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MINERALOGIC STUDY OF SOME JURASSIC AND CRETACEOUS CLAYSTONES AND SILTSTONES FROM WESTERN COLORADO AND EASTERN UTAH*

By

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission

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By Alice Dowse Weeks

ABSTRACT

The clay minerals and water-soluble minerals identified in 50 samples of siltstone and claystone representing formations from the Summerville formation of Jurassic age to the Dakota sandstone of Cretaceous age suggest some distinctive characteristics for these formations and some differences in source area or environment of deposition. Hydromica predominates in the samples of Summerville, Salt Wash member of the Morrison, and Burro Canyon formations, whereas montmorillonite derived from volcanic ash is found in the Brushy Basin member of the Morrison formation, and kaolinite in the Dakota sandstone is probably related to the regional unconformity at the base of the Dakota. Semiquantitative spectrographic analyses show the chief chemical constituents in the order of magnitude indicated by the minerals. Size analyses made by R. A. Cadigan show that most of the samples are siltstones.

INTRODUCTION

Following the summer field season of 1950 a mineralogic study was made in the Trace Elements Section Washington Laboratory of 50 siltstone and claystone samples from four localities in western Colorado and four in eastern Utah (fig. 1). These samples represent the fine-grained components of formations ranging from the Summerville formation of Middle Jurassic age to the Dakota sandstone of early Upper Cretaceous age. Most of the samples

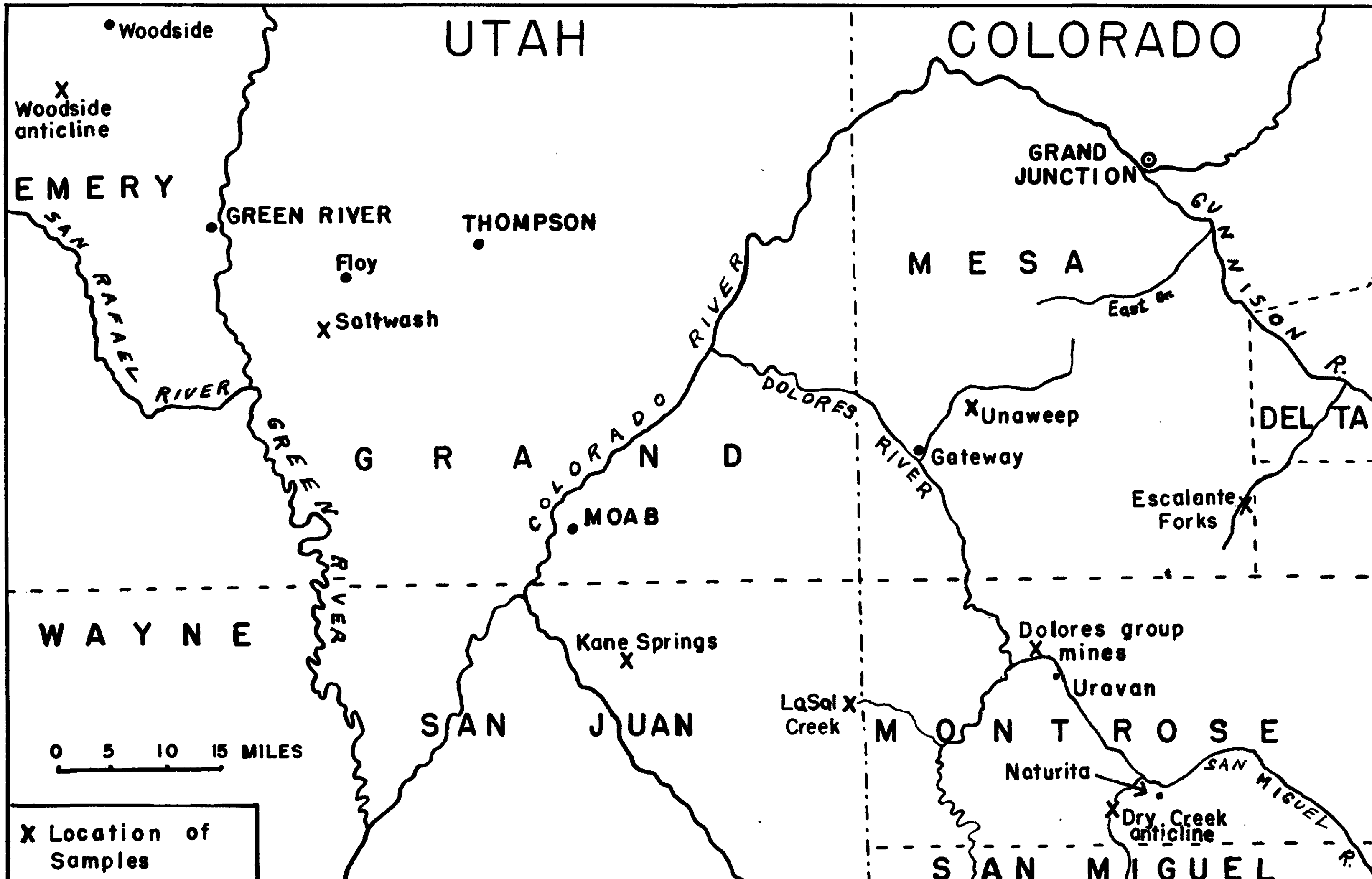

Figure I. Index Map of Localities

were collected by R. A. Cadigan and some by A. D. Weeks under the direction of L. C. Craig. The principal mineral constituents and the water-soluble minerals were identified by means of X-ray diffraction powder patterns, optical properties, and spectrographic analyses. Size analyses of the sediments were made by R. A. Cadigan in the Survey's sedimentology laboratory in Grand Junction, Colo.

