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LITHOFACIES OF THE SALT WASH MEMBER OF THE MORRISON FORMATION, COLORADO PLATEAU

By THOMAS E. MULLENS AND VAL L. FREEMAN

ABSTRACT

The Salt Wash is the basal member of the Upper Jurassic Morrison Formation in parts of Utah, Colorado, Arizona, and New Mexico. Deposited by streams, it comprises lenticular beds of cross-laminated sandstone irregularly interbedded with mudstone, siltstone, claystone, and horizontally laminated sandstone.

The term "lithofacies," as used in this paper, denotes lithologic aspect. The specific lithofacies of the Salt Wash member at a given locality is determined by the thickness, proportion, and continuity of the stream and flood-plain deposits that make up the Salt Wash. Stream deposits include all rocks interpreted as deposited from moving water; flood-plain deposits include all rocks interpreted as deposited from slack water.

Regional differences in lithofacies show that the Salt Wash member is a fan-shaped wedge of sedimentary rocks whose apex is in south-central Utah. Within the wedge, the thickness of the Salt Wash and the thickness, proportion, and continuity of the contained stream deposits decrease relatively uniformly to the north, northeast, and southeast of the apex.

Interpretation of the regional differences in lithofacies indicates deposition by a distributary stream system whose apex was in south-central Utah and which spread sediments to the north, east, and southeast over a nearly flat plain. Irregularities on this plain near the Four Corners area and in west-central Colorado modified the distributary system, and therefore the wedge is not symmetrical.

Most uranium-vanadium ore deposits in the Salt Wash member occur in a lithofacies near the center of the wedge. This may be a genetic relation and can be explained as a function of transmissibility of the particular lithofacies. The ore deposits, however, are concentrated in a relatively small part of the central lithofacies. Because local geologic features such as structure or igneous intrusions might control the localization of ore deposits in the small area, the high degree of correlation of ore deposits and a certain lithofacies may be coincidental.

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Introduction

A lithofacies study of the Salt Wash member of the Upper Jurassic Morrison Formation was part of a detailed stratigraphic study of the Morrison Formation of the Colorado Plateau and adjoining regions made by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Tentative conclusions of the stratigraphic study were published by Craig, *et al.* (1955). They abstracted methods and conclusions reached by combined studies of lithofacies, regional stratigraphy, sedimentary structures, and sedimentary petrography. This paper is to illustrate methods and interpretations resulting from a particular lithofacies study rather than to present new conclusions about the Salt Wash member.

The term "lithofacies" in this paper denotes the total aspect of inorganic elements which furnish record of the depositional environment of a stratigraphic unit. This usage of "lithofacies" follows Krumbein (1948, p. 1923) and Kay (1947, p. 165) but differs from usage proposed by Moore (1949, p. 16); Moore would use the term "physiofacies" (p. 17) to denote the inorganic elements in a sedimentary rock. Moore would retain the term "lithofacies" to denote both inorganic and organic elements of a rock.

Specifically, "lithofacies", as used here, denotes the lithologic aspect as controlled by the thickness, the relative proportions, and the continuity of the two sedimentary types that constitute the Salt Wash member.

The purpose of the lithofacies study was to determine the regional variation in lithofacies of the Salt Wash member with the ultimate goals of determining: (1) some aspects of the depositional environment of the Salt Wash, and (2) relations between lithofacies and uranium-vanadium deposits in the Salt Wash.

Morrison Formation

Nomenclature

The Morrison Formation, defined originally by Cross (1894, p. 2), is present in much of the western interior of the United States. In the Colorado Plateau region the Morrison has been divided (in ascending order) into the Salt Wash member, defined by Lupton (1914, p. 127) and by Gilluly and Reeside (1928, p. 82), and the Recapture, Westwater Canyon, and Brushy Basin members, defined by Gregory (1938, p. 58–59). Table 1 shows a generalized section of the Morrison and adjacent formations in the Colorado Plateau region.

Salt Wash Member

The Salt Wash is best developed in southeastern Utah and in southwestern Colorado. As a recognizable unit the Salt Wash extends a short distance into northeastern Arizona and northwestern New Mexico where it disappears by depositional pinchout and by intertonguing and intergrading with the Bluff sandstone below and the Recapture member of the Morrison above. Southwest of a line trending northwestward through Lee's Ferry, Arizona, the Salt Wash was removed by erosion before the deposition of the Dakota sandstone. The western limit of Salt Wash is concealed in most places by younger sedimentary rocks in the Wasatch Plateau but locally can be determined accurately along the southwest part of the San Rafael Swell. The northern and eastern limits of recognizable Salt Wash are near Vernal, Utah, and Glenwood Springs and Gunnison, Colorado. Salt Wash is a sandstone-bearing portion at the base of the Morrison Formation. Where this sandstone-bearing portion is absent, as in parts of northeastern Utah and northwestern and central Colorado, the Morrison Formation is not divided into members. Beds equivalent to Salt Wash, however, are probably present in the lower part of the undifferentiated Morrison Formation (Craig *et al.*, 1955). Figure 1 shows the outcrop pattern of the Morrison Formation in parts of Utah, Colorado, Arizona, and New Mexico and the areal extent of the Salt Wash member.

The Salt Wash member consists mainly of lenticular cross-laminated sandstone and conglomeratic sandstone interstratified with claystone, mudstone, siltstone, and structureless to horizontally laminated sandstone. Thin beds of limestone, locally containing fresh-water fossils, occur near the base of the Salt Wash in east-central Utah and west-central Colorado.

The cross-laminated sandstone is generally light-colored and ranges from fine- and medium-grained in Colorado to coarsely conglomeratic rock commonly containing lenses of cobble conglomerate in south-central Utah. The cross-laminated sandstone occurs as a single lensing bed 2–20 feet thick that extends less than 300 feet or as many cross-laminated sandstone beds which make up a composite bed. The composite beds are more abundant and generally much thicker than the single cross-laminated beds; some composite units form lenses that are more than 80 feet thick and extend several miles. All cross-laminated beds have gently undulatory to well-defined scour surfaces at the base.

The claystone, mudstone, siltstone, and structureless to horizontally laminated sandstone are mainly reddish brown. All gradations and mixtures of grain size between very fine-grained sand and clay are common among these rock types. Bedding in these rocks ranges from horizontal to gently lensing; fissility is rare.

The Salt Wash member is characterized by a steep ledgy outcrop. The cross-laminated

TABLE 1.—GENERALIZED SECTION OF MORRISON AND ADJACENT FORMATIONS IN THE COLORADO PLATEAU REGION

System	Formation	Member	Character
Cretaceous	Burro Canyon		Light-colored conglomeratic sandstone and green and red mudstone; mesa capping
Jurassic	Morrison	Brushy Basin	Variegated claystone and mudstone, some sandstone lenses; forms slopes
		Westwater Canyon	Light-colored sandstone with minor light-green mudstone; forms cliffs
		Recapture	Light-colored sandstone and red mudstone; generally less resistant than overlying and underlying members
		Salt Wash	Light-colored sandstone and red mudstone; forms cliffs and benches
	Bluff sandstone		Massive eolian sandstone; present only in Four Corners area
	Summerville		Evenly bedded red siltstone and very fine-grained sandstone
	Curtis		Glauconitic sandstone and greenish-gray shale

