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Depositional Environments of the Uranium bearing Cutler Formations, Lisbon Valley, Utah

by

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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ABSTRACT

The Cutler Formation in Lisbon Valley, San Juan County, Utah, is composed predominantly of fluvial arkosic sandstones, siltstones, shales, and mudstones that were deposited by meandering streams that flowed across a flood plain and tidal flat close to sea level. Two types of channel deposits are recognized from their sedimentary structures: meandering and distributary. The flood plain was occasionally transgressed by a shallow sea from the west, resulting in the deposition of several thin limestones and marine sandstones. The marine sandstones were deposited as longshore bars. Wind transported sand along the shoreline of the shallow sea, forming a coastal dune field. Marine sandstones and eolian sandstones are more common in the upper Cutler in the southern part of the area, whereas in the central and northern part of the area the formation is predominantly fluvial. Crossbed orientation indicates that Cutler streams flowed S. 67^{o} W. on the the average, whereas marine currents moved sediment S. 36^{o} E. and N. 24^{o} W., and wind transported sand S. 80^{o} E.

The uranium in the Cutler is found in the central and northern part of the area, in the upper part of the formation, in small fluvial sandstone bodies that were deposited predominantly in a distributary environment. No uranium is known in the marine or eolian sandstones. Petrographically, the uranium-bearing sandstones are identical to other Cutler fluvial sandstones except that they contain less calcite and more clay and are slightly coarser grained. Ore formation has modified the host sandstones very little.

INTRODUCTION

The Lisbon Valley uranium district has produced about 2.4 million pounds of U_3O_8 as of 1975 (Chenoweth, p. 256) from the Permian Cutler Formation. Mining of ore has continued through 1977. This production and the high potential for further uranium occurrences in the Uncompahgre (Paradox) Basin (Campbell and Steele, 1976, p. 24) prompted this detailed study of host rock depositional environments.

Location

The district is located 35 miles southeast of Moab in the northeastern corner of San Juan County, Utah. It can be reached by following U.S. Highway 163 (marked 160 on many highway maps) from Moab to La Sal Junction, turning east on State Highway 46 and going 7 miles, turning south on an unmarked paved county road and traveling 8 miles to Lisbon Valley (fig. 1).

Purpose

The purpose of this study was to detail the sedimentary depositional environments of Cutler rocks and relate these environments to uranium occurrences. A better understanding of the uranium occurrences, some new ideas on ore guides for prospecting, and the location of new areas for prospecting are the goals of this research. In addition, an estimation of uranium resources in Permian rocks in the Uncompahgre Basin will be made after study of the entire basin.

Three stratigraphic sections in the Lisbon Valley area (fig. 1) were measured, described, and sampled for this study. The stratigraphic sections measured were chosen for exposure and completeness of outcrops (fig. 1). Emphasis was on sedimentary structures and petrology of Cutler rocks. Section data are shown on Plates 1, 2, and 3 in the pocket at the end of the report.

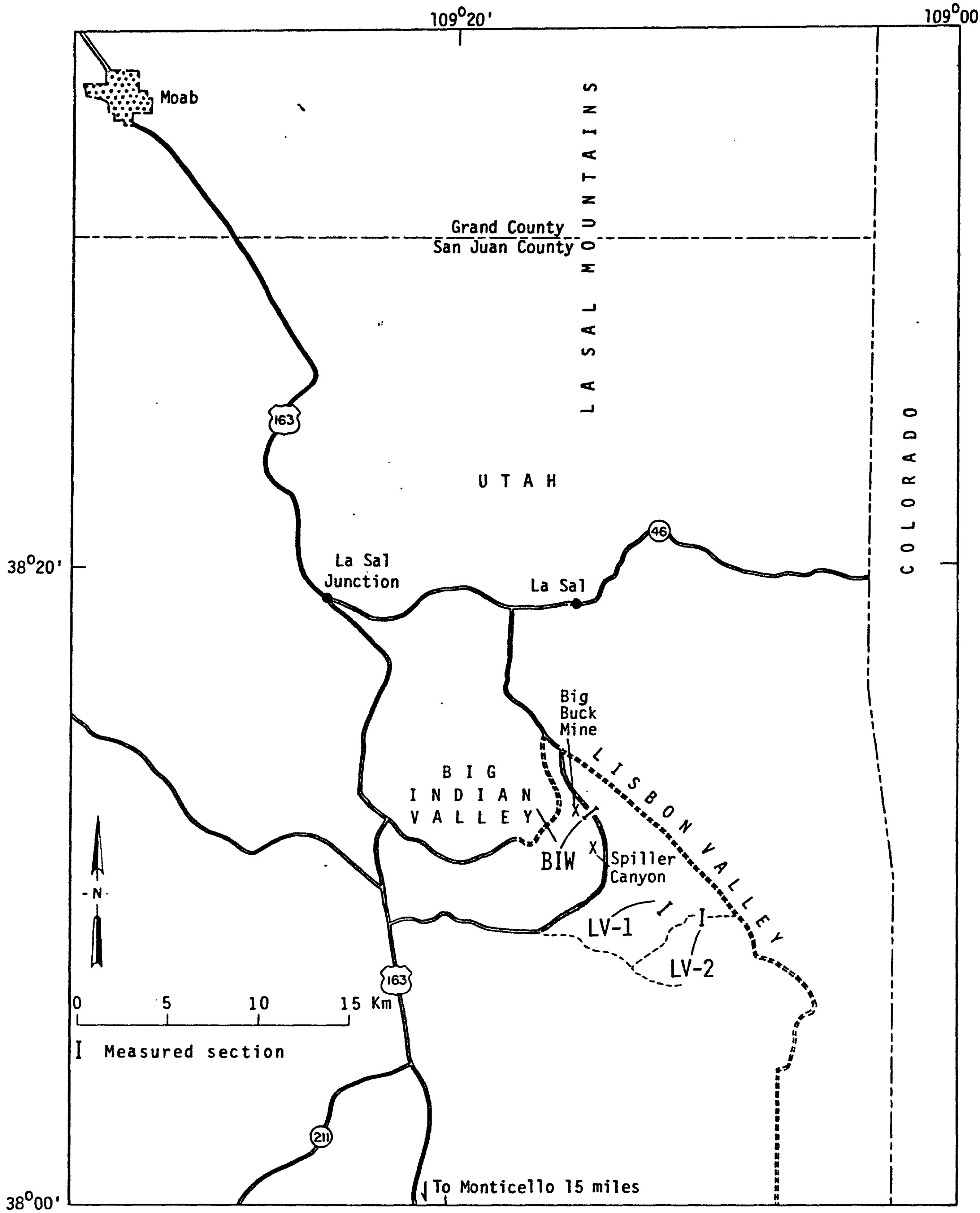


Figure 1.--Index map showing location of Lisbon Valley uranium district, measured sections, Spillar Canyon, and Big Buck mine.

Geologic setting

Lisbon Valley is one of a number of northwest-southeast-trending salt anticlines in eastern Utah and southwestern Colorado (fig. 2). Solution of salt, subsequent collapse, followed by erosion of the anticlines has exposed rocks ranging in age from Pennsylvanian to Jurassic. The Lisbon Valley salt anticline is cut lengthwise by the Lisbon Valley fault so that the Paleozoic rocks crop out only on the southwest flanks.

The structural trend in the Cutler along the southwest flank is slightly different from that of the overlying Chinle. The dip of the Cutler is steeper and the dip direction more to the south than that of the Chinle, indicating pre-Chinle structural movement. The absence of the Triassic Moenkopi Formation could be due either to nondeposition, or to removal after deposition caused by uplift of the anticline prior to deposition of the Chinle.

STRATIGRAPHY

The Permian rocks in the Lisbon Valley salt anticline have been previously mapped as "Cutler Formation undifferentiated" (Williams, 1964). Other subdivisions of Permian rocks recognized elsewhere in the Moab area, including the Rico Formation, have not been used or mapped in Lisbon Valley. Lithologies representing facies of the other subdivisions are present in parts of the valley, but no new mappable units are suggested in this report.

The age of the Cutler Formation in Lisbon Valley is probably entirely Wolfcampian. Both Baars (1962, p. 154) and McKee and others (1967, table 1) state that the Cutler is principally Wolfcampian but the upper part may be Leonardian. The upper part of the Cutler in the Lisbon Valley area has been removed by erosion.

