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AN X-RAY AND OPTICAL STUDY OF CUTTINGS FROM THE U.S. BUREAU OF RECLAMATION MESA 6-1 DRILLHOLE, IMPERIAL COUNTY, CALIFORNIA

By

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ABSTRACT

The Mesa 6-1 drillhole penetrates 8,031 feet of sediments. Cuttings are chiefly siltstones, but with varying amounts of sandstones ranging from very fine sand to very coarse sand size. Color changes in the siltstones constitute the only systematic changes of lithology with depth; these are considered to be the result of variations in oxidation-reduction conditions, not the result of depositional factors. Fragments of igneous and metamorphic rocks occur sporadically in trace amounts. A pebble horizon at least 30 feet thick but of questionable lateral extent is the only distinctive sedimentary horizon.

Montmorillonite was found in siltstone fragments at and above 1,450 feet, but not in siltstone fragments at or below 1,690 feet. Quartz, calcite, microcline, albite, chlorite, and illite are present in whole-rock diffractograms throughout the hole. Dolomite occurs in most samples to a depth of 4,910 feet, and is present intermittently to a depth of 7,697 feet. Pyrite is present intermittently. No zeolites were found. Black, dominantly amorphous grains of native sulfur, which may easily be confused with asphalt, are abundant at one horizon.

OBJECTIVES

Objectives of the present study were:

(1) To determine the variations in lithology with depth;

(2) To determine the mineralogy of the cuttings;

(3) To determine whether there are any systematic changes in mineralogy which may be correlated with depth or with structural features;

(4) To determine compositions of mineral phases where possible;

(5) To identify any rock types which might serve for correlation with other drillholes;

(6) To correlate variations in lithology with porosity or other physical properties displayed in logs of the hole.

METHODS

The cuttings furnished for this study had been taken at intervals ranging from 5 to 30 feet. Below a depth of 700 feet, the interval generally was 30 feet. Using a binocular microscope (30X magnification), the lithologic types present in each interval were identified and their percentages estimated. Numbers used to specify intervals are the reported well depths, in feet below land surface. In almost every sample there was a mixture of rock types, suggesting that much of the hole penetrated thinly bedded siltstones and sandstones. However, the relative distribution of siltstones and sandstones described in this report is based on the cuttings furnished, which are not necessarily representative of the section penetrated by the drillhole. Poorly consolidated sandstones could easily be lost in drilling.

Standard optical and X-ray diffraction methods of mineral identification were used in this study. Every interval was examined visually. Whole-rock X-ray studies were conducted on cuttings at 100-foot intervals, except between 5,790 and 6,300 feet, where each set of cuttings was X-rayed. At selected intervals certain minerals and(or) rock types were separated from the cuttings for individual detailed study.

Additives were a problem in the interpretation of results. The use of a drilling mud which reportedly contained montmorillonite (no samples of it were supplied) made it necessary to look for clay minerals in hand separated rock fragments rather than in the clay fraction of whole rock samples. This precluded using oriented clay samples, as amounts of material were small. Coarse white mica, and possibly some coarse chlorite (plates about 1 mm in diameter), were introduced into the hole to restore circulation, preventing any determination of the amount of illite present in the rock fragments of a whole-rock sample. Wood splinters and fibers were found in the cuttings at 7,896 feet, between 7,930 and 7,958 feet, and between 8,020 and 8,031 feet. Some of the wood splinters have a whitish frosted surface reminiscent of wood found in or near hot springs. Except for the frosting, the wood splinters are very similar to those commonly used in commercial additives.

The cement slurries pumped into the hole at various times contained large amounts of perlite and pumice, which produced cuttings that simulate volcanic tuff. The cuttings are porous, lack parallel structures, contain angular quartz fragments and, in the 2,506-2,580-foot interval, enclose regions of isotropic material (glass) which display curving fractures. Crystalline phases characteristic of hydrated Portland cement are absent in the 2,506-2,580-foot interval. In the 490-500 and 730-760-foot intervals, aragonite and vaterite (μ-$CaCO_3$) occur in addition to quartz and calcite, but only one or occasionally two diffraction maxima characteristic of portlandite ($Ca(OH)_2$) appear on the X-ray diffractograms, and are visible only in diffractograms of hand-separated samples. Where crystalline compounds characteristic of cement are absent and volcanic glass is present, recognition of the cement on the basis of petrographic character alone becomes difficult if not impossible. In this particular suite of sediments, absence of feldspar is a clue if hand separated samples, not whole-rock samples, are used; but in other stratigraphic sections containing less feldspar this criterion might not apply.

ACKNOWLEDGMENTS

The material studied was supplied by the U.S. Bureau of Reclamation, who also in part supported this study.

LITHOLOGY

Siltstones

Siltstones make up a large part of the section as represented by the cuttings. Measurements of grain sizes in thin sections of core (from the 2,548-2,580, 4,432-4,480, and 6,988-7,010-foot intervals) showed that five of the eight samples which were thin sectioned were in the siltstone range according to the Wentworth scale (0.004-0.625 mm); one was of mud grain size, one graded from fine silt to mud, and one had a mud matrix with coarser-grained particles embedded in it. Most of the finest-grained rock fragments seen through the binocular microscope, using a calibrated eyepiece, appear coarser-grained than mud. Therefore the term siltstone is used throughout this study, although there is some claystone (indurated mudstone) present in the section.

