Reconnaissance Study of the Wasatch, Evanston, and Echo Canyon Formations in Part of Northern Utah

GEOLOGICAL SURVEY BULLETIN 1311-D

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By THOMAS E. MULLENS

CONTRIBUTIONS TO GENERAL GEOLOGY

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Description, distribution, and heavy-mineral content of some Upper Cretaceous and lower Tertiary orogenic conglomerates in northern Utah

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RECONNAISSANCE STUDY OF THE WASATCH, EVANSTON, AND ECHO CANYON FORMATIONS IN PART OF NORTHERN UTAH

By Thomas E. Mullens

ABSTRACT

Reconnaissance study of some Upper Cretaceous and lower Tertiary orogenic conglomerates in part of northern Utah indicates that they can be divided into three formations. The Echo Canyon Conglomerate, 0–3,100 feet thick, of Late Cretaceous age is at the base. It is reddish brown and consists mainly of clasts derived from post-Middle Cambrian sedimentary rocks. The overlying Evanston Formation is 0–1,400 feet thick and has two parts, a basal conglomerate and an upper gray grit and silty sandstone. The basal conglomerate is of Late Cretaceous age and contains abundant tan, purple, pink, and green rounded quartzite clasts probably derived mainly from quartzite of Cambrian and Precambrian age. The upper unit is of Late Cretaceous and Paleocene age and contains much quartz grit probably derived from the Precambrian Farmington Canyon Complex of Eardley and Hatch (1940). The Wasatch Formation is as much as 5,000 feet thick and is of Paleocene and Eocene age. Locally, the Wasatch contains a basal conglomerate as much as 1,000 feet thick that is composed mainly of rounded quartzite clasts derived from Cambrian and Precambrian formations. In the area of study, most of the formation, however, is reddish-brown conglomerate composed of quartzite, sandstone, siltstone, and limestone clasts interbedded with reddish-brown conglomeratic sandstone and mudstone. The Wasatch Formation grades eastward to a finer grained facies in which conglomerate is less conspicuous.

The three formations were sampled for placer gold by obtaining a concentrate of heavy minerals from about 15,000 grams of outcrop samples or stream sediment derived from the formations at 150 localities. Only a few flakes of gold were found in the concentrates, and there seems to be no gold of economic importance in the formations. Heavy minerals retained in the pan concentrates are of slight use in correlating units or determining provenance.

INTRODUCTION

A sequence of orogenic conglomerate exposed in northeastern Utah was sampled for gold in July and August 1967 by me and Douglas Knox. The conglomeratic sequence, which is divided into the Echo Canyon (Late Cretaceous), Evanston (Late Cretaceous and Paleocene), and Wasatch (Paleocene and Eocene) Formations, was derived principally from rocks exposed in Late Cretaceous and early Tertiary folds, thrust plates, and normal fault blocks along the north-central Wasatch Mountains. Much of this conglomerate is somewhat analogous in structural setting, type of source rock, and environment of deposition to the gold-bearing Pinyon Conglomerate of northwestern Wyoming (Antweiler and Love, 1967). The rocks in northeastern Utah were sampled to determine if the formations contain placer gold similar to that in the Pinyon Conglomerate and if the source rocks might contain unrecognized pre-lower Tertiary deposits of gold coarse enough to form placer deposits.

Sampling was restricted to the area of northern Utah shown on the relief map (fig. 1), where conglomerate is the dominant rock in the sequence studied. Heavy minerals in the conglomerate were concentrated by panning 13,000 to 15,000 grams, or about 30 pounds, of disaggregated pebbles and finer detritus from exposures of conglomerate or from stream sediment derived from the conglomerate. The weight of the original sample generally exceeded 15,000 grams; all cobbles and boulders were removed before panning. The weight of heavy minerals with specific gravity greater than 3.0 retained in the concentrates was generally less than 3 grams. No significant amounts of gold were found in the concentrates from any of the samples. About 170 samples were panned during the study; of these, 150 were from the Wasatch, Evanston, and Echo Canyon Formations. The remaining samples were gravel from metamorphic and quartzitic rocks of Precambrian age and from conglomerates younger than the Wasatch Formation. Distribution of the Echo Canyon, Evanston, and Wasatch Formations in part of northern Utah and sample localities are shown on plate 1. The extent of the Evanston Formation and undivided Wasatch and Evanston Formations, as shown on plate 1, is based on detailed mapping in the Devils Slide, Morgan, and Causey Dam 7½-minute quadrangles and in the northeast quarter of the Morgan 15-minute quadrangle, but on reconnaissance mapping elsewhere. The quality of reconnaissance mapping is fair along lower Lost Creek but poor in other areas. No work was done along Lost Creek above the junction at Killfoil Creek. The presence of Evanston Formation in the

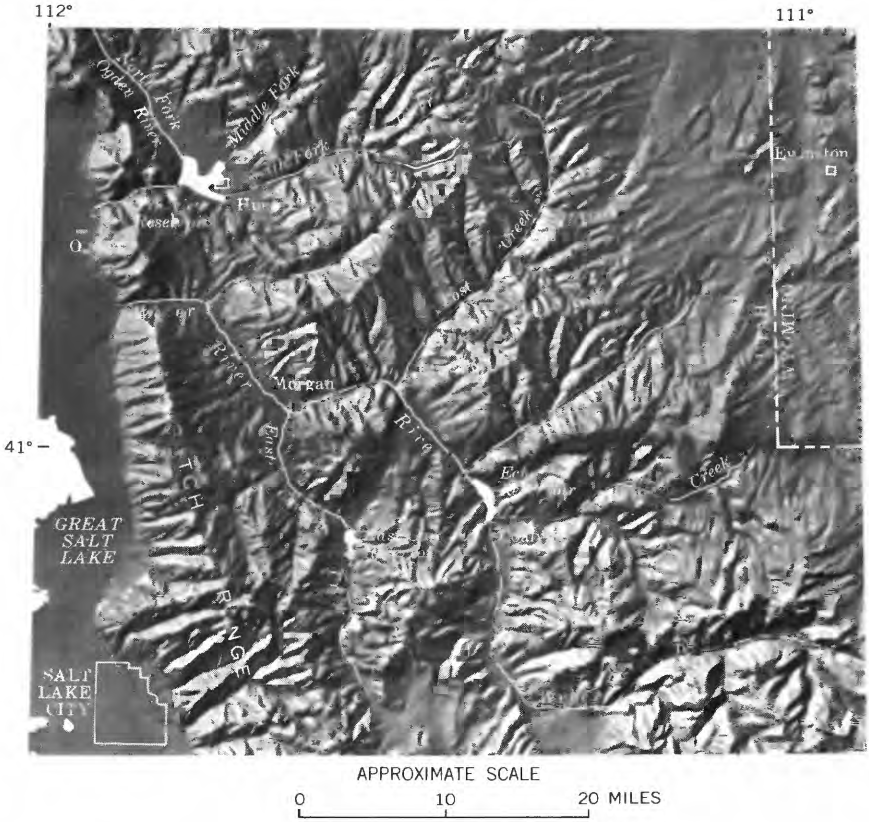

Figure 1.—Relief map of part of northern Utah.

unit shown as Wasatch and Evanston Formations in this area is inferred from relations observed along lower Lost Creek and in the Causey Dam quadrangle.

PURPOSE OF REPORT

Information gathered in sampling the conglomerate sequence for gold is of two types: that from general reconnaissance study of the distribution and composition of subdivisions of the sequence and that from study of heavy minerals retained in pan concentrates of outcrop samples and stream sediment derived from the conglomerates. The purpose of this report is to summarize the reconnaissance information obtained, with emphasis on distribution and gross composition of subdivisions of the conglomerate. Previous studies have tended to classify the entire sequence as Tertiary or to recognize only one Cretaceous unit at the base. Reconnaissance shows that rocks similar to and correlative with the Upper Cretaceous and Paleocene Evanston Formation of southwestern Wyoming are present in much of the area studied. The Evanston lies above a unit locally recognized as Cretaceous by previous authors and forms the lower part of rocks variously referred to as Knight, Fowkes, Almy, and Wasatch Formations. Recognizing rocks equivalent to the Evanston Formation allows a more correct correlation of conglomeratic units in northern Utah as well as correct correlations to conglomerates in southwestern Wyoming. The results of the study of pan concentrates are mainly negative. The conglomerates contain no significant quantities of gold, and heavy minerals retained in pan concentrates are of slight value in correlating units or in determining provenance.