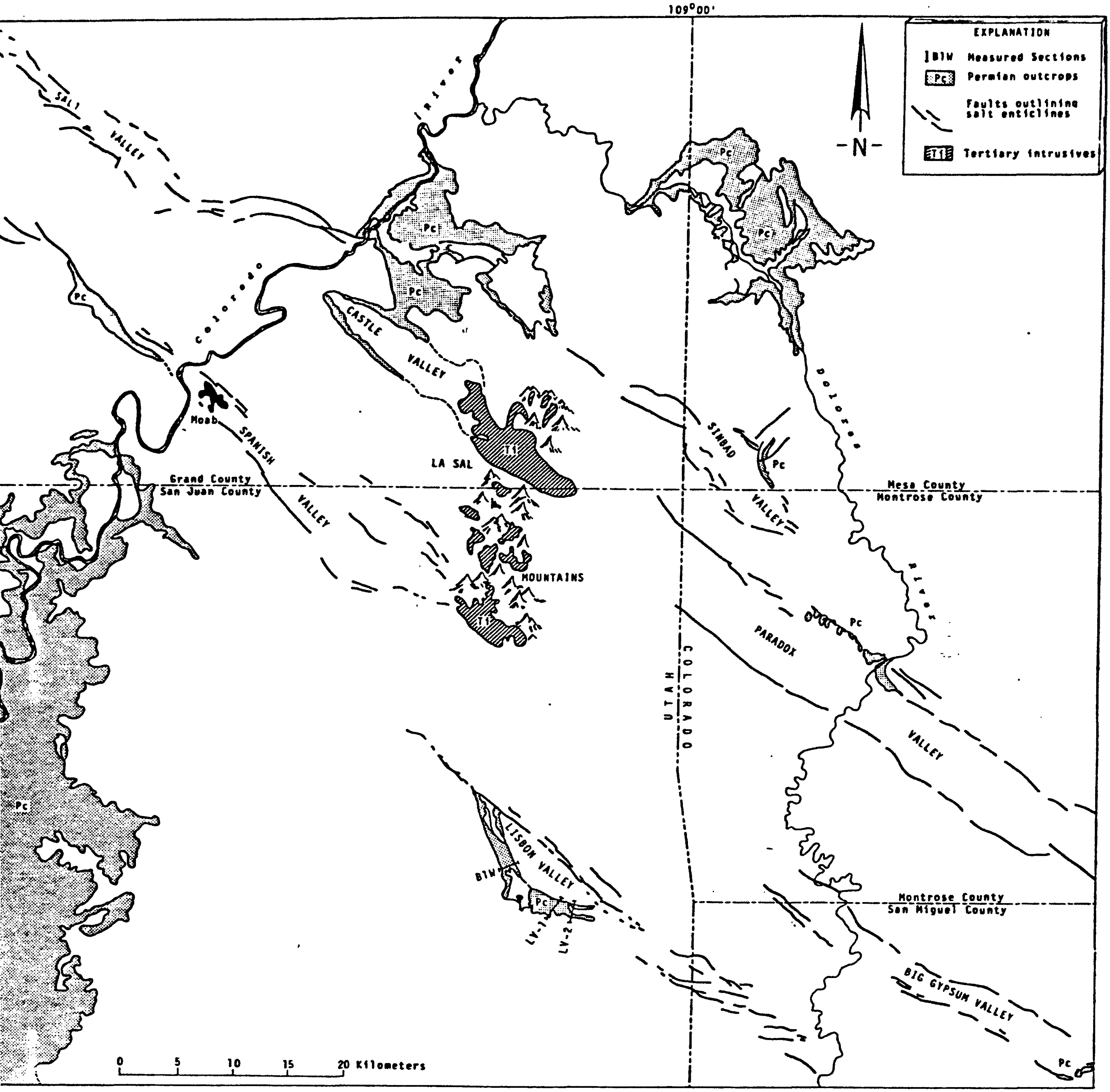


Figure 2.--Regional geologic setting of the Lisbon Valley uranium district.

LITHOLOGIES

Plates 1, 2, and 3 show the measured sections and the major lithologies that make up each section. Red sandstones and shales, siltstones and mudstones that were deposited in a number of different environments, and a few limestone beds that are largely marine are the dominant lithologies in the Cutler. Sand-shale ratios range from 1:2 to 1:4; thus the fine-grained rocks are much more abundant than coarse-grained sandstones. Limestones makeup less than 1 percent of the sections.

The arkosic sandstones of the Cutler Formation were deposited in three principal environments: fluvial, eolian, and marine. The criteria used for making the determination of paleoenvironments were sedimentary structures, petrology, fossils, rock sequences, and associations.

Fluvial sandstones

The purple-red fluvial sandstones occur in large lenticular bodies that are hundreds of meters long and range in thickness from less than 1 m to over 25 m. Poor lateral exposure prevented better descriptions of sandstone body geometry. Laterally these lenses thin and grade into the shale, mudstone, and siltstone sequences. Upper contacts where visible are gradational into the overlying shale, mudstone, and siltstones, whereas basal contacts are sharp.

Sedimentary structures

The most common type of sedimentary structure in Cutler fluvial sandstones is trough cross stratification. Some horizontal stratification and minor tabular cross stratification are also present. Trough crossbeds are found in all the fluvial sandstones, whereas horizontal stratification occurs in about 20 percent and tabular crossbeds in about 14 percent of the fluvial sandstones. Trough cross strata range in size from 2 to 3 m thick, 6 to 10 m wide, and tens of meters long; to 10 to 20 cm thick, a meter wide, and several meters long. In about one-third of the sandstones the large trough crossbeds are present in the lower part of the sand body, with the size of the troughs gradationally becoming smaller upward; in another one-third of the sandstones there is no apparent difference in size of the troughs from bottom to top of the sand body; and in the remaining third the larger troughs may be in the middle or at the top of the body.

The horizontal stratification occurs in zones 1 to 2 m thick, some with good current lineation. These structures occur randomly at various horizons throughout the sand bodies. The tabular cross stratification occurs in beds one-half to 1 m thick, most frequently in the lower one-half to one-third of the sand body. Crossbedding directions were obtained principally from measurements of the long axis of trough cross stratification, but also from current lineation and tabular foresets, and are shown on figure 3.

Additional sedimentary structures found in the fluvial sandstones include slump structures and occasional ripple marks. Convolute bedding produced by slumping of wet sand is common in many sandstones, whereas ripple marks and ripple crossbedding are rare. A few of the finer grained sandstones contain ripple marks, and some 1-3 cm thick tabular ripple crossbedding is present at the top of a few of the coarser grained sandstones.

Petrography

The petrography of Cutler Formation sandstones, as determined from thin section studies, is summarized on table 1. The fluvial sandstones are composed of subequal amounts of quartz, feldspar, and rock fragments. The feldspar is predominately microcline with minor amounts of plagioclase and untwinned feldspar. The rock fragments are mainly polycrystalline quartz or quartz with microcline or mica. These rock fragments are the most abundant constituent and were judged to be of igneous origin. Fragments with similar

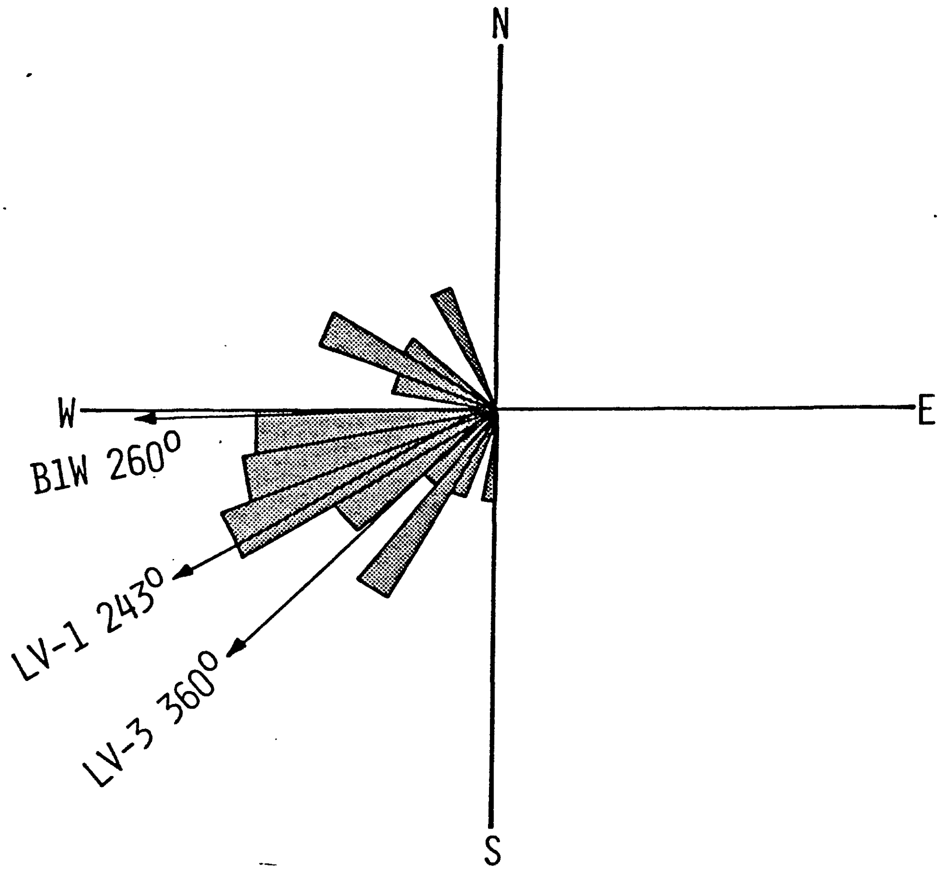


Figure 3.--Crossbedding directions in fluvial sandstones of the Cutler Formation, Lisbon Valley, Utah. Based on 404 measurements.

