Petrology of the Triassic Moenkopi Formation and Related Strata in the Colorado Plateau Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 692

Prepared on behalf of the
U.S. Atomic Energy Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By ROBERT A. CADIGAN

With a section on STRATIGRAPHY

By J.H. STEWART

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Sedimentary petrology of a continental–marginal marine red-bed sedimentary formation interpreted from regional trends of mineral composition and textural measures, and orientation of depositional slope directions

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1971

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 74–611066

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.50 (paper cover)

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PETROLOGY OF THE TRIASSIC MOENKOPI FORMATION AND RELATED STRATA IN THE COLORADO PLATEAU REGION

By Robert A. Cadigan

ABSTRACT

The Moenkopi Formation of Triassic(?) and Early and Middle(?) Triassic age underlies the Shinarump Member of the Chinle Formation, one of the major uranium-ore-bearing rock units in the Colorado Plateau region. For this reason, and to provide stratigraphic control for further exploration, an investigation of the stratigraphy and petrology of the Moenkopi Formation was made. This is a report on the petrologic part of the investigation.

The Moenkopi Formation in the Colorado Plateau region disconformably overlies various Permian age formations. Its lower boundary is the contact of Permian and Triassic rocks in the region. It is disconformably overlain by the Upper Triassic Chinle Formation.

The Moenkopi is one of the typical "red-bed" units in the region of study. It is divided into 12 formal and seven informal members. The members at each area, listed in ascending order, are: in southwestern Utah and northwestern Arizona, Timpoweap, lower red, Virgin Limestone, middle red, Shnabkaib, and upper red; in north-central and east-central Arizona, the Wupatki, Moqui, and Holbrook; in southeastern Utah, the Hoskinnini, lower slope-forming, Sinbad Limestone, ledge-forming, upper slope-forming, and cliff-forming; and in the salt anticline region of east-central Utah and west-central Colorado, the Tenderfoot, Ali Baba, Sewemup, and Pariott. In northeastern Utah, northwestern Colorado, and northwestern New Mexico the Moenkopi is of Early Triassic age and is not divided into members. The Woodside, Thaynes, and Mahogany Formations are laterally equivalent predominantly red strata in the western Uinta Mountains of northern Utah. The red beds of the Lower Triassic upper member of the Permian and Triassic State Bridge Formation in northern Colorado are considered as equivalent to the Moenkopi.

The Moenkopi was deposited in continental fluviatile environments in the east and south, and in marginal marine and marine environments in the west. The depositional area drained generally northwestward and occupied at least the central, southern, western, and northern parts of the Colorado Plateau, and additional areas in eastern Nevada, northwestern Utah, and southern Wyoming and Idaho. The sequence of tectonic events preceding and accompanying deposition of the Moenkopi sediments is interpreted to have affected much of what are now the southwestern and Rocky Mountain regions of the United States. The principal rock facies of the Moenkopi are thin- to thick-bedded siltstone and sandstone, shaly siltstone, structureless mudstone, mud-pellet conglomerate, limestone gravel conglomerate, gypsum, and limestone. Most rock units are flat bedded with horizontal laminae, ripple-marked bedding planes, or small-scale cross-laminations within the beds, although some of the thick coarser textured sandstones are crossbedded, have cut-and-fill structures, and contain pebbles.

The samples studied for this report were predominantly of red coarse siltstone and very fine grained sandstone which occur together to form the most typical strata. Samples were collected from 71 localities. Petrographic data were obtained from the samples by grain-size analyses, mineral grain counts, point-count modal analyses, and rock classification studies. Variation in the compositional and textural data was studied and tested for regional trends using maps, statistical procedures, and trend-surface analysis.

The rocks of the Moenkopi are chiefly varieties of orthoquartzite, arkose, graywacke, limestone, and gypsum. The major detrital mineral components are grains of quartz, chert, chalcedony, albite, oligoclase, orthoclase, and sanidine(?) and fragments of quartzite, granite, felsite, rock of unknown origin, and altered silicified devitrified tuff. Present in smaller proportions are flakes of biotite, muscovite, and chlorite and, in still smaller amounts, grains of zircon, tourmaline, garnet, staurolite, rutile, apatite, magnetite, ilmenite, leucoxene, altered amphibole, and miscellaneous minerals. The nondetrital mineral components are calcite, dolomite, gypsum, barite, authigenic quartz as overgrowths on quartz grains, anatase, and authigenic orthoclase as overgrowths on detrital particles of orthoclase. Iron oxides, either alone or mixed with clay, are common. cementing components.

The sandstones of the Moenkopi are generally very fine grained and moderately sorted, with slightly skewed and moderately peaked grain-size distributions. The siltstones are generally coarse grained and are moderately to poorly sorted, with slightly skewed and moderately peaked grain-size distributions. The claystones are coarse grained and poorly sorted, with negatively skewed and flattened grain-size distributions.

Classes of rocks and rock components are partly affected by diagenesis. Diagenetic change has altered both the particle-size distributions and the composition of the original sediment. The detrital components most affected were feldspars, biotite and the other heavy minerals, volcanic ash, tuff and pumice fragments, and detrital clays.

Textural changes have resulted from the loss of particles which have been replaced by carbonates or altered to clay and from the formation of overgrowths on grains of quartz and feldspar. In many rocks the clay or silt matrix has been partly or completely replaced by carbonates.

Illite is the dominant clay mineral; compared with illite, quantities of kaolinite and chlorite clays are generally minor, although both are singly dominant in some strata. Combinations of illite-montmorillonite and chlorite-illite with mixed-layer montmorillonite also occur.

Sediment moved across the sloping area of deposition of the Moenkopi generally from southeast to northwest. Source areas are interpreted to have been the tectonically active Uncompahgre highland area of southwestern and central Colorado and the slowly rising positive areas located in what is now the Basin and Range province of southern Arizona and southern New Mexico.

Relatively high proportions of certain detrital minerals are present in sediments adjacent to specific source areas. The Uncompahgre, southeastern Arizona, and southwestern New Mexico highlands seem to have been sources of feldspar. The highlands of southern New Mexico and southern Arizona seem to have been sources of silicified-rock fragments. Regional variation in grain-size properties shows trends of decreasing grain size, improved sorting, and decreasing skewness and kurtosis from southeast to northwest.

The Moenkopi Formation was laid down on a partly eroded depositional plain which subsided at a low to moderate rate. The source areas underwent tectonic uplift at a rate that varied from low to very low. Sediments eroded from the weathered source areas were fine textured and altered. Erosion and deposition took place in a warm arid climate which produced oxidized sediments and evaporite basins.

Decreases in the rate of uplift of the source areas at times reduced the supply of detritus and permitted the invasion of alluvial areas by marine environments from the west. Toward the end of Moenkopi deposition, the rate of source area uplift slowly increased and the increasing flow of detritus caused the marine environment on the west to retreat westward beyond the borders of the Colorado Plateau region.

Deposition of the Moenkopi was halted by tectonic adjustments that resulted in possibly slight regional uplift, or at least termination of subsidence in the area of deposition, and fluviatile erosion of the depositional surface.

INTRODUCTION

A program of stratigraphic studies in the Colorado Plateau region was begun in July 1947 by the U.S. Geological Survey on behalf of the U.S. Atomic Energy Commission. One of the objectives of the program was to provide a sound foundation for stratigraphic nomenclature within the Colorado Plateau region as a guide to contemporary and future geologic mapping and uranium exploration programs.

As a part of this program the U.S. Geological Survey made a study of the Triassic formations in the Colorado Plateau region as related to the uranium ore deposits in the basal strata of the Triassic Chinle Formation. The Chinle Formation and the underlying Moenkopi Formation were of principal interest. Under the leadership of L. C. Craig and later G. A. Williams and finally J. H. Stewart, fieldwork was carried on from 1952 to 1957. Full-time participants in the program were H. F. Albee, F. G. Poole, O. B. Raup, William Thordarson, R. P. Wilson, and R. A. Cadigan.

The geologic investigation of the Triassic strata in the Colorado Plateau region was divided into five mutually supporting parts, as follows: (1) A regional study of the stratigraphy of the Chinle Formations and to a lesser extent of the Moenkopi, Wingate, and the Kayenta Formations, including lithologic definition, regional extent, and facies changes of the formations and their component members; (2) a petrologic study of the sedimentary rocks which make up the formations; (3) a lithofacies study; (4) a study of the orientation of sedimentary structures in each formation; and (5) a study of the regional variation in pebbles in the conglomerate beds of, principally, the Chinle Formation.

This report presents the data and conclusions obtained in the petrologic study of the Moenkopi Formation. The data consist mostly of observations of composition and texture of fine-grained sandstones and coarse-grained siltstones, and their regional variations. The conclusions consist of interpretations of diagenesis, tectonic environment, and provenance of the Moenkopi Formation and lithologically related strata.

A terminal report on the stratigraphic, lithofacies, and sedimentary structure orientation investigations is presented by Stewart, Poole, and Wilson (1971).

ACKNOWLEDGMENTS

Indispensable help in this petrologic study was received from J. H. Stewart, F. G. Poole, Jean M. Roach, R. P. Snyder, W. D. Quinlivan, L. G. Schultz, Esther W. Renaud, Barbara V. Walker, and others of the U.S. Geological Survey. Stewart and Poole provided samples and stratigraphic guidance for fieldwork and sampling by the author. Roach, Snyder, and Renaud did most of the routine laboratory work. Schultz provided information and guidance on clay minerals. Quinlivan did most of the heavy-mineral counts. Walker helped in the preparation of illustrations and tables.

GEOGRAPHIC AND GEOLOGIC SETTING

The Colorado Plateau region includes western Colorado, the northwestern quarter of New Mexico, most of the eastern half of Utah, and the northeastern quarter of Arizona (fig. 1). The elevation of the region is predominantly within the range of 4,000–8,000 feet above sea level and averages about 6,000 feet. Minimum elevations are along the Colorado River, which drops from about 5,700 feet at Glenwood Springs, Colo., near the northeast edge of the region, to about 3,100 feet at Glen Canyon, where the river crosses the Utah-Arizona border in the west-central part of the region. Maximum elevations, 12,000–13,000 feet, are along the west edge of the southern Rocky Mountains and in the La Sal Mountains, 20 miles southeast of Moab, Utah.

FIGURE 1.—Western United States, showing the Colorado Plateaus and adjoining physiographic provinces. From Fenneman (1931).

The climate is semiarid to arid in most of the region. Vegetation is sparse to almost absent in the lower elevations and increases in abundance with the increase in elevation owing to the lower mean temperatures and significant increases in total precipitation.

Regionwide geologic structures form the boundaries of the Colorado Plateaus province but are generally absent in the central part. Sedimentary beds are flat lying or gently warped in roughly four-fifths of the area; in the remainder, the beds reflect the tectonic disturbances of rising salt anticlines (such as are found in the Paradox Basin), major faulting at depth which has resulted in sharp monoclinal folds (such as Comb Ridge monocline), intrusion by laccoliths and volcanic plugs (such as the Henry Mountains), and other structures as shown by Finch (1959, pl. 6).

The rocks exposed in the region range in age from Precambrian to Holocene. Newman (1962, figs. 42–68) published small-scale outcrop and subsurface isopach maps for various stratigraphic subdivisions. Rocks of Precambrian age are mostly granitic igneous and metamorphic rocks. Those of Paleozoic age are marine carbonate and quartzitic clastic rocks in the lower part and marginal marine, continental evaporites, and quartzitic-feldspathic clastic rocks in the upper part. Rocks of Mesozoic age, the most widely exposed in the Colorado Plateaus province, include dominantly terrestrial quartzitic and quartzitic-feldspathic-tuffaceous clastic rocks interlayered with minor marginal marine rocks of similar composition. Rocks of Cenozoic age are mostly continental quartzitic-feldspathic-tuffaceous clastic rocks with minor amounts of andesitic to basaltic intrusive and extrusive igneous rocks in the form of laccoliths, plugs, dikes, and flows.

The dry climate, combined with the relatively undisturbed resistant quartzitic sandstone in the sedimentary strata, yields excellent rock exposures both in the steep-walled canyons of the major streams and in the canyons and valley slopes of the minor and intermittent streams. The formations in most areas can be traced in continuous exposures over many miles without interruption.

PREVIOUS STRATIGRAPHIC AND PETROGRAPHIC WORK

The name "Moencopie beds" was applied to some strata of dark-reddish-brown shale and argillite at the mouth of Moencopie (Moenkopi) Wash (fig. 2) in the valley of the Little Colorado River in Arizona by Ward (1901, p. 403). Gregory (1916, p. 79) first used the revised spelling, Moenkopi. Longwell, Miser, Moore, Bryan, and Paige (1923) and Baker and Reeside (1929) correlated the Moenkopi Formation over much of the Colorado Plateau region. Wengerd (1950) and others extended Moenkopi correlations into west-central New Mexico. McKee (1954) correlated various members of the Moenkopi throughout the region.

Stratigraphers correlated the Moenkopi throughout the Colorado Plateau region on the basis of its physical continuity; its distinctive dark-reddish-brown color; the poorly resistant, slope-forming, flat-bedded, even-bedded, and very thin bedded appearance in outcrop; its common to abundant ripple-marked bedding surfaces; and its relation to certain fossil ammonites (*Meekoceras*) and stratigraphic horizons. Figure 3 illustrates its flat-bedded character. The Moenkopi and lithologically related strata extend through all of the western half of the Colorado Plateau region in Arizona, Nevada, and Utah, and into some parts of the eastern half of the region in Colorado and New Mexico. It is present or has equivalents in Nevada and California (Muller and Ferguson, 1939; Nolan, 1943), in northern Utah (Gilluly and Reeside, 1928), and in southeastern Idaho (Scott, 1950).

Figure 4 shows the stratigraphic position of the Moenkopi Formation with regard to underlying Permian and overlying Triassic rocks. Ward (1901, p. 404–406) reported an unconformity at the lower contact with the "Upper Aubrey" (Kaibab Limestone) and a transitional contact at the upper contact with the

FIGURE 2.—Moenkopi Wash, showing a 150-foot thickness of type Moenkopi Formation strata capped by the sandstone ledge of the Shinarump Member of the Chinle Formation. The rock outcrop shown in the left foreground is part of a Holocene basalt flow. The photograph was taken facing northward from the top of the flow about a quarter of a mile upstream from the junction of Moenkopi Wash with the Little Colorado River, 2 miles west of Cameron, Ariz. (pl. 1).

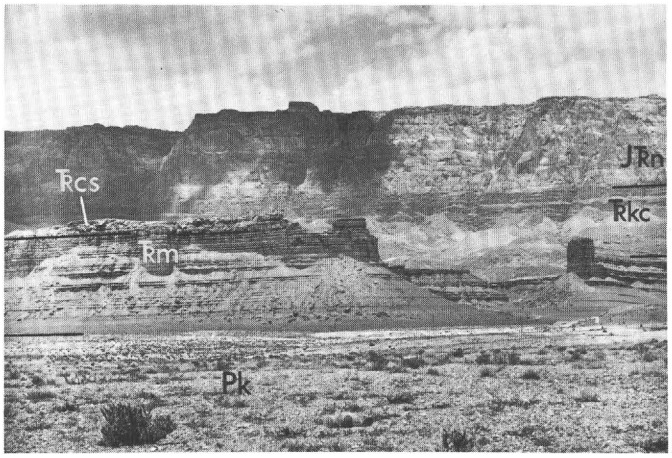

FIGURE 3.—The Triassic Moenkopi Formation (₸m) forms the butte in the foreground and is capped by the sandstone ledge of the Shinarump Member (₸cs) of the Chinle Formation at Navajo Bridge, Ariz. (pl. 1). The desert floor is the top of the Permian Kaibab Limestone (Pk). The Moenkopi is 571 feet thick at this location according to McKee (1954). Cliffs in the background are topped by thick Jurassic and Triassic(?) Navajo Sandstone (J₸n), underlain by undifferentiated Triassic Chinle Formation and Triassic(?) Moenave and Kayenta Formations (₸kc).

"Shinarump conglomerate" (Chinle Formation) in northeastern Arizona. Gregory (1916, p. 79 and pl. 21) reported unconformities at both top and bottom of the Moenkopi in the same area. Gilluly and Reeside (1928, p. 64–66) recognized unconformities at the top and bottom of the Moenkopi in eastern Utah. Baker (1933, p. 34–37) recognized local angular discordance at both top and bottom contacts of the Moenkopi at some exposures in the Moab, Utah, area, and also apparent local conformity at both contacts at other exposures.

No regional petrographic work had been done on the Moenkopi Formation in the Colorado Plateau region at the time the present study was begun in 1952. McKee (1954) described the lithology and petrography of the strata in an intensive study of the Moenkopi and its members in northern Arizona. Lithologic facies identified and described in detail by McKee are thick-bedded sandstone and siltstone, shaly siltstone, structureless mudstone, mud-pellet conglomerate, limestone gravel conglomerate, gypsum, and limestone. Schultz (1963, p. C18) made a comprehensive study of the composition and regional distribution of clay minerals in the Moenkopi Formation.

PERIODS	NORTHERN ARIZONA EASTERN NEVADA SOUTHERN UTAH WESTERN UTAH	SAN RAFAEL SWELL* EAST-CENTRAL UTAH	NORTHERN UTAH TO NORTHWESTERN COLORADO		SOUTHWESTERN COLORADO SOUTHEASTERN UTAH	WESTERN NEW MEXICO
TRIASSIC	CHINLE FORMATION	CHINLE FORMATION	CHINLE FORMATION		CHINLE FORMATION	CHINLE FORMATION
	MOENKOPI FORMATION	MOENKOPI FORMATION	MAHOGANY, THAYNES, and WOODSIDE FORMATIONS / MOENKOPI FORMATION	STATE BRIDGE FORMATION	MOENKOPI FORMATION	MOENKOPI ? FORMATION
PERMIAN	KAIBAB LIMESTONE	COCONINO SANDSTONE	PARK CITY FORMATION	WEBER SANDSTONE	CUTLER FORMATION	SAN ANDRES LIMESTONE

*Use of Coconino in San Rafael Swell uncertain.

FIGURE 4.—Generalized chart showing relationships of the Moenkopi Formation and related strata in different parts of the Colorado Plateau and contiguous regions.

PURPOSE AND SCOPE OF THE MOENKOPI STUDY

Limitations of the study.—This report is concerned chiefly with the regional petrologic study of the coarse siltstone and the sandstone strata, and to a smaller extent with the finer siltstone, claystone, and mudstone strata, of the Moenkopi Formation and lithologically related strata. Very little work was done on conglomerate, limestone, and gypsum rock types. This limitation of the investigation was imposed for several reasons. The sandstones yield more geologic information regarding source areas, areas of deposition, and their tectonic environment than do the other rock types. The composition of mudstone and finer sediment is difficult to determine because of the fine size of the constituent mineral fragments and crystals. The fine clayey sediments contain much larger proportions of diagenetic mineral components than do the sandy sediments, and they are thus generally less satisfactory for studies of origin and depositional processes. Accessory detrital heavy minerals are almost absent from fine clayey rocks and from coarse conglomeratic rocks, or if they are present in the fine clayey rocks, they may be indistinguishable from authigenic minerals (products of diagenesis or mineralization). Texture variation in fine silts and in clays is more strongly influenced by diagenesis than it is in sandstone. Finally, and most importantly, the uranium deposits, which were the original motive for the study, are nearly all in sandstone host rocks.

Results of the study of the regional variation of size and composition of pebbles in the conglomeratic strata are presented by Stewart, Poole, and Wilson (1971).

Limitations on data.—The Colorado Plateau region contains only about 50 percent of the total Moenkopi Formation and correlative formations. The data available may be representative only of the Moenkopi in the region of study and not of the Moenkopi as a whole.

The petrographic data when plotted on maps show a high degree of local variation. Attempts to construct isopleths or contour lines on these data require many arbitrary decisions which cannot be made objectively. The variation can be reduced only by greatly increasing the number of samples. An alternative, and the course of action adopted for this study, was to use statistical methods of analysis. Trend-surface analysis was used in this study for the purpose of obtaining mathematically, and therefore objectively, derived trends and contoured surfaces. The evidence so obtained is used to interpret the tectonic environment and provenance of the Moenkopi Formation.

STRATIGRAPHY

By J. H. STEWART

Stratigraphic relations of the Moenkopi Formation are covered in detail in the report by Stewart, Poole, and Wilson (1971). Only a brief summary of the stratigraphy is presented here.

The Moenkopi Formation in the Colorado Plateau region is generally the basal Triassic formation and unconformably overlies several different Permian formations and is overlain unconformably by the Chinle Formation of Late Triassic age. Figure 4 illustrates the general regional relationships.

The regional changes in the underlying Permian formations represent mostly facies changes from west to east, from the gray to pale-yellow marine limestones of the Kaibab in western Utah and eastern Nevada to the pale-yellowish-gray to pale-brown eolian sandstones of both the Coconino and some western members of the Cutler, and to the thick red to purple alluvial arkosic facies of the Cutler adjacent to the old Uncompahgre highland in western and southwestern Colorado.

The Moenkopi Formation of Triassic(?) and Early and Middle(?) Triassic age is one of the typical red-bed

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units which characterize the upper Paleozoic and lower and middle Mesozoic of the Colorado Plateaus province. The formation crops out throughout most of the western two-thirds of the Colorado Plateau region, and it ranges in thickness from more than 2,000 feet in the westernmost part to a thin parting in the East.

The Moenkopi Formation exhibits a gradual change in facies to the west and northwest across the region. Along the east margin of the formation it contains common to abundant cross-stratified sandstone and siltstone and other current-deposited strata. In the western part of the region, it consists almost entirely of horizontally stratified siltstone, claystone, limestone, dolomite, and gypsum.

Many members are recognized, but none of them extend throughout the entire depositional area of the formation, and most occur in only a relatively small part of the region (fig. 5).

In southwestern Utah, northwestern Arizona, and part of southern Nevada, six members are recognized in the Moenkopi Formation. These are, in ascending order, the Timpoweap Member, lower red member, Virgin Limestone Member, middle red member, Shnabkaib Member, and upper red member. The Timpoweap Member consists of red siltstone, gray limestone, and a remarkable chert pebble conglomerate in fossiliferous marine limestone. The Virgin Limestone Member consists of gray limestone and siltstone which thin and pinch out to the east. The Shnabkaib Member consists of red siltstone, white gypsum, and gray limestone. It grades to the east into red siltstone. The lower, middle, and upper red members consist dominantly of red siltstone.

Three members make up the Moenkopi Formation in most of north-central and east-central Arizona. The lowest, the Wupatki Member, is composed mostly of pale-reddish-brown siltstone. It contains one thin widespread sandstone unit, referred to as the lower massive sandstone. This sandstone extends to the west beyond the limits of the upper and lower parts of the member. The Moqui Member overlies the Wupatki Member and is composed dominantly of pale-reddish-brown siltstone and minor amounts of white gypsum. The highest member, the Holbrook Member, is composed of interstratified and interfingering lenses of brown and reddish-brown sandstone and siltstone.

In west-central New Mexico, a thin unit of red siltstone and sandstone is tentatively correlated with the Moenkopi Formation. This unit probably extends as far east as the Lucero uplift (southwest of Albuquerque) and as far south as Socorro (pl. 1).

In southeastern Utah, six members are recognized in the Moenkopi Formation. These members, in ascending order, are the Hoskinnini, lower slope-forming, Sinbad Limestone, ledge-forming, upper slope-forming, and cliff-forming members. The Hoskinnini Member consists of pale-reddish-brown siltstone and very fine grained sandstone containing scattered fine, medium, and coarse sand grains. The lower slope-forming member consists of grayish-red, yellowish-gray, and light-greenish-gray siltstone and sandy siltstone. The Sinbad Limestone Member is composed of gray limestone and dolomite and is a marine unit that thins and pinches out to the east. The ledge-forming member is composed of red siltstone and sandy siltstone or sandstone. The sandy siltstone or sandstone weathers to form ledges, and the member as a whole forms a ledgy interval in the formation. The upper slope-forming member consists of grayish-red and pale-reddish-brown siltstone. The cliff-forming member is composed of pale-reddish-brown and grayish-red siltstone characterized by abundant ripple laminae. The latter two members are separable at only a few localities.

In the salt anticline area of east-central Utah and west-central Colorado, the Meonkipo Formation is exposed in and around a series of northwest-trending salt anticlines that started to form during Pennsylvanian time. Uplift of the salt anticlines during Triassic time affected the deposition of the Moenkopi Formation; local downwarped basins adjacent to the anticlines contain thick deposits of sediment; uplifted areas on the crests of the anticlines received little or no sediment. Gypsum occurs locally at the base of the formation. The Moenkopi Formation in this area is divided into four members, which are, in ascending order, the Tenderfoot, Ali Baba, Sewemup, and Pariott Members. The Tenderfoot Member consists of pale-reddish-brown siltstone, very fine grained sandstone and near the base, thin local units of conglomerate and gypsum. The Ali Baba Member consists of conglomeratic sandstone and sandstone interstratified with siltstone. The Sewemup Member consists of pale-reddish-brown and grayish-red siltstone. The Pariott Member is a local unit of red-brown, purplish-brown, chocolate-brown, orange, and red sandstone, mudstone, siltstone, and shale.

As shown in figure 5, red beds in the eastern part of the Uinta Mountains in northeastern Utah and northwestern Colorado are referred to as the Moenkopi Formation, whereas laterally equivalent, but thicker, strata in the western Uinta Mountains are assigned to the Woodside, Thaynes, and Mahogany Formations. The Moenkopi Formation as recognized in the eastern Uinta Mountains, and the Woodside and Mahogany Formations in the western Uinta Mountains are composed largely of red siltstone, sandstone, and some gypsum. The Thaynes Formation is a marine limestone unit that

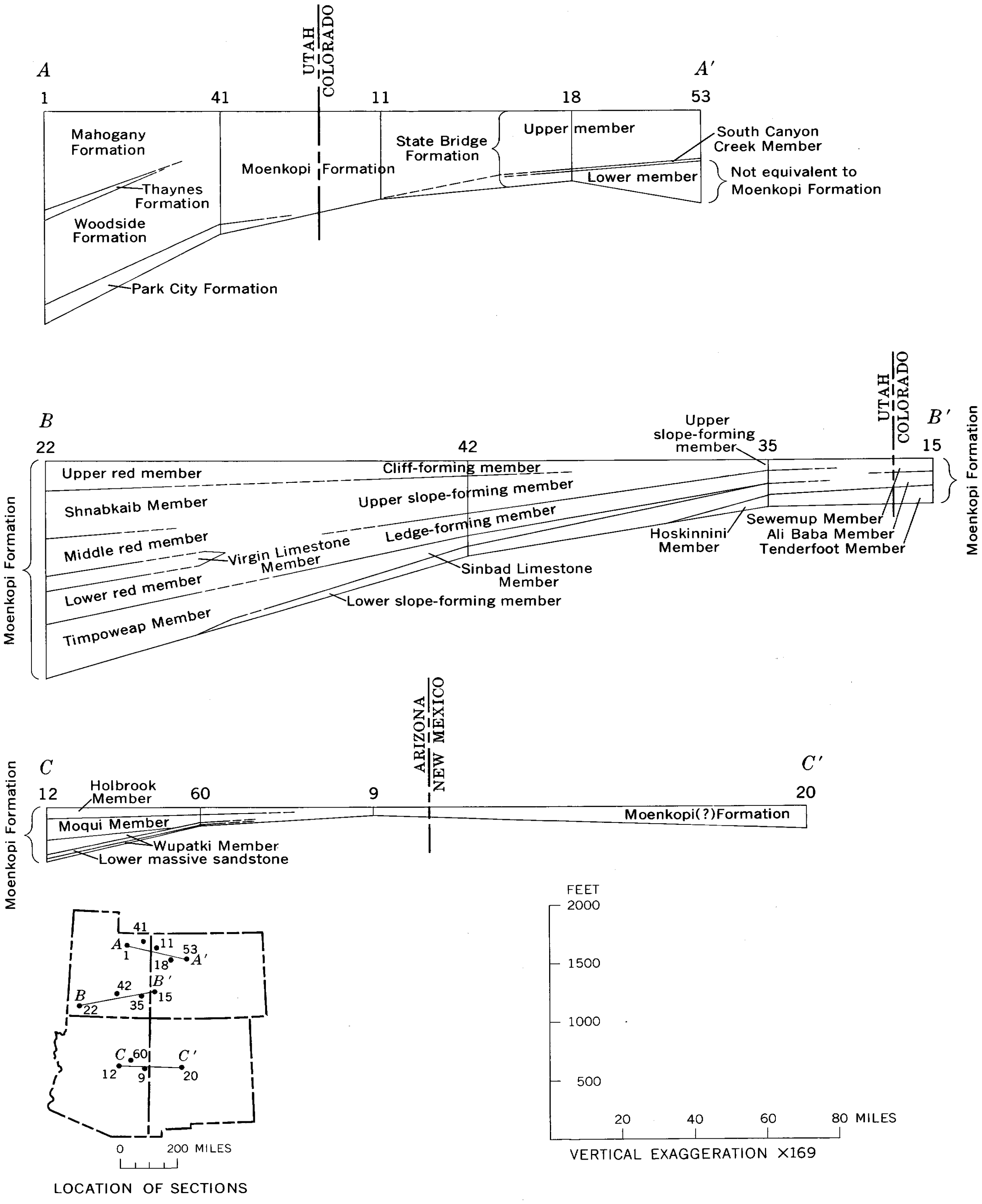


Figure 5.—Formal and informal members of the Moenkopi Formation and related strata in the Colorado Plateau region. Intertonguing relationships at upper and lower boundaries of members are not shown. Numbers refer to localities in table 1, on plate 1, and in unpublished data. Thickness and horizontal distances are according to the scale shown. Data from numbered sections not on the line of section have been projected.

becomes thinner to the east and grades into the red beds of the Moenkopi Formation.

Strata equivalent to the Moenkopi Formation in northwestern Colorado (referred to as the upper member of the State Bridge Formation) consist of red siltstone and minor amounts of sandstone, claystone, and gypsum. A thin carbonate unit (South Canyon Creek Member) occurs in the State Bridge beneath the upper member in much of northwestern Colorado.

The Moenkopi Formation contains a varied, although not abundant, assemblage of fossils. Worms, brachiopods, pelecypods, gastropods, cephalopods, arthropods, and echinoderms occur in the marine limestones in the western part of the Colorado Plateau region. Fish, amphibians, reptiles, and plants occur in the continental deposits in the eastern part of the depositional basin.

PETROLOGIC METHODS

Laboratory analytical procedures, with the exception of those used in the treatment of thin sections, were similar to those described by Krumbein and Pettijohn (1938). The procedures followed are shown in figure 6. In addition to geographic and stratigraphic locality recorded for all samples, data compiled for selected groups of samples include: (1) Thin-section modal analyses; (2) statistical measures of the grain-size distributions; (3) percentage acid-soluble material in the rock; (4) heavy-mineral ratios—the proportions of certain individual heavy detrital minerals within a suite of selected minerals; and (5) proportions of total heavy minerals.

Sampling.—Most of the sampling and other fieldwork was done during the period 1952–57. All field localities used in the project were numbered, but not all were sampled; this is the reason for the gaps in the numerical sequence of sample localities. Table 1 lists the sampled localities, the number of samples of each member taken, and the approximate geographic coordinates of the localities. Plate 1 shows the sample localities.

TABLE 1.—*Index of sample localities, units sampled, and number of samples—petrologic study of Moenkopi Formation and related strata*

[All units sampled are members, or undifferentiated parts (undif.), of Moenkopi Formation or of contiguous, lithologically identical units]

Locality				Unit sampled	Number of samples
No. (pl. 1)	Name	Long W.	Lat N.		
ARIZONA					
1	Black Creek	109.23°	35.33°	Undif	3
5	Hunters Point	109.13°	35.60°	Undif	2
9	St. Johns "A"	109.37°	34.43°	Undif	2
				Holbrook	3

TABLE 1.—*Index of sample localities, units sampled, and number of samples—petrologic study of Moenkopi Formation and related strata*—Continued

Locality				Unit sampled	Number of samples
No. (pl. 1)	Name	Long W.	Lat N.		
10	Black Point	111.27°	35.73°	Moqui	1
				Wupatki	2
12	Sunset Mountain	110.90°	34.87°	Holbrook	3
15	Big Canyon	111.55°	36.15°	Moqui	2
				Wupatki	3
60	Holbrook	110.16°	34.88°	Holbrook	2
				Moqui	1
				Wupatki	1
70	Winslow	110.83°	35.08°	Holbrook	4
81	Shinumo Altar	111.72°	36.44°	Undif	2
				Lower massive ss., Wupatki.	2
210	14 miles west of Navajo Bridge.	111.82°	36.70°	Upper red	2
				Shnabkaib	2
				Lower red	1
211	Kato Sells No. 2	109.86°	36.93°	Upper slope-forming	2
				Hoskinnini	2
COLORADO					
3	Sheephorn Creek	106.52°	39.91°	Upper member, State Bridge Formation.	1
				South Canyon Creek Member, State Bridge Formation.	1
4	South Canyon Creek	107.43°	39.56°	Upper member, State Bridge Formation.	1
				Lower member, State Bridge Formation.	1
8	The Palisade	108.99°	38.68°	Ali Baba	2
				Tenderfoot	4
15	Paradox Valley	108.85°	38.35°	Sewemup	1
				Ali Baba	3
				Tenderfoot	2
18	Meeker	107.80°	39.97°	Upper member, State Bridge Formation.	3
				Lower member, State Bridge Formation.	1
139	Gore Pass	106.58°	40.16°	Undif. State Bridge Formation.	1
186	Main Elk Creek	107.59°	39.63°	Upper member, State Bridge Formation.	1
188	Skull Creek	108.68°	40.33°	Undif	2
189	Deer Creek	106.54°	40.20°	Undif. State Bridge Formation.	1
NEVADA					
1	Horse Spring Valley	114.13°	36.36°	Upper red	2
				Middle red	1
NEW MEXICO					
1	Chavez-Prewitt "A"	108.06°	35.32°	Undif	3
3	Fort Wingate "A"	108.57°	35.48°	Undif	2
16	Riley	107.21°	34.38°	Undif	3
20	Mesa Gallina	107.24°	34.67°	Undif	3
UTAH					
6	Muddy River	110.97°	38.57°	Upper slope forming	1
				Ledge forming	1
				Lower slope-forming	1
7	Straight Wash	110.52°	38.78°	Upper slope-forming	1
				Lower slope-forming	1
8	Temple Mountain	110.67°	38.68°	Upper slope-forming	1
				Ledge forming	1
				Sinbad Limestone	1
				Lower slope-forming	3
9	Poison Spring Wash (Buckacre Point).	110.40°	38.10°	Upper slope-forming	1
				Ledge-forming	2
				Lower slope-forming	2
10	Horse Canyon (Lampstand Draw, Long Canyon).	111.22°	37.95°	Upper slope-forming.	1
				Ledge-forming	2
				Sinbad Limestone	1
				Lower slope-forming	1
11	Muley Twist	111-03°	37.83°	Cliff-forming	1
				Upper slope-forming	2
				Ledge-forming	2
14	Silver Falls	111.15°	37.74°	Cliff-forming	1
				Upper slope-forming	4
				Ledge-forming	3

TABLE 1.—*Index of sample localities, units sampled, and number of samples—petrologic study of Moenkopi Formation and related strata*—Continued

Locality				Unit sampled	Number of samples
No. (pl. 1)	Name	Long W.	Lat N.		
UTAH—Continued					
18	Richardson Amphitheater.	109.32°	38.78°	Sewemup	1
				Ali Baba	2
				Tenderfoot	2
22	Kanarraville "A"	113.20°	37.50°	Upper red	2
				Lower red	1
				Timpoweap	1
24	Paria	112.00°	37.25°	Upper red	2
25	Bears Ears	109.87°	37.64°	Ledge-forming	2
				Lower slope-forming	2
				Hoskinnini	4
26	Bridger Jack Mesa	109.68°	37.97°	Hoskinnini	3
27	Comb Wash	109.65°	37.32°	Hoskinnini	2
28	Cottonwood Creek	109.68°	37.77°	Hoskinnini	4
29	Hite	110.43°	37.78°	Upper slope-forming	6
30	Jacobs Chair	110.23°	37.73°	Upper slope-forming	1
				Ledge-forming	2
				Hoskinnini	3
32	Lockhart Canyon	109.68°	38.35°	Hoskinnini	3
33	Milk Ranch Point	109.68°	37.61°	Hoskinnini	3
34	Monitor Butte	110.43°	37.23°	Ledge-forming	3
				Hoskinnini	1
35	North Sixshooter Peak	109.66°	38.15°	Upper slope-forming	1
				Ledge-forming	1
				Lower slope-forming	1
				Hoskinnini	2
36	Poncho House	109.75°	37.12°	Lower slope-forming	1
				Hoskinnini	1
38	Steer Mesa	110.00°	38.42°	Lower slope-forming	2
				Hoskinnini	4
41	Vernal	109.48°	40.60°	Undif.	2
43	Chimney Rock	111.30°	38.33°	Ledge-forming	1
				Upper slope-forming	1
				Sinbad Limestone	2
				Lower slope-forming	1
45	Leeds	113.35°	37.20°	Upper red	2
47	St. George "A"	113.67°	37.05°	Upper red	3
				Shnabkaib	6
				Middle red	2
				Virgin Limestone	4
				Lower red	8
49	Clay Hills Pass	110.31°	37.44°	Upper slope-forming	3
				Ledge-forming	1
				Lower slope-forming	1
				Hoskinnini	4
64	Pleasant Creek (Miners Mountain).	111.20°	38.17°	Upper slope-forming	2
				Ledge-forming	3
				Sinbad Limestone	5
				Lower slope-forming	1
93	Nokai Canyon	110.56°	37.07°	Undif.	1
160	Torrey	111.39°	38.35°	Upper red	1
173	Clay Gulch	110.40°	37.34°	Ledge-forming	1
				Hoskinnini	2
200	White Canyon	110.30°	37.75°	Upper slope	6
286	Cedar City	113.07°	37.72°	Upper red	1
300	Dynamite Point	110.53°	39.05°	Upper slope-forming	2
304	Virgin	113.12°	37.25°	Upper red	1
305	The Peaks	111.17°	37.87°	Cliff-forming	1
				Ledge-forming	1
				Sinbad Limestone	1
				Lower slope-forming	1
307	Farm Creek	116.72°	40.38°	Mahogany Formation	1
				Thaynes Formation	4
309	Deer Flat (Hide-out Mine).	110.02°	37.66°	Upper slope-forming	4
310	Mineral Canyon	109.92°	38.55°	Upper slope-forming	3
312	3 miles south of Kanab	112.55°	37.00°	Upper red	2
313	Red House Cliffs:				
	(Midway section)	110.27°	37.43°	Upper slope-forming	1
				Ledge-forming	1
				Lower slope-forming	1
				Hoskinnini	2
315	(North section)	110.23°	37.45°	Hoskinnini	3
319	Bicknell	111.53°	38.33°	Upper red	1
323	Oljato Trading Post	110.26°	37.05°	Undif.	1
325	Moab	109.60°	38.62°	Ledge-forming	1
				Lower slope-forming	1
326	Junction Butte	109.83°	38.33°	Hoskinnini	3

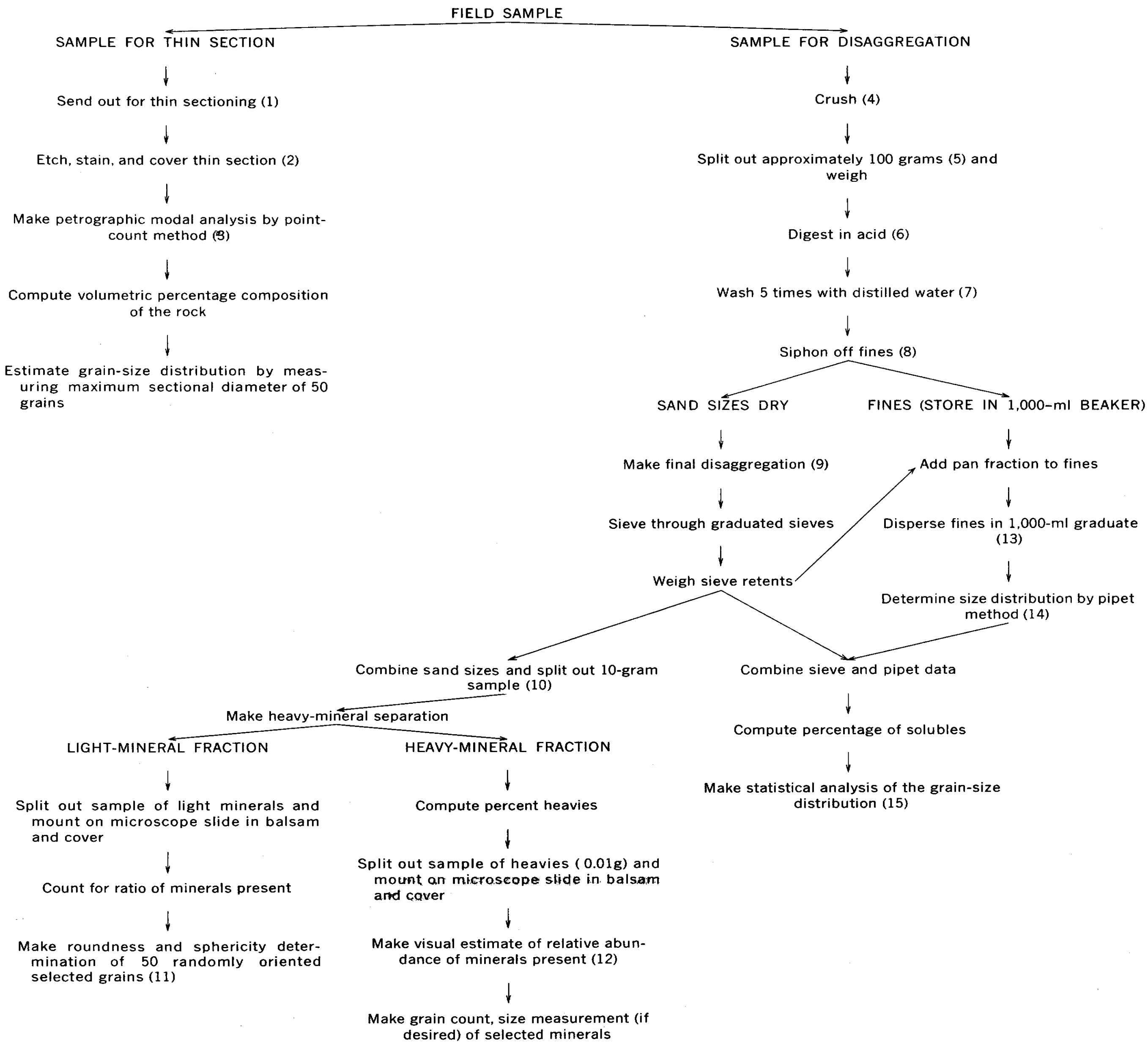
Most samples were collected from outcrops at measured stratigraphic sections. At some localities only the upper part of the Moenkopi was sampled because of limited exposures. Beds to be sampled were selected, at the discretion of the sampler, to be representative of the strata in the outcrop.