The purpose of the study was to find out what minerals, particularly what clay minerals, characterize the fine sediments in each formation of this Jurassic-Cretaceous sequence that includes the important uranium-bearing strata of the Salt Wash member of the Morrison formation. Knowledge of the mineralogy might aid the stratigraphers in interpreting conditions of deposition, source of the sediments, stratigraphic breaks, and geologic history of the region. This work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Acknowledgments

Thanks are due L. C. Craig who discussed the stratigraphic problems of this group of formations in the field, and directed the collecting of the samples; R. A. Cadigan who collected most of the samples, and made the size analyses; E. A. Cisney for X-ray diffraction powder patterns; M. Ross for X-ray spectrometer patterns; H. W. Worthing, C. S. Annell, and J. N. Stich for spectrographic analyses; and M. E. Thompson for radiometric counts.

SAMPLE PREPARATION AND METHODS OF STUDY

Each sample was split into several portions: 200 g for mineralogic study, 50 g (sent to R. A. Cadigan) for size analysis, and 50 g (ground) for radiometric counting and other tests.

For mineralogic study 200 g of each sample was put in a large beaker with two liters of distilled water. Most of the samples were so friable and poorly cemented that they disaggregated easily in water. If not completely broken down at least enough fine clay was obtained for identification. Only two samples were so well cemented that they had to be disaggregated by repeated freezing and thawing. In order to avoid chemical change in the clay or water-soluble minerals no treatment other than stirring in distilled water and freezing and thawing was used for disaggregating. When each sample was sufficiently disaggregated, it was allowed to settle in water for several days or more. The water was siphoned from the beaker, filtered if not completely clear, and evaporated to obtain the water-soluble substances. The sediment settled with the coarse material on the bottom of the beaker, grading up into finer and finer-grained material. The sediment was undisturbed while drying under a heat lamp and the fine clay and silt were removed from the top layers for identification of clay minerals. Two samples were dried, crushed gently, and separated in the infrasizer. Although the infrasizer yields an excellent separation of fine fractions, it requires too large a sample and too much time to be practical for a large number of samples. The coarse fractions of a few samples were separated in heavy liquids for further mineralogic study. The clay fraction of each sample was examined with the petrographic microscope although some were too fine-grained, impure, or the grains were too coated with iron oxide to determine optical properties satisfactorily. The benzidine staining test was made on the ground rock sample and on the separated clay fraction.

X-ray diffraction powder patterns were obtained on the water-soluble minerals (residue from evaporated water in which sample was disaggregated), on the fine clay fraction and, for most samples, on a slightly coarser fraction. In December 1951 some of the samples were rerun on the X-ray spectrometer to check the powder pattern identification of clay minerals because of some conflicting results of the benzidine test.

Semiquantitative spectrographic analyses for more than 60 elements were made on the ground rock sample, and for Si, Al, Fe, Mg, K, Na, and Ca on the fine clay fraction. Qualitative spectrographic analyses were made on most of the water-soluble minerals. Some clay separates were examined with the electron microscope. Radiometric counts were made on the ground rock samples.

A brief description of the differences between the three principal groups of clay minerals and of the methods useful in distinguishing between the clay minerals follows:

In general the clay minerals cannot be satisfactorily distinguished from one another by methods based on optical and physical properties and chemical composition. Except for some dickite and kaolinite samples, clays are too fine-grained for much optical study, and in the types with considerable range of chemical composition the indices of refraction vary so that there is overlap between the groups. Also the red clays have a thin ferric oxide coating that may obscure the birefringence and refractive indices of the clay particles.

The kaolinite group is the only clay group with a fairly uniform chemical composition and little or no substitution. The hydromicas to a limited extent and the montmorillonite group of clay minerals to a great extent have a range in chemical composition because of substitution of various elements in the crystal lattice and exchange of cations (generally referred to simply as base exchange) between layers of the lattice. In general, montmorillonite adsorbs more water and swells much more than other types of clay, but the montmorillonite saturated with calcium swells much less than that saturated with sodium. The benzidine test distinguishes between the types of clay fairly well because montmorillonite usually gives a bright blue reaction, kaolinite rarely gives any reaction, and illite or hydromica gives no (or a faint blue) reaction.

Ideally the three principal groups of clay minerals--kaolinite, hydromica, and montmorillonite groups--can be distinguished from one another by X-ray diffraction patterns and by differential thermal analyses. To distinguish by X-ray between hydromica and montmorillonite we have used a 114.6-mm diameter camera and collimator that will show lines with *d*-spacings as large as 15 angstrom units, or an X-ray spectrometer which will show even larger spacings. Differential thermal analysis is considered an important means of distinguishing between the clay types. We have found that pure samples can be easily identified but mixtures seem to be as difficult to study on the differential thermal unit as by X-ray, and more difficult than by X-ray spectrometer. The electron microscope is useful in research on pure clay minerals but without time-consuming separations of fine-size fractions it does not help to identify the mixture of clay minerals in the fluvial and lacustrine mudstones of the Plateau.