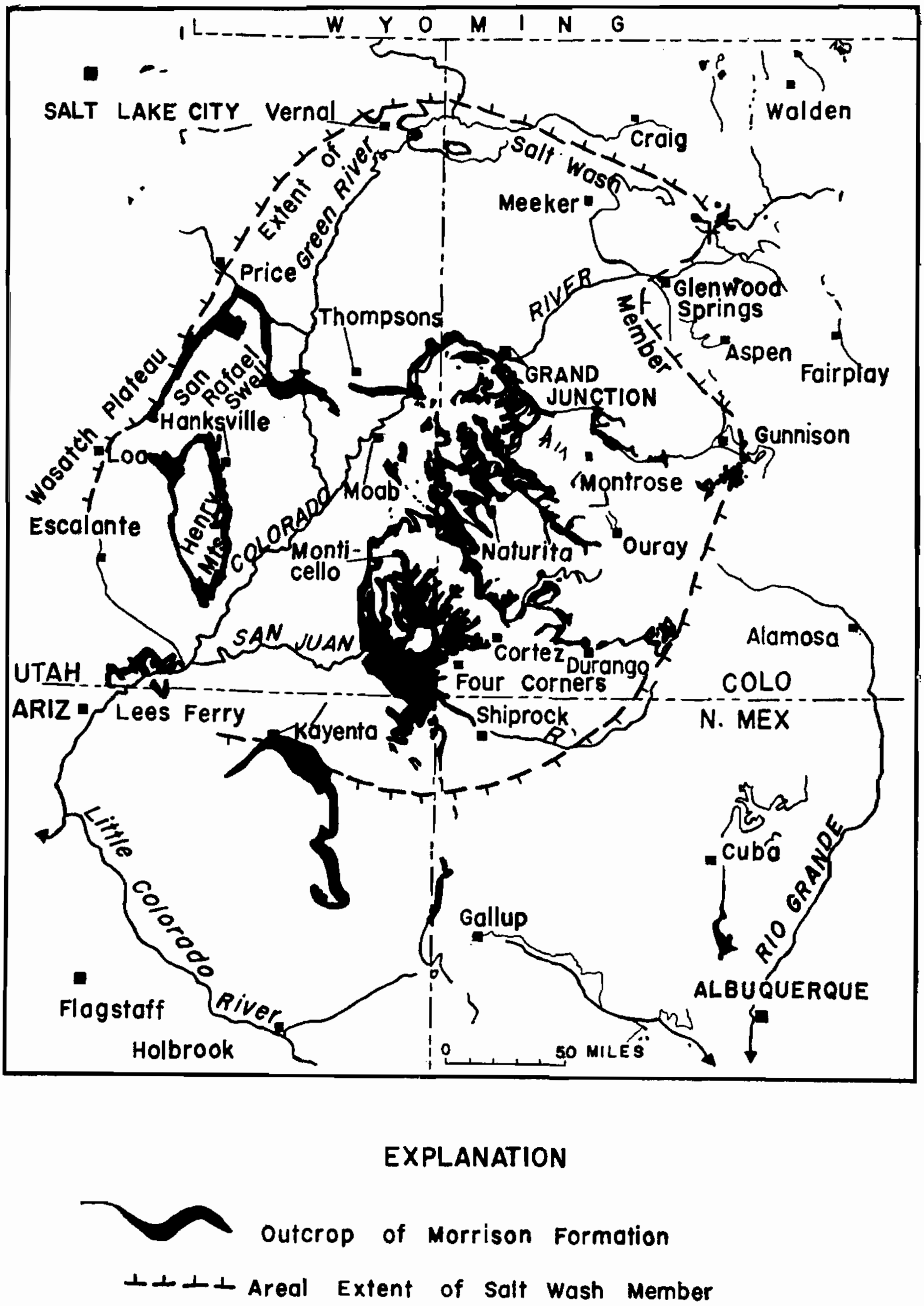


FIGURE 1.—MAP SHOWING OUTCROP PATTERN OF MORRISON FORMATION AND AREAL EXTENT OF SALT WASH MEMBER

sandstone forms steep-faced ledges; the finer-grained units form rubble-covered slopes between the ledges.

Because of the irregular assemblage of sandstone, siltstone, claystone, scour surfaces, and other sedimentary structures in the cross-laminated sandstone, the Salt Wash member is interpreted as a product of stream deposition (Craig *et al.*, 1955; Stokes, 1944; Mook, 1916).

Stratigraphic Relations of Salt Wash Member

The basal contact of the Salt Wash member in most areas is the base of the fluviatile deposits above the marine and marginal marine deposits of the Curtis and Summerville formations. The contact represents a change in depositional environment and is conformable in most places. In the San Rafael Swell and Henry Mountains area in Utah, however, contorted beds in the Summerville Formation are locally bevelled by the Salt Wash member; and over the crests of the salt anticlines in western Colorado the Salt Wash bevels older formations. Near Gunnison, Colorado, the Salt Wash rests on Precambrian rocks; and in Arizona, New Mexico, and in parts of Colorado and Utah near the Four Corners area the Salt Wash rests on the dominantly eolian Bluff sandstone. This second contact is a scour surface on the Bluff sandstone in most places, but locally fluviatile and eolian deposits intertongue.

In the Four Corners area most of the upper part of the Salt Wash member grades laterally into the Recapture member of the Morrison Formation. In other places the upper contact of the Salt Wash represents a change from a fluviatile environment to the dominantly lacustrine environment of the Brushy Basin member of the Morrison Formation. This change in environment is transitional; however, in many places where the basal deposits of the Brushy Basin are fluviatile a distinct composition and textural change between the Salt Wash and Brushy Basin members is noted.

Method of Study

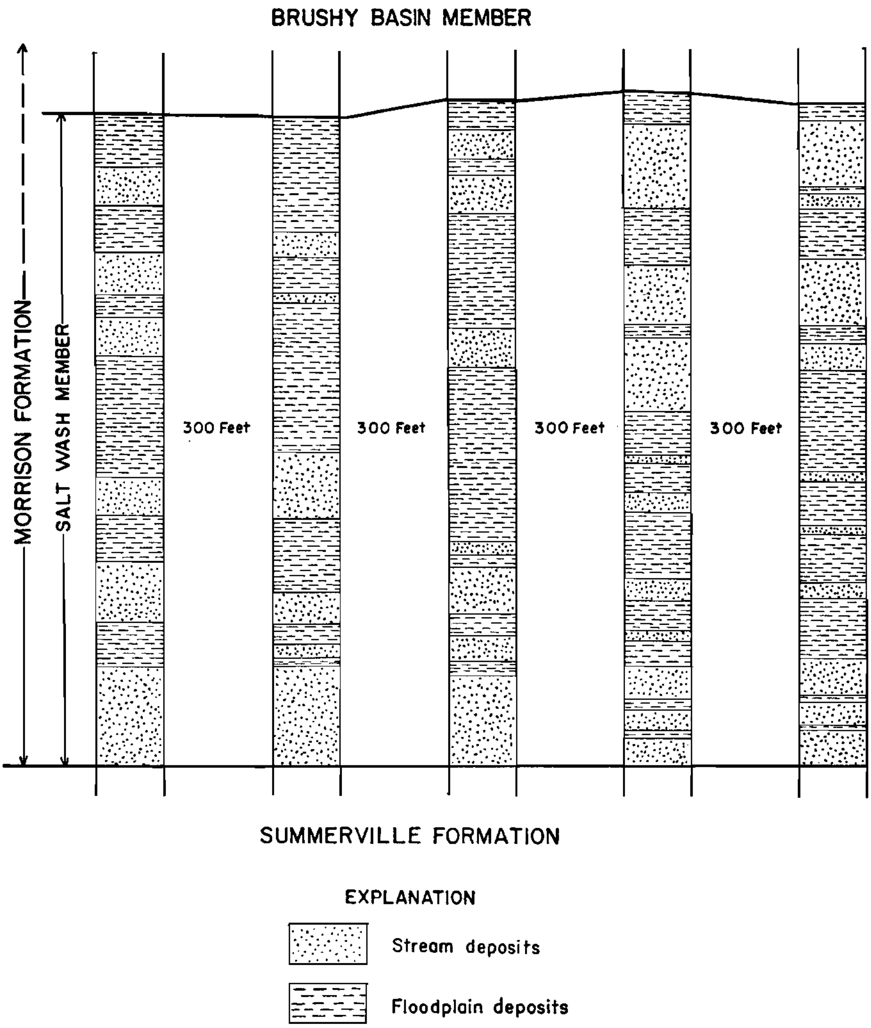
Classification of Sedimentary Units

Genetically the rocks in a fluviatile environment may be separated into stream deposits[1] and flood-plain deposits. The stream deposits consist of rocks which were deposited where sedimentation was noticeably influenced by water currents. In a fluviatile system these areas are restricted to channels and areas closely bordering the channels. The flood-plain deposits consist of rocks deposited from water in areas not noticeably influenced by current section. These areas are the relatively flat surfaces adjacent to stream channels where sedimentation from slack water occurs during and after floods.

The sandstone-shale classification of sedimentary units used in other lithofacies studies (Dapples *et al.*, 1948; Read and Wood, 1947; Sloss *et al.*, 1949) is not followed in this study for two reasons: (1) The genetic stream—flood-plain classification shows the relations between areas of current action and areas of no current action, whereas sandstone occurs in both stream and flood-plain deposits. Thus, drainage patterns based on stream deposits and flood-plain deposits should be more accurate than those based on sandstone and shale; (2) The genetic classification made possible a standardization of units measured. Gradation between claystone and sandstone is common, and sandy claystone or clayey sandstone is encountered in every measured section of the Salt Wash member. These units commonly form poorly exposed slopes between ledges of cross-laminated sandstone, and the relative amount of sandstone in the poorly exposed interval is difficult to determine. The problem of measuring the amount of sandstone in the clayey sandstone and sandy claystone was avoided by using a genetic classification, for these rock types are both flood-plain deposits.

The field distinction between stream and flood-plain deposits is clear in most cases. In this study a unit is considered a stream deposit if it is cross-laminated, has a basal scour surface, is composed of fine or larger grains, and is free of clay matrix. A unit is considered a flood-plain deposit if it is structureless or horizontally laminated and is composed of very fine-grained sand or smaller particles. Limestone, a minor rock type in the Salt Wash member,

[1] Many geologists would prefer "channel deposits" instead of "stream deposits" to describe sediments deposited where water currents influenced sedimentation. The writers use stream deposits to avoid conflict with a current Colorado Plateau use of "channel" to describe erosional features on the top of the Triassic Moenkopi Formation.



Vertical scale: 1 inch = 95 feet

FIGURE 2.—SECTIONS SHOWING LENTICULAR NATURE OF STREAM AND FLOOD-PLAIN DEPOSITS IN SALT WASH MEMBER OF MORRISON FORMATION

Sections measured at Head of Blue Canyon lithofacies locality, Mesa County, Colorado.

probably was deposited in shallow bodies of water on the flood plain and is included with the flood-plain deposits. The transitional rock in the stream—flood-plain deposits classification is very fine-grained well-sorted sandstone with poorly defined sedimentary structures. During field work most sandstone beds more than 2 feet thick were identified on the basis of the above criteria as stream deposits, and thinner sandstone beds were identified as flood-plain deposits. Consequently, very fine-grained sandstone beds 2 feet thick or less are considered flood-plain deposits and those more than 2 feet thick are considered stream deposits.