Each rock sample consisted of 1–2 kg (kilograms) of rock from which weathered surfaces had been removed and which had been taken from a single bed and from an area no larger than 1 square foot. In highly fractured, deeply weathered siltstone, a small pit was dug to the depth necessary to obtain fresh-looking fracture fragments.

Sample density for the Moenkopi is slightly greater in the areas where overlying basal Chinle rocks are being mined for uranium ore. For the most part, though, the Moenkopi was sampled with appropriate spacing as permitted by its outcrop pattern.

Mechanical analysis.—Sandstone and coarse siltstone samples received initial coarse crushing by a power-driven jaw crusher. Disaggregated material was sieved through a set of twenty-five 8-inch-diameter brass sieves with openings graduated at ½ phi intervals from 8 mm (millimeters) (−3 phi) to 1 mm (0 phi) and at ¼ phi intervals from 1 mm to 0.044 mm (4.5 phi). The phi scale was explained by Krumbein and Pettijohn (1938, p. 84–85) and by Krumbein (1936, p. 36–38). Sieves were shaken mechanically for 15 minutes for particles 0.125 mm or coarser and 20 minutes for particles finer than 0.125 mm. Gross samples were weighed to 0.01 g (gram), and refined samples (heavy minerals, clay decrements) were weighed to 0.1 mg (milligram).

Modal analysis.—Modal analysis of the rocks was made from thin sections using the point-count method described by Chayes (1949, p. 2–4; 1956, p. 4–15). Ideally, a 10×50 intersection point grid (10 traverses of 50 counts) was used to yield 500 identification counts on each thin section. For siltstone with detrital grains obscured by iron oxide impregnated clay and carbonate minerals, the composition was estimated on the basis of only 100 counts (two traverses of 50 counts each). To facilitate rapid mineral identification of the potassic feldspars, uncovered thin sections were etched with hydrofluoric acid fumes and treated with sodium cobaltinitrite (Gabriel and Cox, 1929; Keith, 1939). A canary-yellow stain appears on, and effectively delineates, potassic feldspar detrital grains and potassic feldspar crystals in fragments of granite, felsite, and lithic tuff, and this stain serves to identify altered potassic vitric tuff. This stain, if properly applied, does not interfere with the optical properties beyond changing the surface color of the grains. The etching process is more rapid on weathered than on fresh grains of feldspar; the weathered grains adsorb more of the stain and become brighter yellow. The etching also affects the sodic feldspars, tending slightly to accentuate the dull grayish-white sometime ragged appearance of the grains between crossed nicols, especially the weathered grains. After staining, each thin section was covered



KEY TO NUMBERS IN PARENTHESES

(1) Request thin sections without cover glasses.
(2) Etch with hydrofluoric acid fumes for 1 minute; stain in sodium cobaltinitrite solution for 2 minutes to aid identification of feldspars (Keith, 1939; Gabriel and Cox, 1929).
(3) Chayes (1949, 1956).
(4) To pass through U.S. No. 5 sieve if nonpebbly.
(5) 100 grams for sandstone; 50 to 20 grams for medium to fine siltstones or claystones.
(6) Boil in 400 ml of 20-percent citric acid, cool, add 20 ml concentrated hydrochloric acid. Add additional increments of cold concentrated hydrochloric acid if undissolved calcite or curds of calcium citrate are present.
(7) Allow to settle 24 hours or longer between washings; siphon off supernatant liquid.
(8) Put poorly disaggregated claystone and medium and fine siltstone in a homogenizer for 1 minute.
(9) Hand crush aggregate with a rubber bulb or porcelain pestle on brown wrapping paper.
(10) More may be required if there are few heavy minerals.
(11) Krumbein (1941); Rittenhouse (1943); Wadell (1932, 1935).
(12) Record minerals in order of abundance.
(13) Disperse with sodium oxalate (N/100 concentration).
(14) Krumbein and Pettijohn (1938, p. 166–168).
(15) Krumbein and Pettijohn (1938, p. 239–253).

FIGURE 6.—Flowsheet showing steps in laboratory study of samples.

with a glass slip, using uncooked balsam, and allowed to dry for a month or more. To avoid injury to the thin sections, neither heat nor solvents such as xylene were used in the procedures.

Heavy-mineral separation and count.—A modified study was made of regional variation in the ratios of several nonopaque detrital minerals with a specific gravity greater than 2.90. The minerals used were biotite, muscovite, tourmaline, zircon, garnet, staurolite, amphibole, epidote, and rutile. The opaque varieties of heavy minerals, mostly ilmenite, magnetite, and leucoxene, were counted together. Consideration was given to the fact that heavy-mineral ratios or percentages are quantitative measures that add up to a constant sum and are thus subject to the limitations discussed by Chayes (1960, p. 4187), in that such numbers cannot be treated statistically as independent measurements.

The heavy minerals were separated from the size fraction retained between the U.S. No. 325 (44-micron openings) sieve and the U.S. No. 50 (297-micron openings) sieve for all sandstone and coarse siltstones. The quantity of heavy minerals, by weight, obtained from this size fraction was used as the percentage figure for total heavy minerals. The separation of the heavy minerals was done in tetrabromoethane (specific gravity 2.95 at 20°C) as described by Krumbein and Pettijohn (1938, p. 335). The heavy-mineral grains, after being washed with alcohol or acetone and then dried, were weighed to determine the proportion of heavies in the size fraction used, and a split of the concentrated grains was mounted on a glass microscope slide for study. The study utilized a petrographic microscope and consisted of counting the grains of the selected minerals intersected by the ocular crosshair during equally spaced traverses across the slide, until a total of 100 nonopaque mineral grains had been counted; additional grains of tourmaline, garnet, and zircon were counted to bring a total of these three also to 100. These data were used to compare proportions of certain mineral grains; for example, the ratio of opaques to nonopaques, of biotite to tourmaline, or of tourmaline to zircon.

Acid-soluble fraction.—The acid-soluble fraction of each sample disaggregated for study was measured in percent by weight. The soluble material is composed of carbonates, certain iron oxides, gypsum in some samples, and small amounts of other minerals and trace elements taken into solution during the digestion process (fig. 6). The weight data served as a check on the volumetric modal analysis.

TREND-SURFACE ANALYSIS METHODS

Trend-surface analysis is defined by Krumbein (1959, p. 823) as "a procedure for separating the relatively large-scale systematic changes in mapped data from essentially nonsystematic small-scale variations due to local effects." Trend-surface analysis was applied to the Moenkopi Formation data for the purpose of determining regional trends and appraising the evidence of regional variation of petrographic parameters mathematically, prior to interpretation. Further discussion of trend-surface analysis was presented by De Lury (1950) and Krumbein (1956, 1959).

Terms used in this report pertaining to trend surface are defined as follows:

Degree of trend surfaces.—First-degree, second-degree, third-degree, and so forth (also termed "linear," "quadratic," and "cubic") surfaces which may be conceived of as referring to computed surfaces of increasing capability of flexure (Krumbein, 1956, p. 2173).

First-degree (linear) surface.—A computed planar surface, located in three dimensions, which is the best fit of a plane to a group of points located in three dimensions and which slopes according to the computed regional slope of the data. The mathematical relation for irregularly spaced data points is of the form

$$X_c = b_0 + b_l\, U + b_2 V + R_l,$$

where X_c is the computed value of a regional distributed parameter, b_l and b_2 are coefficients, b_0 is the mean, U and V are the regional coordinates, and R_l is the residual or deviation from the linear surface. The X axis lies in a vertical plane perpendicular to the horizontal plane containing the U and V axes. The three axes are mutually perpendicular. (See Allen and Krumbein, 1962, p. 517–522.)

Observed Data (X_o).—Observed values of the regionally varying parameter.

Residuals.—Values of the respective differences between individual sets of observed and computed data for the same points on a specific computed surface, otherwise known as deviations from the computed surface.

Residual surface.—A hypothetical surface formed by the residuals or deviations from a single computed surface; it is illustrated by contouring on the residual values.

Sum of squares of residuals (SS_R).—The result of squaring the residuals and then summing the squares.

Total sum of squares (SS_X).—The sum of the squares of the deviations of the individual observed values (X_o) from the mean of the observed values ($\overline{X}$), or computed from the formula

$$SS_X = \sum X^2 - \frac{(\sum X)^2}{N}$$

(N=number of observed values).

Percent reduction of sum of squares (E_R).—The difference between total sum of squares (SS_X) and sum of squares of residuals (SS_R) in terms of percent of SS_X or

$$E_R = \frac{SS_X - SS_R}{SS_X} \times 100.$$

In this paper, percent reduction of the sum of squares (E_R) is used to evaluate the effectiveness or strength of a computed surface. Using 50–100 data points, a surface which has an E_R of 80–100 percent is considered valid for purposes of prediction (Allen and Krumbein, 1962, p. 521). An E_R of 50–79 percent is a very strong trend; an E_R of 25–49 percent is a strong trend; an E_R of 10–24 percent is a moderately strong trend; and, an E_R of 0–9 percent is considered to be a weak trend. As the number of data points increases, the significance of low E_R's increases; conversely, as the number of data points decreases, high E_R's decrease in significance.

Regional mean.—The mean of the data point values, or "observed values," used in the trend-surface analysis. It is not necessarily the same as the mean of all the samples.

Trend-surface analysis yields computed polynomials for each surface. These polynomials may be used with additional U and V values (geographic coordinates) to extend the computed surface to areas in which there are no X_o values. This was done for fifth-degree surfaces for which the data-point computed values were too few to give the areal coverage needed to accurately reproduce the contours of the computed surface.

The trend surfaces were computed by the U.S. Geological Survey by use of a least-squares surface-fitting program and a Burroughs 220 computer. The X variable was the value of the parameter being studied—percent feldspar, phi median grain size, and so forth; U and V variables were coded values of the geographic coordinates of the data points read out in degrees and hundredths. Longitude was coded by subtracting 109.00°, and latitude by subtracting 37.00°, in effect placing the origin at long 109° W. and lat 37° N. Thus, the U and V values consisted of small positive and negative numbers. As pointed out by Mandelbaum (1963, p. 507), the use of large U and V numbers in the input of a computer results in the generation of very large products in the computer, particularly for cubic and higher surfaces. These large products exceed the computer's digit capacity and are rounded off, which results in a loss of significant figures and the calculation of surfaces which bear decreasing relationship to the data.

The computer program used nonorthogonal least-squares computation because the data points were irregularly spaced. Computer output was tested by analysis of variance in the manner described by Allen and Krumbein (1962, p. 521–524). First- through fifth-degree surfaces and their residuals were computed for most experiments.

The output data for each surface computed consisted of a recapitulation of the U and V coordinates, the observed data together with computed data, and the residuals. Also furnished were the total sum of squares, sum of squares of the residuals, mean and standard deviation of the observed data, and the standard error of the estimate. Computed trend-surface and residual-surface data were plotted on maps and contoured by hand for study.

Interpretation of the contoured reproduction of a computed surface is based on a number of considerations. An ordinary isopleth or contour map is one which is constructed over a horizontal reference plane which in most instances coincides with the plane of X=0. A computed linear (plane) surface or least-squares surface is, in most instances, a sloping reference plane which passes through the moment center of the three-dimensionally located X values. The X values may be thought of as points suspended in space. The linear residual surface may be shown by an isopleth map with positive and negative values, which have reference to the computed linear surface. Zero values would represent points of intersection with the linear surface. Thus, high or positive areas on a linear residual map rise above the computed linear surface, and low or negative areas lie below the computed linear surface. Experience indicates (Allen and Krumbein, 1962) that linear residual surfaces may reflect many local and regional effects stripped of the major regional linear trend, and that these surfaces thus may furnish valuable evidence for interpretation of details of local effects of sources and of patterns of transportation and deposition.

Locality data based on averages of two or more samples were found to yield better trends than locality data based on a single sample at each locality (Whitten, 1959, p. 844). Averaging reduces the range of variation. The effects of clusters and the methods used to reduce the effects of clusters of closely spaced data points were discussed by Krumbein (1956).

For this report, trend analyses were made on untreated averages of sample locality data which were declustered by combining (averaging together) data from any samples that were collected within the same 80-square-mile circle (10-mile diameter). This declustering reduced the number of data points but greatly improved their spacing without omitting any sample data.

PETROLOGIC CLASSIFICATION

The petrologic methods described were applied to the rock samples from the Moenkopi Formation and related strata. Information obtained consisted of data on the mineral composition and granular texture of the rocks, measures obtained from statistical analyses of the data, and computed analyses of the regional variations of these parameters. To simplify description, comparison, and interpretation, composition and textural data were used to classify the rocks according to appropriate classification systems.

COMPOSITION

Petrographic modal analysis of the coarse siltstone and very fine grained sandstone samples revealed a wide variation in the proportions of minerals present as cement, granular particles, and matrices of these rocks. The cementing materials of the siltstone and sandstone are commonly calcite, optically continuous quartz overgrowths on detrital quartz grains, dolomite, and iron oxide (mostly hematite); less common cements are microcrystalline silica or chert, barite, and gypsum. In some clayey siltstone and sandstone, matrix minerals combine with cementing minerals to form a brown or red iron oxide impregnated interstitial semiopaque material, which acts as a cement. Orthoclase feldspar overgrowths, which fill interstices of some feldspar-rich arkoses, also act as a cement.

The granular particles composing the siltstone and sandstone are detrital rock fragments. Conventionally, though, the monomineralic fragments are called grains, and the mineral-aggregate particles are called rock fragments.

Quartz grains volumetrically make up the largest proportion of the particles. Other grains include potassic and sodic feldspars, mica, and heavy minerals. The potassic feldspars are orthoclase and microcline. Sodic feldspars are albite and albite-oligoclase. Muscovite and biotite, together with their alteration product, chlorite, constitute the micas. Heavy minerals (specific gravity >2.90) constitute the smallest proportion of the grains.

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The most abundant rock fragments in the Moenkopi Formation are those of silicified rock derived from source rock of unknown petrogenesis. Others are fragments of chert, quartzite, granite, felsite, phyllite or mica schist, and altered tuff.

The matrices of most siltstone and sandstone are composed of combinations of various clay minerals, fine silt- and clay-sized quartz and feldspar, and mica, impregnated to some degree with red iron oxide. The clay minerals include mica clay (the illite of Schultz, 1963), chlorite, kaolinite, mica-montmorillonite, and mixtures of these minerals. Some matrices contain isolated anhedral patches of calcite or euhedral rhombs of dolomite, which vary in size; this suggests incipient replacement of the matrix minerals by carbonate cements.

Microstructure—defined as the physical arrangement of grains, matrix, and cement—includes several common types. Moenkopi siltstone and sandstone microstructures range in type from homogeneous to heterogeneous; the homogeneous types are composed almost exclusively of detrital grains with little cement or matrix; the heterogeneous types are composed of detrital grains suspended in carbonate cement or clay matrix, or both. Limestones include both homogeneous megacrystalline calcite rocks and rocks that are heterogeneous mixtures of microcrystalline calcite and clastic calcite in the form of oolites or fossil clasts.

MINERAL AND MINERAL-AGGREGATE GROUPS

For the purpose of classifying the rocks in terms of proportions of their major constituents, rock-forming minerals and mineral aggregates were divided into 19 mineral groups. These groups and the rock-forming constituents assigned to them are discussed in a previous report (Cadigan, 1967, table 4) and are listed in this report in table 2. To decide which mineral constituents should be point-counted individually and which should be grouped, the following factors were considered: (1) Precision—possibility of good and consistent petrographic identifications; (2) speed—the rapidity with which particular mineral constituents could be identified and counted; (3) importance of detail—the particular minerals or rock fragments whose quantitative occurrence should, in the opinion of the author, be recorded if the objectives of the study are to be realized; (4) similarities in properties, occurrence, or genetic origin of certain minerals; and (5) the problems inherent to sedimentary rock classification (Pettijohn, 1957, p. 238).

ROCK-FORMING COMPONENTS

The 19 mineral and mineral aggregate groups are in turn grouped for purposes of rock classification into the five major rock-forming components shown in table 2. The assignment of specific clay minerals to specific components is probably the biggest problem. Kaolinite was assigned to the feldspathic components mostly on the basis of the conclusions of Ross and Kerr (1931, p. 171–174), who named feldspars as the major source of kaolinite, and partly on the basis of work done for this and other reports on Colorado Plateau sedimentary rocks, which confirms the high degree of association between kaolinite and highly feldspathic rocks. Montmorillonite was assigned to the volcanic components because of the observed association of montmorillonite clay with recognizable volcanic debris. Bentonites—montmorillonitic siltstones, mudstones, or claystones—are generally regarded as alteration products of sediments which were rich in volcanic glass (Hewett, 1917; Ross and Hendricks, 1945, p. 64–68). Mica clay (illite, sericite) and chlorite were assigned to dark minerals and micas on the basis of mineralogy and the critical relationship of these clay minerals to rocks classified as graywackes (Pettijohn, 1949, p. 245).

TABLE 2.—*Major rock-component groups*

Rock components	*Rock classification equivalents*
I. Chemical (cementing) components except silica.	I. Chemical and chemiclastic rocks.
a. Carbonates and sulfates.	
b. Red iron oxides.	
II. Siliceous components	II. Orthoquartzites.
a. Quartz grains.	
b. Quartzite fragments.	
c. Chert, detrital.	
d. Chert, authigenic.	
e. Silicified-rock fragments.	
f. Silicified-limestone fragments.	
III. Feldspathic components	III. Arkoses.
a. Potassic feldspar.	
b. Plagioclase feldspar.	
c. Kaolinitic clays.	
IV. Dark-mineral and mica components.	IV. Graywackes.
a. Mica flakes and books.	
b. Chlorite and mica clays.	
c. Micaceous and mafic rock fragments.	
d. Heavy minerals (nonopaque).	
e. Miscellaneous.	
V. Volcanic components	V. Tuffaceous rocks.
a. Tuff and felsite fragments.	
b. Montmorillonitic clays.	
c. Altered ash.	

On the basis of thin-section data, rocks were classified according to a binary logic design illustrated in figure 7. In general, the rock terminology follows Pettijohn (1949, p. 227) and Krynine (1948), but the classification procedure and the treatment of the modifying terms and clay minerals follow the author's previous reports (Cadigan, 1959, 1967). As used here, and in accordance with a suggestion by Pettijohn (1957, p. 381, footnote), limestone contains a minimum of 75 percent carbonates. The treatment of tuffaceous material follows that of a previous report (Cadigan, 1959, p. 534–536).

The term "binary logic design" is used to indicate that the process of classification operates through a sequence of decision points. Numerically the "yes" or "no" decisions could be expressed as "0" or "1," a binary system. Each decision narrows the field of consideration. The system is open ended and could be expanded, if so desired, to include all rocks.

Rocks that do not contain enough of any one component to be assigned to one of the rock series of figure 7 are referred to as unclassified sedimentary rocks. Most such rocks in the Moenkopi are calcareous (25–74 percent calcite), and many may be partially products of the diagenetic replacement of noncalcareous particles by calcite.

Orthoquartzites are defined as containing more than 74 percent siliceous components. Quartzite rocks that fail this requirement are classified as suborthoquartzites, which contain 74–25 percent siliceous components. Most suborthoquartzites in the Moenkopi are high in carbonates (> 24 percent) and, like the unclassified rocks, may be partially products of diagenesis. This usage of suborthoquartzite is substituted for the term "impure (or modified) orthoquartzite" as used previously (Cadigan, 1967, fig. 17).

CLASSIFICATION PROCEDURE

The classification procedure outlined in figure 7 is applied directly to modal analysis data without preliminary classification on the basis of either texture or composition. Classification is based on modal composition only, to minimize the influence of genetic concepts, which, as noted by Pettijohn (1957, p. 238), are the main sources of conflict among proposed systems of sedimentary rock classification.

The suborthoquartzites and unclassified sedimentary rocks of the present report correspond to Krynine's (1948) "impure sandstones" and other unclassified rock types. For a further discussion of the classification system and the rock names used, other than suborthoquartzite, the reader is referred to Cadigan (1967, p. 22).

LITHIFICATION AND DIAGENESIS

Lithification is defined as those physical and diagenetic changes which solidify the constituent sediment into rock. The term "diagenesis" is here used as defined by Sujkowski (1958, p. 2692) and Pettijohn (1957, p. 648–649) and is taken to mean all changes that occur in a sediment after it is deposited. The detailed diagenetic changes of the various allogenic and authigenic constituents in the Moenkopi Formation follow generally those described in an earlier report (Cadigan, 1967, p. 27–30) on the Morrison Formation.

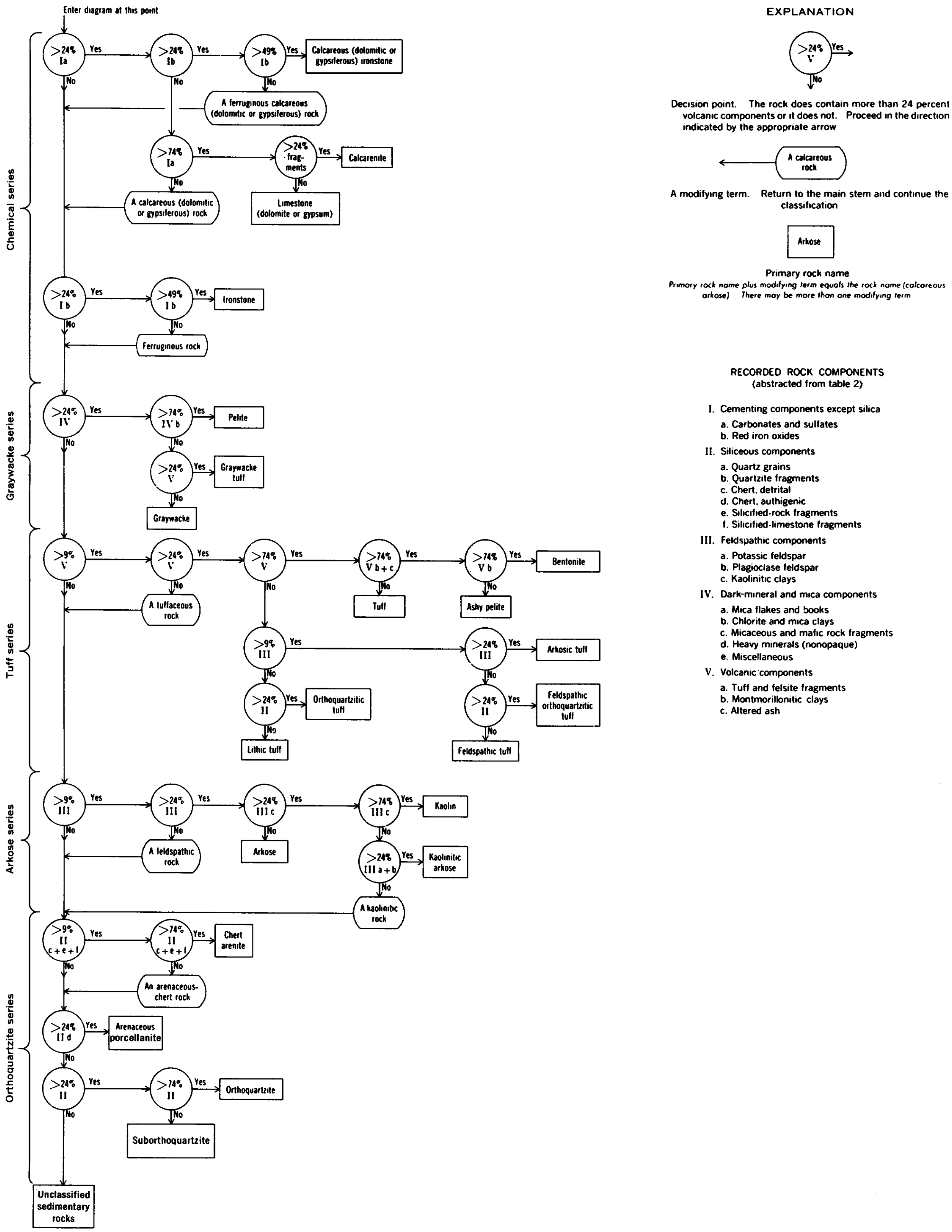

FIGURE 7.—Binary logic design of procedure for classifying sedimentary rocks of the Moenkopi Formation and related strata.

The major systematic diagenetic compositional change discernible in the Moenkopi Formation as a whole is an apparent increase in proportion of carbonate minerals at the expense of detrital minerals and earlier products of diagenesis. In some thin sections, calcite has made such progress in filling interstices and replacing matrix and detrital grains that the end product of diagenesis would seem to be a limestone. In a few others the replacement of the clay matrix by quartz overgrowths has produced quartzites composed almost entirely of detrital quartz grains with interlocking quartz overgrowths. The term "replaced" refers to the occupation by one mineral of an area in a thin section that microstructural relationships suggest was formerly occupied by another mineral.

Many thin sections show only (1) partial alteration of sodic and potassic feldspar fragments to small, scale-like colorless crystals of chlorite intergrown with the feldspar, (2) recrystallization of the clay minerals in the matrix, and (3) impregnation of the matrix with iron oxide (hematite?).

Diagenetic changes affect texture as well as composition. The replacement of detrital grains by carbonates and the alteration of sand- and silt-size tuffaceous and feldspathic detrital particles to finer grained clay minerals has the effect of greatly increasing the proportion of clay- and silt-size particles, and thus decreasing average particle size. On the other hand, the replacement of clay minerals by chemically precipitated cements, the recrystallization of clays, and the addition of overgrowths to quartz and feldspar grains increase average particle size.

Some diagenetic changes are almost certainly unidirectional. Cementing minerals are observed to replace all matrix materials and, in some rocks, each other, but the matrix materials show no evidence of being reconstituted from cements. Calcite and dolomite replace both detrital quartz and feldspar and their respective authigenic overgrowths, and barite replaces calcite. Iron oxides and other metallic oxides and sulfides can apparently replace everything. Relationships between calcite and dolomite cements may not be unidirectional but may include examples of dedolomitization such as described by Evamy (1967).

The greatest changes observed within the rocks are reflected in the clay minerals, which are interpreted to be mostly products of diagenesis. Detrital clays are probably present but unrecognizable; recrystallization of the clay minerals, possibly a continuing process, tends to obscure evidence of their origin. Interstitial mica and chlorite clays are believed to be derived from fine silt- and clay-size detrital mica and feldspar, and from montmorillonite. Montmorillonite is believed to be a primary alteration product of glassy volcanic debris, and itself alters to montmorillonite-mica clay mixtures or to mica clay; or, in the presence of potassic feldspar or ash, alters through chlorite-montmorillonite to chlorite or kaolinite; or, in the absence or near absence of potassium and presence of abundant sodic feldspar or ash, alters to chlorite alone.

TEXTURAL MEASURES

PARTICLE SIZE

The study of the particle-size distributions in siltstone and sandstone of the Moenkopi Formation consisted of mechanical analysis of rock samples as described on p. 9 and indicated in the flowsheet (fig. 6), followed by calculations of the statistical measures for each sample. All samples were treated by the same procedures unless otherwise noted; thus, the computed measures of the grain-size distribution are mutually comparable.

To determine the grain-size distribution of the samples, sand-size particles were divided into the conventional size classes by means of calibrated sieves. The size distribution by classes of silt and clay particles was determined by means of the pipet method (Krumbein and Pettijohn, 1938, p. 165–172), a sedimentation method which measures particle size in terms of settling velocity. The size classes used are those originally defined by Udden (1914, p. 657–658), revised by Wentworth (1922), and adopted with further refinements by the National Research Council (1947, p. 937). Table 3 lists Udden's classes, those adopted by the National Research Council, the class limits (in millimeters), and phi scale. The millimeter values of the class limits progress (increase) and regress (decrease) in geometric fashion. The phi values, which progress and regress in algebraic fashion, are negative logarithms to the base of 2 ($-\log_2$) of the millimeter class limits. A millimeter phi scale conversion table was published by Page (1955). Concepts of size of sedimentary particles were discussed by Wadell (1932, 1934), Pye (1943), and Pettijohn (1949).

All computations of statistical measures of particle-size distributions were concerned with the logarithmic (phi) grain-size distribution. The statistical measures obtained were the mean, standard deviation, skewness, and kurtosis determined by moment computation; the modal grain size, estimated from the frequency distribution of the weights of sieve retents and pipet aliquots; and the median size (ϕ_{50}) and the other phi percentiles, ϕ_2, ϕ_5, ϕ_{16}, ϕ_{84}, ϕ_{95}, and ϕ_{98}, determined graphically from cumulative frequency curves. Moment computations follow the method detailed by Krumbein and Pettijohn (1938, p. 250–252).

TABLE 3.—*Systems of grain-size classification of sediments and their class limits, expressed in millimeters and phi scale*

Class limits (mm) [1] From	Class limits (mm) [1] To	Udden's classification (1914)	Krumbein's class limits phi scale (1934) [2]	National Research Council classification (1947)
			−12	
*2048	4095			Very large boulders.
			−11	
*1024	2047			Large boulders
			−10	
*512	1023			Medium boulders.
			−9	
*256	511			Small boulders.
			−8	
128	255	Large boulders		Large cobbles.
			−7	
64	127	Medium boulders		Small cobbles.
			−6	
32	63	Small boulders		Very coarse gravel.
			−5	
16	31	Very small boulders		Coarse gravel.
			−4	
8	15	Very coarse gravel		Medium gravel.
			−3	
4	7. 999	Coarse gravel		Fine gravel.
			−2	
2	3. 999	Medium gravel		Very fine gravel.
			−1	
1	1. 999	Fine gravel		Very coarse sand.
			0	
. 5	. 999	Coarse sand		Coarse sand.
			1	
. 25	. 499	Medium sand		Medium sand.
			2	
. 125	. 249	Fine sand		Fine sand.
			3	
. 062	. 124	Very fine sand		Very fine sand.
			4	
. 031	. 061	Coarse silt		Coarse silt.
			5	
. 016	. 030	Medium silt		Medium silt.
			6	
. 008	. 015	Fine silt		Fine silt.
			7	
. 004	. 007	Very fine silt		Very fine silt.
			8	
. 002	. 003	Coarse clay		Coarse clay size.
			9	
. 001	. 0019	Medium clay		Medium clay size.
			10	
. 0005	. 0009	Fine clay		Fine clay size.
			11	
*. 00025	. 00049			Very fine clay size.
			12	

[1] All limits except those starred (*) are from Udden (1914).
[2] Phi scale is arranged to show upper and lower class limits of each textural class. Thus, medium sand lies between 2 phi and 1 phi. Millimeter class limits are 0.249 and 0.500 mm.

The mean, modal, and median grain sizes are estimates of the average grain size. The mean is the computed average size. The modal size is the most plentiful one by weight; it more often coincides with the grain size estimated by hand lens than does the mean. The median size is the middle size of the distribution—half the grains by weight are finer and half are coarser.

SORTING

The standard deviation, skewness, and kurtosis were used as measures of average and internal sorting. These measures were discussed in a previous paper in which systems of classification of sorting, skewness, and kurtosis of a size distribution were suggested (Cadigan, 1961, p. 123–131). Sorting is a geologic concept of the effect on a sediment of what Gilbert (1914, p. 152) described as a sorting process. A medium of sediment transport, such as moving water or air, tends to exert a size grading influence on the sedimentary material transported and deposited. The degree to which the grading action has been carried out prior to final deposition and burial of the sediment is referred to as the degree of sorting. The standard deviation of a grain-size distribution is a good measure of the overall average sorting of the sediment represented by a disaggregated sample (Krumbein, 1936, p. 43).

Skewness is a measure of the contrast in internal sorting between the fine and coarse ends of the particle-size distribution. Positive values indicate poorer sorting in the finer sized material; negative values indicate poorer sorting in the coarser sized material.

Kurtosis (peakedness) of a grain-size distribution is a measure of the contrast in internal sorting between the average of the extremes of the size distribution and the center (Cadigan, 1961, p. 128–129). A highly peaked size distribution is one in which the center is better sorted than the average of the extremes. Skewness and kurtosis values represent the measures of deviation from the theoretical normal, or Gaussian, distribution. Thus, zero values for both would indicate that the particle sizes for a particular sediment were normally distributed and that the degree of sorting in all parts of the particle-size distribution is about the same.

MOENKOPI FORMATION AND RELATED STRATA

STRATIGRAPHIC RELATIONS AND CHARACTER

The individual members of the Moenkopi Formation and lithologically related strata (fig. 5) are generally conformable with overlying and underlying members. The sediments that compose the Moenkopi and related strata can be divided into three general facies: (1) marginal marine and alluvial red and gray coarse siltstone and very fine to fine-grained sandstone facies, which includes undifferentiated red Moenkopi, all of the informal red and gray members, and the Moqui, Wupatki, Sewemup, Pariott, and Ali Baba Members, the Woodside, and Mahoghany Formations, and the upper member of the State Bridge Formation; (2) alluvial coarse sandstone facies, which includes parts of the Tenderfoot, Holbrook, and Hoskininni Members; and (3) limestone and evaporite facies, which includes the marine Virgin and Sinbad Limestone Members, the marginal marine Timpoweap (limestone and conglomerate) Member, and marine to marginal marine Shnabkaib (gypsum and limestone) Member, the Thaynes (limestone) Formation, and scattered undesignated gypsum beds occurring mostly in the basal strata of the Moenkopi.

The coarse siltstone and very fine to fine-grained sandstone facies, which is dominant in the Moenkopi, is characterized by an overall reddish-brown color, although individual beds and members are brownish gray, gray, or brown. The strata of this facies are typically flat bedded and weather to slopes covered with platy fragments commonly ranging in size from 1 mm thick and 10 mm wide to 25 mm thick and 1 meter wide. Ripple-marked bedding surfaces are common. Some members show crossbedding on a relatively small scale. Some strata associated with gypsum have contorted bedding structures which are evidence of collapse or slumping. This siltstone-sandstone facies is the most common one in most localities throughout the Colorado Plateau region, including the type locality (fig. 2).