The siltstones can be divided into types by color; however, the color differences may have been imposed by secondary conditions, such as oxidation. One siltstone fragment from the 2,840-2,870-foot interval shows an interface between red siltstone and grey siltstone. The boundary is at right angles to the laminae in the fragment and hence is not a sedimentary feature. The mineral compositions of 25 hand separated samples of siltstone were determined by X-ray diffraction. Nineteen samples, representing all color types and derived from the 1,690-foot level or lower, are composed of quartz, calcite, illite, and chlorite. One sample, a light-gray siltstone from the 6,180-6,210-foot interval, also contains moderate amounts of plagioclase (albite). Six samples of pink siltstone, from the 1,450-foot level or above, contain quartz, calcite, montmorillonite, and little or no illite and chlorite.

Pink siltstone: abundant above 2,500 feet, less abundant down to 3,050 feet, absent below 3,050 feet.

Red siltstone: present below 1,350 feet; generally not abundant (less than 20 percent of total cuttings in any given interval), but present in larger amounts in certain intervals (fig. 1).

Medium gray to light gray siltstone: the most abundant type of siltstone below 2,600 feet. It is first found in small amounts in the intervals 1,510-1,540, 1,570-1,600, and 1,840-1,870 feet, and occurs in substantial amounts beginning at 1,870 feet.

Dark gray siltstone: almost a black rock, commonly with lustrous cleavage surfaces. It occurs sporadically between 2,930 and 5,820 feet, but becomes abundant only below 5,820 feet (fig. 1).

In some intervals of the section (4,070-4,190, 5,190-5,210, 5,390-5,510, and 6,680-6,760 feet), the siltstones as a group have cleavage approaching that of a shale. However, there is no simple correlation between type of cleavage and depth; blocky siltstones also occur at comparable depth intervals (5,120-5,150, 5,270-5,300, 7,040-7,070, and 7,130-7,160 feet).

Sandstones

It is not known to what extent the sandstone fragments observed in the cuttings represent pieces of fine-grained sandstone layers which were intersected by the drillhole, and to what extent they are pieces of preexisting sandstones which have been incorporated into second-generation sandstones and siltstones. For example, thin section 2.3 V from Core 2 (4,432-4,480 feet) is a fine- to medium-grained sandstone (on the Wentworth scale) which contains grains of quartz, twinned microcline, at least one plagioclase grain, and several rounded fragments of sandstone. Each sandstone fragment has a different range of grain sizes within it, and some of these correspond to the size ranges observed in the sandstones which are described below.

Silty, very fine-grained light gray sandstone containing biotite (0.03-0.09 mm): Minerals other than biotite which were identified in X-ray diffraction patterns of three hand separated samples of this rock type are major quartz and calcite, plagioclase (albite), microcline (in two of the three samples), chlorite, and minor illite. This rock occurs throughout the hole below 1,500 feet. It seldom makes up more than 20 percent of the rock fragments in the cuttings of a given interval. Exceptions are the intervals 5,120-5,160, 5,210-5,240, and 6,420-6,520 feet (fig. 1). In the latter two intervals, as well as in many other intervals, pyrite occurs in small amounts in this sandstone.

Silty, very fine-grained pink sandstone, without biotite (0.03-0.09 mm): This rock type occurs in small amounts above 1,400 feet. Some fragments of silty, very fine-grained pink sandstone also occur in the intervals 2,490-2,505 and 2,603-2,660 feet.

Very fine to fine-grained white sandstone (0.06-0.15 mm): This rock occurs throughout the section. Below 6,500 feet it commonly contains pyrite; however, pyrite also occurs higher in the section. One sample from 7,896 feet was hand separated for X-ray study. It contains major quartz, calcite, and albite; also microcline, minor chlorite, and a trace of illite.

Very fine to fine-grained pink sandstone (0.06-0.15 mm): This rock type occurs sporadically above 2,660 feet, and in the 3,755-3,785-foot interval. Fragments of pink very fine to fine-grained sandstone are found in the same interval with white very fine to fine-grained sandstone. It is possible that the pink sandstone is an oxidized variety of the white sandstone.

Fine to medium-grained white sandstone (0.15-0.32 mm): This rock is common below 1,150 feet (fig. 1). Hand separated samples of this sandstone from five different intervals were X-rayed. They all contain major quartz and calcite, minor microcline and chlorite, and little or no illite. Plagioclase (albite) occurs in four of the five samples. Pyrite is found in this rock type in most intervals below 6,150 feet, and is especially abundant from 6,680 to 6,800 feet. Many fine to medium-grained sandstone fragments contain one or more mineral grains which were not positively identified. Some are dark green; others are orange, dark red, or black. The green grains are probably chlorite-rich, but some may contain epidote.

Other rock types

Several other lithologic types are found as fragments, usually

1-3 mm in diameter, in the cuttings.

Bright pink, dense quartzite: This rock type occurs sporadically only above 1,870 feet, and always in small amounts, less than a few percent of the total cuttings in any given interval. It is doubtful that it represents a specific horizon; it seems more probable that it has weathered out from some other site.