Table 1.—Petrography of sandstones in the Cutler Formation, Lisbon Valley, Utah

Sample Information		Composition								Texture					
Sample no.	Location in section (m above base)	Quartz (%)	Feldspars (%)	Rock fragments (%)	Mica (%)	Carbonate cement (%)	Matrix (%)	Accessory minerals (%)	Fossil fragments (* means present)	Mean grain size (mm)	Maximum grain size (mm)	Mean roundness	Standard deviation (mm)	Environment of deposition	Classification modified from Folk, 1974
BIW-1	4.5	36.	36.	20.	2.	2.	1.	1.	--	.32	.67	--	.174	Fluvial...	Arkose.......
BIW-2	12.5	48.	33.	9.	--	--	7.	1.	--	.24	.69	--	.011	Fluvial...	Arkose.......
BIW-3	19.	30.	24.	33.	1.	11.	--	--	--	.36	1.06	--	.223	Fluvial...	Arkose.......
BIW-4	31.	29.	25.	27.	1.	5.	9.	4.	--	.52	2.35	--	.375	Fluvial...	Arkose.......
BIW-5	34.5	38.	24.	18.	8.	--	7.	5.	--	.24	1.11	--	.184	Fluvial...	Arkose.......
BIW-6	58.5	27.	17.	23.	--	34.	--	--	--	.36	1.02	--	.166	Fluvial...	Arkose.......
BIW-7	69.5	36.	18.	42.	1.	--	--	3.	--	.31	1.30	--	.172	Fluvial...	Arkose.......
BIW-8	80.	39.	23.	22.	4.	2.	5.	5.	--	.27	.96	--	.146	Fluvial...	Arkose.......
BIW-9	85.	25.	28.	22.	2.	23.	--	--	--	.44	1.39	--	.198	Fluvial...	Arkose.......
BIW-10	93.	37.	31.	24.	7.	1.	1.	--	--	.16	.83	.47	.099	Fluvial...	Arkose.......
BIW-12	141.	19.	21.	30.	5.	23.	1.	1.	--	.74	3.17	--	.610	Fluvial...	Lithio arkose.
BIW-13	167.	38.	27.	29.	1.	2.	3.	1.	--	.50	1.48	--	.295	Fluvial...	Arkose.......
BIW-18	286.	45.	21.	16.	8.	--	3.	6.	--	.16	.74	--	.987	Fluvial...	Arkose.......
BIW-19	320.	30.	20.	41.	1.	--	8.	--	--	.71	8.30	--	.790	Fluvial...	Arkose.......
BIW-22	362.	37.	22.	17.	3.	17.	1.	3.	--	.35	1.11	--	.213	Fluvial...	Arkose.......
BIW-24	388.	36.	13.	8.	1.	37.	4.	2.	--	.29	.77	.47	.153	Fluvial...	Arkose.......
BIW-25	435.	34.	25.	37.	1.	--	--	3.	--	.63	3.76	.51	.404	Fluvial...	Arkose.......
BIW-26	507.5	75.	10.	1.	3.	8.	3.	--	--	.10	.32	--	.048	Eolian....	Subarkose....
BIW-27	527.	28.	21.	10.	1.	33.	2.	6.	--	.19	1.09	--	.113	Fluvial...	Arkose.......
BIW-28	537.	59.	9.	11.	--	9.	11.	1.	--	.15	.41	.66	.077	Eolian....	Arkose.......
BIW-29	549.	68.	13.	11.	--	--	7.	1.	--	.19	.65	.69	.113	Eolian....	Arkose.......
LV1-1	12.	33.	22.	19.	2.	15.	10.	--	--	.42	1.14	--	.261	Fluvial...	Lithic arkose.
LV1-2	42.	33.	19.	24.	3.	1.	18.	1.	--	.37	1.11	--	.247	Fluvial...	Arkose.......
LV1-2a	42.	30.	18.	22.	1.	10.	17.	1.	--	.43	1.09	--	.296	Fluvial...	Lithic arkose.
LV1-3	102.	28.	22.	20.	2.	28.	1.	--	--	.51	1.36	--	.237	Fluvial...	Arkose.......
LV1-4	144.	30.	14.	12.	4.	7.	31.	3.	--	.24	.81	--	.187	Fluvial...	Lithic arkose.
LV1-5	213.	39.	27.	24.	6.	--	--	4.	--	.34	3.79	--	.201	Fluvial...	Arkose.......
LV1-8	271.	16.	18.	47.	--	13.	3.	--	--	.81	2.09	.51	.522	Fluvial...	Lithic arkose.
LV1-10	310.	58.	9.	13.	--	15.	4.	1.	*	.11	.54	--	.062	Marine....	Lithic arkose.
LV1-15	367.5	55.	4.	6.	2.	30.	--	3.	*	.13	.33	--	.071	Marine....	Subarkose....
LV1-16	381.	52.	7.	9.	--	31.	--	--	--	.13	.44	.52	.054	Eolian....	Subarkose....
LV1-17	411.5	23.	17.	34.	--	22.	4.	--	--	.48	2.09	.46	.238	Fluvial...	Lithic arkose.
LV1-18	422.	66.	13.	8.	--	12.	--	1.	--	.17	.49	.67	.076	Eolian....	Subarkose....
LV1-19	431.5	55.	2.	11.	2.	27.	2.	1.	--	.11	.56	.67	.076	Eolian....	Subarkose....
LV1-20	435.	66.	--	15.	1.	1.	--	1.	*	.16	.45	.58	.084	Marine....	Subarkose....
LV1-21	442.5	69.	3.	3.	1.	23.	--	1.	*	.14	.71	.60	.073	Marine....	Subarkose....
LV1-22	460.	48.	2.	8.	--	40.	1.	1.	*	.14	.49	.62	.062	Marine....	Subarkose....
LV2-1	7.	31.	32.	34.	3.	--	--	--	--	.51	1.67	--	.254	Fluvial...	Arkose.......
LV2-2	41.	26.	19.	35.	--	14.	5.	--	--	1.00	2.44	.51	.543	Fluvial...	Arkose.......
LV2-3	108.	34.	29.	31.	3.	--	--	1.	--	.50	1.68	.48	.262	Fluvial...	Arkose.......
LV2-4	167.5	40.	29.	22.	3.	--	5.	1.	--	.52	2.30	--	.245	Fluvial...	Arkose.......
LV2-5	206.5	33.	14.	11.	--	27.	15.	--	--	.33	4.61	--	.630	Fluvial...	Arkose.......
LV2-7	257.5	69.	1.	5.	1.	23.	--	1.	--	.11	.30	.67	.047	Fluvial...	Subarkose....
LV2-9	312.	19.	13.	30.	2.	36.	--	1.	--	.85	2.44	--	.468	Fluvial...	Arkose.......
LV2-10	324.	67.	3.	13.	2.	12.	--	1.	--	.13	.43	.68	.078	Marine....	Subarkose....
LV2-12	349.	36.	3.	14.	1.	46.	--	1.	*	.15	.62	.67	.105	Marine....	Arkose.......
LV2-13	375.	58.	6.	10.	2.	21.	3.	1.	*	.10	.39	.61	.055	Marine....	Subarkose....
LV2-14	386.	28.	24.	12.	3.	30.	2.	--	--	.26	1.14	.43	.161	Fluvial...	Arkose.......
LV2-15	426.	54.	3.	5.	--	35.	--	2.	*	.13	.37	--	.076	Marine....	Subarkose....
LV2-16	447.	59.	7.	9.	1.	22.	--	1.	*	.12	.27	--	.067	Marine....	Subarkose....
LV2-17	478.	53.	4.	17.	--	24.	1.	1.	--	.14	.49	.73	.062	Eolian....	Arkose.......
LV2-18	488.	55.	9.	15.	1.	24.	2.	--	--	.14	.52	.72	.085	Eolian....	Arkose.......
LV2-19	501.	21.	22.	44.	--	6.	6.	--	--	1.13	4.34	--	.775	Fluvial...	Arkose.......
LV2-20	520.5	69.	4.	8.	--	22.	--	2.	--	.14	.41	.64	.070	Marine....	Subarkose....

compositions but with sutured contacts between crystals or notable schistosity were classified as metamorphic in origin. Rounded grains of shale, mudstone, and siltstone constitute the least abundant types of rock fragment present.

Minor constituents include mica (both muscovite and biotite) and accessory minerals. The accessory minerals include black opaques, chert grains, zircon, tourmaline, and apatite, in order of decreasing abundance. The black opaques are predominantly magnetite, usually altered to hematite. In some samples the black opaques are flakes of biotite that have been altered to hematite.

The cementing agent in the Cutler fluvial sandstones is either calcite or secondary overgrowths on the quartz grains. Some samples have both. A clay matrix as binding agent was present in a few samples. The porosity as determined from thin sections ranges from 1 to 18 percent for the fluvial sandstones but averages about 4 percent.

The sandstones were classified following a modified version of the scheme proposed by Folk (1974). The modification consisted of combining igneous rock fragments, including polycrystalline quartz of igneous origin, with the feldspars and combining polycrystalline quartz of metamorphic origin with the lithic fragments. The fluvial sandstones are predominantly arkosic with some lithic arkoses or subarkoses (fig. 11). The lithic arkoses contain more rock fragments than arkose, whereas the subarkoses have less feldspar than arkose.

The mean and maximum grain size of the fluvial sandstones as determined from thin-section analysis is shown in table 1. Variation in grain size in the measured sections, as determined from both thin sections and field observations, is shown on plates 1, 2, and 3. The overall mean grain size is 0.4 mm, with 40 percent of the samples having means greater than 0.5 mm; thus these sandstones are medium to coarse grained. Of the sandstone sequences, 35 percent are coarser grained at the base and fine upward, 21 percent are fine grained at the base and become coarser upward, and 44 percent are about the same grain size at the base and top (Plates 1, 2 and 3).

Zones in the fluvial sandstone sequences are conglomeratic. The conglomeratic zones are generally associated with the base of the sequence or with the larger scale trough cross stratification. The clasts in the conglomeratic zones range from 1 to 40 cm in maximum diameter; however, clasts from 1 to 3 cm are most common. The largest clasts are found at the base of sandstone sequences where channeling has occurred and are intraclasts of siltstone, mudstone, or shale. These intraformational clasts are produced by bank erosion. Other clasts at the base of the sandstones are rounded igneous and metamorphic rock fragments which reach a maximum size of about 12 cm but average 2 to 3 cm.

Marine sandstones

Sedimentary structures

The marine sandstones are light colored, often white, and occur in tabular bodies from 1 to about 5 m thick. Basal contacts of these bodies are sharp and flat; upper contacts are sharp and range from flat to convex upward in bar-like buildups. Crossbedding is of the tabular type in units approximately 0.5 m thick. Some of these bodies may have several crossbedded units with the crossbeds dipping in the opposite directions, while others are structureless. Crossbedding directions for the marine sandstones are shown on figure 4.

