrologic gradient, and precipitated at the cell edge. The distribution of these cells was generally restricted to the basal portion of the channel system. The uranium deposits are believed to have been formed by tubular-like cells which are tabular in nature due to modification by humic bodies.
SUMMARY AND CONCLUSIONS

The sandstones of the lower portion of the Chinle Formation at Lisbon Valley were deposited in a fluvial environment. Facies analysis of these sandstones suggests that this fluvial environment was of the coarse-grained, point bar, meander-belt type or possible the Donjek type braided stream of Miall (1977a). Sedimentation during Moss Back time, as well as for the rest of the Chinle Formation, appears to have been influenced by tectonic activity. This is shown by the subsurface geometry of the sandstones of the Moss Back Member as well as the thinning of the total Chinle Formation to the north towards the Lisbon Valley salt anticline.

Two separate fluvial depositional systems and possibly a third were identified along the outcrops of Triassic rocks at Lisbon Valley. These systems were identified by lateral relationships of the facies, cross-bedding directions, and the sequence of primary sedimentary structures. Along the outcrop in the central part of the district near Spiller Canyon, a thick sandstone body (unit A) is present. The channel which deposited this sandstone may have been the first stream to be abandoned because it appears to be overlain by fine-grained material associated with a different channel system to the north. The abandonment of the channel occurred as the stream migrated northward resulting in a similar shift
of active channel deposition. Overbank sedimentation covered this abandoned area. Throughout the rest of Moss Back deposition, the main channel portion of the streams was generally restricted to this northern area.

Direction of sediment transport for the Moss Back Member is generally of a northwesterly direction. However, the basal channel system in the northern area (unit B) may have a more southwesterly transport direction as indicated by the cross-bedding readings. If this is the case, then the stream associated with this depositional episode is believed to have turned northwestward after crossing the Lisbon Valley area. The current directions of the upper system (unit C) indicate that the stream which deposited these sediments may have been from a different area separate from the lower stream system. This stream approximately parallels the regional direction of the salt anticlines (fig. 12) which are believed to have influenced the Moss Back sedimentation.

Primary sedimentary structures which are characteristic of the fluvial depositional environments also indicate at least two separate stream systems (units B and C) are present along the outcrop (Plate II). Both sequences start with sedimentary structures that are believed to originate in the channel floor facies. These sedimentary structures are in turn overlain by in-channel facies usually represented by trough cross-bedding. In the case of the lower system (unit B),
the channel floor facies frequently has an upward transition to fine-grained overbank facies with the in-channel facies absent, or if it is present, the thickness is greatly diminished. Both systems are capped by the vertical accretion deposits of the overbank facies.

Uranium mineralization in the Lisbon Valley district occurs in the basal sandstones and conglomerates of the Moss Back Member. In the northern part of the district, the large linear ore bodies are believed to be generally confined to unit B. The long axes of these ore bodies are approximately perpendicular to the northwest-trending channel system as mapped in the subsurface. The uranium mineralization is not solely hosted by channel sandstones. In the Rio Algom mine (Lisbon mine), the host rock for the mineralization is believed to be of crevasse-splay origin.

The geochemistry of the uranium deposits reveals similarities to the oxidation-reduction geochemical cell uranium deposits of the Wyoming basins. The distribution of elements in a vertical sequence from the top downward has been reported to be molybdenum, calcium, uranium, vanadium, and copper. This sequence resembles the upper limb of a geochemical cell-type deposit. The Lisbon Valley deposits are believed to have formed by oxidizing ground waters which were introduced along the flanks of active salt anticlines. These solutions migrated down the hydrologic gradient and created a
geochemical cell which mobilized the metals in the host sandstones. With continued recharge of oxygenated water, the geochemical cells had sufficient strength to expand into the border areas of the salt anticline region.

Favorable geologic conditions associated with the Lisbon Valley district and its regional setting include:

1. Fluvial sandstones which were deposited in a basin that formed off the margins of large-scale uplifts.

2. Initially, these streams were cutting valleys into underlying formations. However, with a change in the stream gradient due to erosion in the source area, the streams began to aggrade and fill the subaerial portion of the basin with clastic sediment. Local structures tended to constrict the stream systems into certain areas.

3. Abundant vegetation flourished in the flood basin and associated fluvial environments. The decaying vegetation which occurred in the well drained and poorly drained swamps produced humic acids which entered the shallow subsurface waters. Rapid burial preserved the plant material that accumulated in the channel and channel margin areas.
4. Volcanic activity is recorded by the presence of clays altered from ash in the Chinle strata. These clays occur throughout the sandstone sequence. A period of sedimentation dominated by volcanism occurred after the sandstones were deposited. Streams transported the volcanic material to the depositional sites of the flood plain and lacustrine environments. These sediments blanketed the area and covered the sandstones. Uranium ions leached from the volcanic ash were probably trapped by the humates that had collected in the less permeable facies of the fluvial system.

5. Tectonic uplift and climatic changes which accompanied this period of extensive volcanism allowed the introduction of large quantities of oxidizing waters into the shallow subsurface channel sandstones. The geochemical cell may have been initiated at this time.

6. The ground water flow generally followed the paleochannels located in between the positive anticlinal areas. The cell probably continued to grow and migrate so long as ample oxidizing waters were available. This migration proceeded as far as the border area of the tectonically
disturbed region. Here, humates and bacterial-generated reducing conditions created a favorable environment for uranium mineralization.
REFERENCES CITED


Cooper, J. C., 1960, Cambrian, Devonian, and Mississippian rocks of the four corners area, in Geology of the Paradox basin fold and fault belt: Third field conference, Four Corners Geol. Soc., p. 69-78.


Galloway, W. E., and others, 1978, Depositional and ground water flow systems in exploration for uranium, a research colloquium, Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas.

Gross, E. B., 1956, Mineralogy and paragenesis of the
uranium ore, Mi Vida mine, San Juan County, Utah:
Econ. Geol., V. 51, p. 632-648.

Gruner, J. W., and others, 1954, The mineralogy of the
"Mi Vida" uranium ore deposits of the Utex
Exploration Company in the Indian Wash area,

Hafen, P. L., and others, 1976, Application of magnetic
susceptibility measurements to uranium explora-
tion in sandstones, in Exploration for uranium
ore deposits: International Atomic Energy Agency,
p. 367-378.

Hansen, M. V., 1972, Distribution of reserves and past
production: Atomic Energy Commission

Harms, J. C., and Fahnestock, R. K., 1965, Stratification,
bed forms, and flow phenomena (with an example
from the Rio Grande), in Primary sedimentary
structures and their hydrodynamic interpretation:
Soc. Econ. Paleontologists and Mineralogists
special publication No. 12, p. 84-115.

Harms, J. C., and others, 1975, Depositional environments
as interpreted from primary sedimentary struc-
tures and stratification sequences: Soc. Econ.
Paleontologists and Mineralogists short course
No. 2, 161 p.

Harshman, E. N., 1974, Distribution of elements in some
roll-type uranium deposits, in Formation of
uranium ore deposits: International Atomic Energy

Hawley, C. C., and others, 1968, Geology, altered rocks,
and ore deposits of the San Rafael Swell, Emery
County, Utah: U. S. Geol. Survey Bull. 1239,
115 p.

Hite, R. J., 1972, Pennsylvanian rocks and salt anticlines,
Paradox basin, Utah and Colorado, in Geologic
atlas of the Rocky Mountains: Rocky Mountain
Assoc. Geologists, p. 133-137.