RESULTS OF STUDIES

Mineralogy

The principal mineral constituents and water-soluble minerals of each sample are given in table 1. It should be noted that the water-soluble "minerals" were identified from the residue obtained by evaporating the water in which the sample was disaggregated and that they might not have been in the same form in the rock. The problems involved in the study of water-soluble salts in clays with high base exchange are familiar to soil scientists (Kelley, 1951). In a few samples containing montmorillonite clay and water-soluble salts, base-exchange may have taken place during the disaggregation process. If gypsum is present and a large amount of water is used in the laboratory treatment, gypsum will be dissolved and calcium will replace sodium in the montmorillonite, thereby changing the clay from a highly swelling to a slightly swelling type. This probably took place in the specimen of Brushy Basin shale from Kane Springs, Utah (table 1), which swelled when first placed in water and after two treatments it ceased swelling.

The number of samples from each formation is small and the following statements therefore are tentative. The chief clay mineral of the Summerville formation and Salt Wash member of the Morrison formation is hydromica. Samples of the Brushy Basin member of the Morrison from Utah contain chiefly montmorillonite, whereas most of the Brushy Basin samples from Colorado contain hydromica and kaolinite. Hydromica predominates in most of the samples of Burro Canyon formation but montmorillonite is the chief mineral in three samples of the same age collected in Utah. Kaolinite is the chief clay constituent in the two samples from the Dakota sandstone. Most of the X-ray powder patterns of the suspended material show quartz as well as clay minerals and indicate the presence of considerable finely divided quartz. Calcite is present in 46 percent of the gray samples and in 67 percent of the red samples and it seems to favor the red portion of the Summerville, Salt Wash, and Brushy Basin. Gypsum occurs in only 10 percent of the samples. Water-soluble sodium minerals such as thenardite, burkeite, halite, and soda niter occur in the samples near Woodside and Floy, Utah. Halite occurs also in samples from Dry Creek anticline, Dolores group and Escalante Forks, Colo. (fig. 1).

Spectrographic analyses

Semiquantitative spectrographic analyses made on the ground rock samples for more than 60 elements (table 2) show that only seven elements, Si, Al, Fe, Mg, K, Na, and Ca, occur in amounts greater than 0.1 percent. These elements go to make up quartz, various clay minerals, calcite, gypsum, and iron oxide pigment. In three samples barium is in the 0.1 to 1.0 percent spectrographic range and probably is present in barite. Of the elements in the range of 0.01 to 0.1 percent, Ti, Zr, and Cr probably occur chiefly in the heavy minerals and Mn in thin coatings of wad that may be seen in some clay samples.

Analyses were made of the fine clay separates for Si, Al, Fe, Mg, K, Na, and Ca. All of the clay samples contain more than 10 percent Si and Al, and 1.0 to 10 percent Fe, which may be either in the clay mineral or in pigment. Whether the elements Mg, K, Na, and Ca are present in amounts greater or less than 1.0 percent seems to be closely related to the kind of clay mineral that is present and to the presence of calcite or gypsum. Magnesium is greater than 1.0 percent in 88 percent of the montmorillonite samples and in 64 percent of the hydromica samples and less than 1.0 percent in the kaolinite samples. Sodium is greater than 1.0 percent in 87 percent of the swelling clay and in only 8 percent of the nonswelling clays. Potassium is present in amounts greater than 1.0 percent and there is more potassium than sodium in all of the hydromica samples. Calcium is greater than 1.0 percent in most of the samples known to contain gypsum or calcite.

Size analyses

R. A. Cadigan used 50 g of each sample in making the size analyses (table 3). Although the fine-grained layers of these formations are commonly referred to in the field as shale, claystone, or mudstone, the size analyses show that this group of 50 samples is chiefly siltstone; it includes 1 claystone, 9 silty claystones, 16 siltstones, 23 sandy siltstones, and 1 silty sandstone. Most of the claystone samples are from the Dakota sandstone and from the Brushy Basin member of the Morrison formation.

Radioactivity

The average equivalent uranium indicated by radiometric counts is 0.001^{+} percent for the 11 samples from the Salt Wash member of the Morrison formation and for the 9 samples from the Summerville formation, 0.001 percent for the 18 samples from the Brushy Basin member of the Morrison, 0.0007 for the 9 samples from the Burro Canyon formation, and negligible for the two samples from the Dakota sandstone. The number of samples is too small to indicate accurately the relative radioactivity of the formations.

A flux test for uranium on the residues obtained by evaporating the water in which the samples were disaggregated was negative. This suggests that water-soluble uranium, if present, is less than 0.1 part per million.

INTERPRETATION OF RESULTS

The samples of the Summerville formation and those of the Salt Wash member of the Morrison formation have similar clay constituents and are chiefly siltstones. No significant difference in source area is apparent but a difference in environment of deposition is suggested by the dominant red color of the Summerville samples.