Green clay-rich material: Aggregates of pale green, very fine-grained material, found throughout the section below 1,750 feet, commonly have indented surfaces, as if they had previously been matrix material in which grains of sand or silt were embedded. They were at first thought to be glauconite, but X-ray study indicates that they are a mixture of illite, quartz, and a trace of calcite. (See discussion in Mineralogy, p. 18.) These fragments are especially abundant in certain intervals between 2,750 and 3,950 feet; in some intervals they make up about 5 percent of the total cuttings.

Chlorite-rich fragments: Polymineralic, dark green grains occur throughout the section, comprising 5 percent or more of the total cuttings in some intervals, especially above 2,840 feet. X-ray study of hand separated material shows that the grains are composed of quartz, large amounts of chlorite, pyrite, and some calcite. In two intervals (2,080-2,110 and 3,740-3,755 feet), chlorite occurs as tablets or clumps in a rock fragment.

Individual large (~1 mm) platy grains of chlorite also occur in many intervals from 1,200 to 3,755 feet, and in the interval 830-860 feet. If the coarse-grained chlorite plates were not introduced during drilling, they are probably derived from a chlorite schist. This may be related to the chlorite-rich rock described above, although the distribution of the two types of grains in the hole is somewhat different. Chlorite schist pebbles also were mentioned in the report (Elders, 1973) on the DWR Dunes #1 drillhole.

Many other rock types, both igneous and metamorphic, were found in the cuttings. Generally only one or two such grains were found in a given interval; some were probably overlooked in other intervals. Their distribution is summarized in table 1.

Monomineralic fragments

In addition to the lithologic types described above, most samples contain varying proportions, up to 90 percent, of monomineralic grains. Grain size is generally 1-2 mm (very coarse sand). In figure 1, the monomineralic fragments are plotted as if they were a lithologic type. No attempt was made to estimate proportions of quartz, feldspar, and calcite within this fraction of the cuttings.

The most abundant mineral in this fraction is always quartz. It commonly occurs in two size fractions, 1-2 mm and 0.2-0.3 mm (fine sand). In some intervals, some quartz grains in the 1-2 mm size fraction are orange or yellow or brown, but the quartz grains of the fine sand fraction are clear or white, and generally are rounded. The coarser fraction ranges from rounded to subangular. At 3,380 to 3,410 feet there are many angular quartz grains. This is also a zone in which there are a number of rounded granules and pebbles (2-8 mm) of volcanic and metamorphic rocks (table 1). It is not

Table 1.--Distribution of miscellaneous minor rock types

Depth interval (feet)	Volcanic					Plutonic		Metamorphic		
								Quartzite		
	Pink	Red	Gray	Basalt	Misc. volcanic	Granitic	Dioritic	Red	Purple	Misc. Meta.
400-410--------	------	------	------	------	Pumice	------	------	X	-----	-----
420-430--------	X	------	------	------	------	------	------	-----	-----	-----
520-530--------	X Large phenocrysts	------	------	------	Purple, w/ flow banding	------	------	-----	-----	-----
530-540--------	X	------	------	------	------	X	------	-----	X	-----
540-550--------	X	------	------	------	------	------	------	-----	-----	-----
550-560--------	X With phenocrysts	------	------	------	Red breccia	------	------	-----	-----	-----
560-570--------	X With phenocrysts	------	X With feldspar	------	------	------	------	-----	-----	-----
570-580--------	X With phenocrysts	------	------	------	------	------	------	-----	-----	-----
580-590--------	X With Phenocrysts	------	------	------	------	------	------	X	-----	-----
590-600--------	X	------	------	------	------	5 percent of sample	------	-----	-----	-----
600-610--------	------	------	------	------	------	------	------	X	-----	-----
990-1,020------	------	------	------	------	------	Pebbles	------	-----	-----	-----
1,050-1,080-----	------	X	------	------	------	------	------	-----	X	-----
1,570-1,600-----	------	------	------	------	Breccia	------	------	-----	-----	-----
1,660-1,690-----	------	------	------	------	------	X	------	-----	-----	-----
1,780-1,810-----	------	------	------	------	------	X	------	-----	-----	-----
1,840-1,870-----	------	------	X Light gray w/feldspar	------	------	------	------	-----	-----	-----