The coarse sandstone facies constitutes a minor part of the Moenkopi and is characterized by a reddish-brown color but with variations similar to those of the siltstone-sandstone facies. The strata are typically crossbedded and weather to resistant ledges; however, where they contain a high proportion of mud they weather to poorly resistant muddy slopes. The muddy sandstone strata tend to form rather massive units compared with the thinner better sorted ledge-forming strata. The coarse sandstone facies is most common along the east and south margins of the area of deposition.

The limestone and evaporite facies, like the coarse sandstone facies, constitutes a minor part of the Moenkopi and is characterized by gray and yellowish-gray limestone beds and thin to thick massive beds of white gypsum. The limestone beds in most localities form continuous resistant massive ledges. The gypsum in some localities forms moderately resistant thin to thick, massive beds, and in other localities, poorly resistant beds of gypsum interbedded with gray limestone, or gray or red siltstone, or limy siltstone. Gypsum beds in the eastern localities tend to be basal units; but in western localities they occur throughout the section, and in the west (fig. 5), dominate the Shnabkaib Member.

COMPOSITION OF THE SILTSTONE-SANDSTONE STRATA

The siltstone-sandstone strata include rocks of the sedimentary orthoquartzite and arkose series. The most common varieties are feldspathic suborthoquartzites, calcareous feldspathic suborthoquartzites, arkoses, and suborthoquartzites (<75 percent siliceous components). These rocks are composed of granular particles, matrices, and cements, all of which vary in kind and proportion from one part of the region to another.

The granular particles are grains of quartz and potassic and sodic feldspars; fragments of silicified metamorphic, sedimentary, and igneous rocks; flakes and shreds of biotite and muscovite; and detrital heavy-mineral grains including magnetite-ilmenite, leucoxene, zircon, tourmaline, garnet, staurolite, epidote, rutile, apatite, and an amphibole resembling hornblende.

Matrices of the rocks, in addition to silt- and clay-size quartz, feldspar, and mica, consist of clay minerals—

dominantly of mica clay, and to a lesser extent, chlorite, kaolinite, montmorillonite, and various clay mineral intermixtures.

The cements are composed, in estimated order of abundance, of calcite, authigenic quartz, dolomite, red iron oxide, gypsum, microcrystalline quartz, and barite.

QUARTZ AND OTHER SILICA

The dominant mineral in the siltstone-sandstone strata is quartz, in detrital grains. Most quartz grains consisting of a single crystal show unstrained extinction, and many have microlitic inclusions of tourmaline. Most aggregated quartz grains that compose quartzite fragments show strain extinction. Grains are angular to rounded. Coarse grains in the Hoskinnini Member tend to be rounded to subrounded; very fine sand grains in other members tend to be more angular; and coarse silt grains are dominantly angular and, in some strata, resemble a microbreccia. Detrital quartz also occurs in several forms of microcrystalline aggregates, including homogeneous grains of chert; heterogeneous-looking silicified-rock fragments with inclusions of microlites of mica, calcite, and partially isotropic interstitial silica; and poorly crystallized microcrystalline quartz aggregates which contain isotropic or amorphous silica and which could be fragments of either silicified limestone or devitrified silicified glass.

Interstitial silica occurs as authigenic optically continuous overgrowths on detrital quartz grains and as microcrystalline interstitial growths with aggregate polarization like that of chert. In some strata, extreme authigenic quartz overgrowth has produced nearly pure quartz sandstone in which detrital quartz grains are cemented tightly with quartz overgrowths to give a mosaic appearance to thin sections between crossed nicols (fig. 8). More commonly, detrital quartz grains have only a thin skin of authigenic quartz over their abraded surfaces.

FELDSPAR

Feldspar grains in analyzed samples constitute a few percent to more than 25 percent of the rock and include the potassic varieties orthoclase, microcline, and sanidine(?) and the sodic varieties albite, ogligoclase, and anorthoclase(?). Detrital grains include angular euhedral particles and angular to rounded fracture fragments. Overgrowths are common in some strata with orthoclase overgrowths on orthoclase (fig. 9) and albite grains, and albite overgrowths on oligoclase grains. Grains with albite to oligoclase composition appear to be the most weathered and appear to be readily susceptible to alteration and replacement. Albite where abundant usually shows from very slight to almost total alteration to chlorite (clinochlore?).

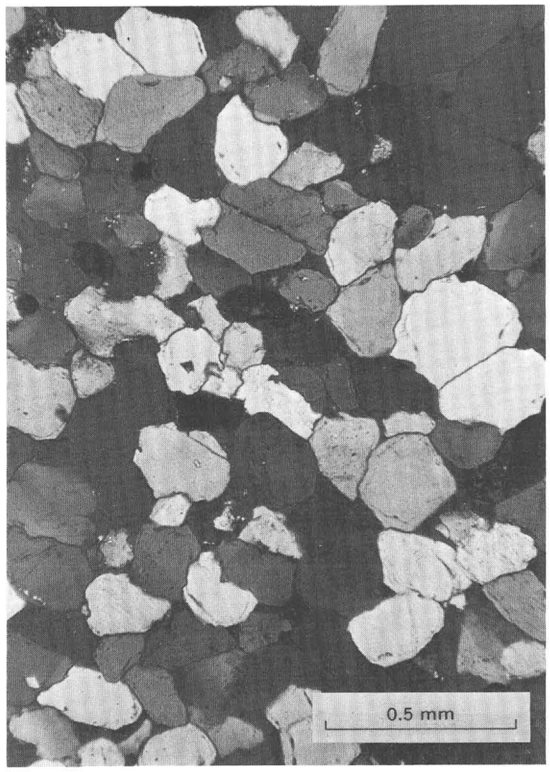

FIGURE 8.—Sandstone (orthoquartzite) in the Moenkopi Formation, lower slope-forming member (sample L3169), illustrating mosaic microstructure in which the rock is composed almost entirely of quartz grains and overgrowths. Crossed nicols.

Most of the feldspar grains do not show twinning, but carlsbad twinning is common in some orthoclase; microcline shows polysynthetic twinning (fig. 10); some albite and oligoclase show albite twinning (fig. 11); and anorthoclase shows pseudopolysynthetic twinning. Many rounded untwinned very slightly altered albite-oligoclase grains resemble quartz in thin section and are differentiated with difficulty.

TUFFACEOUS DETRITUS

Tuffaceous detritus consisting of altered silicic glassy potassic and sodic tuff fragments, shards, and ash (figs. 12 and 13) is recognized in significant amounts (5–15 percent) in the Ali Baba Member and possibly equivalent strata in southwestern Colorado, and in the unrelated Holbrook Member in east-central Arizona. Most of the Moenkopi contains, on the average, less than 1 percent recognizable tuffaceous detritus, and strata possibly equivalent to the tuff-bearing members contains 1–5 percent.

The tuff fragments were derived from potassic and sodic varieties of crystal, vitric, and lithic tuff. The fragments have been devitrified, but in many examples the matrix of the crystal and vitric tuff appears iso-

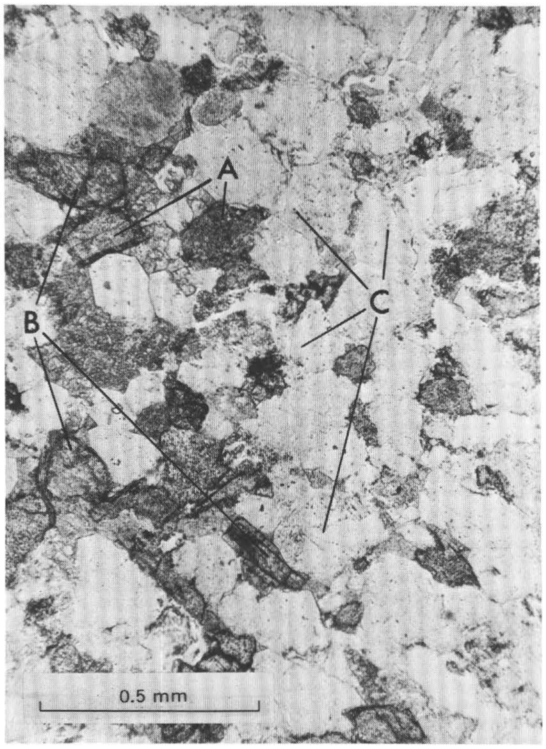

FIGURE 9.—Sandstone (feldspathic suborthoquartzite) in the Moenkopi Formation, upper slope-forming member (sample L1914). A, cobaltinitrite-stained grains of orthoclase feldspar with overgrowth rims; B, calcite ghosts of feldspar grains with stained feldspar overgrowth rims; C, quartz grains. Calcite replacement of detrital grains but not the overgrowths suggests differences in composition between the two. Polarized light.

tropic, although the indices of refraction of the fragments are estimated to be in the range of 1.51 to 1.54. The altered crystal tuff fragments contain subhedral phenocrysts of potassic and sodic feldspar. The composition of the tuff fragment matrices appears to be quartz and sanidine(?) in the potassic tuff and quartz and albite in the sodic tuff. The lithic tuff fragments contain anhedral crystal forms with flamboyant extinction; these amorphous forms are suggestive of development by radial crystallization of either potassic or sodic feldspars from a glassy matrix before, after, or during devitrification. Tuff fragments show various types of alteration, which include the previously mentioned devitrification and silicification, alteration to montmorillonite, and, in sodic fragments, alteration to chlorite clay minerals. Crystal and lithic tuff fragments that contain anhedral quartz tend to grade into those fragments that are classified as silicified-rock fragments of unknown origin. Silicic ash has altered to montmorillonitic and chloritic clays and to interstitial microcrystalline silica and may have been replaced by carbonate or iron oxide cements. Much altered ash is practically indistinguishable from other altered detrital siliceous or clayey maxtrix components.

CLAY MINERALS

Mica clay (illite) moderately to lightly impregnated with red iron oxide and microlites of calcite or dolomite is the dominant interstitial clay mineral group in the siltstone-sandstone strata of the Moenkopi. Mica clay appears as reddish-brown moderately to poorly crystallized interstitial aggregates or platelets of low birefringence or as highly crystallized (probably recrystallized) highly birefringent red rims on the detrital grains.

Chlorite clay is the dominant clay in part of the siltstone-sandstone strata. It is present as bright colorless crystalline scales (clinochlore?) on altered grains, as sand-grain-size aggregates of colorless dull parallel fibrous crystals (clinochlore?), or as a dull pale-green low-birefringent anhedral crystalline material (pennine?). This anhedral material occurs interstitially or

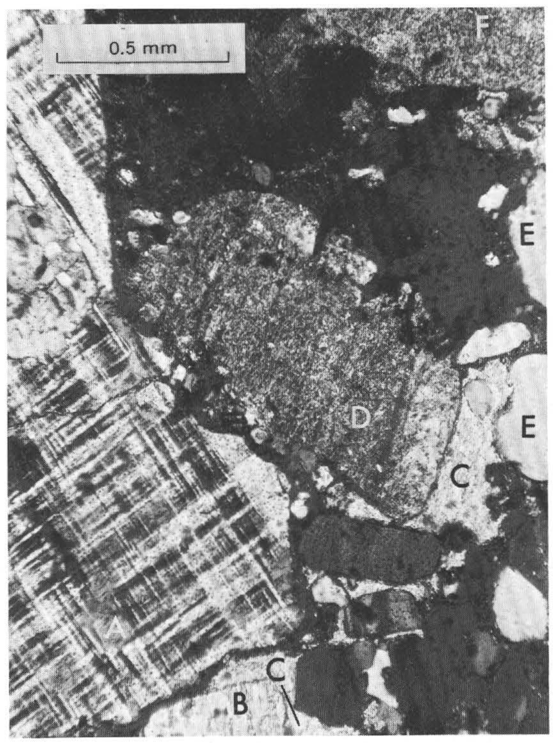

FIGURE 10.—Very coarse granite fragment in fine-grained arkose, Moenkopi Formation, Tenderfoot Member (sample L2612). A, cobaltinitrite-stained microcline showing polysynthetic twinning; B, albite-oligoclase being replaced and invaded by calcite; C, calcite cement; D, partly altered albite; E, quartz; F, partly altered potassic feldspar or potassic tuff fragment. Crossed nicols.

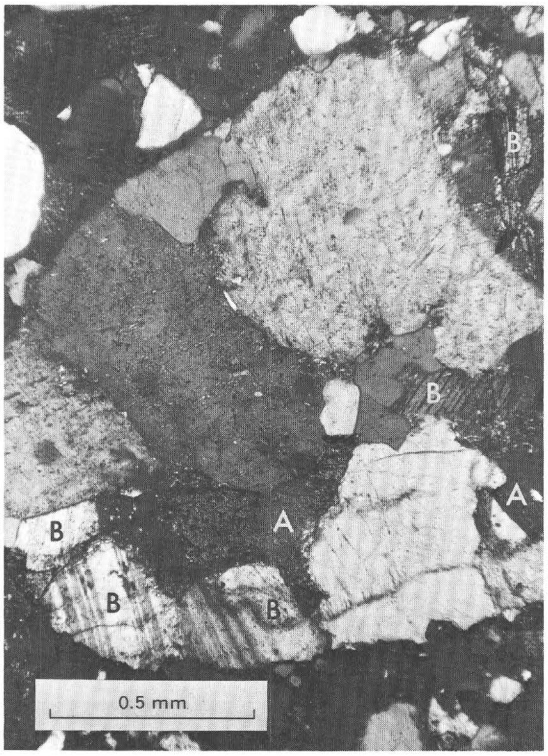

FIGURE 11.—Very coarse (sodic) granite fragment in fine-grained arkose, Moenkopi Formation, Tenderfoot Member (sample L2612); A, biotite; B, albite and oligoclase grains showing albite twinning. Crossed nicols.

is included in altered albite and sodic tuffaceous detritus. Chlorite also occurs, in some strata, as a poorly crystallized mixed-layer clay with montmorillonite or mica clay.

Kaolinite occurs as a colorless, usually well crystallized interstitial clay in wormlike aggregates of parallel hexagonal plate-shaped crystals of high relief. It is relatively abundant in some strata.

Montmorillonite occurs rarely as a pure brownish-red poorly crystallized interstitial crystalline clay. Under crossed nicols it has "swirling" pattern of oriented platelets. Mostly, however, it occurs in poorly crystallized physical or mineralogical clay mixtures, with mica clay or chlorite. Montmorillonite-mica clays are believed to be alteration products of tuffaceous fragments. In the red or reddish-brown rocks, mica and mica-montmorillonite clays contain various amounts of microscopic dustlike crystals of hematite of probable diagenetic origin.

HEAVY MINERALS

Detrital heavy-mineral grains represent less than 0.5 percent of the siltstone-sandstone strata. When examined with a petrographic microscope, magnetite, magnetite-ilmenite, and ilmenite appear as black to brown or altered hematite-red rounded to subangular opaque grains. Some jet-black magnetite grains have vitreous euhedral crystal faces. Leucoxene occurs as white opaque well-rounded spherical grains or as rims, halos, or seams on ilmenite and ilmenite-magnetite grains.

Zircon is present in several varieties. Most common is the rounded clear, colorless zircon. Other forms are colorless euhedral zircon in elongated dipyramidal prisms, rounded pale-pink zircon, and rounded clouded or metamict zircon. Some of the euhedral zircon shows zoning and crystal intergrowths. All varieties show various kinds of inclusions.

Tourmaline is present as rounded grains and has many pleochroic colors; green, brown, and yellow appear to predominate. Garnet, variety grossularite(?), occurs as clear, pink to colorless grains. Some grains have uneven building-block forms (irregular arrangements of cubes) which suggest etching by interstratal solutions; other angular grains show only fracture surfaces; many grains are rounded to subrounded. Staurolite, a rare mineral, occurs in pale-golden to brownish-

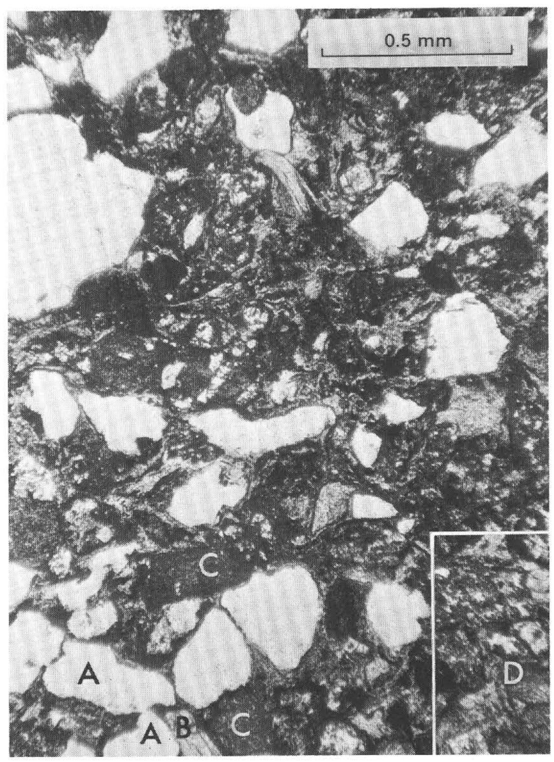

FIGURE 12.—Composition and fabric of sandstone (arkosic tuff) in the Moenkopi Formation, Ali Baba Member (sample L2628). A, quartz grains; B, muscovite; C, cobaltinitrite-stained potassic fedspar grains; D, matrix of cobaltinitrate-stained altered potassic tuff and glass fragments (outlined in lower right). Polarized light.

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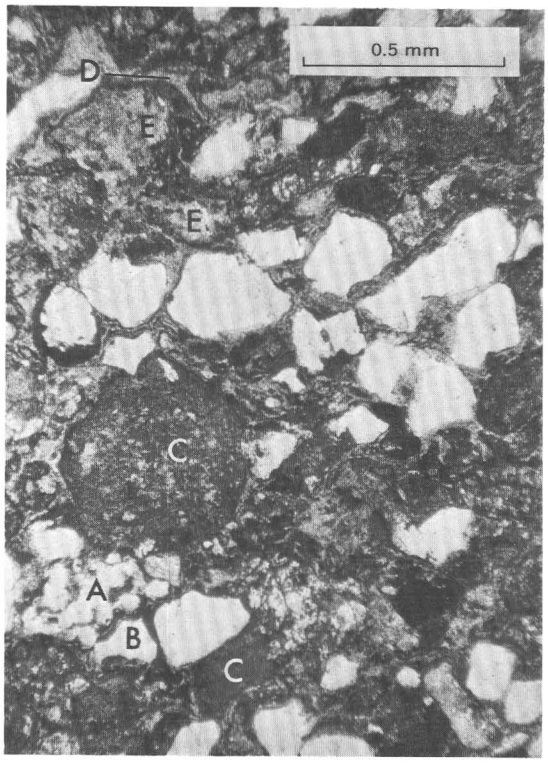


FIGURE 13.—Composition and fabric of sandstone (arkosic tuff) in the Moenkopi Formation, Ali Baba Member (sample L2628). A, quartzite fragment; B, volcanic quartz fragment; C, and E, altered potassic tuff; D, altered potassic glass shard. Grains and fragments are darkened by cobaltinitrite staining on both potassic tuffaceous detritus and potassic feldspars (orthoclase and sanidine) which together make up more than half the rock. Polarized light.

yellow subangular concertina-shaped or splintery-looking grains.

Anatase occurs as a golden-yellow cloudy, translucent mineral, as rounded grains, as grains bounded by cubic, euhedral, cloudy, or, rarely, clear overgrowths, or as aggregates of euhedral crystals. The cloudiness of the particles together with their degree of relief causes them to appear almost opaque in polarized transmitted light. Use of the condenser confirms their translucency. The cloudiness is caused by white semiopaque inclusions which are probably leucoxene. Brookite occurs as golden-brown rounded semieuhedral or euhedral grains, with striated crystal faces. Some brookite grains are very dark, which suggests variations in composition.

Rutile occurs as reddish-brown or golden rounded grains. Apatite and chlorapatite occur as rounded, oval-shaped pale-gray and pale-greenish-gray grains, respectively. Biotite occurs as dark-brown and altered greenish-brown angular, euhedral, or rounded flakes, and as bundles. Some altered biotite is almost colorless, probably as the result of a loss of iron. Muscovite occurs as colorless to pale-green angular to rounded flakes and is common in thin sections of siltstone, where between crossed nicols it appears in longitudinal sections as a threadlike, fibrous highly birefringent mineral, curved or slightly contorted in some instances. Some mica flakes are altered to chlorite (pennine?); rarely, some are altered to or replaced by iron oxide in semiopaque mica-bundle shaped ghosts.

An amphibolite hornblende (?) occurs as partly clouded grass-green to light-yellowish-green slightly ragged subangular to subrounded grains. Some of it is pleochroic, but it is seemingly variable in optical properties from grain to grain, which suggests incipient alteration. Some grains show pale-green overgrowths on abraded rounded surfaces.

Some of the heavy minerals are definitely authigenic in origin. Barite, as colorless, clear to cloudy ragged-looking to subangular fragments, occurs in most heavy-mineral concentrates. The fragments are probably derived from authigenic euhedral barite crystals that were fractured during digestion and disaggregation of the rock samples. Pyrite and hematite are less common than barite; pyrite occurs as euhedral to subeuhedral brassy crystals, and hematite occurs as euhedral to anhedral dark-blood-red semiopaque crystals. The iron minerals are believed to have been derived by alteration of allogenic heavy minerals or possibly, like the barite, to have been deposited from intrastratal solutions.

CEMENTING AND ACID-SOLUBLE MINERALS

Calcite, next to detrital quartz, is the most abundant mineral in the Moenkopi Formation. It impregnates the red clayey matrix in clayey siltstones and occurs as an interstitial cement in the siltstone-sandstone strata. In some samples it forms discontinuous coarsely crystalline anhedral octopuslike patches; in others it forms a continuous cement. Commonly the calcite cement contains fine-sand-size rhombs of dolomite (figs. 14 and 15). Calcite has replaced and possibly is replacing detrital sand and silt grains as indicated by the partially removed or skeletal feldspar, tuff, and quartz grains in contact with or surrounded by calcite, and by the optically anomalous detrital-grain-shaped ghosts formed by calcite. Similarly, the irregularly shaped calcite crystals and microlites and the dolomite rhombs suspended in the matrix suggest that some of the clay minerals, silt- and clay-size detrital minerals, and precipitated silica that form the matrix have been replaced by calcite and dolomite. Calcite crystals filled with detrital particles range from micron-sized microlites to centimeter-sized megascopic "sand crystals."

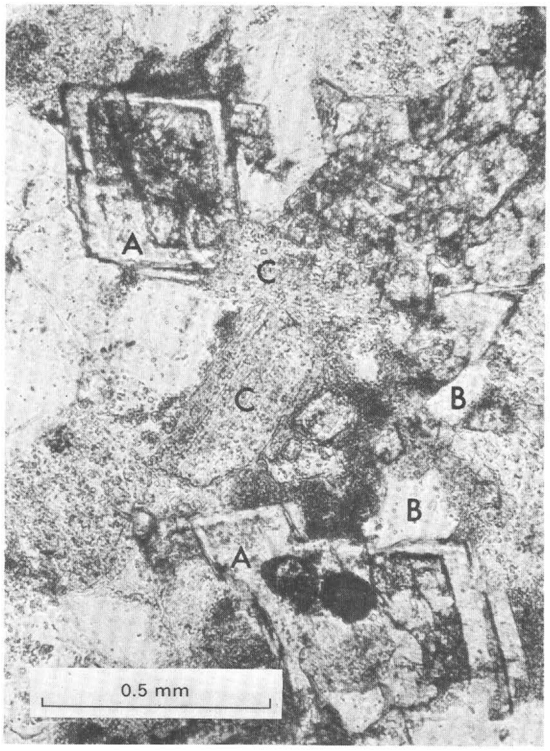


FIGURE 14.—Sandstone (feldspathic suborthoquartzite) in the Moenkopi Formation, upper slope-forming member (sample L1751). A, dolomite rhombs; B, quartz grains; C, cobaltinitrite-stained orthoclase grains. Opaque (black) dustlike substance is yellowish-orange microcrystalline iron oxide. The two dark rounded grains near the bottom are heavy (titanium) mineral inclusions. Polarized light.

Dolomite is everywhere associated with and surrounded by calcite, and it forms sand- and coarse-silt-size rhombs, many of which are zoned. Rarely, dolomite replaces rounded quartz grains to form conspicuous ghosts of relatively high relief surrounded by calcite (fig. 16). In most thin sections dolomite rhombs appear to replace calcite or to have been precipitated on microcrystals of calcite which gives them a dusty appearance.

Red and brown iron oxides, presumably mixtures of hematite and limonite, are present in nearly all strata of the Moenkopi Formation and are responsible for its typically reddish-brown color. Iron oxide crystals range from fine, dustlike hematite microcrystals found in red silt and clay to a dense amorphous to coarsely crystalline interstitial cement. The cement is probably the result of diagenetic replacement of interstitial matrix by iron oxides.

Barite, where conspicuous in thin section, occurs as colorless interstitial bladed or tabular sand-sized crystals. In most sections it is inconspicuous and constitutes less than 1 percent of the rock. It appears to be a late-crystallizing mineral which has replaced interstitial calcite to a minor extent and is intergrown with calcite.

Gypsum is a significant cementing mineral at several localities. In thin sections of gypsum-cemented rock, interstitial gypsum forms bladed fibrous aggregates of negative relief which tend to saturate the rock in the manner of a late-crystallizing invading mineral. This effect is probably the result of the movement and recrystallization of the gypsum that was deposited contemporaneously with the detrital components. Detrital grains show corrosion where they are in contact with gypsum cement. The absence of clay minerals in a gypsum-cemented sandstone suggests complete diagenetic replacement of the clay by the gypsum.

Quartz occurs commonly as an authigenic cement, both as optically continuous overgrowths on detrital quartz grains and as poorly crystallized microcrystalline silica cement.

COMPOSITION OF CLAYSTONES AND FINE SILTSTONES

Claystone and fine siltstone rocks of the Moenkopi are predominantly of the graywacke series (fig. 7). This classification is determined chiefly by their mica clay

FIGURE 15.—Sandstone (feldspathic suborthoquartzite) in the Moenkopi Formation, upper slope-forming member (sample L1751). A, quartz grains; B, phyllite fragment; C and F, dolomite rhombs; D, altered potassic tuff(?) fragment; E, orthoclase grains. Opaque dustlike substance is yellowish-brown microcrystalline iron oxide. Polarized light.

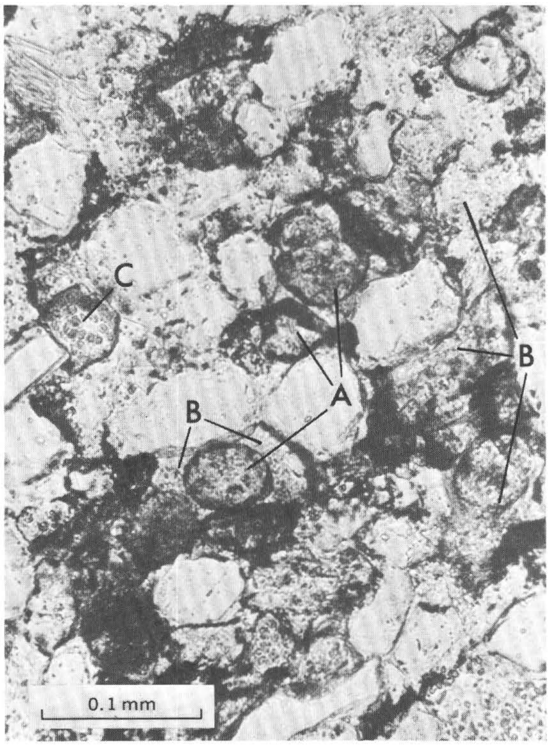


FIGURE 16.—Very fine grained sandstone (calcareous feldspathic suborthoquartzite) in the Moenkopi Formation, lower slope-forming member (sample L3133). A, ghosts of detrital grains replaced by dolomite(?); B, calcite; C, stained orthoclase grain. Opaque material (black in photomicrograph) is orange-red microcrystalline iron oxide. Clear grains are quartz with irregular overgrowths. Polarized light.

and chlorite clay mineral content. The strata, mostly siltstones, are typically red and contain clay- and silt-sized and very fine sand sized grains of quartz and feldspar, abundant flakes of muscovite and biotite, and various clay minerals. The clay minerals include mica clay, mica-montmorillonite, and either chlorite or isolated crystal aggregates of kaolinite, and they are impregnated with calcite and iron oxide minerals.

The dominant clay mineral in the claystone and fine siltstone is illite (mica clay). According to Schultz (1963), the illite occurs with minor amounts of mixed-layer illite in which expandable montmorillonite layers constitute a third or less of the composite mineral. Either chlorite or kaolinite generally occurs in accessory amounts with the illite and mixed-layer illite, but chlorite and kaolinite rarely occur in the same rock. Mixed-layer illite-montmorillonite, in which montmorillonite layers are estimated to constitute from one-third to about half of the mineral, occurs in places along with illite and chlorite.

Schultz found that in the northwestern part of the region and in New Mexico the claystone and fine siltstone of the Moenkopi Formation contain minor amounts of kaolinite. Minor amounts of chlorite occur in the claystone and siltstone of the northeastern part of the region, in and below the lower massive sandstone in northeastern Arizona, and in the siltstone of northwestern Arizona and southwestern Utah. In a few samples from the Comb Ridge area (locality 27) in southeastern Utah, chloritic strata of the Moenkopi also contain mixed-layer montmorillonite, in which montmorillonite layers exceed illite (mica clay) layers.

In the present study it was found that real claystone, composed of 80 percent clay-sized particles, is relatively rare. Some chloritic claystone beds are composed dominantly of chloritic clay in the form of micaceous or fibrous-looking crystals apparently derived from a sediment composed chiefly of parallel-bedded mica flakes.

COMPOSITION OF CARBONATES AND EVAPORITES

The carbonate rocks are almost exclusively limestone and contain both massive crystalline and clastic microstructures. The Sinbad Member is marked by beds of concentrically zoned, radially crystallized oolites. Limestones of the Timpoweap, Shnabkaib, and Virgin Members and the Thaynes Formation contain marine fossil forms and bioclasts (fig. 17). The Shnabkaib also contains oolite zones (fig. 18).

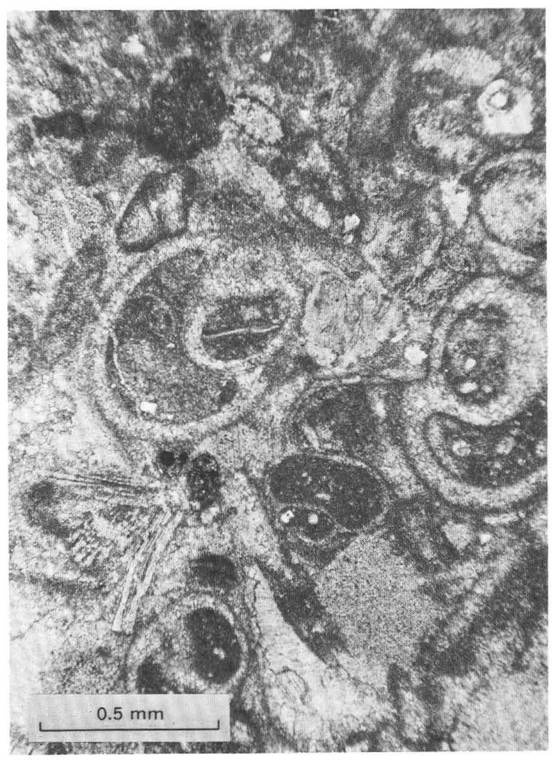


FIGURE 17.—Fossiliferous limestone in the Moenkopi Formation, Timpoweap Member (sample L2231). Fossils are chiefly gastropods, pelecypod shell fragments, and algae. Polarized light.

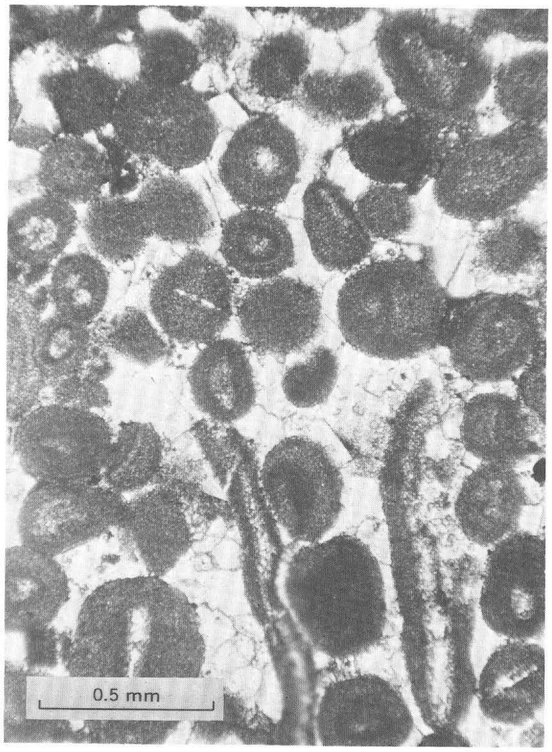


FIGURE 18.—Oolitic limestone in the Moenkopi Formation, Shnabkaib Member (sample L1635). The rock is composed of microcrystalline calcite oolites in coarsely crystalline calcite cement. Polarized light.

Evaporites are almost exclusively gypsum. Gypsum beds of significant thickness are present at the base of the Moenkopi at some localities in southwestern Colorado—the Paradox Basin area—and in southwestern Utah. The most conspicuous occurrence of bedded gypsum is in the Shnabkaib Member in southwestern Utah, northwestern Arizona, and southeastern Nevada, where it forms the dominant facies and is interbedded with gray calcareous siltstone, silty limestone, and oolitic limestone.

ROCK CLASSES

Petrologic modal analyses were made of thin sections of 145 sandstones, 90 siltstones, 8 claystones, 13 crystalline limestones, two coquinites, three nonfossiliferous chemiclastic limestones, four chemiclastic oolitic limestones, and two samples of bedded gypsum. Results are summarized in table 4.

Of the noncarbonate detrital rocks, 158 belong to the orthoquartzite series, 25 to the arkose series, 53 to the graywacke series (based chiefly on mica and chlorite content), three to the tuff series, and four are unclassified calcareous siltstones and sandstones. From modal composition averages in table 4, the average sandstone is a feldspathic suborthoquartzite, the average siltstone is a calcareous graywacke, and the average claystone is a pelite.

The distribution of compositional rock types by textural rock type is given in table 5. Only detrital rock samples, for which thin-section data were available, were used. The first 11 rock types account for 90 percent of the samples considered. Note that contrary to the impression given by the averages (arithmetic means) in table 4, most siltstones are in the orthoquartzite series.

TEXTURAL PROPERTIES

The texture of the strata of the Moenkopi Formation ranges from pebble or breccia conglomerates to claystones. The characteristic textural types, however, are the coarse-grained siltstones and the very fine grained sandstones.

Statistical analyses were made of the grain-size distributions of the detrital grains from 265 samples collected from the Moenkopi Formation. The results are shown in table 6.

According to a previously used classification system (Cadigan, 1961, tables 2, 3, 4, 5), the average Moenkopi sandstone is very fine grained (median size: 0.092 mm) and moderately sorted (standard deviation: 1.78), with a slightly skewed (skewness: 0.94) and moderately peaked (kurtosis: 3.9) grain-size distribution. The average siltstone is coarse grained (median size: 0.038 mm) and moderately to poorly sorted (standard deviation:

TABLE 5.—*The distribution of compositional rock types by textural rock types in the Moenkopi Formation and related strata*

[Rock type symbols taken from table 4. Data available for 243 samples]

Rock type	Sandstone	Siltstone	Claystone	Total
CFOs	31	30		61
FOs	34	9		43
G	13	21	3	37
A	15	3		18
Os	13			13
COs	6	5		11
CG		9	1	10
Pe		5	3	8
SOs	6			6
O	5	1		6
CA	3	3		6
TFOs	4			4
FO	3			3
CFU	1	1		2
CSOs	2			2
FSOs	1	1		2
CU	1	1		2
CFO	1			1
CTU		1		1
CO	1			1
FeT			1	1
CTFOs	1			1
CFT	1			1
AT	1			1
TA	1			1
SO	1			1

1.90), with a slightly skewed (skewness: 0.72) and moderately peaked (kurtosis: 3.0) grain-size distribution. The average claystone is coarse grained (median size: 0.0025 mm) and poorly sorted (standard deviation: 2.20), with a negatively skewed (skewness: −0.17) and flattened (kurtosis: −1.0) grain-size distribution.

Roundness and sphericity measurements were not made on detrital grains of the Moenkopi.

REGIONAL VARIATION, SOURCE, AND ORIGIN

ANALYSIS OF THICKNESS DATA

Trend-surface analysis of Moenkopi Formation (and related strata) thickness data from 62 data points yielded two main products: the average direction of slope of the area of deposition, and the final topographic configuration of the original surface of deposition. Basic data were obtained from Stewart, Poole, and Wilson (1971).

Thicknesses of the Moenkopi and lithologically related contiguous strata, which appear to be parts of the same sedimentation unit and therefore products of the same tectonic events, are used in this analysis, including thicknesses of the State Bridge Formation of Permian and Triassic age in northern Colorado.

The computed first-degree (linear) surface (fig. 19*A*), a sloping plane, has a very strong trend (E_R=53 percent). This computed plane fitted to points on the depositional surface dips N. 60° W. at the average rate of 3.5 feet per mile. The contoured residuals from the first-degree surface (fig. 19*B*) show shelflike (shaded) shallow areas which depart from the computed sloping surface. Unshaded contoured residuals are deep areas. The shallow areas are those that experienced less than the predicted subsidence. The isolated deep area on the Colorado-Utah border is a local differentially subsiding basin, possibly related to shifting of the local underlying thick Permian evaporites (Paradox Member of the Hermosa Formation).

The computed second-degree (quadratic) surface (not shown) is the only surface that is a statistically significant improvement over the first-degree surface; it has an E_R of 87 percent and thus has a predictive capability. The fifth-degree (quintic) surface, with an E_R of 92 percent (fig. 19*C*), is an improvement over, but not significantly different from, the second-degree surface and predicts that the slope of the subsided surface is curvilinear with strikes ranging clockwise from due north in northern Arizona to almost due east in northern New Mexico and northwestern Colorado. The interval between the zero and the 400-foot contours is shaded to suggest a shelflike depositional area adjacent to the pattern-marked Uncompahgre highland, a part of the ancient Uncompahgre–San Luis highland of Baker, Dane, and Reeside (1933, p. 975). Spacing between contours suggests that subsidence increased at a geometric rate to the west. The computed zero isopach marks the theoretical hinge line between what was the rising Uncompahgre highland and the subsiding area of deposition. The shape of the three-dimensional [1] depositional surface of the Moenkopi in the Colorado Plateau region suggests that the region of study was not a focal point of deposition of the Moenkopi sediments, but rather contains only a part or segment of the sedimentary basin involved.