A greater difference may be observed between the samples of Salt Wash and those of Brushy Basin members of the Morrison than between the samples of Salt Wash member and those of the Summerville formation. The chief clay constituent of the Brushy Basin samples is montmorillonite derived from volcanic ash, and these samples are finer grained than the samples from the Salt Wash. Montmorillonite is present in one of the 11 samples from the Salt Wash indicating that some volcanic activity preceded the main period of activity. The heavy minerals (fig. 2) in a sample of Brushy Basin from south of Floy, Utah, (fig. 1) consist chiefly of "books" of biotite, and euhedral crystals of apatite and zircon with some rounded grains of zircon and rutile. The biotite, euhedral zircon, and particularly the apatite could not have been transported far; therefore these are interpreted as phenocrysts from a crystal tuff or ash. Some nonvolcanic material was mixed with the volcanic ash of the Brushy Basin sediments. The Brushy Basin shale is typically a variegated unit with grayish red, reddish brown, and light greenish gray predominating. Locally, as near the Dolores group mines on Atkinson Mesa and on Blue Mesa (5 miles to the north), Colo., the color is chiefly light greenish gray, and some samples of this material contain kaolinite and hydromica. Tentatively, this green shale is thought to be an alteration of the variegated montmorillonitic shale.

One of the samples of Brushy Basin from the Woodside anticline, Utah, contains fossils that were identified by Raymond E. Peck (personal communication) as two common species of charophytes that indicate the shale from which the fossils were taken is Jurassic in age and correlates closely with the Morrison formation at the type locality near Denver.

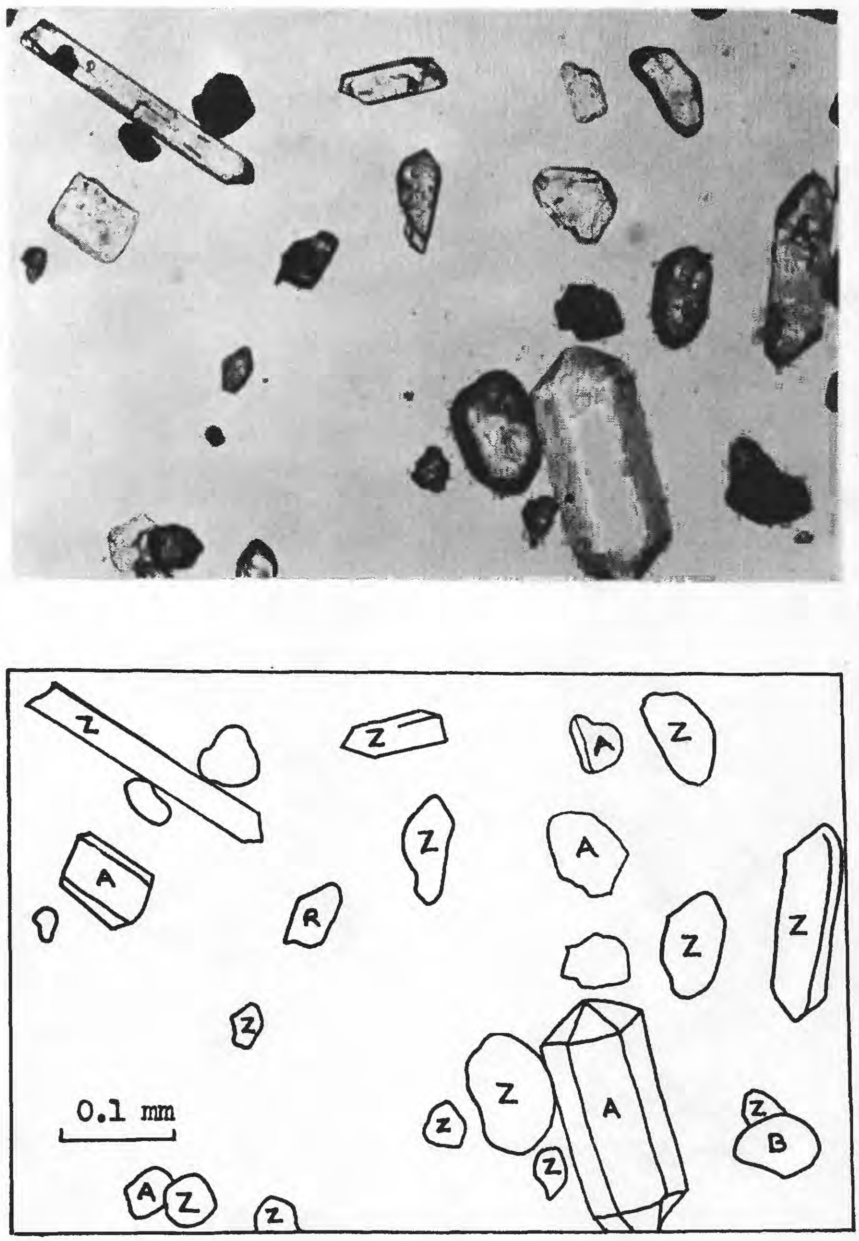

Figure 2.--Photomicrograph of heavy minerals in Brushy Basin shale member of the Morrison formation: zircon Z, apatite A, biotite B, and rutile R.