Petrography

The marine sandstones are composed of the same major constituents as the fluvial sandstones; quartz, feldspar, and rock fragments (table 1). The compositional difference between the fluvial and marine sandstones is in the

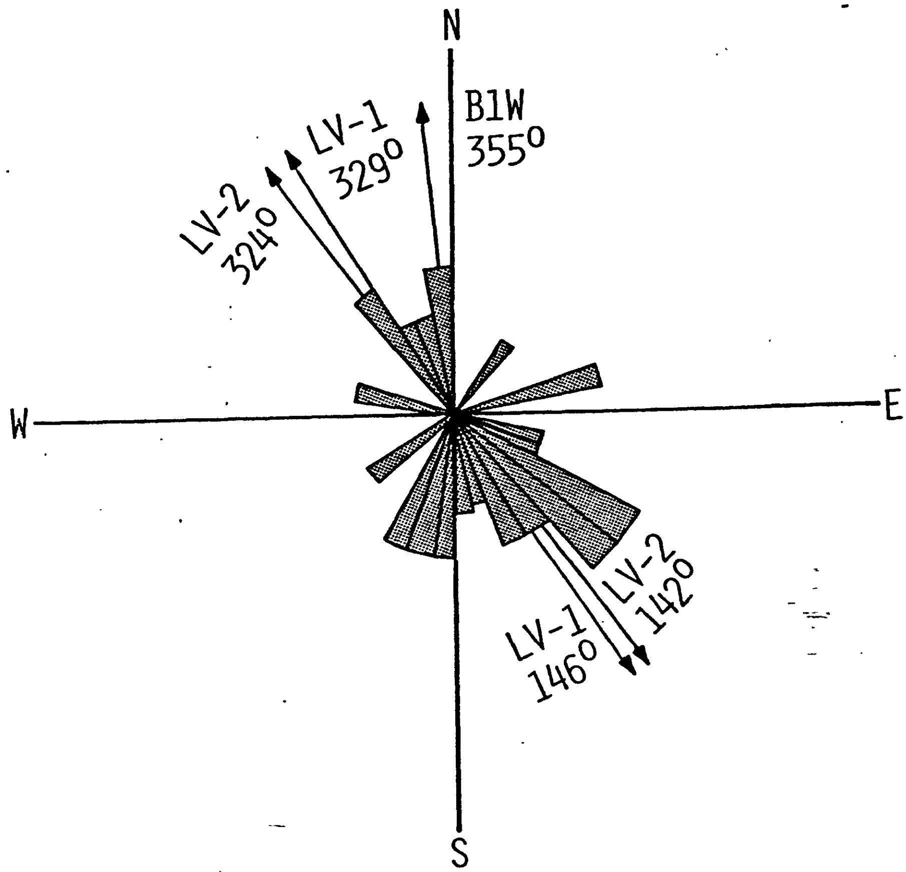


Figure 4.--Crossbedding directions in marine sandstones of the Cutler Formation, Lisbon Valley, Utah. Based on 142 measurements.

amounts of these constituents. The marine sandstones have only one-eighth to one-tenth as much feldspar and about one-third as many rock fragments as the fluvial ones. Terrigenous sedimentary rock fragments are absent; metamorphic rock fragments range in abundance from less than 1 to 3 percent; and igneous rock fragments range in abundance from 2 to 10 percent. Intraclastic limestone rock fragments are present in these marine sandstones in amounts from less than 1 to 4 percent.

Minor constituents include mica, tourmaline, apatite, zircon, and chert. In addition to these constituents, fragments of fossils are present in these sandstones. Fragments of brachiopods, bryozoans, and echinodermata were noted, as well as some oolites.

These sandstones are cemented with calcite; although a few samples contain a small percentage of matrix. Porsity in these rocks ranges from zero to 10 percent but averages about 4 percent.

Subarkose is the dominant rock type, and sublitharenite is the second most common type in these sandstones. Reworking of arkosic sands in a marine environment would reduce the amount of rock fragments and feldspar and produce these rock types.

The overall mean grain size for the marine sandstones is 0.13 mm, and they range from 0.10 to 0.16 mm; thus they are fine-grained to very fine grained sandstones. The standard deviation of the grain sizes (table 1) is 0.1 or less, and thus these sandstones are much better sorted than the fluvial sandstones, which average about 0.3.

Eolian Sandstones

Sedimentary structures

The orange-red to buff colored eolian sandstones in Lisbon Valley occur in laterally continuous tabular bodies. These beds range from 5 to 20 m thick but thicken and thin laterally. The basal contact is flat and sharp, whereas the upper contact is sharp but irregular laterally over distances of 100 m or more.

The most common sedimentary structures in these eolian sandstones are large-scale, 1- to 3-m-thick, tabular crossbeds. Dips of these crossbeds range from 10^{0} to 40^{0} and average about 25^{0}. About 40 percent of the crossbeds measured dip between 25^{0} and 35^{0}, and 48 percent dip between 15^{0} and 25^{0}. Crossbedding directions are shown on figure 5.

In addition to the large-scale crossbedding, other sedimentary structures which support an eolian origin for these sandstones are present. These minor but important structures include high-index ripples developed on foreset bedding surfaces, lag deposits, inverse-graded bedding in ripple laminations, avalanche structures on foreset bedding, and raindrop impressions.

Petrography

The eolian sandstones are composed of the same major constituents as both the fluvial and marine sandstones (table 1), with the amounts of quartz, feldspar, and rock fragments being very similar to those in the marine sandstones. The amounts of feldspar and rock fragments are less than in the fluvial sandstones. Both terrigenous sedimentary and metamorphic rock fragments are absent in half of the samples studied. Several samples contain 1-3 percent limestone fragments similar to those noted in the marine sandstones.

The minor constituents include mica, zircon, apatite and tourmaline. The amount of mica present is much less than in either the marine or fluvial sandstones. The cementing agent is predominantly calcite, as it is in the marine sandstones. The porosity is higher than in either the fluvial or marine sandstones, averaging 6.5 percent.

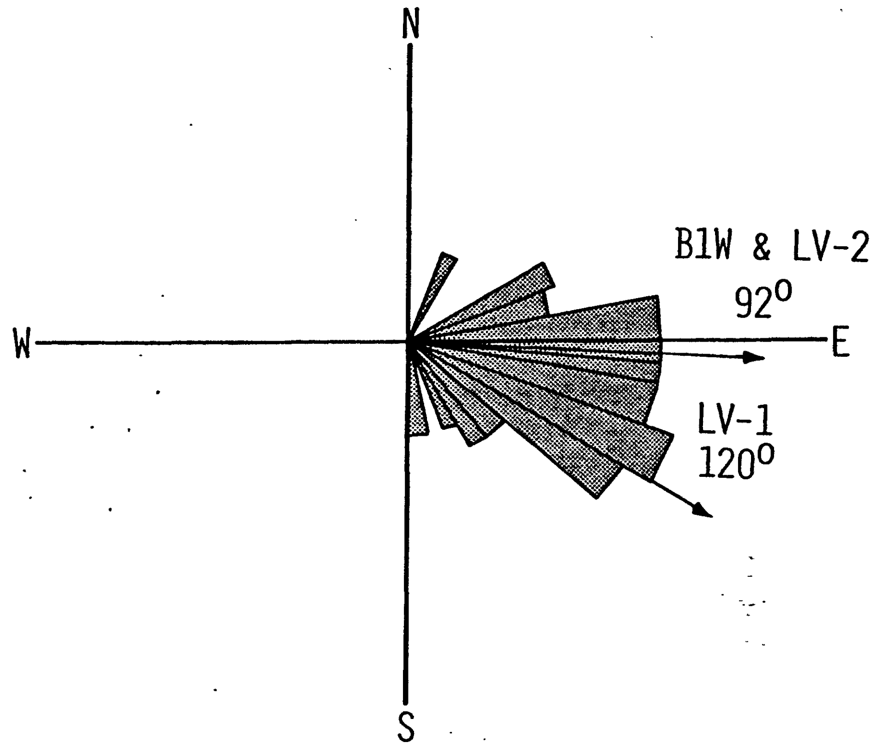


Figure 5.--Crossbedding directions in eolian sandstones of the Cutler Formation, Lisbon Valley, Utah. Based on 55 measurements.

Table 2.--Petrography of limestones in the Cutler Formation, Lisbon Valley, Utah

Sample information		Composition (* means present)										
Sample no.	Location in section (m above base)	Intraclasts	Oolites	Pellets	Fossils	Micrite	Spar	Chert	Quartz	Feldspar	Rock fragments	Classification (Folk, 1959)
BIW-11	130.5	*	*	--	*	*	*	--	*	*	--	Biomicrite...
BIW-14	173.	*	*	--	*	--	*	--	*	*	*	Biosparite...
BIW-15	173.5	*	--	--	*	--	*	--	*	*	--	Biosparite...
BIW-16	173.5	*	--	--	*	--	*	--	*	*	--	Biosparite...
BIW-17	167.5	*	--	*	*	*	--	--	*	--	--	Micrite......
BIW-21	248.5	*	--	*	*	*	--	--	*	*	--	Pelmicrite...
BIW-23	372.5	--	--	*	*	*	*	--	*	--	--	Micrite......
LV1-6	230.	*	--	*	--	*	*	*	*	--	--	Micrite......
LV1-7	251.	--	--	*	*	*	*	--	*	--	--	Biomicrite...
LV1-9	297.5	*	--	*	--	*	*	--	*	--	--	Pelmicrite...
LV1-11	316.5	--	--	--	*	--	*	*	--	--	--	Chert replacing spar replacing fossils.
LV1-12	317.	--	--	--	--	--	*	*	--	--	--	Chert replacing spar.
LV1-13	321.5	--	*	*	*	*	*	--	--	--	--	Pelmicrite...
LV1-14	324.5	--	--	*	*	*	*	--	--	--	--	Biomicrite...
LV2-6	220.5	*	--	--	*	*	*	--	*	--	--	Micrite......
LV2-8	260.5	*	--	*	*	*	*	--	*	*	--	Intramicrite.
LV2-11	344.	*	--	*	*	*	*	--	*	--	--	Pelmicrite...