ANALYSIS OF PETROLOGIC DATA

Trend-surface analysis of petrologic data was done (1) to obtain an objective mathematical measure of the strength of the compositional and textural trends (in the Moenkopi Formation) and therefore an indication of their significance and (2) to obtain objective reproducible graphic evidence of the regional variation of specific rock components and rock properties for use in the petrologic interpretation of terrestrial source area direction and probable source terrane composition.

The predominantly marine limestone members of the Moenkopi have been excluded from this analysis. These excluded members—the Sinbad and Virgin Limestone Members and the Timpoweap and Shnabkaib Members—and the Thaynes Formation thicken westward (fig. 5) and are related to a marine source and marine incursions into the area of deposition.

Of the rocks derived from terrestrial sources, arkoses are most common in sediments bordering and west of the Uncompahgre highland in southwestern Colorado and the Uncompahgre–San Luis highland in south-central Colorado and north-central New Mexico; arenaceous chert orthoquartzites (fig. 20) are most common in the southern to southeastern parts of the region. Relative abundance of most rock components, however, cannot be easily or objectively delineated in the region of study. For this reason, the regional distributions of the five principal rock components and some of their constituent mineral groups were tested by trend-surface analysis. The components are cementing (except silica), siliceous, feldspathic, dark-mineral and mica, and volcanic components. The mineral groups tested consist of quartz grains, combined rock fragments, feldspar grains, mica flakes and books, chlorite and mica clays, tuff fragments, and heavy minerals.

Input data for each rock component and mineral group consisted of *U* and *V*, the coded geographic (longitude and latitude) coordinates of each of the

[1] The term "three-dimensional surface" (Allen and Krumbein, 1962, p. 511) indicates a surface on which a point can move in three dimensions.

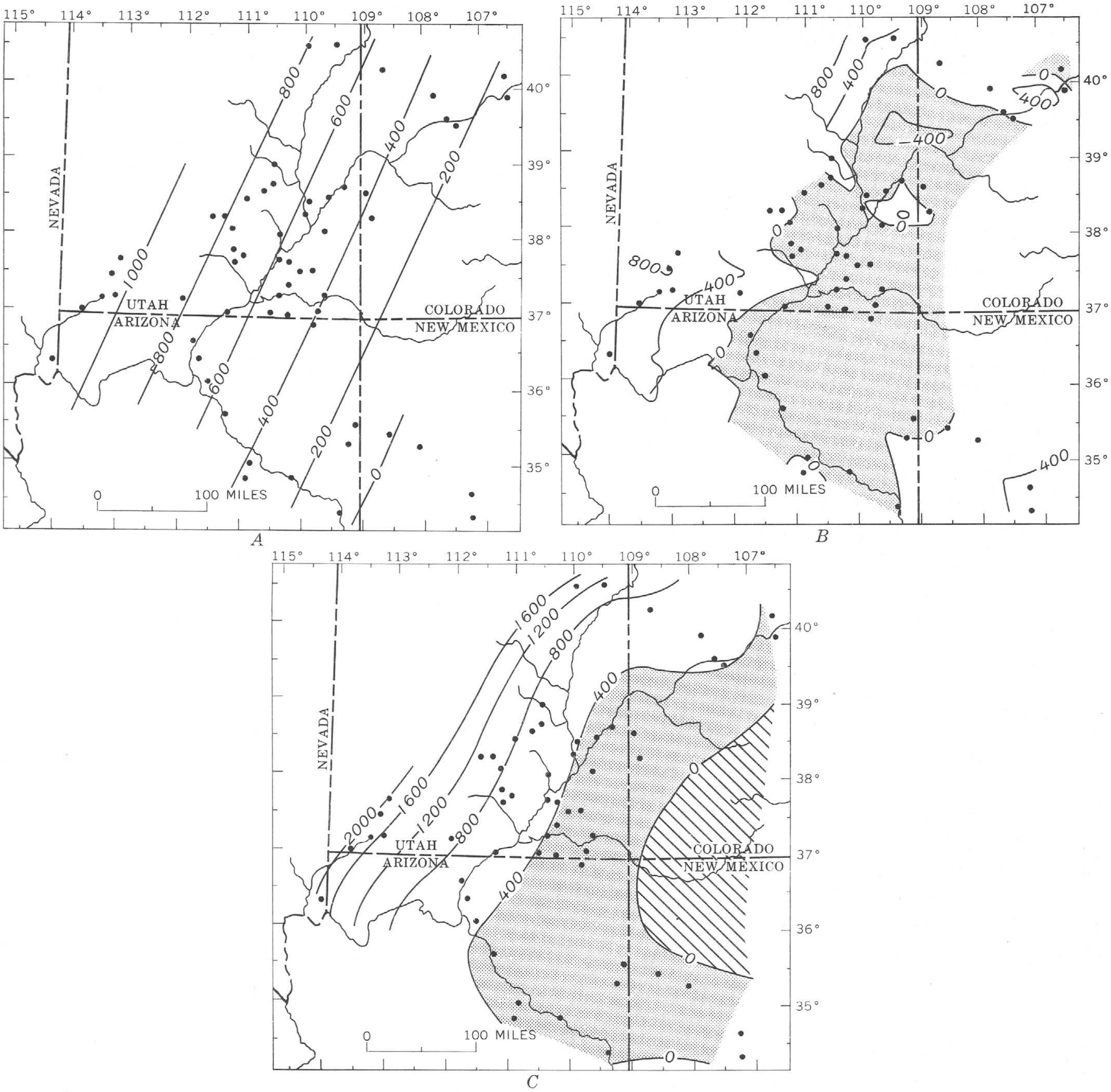


FIGURE 19.—Computed trend surfaces fitted to the relief of the surface of deposition underlying the Moenkopi Formation and related strata, Colorado Plateau region. *A*, First-degree surface; *B*, residual surface from *A*; *C*, fifth-degree surface shows shaded area of the shelf and pattern-marked possible source area or area of nondeposition as defined by the computed surface. Contours show depth, in feet below present eroded top of Moenkopi. Black dots are thickness data control points from Stewart, Poole, and Wilson (1971).

selected sample localities (table 1) for which there were modal compositional data, and X_o, the sample mean of the observed percentages of the mineral group or component at each of these localities. Because clusters of closely spaced locality points adversely affect a trend-surface analysis, the sample data for each of the following sets of adjacent localities were combined to yield a single mean value for each set: in Colorado, 139 and 189; in Utah, 10 and 305, 30 and 200, 34 and 173, 43 and 160, and 49, 313, and 315. These modifications reduced the number of input data points from 65 to 58.

Output for each analysis consisted of X_c, the pre-

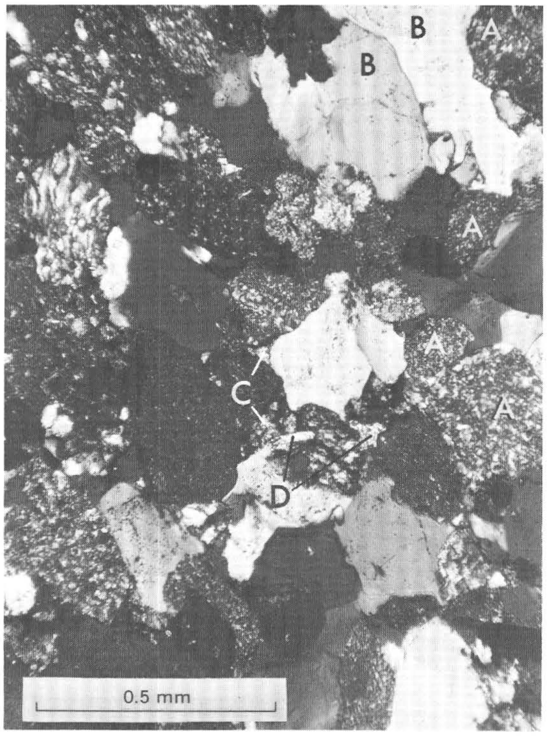


FIGURE 20.—Fine-grained sandstone (arenaceous chert orthoquartzite) in the undifferentiated Moenkopi(?) Formation of northern New Mexico (sample L2426). A, typical silicified-rock fragments; B, typical quartz grains with extensive irregular overgrowths; C, interstitial calcite; D, interstitial barite, Crossed nicols.

dicted percentages of the mineral group or component for each data point, and the residuals or deviations of the observed values from the calculated values. The calculated data can be shown as two kinds of surfaces, the fitted surfaces (predicted values) and the residual surfaces (deviations of predicted values from observed values).

CEMENTING COMPONENTS EXCEPT SILICA

The minerals that have been defined as cementing components except silica consist chiefly of calcite, dolomite, gypsum, iron oxides, and barite. Carbonate minerals dominate the group. Trend-surface analysis yields a regional average of 19 percent cementing components in the detrital rocks. The computed first-degree surface (not shown) strikes N. 30° E. and dips southeastward. The linear trend of increasing cementing components to the northwest is a moderately weak one as indicated by an E_R of 8 percent. The first-degree residual surface (not shown) contains much variation, and the high areas are located on the west margin. The linear trend of increasing cementing components is parallel to the linear trend of increasing thickness, increasing subsidence, and direction of basin slope.

Figure 21 is the best fit of a fifth-degree surface to the regional pattern of variation of cementing components in detrital Moenkopi rocks. The surface has an E_R of 56 percent, indicating that it is a good objective generalization, but cannot be used as a basis for prediction. The high value areas in the west and north coincide with the locations of thick marine limestone and gypsum strata which suggests that the proportions of cementing components in the detrital rocks are related to the marine incursions.

SILICEOUS COMPONENTS

Siliceous components consist of quartz grains and authigenic quartz overgrowths, fragments of quartzite, chert, silicified rock, silicified limestone, silicified rock of unknown origin, and authigenic chert and chalcedony cements. Trend-surface analysis yields a regional average of 39 percent siliceous components in the sandstones and coarse siltstones of the Moenkopi. The computed first-degree surface strikes N. 50° E. and dips northwestward. The trend of decreasing siliceous components to the northwest is moderately strong as indicated by an E_R of 18 percent. The first-degree residual surface shows highest areas to be in the western part of the Four Corners area—the area around the junction of the States of Utah, Colorado, New Mexico, and Arizona.

Figure 22 is the best fit of a fifth-degree surface to the regional variation of observed percentages of siliceous components. The surface has an E_R of 54 percent indicating generalization but no predictive capability.

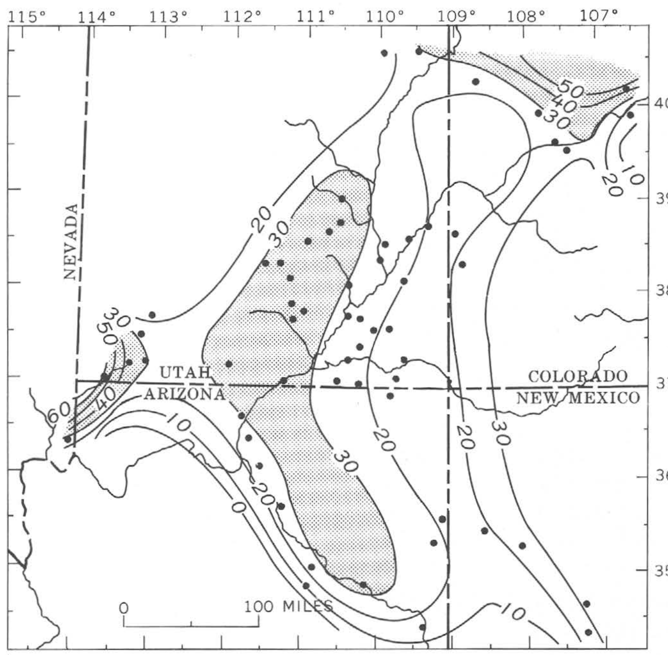


FIGURE 21.—Fifth-degree surface fitted to regional variation in the proportions (percent) of cementing components in the Moenkopi Formation and related strata. High areas (30 percent or greater) are shaded. Black dots are localities from plate 1.

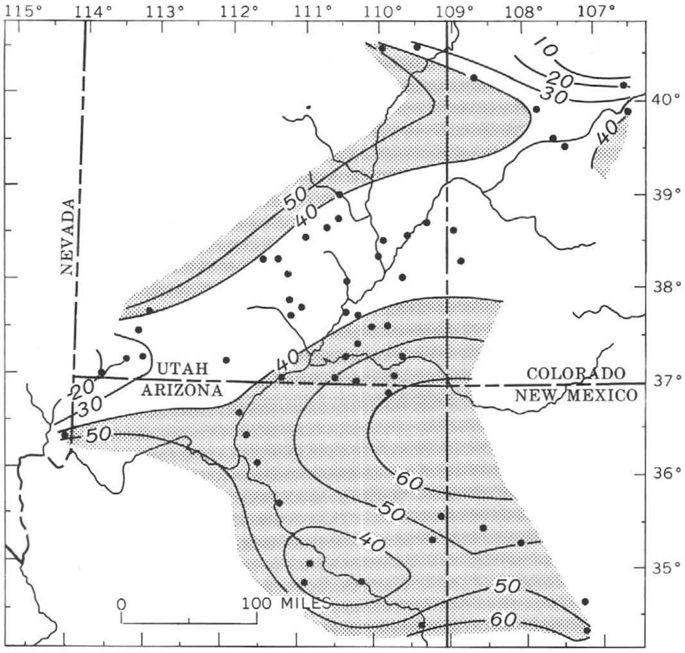


FIGURE 22.—Fifth-degree surface fitted to regional variation of the proportions (percent) of siliceous components in the Moenkopi Formation and related strata. High areas (40 percent or greater) are shaded. Black dots are localities from plate 1.

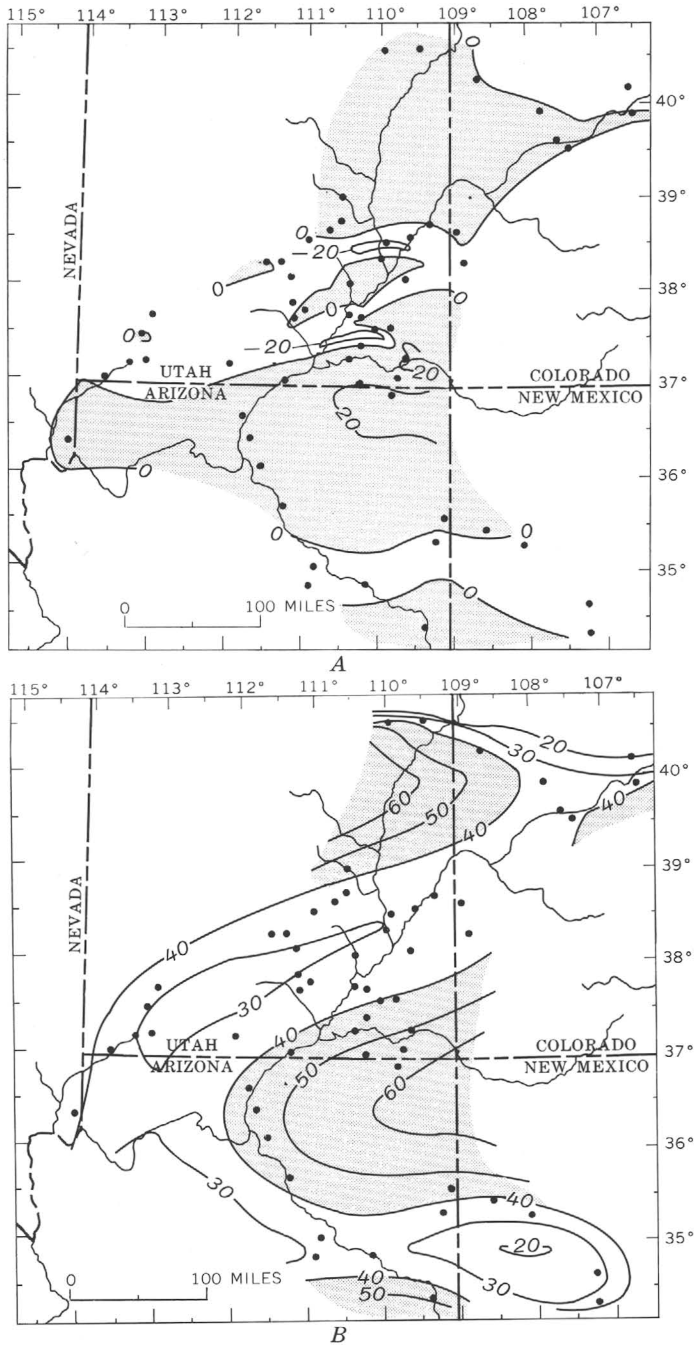


FIGURE 23.—Regional variation of proportions (percent) of quartz grains. *A*, First-degree residual surface; *B*, fifth-degree surface. High areas are shaded. Black dots are localities from plate 1.

The area of highest siliceous components within the shaded areas is in the southwest quadrant of the Four Corners. The low-value area (unshaded) is a northeast-oriented zone which coincides roughly with the north lobe of the boomerang-shaped high cement area of figure 21, and which includes and connects the two areas of highest cementing components. This would suggest that the influence of marine incursions from the west along the low-silica zone may have increased the cementing components of the rocks at the expense of the silica content. Overlapping of the high areas of the computed surfaces for cementing and siliceous components does not detract from the interpreted presence of general trends. The E_R values for the two sets of components indicate only a fair fit of the surfaces to the data.

Separate surfaces were computed for percent quartz grains and percent combined rock fragments from all component groups.

Quartz.—The regional mean proportion of quartz grains was found to be 37 percent. The computed first-degree surface based on 58 data points strikes N. 70° E. and dips northwestward. The linear trend of decreasing volume of quartz grains to the northwest is very weak as indicated by E_R of 1.3 percent. The residual map (fig. 23*A*) indicates high variability, but its dominant features include areas of relatively high-percent quartz grains to the north and south (shaded), and an area of relatively low-percent quartz grains in Colorado that extends westward into south-central and southwestern Utah and northwestern Arizona. Low-percent quartz grain areas also appear to extend westward from northern Colorado and from central New Mexico.

Figure 23*B* shows the best fit of a fifth-degree surface to the regional variation in percent quartz grains. The

E_R of the surface is 47 percent which indicates that the surface is a moderately good generalization. High-quartz-value areas (shaded) agree fairly well with, but are slightly smaller than, the high-silica component areas (fig. 22). A low-quartz-value zone extending diagonally across the region coincides generally with the low-silica zone shown in figure 22. The decrease in strength of the first-degree trend for quartz (1.3 percent) compared with that for siliceous components (18 percent) suggests that most of the regional linear trend for siliceous components is in mineral groups other than quartz grains.

Combined rock fragments.—Percentages of rock fragment mineral groups from all component groups were combined to yield one value for each locality. These percentages included quartzite, silicified rock, chert, and silicified limestone from the siliceous components group, micaceous rock fragments from the dark-mineral and mica components group, and tuff and felsite fragments from the volcanic components group.

The first-degree surface (fig. 24*A*) strikes N. 60° E. and dips northwestward. The regional average combined rock fragment content of the detrital rocks is 4.7 percent. The linear trend of decreasing proportions of total rock fragments to the northwest is a very strong one; E_R equals 54 percent. The residual surface (fig. 24*B*) contains three high areas: (1) one extending from central Arizona to central New Mexico which arcs around a low at the border of the two States; (2) one in southwestern Utah near the Nevada border; and (3) one on the Colorado-Utah border. The fifth-degree surface (not shown) contains the same general highs and lows as the first-degree residual surface and has an E_R of 79 percent, which is evidence of a very strong, almost predictive trend surface. This fifth-degree surface, as well as the third- and fourth-degree surfaces, contains a number of negative values indicating the effect of sharply contrasting high and low values in the data. Such surfaces may be confusing when used for illustrative purposes. The first-degree residuals as confirmed by the fifth-degree surface are presented as evidence of the significant variation of the regional distribution of the combined rock fragments. The strong rock fragment trends suggest that the strength of the siliceous components first-degree trend is largely controlled by the strength of trend of the siliceous-rock fragments in it.

FELDSPATHIC COMPONENTS

Total feldspathic components consist of combined volumetric percentages of potassic and sodic feldspars and kaolinite clays. The first-degree trend surface of the feldspathic components percentage values strikes N. 85° W. and dips southward. The E_R of 25 percent indicates a strong trend of decreasing feldspathic components from north to south. The regional average feldspathic components content of the sandstones and siltstones is 14 percent. To eliminate the possible confusing effects of kaolinite, an alteration product, the feldspar mineral groups were analyzed alone.

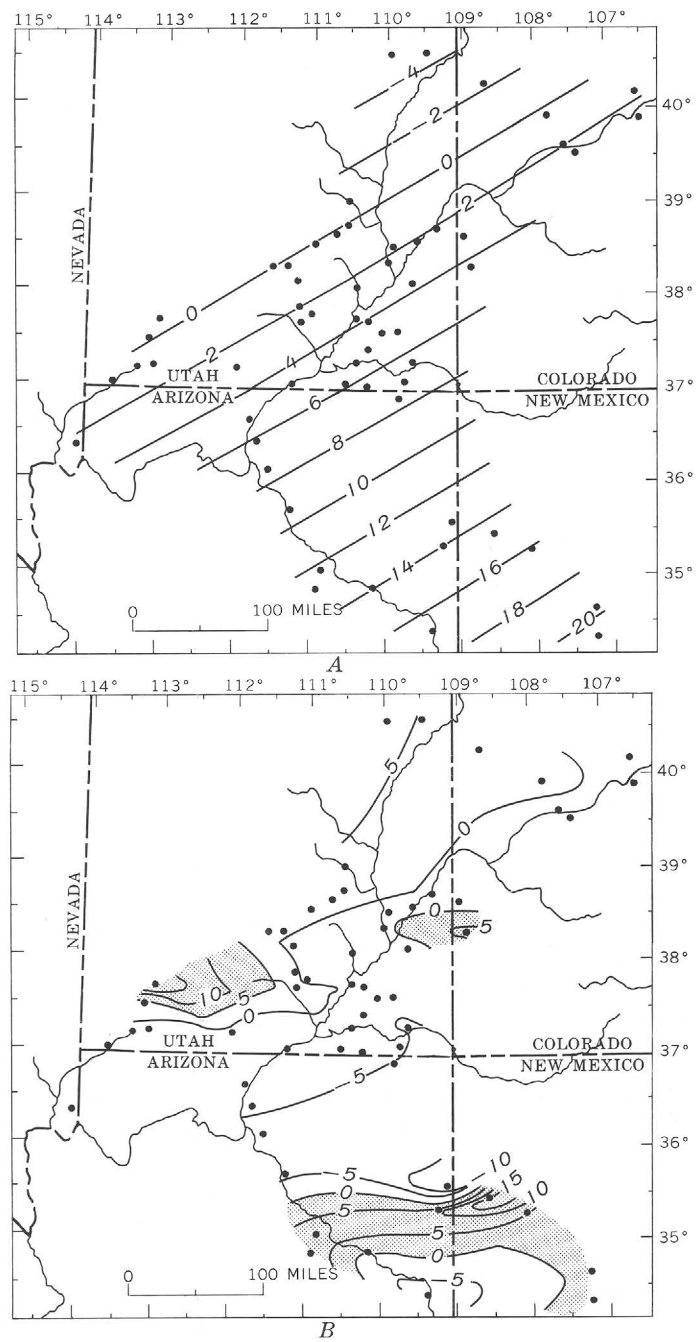


FIGURE 24.—Regional variation of proportions (percent) of all rock fragments. *A*, First-degree surface; *B*, first-degree residual surface. High areas are shaded. Black dots are localities from plate 1.

Feldspar.—Three different trends were analyzed—for potassic feldspar, sodic feldspar, and total feldspar (grains plus overgrowths). The linear surfaces for percent potassic feldspar and for percent sodic feldspar based on the 58 data points have E_R's of 19 and 10 percent, respectively. They are parallel, each having a strike of N. 85° W. and showing trends of decreasing amounts of feldspar to the south. Residuals from the two surfaces yielded similar regional patterns. Regional means were approximately 8 percent for potassic feldspar and 6 percent for sodic feldspar.

The agreement between the trend and residual surfaces suggests that potassic and sodic feldspar came from the same directions and probably from the same source areas. On the basis of this parallelism, trend surfaces for total feldspar were used with the expectation that they would yield valid evidence useful in interpretation of sources. The first-degree surface for total feldspar (fig. 25*A*) has a N. 80° W. strike and a moderately strong trend (E_R=24 percent) of decreasing feldspar to the south. The regional mean is 14 percent.

The first-degree residual map (fig. 25*B*) shows the highest positive residual feldspar percentages in an area just west of the central part of the Utah-Colorado State boundary and in north-central Arizona. The fifth-degree surface (fig. 25*C*), which is fitted to the feldspar data, has an E_R of 54 percent and thus may be considered as presenting a good objectively generalized pattern of the regional variation in feldspar content of the siltstone-sandstone facies of the Moenkopi Formation and related strata. As in the residual map, feldspar content is highest in areas (shaded) that are adjacent to east and southwest margins of the depositional area of the Moenkopi.

DARK-MINERAL AND MICA COMPONENTS

Total dark-mineral and mica components consist of combined percentages of mica flakes and books, chlorite and mica clays, heavy minerals, micaceous and mafic rock fragments, and miscellaneous minerals. Trend-surface analysis yielded a regional mean of 19 percent of these components in the siltstone-sandstone facies of the Moenkopi and related strata.

The computed first-degree surface (not shown) of the dark-mineral components strikes N. 25° E. and dips southeastward. The trend of decreasing proportions of dark-mineral and mica components to the southeast is very weak as indicated by an E_R of 2 percent. The isolated highs on the first-degree residual surface appear rather random and contain little evidence for paleogeologic interpretations. The computed fifth-degree surface (not shown) has an E_R of only 21 percent and thus provides no reliable generalization of regional variation. To search for other, more useful information on the variation of these components, separate trend surfaces were computed for each of two mineral groups: mica flakes and books, and chlorite and mica clays.

Mica flakes and books.—The regional mean proportion of mica flakes and books in the siltstone-sandstone strata is 2 percent. The computed first-degree surface (fig. 26*A*) strikes N. 60° E. and dips southeastward. The trend of decreasing proportions of mica flakes to the southeast is weak as indicated by an E_R of 5 percent. The first-degree residual surface (fig. 26*B*) shows high values in all parts of the region and particularly in southeastern Utah and northwestern Colorado. The weak southeastward tilt of the linear surface indicates only that the Moenkopi in Utah contains on the average slightly more mica than it does in Arizona and New Mexico.

Chlorite and mica clays.—Chlorite and mica clays constitute the dominant mineral group in the dark-mineral and mica components. Trend-surface analysis yields a regional mean of 14 percent for the siltstone-sandstone strata. The computed first-degree surface, like that for mica flakes, strikes N. 40° E. and dips southeastward. The trend of decreasing chlorite and mica clays to the southeast is very weak or almost nonexistent as indicated by an E_R of 1.2 percent. The first-degree residual surface (fig. 27) shows areas (shaded) in the west, center, south, and northeast that have higher-than-average chlorite and mica clay content; mica flakes and books generally occur in the same, but smaller, areas. The central high area in southeastern Utah appears to be the dominant area. The lack of any regional concentration of highs except near the center of the region partly accounts for the lack of a significant first-degree trend.

VOLCANIC COMPONENTS

Most samples of Moenkopi sandstone and coarse siltstone contain only minor amounts of volcanic components such as tuff fragments, altered ash, or montmorillonite clay. Trend-surface analysis yields a regional mean of 2 percent volcanic components. The first-degree surface strikes N. 65° E. and dips northwestward. The trend of decreasing amounts of volcanic components from southeast to northwest is moderately strong, as indicated by an E_R of 13 percent. The regional distribution of volcanic components as fitted by a computed fifth-degree surface (fig. 28), which has an E_R of 60 percent, shows a significant and continuous high area (shaded) along the east, southeast, and particularly the south margins of the area of deposition.

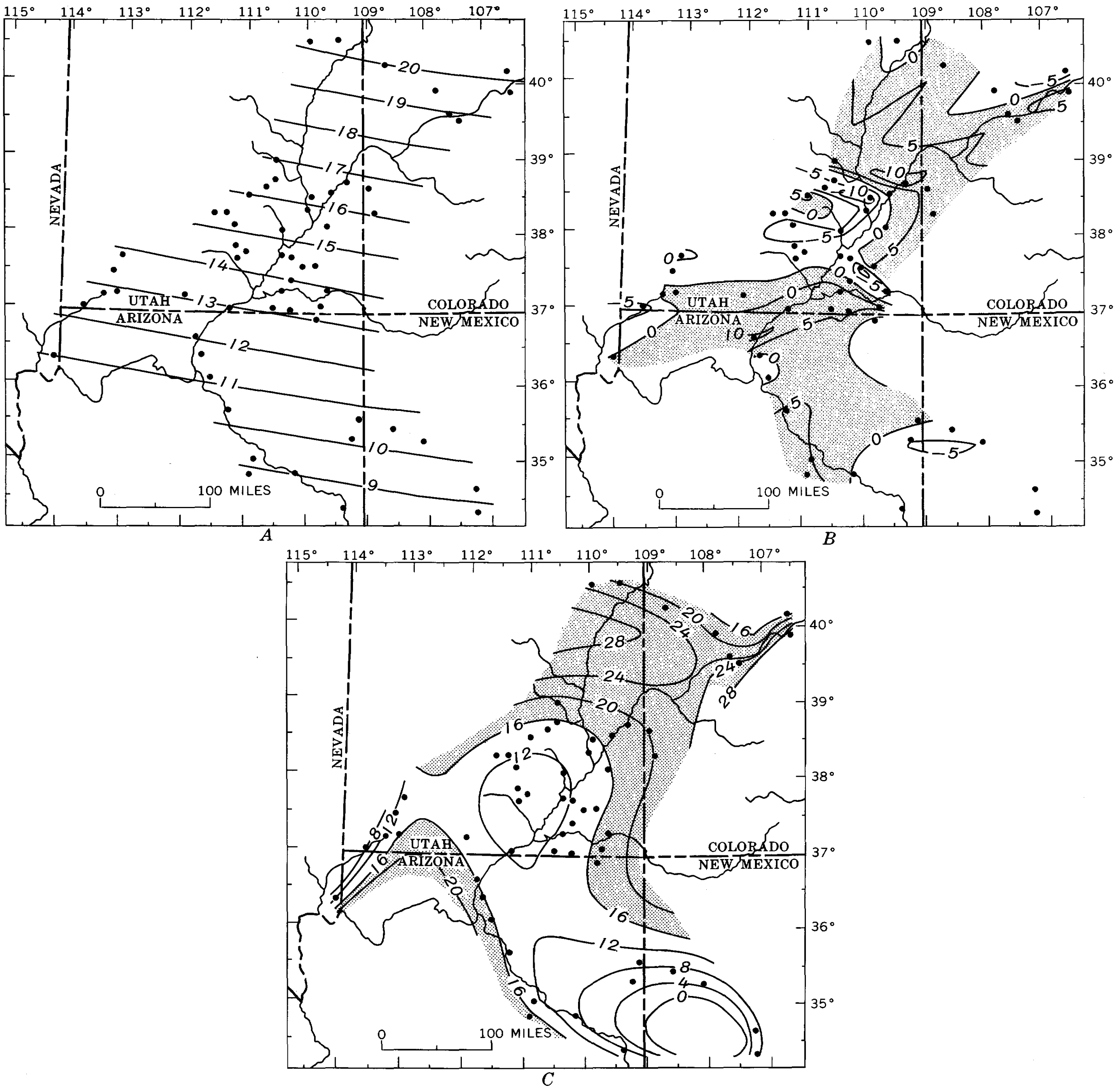
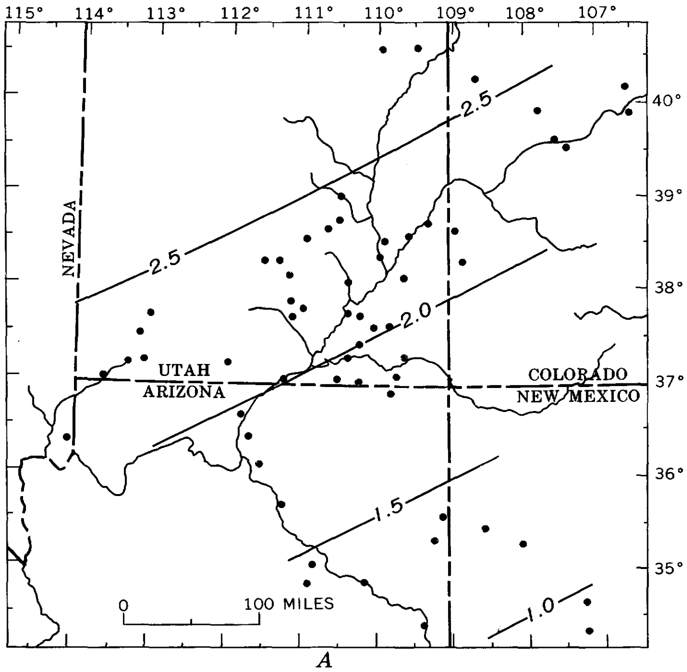


FIGURE 25.—Regional variation of proportions (percent) of feldspar (grains plus overgrowths). *A*, First-degree surface; *B*, first-degree residual surface; and *C*, fifth-degree surface. High a reas are shaded. Black dots are localities from plate 1.



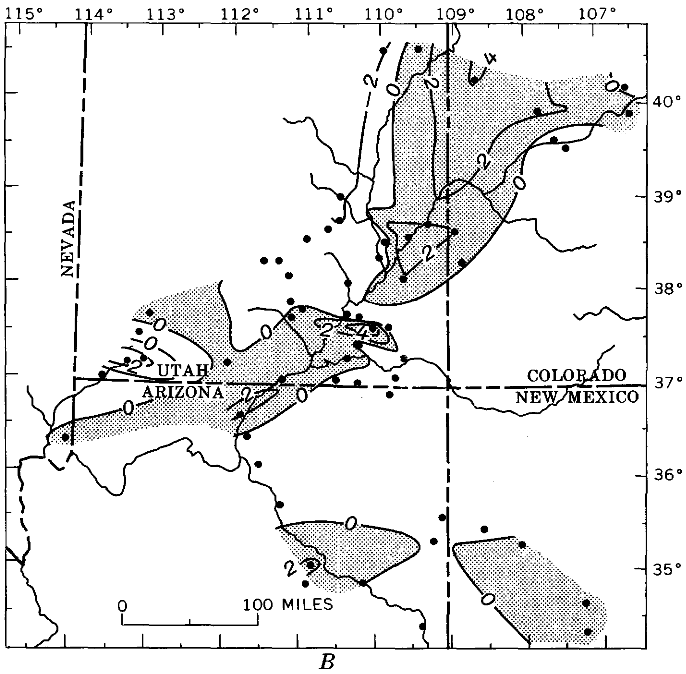


Figure 26.—Regional variation in proportions (percent) of mica flakes and books. *A*, First-degree surface; *B*, first-degree residual surface. High areas are shaded. Black dots are localities from plate 1.

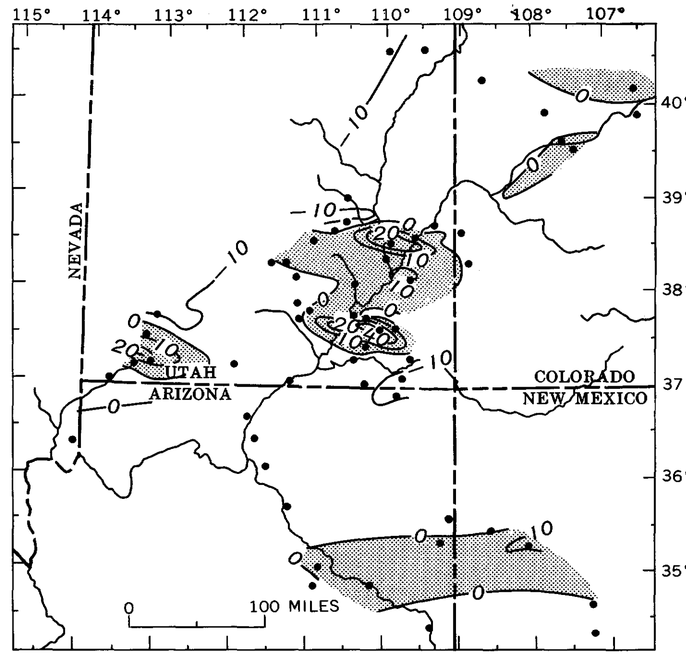


Figure 27.—First-degree residual surface of the regional variation in proportions (percent) of chlorite and mica clays. High areas are shaded. Black dots are localities from plate 1.

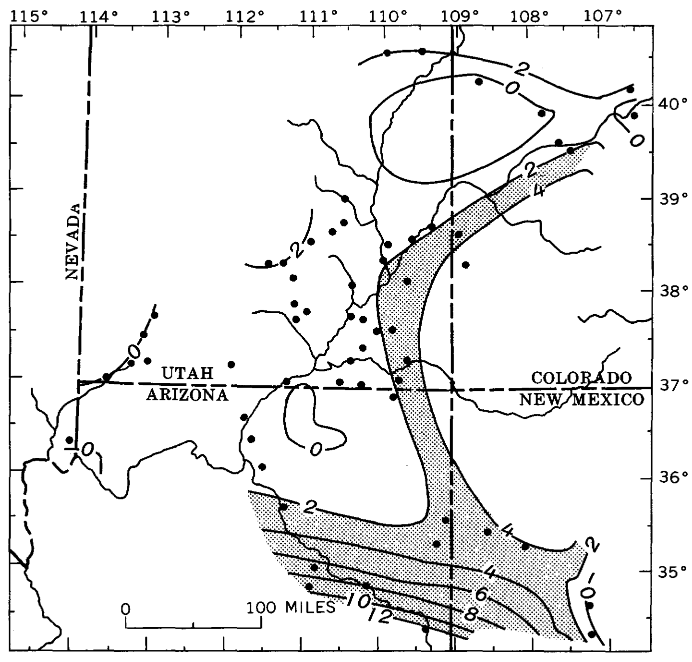


Figure 28.—Fifth-degree surface fitted to regional variation in proportions (percent) of volcanic components, Moenkopi Formation and related strata. High areas are shaded. Black dots are localities from plate 1.