Table 1.--Distribution of miscellaneous minor rock types--Continued

Depth interval (feet)	Volcanic					Plutonic		Metamorphic		
								Quartzite		
	Pink	Red	Gray	Basalt	Misc. volcanic	Granitic	Dioritic	Red	Purple	Misc. Meta.
1,870-1,900-------	------	------	------	------	------	X	------	X	-----	-----
2,080-2,110-------	X	------	------	------	------	------	------	-----	-----	-----
2,280-2,310-------	------	X With feldspar	------	------	------	------	------	-----	-----	-----
2,310-2,340-------	------	------	X	------	------	------	------	-----	-----	-----
2,340-2,370-------	X	X With feldspar	------	------	------	------	------	-----	-----	-----
2,400-2,430-------	------	------	------	X	------	X	------	-----	-----	-----
2,430-2,460-------	------	X With feldspar	------	------	------	Graphic	------	-----	-----	-----
2,545-2,550-------	------	------	------	Pebble	------	------	------	-----	-----	-----
2,750-2,780-------	------	------	X With black minerals	------	------	------	------	-----	-----	-----
2,780-2,810-------	X	------	------	X	------	------	------	-----	-----	-----
2,870-2,900-------	------	------	X With hornblende	------	------	------	------	X	-----	-----
3,110-3,140-------	------	------	------	Pebble	------	------	------	-----	-----	-----
3,320-3,350-------	------	------	------	------	------	X	------	-----	-----	-----
3,880-3,410-------	Pebble	------	------	Pebble	------	------	------	-----	-----	Green pebble
4,370-4,400-------	X	------	------	------	------	------	------	-----	-----	-----
4,500-4,530-------	-----	------	------	------	------	------	X	-----	-----	-----
4,530-4,560-------	------	------	X With hornblende	------	------	------	------	-----	-----	-----

Table 1.--Distribution of miscellaneous minor rock types--Continued

Depth interval (feet)	Volcanic					Plutonic		Metamorphic		
								Quartzite		
	Pink	Red	Gray	Basalt	Misc. volcanic	Granitic	Dioritic	Red	Purple	Misc. Meta.
4,820-4,850---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
5,000-5,030---------	-----	-----	X With hornblende	-----	-----	-----	-----	-----	-----	Gray/w hornblende
5,030-5,060---------	-----	-----	-----	-----	-----	-----	X	-----	-----	-----
5,210-5,240---------	-----	-----	-----	-----	-----	-----	X	-----	-----	-----
5,600-5,630---------	-----	-----	-----	-----	White	-----	-----	-----	-----	-----
5,620-5,640---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
5,940-5,960---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
6,000-6,030---------	X With biotite	-----	-----	-----	-----	-----	-----	-----	-----	-----
6,060-6,090---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
6,120-6,150---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
6,240-6,270---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----
6,330-6,360---------	-----	-----	-----	-----	-----	-----	-----	X	-----	-----
6,360-6,390---------	X	-----	-----	-----	-----	-----	-----	-----	-----	-----

known whether this material is a real stratigraphic feature or was artificially introduced.

Feldspar grains are common in the monomineralic fraction. Visual identification of separate feldspar fragments was positively noted only at 3,560-3,620 feet and below 5,400 feet, but detrital feldspar grains probably occur throughout the section, as both microcline and albite diffraction maxima are everywhere prominent in the whole-rock X-ray diffraction patterns. It would require considerable additional work, however, to be sure of the distribution of feldspars between lithologic types.

Calcite occurs as monomineralic grains in some intervals. Some monomineralic calcite grains are clear rhombs; in some, twinning is visible. Other grains are pink fibrous "satin spar" calcite. The fibrous calcite is common in the upper part of the section, above 2,250 feet; it is most prominent between 1,110 and 1,540 feet, less so from 1,840 to 2,250 feet. Clear rhombohedral calcite, on the other hand, is chiefly found in intervals below 5,300 feet.

Fossils (?)

Snail shells a few millimeters in length were found in the cuttings from 400 to 1,630 feet. In the interval 400-410 feet, they make up about 10 percent of the total material, and from 490-500 feet, about 5 percent is snail shells. They were never found embedded in any of the rock fragments. They are freshwater snails, not earlier than Pliocene, and probably of Pleistocene or more recent age (Warren Addicott, oral commun., June 6, 1973). It is not known whether these shells were introduced in the course of the drilling procedure or are indigenous to these horizons.

MINERALOGY

Seven mineral phases recur throughout the section: quartz, calcite, dolomite, potassium-rich feldspar, plagioclase (albite), chlorite, and illite. Quartz and calcite occur in every sample. Chlorite and illite are present in every sample X-rayed at or below 1,690 feet. A chlorite which survives heat treatment also occurs at 470-480 feet; between 400 feet and 1,450 feet it may be present but masked by montmorillonite. Illite occurs in small amounts at and below 500 feet. Quartz varies from 37 to 84 weight percent; calcite from 4 to 29 weight percent. Calcite occurs both as detrital grains and as fine-grained interstitial material in both siltstones and sandstones, as can be seen by immersing individual rock fragments in cold dilute HCl. Dolomite is present sporadically throughout the section down to 6,620 feet (table 2), and at 6,485-6,500 feet. The maximum amount of dolomite in any sample is 12 to 13 weight percent (at 830-860 feet), and it is generally less than 7 percent. It was never found visually, and its textural relationship to the other minerals is not known. Ankerite was tentatively identified at 3,680-3,710 feet, and possibly in six intervals between 5,190 and 6,500 feet.

The potassium-rich feldspar is present in all but six of the samples which were X-rayed; it varies in abundance from 7 to 40 weight percent (table 2). Seventy percent of all samples contain 15 percent or less K-feldspar, and only eight samples contain more than 20 percent K-feldspar.