These eolian sandstones are classified as arkose, lithic arkose, subarkose, or sublitharenite. The variety of rock types reflects a greater variation in mineralogy in the eolian sandstones than in either fluvial or marine sandstones.

The overall mean grain size for the eolian sandstones is 0.15 mm, but the grains range from 0.11 to 0.17 mm; the standard deviation is 0.08. The eolian sandstones are a little better sorted than the marine sandstones, but are about the same grain size (table 1).

Limestones

Limestones make up a very small part of the Cutler in Lisbon Valley. They occur in the lower half of the Cutler interbedded with fluvial sandstones and in the upper half associated with the marine sandstones. The lower limestones are perhaps tongues of the Elephant Canyon Formation, also mapped as Rico by many workers, and the upper limestones are a part of the marine facies of the Cedar Mesa Sandstone.

The gray to red limestones are tabular to lenticular beds that range in thickness from less than 10 cm to about 2 m. Thin lenticular beds commonly are covered and can be found only in float. They commonly show little internal sedimentary structure although a few are horizontally laminated and one bed contains tabular crossbedding.

The limestones contain a variety of constituents (table 2) including fossils, intraclasts, oolites, pellets, and detrital material ranging in size from coarse silt to very fine sand, in a micrite matrix or calcite spar cement. The detrital material composes from less than 1 percent to about 8 percent in amount, and consists of quartz, feldspar (largely microcline), a few rock fragments, and mica flakes. In order of decreasing abundance, fossils include echinoderm fragments, bryozoan and or brachiopod fragments, and mollusca (largely gastropod fragments). Evidence of burrowing is present in a number of the thin sections studied.

The limestones were classified following the scheme proposed by Folk (1959). These limestones are largely biomicrites or biosparites with a few intramicrites, pelmicrites, or micrites.

Shales, siltstones, and mudstones

The bright brick-red shales, mudstones, and siltstones are 2 to 4 times more abundant than the sandstones and have an average sand-shale ratio of 1:3. These rocks are more easily eroded than the sandstones and are generally covered with soil and float. Sedimentary structures useful for environmental intrepretation are not prevalent, and the general depositional environment of these rocks was determined by their association with fluvial sandstone and marine sandstone and limestone (plates 1, 2, and 3).

The fluvial shales, mudstones, and siltstones are associated with the fluvial sandstones. The siltstones often contain trough crossbedding which indicates current directions similar to those of the fluvial sandstones. In addition, asymmetrical ripple marks, mudcracks, and varves are found in these lithologies. These rocks were deposited in overbank-channel, floodplain, natural levee, and lacustrine environments. Orange-red siltstones found in the upper portions of the Cutler associated with the fluvial sequences may have been deposited as small eolian dunes on the floodplain.

The marine shales, mudstones, and siltstones are associated with marine sandstone and limestone. Tabular to trough type crossbeds occur in the siltstones and have paleocurrent directions similar to those found in the marine sandstones. Symmetrical ripples and horizontal burrows are also found in these rocks. These rocks were deposited in shallow nearshore and tidal-flat environments.

DEPOSITIONAL ENVIRONMENTS

Experimental flume studies, studies of modern sedimentary environments, and detailed examination of rock sequences have greatly improved the determination of paleoenvironments. Primary sedimentary structures and stratification sequences are especially useful in determining paleo-fluvial sequences. Two excellent works, Harms and others (1975) and Miall (1977), have summarized these developments. In this study, paleoenvironmental interpretations of the fluvial sequences and the methods used are based largely on these reports.

Development of models from stratification sequences using nonparametric statistics is discussed by both Harms and others (1975, p. 69) and Miall (1977, p. 3). The method suggested by Harms and others is based on chi-square contingency analysis, wherein a calculated expected frequency is compared to the actual frequency. The method suggested by Miall involves embedded Markov chain analysis, in which a calculated random probability is compared to the actual probability. Both methods allow for testing the null hypothesis that the vertical succession of sedimentary structures was derived by random processes by using the chi-square test. Both methods of building models were tested in this study and found to give identical results. The chi-square method is easier to calculate and to interpret and is recommended for any future model building.

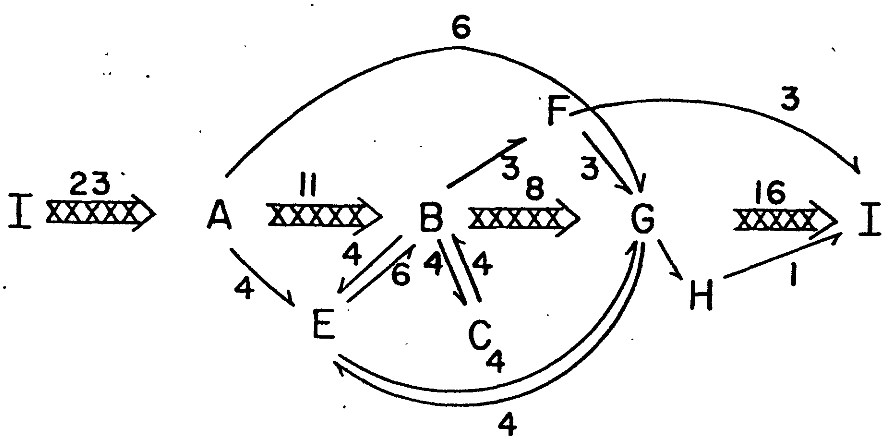
Fluvial Environments

Examination of the fluvial sandstone bodies and the sequences of sedimentary structures in these bodies (plates 1, 2, and 3) indicates two types based on size. The larger bodies consist of thick, coarse-grained sandstones that display a high degree of variability of grain size and contain large sedimentary structures. The sequence of sedimentary structures varies greatly, and they commonly contain coarse material such as clay clasts at the bottom of the sequence. The thinner sandstone bodies consist of finer, more uniform grains and have a more uniform size and sequence of sedimentary structures. The smaller sandstone bodies occur predominantly in the upper half of each section, whereas the larger bodies occur in the lower half. A fluvial model was developed for each of these types.

The first model (fig. 7) is for the larger sandstone bodies and was synthesized from 29 sequences with 105 transitions from one type of sedimentary structure to another. The facies relationship diagram and a list of the facies transitions are shown on figure 6. The second model for the sequence (fig. 9) was developed from 21 different bodies with a total of 76 facies transitions (fig. 8).

The two models are similar, differing only in thickness and size of sedimentary structures. Both compare well with the generalized model for meandering stream deposits developed by Allen (1970) and the more specific model for the meandering Wabash River described by Jackson (1976). The larger sandstone bodies in the Cutler are associated only with fluvial deposits, whereas the smaller sequences are associated with marine sandstones and limestones. Marine fossil fragments are found in some of these smaller fluvial sequences (plates 2 and 3). These associations suggest that the smaller sequences may be meandering distributary deposits formed by streams flowing across tidal mud flats.

To obtain some idea of what the streams were like that made the Cutler deposits, estimates of the paleohydrology were calculated following the formulas presented by Schumm (1972). The results are shown in table 3. Widths and depths were estimated from 60 sandstone sequences and averaged for each type of meandering deposit. At best these data can be considered only



Transitions for meandering fluvial sequences from
- I. Horizontally bedded lenticular siltstone, shale, or mudstone and very fine grained sandstone to
- A. Coarser grained channel sandstone often with clay clasts and erosional base, to (or with)
- B. Large trough cross stratification, to
- E. Horizontally laminated sandstone, or to
- C. Tabular-planar cross stratification, to
- F. Convolute bedding (slumping), to
- G. Small trough cross stratification, to
- H. Horizontal ripple lamination, to
- I. Horizontally bedded lenticular siltstone, shale or mudstone and very fine grained sandstone.

Figure 6.--Facies relationship diagram with list of transitions for large meandering fluvial sequences in the Cutler Formation. Based on 105 transitions studied in 29 sequences. Numbers show how many transitions of each type were found.