HEAVY MINERALS

Heavy-mineral separations were made on 263 samples of sandstone, siltstone, and limestone from 66 locations. Trend-surface data for heavy-mineral content were computed from 59 data points after "declustering." The regional average heavy-mineral content, a product of the trend-surface analysis, was found to be 0.26 percent.

The heavy-mineral samples consisted of grains of detrital opaque and nonopaque minerals, alteration products such as iron oxides and anatase probably derived from detrital magnetite and ilmenite, and fragments of authigenic minerals such as barite.

Trend-surface analysis of the regional heavy-mineral data yielded a first-degree surface (fig. 29*A*), which strikes N. 45° E. and dips northwestward. The illustrated trend of decreasing heavy-mineral content to the northwest is strong, as indicated by the E_R of 25 percent. The first-degree residual surface (not shown) indicates irregular variation but does not conflict with the fitted fifth-degree surface (fig. 29*B*), which has an E_R of 50 percent, and which shows highs along the east and south margins of the area of deposition.

Counts of heavy-mineral grains were made on prepared slide mounts from 47 samples representing 10 localities in the seven named areas of figure 30.

Average proportions of opaque to nonopaque to authigenic minerals in the 10 localities was determined to be approximately 15 : 3 : 1. Other mineral ratios were determined within the suites of minerals shown in table 7.

TABLE 7.—*Various heavy-mineral ratios and their occurrence in designated areas of the Colorado Plateau region*

[See fig. 30 for localities]

Minerals	Moab	Vernal	Bears Ears	St. George	Hunters Point	Chimney Rock	Big Canyon
Biotite	72	32	8	7	0	17	2
Muscovite	12	48	21	49	15	6	1
Tourmaline	4	13	26	13	52	38	36
Zircon	6	3	32	13	31	20	52
Garnet	6	3	12	8	0	14	4
Staurolite	0	0	<.5	<.5	0	1	0
Amphibolite	0	0	0	8	0	0	0
Epidote	0	0	0	1	0	0	0
Rutile	<.5	1	1	1	2	4	5
Tourmaline	26	82	36	41	63	53	41
Garnet	33	9	14	21	0	18	5
Zircon	41	9	50	38	37	29	54
Opaque	65	88	88	84	75	78	76
Nonopaque	35	12	12	16	25	22	24
Number of samples	13	4	4	16	2	3	5

Even by inspection it appears highly probable that regional variation within the nine-mineral nonopaque heavy-mineral suite is not random. Biotite is most abundant in the Moab, Utah, area; it is least abundant in the Hunters Point and Big Canyon areas of Arizona. Muscovite is most abundant in the St. George and Vernal areas of Utah; it is least abundant in the Big Canyon, Ariz., and Chimney Rock, Utah, areas. In relation to tourmaline and zircon, garnet is most abundant in the Moab area; it is least abundant in the Hunters Point and Big Canyon areas of Arizona.

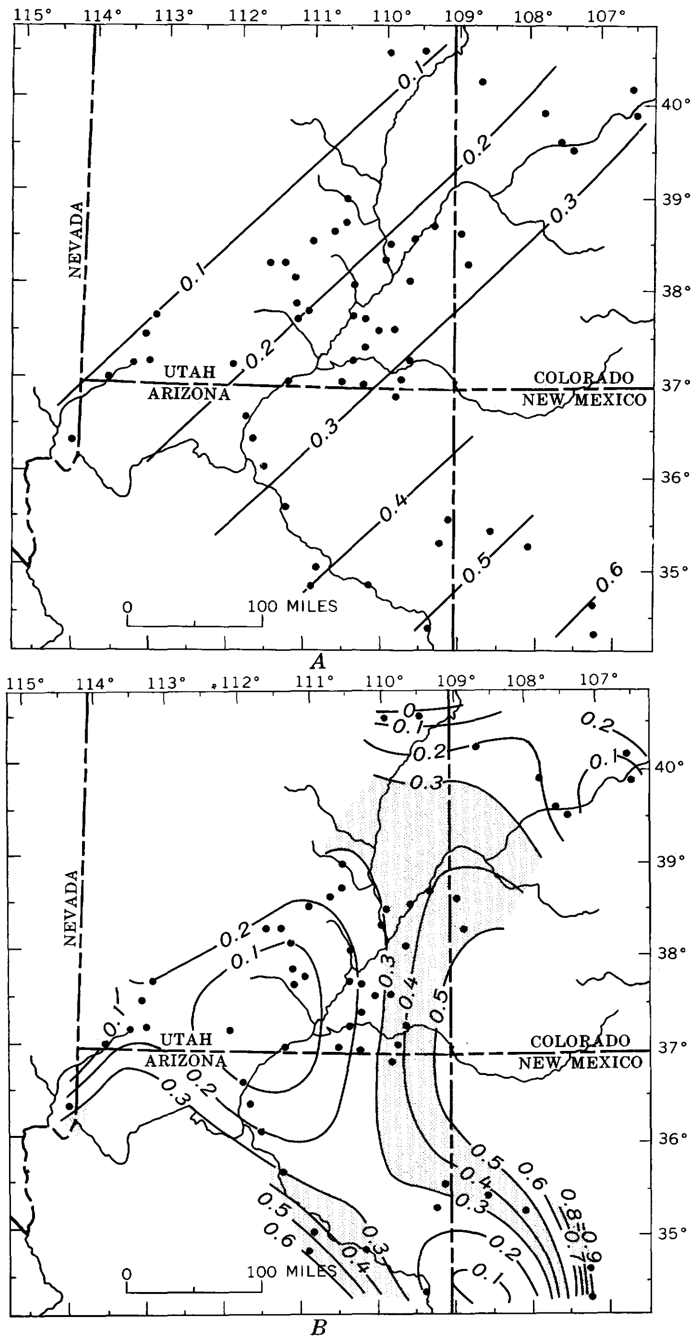


FIGURE 29.—Regional variation in proportions (percent) of all heavy minerals in sandstone and coarse siltstone of the Moenkopi Formation and related strata. *A*, First-degree surface; *B*, fifth-degree surface. High areas are shaded. Black dots are localities from plate 1.

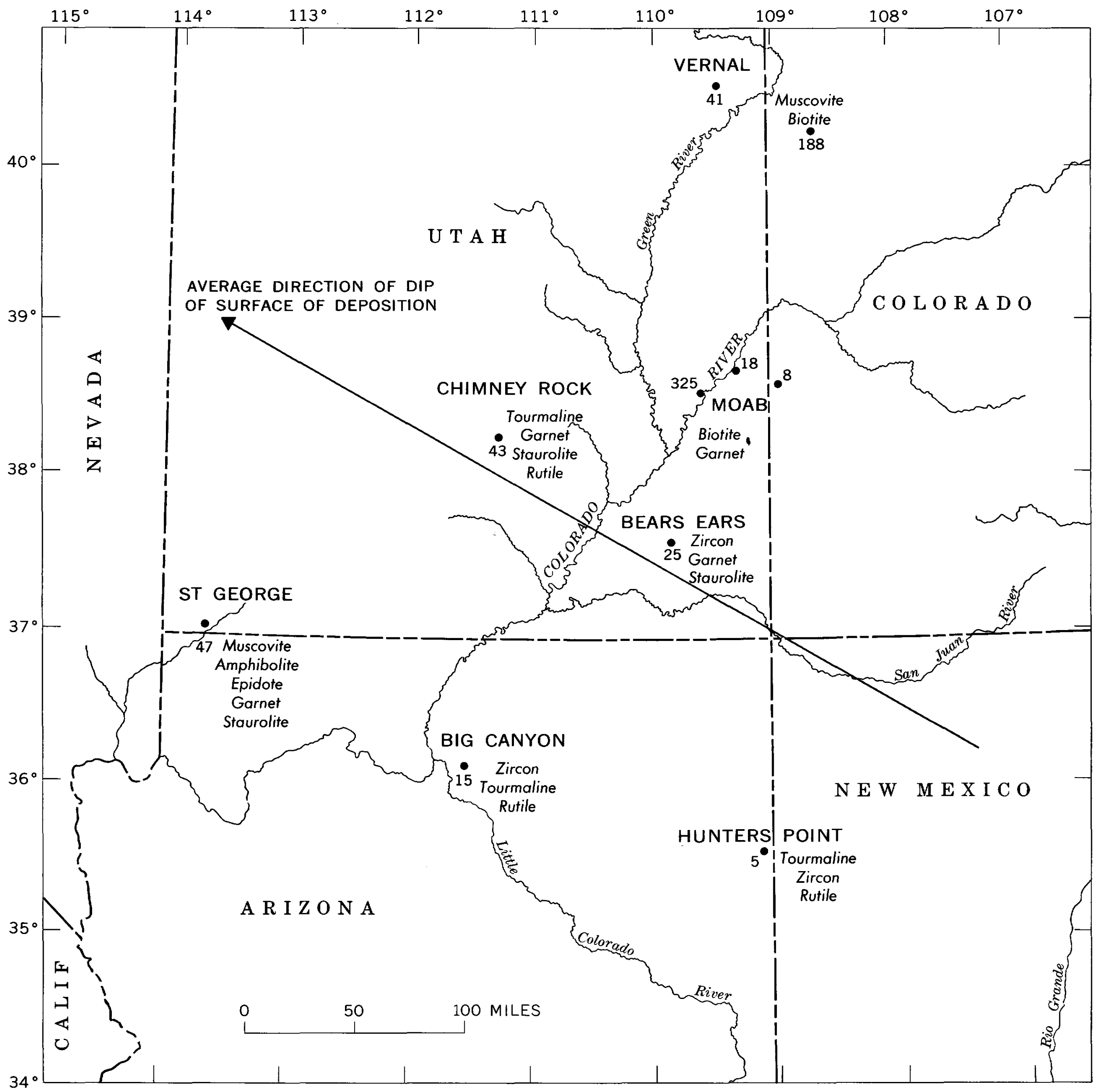


FIGURE 30.—Named areas for which heavy mineral ratio counts were made. Mineral names have been inserted near the area name where minerals have been found in relative abundance (table 7). Samples used in the heavy-mineral study were collected at localities indicated by numbered dots (pl. 1 and table 1).

A rough pattern of the distribution of the nine-mineral nonopaque mineral suite is evident from examination of the mineral data on figure 30 and table 7. Sediment on the south and southeast margins is dominated by the zircon-tourmaline-rutile suite. The Moab-Vernal (Utah) margin area is dominated by biotite and muscovite with a high proportion of garnet. The Chimney Rock-Bears Ears (Utah) area contains a mixture of the zircon-tourmaline-rutile suite plus garnet and the rare mineral staurolite. The St. George (Utah) area suite resembles the Bears Ears suite with the addition of high muscovite and sparse ampibolite and epidote.

GRAIN-SIZE STATISTICAL MEASURES

Regional variation in the grain-size distributions of the siltstone-sandtone strata of the Moenkopi Formation was studied by use of trend-surface analysis applied to the location averages of the phi median grain size (Mdϕ), phi standard deviation ($\sigma\phi$), phi skewness (Skϕ), and phi kurtosis (Kϕ), as determined for 66 sample localities. Declustering in the manner previously described (p. 13) reduced these to 59 data points, one more point than was used for the thin-section studies. The additional data point is locality No. 93.

Grain size.—The average grain size, as measured by the phi median—the same value as the 50th percentile (p. 16)—was used in preference to the phi mean ($M\phi$), because the median is mathematically more independent of size distribution characteristics which strongly affect the standard deviation, skewness, and kurtosis. Thus, regional variation of the median will tend to correlate with regional variation of any one of the other three measures only in response to geologic factors.

Trend-surface analysis was made of the phi median grain size averages for the 59 data points. The regional average was computed to be 4.25ϕ (0.053 mm), the texture of coarse siltstone. The computed first-degree surface (fig. 31*A*) strikes N. 35° E. and dips southeastward. E_R is 20 percent, which suggests a moderately strong regional trend of decreasing grain size from southeast to northwest (phi values increase as grain size decreases). The trend of decreasing grain size is parallel to the computed direction of dip of the area of deposition (fig. 19). The first-degree residual map (fig. 31 *B*) shows areas of relatively coarser texture (shaded) west of west-central Colorado and west of the Four Corners area. Shading was done within the contours of −1 and lower values only, to emphasize locations of coarsest sediment.

The best fit of a fifth-degree surface to the regional variation of grain size (fig. 31*C*) is a moderately good generalization, but with an E_R of 46 percent it lacks predictive capabilities. Areas of relatively coarser textured rock (shaded) are in east-central Utah and along the east and south margins of the area of deposition. Lower (phi) numbered contours indicate coarser texture.

Sorting.—Trend-surface analysis of regional variation of sorting as measured by the standard deviations of the grain-size distributions ($\sigma\phi$) was based on the same data points. The regional average phi standard deviation is 1.85 (moderate sorting). The computed first-degree surface (fig. 32*A*) strikes N. 80° E. and dips northward. The surface has an E_R of 3.3 percent, which is evidence of a very weak regional trend of improved sorting of silt and sand from south-southeast to north-northwest. The first-degree residual map (fig. 32*B*) shows areas of relatively poor sorting (shaded) in west-central New Mexico, east-central Utah, and western Colorado.

Figure 32*C* shows the best fit of a fifth-degree surface to the regional sorting data. With an E_R of 49 percent, the surface represents a moderately good generalization of the regional variation. Major areas of relatively poor sorting (shaded) are in east-central Utah and western New Mexico; minor areas are in extreme southwestern Utah, southeastern Nevada, and northern Colorado.

The lack of high residuals from both first- and fifth-degree surfaces also suggests that there are probably no significantly large regional differences in sorting; thus, the described trends must be viewed as weak and highly generalized.

Skewness.—Trend-surface analysis of the regional variation in phi skewness of the grain-size distribution of coarse siltstones and sandstones in the Moenkopi yielded a computed first-degree surface (fig. 33*A*) which strikes N. 60° E. and dips northwestward. The first-degree surface has an E_R of 7 percent, which is evidence of a weak trend of decreasing skewness from southeast to northwest. Regional average skewness is 0.80.

The first-degree residual map (fig. 33*B*) has areas of relatively low skewness values (shaded) in the central part of the region, on the southeast corner, on the northeast edge, and in the west. The pattern is similar to that of sorting (fig. 32*B*).

The four principal areas (shaded in fig. 33*B* where lower skewness is present in the sediments) are also indicated in the computed fifth-degree surface (fig. 33*C*). This surface, with an E_R of 39 percent, is a rough generalization of regional variation in particle-size distribution skewness. Sediments which combine the textural properties of relatively low skewness with relatively poor sorting are usually those closest to crystalline or highly consolidated source rocks (Cadigan, 1961, p. 129–134).

Kurtosis.—Variation in kurtosis is similar in regional pattern to that of skewness and sorting. The computed first-degree surface (fig. 34*A*) strikes N. 70° E. and dips northwestward. Regional average phi kurtosis is 3.18. The first-degree surface has an E_R of 3 percent, evidence of a very weak regional trend of decreasing kurtosis from southeast to northwest. The computed fifth-degree surface (fig. 34*B*) with an E_R of 45 percent has the same features as the skewness fifth-degree surface (fig. 33*C*).

In summary, regional trends of grain-size measurements are generally toward the northwest and parallel to the general direction of dip of the area of deposition of the Moenkopi. Source areas of the sediments appear to have been on the south and east sides of the depositional basin.

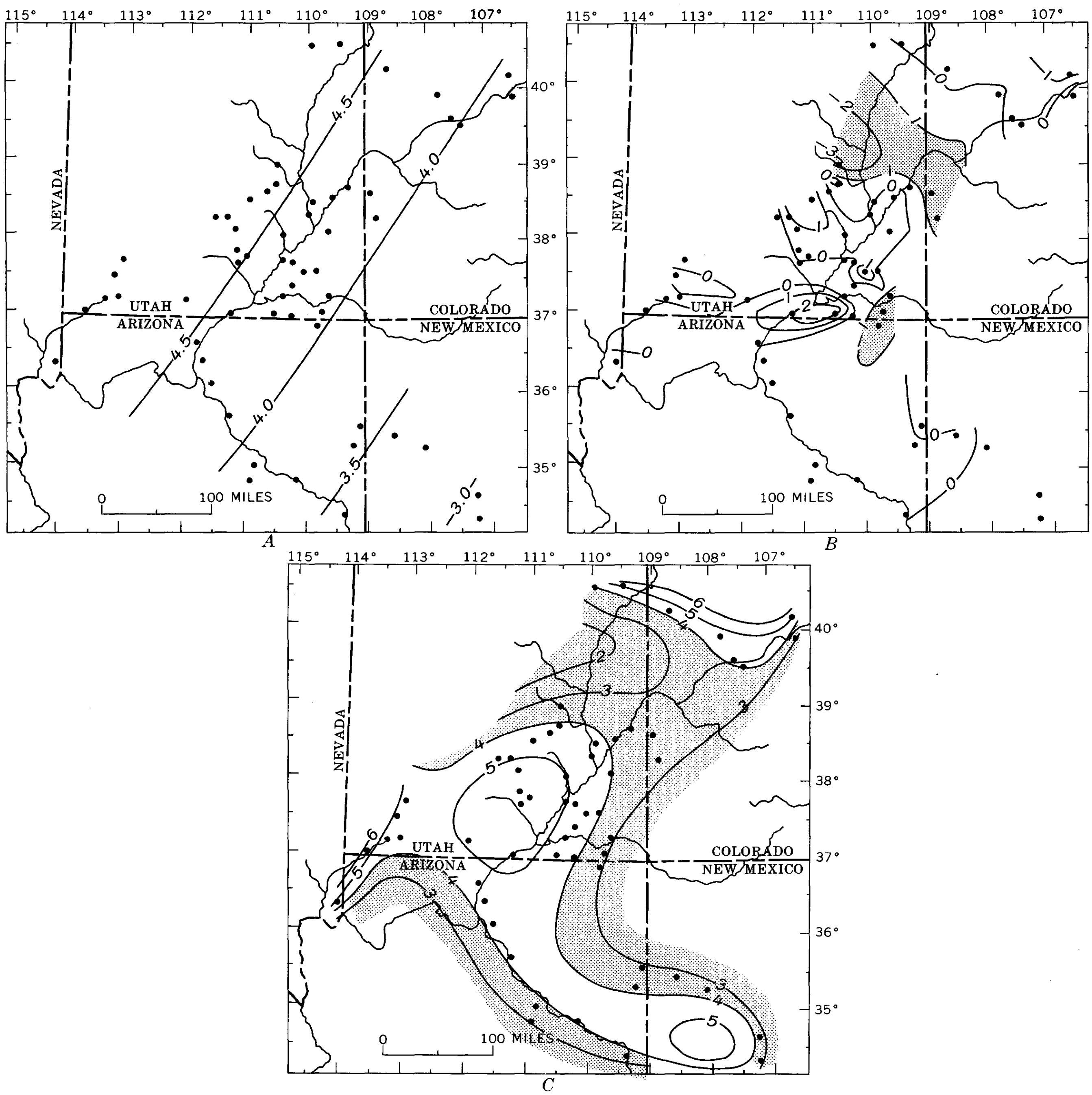


Figure 31.—Regional variation in median grain size in phi units of coarse siltstone and sandstone in the Moenkopi Formation and related strata, Colorado Plateau region. *A*, First-degree surface; *B*, first-degree residual surface; *C*, fifth-degree surface. Areas of relatively coarser texture are shaded. Black dots are localities from plate 1.

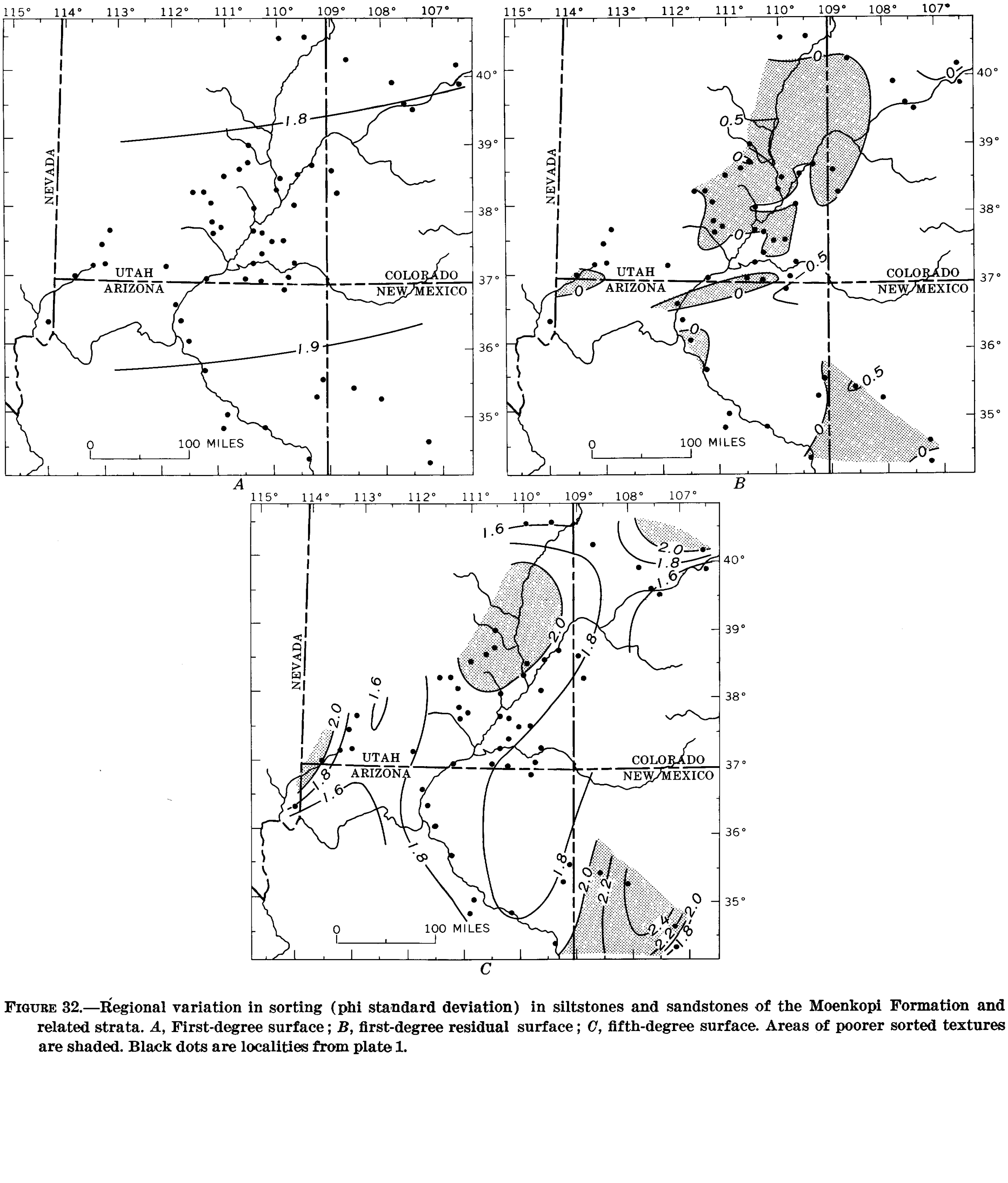


Figure 32.—Regional variation in sorting (phi standard deviation) in siltstones and sandstones of the Moenkopi Formation and related strata. *A*, First-degree surface; *B*, first-degree residual surface; *C*, fifth-degree surface. Areas of poorer sorted textures are shaded. Black dots are localities from plate 1.

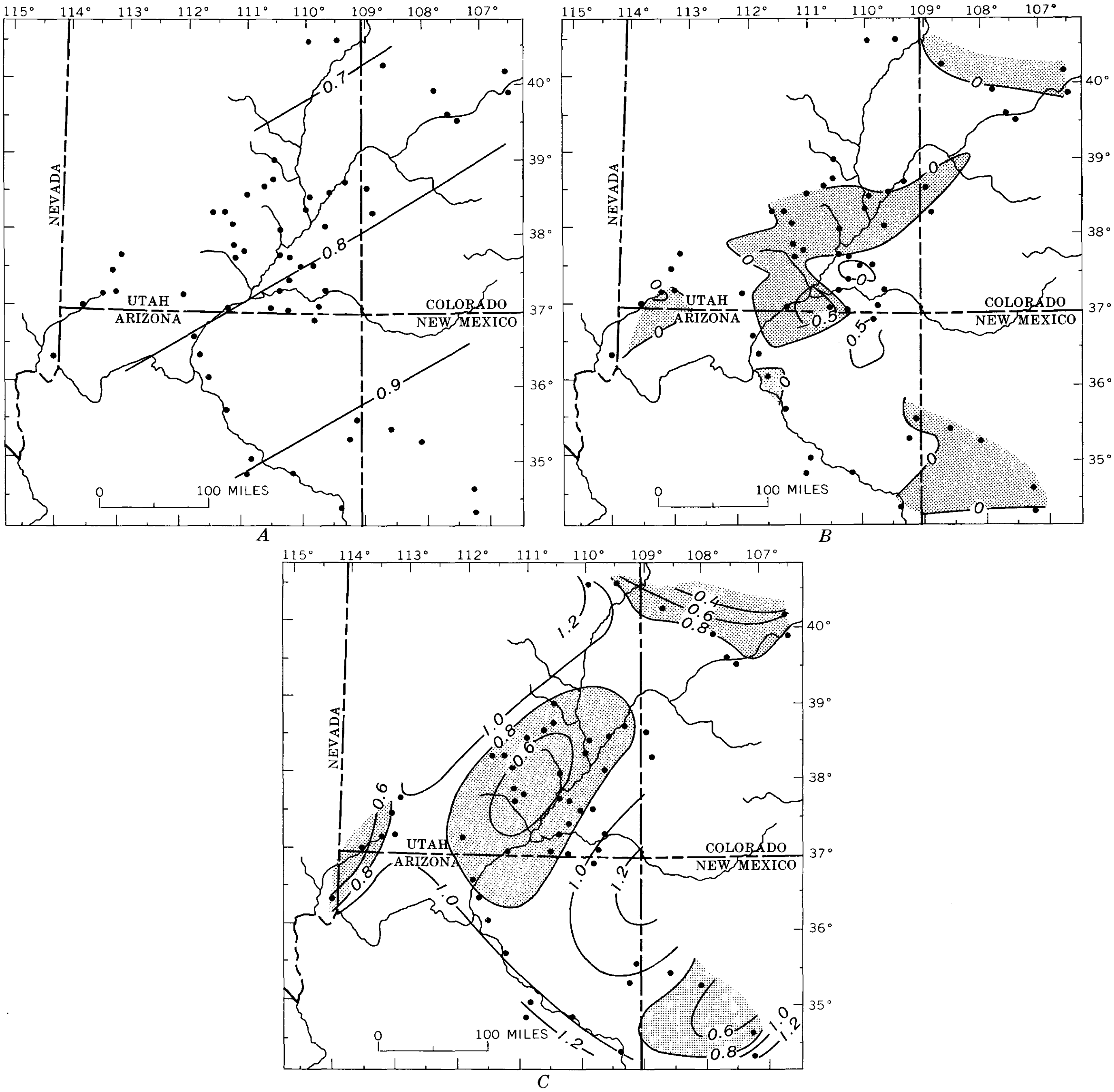


FIGURE 33.—Regional variation in phi grain-size distribution skewness in sandstones and coarse siltstones of the Moenkopi Formation and related strata. *A*, First-degree surface; *B*, first-degree residual surface; *C*, fifth-degree surface. Areas of low skewness are shaded. Black dots are localities from plate 1.

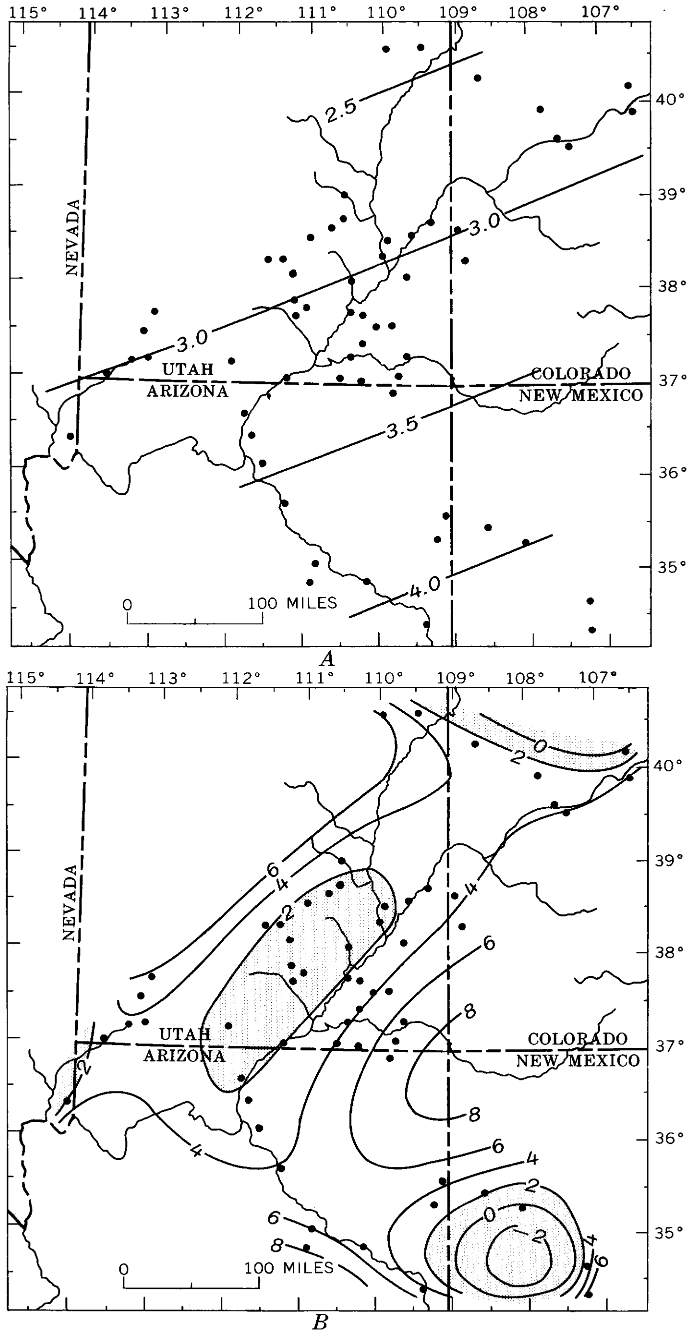


FIGURE 34.—Regional variation in phi grain-size distribution kurtosis in siltstone-sandstone strata of the Moenkopi Formation and related strata. *A*, First-degree surface; *B*, fifth-degree surface. Areas of low kurtosis are shaded. Black dots are localities from plate 1.

SUMMARY AND CONCLUSIONS

The Moenkopi Formation of Triassic(?) and Early and Middle(?) Triassic age was deposited on a subsiding alluvial-marginal marine plain west and north of the rising Uncompahgre highland of Colorado and north and northwest of rising positive areas in what is now the Basin and Range province of New Mexico and Arizona. The area of deposition occupied the western two-thirds of the area now known as the Colorado Plateau region and additional areas to the west and north.

Petrographic evidence suggests that the average direction of movement of sediment was northwestward, which is the direction of average regional dip of the depositional surface. This was also the direction of increasing carbonate deposition; decreasing proportions of rock fragments, heavy minerals, volcanic detritus, and quartz content; decreasing grain size; and increased sorting.

The regularly bedded character of the siltstone-sandstone strata—the dominant facies—the general lack of good sorting, the fineness of most of the detrital sediments, and the relative lack of cut-and-fill and diastemic structures all suggest a tectonic environment of low to very low rates of uplift in the source areas and a relatively uninterrupted low to moderate rate of subsidence in the area of deposition.

Carbonate rocks and evaporites in some areas are evidence that marine environments prevailed at certain times and in certain places during deposition of the Moenkopi. Examples of deposits under such conditions are the shallow-water clastic carbonate rocks of the Sinbad Member in south-central Utah and the thick gypsum and limestone of the Shnabkaib Member in the western and southwestern parts of the region. Clastic material was deposited only marginal to the areas in which the evaporite and carbonate rocks were formed. This suggests that for moderately long intervals of time the source areas were low and providing relatively small amounts of detritus.

Such periods of inactivity in the source areas suggest that the exposed terranes were probably subject to deep weathering and that erosion and transportation of detritus from these areas to the area of deposition was slow. The evaporites in the Moenkopi and the oxidized condition of the sediments indicate that the climate was probably arid to semiarid in both the depositional area and the source area. The marine intrusions themselves were probably a result of the imbalance between the steady subsidence of the area of deposition and the dwindling supply of silt and sand from the semiquiescent source areas.

Evaporites underlying anomalously thick (fig. 19*B*) basal deposits along the east margin constitute evidence of a local basin of deposition on the Utah-Colorado border; this together with associated areas of nondeposition (mentioned by Stewart, p. 6) suggests that there was local differential tectonic subsidence on the edge of the Uncompahgre source area. The doming and local thickening by flowing of the evaporites in the Pennsylvanian Paradox Member of the Hermosa Formation in that part of the region may have been the cause of the apparent local tectonism (Cater and Elston, 1963).

The interpreted sequence of tectonic events in the Colorado Plateau region which produced the Moenkopi and related strata was: (1) Slight uplift of the entire area of deposition of Permian sediments; (2) regression westward of the marginal marine environment; (3) slight to locally active fluviatile erosion of the terrestrial surface of various Permian formations and exposed Precambrian rocks and accumulation of thin deposits over parts of the eroded surface; (4) beginning of a relatively constant rate of subsidence in the new (Moenkopi) area of deposition; (5) beginning of a slower but varying rate of uplift in old and new source areas; (6) east-west fluctuations of the western marine environment in response to variation in source area uplift and resulting changes in volume of weathered detritus transported from the generally low-lying source areas; and finally (7) a slow increase in the rate of uplift of the source areas with the resulting increase in amounts of sediment which filled the depositional basin and thus forced the fluviatile-marine environment boundary westward across the westernmost limits of the Colorado Plateau region.

Conspicuous lenses of conglomerate have been preserved in places at the base of the Moenkopi. These include locally derived alluvial chert-breccia conglomerates in northern Arizona and central Utah, the granite-fragment conglomerates at the base of the alluvial Tenderfoot Member in Colorado derived from the nearby Uncompahgre highland, and the massive thick coarse well-rounded chert gravel conglomerate in limestone of the marine Timpoweap Member in southwestern Utah probably derived from a distant Permian sedimentary terrane. The presence of these coarse gravels and the lack of continuous conglomeratic units suggest that (1) at certain locations the environments of erosion and transportation were of high energy, (2) the areas of transportation between sources and areas of deposition of the conglomerates were not subsiding sufficiently to accumulate continuous deposits and probably not at all, and (3) the deposits represent an interval of time at least long enough for the erosion and transportation of the coarse detritus to the area of deposition. A relatively short time interval would have been required for the deposition of the breccia conglomerates, but a relatively longer time interval would have been required for the deposition of the marine conglomerate of the Timpoweap which probably continued well into event (4) mentioned in the preceding paragraph.

Widespread medium- to fine-grained sandstone strata reflect intervals of unusual rates of uplift in sources areas. The Tenderfoot and Hoskinnini Members, derived from Precambrian granite and metamorphic rocks and Pennsylvanian and Permian arkoses, probably were deposited during the early period of uplift in the Uncompahgre source area.

The conglomerates and coarse (sand-size) volcanic detritus in the overlying Ali Baba Member are evidence of an unusual period of volcanic activity in the Uncompahgre after regionwide deposition of the Moenkopi had begun. Some exotically colored local beds of mudstone in the Pariott Member resemble deposits of altered ash and are evidence of minor volcanic activity in the highlands toward the end of Moenkopi deposition. The Holbrook Member, containing fine to very fine grained sandstone, suggests a slightly higher than average rate of uplift of the southern source areas during the later part of Moenkopi deposition. It also contains sand-size fragments of altered tuff in quantities sufficient to suggest that volcanic activity in the southern sources was also partly responsible for the increase in volume of sediments being transported northward.

The principal sources, (that is, the positive land masses south and east of the area of deposition) are arbitrarily divided for purposes of discussion into four general areas (table 8): Uncompahgre highland (western Colorado), southwestern (south-central Arizona), southern (southeastern Arizona-southwestern New Mexico), and southeastern (south-central and central New Mexico). All produced detritus containing at least some quartz, feldspar, mica, and volcanic igneous, metamorphic, and sedimentary rock fragments, but in greatly different proportions. The minerals or components listed in table 8 are those supplied in greater-than-average proportions by the particular sources. From evidence of the differences in composition of the detritus shown by the trend-surface analyses, certain rock type terranes are proposed as being dominant in certain source areas (table 8). It is assumed that weathering in the source areas altered the surface of the source rocks. Detritus from the weathered surfaces was deposited and subjected to further change during diagenesis. The terranes listed in table 8 are suggested as the dominant source rocks of the Moenkopi sediments with the realization that rocks such as sodic andesite (in the southwestern source), for example, may have been present. As a result of the combined effects of weathering and diagenesis, a sodic andesite might yield no recognizable stable detrital minerals with the exception of a few hornblende(?) grains preserved under rather optimum conditions. The amphibolite grains in the rocks at St. George, Utah (table 7), may have originated in such a manner. Any such source rocks, susceptible to weathering, may also have completely altered to clay minerals, quartz, silica, and iron oxides prior to erosion.

TABLE 8.—*Summary of higher-than-average amounts of rock components contributed to the Moenkopi Formation and related strata by the four general source areas, and interpreted dominant source terranes*

Mineral or component	Source area: Uncompahgre highland (Colorado)	Southwestern (Arizona)	Southern (Arizona–New Mexico)	Southeastern (New Mexico)
Quartz	×	—	×	—
All rock fragments	×	×	—	×
Feldspar	×	×	—	—
Mica flakes	×	×	—	—
Volcanic	×	—	×	—
Heavy minerals	×	—	×	×
Siliceous rock fragments	—	×	—	×
Order of decreasing importance	**Terranes**			
Major	Granite.	Silicified sedimentary rock.	Quartzitic sedimentary rock.	Metamorphic rock.
	Metamorphic rock.	—	—	Silicified sedimentary rock.
	Arkose.	Granite.		
Minor	Rhyolite.	Andesite(?).	Rhyolite.	—

The Uncompahgre highland produced relatively high proportions of detritus derived from granitic, arkosic, and minor potassic volcanic terranes. The southwestern source produced much coarse detritus probably derived from silicified sedimentary terranes during the early period of erosion. Later detritus was derived from gneissic, and possibly andesitic terranes, and less evident siliceous rock terranes. The southern source contributed detritus derived from quartzitic sedimentary rock and minor volcanic terranes. The southeastern source produced detritus derived from metamorphic and silicified sedimentary (limestone?) rock terranes.