Although based mainly on reconnaissance study, the observations on distribution and gross composition of subdivisions in the conglomerate sequence are reported in some detail. These observations, it is hoped, will furnish a starting point for future work which eventually may relate the subdivisions to specific thrust and block faults in north-central Utah. Relating orogenic conglomerates to specific faults or times of faulting, however, requires much information (Oriel and Armstrong, 1966, p. 2614–2616) of a type not obtained in a reconnaissance study. Thus, only gross relations between the conglomerates and tectonic events will be mentioned here.

PREVIOUS WORK

The conglomerate sequence discussed here has not been of primary interest in most work in northern Utah, but several geologists have studied it and have contributed to knowledge of these rocks. The sequence was first assigned to the Tertiary Wasatch Group by Hayden (1869); indeed, Echo Canyon was one of the localities mentioned in the initial definition of that unit. The presence of both Cretaceous and Tertiary strata was recognized by S. F. Emmons (in King, 1877, p. 334) and by King (1878, analytical geological map III). Much of the conglomerate sequence in the north-central Wasatch Mountains was mapped and described by Eardley (1944, p. 842–845, pl. 1), who assigned the entire sequence to the Tertiary. The Upper Cretaceous and lower Tertiary conglomerates near Salt Lake City were mapped and described, but not named, by Granger and Sharp (1952, p. 15–16) and Granger (1953, p. 5, pl. 2).

The basal unit in the conglomerate sequence studied was defined as the Echo Canyon Conglomerate from exposures near the mouth of Echo Canyon and was dated as Late Cretaceous by Williams and Madsen (1959). Rocks above the Echo Canyon Conglomerate were assigned to the Eocene Knight Formation by Williams and Madsen. In their 1959 paper, Williams and Madsen mentioned a paper in preparation that would give details of Upper Cretaceous and lower Tertiary stratigraphy, but the paper has not been published to date. Part of the Lost Creek–Echo Canyon area was mapped by Madsen (1959), and he assigned rocks above the Echo Canyon Conglomerate to the Knight Formation. In the Devils Slide quadrangle, rocks immediately above the Echo Canyon Conglomerate were recognized by Mullens and Laraway (1964) as probable equivalents of the Upper Cretaceous and Paleocene Evanston Formation instead of the Knight Formation. The Evanston Formation was defined by Veatch (1906, p. 332) as the rocks that directly underlie the Wasatch Formation and overlie the Cretaceous Bear River Formation and Jurassic beds in part of southwestern Wyoming. Trexler (1966, p. 51–59, pl. 1), whose fieldwork was done in 1947–48, was concerned mainly with older Cretaceous rocks; but he mapped the Pulpit Conglomerate, which he considered to be probably of Late Cretaceous age (fig. 2), and he identified but did not map four units in the overlying rocks that he assigned to the Knight Formation. The Pulpit Conglomerate of Trexler is the Echo Canyon Conglomerate of this report; the lower two units of the Knight described by Trexler make up the Evanston Formation, and the upper two, the Wasatch Formation of this report. The conglomerate sequence in the Morgan and Causey Dam 7½-minute quadrangles and in the northeast quarter of the Morgan 15-minute quadrangle was mapped (Mullens and Laraway, 1967; Mullens and Cole, 1967; and Mullens, 1969), but no text report on the sequence was prepared for these areas.

Evolution of nomenclature for the conglomerate sequence along lower Echo Canyon, East Canyon Reservoir, and lower Lost Creek is shown in figure 2. Reasons for assigning rocks above the Evanston Formation to the Wasatch Formation instead of to the Knight Formation are discussed on page D16.

<table>
<tr><th colspan="6">LOWER ECHO CANYON</th></tr>
<tr><th>HAYDEN (1869)</th><th colspan="2">EARDLEY (1944)</th><th>TREXLER (1966)</th><th>WILLIAMS AND MADSEN (1959); STOKES AND MADSEN (1961)</th><th>THIS REPORT</th></tr>
<tr><td rowspan="4">Wasatch Group (Tertiary)</td><td colspan="2">Knight(?) Formation (Eocene)</td><td rowspan="2">Knight Formation (Paleocene ? and Eocene)</td><td rowspan="2">Knight Formation (Eocene)</td><td>Wasatch Formation (Paleocene and Eocene)</td></tr>
<tr><td rowspan="3">Almy Formation (Paleocene)</td><td>Saw Mill Conglomerate</td><td>Evanston Formation (Upper Cretaceous and Paleocene)</td></tr>
<tr><td colspan="4">ANGULAR UNCONFORMITY</td></tr>
<tr><td>Pulpit Conglomerate</td><td>Pulpit Conglomerate (Cretaceous ?)</td><td>Echo Canyon Conglomerate (Cretaceous)</td><td>Echo Canyon Conglomerate (Upper Cretaceous)</td></tr>
</table>

FIGURE 2.—Nomenclature chart for Upper Cretaceous and lower Tertiary
Lost Creek,

<table>
<tr><th colspan="3">EAST CANYON RESERVOIR</th><th colspan="3">LOWER LOST CREEK</th></tr>
<tr><th>EARDLEY (1944)</th><th>STOKES (1963)</th><th>THIS REPORT</th><th>EARDLEY (1944)</th><th>STOKES AND MADSEN (1961)</th><th>THIS REPORT</th></tr>
<tr><td>Knight(?) Formation (Eocene)</td><td rowspan="2">Knight Formation (Eocene)</td><td>Wasatch Formation (Paleocene and Eocene)</td><td rowspan="2">Almy Formation (Paleocene)</td><td rowspan="2">Knight Formation (Eocene)</td><td>Wasatch Formation (Paleocene and Eocene)</td></tr>
<tr><td>Fowkes(?) Formation (Paleocene)</td><td>Evanston Formation (Upper Cretaceous and Paleocene)</td><td>Evanston Formation (Upper Cretaceous and Paleocene)</td></tr>
<tr><td>Almy Formation (Paleocene)</td><td>Echo Canyon Conglomerate (Cretaceous)</td><td>Echo Canyon Conglomerate (Upper Cretaceous)</td><td colspan="3">Echo Canyon Conglomerate (absent)</td></tr>
</table>

conglomerates at lower Echo Canyon, East Canyon Reservoir, and lower northern Utah.

STRATIGRAPHY

The Echo Canyon, Evanston, and Wasatch Formations are separated by major unconformities, and the formations range widely in thickness as well as in abundance, size, and composition of clasts. All the formations contain abundant conglomerate in the area of study, but they grade eastward to a fine-grained facies. Because of the original purpose of work in this area—to sample for placer gold—most of the information is from the conglomerates rather than the finer grained rocks. The conglomerate beds were deposited in and near tectonically active areas. In general, the dominant source area was in the north-central Wasatch Mountains, and the dominant direction of transport was from west to east. The source area contained gneiss, schist, quartzite, carbonate rock, sandstone, and shale, which ranged in age from Precambrian to Late Cretaceous.

Shortly before or during the deposition of the Echo Canyon and Evanston Formations, the source area was deformed by the Nebo-Charleston-Willard thrust system (Crittenden, 1969; Mullens and Crittenden, 1969). To some extent, clasts can be related to the autochthonous and allochthonous rocks of the Willard thrust, which is present in the northwestern part of the report area (pl. 1). The allochthon of the Willard fault includes several thousand feet of red, purple, and green quartzite of Precambrian and Early to Middle Cambrian age (Crittenden, 1968). In contrast, the autochthon includes about 1,000 feet of dominantly tan quartzite of Early and Middle Cambrian age, the Tintic Quartzite. The Tintic rests on gneisses and schists of the Precambrian Farmington Canyon Complex of Eardley and Hatch (1940, p. 61) that are not known in the allochthon. An abundance of red, purple, and green quartzite clasts in the conglomerates indicates a probable ultimate source from the allochthon. Clasts from the gneiss and schist of the Farmington Canyon Complex are not durable, and therefore the absence of such clasts cannot be used as evidence that the autochthon did not contribute to the conglomerate. Post-Middle Cambrian rocks in both allochthon and autochthon do not contain unique lithologies that would enable clasts derived from these rocks to be directly related to thrust sheets.