Hite, R. J., 1975, An unusual northeast-trending frac-
ture zone and its relation to basement wrench
faulting in northern Paradox Basin, Utah and
Colorado, Canyonlands Country Guidebook: Four


Kelley, U. C., 1958, Tectonics of the region of the Paradox basin, Guidebook to the geology of the Paradox basin: Intermountain Assoc. Petroleum Geologists, p. 31-38.


Loring, W. B., 1958, Geology and ore deposits of the northern part of the Big Indian district, San Juan County, Utah: Univ. of Arizona Ph.D. thesis.


Miall, A. D., 1977b, Lecture notes on fluvial sedimentology, Calgary fluvial symposium, Canadian Soc. of Petroleum Geologists.


Stewart, J. H., and Wilson, R. F., 1960, Triassic strata of the salt anticline region, Utah and Colorado:


Visher, G. S., 1972, Physical characteristics of fluvial deposits: Soc. Econ. Paleontologists and Mineralogists special publication No. 16, p. 84-97.


APPENDIX I

MEASURED SECTIONS
Section 1: SPILLER CANYON

Location: Section measured in T30S, R24E, Sec. 13, on the north side of Spiller Canyon.

<table>
<thead>
<tr>
<th>Total Thickness</th>
<th>Interval Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft.</td>
<td>ft.</td>
</tr>
<tr>
<td>(m)</td>
<td>(m)</td>
</tr>
</tbody>
</table>

| 524.5            | 122.5              |
| (159.9)          | (37.3)             |

WINGATE SANDSTONE
(not measured)

CHINLE FORMATION

524.5 ft. Siltstone, reddish-brown, partially covered, calcareous cement.

402.0 ft. Siltstone with sandstone, light gray, very fine-grained, subrounded, poor porosity, calcareous cement, minor amounts of clay layers, lower 3 feet is ripple stratified.

396.5 ft. Partially covered, siltstone, some shale, reddish-purple, calcareous cement.

286.5 ft. Partially covered, siltstone, reddish-brown, some very fine-grained sandstones, calcareous cement. (Offset 175 feet south)

231.5 ft. Sandstone, grayish-pink (5YR 7/2), very fine-grained, well sorted, subrounded, low angle cross-bedding, ripple marks present.

223.5 ft. Conglomerate, interbedded very fine-grained sandstone, reddish-brown, some greenish-gray alteration, resembles mottled unit, sandstone is greenish-gray, clay clasts present, calcareous cement.
<table>
<thead>
<tr>
<th>Depth</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>220.5</td>
<td>6.0</td>
</tr>
<tr>
<td>(67.2)</td>
<td>(1.8)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, reddish-brown, very fine-grained, subangular, well sorted, calcareous cement, horizontally bedded.</td>
</tr>
<tr>
<td>214.5</td>
<td>63.0</td>
</tr>
<tr>
<td>(65.4)</td>
<td>(19.2)</td>
</tr>
<tr>
<td></td>
<td>Partially covered, siltstone, some sandstone lenses present, color changes from grayish-green to reddish-brown about midway in unit, secondary gypsum present.</td>
</tr>
<tr>
<td>151.5</td>
<td>7.0</td>
</tr>
<tr>
<td>(46.2)</td>
<td>(2.1)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, yellowish-gray to reddish-brown, very fine-grained, subangular, calcareous cement, low-angle stratification, thickly to very thinly bedded, moderate sorting.</td>
</tr>
<tr>
<td>144.5</td>
<td>28.0</td>
</tr>
<tr>
<td>(44.1)</td>
<td>(8.5)</td>
</tr>
<tr>
<td></td>
<td>Partially covered, siltstones, claystones interbedded with sandstones, greenish-gray, sandstones are very fine-grained, subrounded.</td>
</tr>
<tr>
<td>116.5</td>
<td>5.0</td>
</tr>
<tr>
<td>(35.5)</td>
<td>(1.5)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, light gray, very coarse-grained, subrounded, poor porosity, possible 1% altered feldspars, calcareous cement, horizontally bedded.</td>
</tr>
<tr>
<td>111.5</td>
<td>6.5</td>
</tr>
<tr>
<td>(34.0)</td>
<td>(2.0)</td>
</tr>
<tr>
<td></td>
<td>Covered interval.</td>
</tr>
<tr>
<td>105.0</td>
<td>43.0</td>
</tr>
<tr>
<td>(32.0)</td>
<td>(13.1)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, yellowish-gray (5Y 8/2), fine-grained, rounded, some frosted grains, good porosity, calcareous cement, large-scale trough cross-bedding. (Offset 100' NW)</td>
</tr>
<tr>
<td>62.0</td>
<td>19.5</td>
</tr>
<tr>
<td>(18.9)</td>
<td>(6.0)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, contains conglomerate lenses, pale reddish-brown (10R 5/4) to pale yellowish-brown (10YR 6/2), medium bedded, clay clasts present, abundant organic debris, small amounts of coal (Vitrinite?) present, sand units are medium- to fine-grained, calcareous cement, cross-bedding ranges from horizontal to tabular, the poorly sorted beds contain clay, large pebbles and abundant organics; horizontal</td>
</tr>
</tbody>
</table>
stratification is dominant, sharp scour at base, upper part is mainly trough cross-bedded, grain size decreases upward.

42.5  2.0  
(13.0) (.6)  
Siltstone, greenish-gray (5GY 7/2), contains clay clasts and pebbles, calcareous cement, gradational contact with underlying unit.

40.5  4.5  
(12.4) (1.4)  
Conglomerate, reddish-brown at base, top of unit is bleached, (10R 3/4 to 5GY 7/2), unit is horizontally bedded at base with very low-angle cross-stratification at top, size and quantity of pebbles increase upwards, pebbles up to 10 cm, clay clasts present, calcareous cement, pebble imbrication suggests a southerly transport.

488.5  
(148.9)  
Total Chinle Formation
### CUTLER FORMATION

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Thickness (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.0</td>
<td>2.0</td>
<td>Siltstone, purplish-red to greenish-gray (5P 4/2), micaceous, sharp base.</td>
</tr>
<tr>
<td>34.0</td>
<td>11.0</td>
<td>Covered interval.</td>
</tr>
<tr>
<td>23.0</td>
<td>1.0</td>
<td>Sandstone, white, fine-grained, subrounded, good porosity, calcareous cement, poorly developed horizontal stratification.</td>
</tr>
<tr>
<td>22.0</td>
<td>2.0</td>
<td>Siltstone, white to reddish-brown, very poorly cemented, calcareous.</td>
</tr>
<tr>
<td>20.0</td>
<td>14.0</td>
<td>Covered interval.</td>
</tr>
<tr>
<td>6.0</td>
<td>6.0</td>
<td>Sandstone, reddish-brown (10R 4/6), fine-grained, subrounded, fair porosity, calcareous cement, upper portion of unit bleached white, tabular cross-bedding.</td>
</tr>
</tbody>
</table>

Rest of Cutler Formation not measured.
Section 2: SPILLER CANYON

Location: Section measured in T30S, R24E, Sec. 13, on the north side of Spiller Canyon.