The top of the Moenkopi is marked by an erosional surface of moderate relief which suggests that deposition of the Moenkopi ended with a slight regional uplift, or at least the termination of subsidence of the area of deposition, and a period of fluviatile erosion.

In conclusion, the major features of Moenkopi Formation deposition were: (1) Weathering, erosion, and deposition under arid oxidizing conditions; (2) low rates of tectonic uplift in the source areas; (3) low to moderate rates of continuous subsidence in the area of deposition; (4) derivation of clastic sediment from the Precambrian granite and metamorphic rocks, Permian sedimentary rocks, and minor Permian and Triassic volcanic rocks, and derivation of marine limestones and marginal marine evaporites from a marine environment; and (5) deposition of all sediments in coexisting eastern alluvial and western marginal marine and marine environments which shifted position along a southeast-northwest axis.

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TABLES 4, 6

TABLE 4.—*Modal composition and rock classification of 251 rock*

[Leaders (----) indicate mineral not observed. Symbols for rock classification: A, arkose; G, graywacke; L, limestone; O, orthoquartzite; Os, suborthoquartzite; T, tuff; U, indicates a feldspathic suborthoquartzite; F is the modifier, Os is the primary rock type. SO is the symbol for an arenaceous chert orthoquartzite; S is the modifier, and forming; TRmlm, lower massive sandstone (a persistent unit of less than member rank in the southern part of the region); TRmlr, lower red; TRmls, lower slope-forming; upper slope-forming; TRmw, Wupatki; TRmv, Virgin Limestone. Symbols for related strata: TRm(?), probably Moenkopi Formation; TRmg, Mahogany Formation; TRsu, upper

	Arizona														
Locality (pl. 1)	1	1	1	5	5	9	9	9	9	9	10	10	10	12	12
Sample No. (L–)	2455	2695	2465	2654	2655	2046	[1] 2670	2047	2048	[2] 2057	2035	2036	2037	1986	1987
I. CHEMICAL COMPONENTS (EXCEPT SILICA)															
a. Carbonates and sulfates	27.4	23.4	22.2	[3] 36.6	26.0	16.0	34.6	----	0.2	----	23.4	18.0	34.0	[3] 11.2	13.0
b. Red interstitial iron oxides (in clay)	2.4	.6	2.8	.2	1.2	2.6	.8	0.6	.2	28.8	3.4	4.4	----	1.0	.8
Total	29.8	24.0	25.0	36.8	27.2	18.6	35.4	0.6	0.4	28.8	26.8	22.4	34.0	12.2	13.8
II. SILICEOUS COMPONENTS															
a. Quartz grains and overgrowths	29.6	37.8	23.2	40.4	43.4	68.0	40.6	73.6	68.8	10.4	52.0	47.4	35.8	33.0	30.6
b. Quartzite fragments	3.4	4.0	7.4	----	----	.6	.4	2.8	4.2	----	----	.2	----	2.2	1.2
c. Chert, detrital	.2	.6	2.8	.6	.6	----	3.0	2.8	4.0	----	.2	1.0	.6	1.8	3.4
d. Chert, authigenic	1.0	----	.8	----	----	----	----	.2	----	----	----	----	.2	----	----
e. Silicified-rock fragments	5.6	3.8	14.6	----	----	1.4	----	----	3.6	----	----	----	----	----	----
f. Silicified-limestone fragments	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Total	39.8	46.2	48.8	41.0	44.0	70.0	44.0	79.4	80.6	10.4	52.2	48.6	36.6	37.0	35.2
III. FELDSPATHIC COMPONENTS															
a. Potassic feldspar	4.4	1.8	----	5.2	4.2	2.2	4.8	3.4	2.8	0.8	10.0	9.2	14.0	10.0	10.6
b. Plagioclase feldspar	4.4	2.0	1.8	8.4	5.6	----	1.8	.6	1.2	----	5.4	7.4	4.2	5.8	5.2
c. Kaolinitic clays (alteration products)	----	----	----	----	----	4.8	----	11.4	3.2	----	----	----	----	----	----
Total	8.8	3.8	1.8	13.6	9.8	7.0	6.6	15.4	7.2	0.8	15.4	16.6	18.2	15.8	15.8
IV. DARK-MINERAL AND MICA COMPONENTS															
a. Mica flakes and books (muscovite, biotite)	1.0	0.8	1.4	0.4	0.2	----	1.0	----	----	----	0.2	0.2	1.4	3.4	4.0
b. Chlorite and mica clays	[6] 12.4	[6] 11.8	[6] 11.6	[7] 6.6	[7] 15.2	3.4	3.4	1.4	6.6	----	3.8	8.4	3.0	[6] 10.2	[6] 14.6
c. Micaceous and mafic rock fragments	1.0	2.8	6.0	.4	1.0	.8	3.6	2.8	4.8	----	----	[12] 2.4	[12] 4.4	4.6	7.8
d. Heavy minerals (sp gr 2.90+)	.4	----	----	----	----	----	----	----	----	----	----	----	----	.2	.4
e. Miscellaneous (opaque and unidentified grains)	.8	1.6	----	1.0	1.2	----	.4	----	.2	----	1.2	.8	[13] .8	2.6	1.6
Total	15.6	17.0	19.0	8.4	17.6	4.2	8.4	4.2	11.6	0	5.2	11.8	9.6	21.0	28.4
V. VOLCANIC COMPONENTS															
a. Tuff and felsite fragments (silicified)	[14, 15] 5.8	[15, 16] 8.0	[14, 15] 4.0	0.2	1.4	----	[16] 5.6	0.4	----	----	0.4	0.6	1.6	13.8	5.8
b. Montmorillonitic clays (alteration products)	.2	1.0	1.4	----	----	0.2	----	----	0.2	60.0	----	----	----	.2	1.0
c. Altered ash (chiefly shards and clay)	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Total	6.0	9.0	5.4	0.2	1.4	0.2	5.6	0.4	0.2	60.0	0.4	0.6	1.6	14.0	6.8
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Stratigraphic member	TRm	TRm	TRm	TRm	TRm	TRmh	TRm	TRmh	TRmh	TRm	TRmw	TRmw	TRmm	TRmh	TRmh
Rock classification	CO	Os	SOs	CFOs	CFOs	Os	COs	FO	O	FeT	FOs	FOs	FOs	TFOs	G

See footnotes at end of table.

samples from the Moenkopi Formation and related strata in the Colorado Plateau region

unclassified sedimentary rock; Pe, pelite; S, chert arenite. Modifying terms: C, calcareous; F, feldspathic; Fe, ferruginous; S, arenaceous chert; T, tuffaceous. The symbol FOs O is the primary rock type. Symbols for members of the Moenkopi Formation (TRm): TRma, Ali Baba; TRmc, cliff-forming; TRmh, Holbrook; TRmho, Hoskinnini; TRmlf, ledge- TRmm, Moqui; TRmmr, middle red; TRmsb, Sinbad Limestone; TRmsk, Shnabkaib; TRmsw, Sewemup; TRmtd, Tenderfoot; TRmtp, Timpoweap; TRmur, upper red; TRmus, member, State Bridge Formation; TRt, Thaynes Formation; Psl, lower member, State Bridge Formation; Pss, South Canyon Creek Member, State Bridge Formation]

Arizona																			
12 1988	15 1968	15 1969	15 1967	15 1970	15 1971	60 3218	60 3219	60 3220	60 3221	70 1991	70 1992	70 1993	70 [1] 1994	81 [1] 3196	81 3197	81 3198	81 3199	210 [1] 2644	210 2645
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
17.8	7.0	16.2	39.8	26.6	38.8	19.2	12.0	[4] 31.2	18.4	[3] 19.4	8.0	14.8	17.6	51.4	16.8	7.0	25.2	34.8	[4] 9.0
	.4	2.4	2.0	7.2	1.6		2.8			3.4		.6	.4	2.6	.2	1.2	6.6	4.0	.2
17.8	7.4	18.6	41.8	33.8	40.4	19.2	14.8	31.2	18.4	22.8	8.0	15.4	18.0	54.0	17.0	8.2	31.8	38.8	9.2
II. SILICEOUS COMPONENTS																			
35.4	62.6	51.2	23.2	43.4	41.4	57.0	8.4	39.0	28.8	34.0	31.4	31.8	18.0	26.8	68.6	56.6	40.4	13.2	60.4
3.4		.6			.2			1.6	7.0	.6	2.8	.6			.2				
1.8	.4	.2		.2	.2	.4		2.6	1.2	1.2	1.2	2.8			.2	1.4	.6		.2
									.2										
									17.8										
40.6	63.0	52.0	23.2	43.6	41.8	57.4	8.4	43.2	55.0	35.8	35.4	35.2	18.0	26.8	69.0	58.0	41.0	13.2	60.6
III. FELDSPATHIC COMPONENTS																			
13.8	4.8	3.4	5.6	3.0	4.2	6.8	0.4	9.6	6.0	9.2	9.0	11.8	6.0	6.4	5.8	5.4	8.0	22.4	14.8
6.4	3.6	5.2	8.6	6.6	6.4	5.6	1.2	2.6	1.6	6.0	7.0	6.6	1.8	3.0	.8	6.2	8.4	4.8	5.2
20.2	8.4	8.6	14.2	9.6	10.6	12.4	1.6	12.2	7.6	15.2	16.0	18.4	7.8	9.4	6.6	11.6	16.4	27.2	20.0
IV. DARK-MINERAL AND MICA COMPONENTS																			
[5] 0.6	0.2	1.2	1.6	2.2	0.6	0.2	0.8	0.4	3.6	3.2	5.0	[5] 2.8	4.6	3.6		0.6	0.4	10.0	1.0
4.4	[8] 20.0	[8] 17.6	[8] 17.0	[8] 9.2	[8] 5.0	9.2	73.6	[9] 1.6	4.0	[10] 2.8	7.2	[6] 1.4	[8] 50.6	[10] 4.8	[10] 6.8	19.2	8.6	[11] 10.0	7.8
[6] 6.6		1.2		.2		.2		1.2	3.2	7.8	14.6	12.4				.4			
.2	.2	.2	.2		.4	.8	.4			.2		.2	.2						
[13] .2	.2	.2	2.0	.2	.6	.6	.4	.4	.4	.4	1.0	.8	.6	1.4	.4	.4	.8	.8	
12.0	20.6	20.4	20.8	11.8	6.6	11.0	75.2	3.6	11.2	14.4	27.8	17.6	56.0	9.8	7.2	20.6	9.8	20.8	8.8
V. VOLCANIC COMPONENTS																			
8.8	0.6	0.4		1.2	0.6			[15] 9.8	[15] 6.2	[5, 16] 11.8	[15, 16] 12.8	[15, 16] 13.4			0.2	[15] 1.6	[15] 0.8		[16] 1.2
.6									1.6				0.2				.2		.2
9.4	0.6	0.4	0	1.2	0.6	0	0	9.8	7.8	11.8	12.8	13.4	0.2	0	0.2	1.6	1.0	0	1.4
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TRmh FOs	TRmw Os	TRmw Os	TRmw CFU	TRmm CFOs	TRmm CFOs	TRmw FOs	TRmm G	TRmh CTFOs	TRmh SOs	TRmh TFOs	TRmh G	TRmh TFOs	TRmh G	TRm COs	TRmlm Os	TRmlm FOs	TRm CFOs	TRmlr CA	TRmsk FOs

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Arizona							Colorado						
Locality (pl. 1)	210	210	210	211	211	211	211	3	3	4	4	8	8	8
Sample No. (L–)	2646	2647	3195	870	874	875	879	[1] 2504	4321	[1] 2206	[1] 2509	2612	2613	2614
I. CHEMICAL COMPONENTS (EXCEPT SILICA)														
a. Carbonates and sulfates	19.6	28.2	18.2	1.0	15.2	24.8	38.2	3.4	26.2	38.2	18.0	5.0	4.0	12.6
b. Red interstitial iron oxides (in clay)	2.2	1.0	.6	.2				4.2	.6	4.2	1.0	.8	2.2	3.6
Total	21.8	29.2	18.8	1.2	15.2	24.8	38.2	7.6	26.8	42.4	19.0	5.8	6.2	16.2
II. SILICEOUS COMPONENTS														
a. Quartz grains and overgr wths	62.6	35.0	49.6	81.2	68.2	63.4	46.2	43.2	35.6	25.2	34.4	52.6	35.6	40.8
b. Quartzite fragments			.4	.8	.2	.4	.8		1.2					
c. Chert, detrital	.2		1.0			1.0	.4			.2				
d. Chert, authigenic					.2	.6	.2							
e. Silicified-rock fragments					.2	.4	.6							
f. Silicified-limestone fragments														
Total	62.8	35.0	51.0	82.0	68.8	65.8	48.2	43.2	36.8	25.4	34.4	52.6	35.6	40.8
III. FELDSPATHIC COMPONENTS														
a. Potassic feldspar	9.6	10.6	3.8	6.4	7.0	4.8	7.8	15.2	15.8	8.8	10.6	15.2	14.0	15.4
b. Plagioclase feldspar	4.2	13.6	13.4	3.4	2.2	2.0	3.2	9.2	17.8	4.4	18.2	12.4	5.8	15.8
c. Kaolinitic clays (alteration products)				1.6	2.6									
Total	13.8	24.2	17.2	11.4	11.8	6.8	11.0	24.4	33.6	13.2	28.8	27.6	19.8	31.2
IV. DARK-MINERAL AND MICA COMPONENTS														
a. Mica flakes and books (muscovite, biotite)	0.2	7.0	4.2	0.2	0.2	0.2		4.2	[19] 1.8	0.2	0.8	[20] 2.4	[20] 4.0	[20] 3.6
b. Chlorite and mica clays	[11] 0.4	[10] 4.2	4.2	[6] 5.2	[6] 3.0	[6] 1.0	[6] 0.6	[11] 18.8	1.0	[11] 17.6	[10] 13.6	[11, 21] 10.2	[11] 32.4	[11] 6.6
c. Micaceous and mafic rock fragments		.2	3.0		.2			.2						
d. Heavy minerals (sp gr 2.90+)	.4							.8			.6	.2	.2	.6
e. Miscellaneous (opaque and unidentified grains)	.2	.2	.4			.4	1.2	.6		1.2	2.8	.8	1.0	.6
Total	1.2	11.6	11.8	5.4	3.4	1.6	1.8	24.6	2.8	19.0	17.8	13.6	37.6	11.6
V. VOLCANIC COMPONENTS														
a. Tuff and felsite fragments (silicified)	0.2		1.2		[16] 0.8	[16] 0.8	[16] 0.8	0.2				0.4	0.8	0.2
b. Montmorillonitic clays (alteration products)	.2					.2								
c. Altered ash (chiefly shards and clay)														
Total	0.4	0	1.2	0	0.8	1.0	0.8	0.2	0	0	0	0.4	0.8	0.2
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Stratigraphic member	T̄Rmsk	T̄Rmur	T̄Rmur	T̄Rmus	T̄Rmus	T̄Rmho	T̄Rmho	T̄Rsu	T̄Rmg	T̄Rsu	Psl	T̄Rmtd	T̄Rmtd	T̄Rmtd
Rock classification	FOs	CFOs	FOs	FO	FOs	COs	CFOs	G	CA	CFOs	A	A	G	A

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Colorado																		Nevada	
8 2615	8 2616	8 [17,18] 2617	15 2625	15 [1] 2626	15 2627	15 2628	15 2629	15 [1] 2630	18 [1] 2488	18 [1] 2489	18 2490	18 [1] 2499	139 [1] 3243	186 [1] 2211	188 [1] 2135	188 [1] 2136	189 [1] 3240	1 [1] 2318	1 2319
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
38.4	20.4	----	11.8	24.8	30.2	2.4	13.6	18.6	28.8	27.0	31.0	21.8	41.0	14.4	40.4	----	42.4	31.2	16.4
1.4	4.0	----	1.4	4.0	1.8	3.4	1.8	5.8	----	5.6	----	.6	.6	2.6	3.8	----	1.4	2.8	1.6
39.8	24.4	----	13.2	28.8	32.0	5.8	15.4	24.4	28.8	32.6	31.0	22.4	41.6	17.0	44.2	0	43.8	34.0	18.4
II. SILICEOUS COMPONENTS																			
34.4	33.2	----	47.2	30.0	20.2	32.8	24.0	21.2	24.8	30.0	55.8	44.6	18.8	45.2	27.0	43.4	25.2	10.4	53.0
----	----	----	----	----	1.0	.2	----	----	----	----	----	----	----	----	----	----	----	----	----
.2	----	----	----	----	----	----	----	.2	----	----	2.2	----	.2	----	----	----	----	----	.2
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.8	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
34.6	33.2	----	47.2	30.0	21.2	33.0	24.0	21.4	24.8	30.0	58.0	44.6	19.0	45.2	27.0	43.4	25.2	11.2	53.2
III. FELDSPATHIC COMPONENTS																			
9.0	22.6	----	18.2	19.2	10.0	26.4	41.6	20.2	5.8	7.0	3.2	7.2	7.6	9.0	13.6	14.2	9.2	4.4	8.0
2.6	7.6	----	4.8	1.2	.8	.8	1.0	4.2	22.2	6.0	1.8	11.6	2.8	13.0	3.0	18.0	5.4	----	7.2
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
11.6	30.2	----	23.0	20.4	10.8	27.2	42.6	24.4	28.0	13.0	5.0	18.8	10.4	22.0	16.6	32.2	14.6	4.4	15.2
IV. DARK-MINERAL AND MICA COMPONENTS																			
3.0	[20] 7.6	----	1.0	1.6	0.2	1.4	----	12.4	14.6	4.4	----	0.4	1.2	1.0	[20] 8.0	5.2	2.4	8.0	0.4
[11,21] 9.8	[11,21] 2.2	----	[11,21] 15.4	[11] 18.4	----	[9] 3.4	----	[11] 14.6	.8	[11] 18.6	----	[10] 12.4	[10] 27.2	[11] 13.8	[11] 3.0	16.8	[11] 13.8	42.4	[10] 12.4
----	.6	----	----	----	----	.2	----	----	----	.2	----	.2	----	----	----	----	----	----	----
.4	.4	----	----	.2	----	.2	----	----	.2	.2	----	----	----	.4	.8	.2	----	----	.4
.8	1.4	----	.2	.6	.4	----	0.4	2.8	2.8	1.0	[22] 0.4	1.0	.6	.4	.4	2.2	.2	----	----
14.0	12.2	----	16.6	20.8	0.6	5.2	0.4	29.8	18.4	24.4	0.4	14.0	29.0	15.6	12.2	24.4	16.4	50.4	13.2
V. VOLCANIC COMPONENTS																			
----	----	----	----	----	[16] 31.6	[16] 18.4	[16] 14.4	----	----	----	5.6	0.2	----	0.2	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	[23] 3.8	[23] 10.4	[23] 3.2	----	----	----	----	----	----	----	----	----	----	----	----
0	0	----	0	0	35.4	28.8	17.6	0	0	0	5.6	0.2	0	0.2	0	0	0	0	0
100	100	----	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
T̄Rmtd CFOs	T̄Rma A	T̄Rma A	T̄Rmtd FO	T̄Rmtd CFOs	T̄Rma CFT	T̄Rma AT	T̄Rma TA	T̄Rmsw G	T̄Rsu CA	T̄Rsu CFOs	T̄Rsu COs	Psl FOs	T̄Rm CG	T̄Rsu FOs	T̄Rm CFOs	T̄Rm A	T̄Rm CFOs	T̄Rmmr CG	T̄Rmur FOs

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Nevada	New Mexico											Utah		
Locality (pl. 1)	1	1	1	1	3	3	16	16	16	20	20	20	6	6	6
Sample No. (L–)	2320	[1] 2660	2699	2456	2390	2894	2425	2426	[24] 2427	2462	2463	2454	[1] 2523	2524	[2 18] 2525
I. CHEMICAL COMPONENTS (EXCEPT SILICA)															
a. Carbonates and sulfates		32.4	25.0		[3] 1.2		23.4	4.2	22.6	24.2	21.2	41.2	40.0	22.2	
b. Red interstitial iron oxides (in clay)	3.2	.8	.8	6.2	5.4	8.8	2.0	5.4	13.0	12.2	4.6	3.2	.4	1.2	
Total	3.2	33.2	25.8	6.2	6.6	8.8	25.4	9.6	35.6	36.4	25.8	44.4	40.4	23.4	
II. SILICEOUS COMPONENTS															
a. Quartz grains and overgrowths	67.8	19.0	28.4	23.4	51.8	36.2	42.8	50.2	27.4	24.4	38.0	20.2	14.4	38.8	
b. Quartzite fragments			12.4	7.2	2.0	2.4	1.0	1.6	.2	.2	1.0	1.4			
c. Chert, detrital	.2	.2	2.2	1.6	7.0	8.6	2.4	7.4	3.4	1.6	4.2	2.0			
d. Chert, authigenic			1.2	4.8											
e. Silicified-rock fragments			[23] 15.4	[23] 14.4	5.4	21.6	15.4	16.2	8.8	12.2	11.2	17.2			
f. Silicified-limestone fragments															
Total	68.0	19.2	59.6	51.4	66.2	68.8	61.6	75.4	39.8	38.4	54.4	40.8	14.4	38.8	
III. FELDSPATHIC COMPONENTS															
a. Potassic feldspar	6.8	0.4			0.2			0.2				0.6	33.2	17.2	
b. Plagioclase feldspar	8.0	1.2	2.2	1.8	[23] 3.8	1.6	7.2	4.6	7.8	7.6	5.8	2.0	2.4	11.0	
c. Kaolinitic clays (alteration products)				10.6	6.0	.8		3.8							
Total	14.8	1.6	2.2	12.4	10.0	2.4	7.2	8.6	7.8	7.6	5.8	2.6	35.6	28.2	
IV. DARK-MINERAL AND MICA COMPONENTS															
a. Mica flakes and books (muscovite, biotite)	0.2	1.6	0.2	4.4	0.4	0.4	0.6	0.6	[5] 3.4	2.4	0.4		1.6	0.4	
b. Chlorite and mica clays	12.8	[11] 43.0	[7 19] 9.0	[7 19] 16.2	2.8	[11] 14.0	[6] 1.8	[6] .6	[6] 4.0	8.8	8.6	8.0	7.6	6.6	
c. Micaceous and mafic rock fragments		.4	1.0	3.8	9.4	2.0	3.0	4.0	8.4	6.2	3.6	3.2			
d. Heavy minerals (sp gr 2.90+)	.6	.2					.2					.2		.2	
e. Miscellaneous (opaque and unidentified grains)			.4	.8		.4	.2	1.2	1.0	.2	1.4	.8			
Total	13.6	45.2	10.6	25.2	12.6	16.8	5.8	6.4	16.8	17.6	14.0	12.2	9.2	7.2	
V. VOLCANIC COMPONENTS															
a. Tuff and felsite fragments (silicified)	0.4	0.8	[23 26] 1.8	[26] 1.2	[23] 4.6	3.2							0.4	2.4	
b. Montmorillonitic clays (alteration products)				3.6											
c. Altered ash (chiefly shards and clay)															
Total	0.4	0.8	1.8	4.8	4.6	3.2	0	0	0	0	0	0	0.4	2.4	
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Stratigraphic member	TRmur	TRm	TRm	TRm	TRm	TRm	TRm	TRm	TRm	TRm	TRm	TRm	TRmls	TRmlf	TRmus
Rock classification	FOs	CG	CSOs	G	FSOs	SOs	SOs	SO	SOs	SOs	SOs	CSOs	CA	A	

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																			
6	7	7	8	8	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10
[1] 2526	[1] 1769	1770	[1] 3713	[25] 3714	[1] 3715	[1] 3716	[25] 3717	3718	3719	1872	1873	1874	1875	[1] 1876	[1] 3144	[1] 3146	3147	3148	[25] 3145
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
13.6	62.6	28.8	53.4	95.5	[10] 30.4	[10] 37.8	77.5	[11] 14.8	[11] 20.4	16.0	31.8	36.6	9.0	26.0	30.8	36.8	[11] 30.6	34.2	99.6
14.0	2.8	1.4	1.0					3.2	1.8	1.2		10.8	2.6	4.0	1.6	.2	5.2	7.6	
27.6	65.4	30.2	54.4	95.5	30.4	37.8	77.5	18.0	22.2	17.2	31.8	47.4	11.6	30.0	32.4	37.0	35.8	41.8	99.6
II. SILICEOUS COMPONENTS																			
20.0	20.2	52.2	26.8	3.5	46.6	31.6	13.0	63.4	70.4	73.2	51.4	38.0	51.4	1.0	3.2	45.4	42.0	30.0	0.4
		.2	.4			.4		.6	.4				.8						
	.2				.4	.4		.6	.2				2.2			.4	.4	.6	
	2.8	.4			.2	.8			.2	1.0			4.4		.8			.2	
						.4			.4										
20.0	23.2	52.8	27.2	3.5	47.2	33.6	13.0	64.6	71.6	74.2	51.4	38.0	58.8	1.0	4.0	45.8	42.4	30.8	0.4
III. FELDSPATHIC COMPONENTS																			
4.0	5.8	9.0	8.8	1.0	7.8	6.2	4.5			4.2	8.4	6.2	16.6	1.0	2.4	5.4	7.8	12.8	
.8	2.0	2.8	2.6		3.8	4.4	1.5		0.8	.4	4.2	3.8	4.2		.4	5.8	5.8	5.8	
								2.0	1.8										
4.8	7.8	11.8	11.4	1.0	11.6	10.6	6.0	2.0	2.6	4.6	12.6	10.0	20.8	1.0	2.8	11.2	13.6	18.6	0
IV. DARK-MINERAL AND MICA COMPONENTS																			
0.4		0.4	1.2		0.2	0.2	2.5				0.6	0.4	0.2			1.2	1.6	2.6	
[11] 47.2	1.2	3.4	[9] 4.6		[9] 9.8	[9] 13.8	[10] .5	11.2	3.4		3.2	2.2	2.4	[11] 68.0	[10] 60.4	4.0	5.2	5.6	
					.2	1.6	.5												
	.4	.8	.2			.6						.2	.2				.2	.2	
	.4	.4	.4		.4	.8			.2	[13] 3.8		1.6	[13] 1.0		.4	.8	1.2	.2	
47.6	2.0	5.0	6.4	0	10.6	17.0	3.5	11.2	3.6	3.8	3.8	4.4	3.8	68.0	60.8	6.0	8.2	8.6	0
V. VOLCANIC COMPONENTS																			
			0.6		0.2	1.0				0.2	0.4	0.2	3.6					0.2	
	1.6	0.2						4.2					1.4						
0	1.6	0.2	0.6	0	0.2	1.0	0	4.2	0	0.2	0.4	0.2	5.0	0	0	0	0	0.2	0
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TRmc G	TRmls CU	TRmus CFOs	TRmls CFOs	TRmsb L	TRmlf CFOs	TRmlf CFOs	TRmus L	TRmls Os	TRmls Os	TRmls O	TRmls CFOs	TRmlf CFOs	TRmlf FOs	TRmus CG	TRmls CG	TRmlf CFOs	TRmlf CFOs	TRmus CFOs	TRmsb L

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Utah														
Locality (pl. 1)	11	11	11	11	11	14	14	14	14	14	14	14	14	18	18
Sample No. (L–)	1712	3141	1714	[1] 1711	[25] 1535	1706	[1] 1707	1708	[1 24] 1709	3133	3134	3135	3136	2543	2544
I. CHEMICAL COMPONENTS (EXCEPT SILICA)															
a. Carbonates and sulfates	21.6	[10] 34.6	52.2	21.2	84.0	[10] 45.0	26.8	9.6	53.2	[11] 25.2	22.4	31.4	[3] 11.0	10.0	13.2
b. Red interstitial iron oxides (in clay)	.2		.6	.2	.5	.2	1.6			6.2	4.4	.4	.8	3.8	1.0
Total	21.8	34.6	52.8	21.4	84.5	45.2	28.4	9.6	53.2	31.4	26.8	31.8	11.8	13.8	14.2
II. SILICEOUS COMPONENTS															
a. Quartz grains and overgrowths	49.4	45.4	23.2	33.4	11.5	32.6	19.6	48.4	27.2	50.6	39.0	43.8	43.2	37.6	43.6
b. Quartzite fragments										.2	.4		.6		.2
c. Chert, detrital	.4	3.8	1.2	1.4		.8	.4	6.0		.2	.4	1.0	5.2		
d. Chert, authigenic			1.6									.6	.6		
e. Silicified-rock fragments															
f. Silicified-limestone fragments															
Total	49.8	49.2	26.0	34.8	11.5	33.4	20.0	54.4	27.2	51.0	39.8	44.8	49.6	37.6	43.8
III. FELDSPATHIC COMPONENTS															
a. Potassic feldspar	8.0	11.6	11.8	5.4	0.5	4.8	3.2	11.6	11.6	6.4	6.4	4.0	16.0	9.0	25.0
b. Plagioclase feldspar	7.8	2.4	3.2	11.2	1.0	6.0	2.0	5.2	1.4	4.0	7.2	4.2	7.2	[28] 14.0	5.4
c. Kaolinitic clays (alteration products)															
Total	15.8	14.0	15.0	16.6	1.5	10.8	5.2	16.8	3.0	10.4	13.6	8.2	23.2	23.0	30.4
IV. DARK-MINERAL AND MICA COMPONENTS															
a. Mica flakes and books (muscovite, biotite)	1.0	0.2	[5] 0.8	8.8	2.0	1.0	[21] 5.2	0.2	6.8	1.2	1.0	1.4	0.4	[20] 3.4	[20] 2.6
b. Chlorite and mica clays	9.6	1.4	2.8	15.8	.5	4.2	[11] 40.0	3.4	[21] 9.2	5.0	8.8	1.8	6.4	20.2	[10] 7.6
c. Micaceous and mafic rock fragments		.2	.4			.6		2.0	.2	.2		1.2	.6		
d. Heavy minerals (sp gr 2.90+)	.4			.2			.8				.6			.2	.2
e. Miscellaneous (opaque and unidentified grains).	[29] 1.2	[29] .2		2.4		.6	.4		.4	.4	[13] 9.4	[13] 9.6		1.4	1.0
Total	12.2	2.0	4.0	27.2	2.5	6.4	46.4	5.6	16.6	6.8	19.8	14.0	7.4	25.2	11.4
V. VOLCANIC COMPONENTS															
a. Tuff and felsite fragments (silicified)	0.4	0.2	[16] 2.2			4.2		[6 16] 11.0		0.4		1.2	8.0	0.4	0.2
b. Montmorillonitic clays (alteration products).								[30] 2.6							
c. Altered ash (chiefly shards and clay)															
Total	0.4	0.2	2.2	0	0	[9] 4.2	0	13.6	0	0.4	0	1.2	8.0	0.4	0.2
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Stratigraphic member	Ꞧmlf	Ꞧmlf	Ꞧmus	Ꞧmus	Ꞧmc	Ꞧmus	Ꞧmus	Ꞧmus	Ꞧmc	Ꞧmlf	Ꞧmlf	Ꞧmlf	Ꞧmus	Ꞧmtd	Ꞧmtd
Rock classification	FOs	CFOs	CFOs	G	L	CFOs	CG	TFOs	COs	CFOs	FOs	COs	FOs	G	A

See footnotes at end of table..

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																			
18 2545	18 2546	18 2547	22 [27] 2231	22 [1] 2230	22 2232	22 2233	24 [1] 2246	24 [1] 2247	25 1842	25 1862	25 [1 24] 1861	25 1860	25 [2 18] 1843	25 1844	25 1845	25 1846	26 4788	26 4789	26 4790
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
28.8	19.2	24.4	98.0	4.8	2.6	33.0	[10] 29.6	[10] 40.0	6.0	10.6	11.6	4.8		26.4	18.0	24.4	16.8	10.0	25.4
	5.2	.4		4.0	.4	5.4	7.4	6.2			.8			1.2		.6	2.6	1.6	1.2
28.8	24.4	24.8	98.0	8.8	3.0	38.4	37.0	46.2	6.0	10.6	12.4	4.8		27.6	18.0	25.0	19.4	11.6	26.6
II. SILICEOUS COMPONENTS																			
30.8	28.2	39.2		3.6	69.2	39.2	32.6	28.2	67.0	68.6	48.2	87.0		29.8	37.4	30.6	42.0	52.8	45.0
1.4												.2			.6		.2	.2	.2
	.6			.4	.2	.2	.2	.2			.2	.4		.2	.2	1.0	.2		
			0.4											.2		.4	.6		.2
																	1.4	.4	.6
32.2	28.8	39.2	0.4	4.0	69.4	39.4	32.8	28.4	67.0	68.6	48.4	87.6		30.2	38.2	32.0	44.4	53.4	46.0
III. FELDSPATHIC COMPONENTS																			
21.0	31.0	7.0		0.4	12.0	4.2	9.2	7.0	4.4	1.6	2.0	5.2		4.8	19.0	3.0	8.0	5.0	8.8
16.2	9.8	4.8			10.8	7.6	8.0	5.4	8.0	4.2	10.6	1.2		28.4	20.6	27.0	1.6	1.4	4.6
37.2	40.8	11.8	0	0.4	22.8	11.8	17.2	12.4	12.4	5.8	12.6	6.4		33.2	39.6	30.0	9.6	6.4	13.4
IV. DARK-MINERAL AND MICA COMPONENTS																			
[20] 1.4	0.6	[20] 11.4		1.6		1.2	1.8	3.0	1.0	0.2	2.6	0.2		0.2			4.2	1.6	2.6
	1.6	[10] 11.8		[10] 85.2	[7] 2.6	[7] 7.0	8.8	[10] 8.0	13.2	[10] 14.6	21.6	1.0		[10] 3.4	0.2	9.0	21.2	23.0	9.6
	.4					.4								.2	.4	.8	.2		.2
	.4	.4				.8	.2	.8			1.0			.4	.2		.2	.8	.2
	.4	.4	[22] 1.6		.8	.6	2.0	1.2		.2	.2				.2	1.2	.8	1.6	1.2
1.4	3.4	24.0	1.6	86.8	3.4	10.0	12.8	13.0	14.2	15.0	25.4	1.2		4.2	1.0	11.0	26.6	27.0	13.8
V. VOLCANIC COMPONENTS																			
[16] 0.4	[16] 2.6	0.2			1.4	0.4	0.2		0.2		1.2			2.0	3.0	2.0		1.6	0.2
									.2					2.8	.2				
0.4	2.6	0.2	0	0	1.4	0.4	0.2	0	0.4	0	1.2	0		4.8	3.2	2.0	0	1.6	0.2
100	100	100	100	100	100	100	100	100	100	100	100	100		100	100	100	100	100	100
TRma CA	TRma A	TRmsw FOs	TRmtp L	TRmlr Pe	TRmur FOs	TRmur CFOs	TRmur CFOs	TRmur CFOs	TRmho FOs	TRmho Os	TRmho G	TRmho O	TRmls	TRmls CA	TRmlf A	TRmlf A	TRmho G	TRmho G	TRmho CFO

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Utah														
Locality (pl. 1)	27	27	28	28	28	28	29	29	29	29	29	29	29	29	30
Sample No. (L–)	943	944	4791	4792	4793	4804	[1] 1745	[1] 1746	[1] 1747	[2] 2307	3174	[1] 3175	3176	[2] 3177	[1, 24] 3167
I. CHEMICAL COMPONENTS (EXCEPT SILICA)															
a. Carbonates and sulfates	27.8	18.4	11.6	9.8	35.2	25.4	32.4	26.0	33.6	--	29.0	25.6	29.8	20.4	19.6
b. Red interstitial iron oxides (in clay)	--	.2	.4	.6	1.4	--	4.6	1.8	1.2	16.6	--	1.4	.6	--	
Total	27.8	18.6	12.0	10.4	36.6	25.4	37.0	27.8	34.8	16.6	29.0	27.0	30.4	20.4	20.2
II. SILICEOUS COMPONENTS															
a. Quartz grains and overgrowths	63.6	58.0	51.6	62.2	30.2	60.6	25.2	42.4	40.0	9.2	52.0	32.2	43.6	4.8	57.8
b. Quartzite fragments	1.0	.6	.2	.2	--	.2	--	--	--	--	.2	.2	--	--	--
c. Chert, detrital	.2	--	--	--	--	.8	2.2	.4	--	.2	.4	.2	1.6	--	.2
d. Chert, authigenic	.2	--	--	.2	--	--	--	--	--	--	--	--	--	--	--
e. Silicified-rock fragments	--	--	1.0	.2	1.0	.4	--	--	--	--	--	--	--	--	--
f. Silicified-limestone fragments	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	65.0	58.6	52.8	62.8	31.2	62.0	27.4	42.8	40.0	9.4	52.6	32.6	45.2	4.8	58.0
III. FELDSPATHIC COMPONENTS															
a. Potassic feldspar	4.4	6.6	6.0	4.0	6.2	6.6	16.0	8.8	12.6	0.4	9.6	15.0	11.2	1.2	8.6
b. Plagioclase feldspar	[23] 1.6	4.8	8.0	6.2	3.4	3.0	6.6	8.2	6.2	--	4.0	7.6	7.8	--	2.0
c. Kaolinitic clays (alteration products)	--	--	--	.2	--	.6	--	--	--	--	--	--	--	--	--
Total	6.0	11.4	14.0	10.4	9.6	10.2	22.6	17.0	18.8	0.4	13.6	22.6	19.0	1.2	10.6
IV. DARK-MINERAL AND MICA COMPONENTS															
a. Mica flakes and books (muscovite, biotite)	0.2	0.2	2.2	2.4	2.2	1.2	2.6	1.0	[5] 1.0	0.2	0.2	[5] 1.4	[5] 1.2	2.0	0.6
b. Chlorite and mica clays	.4	[10] 9.8	17.0	13.0	18.2	.8	[10] 4.0	9.2	4.2	[11] 73.4	2.4	11.2	[10] 2.6	[11] 71.6	[11] 10.2
c. Micaceous and mafic rock fragments	.4	--	.2	--	--	.2	--	.2	.2	--	--	.2	--	--	--
d. Heavy minerals (sp gr 2.90+)	--	.2	.8	.2	.2	.2	.8	.2	.4	--	--	.6	.2	--	.2
e. Miscellaneous (opaque and unidentified grains).	.2	.8	.8	.6	1.6	--	1.6	.8	.2	--	1.2	.8	.8	--	.2
Total	1.2	11.0	21.0	16.2	22.2	2.4	9.0	11.4	6.0	73.6	3.8	14.2	4.8	73.6	11.2
V. VOLCANIC COMPONENTS															
a. Tuff and felsite fragments (silicified)	--	[16] 0.2	0.2	0.2	0.4	--	4.0	0.8	0.2	--	1.0	3.4	0.6	--	--
b. Montmorillonitic clays (alteration products).	--	.2	--	--	--	--	--	.2	.2	--	--	.2	--	--	--
c. Altered ash (chiefly shards and clay)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	0	0.4	0.2	0.2	0.4	0	4.0	1.0	0.4	0	1.0	3.6	0.6	0	0
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Stratigraphic member	Ꞧmho	Ꞧmho	Ꞧmho	Ꞧmho	Ꞧmho	Ꞧmho	Ꞧmus	Ꞧmus	Ꞧmus	Ꞧmus	Ꞧmlf	Ꞧmlf	Ꞧmus	Ꞧmus	Ꞧmho
Rock classification	COs	FOs	FOs	FOs	CFOs	CFOs	CFOs	CFOs	CFOs	G	CFOs	CFOs	CFOs	G	FOs