A sample of K-feldspar grains, hand separated from cuttings at 6,180-6,210 feet, was X-rayed at slow scanning speed (1/8° per minute), and the pattern was analyzed by the method of Wright (1968) to determine composition and structural state. This feldspar is a

Table 2.--Variations in Mineral Content

[Numbers are weight percentages, determined from calibrated X-ray diffraction maxima, recalculated so that the sum of the weight percentages of these five minerals equals 100]

Depth interval (feet)	Quartz	Calcite	Dolomite	K-Feldspar	Albite
400-410	45	13	5	18	19
490-500	55	13	6	16	10
590-600	58	10	5	18	9
700-730	45	13	6	16	20
770-780	39	17	8	10	26
830-860	43	18	13	13	13
990-1,020	44	11	--	21	24
1,080-1,110	37	16	4	19	24
1,170-1,200	52	12	--	25	11
1,290-1,320	39	15	4	26	16
1,380-1,420	44	17	6	--	33
1,480-1,510	37	19	5	31	8
1,570-1,600	37	12	--	41	10
1,690-1,720	55	20	7	10	8
1,780-1,810	48	21	7	14	10
1,870-1,900	47	21	3	20	9
1,990-2,020	57	20	6	10	7
2,080-2,110	56	19	5	10	10
2,190-2,220	51	29	6	8	6
2,280-2,310	58	12	--	18	12
2,370-2,400	54	19	3	16	8

Table 2.--Variations in Mineral Content--Continued

Depth interval (feet)	Quartz	Calcite	Dolomite	K-Feldspar	Albite
2,490-2,505----------------	56	19	5	12	8
2,506-2,507----------------	44	29	5	13	9
2,603-2,630----------------	62	20	--	10	8
2,690-2,720----------------	84	6	--	7	2
2,780-2,810----------------	78	6	--	14	2
2,870-2,900----------------	73	14	2	8	3
2,990-3,020----------------	68	11	--	17	4
3,080-3,110----------------	68	16	3	9	4
3,170-3,200 ---------------	66	21	--	9	4
3,290-3,320 ---------------	71	18	--	8	3
3,380-3,410 ---------------	73	6	--	16	5
3,470-3,500 ---------------	58	19	6	12	5
3,590-3,620 ---------------	59	4	--	15	22
3,680-3,710 ---------------	61	16	4	9	10
3,785-3,800 ---------------	70	15	--	9	6
3,890-3,920 ---------------	67	17	--	8	8
3,980-4,010 ---------------	58	23	3	11	5
4,070-4,100 ---------------	59	20	5	10	6
4,100-4,130 ---------------	65	23	6	--	6
4,190-4,220 ---------------	58	19	7	11	5
4,295-4,310 ---------------	69	20	5	--	6
4,370-4,400 ---------------	68	11	2	11	8
4,480-4,500 ---------------	70	13	--	17	--

Table 2.--Variations in Mineral Content--Continued

Depth interval (feet)	Quartz	Calcite	Dolomite	K-Feldspar	Albite
4,580-4,610---------------	70	16	--	10	4
4,670-4,700---------------	64	19	4	9	4
4,790-4,820---------------	65	16	3	12	4
4,880-4,910---------------	52	17	4	27	--
4,970-5,000---------------	68	16	--	12	4
5,090-5,120---------------	69	15	--	11	5
5,190-5,210---------------	67	18	--	8	7
5,270-5,300---------------	67	19	--	8	6
5,390-5,420---------------	74	11	--	7	8
5,480-5,510---------------	66	17	--	11	6
5,570-5,600---------------	67	17	--	12	4
5,680-5,700---------------	69	16	--	10	5
5,790-5,820---------------	61	28	6	--	5
5,820-5,850---------------	58	13	--	10	19
5,850-5,880---------------	75	8	--	10	7
5,880-5,910---------------	71	13	--	10	6
5,910-5,940 --------------	65	17	3	10	5
5,940-5,970---------------	53	26	5	10	6
5,970-6,000 --------------	67	22	--	--	11
6,000-6,030 --------------	56	19	4	17	4
6,030-6,060 --------------	63	13	2	16	6
6,060-6,090 --------------	56	12	--	21	11
6,090-6,120 --------------	59	23	--	12	6

Table 2.--Variations in Mineral Content--Continued

Depth interval (feet)	Quartz	Calcite	Dolomite	K-Feldspar	Albite
6,120-6,150-------------	64	20	--	10	6
6,150-6,180-------------	63	16	--	14	7
6,180-6,210-------------	64	11	--	20	5
6,210-6,240-------------	63	21	--	11	5
6,240-6,270-------------	71	11	--	13	5
6,270-6,300-------------	70	13	--	12	5
6,390-6,420-------------	66	15	--	10	9
6,485-6,500-------------	65	20	4	8	3
6,590-6,620-------------	62	20	4	9	5
6,680-6,710-------------	75	16	--	7	2
6,770-6,800-------------	68	21	--	11	--
6,860-6,890-------------	68	17	--	11	4
6,920-6,950-------------	67	11	--	16	6
7,040-7,070-------------	70	21	--	8	1
7,130-7,160 ------------	56	19	--	17	8
7,190-7,220 ------------	59	25	--	10	6
7,310-7,340 ------------	70	25	--	--	5
7,642 ----------------	63	19	--	11	7
7,697 ----------------	63	16	2	11	8
7,739 ----------------	65	19	--	11	5
7,781 ----------------	73	12	--	11	4
7,790 ----------------	66	15	--	12	7