The occurrence of volcanic ash in the Brushy Basin above the uranium-bearing Salt Wash, in the Chinle formation (Triassic) above the uranium-bearing Shinarump conglomerate of Utah and Arizona, and in the White River formation (Oligocene) above uraniferous lignites in South Dakota has suggested volcanic ash as a source of uranium. Too few samples have been studied to determine accurately the radioactivity of unaltered samples of Brushy Basin shale and whether uranium has been or is now being leached from it. However, these samples do not show more than average radioactivity or give any indication of water-soluble uranium and the writer believes the Brushy Basin shale is not the principal source of the uranium ore in the Salt Wash sandstone.

The samples of Burro Canyon formation are dominantly gray and contain less clay derived from volcanic ash and more detrital material than the samples of Brushy Basin. It has not been determined whether the Burro Canyon formation and its correlative, the Cedar Mountain formation of the Woodside anticline, Utah, are in part reworked Brushy Basin shale.

If kaolinite, found in the two samples of silty claystone from the Dakota sandstone, is typical of the formation, it may be interpreted as non-volcanic in origin. The kaolinite is probably related to the regional uncomformity at the base of the Dakota and is the product of conditions that caused a high degree of weathering of feldspar.

REFERENCES

Kelley, W. P., 1951, Alkali soils, New York, Reinhold Publishing Corp.

Weeks, A. D., 1952, Summary report on Colorado Plateau clay studies through April 30, 1952: U. S. Geol. Survey Trace Elements Mem. Rept. 437, 17 pp. (Official Use Only).

Table 1.--Mineral constituents of claystones and siltstones

	Woodside anticline, Utah	Salt Wash, S. of Floy, Utah	Kane Springs, Utah	La Sal Creek, Utah	Dry Creek anticline, Colorado	Dolores group mines, Colorado	Unaweep Canyon, Colorado	Escalante River, Colorado
Upper Cretaceous Dakota sandstone					L466 Kaolinite, hydromica and quartz 5Y 8/2 Gypsum (L)			L458 Kaolinite, quartz, and hydromica 5YR 7/1 unknown (M)
Lower Cretaceous Burro Canyon and Cedar Mt. fms.	L538 Montmorillonite, quartz, and hydromica N8 Thenardite (M)	L440 Montmorillonite, hydromica, and quartz N7 Gypsum (M)	L477 Hydromica, quartz, and calcite 5Y 8/1 Calcite (VS)	L473 Montmorillonite, quartz, calcite and kaolinite 5GY 8/1 Calcite (VS)	L465 Hydromica, quartz, and calcite 5GY 8/1 Calcite (VS)	L467 Kaolinite and quartz 5Y 8/1 Calcite (VS)	L454 Hydromica, quartz, calcite, and kaolinite 5GY 8/1 Calcite (VS)	L459 Hydromica, quartz, and kaolinite 5Y 8/1 Halite (VS)
	L537 Hydromica, quartz, and montmorillonite 5YR 7/1 Burkeite (S)	L441 Hydromica (?) and quartz 5GY 8/1 Thenardite (S)	L478 Hydromica, quartz, and calcite 5Y 8/1 Calcite (VS)					
Jurassic Morrison formation	L536 Montmorillonite, hydromica, quartz and calcite 5Y 8/1 Burkeite (VS)	L442 Montmorillonite, quartz, and chlorite 5YR 8/1 ---	L479 Montmorillonite and quartz 5YR 8/1 Gypsum (L)	L474 Montmorillonite and quartz 5Y 8/1 ---	L464 Hydromica and quartz 5G 8/1 Halite (VS)	L468 Kaolinite, hydromica, and quartz N8 Halite and unknown (VS)	L455 Montmorillonite and quartz 5Y 8/1 Calcite (VS)	L460 Kaolinite and quartz 10R 7/2 Calcite (VS)
Brushy Basin member	L535 Montmorillonite, hydromica, quartz and calcite 5GY 8/1 Thenardite (M)	L443 Montmorillonite and quartz N6 Thenardite (M)				L469 Kaolinite, hydromica, and quartz 5YR 7/1 Calcite and unknown (VS)		
		L444 Montmorillonite, hydromica, and quartz 5YR 8/1 Thenardite (M)				L470 Montmorillonite and quartz 5GY 8/1 Halite and unknown (VS)		
		L445 Montmorillonite, quartz, and calcite 5YR 7/1 Halite and sodaniter (M)				L539 Montmorillonite and hydromica 5G 7/1 Gypsum (VS)		
		L446 Montmorillonite and calcite 5YR 8/2 ---						
		L447 Montmorillonite, hydromica, quartz, and calcite 5YR 8/1 Thenardite (M)						
Salt Wash member	L534 Hydromica, quartz, and calcite 5YR 7/1 ---	L448 Hydromica and quartz 5GY 7/1 ---	L480 Hydromica, quartz, and calcite 5YR 7/1 Calcite (VS)	L475 Hydromica, quartz, and calcite 5YR 8/1 ---		L471 Hydromica, quartz, calcite, and kaolinite 5Y 8/1 Calcite and unknown (VS)	L456 Hydromica, quartz, and calcite 5GY 7/1 Calcite (VS)	L461 Hydromica, quartz, and kaolinite N7 Halite (VL)
	L533 Hydromica, quartz, and calcite N8 Burkeite (S)	L449 Hydromica and quartz 5YR 8/3 Thenardite (M)						
		L450 Hydromica, quartz, and montmorillonite 5YR 8/1 Halite and sodaniter (M)						
		L451 Hydromica, quartz, and calcite 5YR 8/3 Thenardite (VS)						
Summerville formation	L532 Hydromica, quartz, calcite, and kaolinite 5YR 8/2 ---	L452 Hydromica and quartz 5GY 8/1 Thenardite (S)	L481 Hydromica, kaolinite, and quartz 5YR 8/4 ---	L476 Hydromica, quartz, and calcite 10R 5/4 Calcite (VS)	L463 Hydromica, quartz, and calcite 10R 5/3 Calcite (VS)	L472 Hydromica and quartz 5YR 6/4 Calcite and unknown (VS)	L457 Hydromica, quartz, and calcite 10R 5/3 ---	L462 Hydromica, quartz, and calcite 5YR 7/2 Burkeite (S)
		L453 Hydromica and quartz 5YR 8/1 Thenardite and gypsum (M)						