Brown and gray beds in the upper part of the Evanston Formation form a distinctive unit in the otherwise generally reddish-brown sequence of conglomerate and help to separate the underlying Echo Canyon and lower part of the Evanston from the overlying Wasatch Formation in the Echo Canyon, Lost Creek, Chalk Creek, and East Canyon Reservoir areas. The relation of the three formations to conglomerates exposed near Salt Lake City is imprecisely known, and the conglomerates along the South Fork of the Ogden River lack distinctive features for subdivision. The following generalized descriptions are based mainly on exposures in which the distinctive beds in the upper part of the Evanston are present.

ECHO CANYON CONGLOMERATE

The Upper Cretaceous Echo Canyon Conglomerate was named and described by Williams and Madsen (1959, p. 123–125) as the basal 3,100 feet of the conglomerate exposed near the mouth of Echo Canyon. These authors did not establish an exact type section; therefore, the exposures in sections 18, 19, and 30, T. 3 N., R. 5 E., Summit County, Utah, are here designated as the type section. The lower half of the formation is well exposed along the northeast side of Echo Canyon Reservoir in section 30; the upper half is well exposed in the north side of Echo Canyon in sections 18 and 19. At the type section, the Echo Canyon conformably overlies the Upper Cretaceous Wanship Formation of Williams and Madsen (1959, p. 123) and unconformably underlies the Upper Cretaceous and Paleocene Evanston Formation. The Echo Canyon Conglomerate is of Late Cretaceous age, probably Montana according to Williams and Madsen (1959, p. 125). Near Croydon, the Echo Canyon is 1,400 feet thick; and near East Canyon Reservoir, it is more than 1,500 feet thick.

The Echo Canyon is dominantly reddish brown and forms bold cliffs. In exposures near the mouth of Echo Canyon, the formation is mainly conglomerate but includes sandstone and mudstone beds. Fossils, including *Inoceramus* and brackish-water mollusks collected from fine-grained beds near the mouth of Echo Canyon, indicate that this part of the formation was deposited in or near a sea (Madsen, 1959). Clasts in the conglomerate range in size from pebbles to small boulders, and more than 60 percent by volume are subangular to rounded fragments of carbonate rock, sandstone, and siltstone. Most of the remaining clasts are rounded cobbles and small boulders of tan and pink quartzite that resembles the quartzite in the Cambrian Tintic and Pennsylvanian Weber Quartzites of the autochthon of the Willard fault. The roundness of the quartzite boulders possibly indicates that they were derived mainly from conglomerates in the Upper Cretaceous Frontier Formation, which is exposed several miles west (Granger, 1953, p. 4–5), instead of directly from outcrops of Weber and Tintic. A few purple and green quartzite clasts that may be derived from Cambrian and Precambrian quartzite formations of the allochthon are also present. Five miles above the mouth of Echo Canyon, more than 75 percent of the clasts in the Echo Canyon Conglomerate are rounded pebbles, cobbles, and small boulders of tan and pink quartzite, which were derived mainly from the Tintic and Weber Quartzites. The eastward enrichment in quartzite probably reflects the greater resistance of quartzite to chemical decomposition and mechanical abrasion than of sandstone, shale, and carbonate clasts.

Westward, in exposures extending from south of East Canyon Reservoir to Croydon, Utah, the Echo Canyon is cobble and large-boulder conglomerate and contains only scattered beds of finer material. In these exposures, the clasts are angular to subrounded, and about 70 percent of them are dolomite, limestone, and sandstone, which were derived from Paleozoic and Mesozoic formations. The remaining 30 percent of the clasts are quartzite boulders, which were derived about equally from the Pennsylvanian Weber Quartzite and the Cambrian Tintic Quartzite, although a few may have been derived from older quartzites. Most of the clasts are less than 18 inches in long dimension, but boulders as much as 14 feet long were observed in the basal part of the Echo Canyon where the Echo Canyon overlies Jurassic(?) and Triassic(?) Nugget Sandstone and Jurassic Twin Creek Limestone. In general, the distribution of clasts in the Echo Canyon along the Croydon–East Canyon Reservoir belt is a good example of inverted stratigraphy: clasts from younger rocks are common at the base and clasts from older rocks are more abundant at the top. No fossils have been found in this belt of outcrop, but I interpret the Echo Canyon here to have been deposited in a terrestrial environment.

Near Echo Canyon Reservoir, the Echo Canyon overlies Upper Cretaceous rocks with apparent conformity; but in the westward exposures, it overlies beveled edges of steeply tilted Cretaceous, Jurassic, Triassic, and upper Paleozoic rocks. The original westward extent of the Echo Canyon is not known. Probably the formation was deposited at least several miles west of the westernmost preserved exposures, but this part of the formation was removed by pre-Evanston and pre-Wasatch erosion. The Echo Canyon is absent along the belt of outcrop extending from Henefer to Croydon, where it probably was deposited but eroded before deposition of the Evanston Formation.

The scarcity in the Echo Canyon Conglomerate of red, purple, and green quartzite clasts typical of older rocks in the allochthon of the Willard thrust fault shows that the allochthon furnished little debris to the Echo Canyon that is preserved. It was not determined, however, if the lack of such quartzite was due to the Echo Canyon being older than major movement on the fault system or due to shallow erosion that did not expose the distinctive quartzite in the allochthonous block during deposition of the Echo Canyon.

The Echo Canyon is equivalent to the Cretaceous conglomerate of Granger (1953, p. 5) in the Salt Lake City area and to the Pulpit Conglomerate of Eardley (1944, pl. 1) and Trexler (1966, pl. 2) along Echo Canyon. These rocks are shown correctly as Echo Canyon on the northwest quarter of the State geologic map (Stokes, 1963) and on the northeast quarter of the State geologic map (Stokes and Madsen, 1961). The Echo Canyon is equivalent to the Almy Conglomerate that Eardley (1944, pl. 1) mapped southwest of Croydon, but the belt of outcrop extends southwest from Croydon to East Canyon Reservoir instead of being restricted to the East Canyon Reservoir area, as shown by Stokes (1963). No Echo Canyon was identified north of Croydon and, if deposited there, it was eroded before deposition of the Evanston Formation. Rocks west, north, and east of Croydon that Eardley (1944, pl. 1) included in his Almy Formation are equivalent to the Evanston and Wasatch Formations of this report.

EVANSTON FORMATION

The Evanston Formation was named by Veatch (1906, p. 332) for exposures near Evanston, Wyo., about 10 miles east of the area shown on plate 1. Near Evanston, the Evanston Formation underlies Veatch's Almy Formation of the Tertiary Wasatch Group and unconformably overlies the Cretaceous Bear River Formation and Jurassic beds. The Evanston Formation of the Fossil basin in southwestern Wyoming about 30 miles northeast of the area shown on plate 1 was studied in detail by Oriel and Tracey (1970). The extension of Evanston as a formation name to northern Utah is based largely on the work done by Oriel and Tracey and on field conferences with them in intervening areas.

The Evanston is zero to about 1,400 feet thick in northern Utah. A twofold division of the Evanston, a basal conglomerate and an upper finer grained unit, is recognizable locally. Possibly this basal conglomerate is equivalent to the Hams Fork Conglomerate Member of the Evanston Formation of the Fossil basin in southwestern Wyoming as described by Oriel and Tracey (1970).