<table>
<thead>
<tr>
<th>Total Thickness</th>
<th>Interval Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft. (m)</td>
<td>ft. (m)</td>
</tr>
<tr>
<td>185.5 (56.6)</td>
<td>24.0 (7.3)</td>
</tr>
<tr>
<td>161.5 (49.2)</td>
<td>50.0 (15.2)</td>
</tr>
<tr>
<td>115.5 (35.2)</td>
<td>9.0 (2.7)</td>
</tr>
<tr>
<td>102.5 (31.3)</td>
<td>3.0 (.9)</td>
</tr>
<tr>
<td>99.5 (30.3)</td>
<td>39.0 (11.9)</td>
</tr>
<tr>
<td>60.5 (18.5)</td>
<td>1.5 (.5)</td>
</tr>
<tr>
<td>59.0 (18.0)</td>
<td>13.5 (4.1)</td>
</tr>
<tr>
<td>45.5 (13.9)</td>
<td>26.5 (8.1)</td>
</tr>
</tbody>
</table>

**CHINLE FORMATION**

(Upper portion not measured)

185.5 ft. (56.6 m): Sandstone, pale red (5R 6/2), fine-grained, well sorted, subangular, quartz 95%, mica 10%, other minerals 5%, bedding indistinct, low-angle to horizontal stratification is indicated, calcareous cement, basal contact obscure, concretions present.

161.5 ft. (49.2 m): Partially covered, siltstone, some sandstone, sand units are fine-grained, subrounded, well sorted.

115.5 ft. (35.2 m): Sandstone, grayish-yellow, fine- to very fine-grained, good sorting, subrounded, quartz 80%, micas 10%, others 10%, calcite cement, no bedding recognized.

102.5 ft. (31.3 m): Conglomerate, grayish-purple, pebbles up to 2 cm, calcareous cement.

99.5 ft. (30.3 m): Covered slope.

60.5 ft. (18.5 m): Conglomerate, light gray, subrounded, abundant secondary calcite.

59.0 ft. (18.0 m): Partially covered, claystone, siltstone, olive-gray (10Y 4/2), calcareous cement.

45.5 ft. (13.9 m): Sandstone, yellowish-gray (5Y 7/2), fine-grained, some siltstone and conglomerate lenses, sands are well sorted, subrounded, good porosity,
quartz 95%, feldspar 3%, other minerals 2%, dominant cross-bedding is medium- to large-trough type, some tabular sets, minor amounts of organic material.

<table>
<thead>
<tr>
<th>19.0</th>
<th>7.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5.8)</td>
<td>(2.1)</td>
</tr>
</tbody>
</table>

Sandstone interbedded with siltstone, greenish-gray to reddish-brown, sands are fine-grained, subrounded, poor porosity, quartz 90%, mica 3%, feldspar 2%, other minerals 5%, possible overgrowths, calcareous cement, horizontal stratification, thinly bedded, scour base.

<table>
<thead>
<tr>
<th>173.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(52.9)</td>
</tr>
</tbody>
</table>

Total Chinle Formation

**CUTLER FORMATION**

<table>
<thead>
<tr>
<th>12.0</th>
<th>12.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3.7)</td>
<td>(3.7)</td>
</tr>
</tbody>
</table>

Siltstone, reddish-brown at base turning greenish-gray and purplish-gray upwards, poorly sorted lenses of very coarse-grained sand.

Rest of Cutler Formation not measured.
Section 3: SPILLER CANYON

Location: Section measured in T30S, R24E, Sec. 13, on north side of Spiller Canyon.

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
<th>CHINLE FORMATION (Upper portion not measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>215.0 (65.6)</td>
<td>73.0 (22.3)</td>
<td>Sandstone, pale red (10R 6/2), fine-grained, well sorted, subrounded, good porosity, calcareous cement, lower 10 to 15 foot trough cross-bedded, concretions present.</td>
</tr>
<tr>
<td>142.0 (43.3)</td>
<td>28.0 (8.5)</td>
<td>Partially covered, siltstone, reddish-brown to grayish-green.</td>
</tr>
<tr>
<td>114.0 (34.8)</td>
<td>10.0 (3.1)</td>
<td>Sandstone, reddish-brown, fine-grained, well sorted, subrounded, fair porosity, calcareous cement, horizontally stratified.</td>
</tr>
<tr>
<td>104.0 (31.7)</td>
<td>6.0 (1.8)</td>
<td>Conglomerate, interbedded with light green sandstone, pebbles up to 10 cm, well cemented with calcite, clay clasts present, generally horizontally stratified, sharp basal contact.</td>
</tr>
<tr>
<td>98.0 (29.9)</td>
<td>1.5 (.5)</td>
<td>Conglomerate, purplish-brown to gray, possible angular discordance.</td>
</tr>
<tr>
<td>96.5 (29.4)</td>
<td>68.0 (20.7)</td>
<td>Partially covered, siltstone, some fine-grained sands, color change from greenish-gray to tan about 1/3 up unit.</td>
</tr>
<tr>
<td>28.5 (8.7)</td>
<td>19.0 (5.8)</td>
<td>Sandstone, yellowish-gray (5Y 7/2), sequence fines upwards, lower portion is medium-grained, well sorted, subrounded, upper portion is fine-grained, subrounded, calcareous cement.</td>
</tr>
<tr>
<td>Depth</td>
<td>Thickness</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>9.5</td>
<td>5.5</td>
<td>Conglomerate, grayish-red (5YR 6/1), subrounded, poor porosity, very well cemented, dominantly horizontally stratified, grain size fines upwards.</td>
</tr>
<tr>
<td>211.0</td>
<td>(64.3)</td>
<td>Total Chinle Formation.</td>
</tr>
<tr>
<td>4.0</td>
<td>4.0</td>
<td>Siltstone, purplish-green to grayish-green, calcareous cement.</td>
</tr>
<tr>
<td>4.0</td>
<td>(1.2)</td>
<td>Rest of Cutler Formation not measured.</td>
</tr>
</tbody>
</table>
Section 4: BENCH MARK

Location: Section measured in T30S, R24E, Sec. 12, on north Bench Mark 7125.

<table>
<thead>
<tr>
<th>Total Thickness (ft. (m))</th>
<th>Interval Thickness (ft. (m))</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>394.0  (120.1)</td>
<td>92.0  (25.0)</td>
<td>Covered interval.</td>
</tr>
<tr>
<td>312.0  (95.1)</td>
<td>8.0   (2.4)</td>
<td>Sandstone, reddish-purple, fine-grained, well sorted, subrounded, calcareous cement, trough cross-bedded.</td>
</tr>
<tr>
<td>304.0  (92.7)</td>
<td>115.0 (35.1)</td>
<td>Covered interval.</td>
</tr>
<tr>
<td>189.0  (57.6)</td>
<td>20.0  (6.1)</td>
<td>Sandstone, reddish-brown, fine-grained, well sorted, subrounded, good porosity, calcareous cement, horizontal rippled surfaces which have been cut by trough and tabular cross-bedded.</td>
</tr>
<tr>
<td>169.0  (51.5)</td>
<td>13.0  (4.0)</td>
<td>Covered interval.</td>
</tr>
<tr>
<td>156.0  (47.6)</td>
<td>22.0  (6.7)</td>
<td>Sandstone, reddish-brown, fine-grained, subrounded, calcareous cement, horizontally stratified, tabular cross-bedding present in upper part, moderate sorting.</td>
</tr>
<tr>
<td>134.0  (40.9)</td>
<td>6.0   (1.8)</td>
<td>Conglomerate, light gray, some sandstone lenses, sands are medium-to fine-grained, moderately sorted, subrounded, calcareous cement, sandstones are horizontally stratified, no apparent sedimentary structures in conglomerate.</td>
</tr>
</tbody>
</table>