Collection of Data

Sampling technique.—Several sections were measured through the Salt Wash member at each lithofacies locality to calculate average thickness of the lenticular fluviatile deposits. Average thickness figures at each locality are necessary as a single section may not be representative; a section measured through the fluviatile deposits may be considerably different in thickness of stream deposits and proportion of stream deposits to flood-plain deposits from one only 300 feet away (Fig. 2). Five sections evenly spaced over about 1200 feet of outcrop are thought to give a valid representation of the total lithologic aspect at each locality. Exposures and topography did not permit measuring five sections at all localities; however, all lithofacies localities represent at least three measured sections. The continuity of the sedimentary units at each locality can also be approximated if several sections are measured.

For each locality the average thickness of the Salt Wash member, the average thickness of contained stream deposits, the average thickness of the contained flood-plain deposits, the average percentage of contained stream deposits in the Salt Wash, and the relative continuity of the stream deposits were computed.

Sections were measured by Abney level and tape. The thickness and lithologic description of the units were recorded, and each unit was classified as either stream or flood-plain deposits as the section was measured.

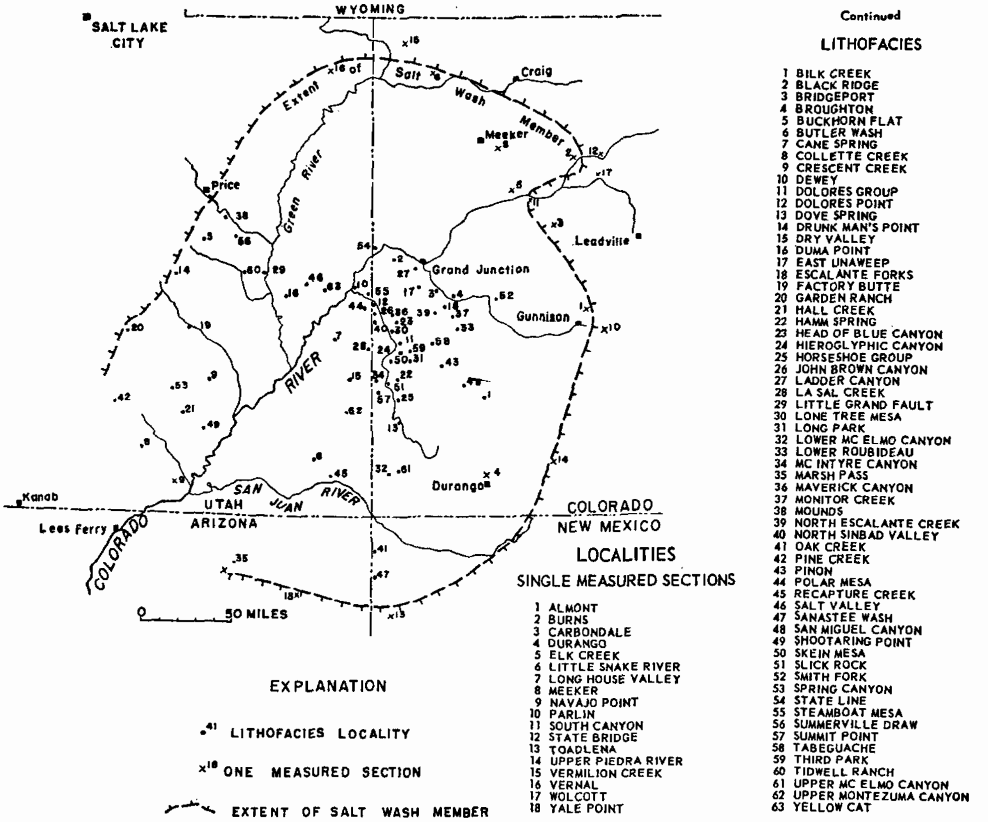


FIGURE 3.—MAP SHOWING AREAL EXTENT OF SALT WASH MEMBER OF MORRISON FORMATION

Includes location of lithofacies localities, and single measured sections.

Field work.—The area of study includes the southeastern quarter of Utah, the southwestern quarter of Colorado, and small parts of northwestern New Mexico and northeastern Arizona. All the Salt Wash member is within the area outlined, but no lithofacies measurements were made in northwestern Colorado and northeastern Utah where poor exposures of the Salt Wash prohibited lithofacies measurements by the sampling technique used. Field work started in western Colorado and was extended radially from this area with a decrease in concentration

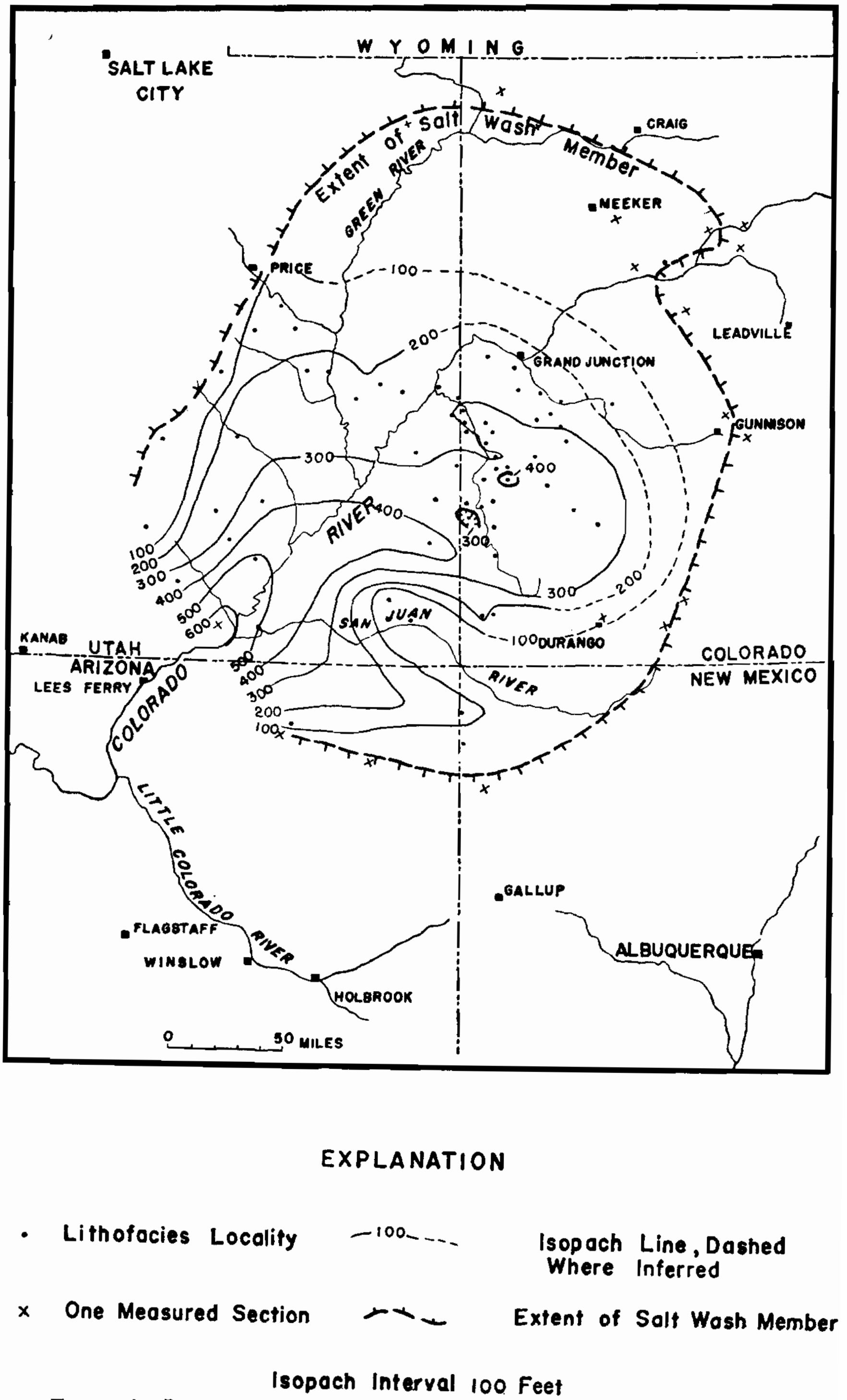


Figure 4.—Isopach Map of Salt Wash Member of Morrison Formation

of lithofacies localities away from western Colorado (Fig. 3).

Field work was begun in 1948 by L. C. Craig *et al.* who developed field techniques and made lithofacies measurements at 5 localities. In 1949, lithofacies measurements were made at 19 more localities by J. D. Ryan and the authors. The writers made lithofacies measurements at 39 additional localities in 1950 and 1951.

Data

Method of Presenting Data

Table 2 summarizes the data collected in the lithofacies study, and three isopach maps (Figs. 4, 5, 6) and two isolith maps (Figs. 7, 8) show the data graphically. In general, the method of converting the data to isopach and isolith maps follow methods of regional stratigraphic analysis proposed by Krumbein (1948, p. 1909–1923).

Except for use of single measured sections to delineate areal extent of the Salt Wash member, all data used in preparing the isopach and isolith maps were averages of measurements obtained from the several sections at each locality. The sections used to delineate the areal extent of the Salt Wash were measured by C. N. Holmes, L. C. Craig, and the writers.

Figures 4–8 represent conditions at the end of deposition of the Salt Wash member. The reconstruction involved drawing lines across areas where the Salt Wash either has been removed by erosion or is covered by younger rocks; however, the subjective element in drawing the isolith and isopach lines was lessened by plotting the lines at proportional intervals between control points. Isopach and isolith lines are not connected on the southwestern side of the maps, because in this area the Salt Wash was removed by Early Cretaceous erosion, and control points are not obtainable.