The basal conglomerate is well exposed along parts of Lost Creek, along lower Echo Canyon, and in the upper reaches of Chalk Creek. It is absent from Croydon to East Canyon Reservoir and has not been identified in the unit shown as Wasatch and Evanston Formations along upper Lost Creek and the South Fork of the Ogden River. The basal conglomerate consists of rounded gray, red, purple, green, and tan quartzite cobbles and small boulders and minor amounts of carbonate cobbles and pebbles. The clasts are mainly in a matrix of rounded to angular quartz grains and angular dark-gray chert grains. Most of the quartzite clasts were derived from Cambrian and Precambrian quartzites of the allochthon of the Willard fault. The conglomerate seems to thin from east to west and tends to be reddish brown in the western exposures and gray to grayish yellow in eastern exposures. For example, at the mouth of Guilder Sleeve Canyon, the conglomerate is about 230 feet thick, is reddish brown, and contains several interbeds of sandstone and much dark-gray chert in the matrix. Eastward, in Toone Canyon, the conglomerate is about 500 feet thick, weathers to a light-colored band, and contains fewer interbeds of sandstone; and dark-gray chert is less conspicuous in the matrix.

The upper finer grained part of the Evanston is as much as 1,000 feet thick and typically forms a shaly to ledgy slope. Along Echo Canyon, Lost Creek, and upper Chalk Creek, it consists of interbedded conglomeratic grit, gray silty micaceous sandstone, gray mudstone, and minor beds of quartzite conglomerate and carbonaceous shale. Thin beds of coal are exposed in the Evanston along Lost Creek and in Toone Canyon. The combination of brown-weathering grit and gray mudstone makes the upper part of the Evanston a distinctive unit in an otherwise generally reddish-brown sequence of conglomerate and conglomeratic sandstone. Much of the brown color is caused by oxidation of the abundant iron sulfide concretions in the grit and sandstone. The grit is composed of very fine to granule-sized angular grains of quartz, dark-gray chert, and other rock fragments. The abundant granule-sized quartz probably was derived from the Precambrian Farmington Canyon Complex of Eardley and Hatch (1940) in the autochthon of the Willard fault. The chert probably was derived from middle and upper Paleozoic cherty carbonate units. Clasts in the conglomeratic sandstone are mainly pebble sized, but cobbles and small boulders are common. About three-fourths of the pebbles are angular fragments of black chert. Most of the other pebbles and larger clasts are rounded quartzite from Cambrian and Precambrian formations in the allochthon. These quartzite clasts could have been derived directly from outcrops of these formations or they might have been reworked from the basal conglomerate of the Evanston.

Mapping was not carried out along the main stem of Lost Creek above Killfoil Creek, and the presence of Evanston in the unit shown as Wasatch and Evanston Formations undivided (pl. 1) in upper Lost Creek is extrapolated from exposures in Killfoil Creek and in the Causey Dam quadrangle. In the upper reaches of Killfoil Creek, the upper unit of the Evanston grades laterally into a reddish-brown conglomeratic sandstone that contains a few sandy siltstone zones, scattered carbonaceous material, and very little chert. These beds greatly resemble the overlying Wasatch Formation.

In the Causey Dam quadrangle, the Evanston cannot be separated consistently from the overlying Wasatch Formation (Mullens, 1969). In the southern part of the quadrangle, gray silty beds typical of the Evanston that contain pollen indicative of a Late Cretaceous age are interbedded with reddish-brown rounded cobble conglomerate and conglomeratic sandstone that are more typical of the overlying Wasatch. In addition, in the southeastern and northwestern parts of the quadrangle, conglomerate composed of angular fragments of Mesozoic and Paleozoic limestone, dolomite, and sandstone forms the base of the sequence shown as Wasatch and Evanston Formations undivided (pl. 1). This conglomerate is not similar to other conglomerates in the Evanston Formation in northeastern Utah, but it may be equivalent to the basal Evanston conglomerate elsewhere, or possibly to the Echo Canyon Conglomerate or older rocks. The conglomerate in the southeastern part of the quadrangle is mappable, and it underlies the interbedded sequence of mixed Wasatch and Evanston aspect. Exposures in the northwestern part of the quadrangle are too poor to permit determination of the lateral relation of the angular-fragment conglomerate, but the conglomerate seems to intertongue with the rounded-cobble conglomerate and the conglomeratic sandstone beds. The angular-fragment conglomerates represent local areas of deposition, and the time of deposition cannot be exactly determined.

Gray-weathering sandy siltstone, sandy claystone, and thin beds of pebble-and-cobble conglomerate make up most of the Evanston Formation exposed west of Echo Canyon. Near East Canyon Reservoir, the Evanston is about 800 feet thick and consists of thinly bedded gray carbonaceous siltstone and claystone and scattered beds of brown-weathering grit. Eardley (1944, p. 844) believed that these rocks (his Fowkes(?) Formation) contain much highly altered volcanic ash of probable rhyodacitic composition.

Pollen indicative of a Late Cretaceous (Lance) age was identified by Estella Leopold (written commun., March 27, 1963) from samples of the upper unit of the Evanston from sec. 3, T. 2 N., R. 3 E., Morgan County, Utah. Pollen indicative of a Late Cretaceous age, identified by Robert Tschudy (written commun., May 9, 1967), was collected from beds of Evanston aspect in undivided Evanston and Wasatch Formations in sec. 13, T. 6 N., R. 3 E., Causey Dam quadrangle, Weber County, Utah. A Paleocene age is assumed for some of the upper unit of the Evanston because Rubey, Oriel, and Tracey (1961) and Oriel and Tracey (1970) reported Paleocene fossils from the upper unit of the Evanston in southwestern Wyoming. Ten-Chien Yen (in Trexler, 1966, p. 58–59) believed that fresh-water gastropods collected from the upper unit of the Evanston (part of the Knight

Formation as used by Trexler) indicated an Eocene or possible Paleocene age for the rocks along Chalk Creek.

In general, the Evanston overlies the Echo Canyon Conglomerate with slight angular discordance, but locally the discordance is as much as 30°. The angular discordance between the formations is well exposed along the north side of Echo Canyon about 5 miles above the mouth of the canyon. Probably 1,500–3,000 feet of the Echo Canyon was removed before the Evanston was deposited in the band of outcrop extending from Henefer to Croydon. The Evanston overlies older Mesozoic and Paleozoic rocks with great angular discordance. The Evanston Formation has not been found in contact with Precambrian rocks, but it may have been deposited on the Precambrian Farmington Canyon Complex of Eardley and Hatch (1940, p. 61) along the southwestern part of Morgan Valley, where Evanston strata were eroded and overlapped by the Wasatch. On the divide between Killfoil Creek and the South Fork of the Ogden River, flat-lying conglomerate that contains beds typical of the upper part of the Evanston overlies lower Paleozoic rocks and possibly unexposed Cambrian and Precambrian quartzites of the allochthon of the Willard fault.

The abundance of purple, red, and green quartzite clasts in the basal conglomerate of the Evanston is interpreted to represent a major contribution of debris transported eastward from the allochthon of the Willard thrust system. This interpretation ignores a possible southeastern source of purple, red, and green quartzite clasts from Precambrian quartzite in the Uinta Mountains about 15 miles southeast of the area shown on plate 1. Information obtained during the study is not sufficient to evaluate a southeastern source for the quartzite clasts, but pebble counts by Eardley (1944, p. 843) show that 90 percent of the quartzite clasts in the basal conglomerate (his Saw Mill Conglomerate) exposed in Echo Canyon are characteristic of Precambrian formations of the northern Wasatch Range. Eardley doubted that any of the quartzite clasts were derived from a southeastern (Uinta Mountains) source. The abundance of quartz grit, probably derived from the Farmington Canyon Complex in the upper part of the Evanston, indicates a major contribution from the autochthon of the Willard fault for that part of the formation. Stratigraphic and structural relations of rocks exposed in the Causey Dam quadrangle and vicinity indicate that major movement on the Willard fault ceased before the deposition of some Upper Cretaceous beds in the upper part of the Evanston (Mullens and Crittenden, 1969).

Evanston strata in northern Utah have been distinguished from other conglomerate units and have been variously designated. The exposures near East Canyon Reservoir, for example, were assigned by

Eardley (1944, p. 844) to the Fowkes(?) Formation on the basis of their position between red beds below, which he assigned to the Almy, and red beds above, which he assigned to the Knight(?) Formation. Exposures of the Evanston along Lost Creek were included by Eardley (1944, pl. 1) in the Almy Formation, and those along Echo Canyon were included in the Saw Mill Conglomerate, which, according to him, was equivalent to the upper part of the Almy. The basal conglomerate and the upper unit of the Evanston along Chalk Creek were designated by Trexler (1966, p. 56–59) as the lower two of the four subdivisions he assigned to the Knight Formation. Evanston strata were not distinguished by Williams and Madsen (1959) and were included in their Knight Formation.