WINGATE SANDSTONE
(not measured)
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Thickness (ft)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.0</td>
<td>56.0</td>
<td>Partially covered, greenish-gray, some rippled sandstone and conglomerate exposed.</td>
</tr>
<tr>
<td>72.0</td>
<td>16.0</td>
<td>Partially covered, sandstone, yellowish-gray, very fine-grained, subrounded, calcareous cement, thinly bedded, rippled, basal contact is gradational.</td>
</tr>
<tr>
<td>56.0</td>
<td>36.0</td>
<td>Sandstone, grayish-yellow (5GY 7/2), some conglomerate and siltstone lenses, pebbles up to 3 cm, sands are fine-grained, subrounded, well sorted, calcareous cement, abundant plant debris in poorly sorted sands, horizontal to low-angle tabular cross-bedding is dominant in middle portion of unit, upper and lower portions are composed of trough and tabular sets, some ripples present.</td>
</tr>
<tr>
<td>20.0</td>
<td>20.0</td>
<td>Siltstone, grayish-green to purple, sandstone beds present, sands are very fine-grained, moderately sorted, subangular, calcareous cement, horizontally stratified, basal 1 foot is locally conglomerate.</td>
</tr>
<tr>
<td>394.0</td>
<td>120.1</td>
<td>Total Chinle Formation.</td>
</tr>
</tbody>
</table>

**CUTLER FORMATION**
(not measured)
### Section 5: MI VIDA

**Location:** Section measured in T30S, R24E, Sec. 11, northeast of Mi Vida Mine.

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
<th>CHINLE FORMATION (Upper portion not measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>239.5 (73.0)</td>
<td>34.0 (10.4)</td>
<td>Sandstone, brownish-gray (5YR 6/1), fine-grained, subrounded, porous, calcareous cement, horizontal to large scale trough cross-stratification, some planar sets present, moderate sorting.</td>
</tr>
<tr>
<td>205.5 (62.7)</td>
<td>9.0 (2.7)</td>
<td>Partially covered, siltstone, reddish-brown.</td>
</tr>
<tr>
<td>196.5 (60.0)</td>
<td>25.0 (7.6)</td>
<td>Sandstone, light gray to purplish-red, some conglomerate, sands in lower 5 feet are fine-grained, well sorted, subrounded, calcareous cement, horizontally stratified with ripple marks, then 1 foot conglomerate zone, followed by fine-grained sandstone which is horizontally stratified, conglomerate and shale beds are in upper portion.</td>
</tr>
<tr>
<td>171.5 (52.3)</td>
<td>86.0 (26.2)</td>
<td>Covered interval, weathers greenish-gray.</td>
</tr>
<tr>
<td>85.5 (26.1)</td>
<td>40.0 (12.2)</td>
<td>Sandstone, grayish-green, conglomerate at base and fines upwards, lenses of poorly sorted sandstone present throughout, grains are subrounded, calcareous cement, zones of abundant plant debris, tabular cross-bedding near base and large-scale trough sets upwards. (Offset 100 feet north)</td>
</tr>
<tr>
<td>45.5 (13.9)</td>
<td>1.5 (.5)</td>
<td>Conglomerate, light gray, heavy limonite staining, pebbles up to 20 cm,</td>
</tr>
</tbody>
</table>
grains are subrounded, very well cemented with calcite, carbonaceous material present, crudely horizontally stratified, gypsum present.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>44.0</td>
<td>23.0</td>
</tr>
<tr>
<td>(13.4)</td>
<td>(7.0)</td>
</tr>
</tbody>
</table>

Partially covered siltstone, greenish-gray to purple, lower contact obscure, gypsum veinlets common in upper 1 1/2 ft.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>21.0</td>
<td>16.0</td>
</tr>
<tr>
<td>(6.4)</td>
<td>(4.9)</td>
</tr>
</tbody>
</table>

Conglomerate, light gray, matrix is very light gray (N3), sands are subrounded to rounded, pebbles made up of quartzite, sandstone and chert, very well cemented with calcite and crudely horizontally stratified.

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>234.5</td>
</tr>
<tr>
<td>(71.5)</td>
</tr>
</tbody>
</table>

Total Chinle Formation.

**CUTLER FORMATION**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>(1.5)</td>
<td>(1.5)</td>
</tr>
</tbody>
</table>

Siltstone, reddish-brown, abundant mica.

Rest of Cutler Formation not measured.
Section 6: MI VIDA

Location: Section measured in T30S, R24E, Sec. 2, just south of sharp switchback in road.

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>470.0 (143.3)</td>
<td>254.0 (77.4)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>216.0 (65.9)</td>
<td>40.0 (12.2)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>176.0 (53.7)</td>
<td>127.0 (38.7)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>49.0 (15.0)</td>
<td>17.5 (5.3)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>31.5 (9.6)</td>
<td>14.5 (4.4)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>17.0 (5.2)</td>
<td>5.0 (1.5)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WINGATE SANDSTONE (not measured)

CHINLE FORMATION
12.0 2.0 Conglomerate, light greenish-gray (5GY 8/1 to 5Y 7/2), average pebble size 2 cm, angular to subangular, clay clasts present, very coarse-grained sandstones are present, well cemented with calcite, scour basal contact.

460.0 Total Chinle Formation.
(140.2)

CUTLER FORMATION

10.0 10.0 Sandstone and siltstone, reddish-brown, sands are poorly sorted, subangular, calcite cemented.
(3.1) (3.1)

Rest of Cutler Formation not measured.
### Section 7: SMALL FRY MINE

Location: Section measured in T29S, R24E, Sec. 34, northwest of the Small Fry Mine.

<table>
<thead>
<tr>
<th>Total Thickness ft.</th>
<th>Interval Thickness ft.</th>
<th>WINGATE SANDSTONE</th>
<th>CHINLE FORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>440.5 (134.3)</td>
<td>9.0 (2.4)</td>
<td>Sandstone, siltstone, reddish-brown, sands very fine-grained, ripple laminated, possible channel.</td>
<td></td>
</tr>
<tr>
<td>432.5 (131.9)</td>
<td>54.0 (16.5)</td>
<td>Partially covered, siltstone?, weathers reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>378.5 (115.4)</td>
<td>5.0 (1.5)</td>
<td>Siltstone, reddish-brown, firmly cemented with calcite, horizontally bedded and rippled.</td>
<td></td>
</tr>
<tr>
<td>373.5 (113.9)</td>
<td>140.5 (42.7)</td>
<td>Partially covered, siltstone, weathers reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>233.0 (71.0)</td>
<td>5.0 (1.5)</td>
<td>Sandstone pale-red, very fine-grained, moderately well sorted, subrounded, ripple marked. (Offset 50 feet north)</td>
<td></td>
</tr>
<tr>
<td>228.0 (69.5)</td>
<td>28.0 (8.5)</td>
<td>Sandstone, pale-red (5R 6/2), fine- to very fine-grained, moderately well sorted, subrounded, mainly horizontally stratified, however, large-scale trough and tabular cross-bedding present.</td>
<td></td>
</tr>
<tr>
<td>200.0</td>
<td>10.0</td>
<td>Covered.</td>
<td></td>
</tr>
<tr>
<td>190.0 (57.9)</td>
<td>27.5 (8.4)</td>
<td>Sandstone, grayish-yellow, fine- to very fine-grained, moderately well sorted, subrounded, composed</td>
<td></td>
</tr>
</tbody>
</table>
of quartz, mica and dark accessory minerals, calcareous cement, lower 12 ft. is horizontally bedded, rest of unit is thinly bedded and ripple marked.