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																			
30	30	30	30	30	32	32	32	33	33	33	34	34	34	34	35	35	35	35	35
[24] 3166	3168	3169	[1] 3170	[1] 3171	4794	4795	4796	4785	4786	4787	936	[1] 937	938	[1] 939	2610	[1] 2611	[1] 2577	[1] 2578	[2] 2579
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
3.8	13.0	1.4	26.6	36.8	11.2	36.6	18.6	6.2	7.2	11.0	[31] 20.8	24.6	20.0	21.6	6.4	18.4	34.8	38.4	
.4						.2	1.4	1.0	.6	.8		1.6		1.8	1.0	1.6	.2	1.6	3.0
4.2	13.0	1.4	26.6	36.8	11.2	36.8	20.0	7.2	7.8	11.8	20.8	26.2	20.0	23.4	7.4	20.0	35.0	40.0	3.0
II. SILICEOUS COMPONENTS																			
68.2	79.8	94.0	44.2	40.8	59.4	39.8	34.4	59.0	59.2	56.0	53.8	28.6	45.2	37.2	52.8	41.8	26.0	33.6	2.0
	.2	.6	.2					1.8	1.2	.8	.2	.2	.6	.6					
			3.8	.2							.4		.2		.2	.4	.6		
						.2						.2	.6						
					.6	.2	.2	2.2	.8	1.0		.6	.6	.6					
68.2	80.0	94.6	48.2	41.0	60.0	40.2	34.6	63.0	61.2	57.8	54.4	29.6	47.2	38.4	53.0	42.2	26.6	33.6	2.0
III. FELDSPATHIC COMPONENTS																			
6.4	5.0	3.6	8.8	10.6	7.8	6.0	13.4	5.8	4.4	3.0	12.8	11.4	9.2	8.0	18.0	5.8	10.6	8.6	1.0
1.0	1.0		2.0	4.6	4.2	2.4	6.8	6.0	4.2	4.2	9.8	5.4	9.6	8.8	3.4	9.0	12.2	9.6	
					.4														
7.4	6.0	3.6	10.8	15.2	12.4	8.4	20.2	11.8	8.6	7.2	22.6	16.8	18.8	16.8	21.4	14.8	22.8	18.2	1.0
IV. DARK-MINERAL AND MICA COMPONENTS																			
3.6		0.2	1.0	0.6	1.8	1.4	6.2	0.4	2.8	2.4		4.0	3.2	[5] 2.0	2.8	1.8	4.4	2.4	
[11] 16.6	1.0	.2	11.2	[10] 5.8	13.6	13.0	19.0	16.4	19.0	19.0	1.0	[10] 22.0	7.2	[11] 16.0	[10] 14.6	[10] 19.8	[10] 6.4	[10] 2.2	[10] 94.0
			.4					.6	.2	.4	.2	.2	.4	.2					
			.2					.2			.4		.4	.2	.2		.2	1.2	
			1.4	.6	.4	.2			.4	1.2	.2	1.0	1.2	2.2	.4	.8	1.6	2.0	
20.2	1.0	0.4	14.2	7.0	15.8	14.6	25.2	17.6	22.4	23.0	1.8	27.2	12.4	20.6	18.0	22.4	12.6	7.8	94.0
V. VOLCANIC COMPONENTS																			
					0.6			0.4		0.2	0.2	0.2	1.6	[16] 0.8		0.6	3.0	0.4	
			0.2								.2				0.2				
0	0	0	0.2	0	0.6	0	0	0.4	0	0.2	0.4	0.2	1.6	0.8	0.2	0.6	3.0	0.4	0
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ŧmho Os	Ŧmho O	Ŧmlf O	Ŧmlf CFOs	Ŧmus CFOs	Ŧmho FOs	Ŧmho COs	Ŧmho G	Ŧmho FOs	Ŧmho Os	Ŧmho Os	Ŧmhos FOs	Ŧmlf CG	Ŧmlf FOs	Ŧmlf FOs	Ŧmhos FOs	Ŧmhos FOs	Ŧmls CFOs	Ŧmlf CFOs	Ŧmus Pe

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Utah													
Locality (pl. 1)	36	36	38	38	38	38	38	38	41	41	43	43	43	43
Sample No. (L–)	891	892	3182	3183	3184	[1] 3185	3186	[2 18] 3239	[1] 2104	[1] 2105	[1] 3151	[25 27] 3153	[25 27] 3152	[1] 3155
I. CHEMICAL COMPONENTS (EXCEPT SILICA)														
a. Carbonates and sulfates	26.0	20.4	4.6	13.6	16.6	17.8	43.8		27.4	21.0	19.0	99.2	98.0	28.6
b. Red interstitial iron oxides (in clay)	1.4			.6	2.2	.4			1.0	2.0	2.0		.8	.4
Total	27.4	20.4	4.6	14.2	18.8	18.2	43.8		28.4	23.0	21.0	99.2	98.8	29.0
II. SILICEOUS COMPONENTS														
a. Quartz grains and overgrowths	42.8	58.6	92.6	58.6	48.2	7.0	28.8		39.6	39.8	1.0			39.2
b. Quartzite fragments														
c. Chert, detrital		1.0	.2	1.2		.6	.6		.2					.2
d. Chert, authigenic													0.8	
e. Silicified-rock fragments														
f. Silicified-limestone fragments														
Total	42.8	59.6	92.8	59.8	48.2	7.6	29.4		39.8	39.8	1.0	0	0.8	39.4
III. FELDSPATHIC COMPONENTS														
a. Potassic feldspar	16.6	8.4	2.0	5.0	8.4	7.4	17.0		11.2	12.8	1.0	0.4		9.0
b. Plagioclase feldspar	6.4	5.0		2.8	3.0	1.4	3.2		4.8	6.8		.4		3.8
c. Kaolinitic clays (alteration products)	.6	.4												
Total	23.6	13.8	2.0	7.8	11.4	8.8	20.2		16.0	19.6	1.0	0.8	0	12.8
IV. DARK-MINERAL AND MICA COMPONENTS														
a. Mica flakes and books (muscovite, biotite).	0.4	0.4		2.4	1.2	0.2	0.6		1.6	7.0				[5] 5.6
b. Chlorite and mica clays	5.4	.4	0.6	[10] 15.8	[11] 19.8	[11] 65.0	3.8		12.8	[11] 9.4	[11 19] 77.0		0.4	[6 11] 10.4
c. Micaceous and mafic rock fragments		.4												.6
d. Heavy minerals (sp gr 2.90+)									.2	.2				
e. Miscellaneous (opaque and unidentified grains).	.4	.6			.4	.2	.4		1.2	1.0				2.2
Total	6.2	1.8	0.6	18.2	21.4	65.4	4.8		15.8	17.6	77.0	0	0.4	18.8
V. VOLCANIC COMPONENTS														
a. Tuff and felsite fragments (silicified)		4.2			0.2		1.4							
b. Montmorillonitic clays (alteration products).		.2					.4							
c. Altered ash (chiefly shards and clay)														
Total	0	4.4	0	0	0.2	0	1.8		0	0	0	0	0	0
Grand total	100	100	100	100	100	100	100		100	100	100	100	100	100
Stratigraphic member	Trmhos	Trmls	Trmhos	Trmhos	Trmhos	Trmhos	Trmls	Trmls	Trmg	Trmg	Trmls	Trmsb	Trmsb	Trmlf
Rock classification	CFOs	FOs	O	Os	FOs	G	CFOs		CFOs	FOs	Pe	L	L	CFOs

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																				
43 3156	45 [1] 2173	45 [1] 2174	47 [23] 2145	47 [32] 2148	47 [25] 2147	47 [25] 2146	47 [2] [18] 2149	47 [25] 2150	47 [1] 2157	47 [33] 2155	47 [25] 2160	47 [25] 2153	47 [2] 2162	47 [2] [18] 2161	47 [34] 2163	47 [34] 2165	47 [34] 2164	47 [1] 2166	47 [33] 2198	47 2199
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																				
33.2	18.0	29.0	100.0	[31] 100.0	99.0	99.0		98.4	53.4	[31] 99.2	100.0	[22] 87.0	[31] 64.0		99.0	[4] 99.6	94.8	30.0	99.2	8.2
.4	6.4	2.6				1.0												1.0		.2
33.6	24.4	31.6	100.0	100.0	99.0	100.0		98.4	53.4	99.2	100.0	87.0	64.0		99.0	99.6	94.8	31.0	99.2	8.4
II. SILICEOUS COMPONENTS																				
33.4	27.0	30.2			1.0			1.2	15.6	0.8		11.4				0.2	2.4	40.0		52.4
.4																				
									.4			.2								
33.8	27.0	30.2	0	0	1.0	0		1.2	16.0	0.8	0	11.6	0		0	0.2	2.4	40.0	0	52.4
III. FELDSPATHIC COMPONENTS																				
12.8	4.6	8.6						0.4	4.8			0.2			1.0	0.2	2.4	15.4	0.8	15.6
7.6	9.8	5.4							1.2			.6						4.4		20.0
20.4	14.4	14.0	0	0	0	0		0.4	6.0	0	0	0.8	0		1.0	0.2	2.4	19.8	0.8	35.6
IV. DARK-MINERAL AND MICA COMPONENTS																				
1.2	9.8	1.6							4.6									4.2		
[6] [10] 10.0	[11] 22.2	[11] 21.8							19.6			0.2	36.0					3.4		3.2
		.2										[29] .4					0.4	.2		
.6	2.2	.6							.4									1.2		.2
11.8	34.2	24.2	0	0	0	0		0	24.6	0	0	0.6	36.0		0	0	0.4	9.0	0	3.4
V. VOLCANIC COMPONENTS																				
0.4																		0.2		0.2
0.4	0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0.2	0	0.2
100	100	100	100	100	100	100		100	100	100	100	100	100		100	100	100	100	100	100
T̄Rmus CFOs	T̄Rmur G	T̄Rmur CFOs	T̄Rmlr L	T̄Rmlr L	T̄Rmlr L	T̄Rmlr L	T̄Rmlr	T̄Rmlr L	T̄Rmlr CG	T̄Rmlr L	T̄Rmv L	T̄Rmv L	T̄Rmmr CG	T̄Rmmr	T̄Rmsk L	T̄Rmsk L	T̄Rmsk L	T̄Rmsk CFOs	T̄Rmsk L	T̄Rmsk A

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Utah													
Locality (pl. 1)	47	47	47	47	47	49	49	49	49	49	49	49	49	49
Sample No. (L–)	2200	2201	[2,18] 2158	[1] 1795	[2,18] 2159	[1] 1327	[1] 1328	[1] 1329	1352	1330	1331	1346	[1] 1345	[1] 1344
I. CHEMICAL COMPONENTS (EXCEPT SILICA)														
a. Carbonates and sulfates	30.6	8.6		20.0		[10] 8.0	[4] 12.4	17.8	[31,35] 42.4	41.0	15.0	13.0	17.0	0.2
b. Red interstitial iron oxides (in clay)	.8	3.4		4.2				1.6		1.4	1.2	3.6	.6	1.2
Total	31.4	12.0		24.2		8.0	12.4	19.4	42.4	42.4	16.2	16.6	17.6	1.4
II. SILICEOUS COMPONENTS														
a. Quartz grains and overgrowths	50.6	57.8		31.8		[24] 57.0	[24] 65.6	32.8	46.8	34.6	34.0	42.0	[24] 21.6	[24] 12.6
b. Quartzite fragments				.2		.2					.2			
c. Chert, deterital		.4		.4		.2				.2	.2	1.2		.2
d. Chert, authigenic				3.8								.4		
e. Silicified-rock fragments														
f. Silicified-limestone fragments														
Total	50.6	58.2		36.2		57.4	65.6	32.8	46.8	34.8	34.4	43.6	21.6	12.8
III. FELDSPATHIC COMPONENTS														
a. Potassic feldspar	7.4	17.6		5.2		9.8	8.2	6.0	6.2	16.0	11.8	12.4	7.2	4.4
b. Plagioclase feldspar	8.6	11.4		8.6		6.8	6.8	8.0	2.8	4.2	24.6	13.4	3.0	.6
c. Kaolinitic clays (alteration products)												.2	.2	
Total	16.0	29.0		13.8		16.6	15.0	14.0	9.0	20.2	36.4	26.0	10.4	5.0
IV. DARK-MINERAL AND MICA COMPONENTS														
a. Mica flakes and books (muscovite, biotite)				1.0		2.2	0.2	1.0			1.0	0.6	2.6	4.6
b. Chlorite and mica clays	0.4	0.2		[11] 22.6		[10] 15.6	[10] 5.2	[11] 32.2	[23] 1.2	[11] 0.4	[11] 6.0	[10] 5.6	[10] 47.2	[10] 76.0
c. Micaceous and mafic rock fragments											.4			
d. Heavy minerals (sp gr 2.90+)	.4	.2					.2	.4	.4		[29] 1.0	.2	.4	.2
e. Miscellaneous (opaque and unidentified grains).	.4	.4		1.4		.2	1.0	.2		.4	.6	1.6	.2	
Total	1.2	0.8		25.0		18.0	6.6	33.8	1.6	0.8	9.0	8.0	50.4	80.8
V. VOLCANIC COMPONENTS														
a. Tuff and felsite fragments (silicified)	0.8			0.8			0.2		0.2	[36] 1.8	[36] 3.4	[36] 5.8		
b. Montmorillonitic clays (alteration products)							.2				.6			
c. Altered ash (chiefly shards and clay)														
Total	0.8	0		0.8		0	0.4	0	0.2	1.8	4.0	5.8	0	0
Grand total	100	100		100		100	100	100	100	100	100	100	100	100
Stratigraphic member	ℜmur	ℜmur	ℜmv	ℜmur	ℜmv	ℜmho	ℜmho	ℜmho	ℜmho	ℜmls	ℜmlf	ℜmus	ℜmus	ℜmus
Rock classification	CFOs	A		G		FOs	FOs	G	COs	CFOs	A	A	G	Pe

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																				
	64 [1] 1581	64 [34] 1635	64 [25] 1636	64 [25] 1638	64 1637	64 [25] 2303	64 [1] 1639	64 [2, 18] 1640	64 [1] 1641	64 [1] 1642	64 [25] 1643	93 [2, 19] 1915	160 [1] 1645	173 3157	173 [1] 1442	173 1443	200 [1] 1548	200 [1] 1748	200 1751	200 1752
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																				
	13.6	99.8	91.2	79.4	73.8	88.0	24.0		30.0	20.0	85.4		52.8	[31] 48.8	8.6	19.4	23.8	41.0	18.6	34.0
	8.0			.2	.6		5.0		5.6	5.0			.2		.4	.6	1.2	.4		1.4
	21.6	99.8	91.2	79.6	74.4	88.0	29.0		35.6	25.0	85.4		53.0	48.8	9.0	20.0	25.0	41.4	18.6	35.4
II. SILICEOUS COMPONENTS																				
	0.6		3.7	7.0	14.0	5.6	28.4		26.4	27.4	9.8		26.4	28.2	40.2	28.6	35.6	42.2	51.6	36.4
													.6			.2	.2		.4	
													.4	1.4		1.2	2.6	1.2	.6	.6
					.4	2.4	.2						1.6			.4	.6			
																	3.6			
	0.6	0	3.7	7.0	14.4	8.0	28.6		26.4	27.4	9.8		29.0	29.6	40.2	30.4	42.6	43.4	52.6	37.0
III. FELDSPATHIC COMPONENTS																				
	2.6	0.2	4.6	4.2	7.0	3.2	6.8		4.2	7.2	1.6		4.6	13.4	5.6	15.6	11.6	3.8	10.6	5.6
					1.8		8.0		5.2	3.4	1.2		7.4	[6] 3.4	17.6	[6] 22.8	9.0	6.2	2.2	7.4
				.2												.2				
	2.6	0.2	4.6	4.4	8.8	3.2	14.8		9.4	10.6	2.8		12.0	16.8	23.2	38.6	20.6	10.0	12.8	13.0
IV. DARK-MINERAL AND MICA COMPONENTS																				
	0.2				0.4		0.4		1.0	2.8	1.0		0.6		11.2	2.8	[23] 1.2	3.4	0.2	1.2
	40.0				2.0	0.8	[11] 25.4		[11] 27.0	[11] 32.0	.2		2.8		[7] 16.0	[7] 3.6	[10] 8.0	[9] 1.6	13.4	[10] 11.2
													.4			1.2	.4		.4	.4
			0.5	0.2			1.6		.6	.6	.2		.4			.2		.2		
				[13] 8.8						1.6	.6		1.6		.4	1.0	.4		.2	.6
	40.2	0	0.5	9.0	2.4	0.8	27.4		28.6	37.0	2.0		5.8	0	27.6	8.8	10.0	5.2	14.2	13.4
V. VOLCANIC COMPONENTS																				
														[36] 4.8		[36] 2.2	[36] 1.4		1.8	1.0
	35.0						0.2						0.2				.4			.2
	35.0	0	0	0	0	0	0.2		0	0	0		0.2	4.8	0	2.2	1.8	0	1.8	1.2
	100	100	100	100	100	100	100		100	100	100		100	100	100	100	100	100	100	100
	TRmls G	TRmsb L	TRmsb L	TRmsb L	TRmsb L	TRmsb L	TRmlf G	TRmlf	TRmlf CG	TRmus G	TRmus L	TRm	TRmur CFOs	TRmho CFOs	TRmho G	TRmlf A	TRmus FOs	TRmus CFOs	TRmus FOs	TRmus CFOs

TABLE 4.—*Modal composition and rock classification of 251 rock samples*

	Utah														
Locality (pl. 1)	200	200	286	300	300	304	305	305	305	305	307	307	307	307	307
Sample No. (L–)	1753	2297	[1] 1807	2548	2549	[1] 1802	[1] 1726	[1] 1727	1728	[1] 2305	[27] 2121	[1] 2122	[33] 2123	[1] 2124	2125
I. CHEMICAL COMPONENTS (EXCEPT SILICA)															
a. Carbonates and sulfates	22.8	39.2	23.6	12.6	20.4	18.4	31.4	35.4	11.8	50.8	99.0	40.2	78.4	22.2	10.4
b. Red interstitial iron oxides (in clay)	1.8		6.8	1.0		.8	3.4	3.0	2.4	3.6					6.4
Total	24.6	39.2	30.4	13.6	20.4	19.2	34.8	38.4	14.2	54.4	99.0	40.2	78.4	22.2	16.8
II. SILICEOUS COMPONENTS															
a. Quartz grains and overgrowths	33.0	34.0	29.2	40.8	43.2	20.4	42.2	39.2	38.2	19.4		33.0	11.8	46.8	46.2
b. Quartzite fragments		.4		.4			.2	.6	1.8	.4					.4
c. Chert, detrital	1.6	.8	1.0				.2	2.2	2.6	.4					.2
d. Chert, authigenic						.2	.8	1.2	2.8	11.0					
e. Silicified-rock fragments			12.2				.8	.8	2.4	.2					
f. Silicified-limestone fragments															
Total	34.6	35.2	42.4	41.2	43.2	20.6	44.2	44.0	47.8	31.4	0	33.0	11.8	46.8	46.8
III. FELDSPATHIC COMPONENTS															
a. Potassic feldspar	6.6	10.4	1.4	21.0	[6] 23.2	5.2	7.4	5.0	9.2	6.4		14.0	5.8	14.0	11.8
b. Plagioclase feldspar	6.4	3.2	[6] 13.0	.6		8.4	4.0	2.2	2.2	1.4		7.2	.6	14.4	[23] 10.2
c. Kaolinitic clays (alteration products)				6.2											.8
Total	13.0	13.6	14.4	27.8	23.2	13.6	11.4	7.2	11.4	7.8	0	21.2	6.4	28.4	22.8
IV. DARK-MINERAL AND MICA COMPONENTS															
a. Mica flakes and books (muscovite, biotite)	0.8		[23] 4.2			5.4	0.2			1.8		0.8	0.8	0.4	1.6
b. Chlorite and mica clays	[7] 23.0	6.8	[10] 3.2	[9] 12.2	[9] 11.4	[10] 38.8	[7, 9] 8.0	[7, 9] 9.6	[9] 21.8	[9] 2.6		3.4	2.0	[6] 1.2	[10, 23] 5.2
c. Micaceous and mafic rock fragments	.6	1.0	5.2				.2		2.0					.2	3.0
d. Heavy minerals (sp gr 2.90+)	.2			.2			.4		.4			.2		.4	
e. Miscellaneous (opaque and unidentified grains).	[29] 1.4	.4	.2			2.2	.6	.4	1.2	2.0	1.0	.2	.6		.8
Total	26.0	8.2	12.8	12.4	11.4	46.4	9.4	10.0	25.4	6.4	1.0	4.6	3.4	2.2	10.6
V. VOLCANIC COMPONENTS															
a. Tuff and felsite fragments (silicified)	1.8	[36] 3.6		[36] 5.0	[36] 1.8	0.2	0.2	0.4	1.0			1.0		0.4	3.0
b. Montmorillonitic clays (alteration products).		.2							.2						
c. Altered ash (chiefly shards and clay)															
Total	1.8	3.8	0	5.0	1.8	0.2	0.2	0.4	1.2	0	0	1.0	0	0.4	3.0
Grand total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Stratigraphic member	T̄Rmus	T̄Rmus	T̄Rmur	T̄Rmus	T̄Rmus	T̄Rmur	T̄Rmls	T̄Rmsb	T̄Rmlf	T̄Rmc	T̄Rt	T̄Rt	T̄Rt	T̄Rt	T̄Rmg
Rock classification	G	CFOs	FSOs	A	FOs	G	CFOs	COs	G	COs	L	CFOs	L	A	FOs

See footnotes at end of table.

from the Moenkopi Formation and related strata in the Colorado Plateau region—Continued

Utah																			
309	309	309	309	310	310	310	312	312	313	313	313	313	313	315	315	315	319	323	325
[2] 1813	[2] 1814	[1] 1826	[2] 1827	[1] 1754	[1] 1755	[1] 2875	[1] 1777	[1] 1784	[1] 1322	[1] 1323	1324	1325	1326	[1] 1321	[37] 1332	[1] 1333	[1] 1644	1914	[1] 2587
I. CHEMICAL COMPONENTS (EXCEPT SILICA)																			
				20.8		61.2	33.2	29.6	10.2	18.8	[4] 12.4	8.6	15.0	6.2	70.0	16.8	31.6	10.8	37.4
2.8		2.6		.8		3.0	2.8		.8	1.4	1.0	.6	.2	.2		1.4	4.0	.2	.6
2.8	0	2.6	0	21.6	0	64.2	36.0	29.6	11.0	20.2	13.4	9.2	15.2	6.4	70.0	18.2	35.6	11.0	38.0
II. SILICEOUS COMPONENTS																			
1.2	14.2	9.6	2.8	14.0	2.0	10.6	30.8	39.6	40.4	33.0	47.2	71.8	32.4	50.2		32.6	40.0	61.8	20.2
		.2							.2		.2	.2	.4	.4		.2		.4	
		1.0							.2		1.0	.4	1.6	.2		.2	.2		.2
									.2		.6		6.4		29.8		2.6		.2
										.2	1.4	.2	3.4	.2			.4		
1.2	14.2	10.8	2.8	14.0	2.0	10.6	30.8	39.6	41.0	33.2	50.4	72.6	44.2	51.0	29.8	33.0	43.2	61.4	20.6
III. FELDSPATHIC COMPONENTS																			
0.4			0.8	0.4		0.2	7.6	9.6	2.2	9.0	16.2	9.6	16.8	8.0		4.2	1.4	17.4	15.2
	2.2	0.8	1.6	1.6		4.6	9.4	9.6	11.0	9.0	6.6	3.0	[23] 9.0	6.6		7.8	10.2	1.6	7.2
											.2								
0.4	2.2	0.8	2.4	2.0	0	4.8	17.0	19.2	13.2	18.0	23.0	12.6	25.8	14.6	0	12.0	11.6	19.0	22.4
IV. DARK-MINERAL AND MICA COMPONENTS																			
6.0	9.2	9.6	8.4	2.4		2.2	1.2	2.2	4.4	2.6	0.6		2.2	2.2		2.0	1.4		4.6
89.2	[11] 62.0	76.0	[4] 86.4	[11] 59.6	[11] 98.0	1.4	[10] 13.8	[10] 7.4	[9 10] 8.6	[10] 24.2	[7] 8.4	[7] 4.6	[7] 3.4	[7 9] 24.4	0.2	[10] 32.2	[7 9] 7.4	4.2	[11] 11.6
										.6	.8	.2	1.4	.4					.2
	.2	.2				.2	.2	.8	.2	.2			.4						
.4	12.0			[29] .4		.2	1.0	.6	1.0	1.0	.4	.6	1.4	.6		2.6	.8		2.4
95.6	83.4	85.8	94.8	62.4	98.0	4.0	16.2	11.0	34.2	28.6	10.2	5.4	8.8	27.6	0.2	36.8	9.6	4.2	18.8
V. VOLCANIC COMPONENTS																			
						0.2		0.6	0.6		3.0	0.2	5.4	0.4				[36] 4.4	
	0.2					12.6							.6						0.2
0	0.2	0	0	0	0	16.4	0	0.6	0.6	0	3.0	0.2	6.0	0.4	0	0	0	4.4	0.2
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TRmus Pe	TRmus G	TRmus Pe	TRmus Pe	TRmus G	TRmus Pe	TRmus CTU	TRmur CFOs	TRmur CFOs	TRmho G	TRmho G	TRmls FOs	TRmlf FOs	TRmus A	TRmho G	TRmho COs	TRmho G	TRmur CFOs	TRm FOs	TRmls CFU

TABLE 4.—*Modal composition and rock classification of 251 rock samples from the Moenkopi Formation and related strata in the Colorado Plateau region*—Continued

	Utah				Average Sandstone [38] (131 samples)	Average Siltstone [39] (90 samples)	Average Claystone [40] (8 samples)	Average Limestone (24 samples)
Locality (pl. 1)	325	326	326	326				
Sample No. (L–)	[1] 2595	4800	4801	4802				
I. CHEMICAL COMPONENTS (EXCEPT SILICA)								
a. Carbonates and sulfates	24.4	12.4	3.4	15.0	20.3	26.9	10.6	93.7
b. Red interstitial iron oxides (in clay)	1.4	1.0	.8	1.8	1.8	2.1	6.4	.1
Total	25.8	13.4	4.2	16.8	22.1	29.0	17.0	93.8
II. SILICEOUS COMPONENTS								
a. Quartz grains and overgrowths	25.8	59.2	66.4	45.0	45.7	29.7	5.6	3.4
b. Quartzite fragments			.2		.7	.1		
c. Chert, detrital					1.0	.3		
d. Chert, authigenic		2.0	.6	2.8	.2	.3		.2
e. Silicified-rock fragments		1.2	.2	.8	1.5	.2		
f. Silicified-limestone fragments								
Total	25.8	62.4	67.4	48.6	49.1	30.6	5.6	3.6
III. FELDSPATHIC COMPONENTS								
a. Potassic feldspar	8.0	5.8	4.2	5.4	9.2	7.8	0.6	1.3
b. Plagioclase feldspar	5.0	1.2	2.8	2.8	6.1	6.0	.5	.2
c. Kaolinitic clays (alteration products)			.2	.2	.4			
Total	13.0	7.0	7.2	8.4	15.7	13.8	1.1	1.5
IV. DARK-MINERAL AND MICA COMPONENTS								
a. Mica flakes and books (muscovite, biotite)	8.4	2.4	5.0	5.8	1.2	3.0	3.2	0.3
b. Chlorite and mica clays	[7] 26.2	14.8	15.6	19.0	7.3	21.5	64.0	.2
c. Micaceous and mafic rock fragments					1.2	.2		
d. Heavy minerals (sp gr 2.90+)	.2		.2	.2	.1	.2		.1
e. Miscellaneous (opaque and unidentified grains)	.6		.4	1.2	.7	.8	1.6	.5
Total	35.4	17.2	21.2	26.2	10.5	25.7	68.8	1.1
V. VOLCANIC COMPONENTS								
a. Tuff and felsite fragments (silicified)					2.3	0.3		
b. Montmorillonitic clays (alteration products)					.2	.6	7.5	
c. Altered ash (chiefly shards and clay)					.1			
Total	0	0	0	0	2.6	0.9	7.5	0
Grand total	100	100	100	100	100	100	100	100
Stratigraphic member	TRmlf	TRmho	TRmho	TRmho				
Rock classification	G	Os	Os	G				

[1] Siltstone.
[2] Claystone.
[3] Contains barite (Ia.)
[4] Gypsum present as interstitial cement (Ia).
[5] Crystalline sand-size chlorite (pennine?) present.
[6] Chlorite alteration products present in grains and clay matrix.
[7] Interstitial red-stained well-crystallized mica clay rims on detrital grains.
[8] Matrix composed of a mica-chlorite clay mixture.
[9] Chlorite clay matrix.
[10] Red (iron oxide) stained.
[11] Impregnated with iron oxide (IVb).
[12] Siliceous, micaceous rock fragments (IVc).
[13] Contains interstitial hydrocarbon (IVe).
[14] Silicified, partly isotropic, rock fragments with dark matrix and phenocrystlike inclusions, presumably basaltic tuff (Va).
[15] Questionable rock fragments (tuff?) included with tuff and felsite fragments (Va).
[16] Potassic grains present.
[17] Granite pebble conglomerate.
[18] No thin section made.
[19] Contains coarsely crystalline clinochlore.
[20] Conspicuous amount of biotite.
[21] Matrix contains ground mica.
[22] Colophane present.
[23] Chlorite.
[24] Breccialike texture.
[25] Limestone.
[26] Predominantly sodic.
[27] Coquina or bioclastic limestone.
[28] Sanidine present.
[29] Glauconite present.
[30] Montmorillonite-chlorite matrix.
[31] Gypsum present as principal cement.
[32] Gypsum rock.
[33] Chemiclastic limestone.
[34] Chemiclastic oolitic limestone.
[35] Calcite pellets present.
[36] Dominantly potassic.
[37] Silicified limestone.
[38] Feldspathic suborthoquartzite.
[39] Calcareous graywacke.
[40] (Pelitic) graywacke.

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*

[Values in parentheses are locality averages (means)]

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							ARIZONA							
1	2455	0.085	0.080	4.141	1.668	1.155	5.102	2.21	2.53	3.10	3.64	4.92	8.26	10.20
	2465	.136	.151	3.257	1.630	1.359	7.560	1.92	2.04	2.21	2.74	3.96	7.18	9.54
	2695	.097	.081	4.330	2.021	.882	2.238	2.12	2.31	2.99	3.63	6.13	9.47	10.50
		(.106)	(.104)	(3.909)	(1.773)	(1.132)	(4.967)	(2.08)	(2.29)	(2.77)	(3.34)	(5.00)	(8.30)	(10.08)
5	2654	.051	.042	5.237	1.921	.754	1.290	3.08	3.23	3.75	4.59	7.26	10.05	10.62
	2655	.063	.053	4.994	1.997	.724	1.034	3.04	3.11	3.37	4.26	7.20	9.81	10.55
		(.057)	(.048)	(5.116)	(1.959)	(.739)	(1.162)	(3.06)	(3.17)	(3.56)	(4.43)	(7.23)	(9.93)	(10.59)
9	2046	.355	.350	2.065	1.837	1.407	7.888	.54	.77	1.10	1.52	2.36	7.13	8.91
	2047	.299	.267	2.449	1.841	1.288	6.505	.92	1.13	1.43	1.91	2.91	7.35	9.02
	2048	.212	.197	3.085	1.874	1.138	4.833	1.55	1.73	1.97	2.35	3.86	7.82	9.50
	2057	.003	.004	7.794	2.199	−.178	−.962	3.81	4.11	5.11	8.00	12.06	15.58	16.59
	2670	.127	.112	4.149	2.285	.719	.990	2.04	2.10	2.34	3.16	6.66	9.63	10.47
		(.199)	(.186)	(3.908)	(2.007)	(.875)	(3.851)	(1.77)	(1.97)	(2.39)	(3.39)	(5.57)	(9.50)	(10.90)
10	2035	.063	.066	4.691	2.006	.917	2.089	3.18	3.30	3.54	3.94	6.17	9.87	10.58
	2036	.063	.062	4.817	1.979	.828	1.591	3.16	3.37	3.61	4.03	6.81	9.71	10.78
	2037	.053	.051	4.945	1.641	.963	3.266	3.36	3.58	3.88	4.31	6.06	9.04	10.55
		(.060)	(.060)	(4.818)	(1.875)	(.903)	(2.315)	(3.23)	(3.42)	(3.68)	(4.09)	(6.35)	(9.54)	(10.64)
12	1986	.126	.131	3.611	1.956	1.133	4.550	2.04	2.21	2.41	2.94	4.37	8.53	11.17
	1987	.126	.115	3.528	2.015	1.081	3.918	2.23	2.37	2.66	3.13	4.54	9.47	11.61
	1988	.126	.071	3.381	1.796	1.324	6.548	2.19	2.29	2.46	3.83	3.86	8.07	10.40
		(.126)	(.106)	(3.507)	(1.922)	(1.179)	(5.005)	(2.15)	(2.29)	(2.51)	(3.30)	(4.26)	(8.69)	(11.06)
15	1967	.045	.030	6.005	2.084	.505	−.249	3.76	3.95	4.28	5.08	8.67	10.84	11.43
	1968	.075	.071	4.514	1.801	.956	2.525	3.27	3.38	3.53	3.84	5.94	8.92	10.00
	1969	.063	.063	4.964	2.186	.684	.590	2.93	3.07	3.34	4.00	7.68	10.17	11.06
	1970	.053	.051	5.347	2.145	.621	.300	3.17	3.38	3.73	4.31	7.98	10.42	11.16
	1971	.053	.045	5.349	1.947	.725	1.114	3.39	3.63	3.96	4.50	7.36	10.33	11.27
		(.058)	(.052)	(5.236)	(2.033)	(.698)	(.856)	(3.30)	(3.48)	(3.77)	(4.35)	(7.53)	(10.14)	(10.98)
60	3218	.071	.081	4.094	1.557	1.343	6.665	2.70	3.03	3.18	3.63	4.58	8.37	9.83
	3219	.071	.032	5.448	2.189	.313	.088	2.08	2.72	3.42	4.98	7.75	10.13	10.65
	3220	.125	.120	3.309	1.244	1.576	13.049	2.04	2.10	2.33	3.06	3.90	5.58	7.58
	3221	.128	.138	3.356	1.533	1.315	7.740	2.02	2.07	2.26	2.85	4.28	6.64	9.20
		(.099)	(.093)	(4.052)	(1.631)	(1.137)	(6.886)	(2.21)	(2.48)	(2.80)	(3.63)	(5.13)	(7.68)	(9.32)
70	1991	.126	.140	3.284	1.608	1.445	21.628	2.16	2.30	2.49	2.85	3.70	7.13	9.80
	1992	.106	.114	3.687	1.727	1.370	7.387	2.52	2.64	2.86	3.14	3.90	8.22	11.70
	1993	.126	.124	3.563	1.762	1.289	6.447	2.35	2.46	2.67	3.02	4.00	7.95	10.76
	1994	.045	.020	6.330	2.070	.379	−.496	3.74	4.00	4.49	5.70	8.72	13.80	15.77
		(.101)	(.100)	(4.216)	(1.792)	(1.121)	(8.742)	(2.69)	(2.85)	(3.13)	(3.68)	(5.08)	(9.28)	(12.01)
81	3196	.042	.033	5.398	1.868	.691	1.349	3.07	3.23	3.83	4.92	6.88	10.09	10.64
	3197	.107	.094	3.723	1.554	1.333	7.595	2.07	2.18	2.58	3.42	4.24	7.67	9.70
	3198	.093	.084	4.017	1.652	1.178	5.407	2.13	2.33	3.02	3.58	4.76	8.31	9.97
	3199	.063	.054	4.843	1.925	.877	2.120	3.03	3.10	3.37	4.22	6.43	9.90	10.58
		(.076)	(.066)	(4.495)	(1.750)	(1.020)	(4.118)	(2.58)	(2.71)	(3.20)	(4.04)	(5.58)	(8.99)	(10.22)
210	2644	.020	.012	6.822	1.951	.281	−.641	3.54	4.12	5.06	6.37	9.29	10.59	10.84
	2645	.070	.078	4.265	1.791	1.191	4.679	2.61	3.03	3.19	3.68	4.80	9.30	10.37
	2646	.064	.070	4.508	1.841	1.049	3.326	3.03	3.08	3.26	3.83	5.16	9.43	10.40
	2647	.044	.040	5.150	1.620	.959	3.200	3.16	3.41	4.06	4.65	6.28	9.29	10.46
	3195	.073	.068	4.167	1.402	1.165	6.985	2.20	2.52	3.14	3.89	4.87	7.19	9.37
		(.054)	(.054)	(4.982)	(1.721)	(.929)	(3.510)	(2.91)	(3.23)	(3.74)	(4.48)	(6.08)	(9.16)	(10.29)
211	870	.210	.195	2.556	1.412	1.370	11.060	.75	1.05	1.65	2.36	3.12	4.75	8.00
	874	.125	.175	2.641	1.335	1.304	10.228	.85	1.20	1.77	2.51	3.22	4.50	8.00
	875	.125	.128	3.034	.976	1.710	17.097	2.10	2.45	2.73	2.97	3.23	4.25	6.50
	879	.105	.103	3.870	1.309	1.451	10.188	2.60	2.90	3.10	3.28	4.20	7.00	9.00
		(.141)	(.150)	(3.025)	(1.258)	(1.459)	(12.143)	(1.58)	(1.90)	(2.31)	(2.78)	(3.44)	(5.13)	(7.88)