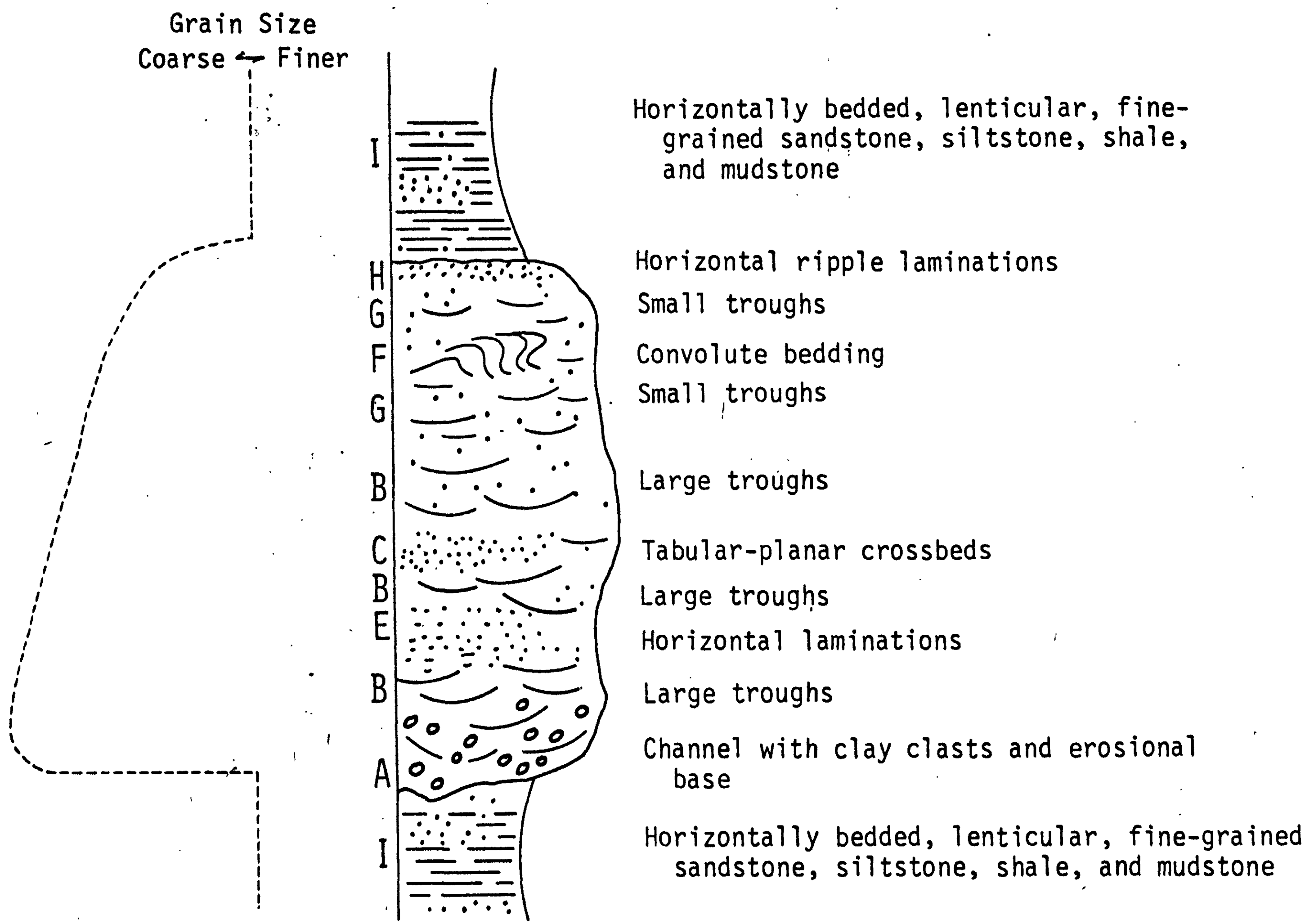
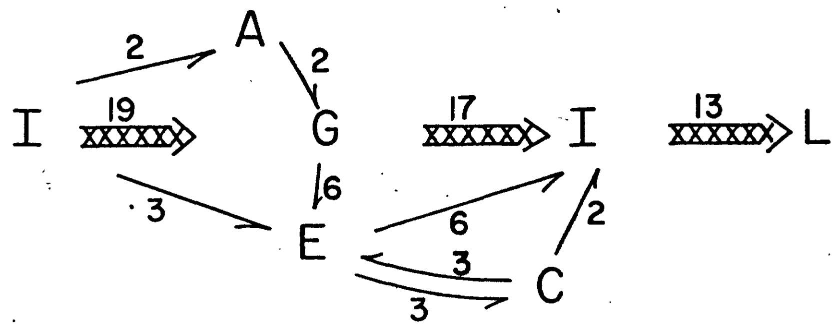


Figure 7.--Model for large meandering fluvial sequences in the Cutler Formation. Based on facies relationships shown in figure 6.



Transitions for meandering distributary sequences from

I. Horizontally bedded siltstone, shale, or mudstone to
A. Coarser grained channel sandstone with sharp basal contact and a few clay clasts or
G. Small trough cross stratification in sandstone with sharp basal contact, to
E. Horizontally laminated sandstone and (or)
C. Tabular-planar cross stratification, to
I. Horizontally bedded siltstone, shale, or mudstone, to
L. Marine sandstone or limestone.

Figure 8.--Facies relationship diagram with list of transitions for small meandering fluvial sequences in the Cutler Formation. Based on 76 transitions studied in 21 sequences. Numbers show how many transitions of each type were found.

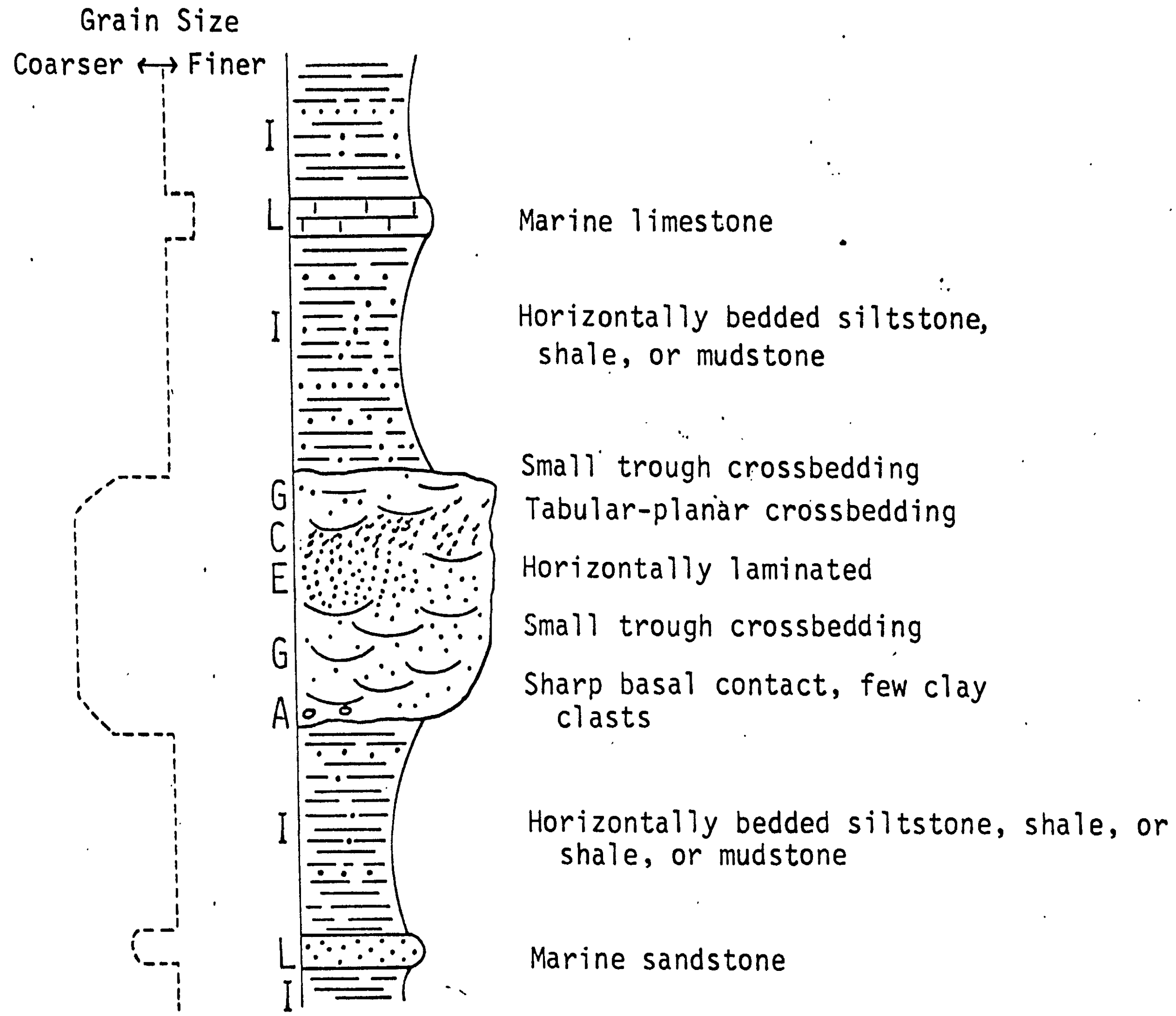


Figure 9.--Model for small meandering fluvial sequences in the Cutler Formation. Based on facies relationships shown in figure 8.

Table 3.--Summary of paleohydrology of streams that deposited the Cutler Formation.

[Calculated following the methods outlined by Schumm (1972).]

Parameters	Meandering streams	Distributary streams
Average depth...............	9.0 m	4.3 m
Average width...............	49.0 m	26.9 m
Width-depth ratio...........	5	6
Meander wavelength..........	431.0 m	312.3 m
Stream gradient.............	0.18 m/km	0.39 m/km
Mean annual flood...........	438.0 m^3/sec	150.8 m^3/sec
Mean annual discharge.......	59.7 m^3/sec	11.1 m^3/sec
Velocity of flood discharge	1.42 m/sec	1.97 m/sec
Sinuosity...................	2.3	2.2
Valley gradient.............	0.42 m/km	0.83 m/km

estimates or "ball-park" figures. If correct, an average Cutler stream that flowed across the Lisbon Valley district was about the size of the present-day San Juan River of southern Utah.

Marine Environments

The marine sandstones and limestones were deposited in shallow, warm, nearshore environments. The petrography of the sandstones indicates reworking, and the crossbedding directions suggest longshore currents as a possible agent. A buildup of sand into bar geometry was found in a number of these sandstones; thus some of these sandstones were probably deposited as longshore bars. The 1-m-thick, horizontal, parallel-laminated sandstone at the base of the prominent eolian sandstone near the top of the measured sections (plates 1, 2, and 3) may be a beach deposit similar to those described by Dickinson and others (1972), which are directly overlain by eolian deposits.