Isopach Map of Salt Wash Member

Figure 4 shows that the Salt Wash member is restricted to a nearly circular area. On the southwestern side a 140-mile gap in the circle indicates where the Salt Wash has been removed by erosion before deposition of the Dakota sandstone. The boundary of the circular area is represented by a hachured line which in part represents a true depositional pinchout and in part a grading of the Salt Wash into other units.

Isopach lines show that the Salt Wash member was deposited as a fan-shaped wedge. The apex of the fan, the area of greatest thickness, is in south-central Utah. Isopach lines, crudely concentric outward to the north, east, and southeast from the apex, are split into two distinct lobes by an area of thin Salt Wash in extreme southeastern Utah.

The southern lobe of the Salt Wash member is narrow and trends slightly south of east through northeastern Arizona and into New Mexico. The Salt Wash in this lobe thins uniformly toward its edge in New Mexico.

The northern lobe of the Salt Wash member is more extensive than the southern one. Isopach lines in the northern lobe form an asymmetric fan with an axis that curves eastward from the apex. Except in western Colorado, thinning in the northern lobe is rather uniform and is most rapid near the apex of the fan. Anomalous thicknesses, more than 400 feet at the Long Park locality and less than 300 feet at the Summit Point, Dolores Group, and North Sinbad Valley localities, prevent symmetry of the isopach lines in western Colorado. Isopach lines in the area of thin Salt Wash which separates the lobes of thicker Salt Wash form an oval whose long axis trends northwestward through the Four Corners area. In this area the Salt Wash overlies the thicker part of the Bluff sandstone which is predominantly wind-deposited. If the isopach lines were connected through this area of thin Salt Wash, they would form the shape of a symmetrical fan.

Isopach Map of Stream Deposits, Salt Wash Member

Figure 5 is similar to Figure 4 but shows more detail because of a smaller isopach interval. Greatest thickness of stream deposits is near the apex of the fan in south-central Utah. As in Figure 4, the isopach lines are divided into two lobes by an area of thin stream deposits in southeastern Utah. These lobes correspond in general to the lobes shown on Figure 4. The southern lobe is narrow and trends slightly

TABLE 2.—LITHOFACIES DATA FOR SALT WASH MEMBER OF MORRISON FORMATION

Lithofacies locality No.	Name	No. of sections at locality	Average thickness of stream deposits (Feet)	Average thickness of flood-plain deposits (Feet)	Average total thickness (Feet)	Average percentage of stream deposits	Percentage mean deviation of the thickness of stream deposits
1	Bilk Creek	3	140	197	337	42	5
2	Black Ridge	5	108	129	237	46	26
3	Bridgeport	4	78	167	245	32	9
4	Broughton	5	66	179	245	27	13
5	Buckhorn Flat	5	37	103	141	27	18
6	Butler Wash	5	42	27	68	64	9
7	Cane Spring	5	138	132	270	51	17
8	Collette Creek	3	240	129	369	67	6
9	Crescent Creek	4	263	110	372	71	5
10	Dewey	4	102	175	277	37	5
11	Dolores Group	5	136	152	288	47	15
12	Dolores Point	5	132	175	307	43	9
13	Dove Spring	3	204	158	361	56	6
14	Drunk Man's Point	5	15	68	83	18	10
15	Dry Valley	4	141	211	352	40	16
16	Duma Point	5	87	115	202	43	22
17	East Unaweep	4	88	194	282	31	15
18	Escalante Forks	3	116	181	296	39	19
19	Factory Butte	5	119	114	233	51	7
20	Garden Ranch	5	37	44	81	45	24
21	Hall Creek	4	249	86	335	74	7
22	Hamm Spring	4	147	198	341	44	11
23	Head of Blue Canyon	5	150	173	323	46	10
24	Hieroglyphic Canyon	4	183	154	338	54	5
25	Horsehoe Group	5	140	172	312	45	8
26	John Brown Canyon	5	117	199	316	37	11
27	Ladder Canyon	3	48	192	240	20	16
28	La Sal Creek	4	156	213	369	42	12
29	Little Grand Fault	4	103	156	259	40	13
30	Lone Tree Mesa	4	149	167	316	47	11
31	Long Park	5	278	134	422	68	5
32	Lower McElmo Canyon	5	140	127	267	52	21
33	Lower Roubideau	4	121	192	312	39	25
34	McIntyre Canyon	4	187	171	358	52	6
35	Marsh Pass	3	121	10	131	92	5
36	Maverick Canyon	4	134	192	326	41	17
37	Monitor Creek	3	135	164	299	45	6
38	Mounds	3	33	176	209	16	22
39	North Fork Escalante Creek	5	108	178	286	38	13
40	North Sinbad Valley	4	121	164	286	42	20
41	Oak Creek	5	170	27	196	87	6
42	Pine Creek	5	47	43	90	52	13
43	Pinon	4	193	128	322	60	8
44	Polar Mesa	5	104	189	293	36	24
45	Recapture Creek	4	32	0	32	93	6
46	Salt Valley	5	79	129	208	38	11
47	Sanastee Wash	3	14	37	51	28	29
48	San Miguel Canyon	5	116	134	316	47	16

TABLE 2.—*Continued*

Lithofacies locality No.	Name	No. of sections at locality	Average thickness of stream deposits (Feet)	Average thickness of flood-plain deposits (Feet)	Average total thickness (Feet)	Average percentage of stream deposits	Percentage mean deviation of the thickness of stream deposits
49	Shootaring Point	5	361	155	517	70	7
50	Skein Mesa	5	162	161	323	50	15
51	Slick Rock	5	165	161	329	50	16
52	Smith Fork	4	48	104	151	32	9
53	Spring Canyon	4	114	124	237	48	11
54	State Line	5	84	132	216	39	22
55	Steamboat Mesa	4	109	132	241	45	8
56	Summerville Draw	5	71	107	178	40	18
57	Summit Point	5	89	199	288	31	9
58	Tabeguache	4	148	154	302	49	3
59	Third Park	5	178	150	340	54	18
60	Tidwell Ranch	4	93	146	239	39	13
61	Upper McElmo Canyon	5	86	93	179	48	17
62	Upper Montezuma Canyon	5	200	220	420	49	15
63	Yellow Cat	3	97	153	250	39	7

south of east into New Mexico; the northern lobe is more extensive, and isopach lines show a crude asymmetric fan with an axis that curves eastward from the apex. In western Colorado isopach lines reveal two areas of anomalous thickness of stream deposits. Both areas are enclosed by isopach lines; however, the lines around the northwestern anomaly, the Long Park locality, indicate thickening of the stream deposits; and the line around the southwestern anomaly, the Summit Point locality, shows a thinning of stream deposits.

The area of thin stream deposits in southeastern Utah overlies the greatest thickness of the Bluff sandstone.

Isopach Map of Flood-Plain Deposits, Salt Wash Member

Figure 6 shows that the area of thickest flood-plain deposits is near the center of the area of Salt Wash deposition. In general, isopach lines are roughly concentric about the area of thickest flood-plain deposits, but the spreading of isopach lines from south-central Utah indicates a fanlike shape for the distribution of the flood-plain deposits.

The flood-plain deposits generally thin progressively from the center of the area, but two notable irregularities exist. One area, controlled by the Mounds and Little Grand Fault localities in east-central Utah, has anomalously thick flood-plain deposits, and another area, controlled by the Long Park, Pinon, and San Miguel Canyon localities in southwestern Colorado, has anomalously thin flood-plain deposits.

The 50-foot isopach line is not extended completely around the area of deposition because of the difficulty in distinguishing rocks of the Salt Wash member on the north and east sides of the Salt Wash area of deposition.

Isolith Map of Percentage of Stream Deposits in Salt Wash Member

Data for Figure 7 were prepared by computing the percentage of stream deposits in each section measured at a locality and then averaging the percentages of the several sections to obtain a value for the locality.

In general, the isolith lines form irregular concentric arcs outward from southeastern Utah. These arcs roughly parallel the boundary of the Salt Wash member except on the southern side where the isolith lines butt into the boundary.

The map shows that the highest percentage of contained stream deposits is in southeastern Utah and northeastern Arizona. North of this area the percentage of contained stream deposits decreases rather gradually. To the northeast the percentage decreases irregularly and is not progressive, as several localities in western Colorado have relatively high percentages of stream deposits, and two, Summit Point and Dry Valley, have anomalously low percentages. South and southeast of the area of highest percentage of contained stream deposits the percentage decreases uniformly and relatively rapidly.

Isolith Map of Percentage Mean Deviation of Thickness of Stream Deposits in Salt Wash Member

The areal distribution of the relative continuity of the stream deposits in the Salt Wash member is shown in Figure 8. Quantitative data are computed in this manner: (1) the average of the thickness of stream deposits in all sections measured at the locality is determined, (2) the amount in feet that each section differs from the average of the locality is determined, (3) the differences are added (nonalgebraically) and divided by the number of sections measured at the locality, (4) the figure determined in (3) is divided by the average thickness of contained stream deposits at the locality, and (5) the figure determined in (4) is converted to a percentage by multiplying by 100.

The percentage mean deviation of thickness of contained stream deposits is a relative index of continuity. The relative index is desirable because it enables a comparison of continuity between localities which contain different thicknesses of stream deposits. In theory, a low-percentage deviation indicates high continuity between stream deposits, and a high percentage deviation indicates low continuity.