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>162.5</td>
<td>39.5</td>
</tr>
<tr>
<td>123.0</td>
<td>54.0</td>
</tr>
<tr>
<td>69.0</td>
<td>28.0</td>
</tr>
<tr>
<td>30.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

Partially covered, sandstone, grayish-yellow, very fine-grained, moderately well sorted, abundant organic debris, rippled, horizontally stratified.

Partially covered, siltstone, light olive-gray (5Y 5/2).

Sandstone, grayish-orange (10YR 7/4), fine- to very fine-grained, moderately well sorted, subangular, composed of quartz, feldspar, mica, dark accessory minerals, calcareous cement, plant debris present, basal 3 feet is conglomerate, rest of unit is horizontally stratified containing ripple marks with some low-angle trough cross-bedding.

Siltstones and sandstones, gray, sands are fine-grained, subrounded, moderately well sorted, well cemented with calcite, contains abundant clay clasts, abundant plant debris.

Total Chinle Formation.

---

**CUTLER FORMATION**

(not measured)
**Section 8: PROSPECT**

*Location: Section measured in T29 1/2 S, R24E, Sec. 35 northwest of the point near Prospect.*

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>74.5 (22.7)</strong></td>
<td><strong>37.0 (11.3)</strong></td>
</tr>
</tbody>
</table>

**CHINLE FORMATION**
(Upper portion not measured)

Sandstone, light olive-green to yellowish-gray, vertical sequence is basal 2 feet of greenish siltstone, then 3 feet horizontally stratified conglomerate and very coarse-grained sandstone, then 4 feet horizontal stratification, then 3 feet greenish siltstone to very fine-grained sandstone, then 2 feet very coarse-grained sandstone to conglomerate, then 4 feet of trough cross-bedding, rest of section horizontally bedded and ripple.

<table>
<thead>
<tr>
<th>37.5 (11.4)</th>
<th>16.5 (5.0)</th>
</tr>
</thead>
</table>

Sandstone, lower 10 feet is greenish-gray (5GY 6/1), upper part is yellowish-gray (5Y 7/2), lower part of unit is very fine-grained, subrounded, calcareous cemented, trough cross-bedded, upper part of unit is fine-grained, subangular, laminated, some trough cross-bedding present, moderate sorting.

<table>
<thead>
<tr>
<th>21.0 (6.4)</th>
<th>19.0 (5.8)</th>
</tr>
</thead>
</table>

Partially covered, sandstone inter-bedded with siltstones.

<table>
<thead>
<tr>
<th>2.0 (.6)</th>
<th>2.0 (.6)</th>
</tr>
</thead>
</table>

Conglomerate, very light-gray (N8) pebbles up to 1.5 cm, sands are subrounded, well cemented with calcite, crude horizontal stratification present.

**74.5 (22.7)**

**Total Chinle Formation.**

**CUTLER FORMATION**
(not measured)
### Section 9: SPILLER CANYON

Location: Section measured in T30S, R24E, Sec. 24, on east side of Spiller Canyon.

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>160.0 (48.8)</td>
<td>21.0 (6.4)</td>
<td>Sandstone, reddish-brown, very fine-grained, subrounded, moderately well sorted, calcareous cement, dominantly ripple laminated but large low-angle trough cross-bedding present.</td>
</tr>
<tr>
<td>139.0 (42.4)</td>
<td>5.0 (1.5)</td>
<td>Conglomerate, reddish-brown, contains pebbles over 10 cm, calcareous cement, contains abundant yellow siltstone pebbles.</td>
</tr>
<tr>
<td>134.0 (40.9)</td>
<td>3.0 (.9)</td>
<td>Sandstone, reddish-gray, very fine-grained, moderately well sorted, contains green and black accessory minerals, horizontally bedded to low-angle trough cross-bedding.</td>
</tr>
<tr>
<td>131.0 (39.9)</td>
<td>5.0 (1.5)</td>
<td>Conglomerate, generally subrounded cobbles, horizontally stratified, calcareous cement, lower portion is composed of up to 10 cm, limestone pebbles are present in upper portion of unit.</td>
</tr>
<tr>
<td>126.0 (38.4)</td>
<td>11.5 (3.5)</td>
<td>Conglomerate, greenish-gray to yellowish-gray, pebbles up to 1 cm, subrounded, well cemented with calcite, contains plant debris, stone lenses present.</td>
</tr>
<tr>
<td>114.5 (34.9)</td>
<td>3.0 (1.0)</td>
<td>Sandstone, greensih-gray, very fine-to fine-grained, subangular, moderately well sorted, contains clay clasts, calcareous cement, ledge former.</td>
</tr>
</tbody>
</table>
111.5  77.0  Partially covered, siltstone, greenish-gray, gypsum present in upper 2 feet along fractures.
(34.0)  (23.5)

34.5  7.0  Conglomerate, gray, pebbles up to 5 cm, calcareous cement, horizontally bedded, basal contact is sharp.
(10.5)  (2.1)

27.5  17.0  Partially covered, siltstone, light gray to olive color, calcareous cement.
(8.4)  (5.2)

10.5  0.5  Sandstone, light gray, very fine-grained and poorly sorted, calcareous cement.
(3.2)  (.2)

150.0  Total Chinle Formation.
(45.7)

**CUTLER FORMATION**

10.0  10.0  Siltstone, reddish-brown.
(3.1)  (3.1)

Rest of Cutler Formation not measured.
Section 10: BIG INDIAN ROCK

Location: Section measured in T30S, R25E, Sec. 30, southeast of Big Indian Rock.

<table>
<thead>
<tr>
<th>Total Thickness</th>
<th>Interval Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft. (m)</td>
<td>ft. (m)</td>
</tr>
<tr>
<td>392.0 (119.5)</td>
<td>101.0 (30.8)</td>
</tr>
<tr>
<td>291.0 (88.7)</td>
<td>17.5 (5.3)</td>
</tr>
<tr>
<td>274.5 (83.4)</td>
<td>32.0 (9.8)</td>
</tr>
<tr>
<td>241.5 (73.6)</td>
<td>4.0 (1.2)</td>
</tr>
<tr>
<td>237.5 (72.4)</td>
<td>85.5 (26.1)</td>
</tr>
<tr>
<td>152.0 (46.3)</td>
<td>21.0 (6.4)</td>
</tr>
<tr>
<td>131.0 (39.9)</td>
<td>2.5 (.8)</td>
</tr>
<tr>
<td>128.5 (39.2)</td>
<td>17.0 (5.2)</td>
</tr>
<tr>
<td>111.5 (34.0)</td>
<td>7.5 (2.3)</td>
</tr>
</tbody>
</table>