The limestones contain appreciable amounts of lime mud and thus must have been deposited in relatively quiet water. Inasmuch as detrital material is neither very abundant nor very coarse in these limestones, the sites of deposition were remote or protected from the influx of sediment. A few of the limestones show the effects of reworking, including crossbedding, and some contain oolites suggesting some current activity. The limestones were deposited in a shallow, quiet to moderately agitated, warm marine environment.

Eolian Environments

The eolian sandstones in the Lisbon Valley area are closely associated with marine sediments. The thin-section studies revealed that carbonate fragments are present in some of these sandstones. These carbonate grains, largely lime-mud fragments, probably had a local origin. The suggested depositional environment for these sandstones is coastal dune field, similar to those described by Dickinson and others (1972, p. 195) along the Gulf Coast. The crossbedding directions (fig. 5) suggest that onshore wind movement was dominant in forming these dunes. McBride and Hayes (1962) noted an onshore mean direction in their study of crossbedding in the dune fields of Mustang Island, Texas. Slump structures similar to those described by McKee and Bigarella (1972) in the Brazilian coastal dunes are also found in the Cutler eolian deposits.

URANIUM-VANADIUM OCCURRENCES

Uranium has been mined from the upper part of the Cutler Formation in the central and northern part of the Lisbon Valley district along Big Indian Wash. The major producing zones in the Cutler occur about 30 to 40 m stratigraphically below the Permian-Triassic uncomformity, and about 300 to 500 m updip and northeast of the eastern limit of the Triassic Chinle ore belt (Chenoweth, 1975, p. 256). Additional orebodies occur in the Cutler at various locations where the Chinle ore belt is in direct contact with the underlying Cutler sandstones (Chenoweth, 1975, p. 256). This study has concentrated on the first type of occurrence, and in the central part of the area. Samples were taken from two prospects in Spillar Cañyon (fig. 1) and from Atlas Mineral's Big Buck Mine.

The ore zones are in bleached fluvial arkosic sandstones associated with marine and eolian sandstones (fig. 10). This association and the sedimentary structures in the sandstones indicate that they are fluvial-distributary in origin. Trends of the crossbedding and of the orebodies are in the same range as shown for the fluvial sandstones on figure 3. Ore is in discontinuous tabular zones which are located at the base, at the top, or close to pinchouts of the sandstone bodies. Ore grade drops toward the middle of the sandstone bodies. Vertical joints that intersect ore and surrounding country rock are also mineralized.

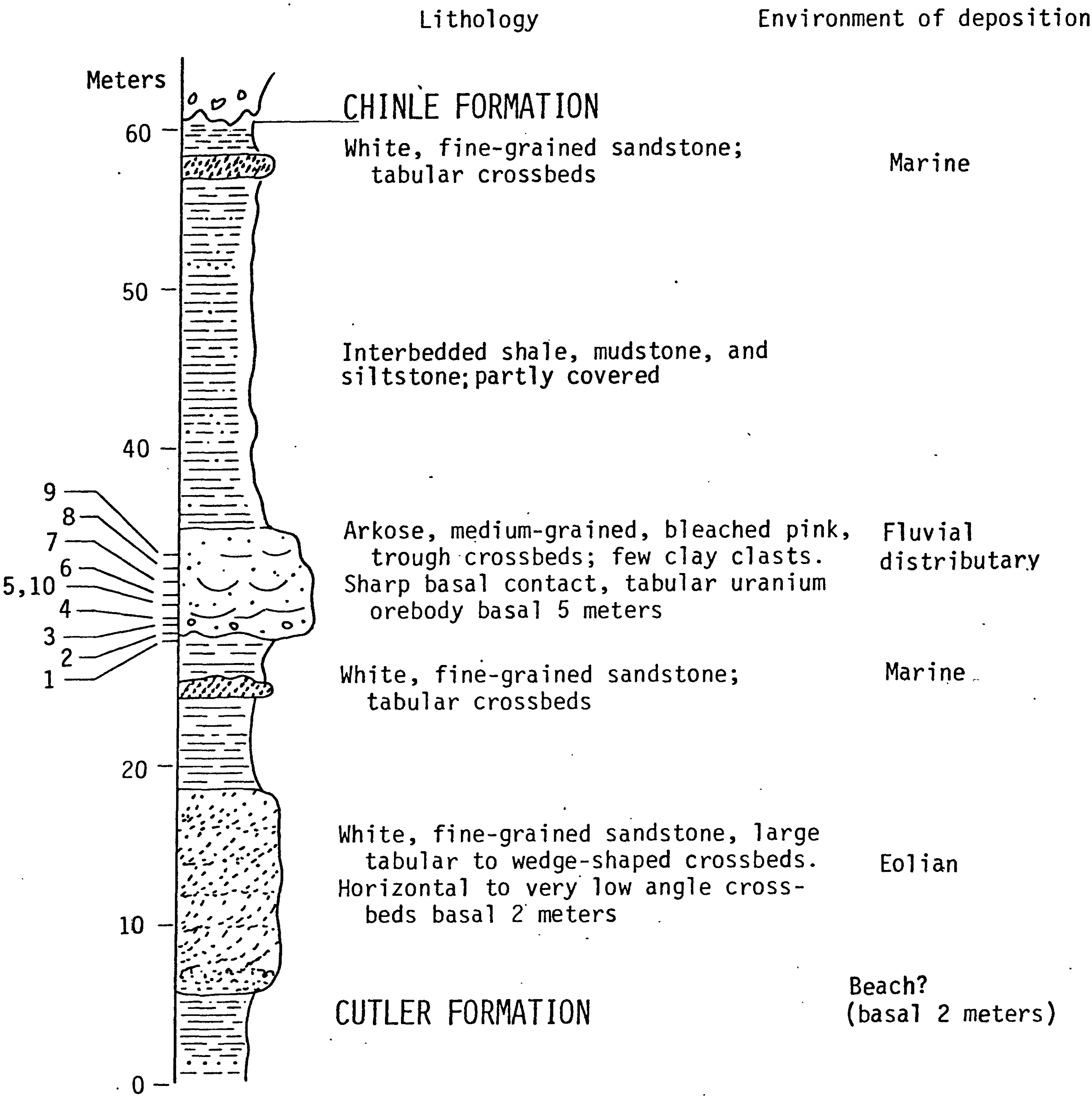


Figure 10.--Partial stratigraphic section for Spillar Canyon, Utah. Small numbers are sample locations across the tabular uranium orebody.

The petrology of the sandstone from the ore zones is shown in table 4 and on figure 11. Comparison of data from table 4 with table 1 and the classifications shown on figure 11 indicates the similarity of the ore-bearing sandstones and to the smaller fluvial sandstones. The difference between these sandstones is shown in table 5. The ore sandstones contain less carbonate cement, but more clay matrix, and are slightly coarser grained than the average Cutler fluvial sandstones (table 5).

SUMMARY AND CONCLUSIONS

The Cutler Formation in the Lisbon Valley area is composed of predominantly fluvial arkosic sandstones and shales that were deposited by meandering streams that flowed across a flood plain and tidal flat close to sea level. Two types of channel deposits are recognized on the basis of sedimentary structures: meandering and distributary. The flood plain was occasionally transgressed by a shallow sea from the west, resulting in the deposition of several thin limestones and a number of marine sandstones. The marine sandstones were deposited as longshore bars. Wind transported sand along the shore line, forming a coastal dune field. Marine sandstones and eolian sandstones are more common in the upper part of the Cutler in the southern part of the area, whereas in the central and northern part of the area the formation is predominantly fluvial.

The uranium in the Cutler is found in the central and northern part of the area in fluvial arkosic sandstones that were deposited predominantly in a distributary environment. No uranium is known in the marine or eolian sandstones. The uranium-bearing sandstones are petrologically very similar to other Cutler fluvial sandstones but contain less calcite and more clay and are slightly coarser grained. Ore formation has modified the host sandstones very little.