Tabel 2.--Variations in Mineral Content--Contined

Depth interval (feet)	Quartz	Calcite	Dolomite	K-Feldspar	Albite
7,800------------------	67	12	--	11	10
7,819------------------	54	9	--	11	26
7,896------------------	59	16	--	10	15
7,949------------------	80	7	--	9	4
7,967------------------	83	6	--	7	4
7,990------------------	72	13	--	11	4
8,010------------------	55	11	--	27	7
8,020------------------	64	19	--	13	4
8,031------------------	67	17	--	11	5

maximum microcline, with Or:Ab ratio 94:6 to 95:5. Because microcline (of undetermined composition and structural state) is also abundant in thin sectioned material from the 4,432-4,480 foot interval (Core #2), it is probable that most if not all the detrital K-feldspar is microcline.

Plagioclase feldspar in these rocks is albite, judging from the position of the strongest peak, which is consistently at 28.0°2θ (3.19Å) (Borg and Smith, 1968). Albite varies in abundance from about 2 to 33 weight percent. Only three whole-rock samples lacked the major plagioclase peak. About 75 percent of all samples contained 10 weight percent or less albite, and about half the samples contained between 5 and 10 weight percent.

Clay minerals

Because the drilling mud contained clay (reportedly montmorillonite), and samples of it were not available for mineralogic comparisons, interpretation of the whole-rock X-ray diffraction patterns is ambiguous. In the whole-rock diffractograms, the presence of montmorillonite is only suggested, but not demonstrated, by a broad low hump which occurs between 6° and 8°2θ (11.0-14.7Å) in most diffraction patterns down to 1,810 feet. In only three (770-800, 830-860, and 1,380-1,420-foot intervals) of 11 patterns is a low peak clearly developed in the 6° to 8°2θ region, and it is at 7.3°2θ (12.1Å), not at 6.3°2θ (14Å) as in the hand separated siltstone samples.

To overcome the ambiguity introduced by the drilling mud, clays were sought in hand separated, mud-free samples of rock types which showed X-ray peaks which might be either clay or chlorite. (The rock types studied were: pink siltstone; light gray siltstone; dark gray siltstone; silty, very fine-grained sandstone containing biotite; and chlorite-pyrite-rich grains.) In six samples of pink siltstone taken from depths ranging from 420 to 1,450 feet, the presence of montmorillonite was indicated by a shift of an X-ray peak at 6.3°2θ (14Å) to 5.2°2θ (16.9Å) upon glycolation. The resulting peak also was intensified.

In the interval 1,690-1,720 feet and below, 14Å peaks were small or absent in hand separated samples, and glycolation produced no changes in the X-ray diffraction pattern. The twelve samples which were glycolated came from intervals at 1,690-1,720, 1,990-2,020, 2,460-2,490, 2,603-2,630, 3,890-3,920, and 6,180-6,210 feet, and included the five rock types named above. The disappearance of montmorillonite does not coincide with change in the color of the siltstones in the 2,500 to 2,600-foot region; at 2,460-2,490 and 2,603-2,630 feet, both pink and light gray siltstones lack montmorillonite. Heat treatments were conducted on six samples in the 3,890-3,920 and 6,180-6,210-foot intervals. Heating at 400°C did not affect the 7Å peak in the silty, very fine-grained sandstone or chlorite-pyrite-rich grains, but slightly decreased the peak height in the light gray and dark gray siltstone samples. Heating at 400°C did not affect the 14Å peaks. Heating to 550°C destroyed the 7Å peaks and intensified the 14Å peaks in all samples; it also shifted the 14Å peaks to slightly lower d-spacings.

It is concluded that montmorillonite is present in the siltstone fragments down to a depth between 1,450 and 1,690 feet, but below that depth chlorite and illite are the dominant clay minerals. The chlorite in the siltstones, although classified as chlorite on the basis of heat treatments, has a weak 14Å peak, and in this respect is unlike the chlorite of the chlorite-pyrite-rich grains (probably of metamorphic origin) in this drillhole. It is not known whether this ambiguous 14Å peak simply results from the presence of very small amounts of chlorite, or whether composition, degree of crystallinity, and(or)fine grain size are contributing factors. Because of the small size and impurity of the samples, no attempt was made to appraise the presence or nature of interlayered illite-montmorillonite. Kaolinite could be present, especially in the siltstones, in minor amounts masked by chlorite. Since the amount of chlorite present in these rock fragments is small, the procedures necessary to establish the presence or absence of kaolin minerals were not undertaken.

White mica (illite)

Investigation of the distribution of white mica was complicated because coarse mica had been pumped into the hole to restore circulation. It is readily visible in the cuttings with the low-power microscope, but it is not possible to sort out in whole-rock X-ray diffractograms how much mica had been introduced and how much was part of the rock fragments. Therefore smear mounts of individual rock types, prepared from hand separated material, were used for identification of white mica. Twenty-two such specimens, representing seven rock types from six different depth intervals, were X-rayed. Seven samples were glycolated and heated. Two (of four) samples of fine to medium-grained sandstone contained no mica. The 10Å peak in each of the other twenty samples was a broad peak characteristic of illite rather than true muscovite. The conclusion is that where a sharp 10Å peak shows up in the whole-rock diffractogram, it is due to introduced mica, and is of no geologic significance.