**WINGATE SANDSTONE**
(not measured)

**CHINLE FORMATION**

- Partially covered, siltstone, reddish-brown.
- Sandstone, pale red to light gray, generally fine-grained, conglomerate lenses present, trough cross-bedded and ripple laminated, moderate sorting.
- Partially covered, siltstone, reddish-brown.
- Siltstone, orange-red, calcareous cement, indistinct bedding.
- Partially covered, siltstone reddish-orange.
- Sandstone, pale-red, very fine-grained.
- Conglomerate, orange-brown to reddish-brown, pebbles up to 10 cm, crude horizontal stratification.
- Partially covered, siltstone, brownish-red.
- Sandstone, pale red (5R 6/2), fine-grained, moderately well sorted, subrounded, calcareous cement, horizontal to low-angle trough cross-bedding, composed of quartz, white mica, green and dark accessory minerals.
104.0 3.0 Partially covered, siltstone, greenish-gray.
(31.7) (0.9)

101.0 23.0 Sandstone, yellowish-gray (5Y 7/2), moderately well sorted, fine- to very fine-grained, subrounded, composed of quartz, mica and colored accessory minerals, calcareous cement, horizontally stratified with abundant ripple marks with some organic debris, sharp basal contact.
(30.8) (7.0)

78.0 66.0 Partially covered, siltstone, greenish-gray, some very fine-grained sandstone beds.
(23.8) (20.1)

12.0 12.0 Conglomerate, grayish-yellow, pebbles up to 20 cm, abundant plant debris, horizontal and trough cross-bedded, calcareous cement, basal contact is sharp.
(3.7) (3.7)

392.0 Total Chinle Formation.
(119.5)

CUTLER FORMATION
(not measured)
Section 11: LITTLE VALLEY

Location: Section measured in T30S, R24E, Sec. 30, on northwest side of Little Valley.

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>131.0 (39.9)</td>
<td>15.0 (4.6)</td>
<td>CHINLE FORMATION (Upper portion not measured)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially covered, sandstone, pale red, very fine-grained, contains green accessory minerals, trough cross-bedded.</td>
</tr>
<tr>
<td>116.0 (35.4)</td>
<td>9.0 (2.7)</td>
<td>Conglomerate, grayish-brown, pebbles average about 1 cm, horizontally bedded, gastropod found within unit, well cemented with calcite.</td>
</tr>
<tr>
<td>107.0 (32.6)</td>
<td>10.5 (3.2)</td>
<td>Partially covered, siltstone and fine-grained sandstone, sharp contacts.</td>
</tr>
<tr>
<td>96.5 (29.4)</td>
<td>10.0 (3.1)</td>
<td>Sandstone, light gray (N7), very fine-grained, well sorted, abundant micas, well cemented with calcite, horizontally rippled, laminated.</td>
</tr>
<tr>
<td>86.5 (26.4)</td>
<td>38.5 (11.3)</td>
<td>Partially covered, siltstone, greenish-gray to purplish-red.</td>
</tr>
<tr>
<td>48.0 (14.6)</td>
<td>5.0 (1.5)</td>
<td>Sandstone, gray, basal 1 foot is poorly sorted, contains clay clasts, average grain size is coarse, horizontally bedded, rest of unit is fine-grained, subrounded, ripple marked.</td>
</tr>
<tr>
<td>43.0 (13.1)</td>
<td>42.5 (12.9)</td>
<td>Partially covered, siltstone, greenish-gray.</td>
</tr>
<tr>
<td>0.5 (.2)</td>
<td>0.5 (.2)</td>
<td>Sandstone, buff, very fine-grained, moderately well sorted, subrounded, very porous, poorly cemented with calcite.</td>
</tr>
<tr>
<td>131.0 (40.0)</td>
<td>Total Chinle Formation.</td>
<td>CUTLER FORMATION (not measured)</td>
</tr>
</tbody>
</table>
Section 12: LITTLE VALLEY

Location: Section measured in T30S, R24E, Sec. 30, on east side of Little Valley.

<table>
<thead>
<tr>
<th>Total Thickness</th>
<th>Interval Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft. (m)</td>
<td>ft. (m)</td>
</tr>
<tr>
<td>107.0 (32.6)</td>
<td>3.0 (.9)</td>
</tr>
<tr>
<td>104.0 (31.7)</td>
<td>2.0 (.6)</td>
</tr>
<tr>
<td>102.0 (31.1)</td>
<td>56.0 (17.1)</td>
</tr>
<tr>
<td>46.0 (14.0)</td>
<td>3.5 (2.6)</td>
</tr>
<tr>
<td>37.5 (11.4)</td>
<td>21.0 (6.4)</td>
</tr>
<tr>
<td>16.5 (5.0)</td>
<td>4.0 (1.2)</td>
</tr>
</tbody>
</table>

CHINLE FORMATION
(Upper portion not measured)

Sandstone, grayish-yellow, fine-grained, well sorted, subrounded, calcareous cement, trough cross-bedded, gradational basal contact.

Conglomerate, light gray, horizontally bedded, contains pebbles up to 4 cm.

Partially covered, siltstone, grayish-green to purple, some very fine-grained sandstones present.

Sandstone, light gray, lower 1 foot is horizontally stratified conglomerate, rest of section is composed of fine- to very fine-grained sandstone, calcareous cement, contains organic debris, ripple laminated sets and trough cross-bedding.

Partially covered, siltstone, grayish-green.

Sandstone, light gray, fine-grained, subrounded, moderately well sorted, local lenses of conglomerate present, calcareous cement, horizontally bedded and ripple laminated, clay clasts present; the lower contact of this ledge-forming unit is gradational.
|   |   |  
|---|---|---|
| 12.5 | 5.5 | Conglomerate, light gray, abundant yellow staining due to limonite, lower part of unit contains pebbles up to 2 cm, grades upwards to very coarse-grained, calcareous cement, abundant plant debris, horizontally stratified, ledge former. |
| (3.8) | (1.7) |  
| 7.0 | 5.0 | Partially covered, siltstone, greenish-red, some sandstone lenses. |
| (2.1) | (1.5) |  

---

105.0   
(32.0)   

Total Chinle Formation.

**CUTLER FORMATION**
(Only upper 2 feet measured)

|   |   |  
|---|---|---|
| 2.0 | 2.0 | Sandstone, reddish-orange (10R 6/6), fine-grained, subrounded, calcareous cement. |
| (.6) | (.6) |  

Section 13: WOODS RANCH

Location: Section measured in T30S, R25E, Sec. 33, about 2 miles west of Woods Ranch.