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*—Continued

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							COLORADO							
3	2504	0.043	0.056	4.826	1.069	0.742	3.067	3.10	3.25	3.45	4.15	5.15	6.65	7.40
	4321	.210	.237	2.240	1.632	.708	5.270	−.98	−.05	1.15	2.08	3.23	4.98	6.90
		(.127)	(.147)	(3.533)	(1.351)	(.725)	(4.169)	(1.06)	(1.60)	(2.30)	(3.12)	(4.19)	(5.82)	(7.15)
4	2206	.053	.048	5.094	1.730	.802	2.124	3.35	3.69	3.92	4.40	6.66	9.24	10.78
	2509	.045	.041	4.966	1.425	1.037	4.705	3.12	3.31	4.01	4.61	5.90	8.20	10.12
		(.049)	(.045)	(5.030)	(1.578)	(.920)	(3.415)	(3.24)	(3.50)	(3.97)	(4.51)	(6.28)	(8.72)	(10.45)
8	2612	.370	.378	1.447	1.963	.337	2.310	−3.54	−1.83	−.40	1.40	3.22	4.55	5.88
	2613	.189	.177	2.866	1.975	.755	3.145	−.01	.34	1.24	2.51	4.34	7.03	9.19
	2614	.055	.097	3.323	1.912	.287	1.571	−.40	.21	1.38	3.38	4.82	6.45	8.39
	2615	.046	.040	5.021	1.539	.874	3.295	3.08	3.22	3.77	4.65	6.12	8.58	10.21
	2616	.152	.143	3.255	2.018	.656	3.651	−1.09	1.00	2.07	2.82	4.57	7.63	10.07
	2617	9.450	1.547	−.118	3.024	.632	1.587	−3.46	−3.38	−2.75	−.63	2.27	6.68	8.74
		(1.710)	(.397)	(2.632)	(2.072)	(.590)	(2.593)	(−.90)	(−.07)	(.89)	(2.36)	(4.22)	(6.82)	(8.75)
15	2625	.178	.158	2.995	1.780	.853	4.062	.32	.88	1.49	2.67	4.19	6.69	8.81
	2626	.036	.030	5.427	1.566	.816	2.736	3.20	3.56	4.18	5.06	6.54	9.28	10.46
	2627	.641	.529	1.159	1.804	.957	6.634	−1.85	−1.00	−.28	.92	2.32	4.41	7.04
	2628	.188	.155	3.449	2.267	.805	2.203	.60	1.13	1.81	2.70	5.47	8.92	10.47
	2629	.750	.643	1.158	2.133	.958	4.763	−1.76	−1.20	−.53	.64	2.82	5.18	8.47
	2630	.041	.034	5.218	1.587	.722	2.278	3.05	3.24	3.91	4.86	6.46	8.80	10.24
		(.306)	(.258)	(3.234)	(1.856)	(.852)	(3.779)	(.59)	(1.10)	(1.76)	(2.81)	(4.63)	(7.21)	(9.25)
18	2488	.040	.035	5.226	1.502	.821	2.988	3.13	3.36	4.06	4.85	6.36	8.62	10.22
	2489	.044	.039	5.059	1.551	.923	3.499	3.10	3.26	3.88	4.67	5.99	8.73	10.33
	2490	.161	.170	2.657	1.562	.822	5.741	.13	.34	1.12	2.55	3.76	5.08	7.50
	2499	.055	.053	4.500	1.976	.546	1.918	.80	1.52	3.09	4.24	5.96	8.91	10.43
		(.075)	(.074)	(4.361)	(1.648)	(.778)	(3.537)	(1.79)	(2.12)	(3.04)	(4.08)	(5.52)	(7.84)	(9.62)
139	3243	.037	.024	5.975	1.962	.464	−.072	3.18	3.58	4.24	5.40	8.22	10.26	10.70
186	2211	.053	.049	4.898	1.554	.956	3.719	3.17	3.50	3.87	4.38	5.91	8.53	10.28
188	2135	.045	.037	5.184	1.627	.673	2.539	2.49	3.37	4.11	4.79	6.32	8.73	10.77
	2136	.027	.032	5.315	1.961	.489	.949	2.16	2.69	3.78	4.98	6.99	10.04	11.39
		(.036)	(.035)	(5.250)	(1.794)	(.581)	(1.744)	(2.33)	(3.03)	(3.95)	(4.89)	(6.66)	(9.39)	(11.08)
189	3240	.042	.035	5.618	2.069	.660	.576	3.13	3.38	4.08	4.83	7.92	10.45	10.78
							NEVADA							
1	2318	0.027	0.014	6.503	1.743	−0.242	−0.051	3.72	3.97	4.94	6.23	8.20	10.16	11.84
	2319	.063	.061	4.629	1.691	.973	3.269	3.13	3.39	3.72	4.05	5.64	8.72	10.31
	2320	.053	.063	4.491	1.632	.960	3.484	2.86	3.04	3.39	4.01	5.36	8.40	9.89
		(.048)	(.046)	(5.208)	(1.689)	(.725)	(2.234)	(3.24)	(3.47)	(4.02)	(4.76)	(6.40)	(9.09)	(10.68)
							NEW MEXICO							
1	2456	0.080	0.067	4.948	2.275	0.623	0.328	2.29	2.71	3.19	3.90	7.65	10.21	10.69
	2660	.043	.019	6.232	2.163	.310	−.747	3.15	3.42	4.16	5.71	8.81	10.48	10.79
	2699	.177	.158	3.506	2.063	1.129	4.723	1.87	2.02	2.20	2.66	4.65	8.50	10.65
		(.100)	(.081)	(4.895)	(2.167)	(.687)	(1.435)	(2.44)	(2.72)	(3.18)	(4.09)	(7.04)	(9.73)	(10.71)
3	2390	.150	.155	3.765	2.164	.859	1.950	1.98	2.07	2.29	2.70	5.84	9.01	10.28
	2894	.210	.161	3.813	2.749	.726	.628	1.13	1.31	2.00	2.64	7.52	10.26	10.71
		(.180)	(.158)	(3.789)	(2.457)	(.793)	(1.289)	(1.56)	(1.69)	(2.15)	(2.67)	(6.68)	(9.64)	(10.50)
16	2425	.126	.122	3.518	1.548	1.214	6.767	2.04	2.10	2.33	3.04	4.54	6.76	9.24
	2426	.213	.191	2.833	1.787	1.195	6.123	1.06	1.15	1.47	2.39	3.84	7.04	9.36
	2427	.077	.075	4.198	1.578	1.146	5.546	2.24	2.60	3.14	3.74	4.99	7.86	10.12
		(.139)	(.129)	(3.516)	(1.638)	(1.185)	(6.145)	(1.78)	(1.95)	(2.31)	(3.06)	(4.46)	(7.22)	(9.57)
20	2462	.089	.069	4.626	2.165	.688	.986	2.11	2.28	2.90	3.85	6.84	9.89	10.57
	2463	.134	.107	4.193	2.347	.685	.793	1.93	2.07	2.32	3.24	6.92	9.78	10.55
	2464	.149	.135	3.856	2.230	.793	1.596	1.40	2.00	2.22	2.89	6.06	9.26	10.42
		(.124)	(.104)	(4.225)	(2.247)	(.722)	(1.125)	(1.81)	(2.12)	(2.48)	(3.33)	(6.61)	(9.64)	(10.51)

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*—Continued

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							UTAH							
6	2523	0.043	0.018	6.179	2.111	0.310	−0.579	3.12	3.33	4.07	5.79	8.56	10.44	10.78
	2524	.058	.052	4.712	1.678	1.015	3.652	3.05	3.13	3.41	4.27	5.75	9.10	10.34
	2525	.010	.007	7.353	1.840	.053	−.642	3.67	4.31	5.48	7.22	9.55	10.61	10.84
	2526	.006	.006	7.181	2.191	−.087	−.744	2.78	3.39	4.68	7.28	9.86	10.67	10.87
		(.029)	(.021)	(6.356)	(1.955)	(.323)	(.422)	(3.16)	(3.54)	(4.41)	(6.14)	(8.43)	(10.21)	(10.71)
7	1769	.027	.026	5.711	1.889	.453	.673	2.62	3.58	4.13	5.26	7.38	10.24	11.87
	1770	.063	.063	4.470	1.546	1.092	4.960	3.11	3.39	3.67	4.01	5.20	8.12	10.06
		(.045)	(.045)	(5.091)	(1.718)	(.773)	(2.817)	(2.87)	(3.49)	(3.90)	(4.64)	(6.29)	(9.18)	(10.97)
8	3713	.044	.034	5.718	2.183	.611	.460	3.11	3.31	4.02	4.88	8.31	10.62	11.40
	3714	.042	.021	6.463	2.465	.318	−.838	3.15	3.45	4.17	5.59	9.45	11.29	11.72
	3715	.051	.043	4.950	1.636	1.059	4.395	3.09	3.23	3.76	4.53	5.87	8.93	10.48
	3716	.056	.045	5.024	1.837	.914	2.587	3.08	3.20	3.64	4.48	6.53	9.53	10.63
	3717	.021	.013	6.785	2.127	.389	−.188	3.46	4.06	4.83	6.28	9.09	11.32	11.73
	3718	.392	.308	2.291	2.155	.848	3.342	−.54	.04	.50	1.70	3.88	6.82	9.65
	3719	.325	.263	2.600	2.365	1.026	3.925	.07	.26	.97	1.92	3.83	9.41	10.53
		(.133)	(.104)	(4.833)	(2.110)	(.738)	(1.955)	(2.20)	(2.51)	(3.13)	(4.20)	(6.71)	(9.70)	(10.88)
9	1872	.126	.139	3.188	1.297	.903	4.092	1.66	1.90	2.34	2.86	4.28	5.82	7.45
	1873	.053	.048	5.237	1.726	.881	2.402	3.61	3.84	4.11	4.41	6.67	9.55	12.10
	1874	.045	.043	5.205	1.677	.842	2.070	3.31	3.63	4.07	4.55	6.67	9.35	10.13
	1875	.126	.092	4.464	2.266	.706	.832	2.53	2.70	2.88	3.46	7.01	9.78	10.51
	1876	.005	.004	7.832	1.959	−.197	−.511	3.97	4.34	5.84	7.89	10.35	11.84	12.82
		(.071)	(.065)	(5.185)	(1.785)	(.627)	(1.777)	(3.02)	(3.28)	(3.85)	(4.63)	(7.00)	(9.27)	(10.60)
10	3144	.006	.005	7.745	1.921	−.118	−.673	3.68	4.30	5.73	7.66	10.06	10.71	10.88
	3145	.001	.002	8.270	2.482	−.519	−.100	2.33	3.08	4.80	9.03	10.53	10.85	10.94
	3146	.049	.041	5.187	1.865	.850	1.927	3.10	3.27	3.88	4.59	6.70	9.98	10.60
	3147	.055	.043	5.152	1.883	.841	1.773	3.09	3.26	3.86	4.54	6.88	9.88	10.55
	3148	.042	.039	5.309	1.748	.847	2.054	3.19	3.54	4.12	4.70	6.82	9.78	10.53
		(.031)	(.026)	(6.333)	(1.980)	(.380)	(.996)	(3.08)	(3.49)	(4.48)	(6.10)	(8.20)	(10.24)	(10.70)
11	1535	.019	.007	7.370	2.255	.133	−.879	3.68	4.10	5.02	7.12	9.98	11.75	13.00
	1711	.038	.038	5.331	1.687	.828	2.221	3.42	3.72	4.14	4.73	6.62	9.56	11.37
	1712	.063	.062	4.661	2.049	.814	1.677	2.71	2.85	3.17	4.02	6.27	9.74	12.22
	1714	.075	.070	4.375	1.486	1.029	3.994	3.07	3.20	3.40	3.86	5.44	7.87	9.35
	3141	.134	.088	4.363	2.377	.609	.311	1.61	2.06	2.40	3.50	7.41	9.66	10.38
		(.066)	(.053)	(5.220)	(1.971)	(.683)	(1.465)	(2.90)	(3.19)	(3.63)	(4.65)	(7.14)	(9.72)	(11.26)
14	1706	.063	.062	4.981	2.124	.719	.782	3.14	3.27	3.51	4.03	7.53	10.43	12.38
	1707	.038	.021	6.229	2.021	.429	−.277	3.75	3.96	4.44	5.62	8.38	11.09	12.57
	1708	.089	.079	4.563	2.067	.784	1.511	2.47	2.72	3.11	3.68	6.58	9.67	11.70
	1709	.027	.015	6.498	2.074	.251	−.670	3.44	3.72	4.50	6.08	8.83	11.12	12.45
	3133	.046	.039	5.463	1.964	.710	.859	3.15	3.43	4.09	4.70	7.74	10.18	10.67
	3134	.054	.046	4.837	1.695	.888	2.929	2.68	3.08	3.49	4.43	6.00	9.07	10.29
	3135	.076	.072	4.207	1.578	1.032	4.811	2.13	2.42	3.10	3.80	4.96	7.89	9.80
	3136	.094	.073	4.546	2.145	.665	.856	2.09	2.23	2.77	3.78	7.06	9.59	10.45
		(.061)	(.051)	(5.166)	(1.959)	(.685)	(1.350)	(2.86)	(3.10)	(3.63)	(4.52)	(7.14)	(9.88)	(11.29)
18	2543	.049	.053	4.342	2.073	.404	1.214	.51	1.17	2.40	4.24	5.95	8.68	10.31
	2544	.049	.053	4.490	2.114	.410	.927	.62	1.36	2.59	4.24	6.35	8.93	10.38
	2545	1.065	.975	.508	1.801	1.422	10.193	−1.53	−.97	−.73	.04	1.33	4.14	6.76
	2546	.088	.078	4.112	1.663	1.013	4.505	2.10	2.26	2.86	3.68	5.16	7.87	10.14
	2547	.043	.039	5.135	1.575	.953	3.464	3.14	3.37	4.05	4.68	6.21	8.98	10.43
		(.259)	(.240)	(3.717)	(1.845)	(.840)	(4.061)	(.97)	(1.44)	(2.23)	(3.38)	(5.00)	(7.72)	(9.60)
22	2230	.027	.015	6.469	1.756	.277	.288	3.70	3.99	5.06	6.11	8.16	10.31	11.04
	2231	.063	.012	6.445	2.931	.003	−1.282	1.18	2.14	3.46	6.44	10.51	12.08	12.51
	2232	.075	.079	3.781	.881	2.758	36.365	3.18	3.30	3.46	3.68	4.06	4.58	5.96
	2233	.045	.041	5.209	1.589	.925	3.063	3.52	3.76	4.14	4.62	6.41	9.18	10.79
		(.053)	(.037)	(5.476)	(1.789)	(.991)	(9.609)	(2.90)	(3.30)	(4.03)	(5.21)	(7.29)	(9.04)	(10.08)

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*—Continued

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							UTAH—Continued							
24	2246	0.045	0.047	4.902	1.605	0.960	3.431	3.43	3.67	4.00	4.42	5.41	8.72	10.89
	2247	.038	.039	5.273	1.726	.773	1.851	3.71	3.81	4.01	4.69	6.72	9.53	10.56
		(.042)	(.043)	(5.088)	(1.666)	(.867)	(2.641)	(3.57)	(3.74)	(4.01)	(4.56)	(6.07)	(9.13)	(10.73)
25	1842	.053	.063	4.280	2.230	.495	.869	.97	1.54	2.29	4.01	6.27	9.18	12.35
	1843	.007	.013	5.910	2.673	–.014	–.985	1.43	1.74	2.69	6.24	8.62	10.82	12.04
	1844	.063	.064	4.787	2.110	.772	1.287	2.82	2.92	3.27	3.98	6.91	10.11	11.06
	1845	.126	.113	3.685	1.682	1.203	5.949	2.29	2.43	2.71	3.16	4.33	7.81	9.97
	1846	.075	.069	4.460	1.725	1.064	3.868	3.04	3.18	3.41	3.87	5.38	8.92	10.55
	1860	.298	.294	1.943	1.146	1.847	20.555	.62	.88	1.31	1.77	2.45	3.39	5.37
	1861	.045	.038	5.355	1.666	.896	2.715	3.65	3.92	4.22	4.73	6.51	9.84	12.63
	1862	.126	.141	3.286	1.720	1.079	5.673	1.44	1.67	2.07	2.84	4.44	6.70	9.85
		(.099)	(.099)	(4.213)	(1.869)	(.918)	(4.991)	(2.03)	(2.29)	(2.75)	(3.83)	(5.61)	(8.35)	(10.48)
27	943	.189	.177	2.741	1.354	1.195	9.020	.85	1.43	1.85	2.50	3.58	4.50	7.50
	944	.177	.126	3.326	1.714	.969	4.864	1.25	1.55	2.05	2.99	4.20	7.25	9.50
		(.183)	(.152)	(3.034)	(1.534)	(1.082)	(6.942)	(1.05)	(1.49)	(1.93)	(2.75)	(3.89)	(5.88)	(8.50)
29	1745	.056	.041	5.240	1.930	.721	5.238	3.17	3.30	3.67	4.61	6.97	10.26	12.24
	1746	.053	.048	5.063	1.828	.773	1.774	3.09	3.21	3.56	4.41	6.55	9.66	11.42
	1747	.063	.052	4.976	1.896	.824	1.773	3.18	3.34	3.69	4.27	6.75	9.77	11.71
	2307	.063	.022	5.813	2.803	.056	–1.105	1.12	1.67	2.76	5.54	9.04	10.72	11.20
	3174	.064	.062	4.586	1.754	1.000	3.423	3.01	3.08	3.30	4.02	5.53	9.13	10.35
	3175	.064	.050	4.906	1.941	.810	1.743	3.01	3.09	3.38	4.31	6.66	9.82	10.55
	3176	.056	.048	4.952	1.955	.805	1.732	3.00	3.09	3.42	4.37	6.73	9.98	10.60
	3177	.011	.010	6.700	2.107	.069	–.671	3.01	3.29	4.41	6.61	8.97	10.51	10.81
		(.054)	(.042)	(5.280)	(2.027)	(.632)	(1.738)	(2.82)	(3.01)	(3.52)	(4.77)	(7.15)	(9.98)	(11.11)
30	3166	.143	.107	3.782	2.084	.765	2.390	.91	1.49	2.22	3.23	5.03	8.68	10.35
	3167	.058	.058	4.295	1.535	.936	5.293	1.85	2.37	3.18	4.10	4.94	7.68	9.91
	3168	.190	.174	2.770	1.385	1.378	10.210	1.06	1.21	1.75	2.52	3.55	5.20	7.77
	3169	.210	.182	2.469	.737	2.343	42.583	1.09	1.33	2.04	2.46	2.88	3.22	3.96
	3170	.057	.049	4.832	1.733	.911	2.713	3.04	3.13	3.46	4.36	6.13	9.19	10.33
	3171	.053	.044	5.116	1.949	.734	1.302	3.01	3.12	3.53	4.52	7.08	9.97	10.59
		(.119)	(.102)	(3.877)	(1.571)	(1.178)	(10.749)	(1.83)	(2.11)	(2.70)	(3.53)	(4.94)	(7.32)	(8.82)
34	936	.072	.101	3.039	1.453	–.221	4.336	–.37	.00	1.90	3.31	4.10	5.25	6.15
	937	.051	.052	4.600	1.314	1.304	7.884	3.25	3.47	3.77	4.26	4.93	7.50	9.50
	938	.062	.062	4.276	1.198	1.471	10.615	3.25	3.43	3.68	4.01	4.55	6.50	8.50
	939	.037	.042	4.807	1.313	1.139	6.351	3.30	3.55	3.83	4.57	5.33	7.75	9.75
		(.056)	(.064)	(4.181)	(1.320)	(.923)	(7.297)	(2.36)	(2.61)	(3.30)	(4.04)	(4.73)	(6.75)	(8.48)
35	2577	.048	.042	5.080	1.786	.803	2.215	2.79	3.13	3.68	4.60	6.46	9.67	10.53
	2578	.046	.042	4.916	1.382	1.317	6.892	3.22	3.55	4.10	4.57	5.37	8.50	10.22
	2579	.006	.005	7.480	2.087	–.103	–.894	3.30	3.75	5.13	7.54	9.98	10.68	10.87
	2610	.050	.047	4.801	2.100	.453	.898	1.02	2.01	3.11	4.43	6.78	9.52	10.48
	2611	.050	.044	4.907	1.752	.744	2.585	2.21	3.04	3.55	4.52	6.14	9.15	10.40
		(.040)	(.036)	(5.437)	(1.821)	(.643)	(2.339)	(2.51)	(3.10)	(3.91)	(5.13)	(6.95)	(9.50)	(10.50)
36	891	.241	.235	2.355	1.663	1.244	8.794	.35	.62	1.18	2.09	3.18	4.75	9.00
	892	.148	.135	3.328	1.592	1.454	8.819	2.25	2.38	2.58	2.89	3.85	7.00	10.00
		(.195)	(.185)	(2.842)	(1.628)	(1.349)	(8.807)	(1.30)	(1.50)	(1.88)	(2.49)	(3.52)	(5.88)	(9.50)
38	3182	.226	.217	2.327	1.207	1.902	21.121	1.01	1.09	1.38	2.21	2.90	3.91	5.79
	3183	.163	.119	3.401	1.681	.860	4.255	1.11	1.30	2.00	3.07	4.71	6.60	8.77
	3184	.160	.080	4.096	2.152	.614	1.314	1.15	1.42	2.17	3.65	5.91	8.93	10.44
	3185	.022	.025	5.494	2.163	.250	–.365	2.11	2.34	3.17	5.33	7.69	9.84	10.54
	3186	.070	.065	4.599	1.883	.914	2.597	2.41	3.00	3.23	3.94	5.87	9.49	10.45
	3239	.038	.011	6.682	2.043	.134	–.718	3.23	3.82	4.49	6.53	8.98	10.45	10.78
		(.113)	(.086)	(4.433)	(1.855)	(.779)	(4.701)	(1.84)	(2.16)	(2.74)	(4.12)	(6.01)	(8.20)	(9.46)
41	2104	.038	.039	5.260	1.664	.938	2.856	3.64	3.81	4.19	4.71	6.28	9.67	11.33
	2105	.038	.033	5.279	1.460	1.008	4.295	3.68	3.83	4.37	4.93	5.89	8.85	11.02
		(.038)	(.036)	(5.270)	(1.562)	(.973)	(3.576)	(3.66)	(3.82)	(4.28)	(4.82)	(6.09)	(9.26)	(11.18)

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*—Continued

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							UTAH—Continued							
43	3151	0.076	0.016	6.154	2.476	0.154	−1.163	2.37	2.93	3.47	5.98	9.14	10.49	10.79
	3152	.001	.003	7.718	2.567	−.300	−.735	2.07	2.90	4.65	8.20	10.44	10.82	10.93
	3153	.001	.005	7.338	2.692	−.324	−.424	1.05	2.02	4.40	7.72	10.25	10.77	10.91
	3155	.042	.036	5.401	1.896	.709	1.301	3.03	3.25	4.03	4.80	6.94	10.13	10.65
	3156	.067	.056	4.716	1.857	.828	1.910	2.46	3.02	3.29	4.17	6.12	9.38	9.97
		(.037)	(.023)	(6.265)	(2.298)	(.213)	(.178)	(2.20)	(2.82)	(3.97)	(6.17)	(8.58)	(10.32)	(10.65)
45	2173	.038	.039	5.304	1.692	.882	2.478	3.67	3.86	4.18	4.71	6.58	9.78	11.18
	2174	.045	.042	5.334	1.815	.767	1.579	3.37	3.66	4.02	4.58	6.95	9.88	10.87
		(.042)	(.041)	(5.319)	(1.754)	(.825)	(2.029)	(3.52)	(3.76)	(4.10)	(4.65)	(6.77)	(9.83)	(11.03)
47	1795	.053	.036	5.668	2.067	.560	.221	3.32	3.63	4.05	4.80	8.08	10.73	11.70
	2145	.053	.016	6.301	2.593	.047	−1.451	2.42	2.68	3.59	6.00	9.41	10.07	10.26
	2146	.038	.039	5.369	2.722	.169	−.667	.42	.94	2.86	4.71	8.90	10.33	10.74
	2147	.053	.052	5.433	2.123	.599	.297	2.66	3.20	3.94	4.29	8.21	10.39	11.18
	2149	.038	.004	7.663	2.489	−.104	−1.450	3.81	3.98	4.61	7.88	12.01	13.47	13.86
	2150	.032	.010	6.702	1.939	.151	−.694	3.75	3.99	4.77	6.67	8.64	11.44	12.62
	2155	.075	.076	3.681	.754	−.204	.152	1.99	2.46	3.01	3.73	4.34	4.74	4.96
	2156	.075	.078	4.303	1.642	1.149	4.904	2.94	3.20	3.42	3.69	5.14	8.50	10.14
	2157	.022	.014	6.519	1.769	.326	−.021	3.86	4.10	5.00	6.14	8.31	10.73	11.80
	2158	.013	.009	7.114	1.775	.212	−.377	4.01	4.72	5.51	6.75	9.16	11.59	12.38
	2159	.027	.022	6.167	1.788	.398	.085	3.64	3.99	4.80	5.52	8.06	10.01	10.82
	2160	.063	.009	7.109	2.335	.007	−1.127	3.16	3.74	4.67	6.76	10.31	12.00	12.45
	2161	.007	.009	6.224	2.853	.095	−1.187	1.26	1.69	2.75	6.81	9.28	10.98	12.57
	2162	.022	.010	6.907	1.905	.176	−.802	3.98	4.29	4.98	6.65	9.06	10.98	11.64
	2163	.003	.002	8.562	2.020	−.466	−.064	3.71	4.19	6.59	8.91	13.16	15.03	15.56
	2164	.038	.014	6.778	2.313	.172	−1.158	3.32	3.95	4.54	6.17	9.95	11.16	11.49
	2165	.054	.004	7.623	2.466	−.149	−1.343	3.29	3.76	4.32	8.18	11.00	12.21	12.54
	2166	.032	.033	5.206	1.420	.897	3.887	3.40	3.74	4.26	4.95	5.98	8.38	10.25
	2198	.032	.011	6.766	2.654	−.028	−1.129	1.76	2.42	4.03	6.58	10.27	11.62	11.98
	2199	.075	.073	3.859	.909	2.387	29.348	3.38	3.45	3.55	3.79	4.14	4.59	6.28
	2200	.053	.060	4.594	1.611	1.215	5.633	3.41	3.51	3.70	4.07	4.97	9.08	10.85
	2201	.075	.070	4.259	1.640	1.373	6.927	3.26	3.42	3.58	3.84	4.47	9.13	10.78
		(.042)	(.030)	(6.037)	(1.990)	(.400)	(1.817)	(3.03)	(3.41)	(4.21)	(5.77)	(8.31)	(10.33)	(11.22)
49	1327	.053	.052	4.730	1.902	.586	2.053	1.52	2.41	3.53	4.27	6.07	9.05	10.95
	1328	.115	.101	3.737	1.857	.932	3.963	1.35	1.82	2.40	3.31	4.68	8.15	10.70
	1329	.060	.047	5.115	1.985	.638	.951	2.77	3.08	3.58	4.43	7.06	9.95	11.65
	1330	.107	.119	3.355	1.451	1.359	9.251	1.72	2.02	2.47	3.07	3.74	6.35	8.75
	1331	.086	.082	4.200	1.689	1.125	4.880	2.68	2.85	3.12	3.62	4.83	8.43	10.55
	1344	.025	.018	6.123	2.245	.177	−.618	2.23	2.72	3.95	5.78	8.53	10.80	12.10
	1345	.036	.025	5.840	1.933	.443	.154	3.15	3.60	4.11	5.34	7.70	10.42	11.90
	1346	.098	.107	3.820	1.661	1.305	6.819	2.55	2.77	2.94	3.22	4.11	7.95	10.90
	1352	.170	.168	3.331	2.075	.672	1.533	.68	1.35	1.82	2.57	4.92	8.25	10.35
		(.083)	(.080)	(4.472)	(1.866)	(.804)	(3.221)	(2.07)	(2.51)	(3.10)	(3.96)	(5.74)	(8.82)	(10.87)
64	1581	.032	.019	6.193	2.305	.191	−.584	2.15	3.12	4.13	5.71	8.97	11.02	12.30
	1635	.250	.239	2.548	1.728	.449	.678	−.45	.51	1.38	2.07	4.31	6.16	6.77
	1636	.006	.006	7.452	2.249	−.094	−1.151	3.47	3.87	4.72	7.50	11.09	13.27	14.60
	1637	.056	.047	5.600	2.262	.478	−.398	3.33	3.54	3.77	4.43	8.49	11.05	12.77
	1638	.075	.042	5.789	2.413	.358	−.863	3.28	3.45	3.66	4.59	8.86	11.58	13.23
	1639	.063	.049	5.137	1.932	.768	1.350	3.47	3.60	3.84	4.36	7.11	9.87	12.22
	1640	.004	.005	7.873	1.753	.027	−.638	4.13	5.12	6.10	7.81	10.14	11.96	13.08
	1641	.013	.008	7.121	2.070	.093	−1.005	3.86	4.12	4.83	7.03	9.70	11.34	12.38
	1642	.038	.029	5.677	1.667	.776	1.861	3.81	4.08	4.45	5.14	6.95	10.85	13.03
	1643	.022	.014	6.636	1.928	.320	−.456	3.86	4.06	4.88	6.17	8.78	10.52	11.48
	2303	.053	.042	5.331	1.802	.778	1.827	3.25	3.74	4.05	4.60	6.86	10.12	11.28
		(.056)	(.045)	(5.942)	(2.010)	(.377)	(.056)	(3.11)	(3.56)	(4.16)	(5.40)	(8.30)	(10.70)	(12.10)

TABLE 6.—*Statistical measures of the phi grain-size distributions of detrital grains in 265 samples from the Moenkopi Formation and related strata*—Continued

Locality (pl. 1)	Sample No. (L–)	Mode	Median	Mean	Standard deviation	Skewness	Kurtosis	ϕ_2	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	ϕ_{98}
		Millimeters		Phi notation										
							UTAH—Continued							
93	1915	0.008	0.005	7.676	2.006	−0.056	−0.949	3.94	4.29	5.52	7.54	10.11	11.63	12.58
160	1645	.038	.022	6.310	2.163	.385	−.674	3.79	3.96	4.42	5.52	9.01	11.68	13.20
173	1442	.043	.044	4.953	1.473	.911	4.242	2.80	3.45	4.02	4.52	5.81	8.20	10.25
	1443	.084	.090	3.909	1.568	1.247	6.745	2.27	2.58	2.95	3.48	4.44	7.60	9.90
	3157	.113	.108	3.692	1.998	1.305	6.096	2.02	2.10	2.37	3.21	4.06	10.21	10.68
		(.080)	(.081)	(4.185)	(1.680)	(1.154)	(5.694)	(2.36)	(2.71)	(3.11)	(3.74)	(4.77)	(8.67)	(10.28)
200	1548	.070	.059	4.887	2.002	.795	1.449	3.10	3.30	3.56	4.08	7.00	9.90	11.75
	1748	.063	.034	5.539	1.904	.628	.817	3.26	3.47	3.99	4.89	7.36	10.08	11.64
	1751	.126	.128	3.442	1.577	1.206	5.815	2.32	2.46	2.68	2.98	4.08	7.38	8.82
	1752	.053	.058	4.786	1.823	.943	2.753	3.14	3.28	3.58	4.12	5.92	9.59	11.72
	1753	.053	.063	4.663	1.871	.782	1.815	2.81	2.95	3.26	4.01	6.42	9.18	10.72
	2297	.126	.118	3.916	2.122	.890	2.425	1.91	2.15	2.48	3.09	5.42	9.30	11.10
		(.082)	(.077)	(4.539)	(1.883)	(.874)	(2.512)	(2.76)	(2.94)	(3.26)	(3.86)	(6.03)	(9.24)	(10.96)
286	1807	.053	.060	4.526	1.611	1.050	4.626	2.92	3.13	3.51	4.07	5.20	8.43	11.00
300	2548	.382	.321	2.394	2.441	.903	2.809	−.44	−.08	.56	1.65	4.09	8.49	10.25
	2549	.409	.353	2.292	2.563	.874	2.513	−.71	−.16	.37	1.50	4.24	8.64	10.37
		(.396)	(.337)	(2.343)	(2.502)	(.889)	(2.661)	(−.58)	(−.04)	(.47)	(1.58)	(4.17)	(8.57)	(10.31)
304	1802	.045	.034	5.529	1.692	.671	1.439	3.76	3.94	4.18	4.88	7.08	9.44	11.97
305	1726	.053	.057	4.795	1.786	.955	2.814	3.26	3.44	3.71	4.14	5.87	9.47	11.27
	1727	.053	.046	5.263	1.869	.834	1.835	3.46	3.68	3.99	4.46	6.76	10.28	12.26
	1728	.089	.087	4.490	2.023	.842	1.736	2.73	2.91	3.12	3.54	6.57	9.47	11.26
	2305	.053	.040	5.311	1.962	.669	.941	3.14	3.28	3.72	4.67	7.13	10.13	11.04
		(.062)	(.058)	(4.965)	(1.910)	(.825)	(1.832)	(3.15)	(3.33)	(3.64)	(4.20)	(6.58)	(9.84)	(11.46)
307	2121	.038	.031	5.767	2.250	.473	−.049	2.39	3.37	4.01	5.01	8.49	11.78	12.66
	2122	.038	.041	4.968	1.442	1.091	5.016	3.38	3.64	4.04	4.63	5.72	8.45	10.47
	2123	.038	.038	5.231	1.545	1.025	4.131	3.84	4.02	4.24	4.74	6.03	9.39	11.32
	2124	.053	.051	4.549	1.008	1.742	16.344	3.54	3.76	3.99	4.31	4.74	5.77	8.57
	2125	.106	.079	4.110	1.702	1.128	5.151	2.66	2.78	2.99	3.67	4.64	8.43	10.61
		(.055)	(.048)	(4.925)	(1.589)	(1.092)	(6.119)	(3.16)	(3.51)	(3.85)	(4.47)	(5.92)	(8.76)	(10.73)
309	1813	.053	.013	6.627	2.334	.184	−1.091	3.24	3.54	4.13	6.32	9.93	11.92	13.30
	1814	.027	.020	6.201	1.966	.401	−.204	3.48	3.82	4.35	5.68	8.26	10.88	12.26
	1826	.045	.005	7.496	2.242	−.073	−1.158	3.60	4.03	4.69	7.54	10.57	12.54	13.78
	1827	.007	.004	7.993	2.108	−.168	−1.036	4.00	4.37	5.56	8.11	10.92	12.64	13.74
		(.033)	(.011)	(7.079)	(2.163)	(.086)	(−.872)	(3.58)	(3.94)	(4.68)	(6.91)	(9.92)	(12.00)	(13.27)
310	1754	.045	.026	5.946	1.875	.493	.092	3.79	3.98	4.31	5.28	7.96	10.04	11.27
	1755	.002	.002	8.283	2.077	.768	.175	3.32	4.12	6.08	8.72	11.28	12.97	13.99
	2875	1.516	1.625	.779	2.723	.803	3.480	−1.92	−1.80	−1.55	−.70	1.45	7.50	9.10
		(.521)	(.551)	(5.003)	(2.225)	(.688)	(1.249)	(1.73)	(2.10)	(2.95)	(4.43)	(6.90)	(10.17)	(11.45)
312	1777	.053	.045	5.166	1.775	.857	2.372	3.42	3.71	3.98	4.49	6.51	9.94	11.71
	1784	.045	.043	5.166	1.598	.877	2.923	3.47	3.72	4.05	4.56	6.47	8.97	10.58
		(.049)	(.044)	(5.166)	(1.687)	(.867)	(2.648)	(3.45)	(3.72)	(4.02)	(4.53)	(6.49)	(9.46)	(11.15)
313	1322	.053	.050	4.940	2.055	.537	1.126	1.45	2.67	3.62	4.32	7.35	9.83	11.70
	1323	.041	.038	5.319	1.667	.848	2.465	3.54	3.74	4.12	4.72	6.58	9.45	11.70
	1324	.100	.078	4.312	1.829	1.015	3.766	2.62	2.82	3.08	3.68	5.22	8.87	11.85
	1325	.117	.119	3.550	1.565	1.263	7.346	2.15	2.43	2.81	3.07	4.26	6.85	9.40
	1326	.074	.076	4.394	1.790	1.026	3.462	2.90	3.07	3.32	3.73	5.62	8.84	11.00
		(.077)	(.072)	(4.503)	(1.781)	(.938)	(3.633)	(2.53)	(2.95)	(3.39)	(3.90)	(5.81)	(8.77)	(11.13)
315	1321	.056	.059	4.592	2.224	.546	1.033	1.12	1.86	2.91	4.08	6.67	10.10	12.20
	1332	.134	.152	3.100	1.868	1.009	4.934	.45	1.22	1.83	2.72	4.08	7.30	9.95
	1333	.143	.081	4.078	2.175	.700	1.594	1.52	1.76	2.28	3.63	5.82	9.35	11.82
		(.111)	(.097)	(3.923)	(2.089)	(.752)	(2.520)	(1.03)	(1.61)	(2.34)	(3.48)	(5.52)	(8.92)	(11.32)
319	1644	.045	.040	5.151	1.620	.864	2.780	3.36	3.57	3.97	4.67	6.28	8.90	10.71
323	1914	.106	.083	4.419	2.264	.660	.786	1.98	2.23	2.64	3.60	6.98	9.68	10.74
325	2587	.040	.035	5.379	1.711	.793	2.038	3.15	3.42	4.10	4.85	6.75	9.76	10.55
	2595	.036	.032	5.594	1.711	.719	1.397	3.34	3.84	4.22	4.97	7.21	9.82	10.57
		(.038)	(.034)	(5.487)	(1.711)	(.756)	(1.718)	(3.25)	(3.63)	(4.16)	(4.91)	(6.98)	(9.79)	(10.56)

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