Pyrite

Pyrite is found sporadically and in small amounts throughout the section below 2,800 feet. There are zones where it is absent and zones where it is more abundant. It is seldom abundant enough to be visible in the whole-rock X-ray diffractograms, being found in only seven patterns.

Native sulfur

Black grains, dominantly composed of amorphous sulfur, were found sporadically in the hole. They have an almost adamantine luster and may easily be mistaken for asphalt-like material. In the interval 2,506-2,507 feet, black sulfur grains comprise about 5 percent of the cuttings. The X-ray pattern of hand separated material shows peaks characteristic of crystalline native sulfur, possibly a trace of anhydrite, and much X-ray amorphous material. Two samples of black grains which were similar in appearance, from the interval 1,990-2,020 feet, produced X-ray patterns typical of amorphous material. The presence of X-ray amorphous sulfur can be demonstrated by heating material in a glass tube sealed at one end. Yellow sulfur crystals form on the cool surfaces of the glass above the heated sample. The presence of sulfur in black amorphous grains was confirmed by this method in the intervals 490-500 and 5,970-6,000 feet. In the latter interval, the black amorphous solid occurs as matrix material in which rock fragments are embedded.

Sulfur would normally be liquid at temperatures above 112.8°C (235°F) at atmospheric pressure. This temperature was exceeded in this hole below 1,300 feet. When the drilling penetrated liquid sulfur-bearing horizons, the sulfur would have been chilled so quickly by the water used in drilling that amorphous material formed instead of the usual crystalline varieties of sulfur. The sulfur is probably naturally occurring. No information has been received about any sulfur-bearing material being introduced into the hole; however, the possibility of contamination during drilling must be kept in mind.

<u>Mineral phases which were looked for but not found</u>

As was discussed in previous sections, kaolinite was searched for but not found.

A hand separated sample of the light green fine-grained material described on page 12 was X-rayed, glycolated, and heated to 400-450°C. The phases present were quartz, illite, and a trace of calcite. The biotite-type second-order basal peak which would be expected at 18°2θ if this were glauconite was absent (Brindley, 1951, p. 60); the biotite-type (060) 1.53-1.55Å peak, at about 60°2θ, would be masked by the quartz peak. None of the peaks were significantly affected by glycolation or heating. It was concluded that glauconite was not present in fragments of this type.

Epidote was tentatively identified in only one interval, 5,570-5,600 feet, but was not found elsewhere, either visually or by X-ray.

Zeolites were looked for, especially analcime, mordenite, clinoptilolite, laumontite, and wairakite. The only indication of any zeolite in the sediments was a single 5.57Å peak (15.9°2θ) in the interval 6,030-6,060 feet; however, the other strong analcime peaks were absent.

Graphite has been reported by Mary Mrose in Cores 1, 2, and 3 (oral commun., May 9, 1973). X-ray patterns of several hand separated samples which looked promising have revealed only quartz-calcite-feldspars-chlorite (a black vein) or X-ray amorphous material, discussed under Sulfur.

VARIATIONS IN MINERAL CONTENT

The variation in weight percentages of quartz, calcite, dolomite, microcline, and plagioclase, as deduced from peak heights in whole-rock X-ray patterns, are summarized in table 2. Illite and chlorite were not included in the calculation; illite because muscovite had been introduced into the hole; chlorite because it occurs in small amounts in every sample, and the variations in amount are probably close to the range of uncertainty of the measurements. Peak heights of the 7.1Å (12.5°2θ) peak range from 0.3 to 1.5 inches above background on a scale on which the major feldspar peaks (3.19Å and 3.24Å) range from 0 to 13 inches above background and the illite 10Å peak (including introduced white mica) ranges from 0.5 to 2.0 inches.

Although there is some tendency for the chlorite peak height to increase from about 0.5 inch above 4,000 feet to more than 1 inch below about 4,650 feet, peak height fluctuates between 0.5 and 1.5 inches down to 7,000 feet, and again below about 7,600 feet. Some samples with the highest chlorite peaks also contain dolomite (at 4,670-4,700, 5,790-5,820, and 6,485-6,500 feet), so that there is no obvious inverse relationship between chlorite and dolomite.

In order to determine approximately what peak heights mean in terms of weight percent, three sets of standards, using weighed amounts of quartz and calcite, quartz and Swiss adularia, and quartz and Amelia albite, were prepared and X-rayed. The height of the one strong calcite peak (3.04Å) was compared in turn to the heights of three different strong quartz peaks (4.26Å, 1.82Å, and 1.54Å) in the same X-ray diffraction pattern. Each of these ratios was plotted against weight percent calcite to establish a set of three determinative curves, one for each quartz peak used. Similar sets of curves were plotted for K-feldspar (3.24Å) and albite (3.19Å). For dolomite, the simplifying assumption was made that the dolomite (104) peak (2.89Å) behaves similarly to the calcite (104) peak (3.04Å), and the calcite curves were used. Because dolomite occurs in small amounts in these samples, the assumption is probably valid within the ±5 weight percent estimated accuracy of the method. The variation introduced by sampling procedures and variability within a single sample is at least 10 percent.