<table>
<thead>
<tr>
<th>Total Thickness</th>
<th>Interval Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft.</td>
<td>ft.</td>
</tr>
<tr>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>397.5</td>
<td>87.0</td>
</tr>
<tr>
<td>(121.2)</td>
<td>(26.5)</td>
</tr>
<tr>
<td><strong>WINGATE SANDSTONE</strong></td>
<td></td>
</tr>
<tr>
<td>(not measured)</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>310.5</td>
<td>30.0</td>
</tr>
<tr>
<td>(94.7)</td>
<td>(9.2)</td>
</tr>
<tr>
<td>Sandstone, pale red, very fine-grained, well sorted, subrounded, contains about 5% colored accessory minerals, mainly ripple laminated, sharp basal contact, several siltstone lenses.</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>280.5</td>
<td>216.0</td>
</tr>
<tr>
<td>(85.5)</td>
<td>(65.9)</td>
</tr>
<tr>
<td>Partially covered, siltstone with small sandstone lenses, color change about midway from grayish-green to reddish-orange, sandstone units are ripple laminated.</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>64.5</td>
<td>3.0</td>
</tr>
<tr>
<td>(19.7)</td>
<td>(.9)</td>
</tr>
<tr>
<td>Sandstone, pale red, very fine-grained, moderately well sorted, subrounded, calcareous cement, ripple laminated.</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>61.5</td>
<td>8.0</td>
</tr>
<tr>
<td>(18.8)</td>
<td>(2.4)</td>
</tr>
<tr>
<td>Sandstone, greenish-gray, very fine-grained, moderately well sorted, subrounded, about 10% mica, calcareous cement, ripple laminated, sharp basal contact.</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>53.5</td>
<td>5.5</td>
</tr>
<tr>
<td>(16.3)</td>
<td>(1.7)</td>
</tr>
<tr>
<td>Sandstone interbedded with siltstone, green-gray to pale red, small lenses of conglomerate present, sands are very fine-grained, horizontally stratified, conglomerate contains clay clasts.</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>48.0</td>
<td>Partially covered, siltstone, greenish-gray, some conglomerate lenses present.</td>
</tr>
<tr>
<td>(14.6)</td>
<td></td>
</tr>
<tr>
<td>397.5</td>
<td>Total Chinle Formation.</td>
</tr>
<tr>
<td>(121.2)</td>
<td></td>
</tr>
</tbody>
</table>

**CUTLER FORMATION**
(not measured)
### Section 14: WOODS RANCH

Location: Section measured in T30S, R25E, Sec. 34 about 1 mile west of Woods Ranch

<table>
<thead>
<tr>
<th>Total Thickness ft. (m)</th>
<th>Interval Thickness ft. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>193.0 (58.8)</td>
<td>38.0 (11.6)</td>
</tr>
<tr>
<td></td>
<td><strong>CHINLE FORMATION</strong></td>
</tr>
<tr>
<td></td>
<td>(Upper portion not measured)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, pale red, very fine-grained, moderately well sorted, subrounded, composed of 5% dark and 5% green accessory minerals, calcareous cement, some siltstone lenses, plant debris present, base is ripple laminated with small-scale trough cross-bedding, upper part is rippled with large-scale trough cross-bedding.</td>
</tr>
<tr>
<td>155.0 (47.3)</td>
<td>44.0 (13.4)</td>
</tr>
<tr>
<td></td>
<td>Partially covered, siltstone, greenish-gray.</td>
</tr>
<tr>
<td>111.0 (33.8)</td>
<td>1.5 (.5)</td>
</tr>
<tr>
<td></td>
<td>Conglomerate, gray, pebbles up to 6 inches, plant debris present.</td>
</tr>
<tr>
<td>109.5 (33.4)</td>
<td>2.0 (.6)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, light gray, very fine-grained, well cemented with calcite, possible root structures.</td>
</tr>
<tr>
<td>107.5 (32.8)</td>
<td>85.5 (26.1)</td>
</tr>
<tr>
<td></td>
<td>Partially covered, siltstones, greenish-gray, contains abundant plant debris.</td>
</tr>
<tr>
<td>22.0 (6.7)</td>
<td>10.0 (3.1)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, light gray, grain size ranges from very fine- to very coarse-grained, generally subrounded, well cemented with calcite, abundant plant debris, trough cross-bedding present, basal contact sharp.</td>
</tr>
<tr>
<td>12.0 (3.7)</td>
<td>12.0 (3.7)</td>
</tr>
<tr>
<td></td>
<td>Sandstone, white, fine- to very fine-grained, well sorted, subrounded, porous, calcareous cement, horizontally bedded.</td>
</tr>
</tbody>
</table>

---

193.0 (58.8) Total Chinle Formation.

**CUTLER FORMATION**

(not measured)
Section 15: WOODS RANCH

Location: Section measured in T30S, R24E, Sec. 35, about 1/2 mile southwest of Woods Ranch.

<table>
<thead>
<tr>
<th>Total Thickness (ft.)</th>
<th>Interval Thickness (ft.)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>385.5</td>
<td>230.0</td>
<td>WINGATE SANDSTONE (not measured)</td>
</tr>
<tr>
<td>(117.5)</td>
<td>(70.1)</td>
<td></td>
</tr>
<tr>
<td>155.5</td>
<td>24.5</td>
<td>CHINLE FORMATION</td>
</tr>
<tr>
<td>(47.4)</td>
<td>(7.5)</td>
<td>Partially covered, siltstone, reddish-brown, some sandstone lenses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sandstone, light gray to pale red, well sorted, subrounded, 15% colored accessory minerals, trough cross-bedded to ripple laminated, some horizontally bedded conglomerate at base, calcareous cement.</td>
</tr>
<tr>
<td>131.0</td>
<td>125.0</td>
<td></td>
</tr>
<tr>
<td>(39.9)</td>
<td>(38.1)</td>
<td>Partially covered, siltstone, greenish-gray, some sandstone lenses.</td>
</tr>
<tr>
<td>6.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>(1.8)</td>
<td>(1.8)</td>
<td>Partially covered, sandstone, very fine-grained, subrounded, calcareous cement, some plant debris, ripple laminated, composed of dark accessory minerals, micas.</td>
</tr>
</tbody>
</table>

385.5 (117.5) Total Chinle Formation.

CUTLER FORMATION (not measured)
APPENDIX II

RIB DESCRIPTION FROM RIO ALGOM MINE
RIB DESCRIPTION -- RIO ALGOM MINE  
(Descriptions are from roof down)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Thickness (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>(20.3)</td>
<td>Mudstone, green, sharp basal contact.</td>
</tr>
<tr>
<td>47</td>
<td>(119.4)</td>
<td>Sandstone, some green mudstone and conglomerate zones, conglomerate contains clay clasts up to 3 inches, sandstone medium-grained.</td>
</tr>
<tr>
<td>3</td>
<td>(7.6)</td>
<td>Mudstone.</td>
</tr>
<tr>
<td>12</td>
<td>(30.5)</td>
<td>Sandstone, fine-grained.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total rib height.</td>
</tr>
<tr>
<td>A-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>(63.5)</td>
<td>Mudstone pebble conglomerate, gradation basal contact, some carbonaceous debris present.</td>
</tr>
<tr>
<td>12</td>
<td>(30.5)</td>
<td>Siltstone, greenish-gray, with some sandstone.</td>
</tr>
<tr>
<td>32</td>
<td>(81.3)</td>
<td>Conglomerate grading up to siltstone.</td>
</tr>
<tr>
<td>1</td>
<td>(2.54)</td>
<td>Siltstone, red, Cutler Formation?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total rib height.</td>
</tr>
</tbody>
</table>
A-3

7
(17.8)
Conglomerate.

24
(61.0)
Sandstone, reddish-purple, very fine-grain.

7
(17.8)
Siltstone at base grading upwards to pebble conglomerate.

11
(27.9)
Sandstone interbedded with siltstone, gray, horizontally bedded.

16
(40.6)
Sandstone, very fine-grained.

65
(165.1)
Total rib height.

B

12
(30.5)
Mudstone pebble conglomerate, fine- to medium-grained matrix, sharp base.

51
(129.5)
Siltstone interbedded with very fine-grained sandstone.

63
(160.0)
Total rib height

C

2
(5.1)
Mudstone pebble conglomerate in roof.

35
(88.9)
Sandstone, medium- to fine-grained, sharp base.

40
(101.6)
Siltstone with some mudstone, gray, conglomerate zone near base.