Explanation:--Each block shows the lab. no.; chief mineral constituents; color of dry samples from Rock Color Chart (Nat. Res. Council, 1948); and relative amounts of water-soluble minerals (approx. percents): VL 5-10, L 2-5, M 0.5-2, S 0.1-0.5, VS less than 0.1, from the formation and locality listed.

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Table 2.--Semiquantitative spectrographic analyses, in percent, of ground rock samples. Analyses by H. W. Worthing and C. S. Annell.

Formation	Sample no.	Over 10	1.0-10.0	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001
Woodside anticline, Utah							
Kcm	L 538	Al Si	Fe Na K Ca Mg	--	Ti Ba Sr Mn Sc	Zr Pb Ga Co Cr V Ni Y Cu	Yb
Kcm	L 537	Al Si	Fe K Na Mg	Ca	Ti Ba Sr Sc Mn	Zr V Ga Ni Y Cr Cu	Yb
Jmbb	L 536	Si Al	Ca Fe Na K	Mg	Mn Ti Ba Sr Sc	Zr V Ga Cr Cu Ni Y	Yb
Jmbb	L 535	Si Al	Ca Fe Na K Mg	--	Ti Ba Mn Sr Sc	Zr V Cr Ga Ni Y Cu	Yb
Jmsw	L 534	Al Si	Fe Ca K Mg Na	--	Ti Ba Sr Mn Sc	Cr Zr V Ni Ga Pb Y Cu	Yb
Jmsw	L 533	Si Al	Ca Fe K	Na Mg	Ba Ti Mn Sr	Zr Cr V Ga Ni Y Cu	Yb
Js	L 532	Al Si	Ca Fe K Mg Na	--	Ba Ti Mn Sr Sc	Zr Co Cr Ni Ga Pb V Y Cu	Yb
Salt Wash, south of Floy, Utah							
Kbc	L 440	Al Si	Ca Mg Fe Na	K	Ti Ba Zr V Mn Sr	Ga Y Pb Ni Cu Cr La	Mo Yb
Kbc	L 441	Al Si	Mg K Na Fe	Ca	Ti V Mn	Ba Co Ga Zr Sr Y Ni Cr Cu	La Yb
Jmbb	L 442	Al Si	Mg Fe Na	K Ca	Ti Ba Zr V Mn Sr	Ga Y Pb Cr Ni La Cu Mo	Yb
Jmbb	L 443	Al Si	Fe Na	Mg K Ca	Ti Ba Zr V Mn	Ga Cr Sr Cu Ni Mo La	Yb
Jmbb	L 444	Al Si	K Na Fe Mg	Ca	Ti V Ba Mn Zr	Cr Ga Sr Ni Cu Y La	Mo Yb
Jmbb	L 445	Al Si	Na Ca Mg Fe	K	Ti Mn Zr	Ba Ga V Sr Pb Y Cu La Ni Cr	Mo Yb
Jmbb	L 446	Al Si	Na Mg Fe	Ca K	Ti Ba Zr V Mn Sr	Y Pb Cr Ni Cu Mo Ga La	Yb
Jmbb	L 447	Si	Al Ca Na Mg K	Fe	Mn V Ti Ba Sr	Ga Zr Y Pb Cr Cu Ni	La Yb
Jmsw	L 448	Al Si	Ca K Mg Fe	Na	Ti V Mn Ba Sr Zr	Ga Cr Y Pb Cu Ni La	Mo Yb
Jmsw	L 449	Al Si	K Fe Mg Na	Ca	Ti Ba V Mn Zr	Cr Ga Sr Pb Cu Y Ni La	Mo Yb

Table 2.--Continued.