The index of continuity used in this study applies to the total Salt Wash member and is not an index for individual lenses of stream deposits in the Salt Wash. The index might possibly indicate high continuity where little or no continuity exists if sections of Salt Wash had the same thickness of stream deposits, but the stream deposits were not continuous between the sections. Possibilities that such conditions are reflected in the data are decreased by measuring several relatively closely spaced sections at each locality.

Figure 8 shows two areas of relatively high continuity of stream deposits. One area is in southeastern Utah and northeastern Arizona, the other is in western Colorado and east-central Utah. Both areas are enclosed by higher-value isolith lines that indicate a relatively low continuity of stream deposits away from the center of both areas. Isolith lines around the southern Utah and northeastern Arizona area of high continuity form roughly concentric arcs elongated northwestward. Continuity of stream deposits decreases progressively away from southeastern Utah in all directions except northeastward. Isolith lines around the Colorado and east-central Utah area of high continuity form a closed irregular lobate pattern.

Interpretation of Data

Method of Interpretation

To present the lithofacies of the Salt Wash on a single map requires a composite map of the three isopach and two isolith maps. Such a composite map is difficult to read and therefore none is presented. However, all interpretations are made on the basis of an integration of the five maps.

Depositional Environment

The first goal of this lithofacies study was to determine some aspects of the depositional environments of the Salt Wash member. The Salt Wash has long been considered a product of aggrading streams (Mook, 1916; Stokes, 1944), but little was known about the habit and distribution of those streams. The lithofacies data make possible some specific interpretations of the habit and distribution of the streams, and the interpretations indicate a specific depositional environment.

The lithofacies maps show the Salt Wash member to be a fan-shaped wedge of sedimentary rocks decreasing both in the relative proportion and continuity of stream deposits outward from the apex of the fan. Thus, the regional variations in lithofacies of the Salt

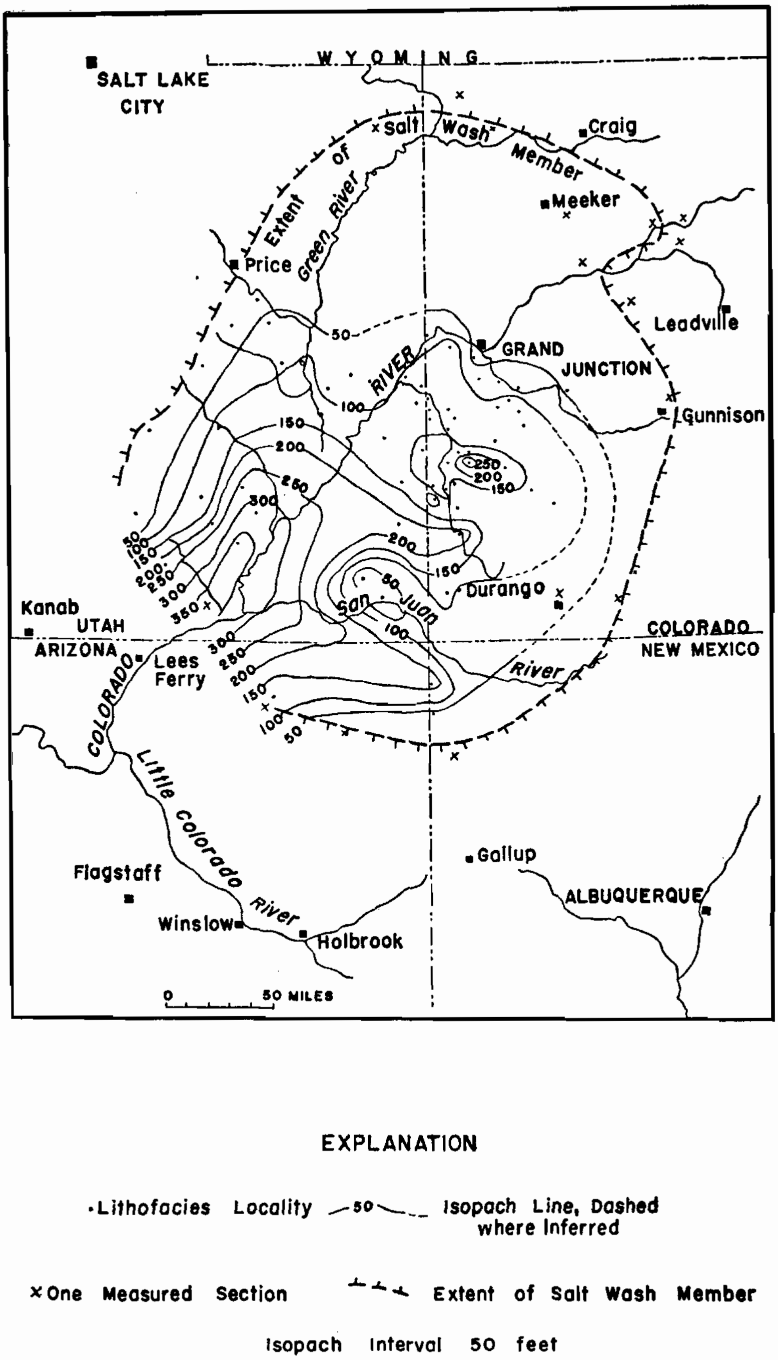


FIGURE 5.—ISOPACH MAP OF STREAM DEPOSITS IN SALT WASH MEMBER OF MORRISON FORMATION

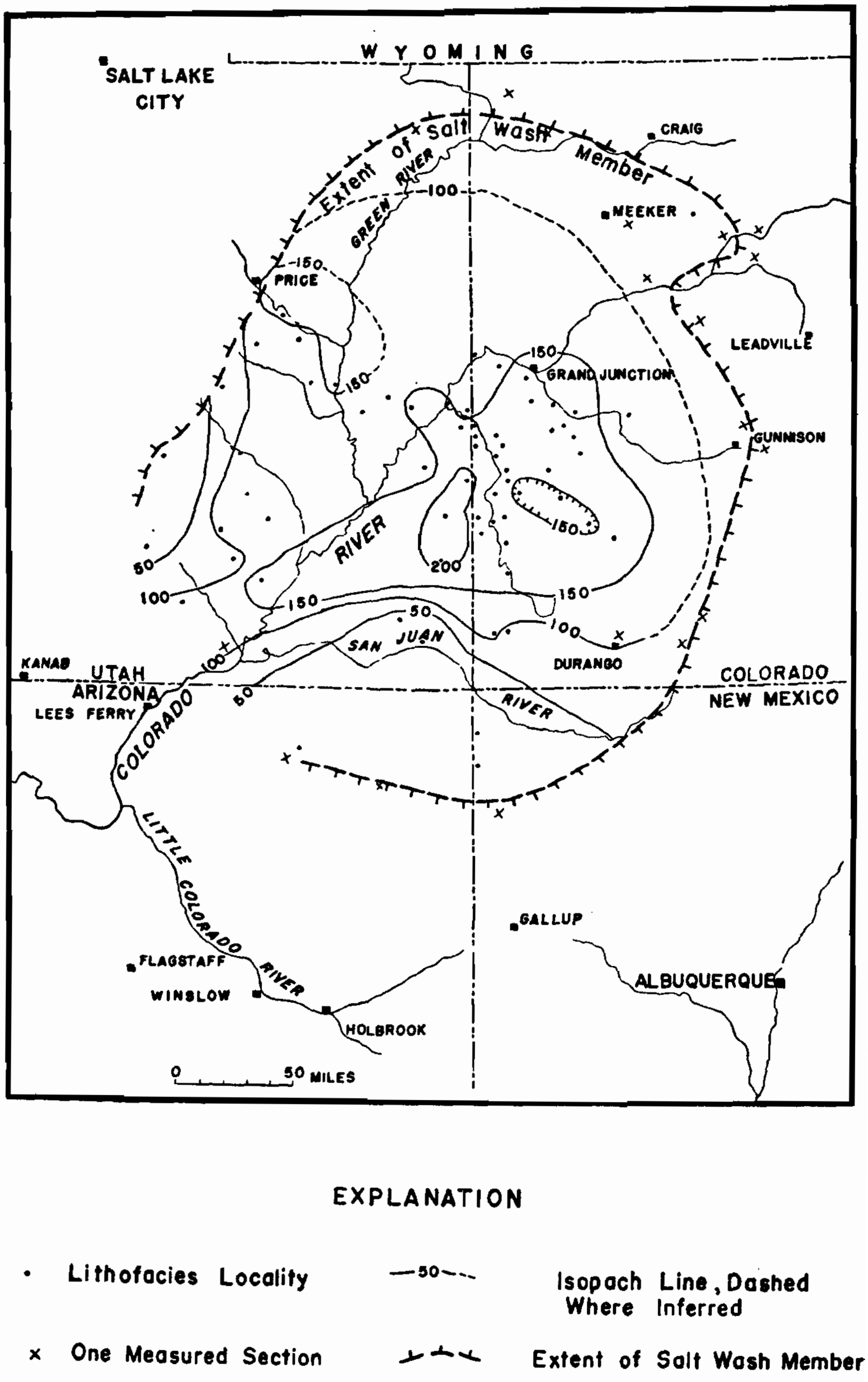


FIGURE 6.—ISOPACH MAP OF FLOOD-PLAIN DEPOSITS IN SALT WASH MEMBER OF MORRISON FORMATION

Wash can best be explained as resulting from a distributary drainage system which spread sediments north, east, and southeast from south-central Utah. The rough symmetry of the fan-shaped wedge of sedimentary rocks indicates that the distributary system was flowing over a nearly flat surface. In general, this surface was floored by marine and marginal marine deposits of the northward-retreating Late Jurassic sea. Therefore, the surface probably has a slight northward dip.