Except for outcrops near Salt Lake City, all rocks shown as Evanston Formation on plate 1 are included as part of the Knight Formation on the State geologic map (Stokes, 1963; Stokes and Madsen, 1961).

Data are inadequate for precise correlation of the Evanston Formation with rocks in the Salt Lake City area. Patches of Evanston Formation shown near Salt Lake City on plate 1 represent a tentative correlation of the basal Evanston conglomerate of the Lost Creek–Echo Canyon area with the Tertiary conglomerate No. 1 of Granger (1953, p. 5, pl. 2). This conglomerate is included as part of the unit shown as unnamed conglomerates of uncertain age on the State geologic map (Stokes, 1963). The tentative correlation is based on the similarity of clasts; both the basal Evanston and the Tertiary No. 1 conglomerates contain abundant quartzite clasts derived from the Cambrian and Precambrian quartzite formations. Another possible correlation of the Tertiary conglomerate No. 1 of Granger is discussed below.

The upper unit of the Evanston is tentatively correlated with the Tertiary limestone and andesite units of Granger (1953, p. 5) that overlie the Tertiary conglomerate No. 1 near Salt Lake City. The limestone is included with the unnamed conglomerates of uncertain age of the State geologic map (Stokes, 1963), and the andesite is included with the lower Tertiary andesite-trachyte-latite pyroclastics of the State map (Stokes, 1963). Basis for this proposed correlation is the similarity of stratigraphic sequence and the content of abundant altered volcanic ash, as suggested by Eardley (1944, p. 848), in the Evanston (Eardley's Fowkes(?) Formation) at East Canyon Reservoir. The Tertiary limestone and andesite units of Granger overlie a conglomerate that contains abundant quartzite debris, and they underlie a conglomerate that is not involved in the major folding. Granger (1953, p. 5) provisionally correlated the uppermost conglomerate with the Knight(?) Formation as used by Eardley (1944), which is the

Wasatch Formation of this report. Possibly, the thin-bedded siltstone of the Evanston exposed at East Canyon Reservoir is a facies of this limestone and andesite unit.

Heylmun (1965, p. 12–13) suggested that the andesite unit of Granger (1953) correlates with Eocene and younger tuffaceous rocks that overlie the Wasatch Formation in Morgan Valley. If Heylmun's suggested correlation is correct, correlation of the conglomerates that underlie and overlie the limestone and andesite units near Salt Lake City must be reconsidered. Evanston equivalents possibly are absent from the Salt Lake City area. The underlying conglomerate (Tertiary conglomerate No. 1 of Granger) could correlate with the Wasatch Formation. The conglomerate that overlies the limestone and andesite could correlate with conglomerates much younger than the Wasatch Formation. A conglomerate that resembles some conglomerates in the Wasatch overlies tuffaceous sediments of Oligocene and Eocene age and forms the upper part of the Salt Lake Formation in the Morgan quadrangle (Mullens and Laraway, 1967).

WASATCH FORMATION

The Wasatch Formation was named by Hayden (1869, p. 91) for Wahsatch, a station on the Union Pacific Railroad in Echo Canyon. The name Wasatch is used here for beds that have been included as part of the Knight Formation in recent reports. The term "Knight" is not used because the rocks are not well enough known to justify the refinement of stratigraphic knowledge implied by use of the term. The Knight originally was defined as the upper dominantly fine grained formation of the Wasatch Group of Veatch (1907, p. 88), which included the Fowkes Formation, presumably in the middle, and the dominantly conglomeratic Almy Formation at the base. The Knight Formation, according to Veatch, consists mainly of reddish-yellow sandy clays and irregular sandstone beds. The Fowkes Formation, however, overlies the Knight, according to Eardley (1959, p. 167) and Tracey and Oriel (1959, p. 129) ; and the separation of the Almy and Knight consistently is difficult to make even near the type localities. Oriel and Tracey (1970, p. 16) stated: "there is no basis for separating the Almy and Knight Formations except * * * [as] peripheral and basinal facies of the Wasatch Formation * * *." Because the rocks in Utah have not yet been separated into basinal (Knight) and peripheral (Almy) facies, the name Wasatch is preferred.

At Wahsatch, the Wasatch is mainly variegated mudstone and scattered beds of conglomerate and conglomeratic sandstone. These rocks are similar to the basinal facies of Oriel and Tracey (1970).

Westward, the thickness and conglomerate content of the Wasatch increase, the variegated mudstone changes to reddish-brown mudstone, and a few beds of silty pale-red limestone and gray algal limestone are present. The conglomeratic facies of the Wasatch Formation in northern Utah is similar to the peripheral facies of the Wasatch of the Fossil basin area described by Oriel and Tracey. The distribution of the rock types in the conglomeratic facies varies both laterally and vertically, and the Wasatch is the most heterogeneous formation in the sequence. The most persistent property of the Wasatch west of Wahsatch is its general reddish-brown tint. Because of the lateral and vertical variation, the following descriptions are tied to specific areas.

Along the western tributaries of Lost Creek from Croydon to Hell Canyon, the Wasatch contains a conspicuous basal reddish-brown boulder conglomerate 500–1,000 feet thick. This conglomerate grades upward to interbedded reddish-brown conglomerate and sandstone that contains scattered lenses of conglomerate. Rocks above the conglomerate and sandstone interval are not well exposed, but scattered outcrops indicate that the uppermost Wasatch beds consist of reddish-purple mudstone and pale-red silty limestone intermixed with beds of large-boulder conglomerate. The total preserved thickness of Wasatch in this area is about 3,000 feet, but the original thickness is not known. The uppermost rocks cap a flat of about 50 square miles, which is part of the Herd Mountain surface of Eardley (1944, p. 873–874). This flat is strewn with quartzite boulders as much as 8 feet in diameter. Eardley (1944, p. 873) thought that the large boulders were part of a pediment surface much younger than the Wasatch Formation. I believe, however, that the surface was caused by the winnowing of fine materials from nearly flat lying coarse conglomerate; the residual quartzite boulders form a resistant surface parallel to bedding.

Westward, in Cottonwood, Sheep Herd, Bennett, and Magpie Creeks, which drain the west and northwest flank of the Herd Mountain surface, the Wasatch probably contains a basal conglomerate similar to that exposed along the west side of Lost Creek. This inference is based on the boulder float covering the west side of the Herd Mountain surface. Clasts in the float range in diameter from a few inches to 15 feet. The great range in size of clasts indicates that the basal conglomerate in the western drainage may be similar to the diamictite facies in the Wasatch reported by Tracey, Oriel, and Rubey (1961) about 30 miles northeast of the area shown on plate 1.

The basal conglomerate consists dominantly of rounded pink, purple, and green quartzite clasts derived from the Cambrian and Precambrian quartzites. It also includes many tan quartzite clasts derived from the Pennsylvanian Weber Quartzite, as well as dolomite, limestone, and sandstone derived from other Paleozoic rocks and from Mesozoic rocks. The average diameter of the clasts is about 6 inches, and the maximum is about 24 inches in the Lost Creek tributaries. In the western drainage, float indicates that the average diameter of the clasts is about 20 inches, although boulders 6–8 feet in diameter are common, and a few 15-foot boulders are present where the conglomerate overlies or is near the Cambrian and Precambrian quartzites exposed east of Huntsville. Conglomerate in the basal part of the Wasatch generally has a matrix of sand and silt, and much of it is poorly sorted. Locally, the conglomerate resembles a consolidated alluvial fan, except for the general roundness of the quartzite clasts.

Conglomerates interbedded with sandstone and mudstone above the basal conglomerate are of two types. The first is a rounded quartzite-clast conglomerate that contains little silt or clay in the matrix. The second contains poorly sorted angular fragments of dolomite, limestone, shale, and sandstone set in a matrix that contains abundant silt and clay.