Formation	Sample no.	Over 10	1.0-10.0	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001
Salt Wash, south of Floy, Utah							
Jmsw	L 450	Al Si	Fe K Na Mg Ca	--	Ti Sc Zr Sr	Ba Pb Mn Ga V Cr Cu Ni	Yb
Jmsw	L 451	Si Al	Fe Ca K Mg Na	--	Sr Ti Ba Sc Mn Zr	Ga V Cr Cu Ni	Yb
Js	L 452	Si Al	K Fe Mg	Ca Na	Ti Ba Sr V Sc Zr	Mn Ga Cr Cu Ni	Yb
Js	L 453	Si	Al Ca Fe K Na	Mg	Ti Sr Sc Zr	V Ba Mn Ga Cr Cu Ni	Yb
Kane Springs, Utah							
Kbc	L 477	Si Al	Fe Mg K Ca	Na	Ti Sr Sc Ba Mn Zr	Ga Ni V Cr Cu Y	Yb
Kbc	L 478	Si Al	Ca Fe K Mg	Na	Ti Ba Sr Sc Mn	Zr Ga V Cr Ni Y Cu	Yb
Jmbb	L 479	Si Al	Mg Fe Ca	Na K	Ti Ba Sr Zr Sc	Mn Ga V Y Cr Cu	Yb
Jmsw	L 480	Si Al	Ca Fe K Mg	Na	Ti Ba Sr Mn Sc Zr	V Ni Cr Ga Y Cu	Yb
Js	L 481	Si Al	K Fe Ca Mg	Na	Ti Cr Zr Sr Ba Sc	Ga Ni Mn V Y	Cu
La Sal Creek, Utah							
Kbc	L 473	Si Al	Fe Ca Mg	K Na Ba	Ti Mn Sr	Zr Ni V Cr Pb Ga Mo Cu	Yb
Jmbb	L 474	Si Al	Fe K Mg Ca	Na Ba	Ti Sr Sc Zr Mn	Ga V Pb Ni Y Cr Cu	Yb
Jmsw	L 475	Si Al	Fe Ca K Mg	Na	Ti Ba Mn Sr Sc	V Co Zr Ga Cr Ni Cu	Yb
Js	L 476	Si Al	Ca Mg Fe K	Na	Ba Ti Sr Mn Sc	Zr Ni Cr V Ga Y Cu	Yb
Dry Creek anticline, Colorado							
Kd	L 466	Si Al	Fe K Mg	Ca Na	Ti Ba Sr Sc Cr Zr	V Ni Ga Pb Mn Y Cu	Yb
Kbc	L 465	Si Al	Fe Ca K Mg	Na	Ti Ba Sr Sc Mn Zr	V Cr Ni Y Ga Cu Mo	Yb
Jmbb	L 464	Si Al	Fe K Mg Na	Ca	Ti Ba Sr Sc	Zr Ga Mn Ni Cr V Y Cu Mo	Yb
Js	L 463	Al Si	Fe K Ca Mg Na	--	Ba Ti Mn Sr Sc	Pb Ni Cr Y Zr Ga V Cu	Yb

Table 2.--Continued.

Formation	Sample no.	Over 10	1.0-10.0	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001
Dolores group mines, Colorado							
Kbc	L 467	Al Si	Fe	K Mg	Ca Na Ti Zr Sc	V Sr Cr Mn Ba Cu Ga Ni	--
Jmbb	L 468	Al Si	Fe	K Ca Mg	Na Sr Ti Sc Zr	Ga Pb V Ba Cr Mn Cu Ni	--
Jmbb	L 469	Al Si	Fe K	Mg Ca Na	Ti Sc Zr Sr	Ga V Cr Ba Cu Mn Ni	Yb
Jmbb	L 470	Al Si	Fe Mg K	Na Ca	Ti Sr Mn Zr Sc	Pb Ba Ga V Cr Cu Ni	Yb
Jmbb	L 539	Al Si	Fe K Mg	Ca Na	Ti Sr Zr Sc Ba Mn	Ga Pb Ni Y V Cr	Cu Yb
Jmsw	L 471	Si Al	Fe K Ca Mg	Na	Ti Mn Sr V Zr Sc	Ba Ga Cr Cu Ni	Yb
Js	L 472	Si Al	Fe K	Ca Mg Na	Ti Mn Ba Sr Zr Sc	Pb V Ga Cr Cu Ni	Yb
Unaweep, Colorado							
Kbc	L 454	Al Si	Fe K	Mg Ca Na	Ti Ba Sr Sc Zr	Cr Ni V Y Mn Ga Cu	Yb
Jmbb	L 455	Al Si	Fe K Ca Mg	Na Ba	Ti Sr Mn Sc	Zr Ni Y V Ga Cr Cu	Yb
Jmsw	L 456	Al Si	Fe K	Na	Ti Sr Ba Sc Mn	Cr Zr Y V Ni Cu Ga	Yb
Js	L 457	Al Si	Fe K Ca Mg Na	--	Ba Ti Sr Sc Mn	Cr Y Zr V Ni Cu Ga	Yb
Escalante Forks, Colorado							
Kd	L 458	Al Si	Fe K	Mg Na Ca	Ti Sr Ba Cr Sc Zr	Pb Ga Ni Y V Cu Mn	Yb
Kbc	L 459	Al Si	Fe K	Mg Ca Na	Ti Ba Sr Sc	Y Ni V Mn Ga Zr Cr Cu	Yb
Jmbb	L 460	Al Si	Fe Ca K	Mg Na	Sr Ti Ba Zr Sc	Pb Mn Y Cr V Ni Cu Ga	Yb
Jmsw	L 461	Si	Al Na Fe K	Mg Ca	Sr Ti Ba	Mn V Ni Zr Cr Ga Cu	Yb
Js	L 462	Si Al	Ca Fe K Mg Na	--	Ba Sr Ti Mn Sc	Ni Cr Pb V Y Cu Ga Zr	Yb

Table 3.--Results of size analysis of samples from the Summerville formation, the Salt Wash and Brushy Basin members of the Morrison formation, the Burro Canyon formation, Cedar Mountain formation, and Dakota sandstone by R. A. Cadigan.