77
(195.6)
Total rib height.
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>58 (147.3)</td>
<td>Sandstone, very fine-grained, mainly ripple laminated with some small sets of tabular cross-bedding.</td>
</tr>
<tr>
<td>5 (12.7)</td>
<td>Mudstone pebble conglomerate, horizontally bedded.</td>
</tr>
<tr>
<td>1 (2.54)</td>
<td>Clay drape.</td>
</tr>
<tr>
<td>6 (15.2)</td>
<td>Sandstone, very fine-grained, sharp basal contact.</td>
</tr>
<tr>
<td>30 (76.2)</td>
<td>Siltstone to mudstone, gray.</td>
</tr>
<tr>
<td>100 (254.0)</td>
<td>Total rib height.</td>
</tr>
<tr>
<td>50 (127.0)</td>
<td>Conglomerate with sandstone, red.</td>
</tr>
<tr>
<td>4 (10.2)</td>
<td>Sandstone, very fine-grained, red.</td>
</tr>
<tr>
<td>8 (20.3)</td>
<td>Sandstone to siltstone, red.</td>
</tr>
<tr>
<td>10 (25.4)</td>
<td>Siltstone with mudstone, gray.</td>
</tr>
<tr>
<td>72 (182.9)</td>
<td>Total rib height.</td>
</tr>
<tr>
<td>18 (45.7)</td>
<td>Sandstone, pinkish-red, fine-grained, some clay clasts present, scour base.</td>
</tr>
<tr>
<td>19 (48.3)</td>
<td>Siltstone, with some sandstone lenses.</td>
</tr>
</tbody>
</table>
21
(53.5)  Sandstone, red, medium-grained, some lenses of flat pebble conglomerate.

2
(5.1)  Mudstone, clay drape.

3
(7.6)  Conglomerate, reddish-maroon.

1
(2.54)  Mudstone.

4
(10.2)  Conglomerate, red.

3
(7.6)  Siltstone, red, Cutler Formation?

71
(180.3)  Total rib height.

G

15
(38.1)  Sandstone and conglomerate, reddish-pink, abundant plant debris, sharp base.

33
(83.8)  Siltstone and mudstone, greenish-gray.

5
(12.7)  Mudstone and siltstone, greenish-gray.

53
(134.6)  Total rib height.

H

24
(60.9)  Mudstone, gray, sharp base.

43
(109.2)  Sandstone and conglomerate, reddish-gray.

6
(15.2)  Siltstone and mudstone.
10
(25.4) Sandstone, red.

83
(210.8) Total rib height.

I

28
(71.1) Flat pebble conglomerate, abundant wood fragments, calcite crystals fill fractures, gradational contact at base.

27
(68.6) Sandstone, fine-grained.

10
(25.4) Siltstone and mudstone.

65
(165.1) Total rib height.

J

10
(25.4) Sandstone and conglomerate, red.

50
(127.0) Siltstone.

14
(35.6) Sandstone, gray.

74
(187.9) Total rib height.

K

40
(101.6) Sandstone contains abundant clay clasts.

2
(5.1) Mudstone.
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Sandstone, maroon.</td>
</tr>
<tr>
<td>88</td>
<td>Total rib height.</td>
</tr>
<tr>
<td>15</td>
<td>Sandstone interbedded with siltstone, some mudstone present, basal contact is gradational.</td>
</tr>
<tr>
<td>24</td>
<td>Siltstone, green, sharp basal contact.</td>
</tr>
<tr>
<td>34</td>
<td>Sandstone, reddish-maroon, contains clay clasts.</td>
</tr>
<tr>
<td>73</td>
<td>Total rib height.</td>
</tr>
<tr>
<td>10</td>
<td>Siltstone, scour base.</td>
</tr>
<tr>
<td>2</td>
<td>Mudstone, green, sharp basal contact.</td>
</tr>
<tr>
<td>60</td>
<td>Sandstone, gray, contains abundant clay clasts.</td>
</tr>
<tr>
<td>72</td>
<td>Total rib height.</td>
</tr>
<tr>
<td>26</td>
<td>Green siltstone interbedded with red sandstone.</td>
</tr>
<tr>
<td>10</td>
<td>Conglomerate, composed of red mudstone pebbles and green mudstone pebbles, sandstone lenses present.</td>
</tr>
</tbody>
</table>
59
(149.9)

Siltstone, green.

95
(241.3)

Total rib height.

32
(81.3)

Siltstone, gray-green, some mudstone.

13
(33.0)

Sandstone, reddish-maroon, fine-grained.

40
(101.6)

Siltstone, gray, some mudstone.

85
(215.9)

Total rib height.

10
(25.4)

Siltstone, some mudstone, sharp contact at base.

8
(20.3)

Conglomerate, greenish-red, abundant clay clasts and plant debris.

7
(17.8)

Sandstone, red, tabular cross-bedding, scour base.

61
(154.9)

Siltstone, green.

86
(218.4)

Total rib height.

11
(27.9)

Sandstone, with flat pebble conglomerate.

10
(25.4)

Siltstone and mudstone, green, gradational base.
8 (20.3) Sandstone, red, clay clasts present, sharp base.
40 (101.6) Siltstone, gray.

69 (175.3) Total rib height.

R
14 (35.6) Conglomerate composed of numerous mudstone and siltstone pebbles, basal 1 foot is mudstone, large fossil tree present.
14 (35.6) Sandstone, pinkish-red, numerous clay clasts and rounded quartz pebbles, sharp base.
23 (58.4) Siltstone, green, sharp base.
11 (27.9) Conglomerate with red siltstone pebbles, bottom contact sharp.
25 (63.5) Siltstone, greenish-gray.

87 (221.0) Total rib height.

S
12 (30.5) Siltstone, greenish-gray, abundant organic debris.
2 (5.1) Mudstone, green.
43 (109.2) Sandstone, red, lower 28 inches are mainly conglomerate composed of green mudstone pebbles.
20 (50.8) Siltstone, green.

77 (195.6) Total rib height.
6 (15.2)  Siltstone, green.

25 (63.5)  Sandstone, purple, sharp basal contact.

26 (66.0)  Siltstone, green.

57 (144.8)  Total rib height.

35 (88.9)  Sandstone, reddish-brown, conglomerate composed of red and green siltstone pebbles, abundant plant debris.

15 (38.1)  Siltstone, green.

0.5 (1.27)  Claystone, green.

38 (96.5)  Siltstone, green.

88.5 (224.8)  Total rib height.

7 (17.8)  Siltstone.

5.5 (13.9)  Sandstone, very fine-grained.

7 (17.8)  Sandstone, very fine-grained, siltstone present.

1.5 (3.8)  Claystone.
44
(111.8) Sandstone, reddish-pink, abundant organics.

11
(27.9) Siltstone, green.

76
(193.0) Total rib height.

25
(63.6) Siltstone.

7
(17.8) Mudstone, green, with mudstone and conglomerate.

8
(20.3) Sandstone and siltstone, horizontally bedded, gradational basal contact.

22
(55.9) Sandstone, reddish-pink.

1
(2.54) Claystone.

21
(53.3) Sandstone, reddish-pink.

9
(22.9) Siltstone, sandstone with some mudstone.

8
(20.3) Sandstone, red.

126
(320.0) Total rib height.

30
(76.2) Sandstone, conglomerate at base.

58
(147.3) Sandstone interbedded with siltstone.

88
(223.5) Total rib height.