Field relations preclude the possibility that the distributary system existed as a delta in a marine environment; no intertonguing of Salt Wash rocks and marine or marginal marine rocks is known. On the other hand, sedimentary features and fossils support the terrestrial environment of the Salt Wash member.

Evidence is found in the Brushy Basin member of the Morrison Formation that, once established, the general pattern of the drainage system persisted throughout deposition of the Salt Wash member. The Brushy Basin is dominantly a lacustrine deposit, but, over much of the area of study, the basal deposits of the Brushy Basin are fluviatile. Although these deposits in the Brushy Basin are different in composition and texture from the underlying rocks of the Salt Wash, they apparently represent a continuation of the Salt Wash distributary system during early Brushy Basin deposition (Craig *et al.*, 1955, p. 157).

The maps compiled in the lithofacies study do not indicate an outlet for the water that transported and deposited the Salt Wash sediments. Possibly no outlet existed, and the water disappeared by seepage and evaporation, or possibly the Salt Wash streams drained by numerous outlets into the Late Jurassic sea north of the Salt Wash fan.

The symmetrical wedge of sedimentary rocks expected of a distributary system discharging on a flat surface is not shown by the lithofacies maps. Instead, the maps show irregularities that the writers believe can be correlated with irregularities on the surface of deposition.

Sand dunes that formed the Bluff sandstone made a highland in the Four Corners area. The highland did not persist throughout Salt Wash deposition, as the Salt Wash streams eventually built up their base level enough to flow across it. The highland, however, apparently split the Salt Wash distributary system into two lobes between which the Salt Wash member is thin because of restricted deposition.

Deviations from the pattern of a fan in west-central Colorado cannot be directly correlated with a particular geologic feature but probably reflect local warps in the Salt Wash basin of deposition; the lithofacies localities are too widely spaced to delimit the outlines of individual warps.

Salt anticlines in west-central Colorado and east-central Utah rose during Summerville deposition and continued rising until early in the time of Salt Wash deposition (Stokes and Phoenix, 1948). Upward movement of the salt anticlines was expressed topographically in the Salt Wash plain of deposition. The low-gradient Salt Wash streams probably were dammed in many places and probably deposited much of their load near the flanks of the salt anticlines.

In western Colorado other deviations from the fan-shaped pattern formed by distributary streams may be related to slight topographic relief of the Uncompahgre highland. During the time of Salt Wash deposition Precambrian rocks of the Uncompahgre highland extended from north-central New Mexico through Gunnison, Colorado. Just north of Grand Junction, Colorado, the highland passed into a structural terrace and had no topographic expression during the time of Salt Wash deposition (Holmes, 1951). The Uncompahgre highland did not stand high enough to contribute more than a minor amount of sediment to the Salt Wash, but it possibly formed a barrier to the low-gradient eastward-flowing Salt Wash streams. Such a barrier would cause unequal distribution of sediments in the Salt Wash fan as a more than normal amount of sediment would be deposited on the west side and a less than normal amount on the east side. The thicker Salt Wash, which had a relatively high proportion and continuity of stream deposits centering at the Long Park locality, may reflect the effect of the Uncompahgre highland.

Another possible effect of the Uncompahgre highland on the Salt Wash wedge is shown by the sharp curve in the boundary of the Salt

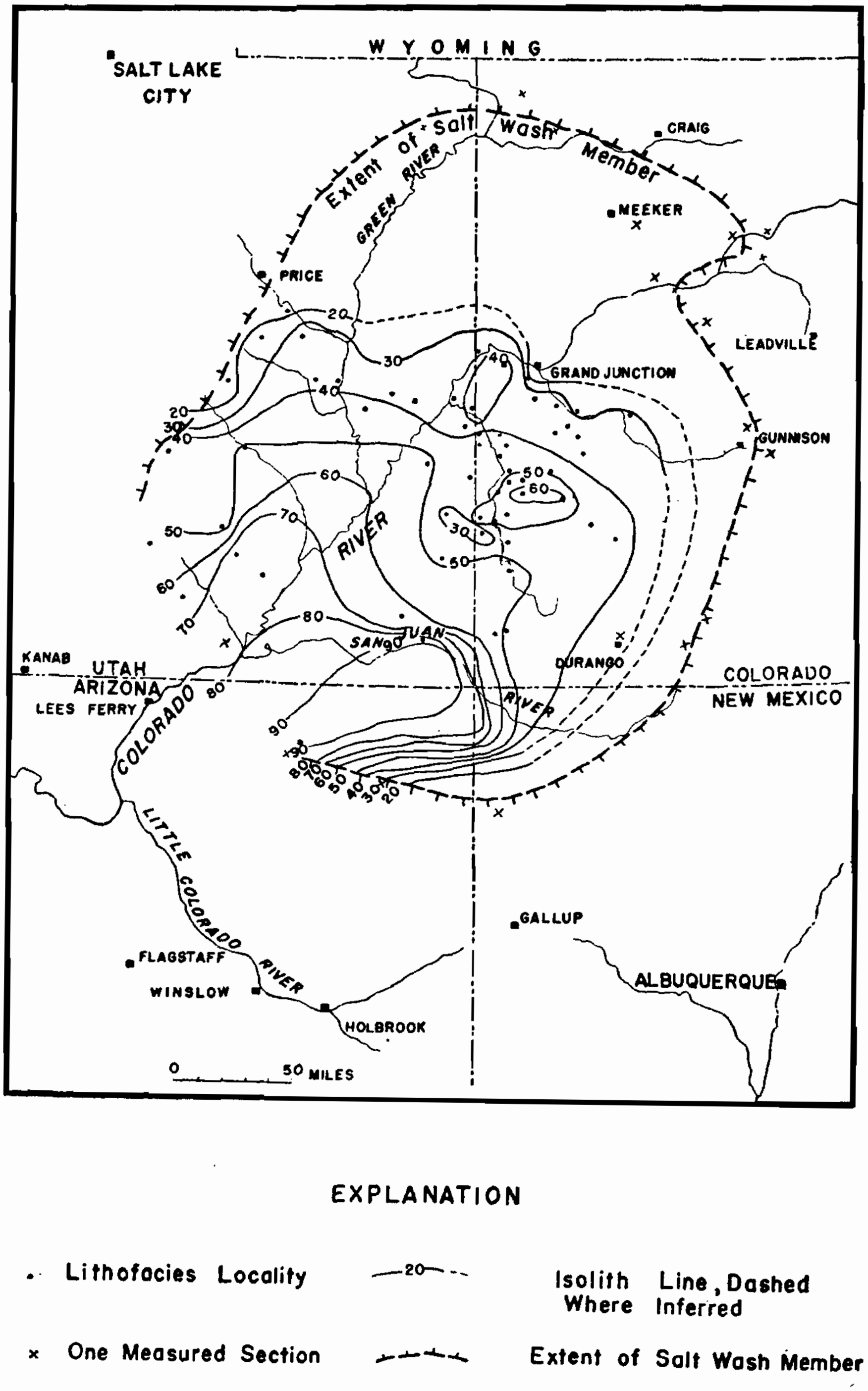


Figure 7.—Isolith Map of Percentage Stream Deposits in Salt Wash Member of Morrison Formation

Wash member between Leadville and Meeker. Sedimentary rocks of the Salt Wash member are present at the Burns and Elk Creek sections, but not at the South Canyon, Wolcott, or State Bridge sections. Southward from the South Canyon section there is no recognizable Salt Wash until the Almont section. This curve in the margin of the Salt Wash member does not correspond to the symmetrical margin of a fan as the northeastern margin extends farther from the apex than the eastern margin. The asymmetry may have been caused by the configuration of the Uncompahgre highland. Salt Wash streams northwest of Grand Junction, Colorado, would not have been affected by the highland barrier. Streams southeast of Grand Junction would decrease in gradient and lose part of their capacity to transport sediments as they neared the highland. Therefore, other things being equal, streams northwest of Grand Junction could transport sediments farther from the apex of the distributary system than streams southeast of Grand Junction. This arrangement could produce an asymmetrical curve at the margin of the Salt Wash fan.

The interpretation of the depositional environment of the Salt Wash member presented here emphasizes a single source area of sediments and a single distributary drainage system to spread the sediments. This interpretation is based on the maps described in this report. The writers are pleased that other studies on the Salt Wash support their interpretations.

Conglomerate dominates the Salt Wash at the apex of the fan and decreases away from the apex (Craig *et al.*, 1955, p. 138). A study of cross-laminations in the stream deposits in the Salt Wash member indicates that Salt Wash streams formed a distributary pattern whose apex was near the apex determined by lithofacies study (Craig *et al.*, 1955, p. 145). Some aspects of the Salt Wash deposition as determined by other stratigraphic studies, however, are not reflected by the lithofacies maps. Conglomerate in the Salt Wash member near the Garden Ranch lithofacies locality and petrographic studies of Salt Wash rocks indicate that the Salt Wash probably had minor contributions of sediment from west-central Utah (Craig *et al.*, 1955, p. 147–150). These minor source areas are not reflected in the lithofacies maps.