From Morgan to near East Canyon Reservoir, the Wasatch is mainly reddish-brown interbedded conglomerate, conglomeratic sandstone, and mudstone. Scattered beds of pale-red silty limestone and gray algal limestone as much as 15 feet thick are present locally. In this area, the Wasatch is about 5,000 feet thick; it unconformably overlies older rocks and, in turn, is unconformably overlain by the upper Eocene rocks assigned to the lower part of the Norwood Tuff. Conglomerates in this area range in thickness from a few feet to 200 feet, and most have a matrix that contains abundant sand, silt, and clay. Clasts in the conglomerate are dominantly rounded quartzite derived from the Weber, Tintic, and older quartzites, but they include much limestone, dolomite, and sandstone from Mesozoic and Paleozoic formations. The clasts average about 2 inches in diameter, but some as large as 18 inches in diameter are common locally. Angular clasts of gneiss derived from the Precambrian Farmington Canyon Complex of Eardley and Hatch (1940) are common where the Wasatch directly overlies the Farmington Canyon. These clasts, however, are not durable and form only a small part of the granule and larger sized material in the Wasatch a mile away from Farmington Canyon outcrops.

The extent of the Wasatch southwestward from East Canyon Reservoir is not definitely known. The Wasatch in this area probably is the same unit that Granger (1953, p. 5) mapped as the Tertiary conglomerate No. 2 near Salt Lake City. (See pages D15–D16.) The conglomerate near Salt Lake City is several thousand feet thick, consists of a heterogeneous mixture of clasts derived from all older formations, and is not involved in the major structures (Granger, 1953, p. 5). In general, the conglomerate is poorly sorted and was derived from nearby areas. Many of the clasts, particularly those derived from the Tintic and older quartzites, are well rounded. Probably many of these rounded clasts were recycled from older conglomerates. Eastward, toward Coalville, the conglomerate becomes better sorted and contains a higher proportion of quartzite clasts and abundant mudstone interbeds.

In the Coalville–Chalk Creek area, the upper two divisions of Trexler's Knight Formation (1966, p. 58), the Wasatch Formation of this paper, consist of (1) brown-weathering cobble conglomerate that thins southward and (2) overlying red and yellow interbedded claystone and sandstone. Most of the cobbles are well rounded and are sandstone, limestone, dolomite, and quartzite. Much of the quartzite is purple, pink, and green, thus indicating a probable source from Cambrian and Precambrian quartzites, although the clasts might have been recycled from older conglomerates.

Between Lost Creek and Echo Canyon, the basal few hundred feet of the Wasatch is reddish-brown conglomerate and thin, minor beds of reddish-brown partly conglomeratic sandstone and reddish-brown mudstone. This zone grades upward into reddish-brown mudstone that contains thin beds of conglomerate and algal limestone. At Cedar and Toone Canyons, much of the conglomerate near the base is poorly sorted and contains abundant clasts derived from Mesozoic and upper Paleozoic formations, even though it mainly overlies the Evanston Formation. The poorly sorted conglomerate is well exposed in badland topography at the head of Toone Canyon.

The only fossils collected from the Wasatch in northeastern Utah are molds of land and fresh-water gastropods. Most of these gastropods were collected from basal Wasatch exposures half a mile west of Henefer, where the Wasatch overlies Lower Cretaceous and Jurassic beds. In this area, the Evanston and Echo Canyon were removed by erosion before the Wasatch was deposited. The other gastropods were collected in a zone 2,000–4,000 feet above the base of the Wasatch where the Wasatch overlies the Evanston Formation in the southern part of the Morgan 15-minute quadrangle. The gastropods were studied by D. W. Taylor, who reported (written commun., Jan. 16, 1963) that similar gastropods occur in the Green River and Wasatch Formations above the Chappo Member of the Wasatch Formation in

Wyoming. The Chappo Member of the Wasatch is latest Paleocene and earliest Eocene in age (Oriel, 1962, p. 2167). The rocks from which the gastropod molds were collected are not as old as the basal conglomerate exposed along the west side of Lost Creek. No fossils were found in the basal conglomerate, which is probably of Paleocene age.

The Wasatch is unconformably overlain by the Norwood Tuff in the Morgan quadrangle. The lower part of the Norwood exposed just south of the Morgan quadrangle has been dated as latest Eocene by vertebrate fossils (Gazin, 1959, p. 137) and by radiometric dating—37.5 million years B.P. (Evernden and others, 1964, p. 165).

The Wasatch rests unconformably on all older rocks. It overlies all rocks older than the Echo Canyon with great angular unconformity. In most places it overlies the Echo Canyon or Evanston with only slight angular unconformity, but locally the Evanston and Echo Canyon were strongly folded and eroded before the Wasatch was deposited. The Wasatch in northeastern Utah was deposited considerably after the major movement on the Willard thrust had ceased. The relation of source areas to post-thrust fault topography is not known, but the abundance of poorly sorted conglomerate probably indicates that there were many local sources associated with post-thrust folding and block faulting. The results of tectonic activity that was later than deposition of the Echo Canyon Conglomerate and Evanston Formation and before deposition of the latest Wasatch are well displayed near Henefer and at Heiners Creek. The Echo Canyon and the Evanston Formations were deposited in what is now the Henefer Valley along the Weber River and then were elevated and eroded prior to deposition of the latest Wasatch. Along the South Fork of Heiners Creek, the discordance between the Wasatch and the underlying Evanston is 3°–5°. The Evanston is cut out along the unconformity and does not crop out in exposures along Echo Canyon just southeast of the South Fork of Heiners Creek. The results of post-Wasatch tectonic activity are evident along Morgan, Henefer, and Ogden Valleys where the Wasatch is locally strongly folded (dips exceed 30°), but in other places the Wasatch is relatively flat lying.

Most rocks here referred to the Wasatch Formation are included as part of the Knight Formation on the State geologic map (Stokes, 1963; Stokes and Madsen, 1961). The major exception is that some rocks just north of Henefer, here called Wasatch (pl. 1), are shown as part of the Cretaceous Wanship Formation on the State map (Stokes and Madsen, 1961).

HEAVY MINERALS

Thirty of the 150 pan concentrates from the Wasatch, Evanston, and Echo Canyon Formations were searched for possible unique assemblages of minerals of specific gravity of more than 3.0 that might be indicative of provenance or that might be useful in correlating the conglomerates. Most concentrates studied were from outcrop samples, but a few were from stream sediment samples. The minerals found are shown in table 1. Pan concentrates are biased toward a proportionally greater recovery of minerals of high specific gravity than of less dense minerals. For example, a concentrate that contains more than 25 percent magnetite, about 5 percent augite, and no biotite could represent an original sample that had an equal amount of each mineral. Magnetite (specific gravity 5.5–6.5) would be selectively enriched over augite (specific gravity 3.19) because of the difference in specific gravity. Biotite (specific gravity 2.7–3.1) would be completely lost, partly because of lesser specific gravity but mainly because the flakes float or "fishtail" to the top of the load and are washed away. Elongate or angular grains, however, are concentrated more than rounded grains of the same specific gravity because the elongate or angular grains do not roll across the top of the load.

Theobald (1957, fig. 3) indicated that after multiple panning, average recoveries of nonflaky heavy minerals from riffle samples ranges from about 30 percent for minerals with specific gravity of 3.0 to about 80 percent for minerals with specific gravity of 5.0. On first panning, about 60 percent of the minerals with specific gravity of at least 4.0 are recovered from samples that contain little clay or silt to interfere with recovery (Theobald, 1957, p. 21). Most samples from the Wasatch, Evanston, and Echo Canyon contain silt and clay, and therefore the recovery rate for heavy minerals is probably less than that reported by Theobald. I estimate that the minimum recovery of heavy minerals was about 50 percent of the nonflaky minerals with specific gravity of at least 4.0 and about 10 percent of those with specific gravity of 3.0.

The 30 concentrates studied in detail weighed 5–10 grams and contained at least two-thirds light minerals and at most one-third heavy minerals. The heavy minerals shown in table 1 are those that remained after separation in a heavy liquid of specific gravity of 3.0 (a mixture of methyl iodide and bromoform). This specific gravity was used because bromoform (specific gravity 2.8) would not consistently float iron-oxide-stained quartz grains that are abundant in most concentrates. The minerals of less than 3.0 specific gravity were not studied.