The figures obtained by use of the calibration curves are ratios of calcite/calcite + quartz, K-feldspar/K-feldspar + quartz, etc. These are converted to absolute percentages by solving four simultaneous equations (five, if dolomite is present) for each sample, yielding the values reported in table 2.

As can be seen from this table, there is no simple variation in proportions of mineral phases with depth, or in relation to the "impermeable zone" reported at about 6,100 feet. Changes in mineralogy, such as the disappearance of dolomite and appearance of chlorite (and epidote) reported by Muffler and White (1969) in the Salton Sea geothermal field and Wilson No. 1 well, are not clearly discernible in the cuttings of the Mesa 6-1 well. Although dolomite seems to decrease below 5,000 feet, chlorite is present in small amounts throughout the hole below about 1,700 feet, and sporadically at shallower depths. (See p. 18.)

LITHOLOGIC UNITS OF POSSIBLE USE FOR CORRELATION

The distribution of lithologic units, with relative abundance in each interval, is presented in figure 1.

There are few horizons in the hole which are of possible value for correlation with other drill holes.

(1) In the 990-1,020-foot interval, the cuttings are dominantly composed of pebbles of quartz, with some pebbles of feldspar, fine-grained pink granite, purple quartzite, sandstone, conglomerate, and miscellaneous metamorphic rocks. This zone is visually distinctive in this hole, but it is doubtful that it is of great lateral extent. However, immediately above it (from 860 to 990 feet) is a zone from

which neither core nor cuttings were available. It would be interesting to know whether that whole zone was composed of loose, pebbly material. There is also the possibility, which cannot be verified by available information, that the pebbles were introduced in the process of drilling.

(2) Several lines of evidence suggest that there is a surface of discontinuity, possibly a fault or an erosion surface, in the 2,500-2,600 foot region.

a) Above 2,500 feet, pink siltstone is the most abundant rock type; below 2,600 feet, medium to light gray siltstone predominates. (Between 2,500 and 2,600 feet, there is very little siltstone, and most of it is red siltstone (fig. 1).)

b) Some pink silty, very fine-grained sandstone occurs in the intervals 2,490-2,505 and 2,605-2,630 feet; and between 2,630 and 2,660 feet both pink silty, very fine-grained sandstone and light gray silty, very fine-grained sandstone with biotite are found. Yet for 1,000 feet above these zones, and throughout the hole below them, the light gray sandstone with biotite is the only silty very fine-grained sandstone.

c) Fibrous pink calcite grains are common above 2,300 feet, but very rare below 2,600 feet. These three sets of facts all suggest a change in oxidation-reduction conditions across the 2,500-2,600 foot zone.

d) Fine-grained green clay grains (illite-quartz-calcite) are abundant below 2,660 feet, but are absent (except a few in one interval) above 2,500 feet.

e) The fact that it was necessary to cement the 2,506-2,580 foot interval suggests the presence of a permeable zone which may be related to an overlying surface of discontinuity. The geophysical logs also indicate a permeable zone in this interval.

(3) Below 2,600 feet, the only possible marker horizons are several thin zones composed dominantly of fine to medium-grained sandstone and monomineralic grains, with very little siltstone. The one at 3,380-3,410 feet contains many angular quartz grains and pebbles (2-8 mm) of miscellaneous types (table 1). Other zones at 3,590-3,620 feet, 4,500-4,530 feet, and 5,000-5,060 feet are less distinctive, and of doubtful value for correlation.

(4) Dark gray siltstone is abundant only below 5,800 feet (fig. 1). There is one zone where almost all the siltstone is dark (6,240-6,330 feet), but this is probably the result of variations in oxidation-, reduction conditions rather than the presence of a stratigraphic unit.

It is interesting to note that in this drillhole, the change in the color of the siltstones at 2,500-2,600 feet coincides with the place where the temperature versus depth curve changes slope (Bureau of Reclamation, 1973, fig. 2, p. 16). This change in slope may be interpreted as occurring at the boundary between an upper zone of largely conductive heat flow and a lower zone of largely convective heat flow (Bureau of Reclamation, 1973, p. 26). Therefore it appears that the color change in the siltstones is correlated with present-day conditions, possibly controlled by preexisting geologic structures.

CORRELATIONS OF LITHOLOGY WITH POROSITY

A preliminary attempt to correlate variations in lithology (specifically percent siltstone) as determined by visual inspection of the cuttings with percent clay as interpreted from electrical logs is disappointing. In some 100-foot intervals the correlation is good, even excellent; but these are cancelled out by other 100-foot intervals in which there is no correlation or a negative correlation, leaving a net random correlation averaged over the entire region from 2,500 to 7,300 feet.

The correlation is especially poor in the intervals between 5,500 and 6,200 feet, where the log gives clay values of less than 50 percent over most of the interval, but visual inspection shows more than 75 percent siltstone for most of the interval and nowhere less than 40 percent. It is probable that the cuttings are biased due to incomplete recovery of poorly consolidated sandstones and sporadic sloughing.

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