Relations of Lithofacies to Uranium-Vanadium Ore in Salt Wash Member

The second goal of the lithofacies study was to determine any relation between lithofacies of the Salt Wash member and the uranium-vanadium deposits in the Salt Wash.

Uranium and vanadium ore is mined from the Salt Wash member in many places in Colorado, Utah, and Arizona. The ore occurs as irregular tabular masses in the thicker part of stream-deposited sandstone lenses and, in general, is restricted to a single zone within the Salt Wash member. The ore deposits have been described in detail by Fischer (1942).

If the uranium and vanadium were transported in solution through the Salt Wash member, the movement of the metal-bearing solution would be affected by factors controlling the transmissibility of the Salt Wash. The stream deposits are more permeable than the flood-plain deposits; therefore, major factors controlling the transmissibility of the Salt Wash are the thickness, continuity, and relative proportion of stream deposits in the Salt Wash. Favorable conditions of these three factors might form traps for concentrations of metal-bearing solutions by density stratification or related phenomena.

Three conditions of transmissibility in the Salt Wash member and the possible relations of transmissibility to localization of ore deposits are illustrated in Figure 9. Permeability of the stream deposits and hydraulic gradient are assumed to be the same in each case illustrated.

A low proportion of stream deposits to flood-plain deposits and little continuity of the stream deposits is shown by *A* in Figure 9. Movement of solutions through the stream deposits is impeded because little continuity exists between individual lenses of stream deposits. The opportunity for concentrations of dissolved metals from weak solutions is unlikely because little solution passes through the stream deposits.

The assumed ideal lithofacies for concentration of ore minerals in the stream deposits of the Salt Wash member is shown by *B* in Figure 9. Stream deposits, which constitute

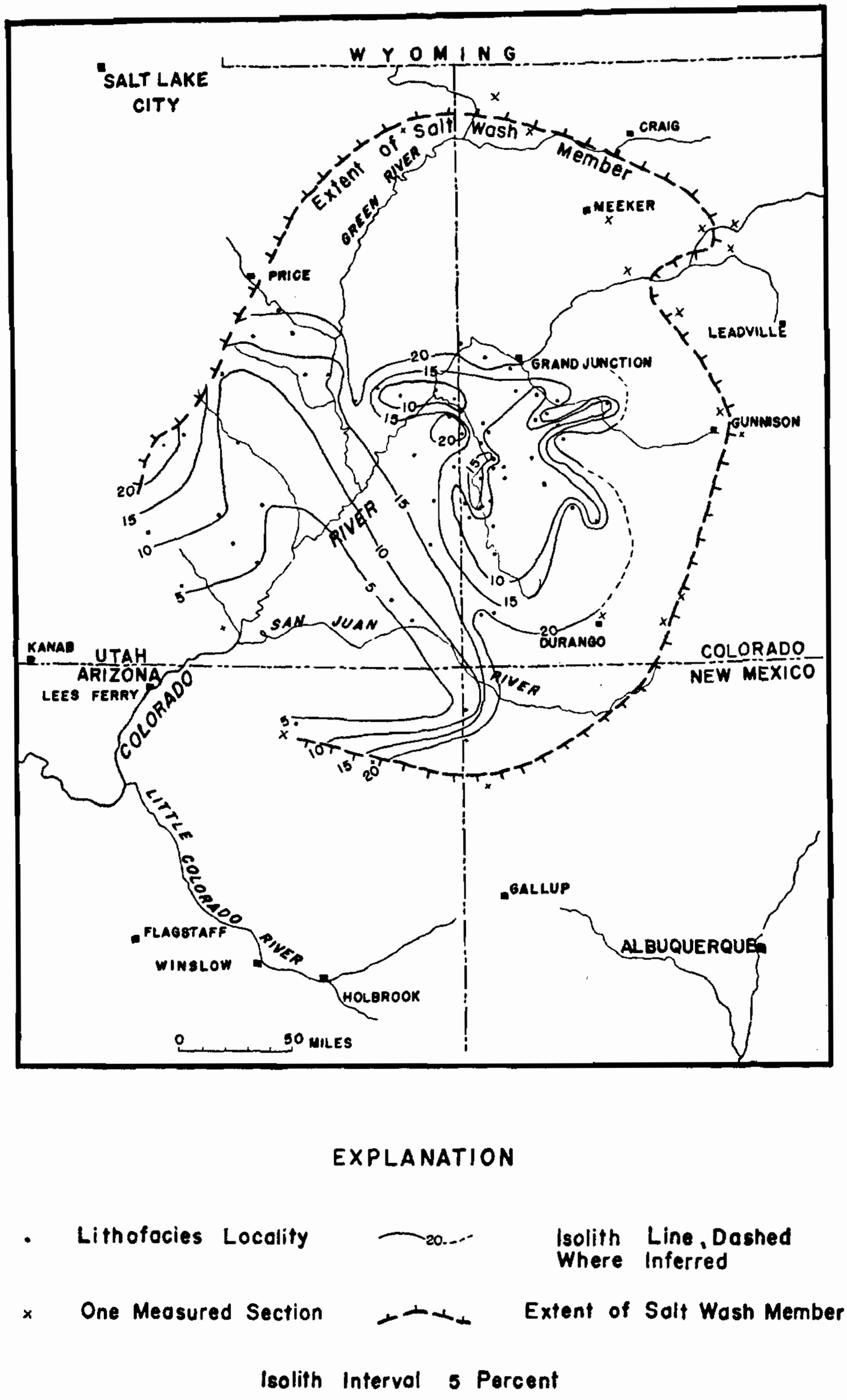


FIGURE 8.—ISOLITH MAP OF PERCENTAGE MEAN DEVIATION IN THICKNESS OF STREAM DEPOSITS IN SALT WASH MEMBER OF MORRISON FORMATION

about half the thickness, are continuous but slightly lenticular. Movement of metal-bearing solutions would be restricted to the stream deposits and the movement of the solution is locally impeded by lenticularity of the stream deposits. Dissolved ore metals might be concentrated at favorable places controlled in detail by sedimentary structures, because the stream deposits are continuous enough to allow inflow of new solution.

Stream deposits that have high continuity and constitute about three-fourths of the thickness are shown by *C* in Figure 9. This lithofacies may be unfavorable for the accumulation of ore deposits. Movement of metal-bearing solutions through the Salt Wash member would not be restricted nor would movement of the solutions be restricted by irregularities in the stream deposits. The metal-bearing solutions could pass freely through this lithofacies, and there would be little chance for concentration of the ore metals.

Regionally, transmissibility of the Salt Wash member probably is greatest near the apex of the fan in south-central Utah. The stream deposits show greatest thickness and continuity and constitute over half the thickness of the Salt Wash in this area. Transmissibility of the Salt Wash probably decreases away from the apex as do the thickness, continuity, and relative proportion of stream deposits. Near the margin of the fan the transmissibility of the Salt Wash is probably lowest, as stream deposits constitute little of the total thickness, and little continuity exists between individual lenses. The assumed ideal conditions of transmissibility for accumulation of ore deposits are in the central part of the Salt Wash wedge.

Quantitative relation of uranium-vanadium ore to lithofacies of the Salt Wash member was obtained by plotting lithofacies parameters of ore-bearing localities in relation to all quantitative lithofacies data. For this purpose a lithofacies locality was considered an ore-bearing locality if at least 100 tons of rock containing 0.1 per cent of uranium oxide was or is known to be within 1 mile of the locality. Of the 63 lithofacies localities, 22 are ore-bearing localities.

Of the 22 ore-bearing lithofacies localities 18 occur where the Salt Wash member is more than 240 feet thick and composed of 40–55 per cent stream deposits, contains 90–200 feet of stream deposits, and has a 5–18 per cent mean deviation in the thickness of stream deposits. As 18 of 37 localities included in the lithofacies outlined by the parameters above are ore bearing and only 4 of 27 localities not in this lithofacies are ore bearing, the parameters seemingly delimit a lithofacies that is more favorable for the accumulation of ore deposits than other lithofacies. The favorable lithofacies for ore deposits is a statistical concept. If parameters from all 22 ore-bearing localities are used to determine a favorable lithofacies for ore deposits, the resulting lithofacies includes about 90 per cent of the Salt Wash wedge.

Figure 10 shows the areal distribution of sedimentary rocks of the Salt Wash member that conform to the quantitative lithofacies limits outlined as most favorable for ore deposits. The area outlined is, in general, the central part of the Salt Wash wedge. The figure also shows that most major ore deposits in the Salt Wash (Fischer, 1942, Pl. 1) conform to the limits of favorability as determined by the lithofacies parameters. This may be a genetic relationship explained as a function of the transmissibility outlined in *B* of Figure 9 if a uniform source of uranium and vanadium is assumed.

Although Figure 10 shows an excellent correlation between a certain lithofacies and ore deposits, the correlation may be coincidental instead of genetic.

In the assumed ideal lithofacies for accumulation of ore deposits, the ore deposits should not be confined to a particular stratigraphic zone. Actually, ore deposits in the Salt Wash member in a given mining district are generally confined to one stratigraphic zone of stream deposits. Therefore, an exact correlation between total lithologic aspect of the Salt Wash and ore deposits confined to a single zone in the Salt Wash may be questioned. The strongest possible correlation is that the favorable lithofacies may represent a depositional environment in which single zones favorable for deposition of ore are more likely to occur than in other lithofacies.