TABLE 1.—*Abundance of heavy minerals of greater than 3.0 specific gravity retained in pan concentrates of the Wasatch, Evanston, and Echo Canyon Formations*

[Sample type: O, outcrop sample; S, stream-sediment sample. Mineral abundance estimated as percentage of volume of total heavy minerals: F, flood, more than 50 percent of all grains; M, major, about 20–50 percent; A, abundant, about 5–20 percent; C, common, about 1–5 percent; S, scarce, about 0.1–1.0 percent; T, trace, less than 0.1 percent; ----, absent]

Sample						Black opaque group	Reddish-brown hematite	Garnet	Zircon	Monazite and leucoxene	Tourmaline	Rutile	Sphene	Phosphate pellets	Augite	Hornblende	Chloritoid	Apatite	Barite	Remarks
No.	Locality			Type	Weight (grams)															
	Sec.	T. N.	R. E.																	
Echo Canyon Formation																				
67-73	24	3	4	O	1.0	F	A	S	A	C	C	S	S	C	----	----	S	----	A	
74	24	3	4	O	.7	F	C	C	A	C	C	S	S	----	C	T	----	----	----	Trace kyanite and staurolite.
108	30	4	4	O	.2	M	A	C	M	C	----	S	T	----	T	----	----	----	C	Trace biotite.
Evanston Formation																				
67-9	17	4	4	O	0.2	F	C	A	A	A	S	S	S	----	----	T	A	----	----	Trace biotite.
29	34	5	5	O	1.4	M	----	A	A	A	S	S	T	S	S	----	A	----	----	Trace clinozoisite and scarce xenotime.
30 [1]	33	5	5	O	.4	A	S	C	F	C	S	T	S	S	T	----	C	----	----	
51	23	4	4	O	.1	F	----	----	C	A	T	T	----	C	C	----	T	----	----	Trace pyrite.
66 [1]	5	2	7	O	.1	F	C	A	M	A	S	T	T	A	S	----	S	----	A	
146	6	4	5	S	1.2	F	C	A	A	C	S	S	S	----	C	----	----	T	C	Trace spinel, andalusite, biotite, and pyrite.
149	3	4	4	S	1.1	F	A	C	A	T	T	S	T	C	T	----	T	----	A	Trace pyrite.

Evanston, Wasatch, and Echo Canyon Formations undivided																				
67-71	25	4	5	S	2.8	F	A	C	A	S	C	T	T	A	C	T	A	T	A	
Wasatch Formation																				
67-12	9	4	4	O	4.3	F	A	C	A	A	S	A	C	T	T	T	----	----	A	Trace spinel.
21	17	5	4	O	1.5	F	A	S	A	C	S	T	----	T	S	T	----	S	C	Trace epidote.
22	29	4	4	O	.1	A	C	C	F	C	C	S	T	M	T	----	----	T	----	Trace biotite.
23	29	4	4	O	.3	A	C	A	F	S	C	T	T	A	T	T	----	T	T	Trace azurite.
28	3	4	5	O	2.6	F	A	C	A	C	S	S	S	S	S	T	T	T	S	Trace epidote.
36	24	6	3	O	1.6	M	A	C	A	A	S	S	S	T	----	T	S	----	----	
47	3	6	3	O	1.9	F	A	C	A	C	S	S	S	----	----	T	----	----	----	
48	21	7	3	S	1.6	F	A	C	A	A	S	S	T	T	T	----	----	T	----	Trace biotite.
54	8	3	4	O	.2	A	C	----	A	T	C	S	----	T	C	T	----	----	F	
62	32	5	7	O	.2	A	----	M	A	C	T	S	C	C	----	T	S	T	C	
63	29	5	7	S	1.7	F	C	A	A	T	T	T	S	----	----	----	S	----	A	Trace pyrite.
64	28	4	6	O	.1	M	----	A	A	C	S	S	T	T	S	----	----	----	A	
93	31	4	3	S	1.0	F	A	M	A	S	T	S	T	T	S	----	----	----	A	
94	1	3	2	O	.9	F	A	S	A	S	S	T	S	C	S	T	----	----	A	Do.
96	25	4	2	O	1.6	F	A	C	A	S	----	S	T	T	C	----	----	T	C	Do.
98	17	3	3	S	1.0	F	A	C	A	C	T	S	T	S	C	----	----	S	A	
101	15	3	3	O	3.0	F	A	C	A	A	S	C	S	S	T	T	----	----	C	
104	34	3	2	O	1.8	F	A	A	A	C	T	S	T	S	T	----	----	----	----	
110	33	6	6	O	1.7	F	C	C	C	C	----	----	----	T	T	----	----	T	A	

[1] Basal conglomerate.

The fractions of greater than 3.0 specific gravity in 13 of the concentrates were further separated into five magnetic groups to facilitate identifications and estimates of abundance. The first magnetic susceptibility group was determined by hand magnet; the other four groups were determined by a Frantz magnetic separator with 10° side slope and 15° forward slope set at greater than 0.2 amp, 0.2–0.5 amp, 0.5–1.2 amps, and less than 1.2 amps.

The heavy minerals were studied with binocular and petrographic microscopes to determine the abundance and habit of individual minerals. Minerals that I could not identify under the microscopes were identified either by using a spindle stage (Wilcox, 1959) attached to a petrographic microscope or by X-ray diffraction. The abundance of each mineral was estimated as a percentage of volume of the total concentrate instead of as number of grains or weight. Volume was the easiest abundance parameter to estimate because grains in the concentrates range in size from very fine to granule.

Table 1 shows that black opaque minerals, hematite, garnet, zircon, monazite and leucoxene group, tourmaline, rutile, sphene, phosphate pellets, and augite were found in most concentrates. Hornblende, apatite, chloritoid, and barite occur in slightly less than half the concentrates; and traces of biotite, spinel, pyrite, azurite, epidote, andalusite, kyanite, clinozoisite, staurolite, and xenotime were found in a few. Black opaque minerals form more than half the volume of about two-thirds of the concentrates studied. If, however, the minerals were reported by size fraction, zircon would make up about 65 percent of the very fine grained sand fraction; black opaques and hematite would make up about 99 percent of the coarse sand and larger fraction; and black opaques, hematite, garnet, and the monazite-leucoxene group in about equal abundance would form about 95 percent of the medium sand fraction.

General descriptions of the minerals retained in the concentrates are given below, although—except for chloritoid and possibly hornblende and apatite—the minerals were not useful in determining provenance or for correlating the conglomerates.

Black opaque grains that are mainly hematite but include magnetite and ilmenite partly altered to hematite form more than half of most concentrates. The abundance of these grains in the samples probably indicates that hematite, magnetite, and ilmenite are moderately abundant in the conglomerates, although their relative abundance in the concentrates is caused largely by enrichment during panning. The black opaque grains range in luster from jet black and metallic to earthy, in degree of abrasion from euhedral crystals to spherical, and in size from silt to very coarse sand. Commonly, only very fine sand-sized magnetite grains retain both their euhedral crystal form and their shiny black metallic luster; most other grains that have a shiny metallic luster are broken crystals. Subrounded to rounded grains have a dull to earthy luster. A few grains have filmlike patches of a dirty-white mineral, and many have filmlike patches and seams of a reddish-brown to greenish-grey mineral or minerals. Most of these filmlike patches and seams are probably leucoxene.

X-ray diffraction studies showed that many shiny black metallic-lustered euhedral crystals of magnetite and ilmenite from the hand magnet and 0.2-ampere fraction are partly altered to hematite and that most rounded black opaque grains, whether magnetic or not, are mainly hematite. This alteration to hematite prevented a clean separation of magnetite, ilmenite, and hematite. Van Houten (1968, p. 399–408) reported similar alteration and difficulty of separating magnetite, ilmenite, and hematite in red beds, which ranged in age from Precambrian to Holocene.