Formation	Sample no.	Percent				Classification 1/
		Sand	Coarse silt	Fine silt	Clay	
Woodside anticline, Utah						
Kcm	L-538	9.81	18.75	29.91	41.53	Siltstone
Kcm	L-537	5.05	40.29	21.94	32.72	Siltstone
Jmbb	L-536	5.42	16.40	18.75	59.43	Silty claystone or silty shale
Jmbb	L-535	8.25	22.71	14.43	54.61	Silty claystone or silty shale
Jmsw	L-534	5.06	10.83	28.64	55.47	Silty claystone or silty shale
Jmsw	L-533	30.50	33.95	8.99	26.56	Sandy siltstone
Js	L-532	9.99	15.55	29.92	44.54	Sandy siltstone
Salt Wash near Floy, Utah						
Kbc	L-440	5.58	41.21	32.48	20.73	Siltstone
Kbc	L-441	3.60	33.05	32.20	31.15	Siltstone
Jmbb	L-442	5.51	33.55	28.62	32.32	Siltstone
Jmbb	L-443	18.51	54.67	16.42	10.40	Sandy siltstone
Jmbb	L-444	2.16	10.79	43.05	44.00	Siltstone
Jmbb	L-445	9.34	21.66	40.54	28.46	Siltstone
Jmbb	L-446	4.07	12.47	33.30	50.16	Silty claystone or silty shale
Jmbb	L-447	8.09	25.91	30.47	35.53	Siltstone
Jmsw	L-448	22.49	22.53	17.40	37.58	Sandy siltstone
Jmsw	L-449	6.47	23.98	30.49	39.06	Siltstone
Jmsw	L-450	4.75	51.25	16.27	27.73	Siltstone
Jmsw	L-451	26.56	34.31	11.84	27.29	Sandy siltstone
Js	L-452	29.24	34.72	17.61	18.43	Sandy siltstone
Js	L-453	15.56	29.75	15.16	39.53	Sandy siltstone

Table 3.--Continued.

Formation	Sample no.	Sand	Percent Coarse silt	Fine silt	Clay	Classification 1/
Kane Springs, Utah						
Kbc	L-477	3.76	40.89	17.90	37.45	Siltstone
Jmbb	L-478	1.32	3.76	15.39	79.53	Claystone or shale
Jmbb	L-479	3.54	17.02	45.28	34.16	Siltstone
Jmsw	L-480	25.30	28.56	14.25	31.89	Sandy siltstone
Js	L-481	1.98	30.88	29.94	37.20	Siltstone
La Sal Creek, Utah						
Kbc	L-473	52.53	31.51	8.01	7.95	Silty sandstone
Jmbb	L-474	5.74	17.36	29.91	46.99	Siltstone
Jmsw	L-475	4.19	38.26	30.32	27.23	Siltstone
Js	L-476	24.18	39.29	19.18	17.35	Sandy siltstone
Dry Creek anticline, Colo.						
Kd	L-466	1.14	14.74	25.78	58.34	Silty claystone or silty shale
Kbc	L-465	17.61	77.19	2.13	3.07	Sandy siltstone
Jmbb	L-464	19.56	35.83	19.34	25.27	Sandy siltstone
Js	L-463	27.14	49.62	13.25	9.99	Sandy siltstone
Dolores Group, near Uravan, Colo.						
Kbc	L-467	23.04	30.87	12.89	33.20	Sandy siltstone
Jmbb	L-468	20.16	21.26	12.79	45.79	Sandy siltstone
Jmbb	L-469	12.01	40.95	23.04	24.00	Sandy siltstone
Jmbb	L-470	7.99	40.59	29.22	22.20	Siltstone
Jmsw	L-471	13.54	49.44	21.01	16.01	Sandy siltstone
Js	L-472	19.08	55.50	16.46	8.96	Sandy siltstone
Unaweep Canyon, Colo.						
Kbc	L-454	20.61	50.01	16.13	13.25	Sandy siltstone
Jmbb	L-455	5.86	17.44	16.51	60.19	Silty claystone or silty shale
Jmsw	L-456	27.19	22.65	12.95	37.21	Sandy siltstone
Js	L-457	17.46	45.73	18.28	18.53	Sandy siltstone

Table 3.--Continued

Formation	Sample no.	Sand	Percent Coarse silt	Fine silt	Clay	Classification 1/
Escalante Canyon near Escalante, Colo.						
Kd	L-458	4.33	2.79	17.12	75.76	Silty claystone or silty shale
Kbc	L-459	10.41	33.74	20.12	35.73	Sandy siltstone
Jmbb	L-460	16.70	39.13	15.65	28.52	Sandy siltstone
Jmsw	L-461	9.88	70.79	8.07	11.26	Sandy siltstone
Js	L-462	7.41	6.16	18.53	67.90	Silty claystone or silty shale

1/ Follows Wentworth classification of fine-grained clastic sediments, modified slightly by R. A. Cadigan, U. S. Geological Survey.