The weakest possible correlation is that there is no genetic relationship between lithofacies

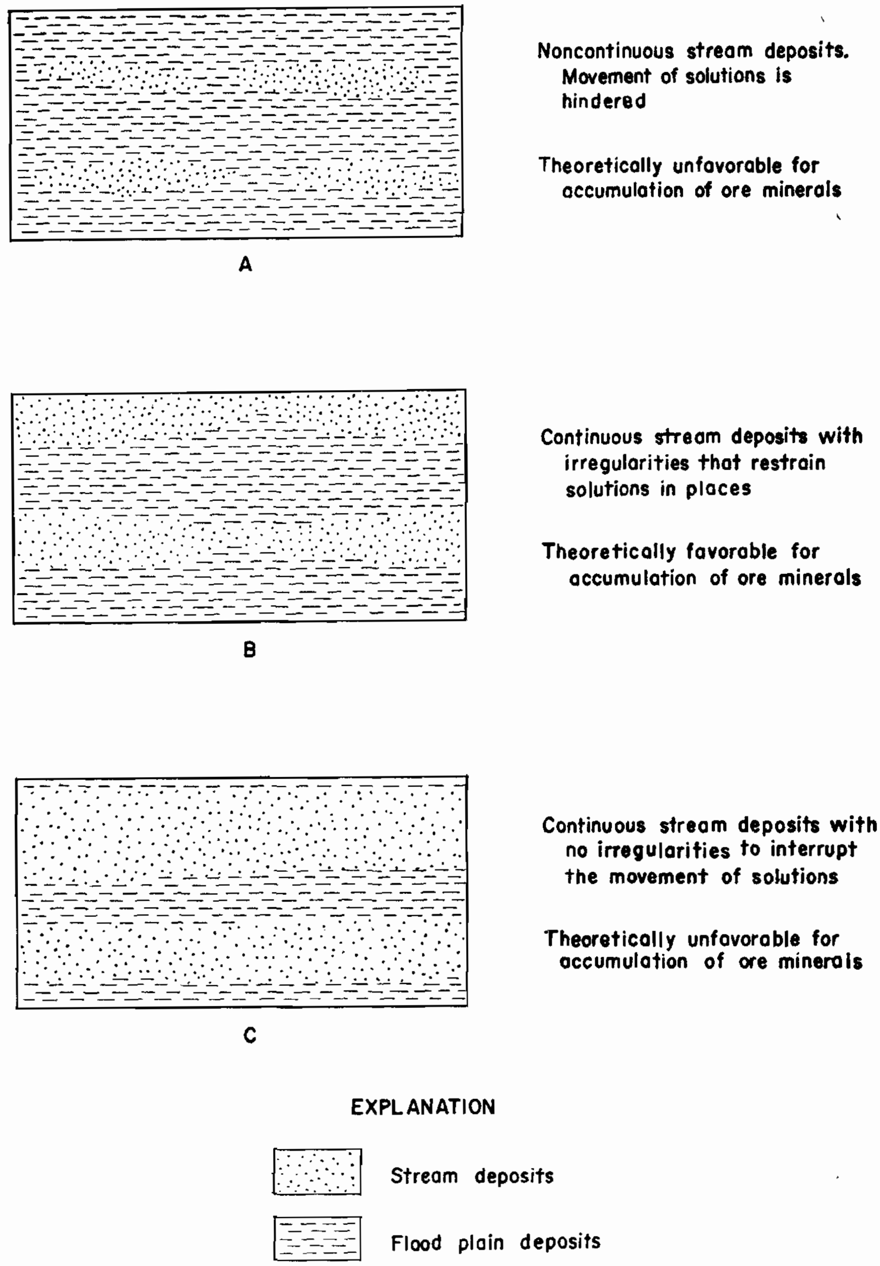
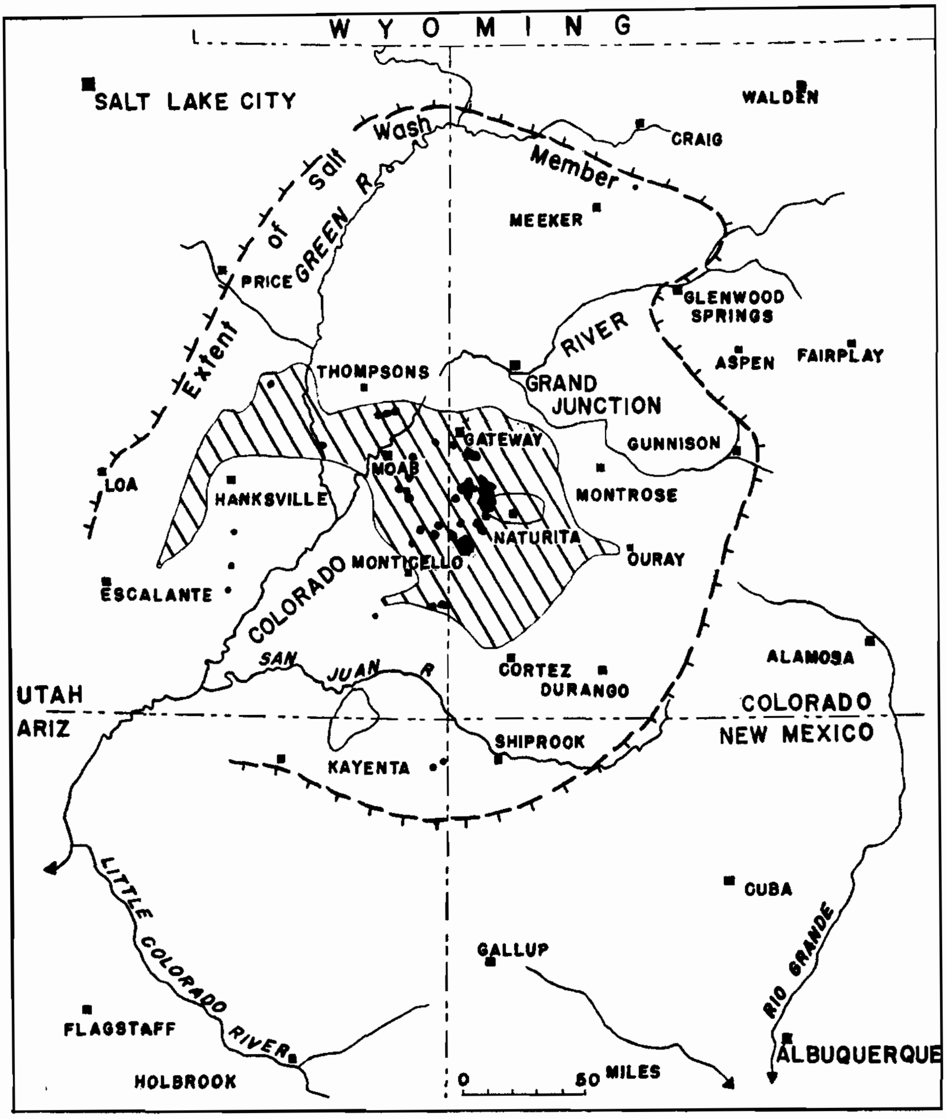


FIGURE 9.—DIAGRAM SHOWING CONDITIONS OF TRANSMISSIBILITY IN SALT WASH MEMBER OF MORRISON FORMATION

and location of ore deposits. Figure 10 shows that ore deposits are not distributed uniformly through the favorable lithofacies. Instead, most ore deposits are concentrated in east-central Utah and west-central Colorado, an area which forms a small part of the favorable lithofacies; and some major ore deposits occur in lithofacies here considered unfavorable for ore deposits. Possibly the ore deposits are related to local structural features, localized hydrothermal actvity, or other unknown local features. Therefore, the good correlation



EXPLANATION

• LOCATION OF MAJOR URANIUM-VANADIUM DEPOSIT

Area of favorable Salt Wash as determined by Lithofacies study (Salt Wash Member over 240 feet, stream deposits comprise 40 to 55 percent of member, thickness of stream deposits is 90 to 200 feet, percentage mean deviation of stream deposits is 5 to 18 percent)

Extent of Salt Wash Member

FIGURE 10.—MAP SHOWING THE LOCATION OF MAJOR URANIUM-VANADIUM DEPOSITS
In Salt Wash member of Morrison Formation and areas of favorable Salt Wash as determined by lithofacies study.

between ore deposits and a particular lithologic aspect of the Salt Wash member may be coincidental.

Summary

Regional variations in lithofacies (lithologic aspect) of the Salt Wash member are the basis for interpretations of the depositional environment of the Salt Wash member. The regional variations in lithofacies indicate deposition by a distributary stream system from an apex in south-central Utah. The distributary system spread sediments to the north, east, and southeast over a nearly flat plain forming a fan-shaped deposit. The symmetry of the Salt Wash wedge of sedimentary rocks was modified by irregularities in the surface of deposition in the Four Corners area and in west-central Colorado.

Theoretical considerations of the lithofacies of the Salt Wash member indicate that a lithofacies near the center of the wedge should be ideal for the accumulation of the uranium-vanadium ore deposits. Quantitative parameters of Salt Wash lithofacies indicate that many uranium-vanadium ore deposits are restricted to this central lithofacies. The ore deposits are not distributed uniformly through this central lithofacies, however; instead most known ore deposits are concentrated in a small part of the central lithofacies zone. Because local geologic features not related to Salt Wash depositional environment might control the distribution of the ore deposits, the high degree of correlation of the central lithofacies and ore deposits may be coincidental.

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