The reddish-brown hematite reported in table 1 occurs mainly as granular and earthy subrounded grains, although a few grains show rhombohedral faces, and about 0.1 percent of the hematite occurs as euhedral cubic pseudomorphs after pyrite. The grains range in size from silt to granule but are mainly medium to coarse sand. Most reddish-brown hematite is interpreted as an alteration product of black hematite, magnetite, and ilmenite during transportation and diagenesis. The pseudomorphs after pyrite are most abundant in concentrates from samples that include some reddish-brown mudstone from directly beneath conglomerate. These pseudomorphs indicate that some of the mudstone was deposited in an environment suitable for deposition of syngenetic pyrite and that the reddish-brown color of some beds probably is secondary.

Garnet in the concentrates ranges from deep to very pale red and is mainly angular fragments of partly rounded grains. The grains range in size from very fine to medium coarse sand. Less than 5 percent of the garnet occurs as rounded spherical grains or euhedral crystals.

About 60 percent of the zircon is colorless or very pale yellow, about 35 percent is pale to deep purple, and about 5 percent is metamict. About 40 percent of zircon grains are well rounded and spherical or subspherical; about 10 percent are euhedral crystals; the remainder range from well rounded to euhedral. All concentrates contain colorless, purple, and metamict zircon; and all contain both well-rounded spherical grains and euhedral crystals of colorless, purple, and metamict zircon. Most zircon occurs as silt or as very fine sand although a few rounded grains are as large as medium sand. In general, the largest rounded grains are purple instead of colorless.

Grains assigned to the monazite-leucoxene group were found in all concentrates studied. These minerals are grouped in table 1 because I found no way of visually distinguishing monazite from leucoxene in the microcrystalline grains that form most of this group. The microcrystalline grains are mainly angular fine- to medium-grained sand sized and indistinctly colored in shades of yellowish gray, greenish gray, and reddish brown. Optical parameters, other than a high index of refraction, could not be determined. At first, all these microcrystalline grains were thought to be leucoxene. X-ray diffraction, however, indicates that most of the microcrystalline grains are monazite, and four of five grains that were analyzed by single-grain spectrographic methods contained lanthanum-group elements and yttrium which would be typical of monazite (Murata and others, 1957, table 2). The fifth grain showed a major titanium content which indicates that some of the angular and rounded microcrystalline grains are leucoxene. Each concentrate also contained a few grains readily identifiable as monazite by optical methods. This monazite is very fine to coarse sand sized, colorless, pale green, pale yellow, and pale red, and the grains range from broken crystals to well-rounded grains.

Rutile and sphene are present in minor amounts in nearly all concentrates. Most rutile occurs as very fine to fine sand-sized well-rounded nearly spherical grains; elongate grains of rutile are sparse. Sphene is mainly fine to medium sand sized and generally occurs as angular grains. No white alteration, which could indicate leucoxene, was observed on the sphene and rutile.

Phosphate pellets are light-gray to black phosphate-bearing grains, whose optical properties could not be determined because of microcrystalline structures and inclusions of organic matter. X-ray diffraction indicates that the grains are mainly fluorapatite. These phosphatic pellets range in size from very fine to coarse sand, and they probably originated in phosphatic beds in the Permian Phosphoria Formation. Clear colorless apatite, present mainly in trace amounts in concentrates from the Wasatch Formation, was excluded from the phosphate pellet group.

Chloritoid, a mineral derived from metamorphic rocks, occurs mainly in concentrates from the Evanston Formation. It occurs mainly as thin irregular flakes that range from 0.25 to 1 mm in diameter and are mainly pale greenish gray. The flakes are nearly opaque in transmitted light and were identified by X-ray diffraction. The chloritoid is believed to have been derived from the Farmington Canyon Complex of Eardley and Hatch (1940) in the autochthon of the Willard thrust fault.

Barite generally is a common to abundant constituent of the concentrates. Though probably authigenic, the source of barium is not known. A little augite was found in 24 of the 30 concentrates, but it is of little value here as a provenance indicator. Augite also occurred in concentrates of the Precambrian quartzites exposed northeast of Huntsville, as well as in concentrates of gravel derived from the Farmington Canyon Complex exposed in Hardscrabble Creek. Biotite, spinel, pyrite, azurite, epidote, clinozoisite, andalusite, kyanite, staurolite, and xenotime occur in trace quantities in a few concentrates.

Although found only in trace amounts, hornblende and clear apatite possibly are useful in correlation. Hornblende was found in only two of the 10 concentrates from the Echo Canyon and Evanston Formations, but it was found in 10 of the 19 concentrates from the Wasatch Formation. Hornblende occurs as angular to subangular grains that range in size from fine to medium-coarse sand. Clear apatite was found in only one of the 10 concentrates from the Echo Canyon and Evanston, but it occurs in nine of the 19 from the Wasatch. Most apatite grains are subrounded and range in size from very fine to medium sand.

The paucity of hornblende is a major unsolved problem. The Farmington Canyon Complex contains abundant hornblende in exposures from Salt Lake City to Ogden (Eardley and Hatch, 1940, table 1; Bell, 1952), and it contributed debris to the Evanston and Wasatch Formations, if not to the Echo Canyon Conglomerate. The general lack of hornblende probably results from loss of hornblende to intrastratal solutions, particularly in altered strata of red, gray, or brown color.

The pan concentrates seemingly indicate that the conglomerates studied have a low heavy-mineral content, but the heavy-mineral content of the sand matrix in the conglomerate probably is about equal to that of other second-generation sandstone. On the average, about 15,000 grams of conglomeratic bedrock produced less than 2 grams of heavy minerals. If an allowance for loss of 60 percent of the minerals during panning were made, the average content of minerals of specific gravity of at least 3.0 would be less than 5 grams. Expressed differently, the conglomerates contain about 0.03 percent heavy minerals of specific gravity of 3.0 and above. Part of the seemingly low heavy-mineral content of the conglomerate is caused by the lack of abundant finer grained material in the conglomerates. No accurate measurements were made on the percentage of sand-sized material in the panned conglomerates, but most samples probably contained less than

20 percent sand by volume. The heavy-mineral content of the sand-sized fraction of the conglomerate, therefore, is probably more than 0.15 percent.

The low heavy-mineral content reflects the lack of heavy minerals in most of the source rocks. The conglomerates were derived mainly from older sedimentary rocks, except for the contribution in them from the metamorphic Farmington Canyon Complex. These sedimentary rocks were deposited in or near the shelf area of a geosyncline (Roberts and others, 1965, p. 1927–1944) and do not contain abundant heavy minerals.

The probable 0.15-percent heavy-mineral content of the sand-sized fraction in the conglomerates is in the general range of heavy-mineral content of the Jurassic Morrison Formation sandstone that was derived from older sedimentary rocks. Cadigan (1967, table 13) reported that 266 samples of sandstone from the Salt Wash Member of the Morrison Formation collected throughout the Colorado Plateau averaged 0.23 percent minerals of 2.8 and greater specific gravity. Bowers and Shawe (1961, table 5) reported 0.31 percent heavy minerals from light-reddish-brown sandstone, 0.16 percent from light-gray unmineralized carbonaceous sandstone, and 0.11 percent from light-gray mineralized (uranium and vanadium minerals) sandstone in the Morrison Formation in the Slick Rock district, Colorado. At the other extreme in source materials, Walker (1967, p. 360) reported that 34 representative samples from Pliocene red conglomerates derived from granitic rocks averaged 4.8 percent heavy minerals.

GOLD

Only a few flakes of gold were detected in the 170 samples collected from northern Utah (pl. 1), and never more than one flake per sample was found. Of the 170 samples collected, about 150 were either outcrop samples or stream-sediment samples derived from the Echo Canyon, Evanston, and Wasatch Formations. The general absence of gold was confirmed by chemical analysis of 81 of the concentrates in the U.S. Geological Survey laboratory in Denver, Colo. Sixty-one concentrates from the Echo Canyon, Evanston, and Wasatch Formations were included in the group analyzed. Thus, there seems to be no placer gold of economic importance in the Echo Canyon, Evanston, and Wasatch Formations in the area of study. Moreover, because the formations represent a sample of most older formations exposed in the north-central Wasatch Mountains, it seems unlikely that undetected deposits of gold of pre-early Tertiary age coarse enough to form placer deposits occur in the older formations.

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