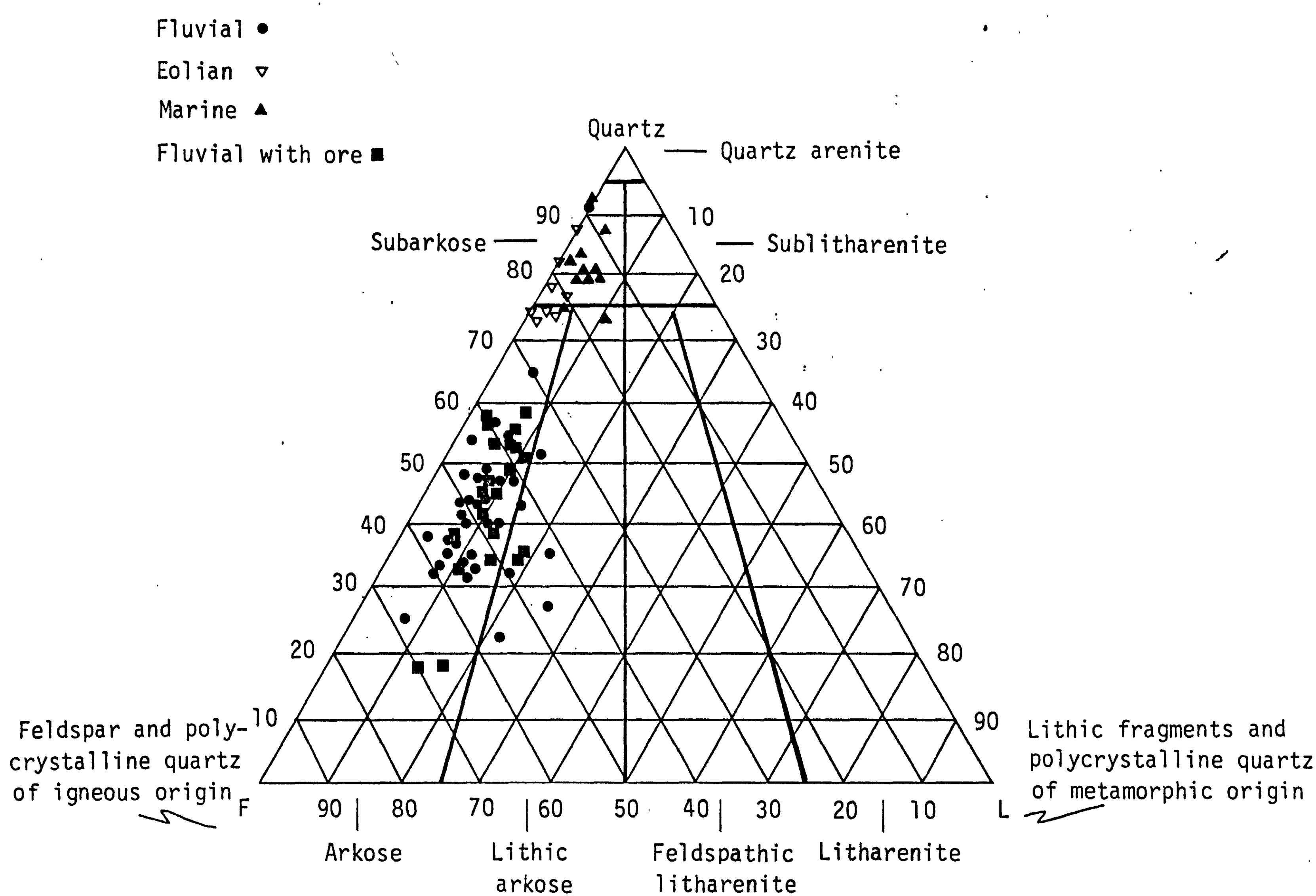


Figure 11.--Classification of sandstones from the Cutler Formation, Lisbon Valley, Utah.

Table 4.--Petrography of uranium-bearing sandstones from the Cutler Formation, Lisbon Valley, Utah

Sample Information	Composition							Texture					
Sample no.	Quartz(%)	Feldspars(%)	Rock fragments(%)	Mica(%)	Carbonate cement(%)	Matrix(%)	Accessory minerals(%)	Mean grain size(mm)	Maximum grain size(mm)	Mean roundness	Standard deviation(mm)	Environment of deposition	Classification modified from Folk, 1974
SCM1-1	36.	7.	17.	--	1.	35.	4.	.51	4.07	.49	.752	Fluvial...	Lithic arkose.
SCM1-2	31.	34.	29.	3.	2.	--	1.	.47	2.17	--	.283	Fluvial...	Arkose........
SCM1-2A	32.	26.	28.	1.	--	7.	6.	.66	2.44	.46	.411	Fluvial...	Arkose........
SCM1-3	46.	20.	26.	1.	1.	3.	2.	.64	1.73	--	.428	Fluvial...	Arkose........
SCM1-4	40.	27.	22.	2.	--	6.	--	.62	2.17	--	.401	Fluvial...	Arkose........
SCM1-5	41.	20.	17.	1.	--	12.	9.	.37	1.57	.47	.224	Fluvial...	Arkose........
SCM1-6	38.	20.	21.	3.	2.	15.	1.	.43	1.30	--	.233	Fluvial...	Arkose........
SCM1-7	45.	25.	11.	2.	--	16.	--	.41	1.90	--	.274	Fluvial...	Arkose........
SCM1-8	38.	18.	14.	5.	--	23.	2.	.39	1.36	--	.237	Fluvial...	Arkose........
SCM1-9	35.	21.	18.	3.	5.	18.	--	.42	2.03	.48	.306	Fluvial...	Arkose........
SCM1-10	32.	24.	22.	2.	--	16.	4.	.47	1.65	--	.222	Fluvial...	Arkose........
SCM2-3	37.	21.	25.	1.	13.	1.	2.	.52	1.54	.49	.277	Fluvial...	Arkose........
SCM2-4	52.	27.	12.	1.	1.	--	5.	.26	.62	--	.113	Fluvial...	Arkose........
SCM2-5	50.	20.	17.	1.	1.	--	11.	.30	.68	.49	.118	Fluvial...	Arkose........
SCM2-6	33.	19.	32.	10.	1.	5.	1.	.21	.89	.46	.131	Fluvial...	Askose........
BB-2	38.	19.	11.	1.	--	17.	13.	.36	1.36	.46	.223	Fluvial...	Arkose........
BB-3	13.	25.	37.	--	22.	2.	1.	.77	2.17	--	.311	Fluvial...	Arkose........
BB-4	26.	23.	26.	4.	--	19.	1.	.78	3.52	--	.533	Fluvial...	Lithic arkose.
BB-5	39.	23.	13.	2.	--	6.	17.	.49	2.11	--	.440	Fluvial...	Arkose........
BB-6	13.	19.	39.	1.	22.	3.	2.	1.43	4.01	.46	.927	Fluvial...	Arkose........
BB-7	26.	26.	26.	--	8.	13.	--	.78	2.22	--	.455	Fluvial...	Arkose........
BB-8	28.	20.	31.	--	1.	21.	4.	.70	2.79	.50	.50	Fluvial...	Lithic arkose.

Table 5.--Petrological comparison of ore-bearing sandstones to to non-ore-bearing sandstones using the paired t test.

[Comparisons were done using the two-tailed t test. H_0: mean of ore sandstones = mean of non-ore sandstones. Degrees of freedom = 55. At = 0.0125 for each tail, t = 1.164.]

Parameters for comparison	Non-ore sandstones	Ore sandstones	t	Significant difference?
Igneous rock fragments.....	16.6%	14.2%	1.16	No
Feldspars..................	22.3%	22.0%	0.23	No
Mica.......................	2.3%	2.0%	0.0	No
Total rock fragments.......	24.1%	22.5%	0.60	No
Matrix.....................	4.8%	10.9%	-2.88	Yes
Mean grain size............	0.44 mm	0.55 mm	-1.48	Yes
Sorting (standard deviation)	0.31 mm	0.35 mm	-0.01	No
Carbonate cement...........	12.1%	4.1%	2.66	Yes
Maximum grain size.........	1.9 mm	2.01 mm	-0.32	No

This study was designed to interpret the depositional environments of Cutler rocks and to relate uranium occurrences to the environments. The following important questions must be addressed before guides for future exploration in Cutler rocks can be suggested: (1) What is the age of ore formation in Cutler rocks? (2) How does the Cutler ore relate chemically and physically to Chinle or Salt Wash ore? (3) What was the reductant that aided in trapping the uranium in the Cutler? To help answer these questions, the diagenesis in ore samples, the elemental variation across ore zones, the X-ray characteristics of ore minerals, the opaque minerals associated with ore, and fission-track maps are all currently being studied.

SELECTED REFERENCES

Allen, J. R. L., 1970, Studies in fluviatile sedimentation: A comparison of fining-upwards cyclothems, with special reference to coarse-member composition and interpretation: Journal of Sedimentary Petrology, v. 40, no. 1, p. 298-323.

Baars, D. L., 1962, Permian System of Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 2, p. 149-218.

Campbell, J. A., and Steele, B. A., 1976, Uranium potential of Permian rocks in the southwestern United States: U.S. Geological Survey Open-File Report 76-529, 26 p.

Chenoweth, W. L., 1975, Uranium deposits of the Canyonlands area: Canyonlands, Four Corners Geol. Soc. Guidebook, 8th Field Conf., J. E. Fassett, ed., p. 253-260.

Dickinson, K. A., Berryhill, H. L., and Holmes, C. W., 1972, Criteria for recognizing ancient barrier coastlines, in Recognition of ancient sedimentary environments, J. K. Rigby and W. K. Hamblin, eds., Society of Economic Paleontologists and Mineralogists Special Publication no. 16, p. 192-214.

Folk, R. L. 1959, Practical petrographic classification of limestones: American Association of Petroleum Geologists Bulletin, v. 43, no. 1, p. 1-38.

______1974, Petrology of sedimentary rocks: Hemphill Publishing Co., Austin, Texas, 182 p.

Harms, J. C., Southard, J. B., Spearing, D. R. and Walker, R. G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course no. 2, 161 p.

Jackson, R. G., 1976, Depositional model of point bars in the Lower Wabash River: Journal of Sedimentary Petrology, v. 46, no. 3, p. 579-599.

Miall, A. P., 1977, Fluvial sedimentology: Canadian Society of Petroleum Geologists, Calgary, Alberta, Canada, 111 p.

McBride, E. F., and Hayes, M. O., 1962, Dune cross-bedding on Mustang Island, Texas: American Association of Petroleum Geologists Bulletin, v. 46, no. 4, p. 546-551.

McKee, E. D., Oriel, S. S., and others, 1967, Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey Professional Paper 515, 271 p.

McKee, E. D., and Bigarella, J. J., 1972, Deformational structures in Brazilian coastal dunes: Journal of Sedimentary Petrology, v. 42, no. 3, p. 670-681.

Schumm, S. A., 1972, Fluvial paleochannels, in Recognition of ancient sedimentary environments, J. K. Rigby and W. K. Hamblin, eds.: Society of Economic Paleontologists and Mineralogists Special Publication no. 16, p. 98-107.

Williams, P. L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Map I-360.