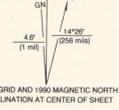


# GEOLOGIC MAP OF ANTELOPE ISLAND, DAVIS COUNTY, UTAH

by  
**Hellmut H. Doelling, Grant C. Willis, Mark E. Jensen,  
Suzanne Hecker, William F. Case, and John S. Hand**  
with contributions by  
**Fitzhugh D. Davis, Robert H. Klauk, J. Wallace Gwynn,  
Charles E. Bishop, and Genevieve Atwood**  
1990

SCALE 1:24,000  
1 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET  
1 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 METERS  
CONTOUR INTERVAL 20 FEET  
DATUM IS MEAN SEA LEVEL



Base from U.S.G.S. Antelope Island, Antelope Island North, Antelope Island South, Buffalo Point, and Plug Peak NE quadrangles. Cartography by J. Parker.



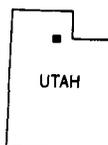
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MAP 127

1990

UTAH GEOLOGICAL AND MINERAL SURVEY

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*Strongly layered migmatitic granitic gneiss in the Red Rocks area on the west side of Antelope Island. This outcrop is unusual because of its strong planar fabric.*

# GEOLOGIC MAP OF ANTELOPE ISLAND DAVIS COUNTY, UTAH

## ABSTRACT

Antelope Island is the largest island in the Great Salt Lake. It contains Precambrian (Archean and Early Proterozoic) high-grade metamorphic rocks of the Farmington Canyon Complex, Late Proterozoic and Cambrian metasedimentary rocks of the Mineral Fork Formation, the Kelley Canyon Formation, and the Tintic Quartzite, rocks of an Eocene or younger conglomeratic unit, and rocks of the Miocene-Pliocene Salt Lake Formation. Most of the rock units are separated by major unconformities that represent long periods of time from which no rock record is preserved. A variety of lacustrine, alluvial, colluvial, eolian, and mass-movement deposits mantle much of the island. The island records two episodes of high-grade metamorphism, an event about 2600 million years ago and an event about 1700 million years ago. Both events were accompanied by granitic igneous intrusions. In addition, granitic gneiss on Antelope Island yielded an age of 2020 Ma (million years). The next deformational event recorded was the Late Jurassic to Cretaceous Sevier orogeny (150 to 65 million years ago). During this event, rocks on the island were sheared, retrogressively metamorphosed, brecciated, faulted, and thrust eastward. High-angle normal and strike-slip faults associated with late Tertiary to Quaternary Basin and Range extension (last 17 million years) cut and tilt consolidated rocks on the island.

Lake Bonneville covered most of the island thirty to thirteen thousand years ago. As a result, the island is encircled by numerous wave-cut and wave-built shorelines, and mantled in various places by tufa, gravel, sand, and finer lacustrine deposits. Since the retreat of Lake Bonneville, erosion and alluvial-fan deposition have modified the face of the island. Currently, active geologic processes on and near the island have created geologic hazards such as earthquakes, landslides, rock falls, debris flows, and lake flooding.

Several small pits and mines were opened during extensive mineral prospecting on the island. Oil and gas discoveries have been made in the Great Salt Lake basin around the island and an exploration well was started on Antelope Island, but never completed.

The State of Utah recently acquired Antelope Island for use as a state park. The geology, oolite sand beaches, relatively unaltered landscape, and wildlife, including buffalo, are the main attractions.

## INTRODUCTION

Antelope Island is a small fault-block mountain range in the Basin and Range physiographic province which extends from the Wasatch Front to the Sierra Nevada Range and includes many similar fault-block ranges. The island consists of a principal north-trending backbone ridge (Daddy Stump Ridge) with subsidiary ridges projecting to the west and east. The major fault boundary on the west side of the island is known as the East Great Salt Lake fault zone. Other faults are present under the lake on the east side of the island, but they probably have less displacement (figures 1 and 2).

Exposed rocks on the island can be grouped into seven major divisions that are separated by major unconformities (figure 1; [and] plate II, lithologic column). The rocks of each division were formed or deposited at widely spaced times and under diverse geologic conditions. The oldest division contains some of the oldest rocks in Utah.

Antelope Island is the largest island in the Great Salt Lake. It is approximately 15 miles (24 km) long, 5 miles (8 km) across at the widest point, and is about 40 square miles (104 km<sup>2</sup>) in area. It is 17 miles (27 km) west of Farmington, the Davis County seat, and 21 miles (34 km) northwest of Salt Lake City. The highest peak on Antelope Island (Frary Peak) stands at 6597 feet (2011 m), about 2400 feet (732 m) above the present lake level.

The island was used as a hunting ground and was probably inhabited by Indians for many centuries. Historical records show that the first non-Indian to visit the island was Captain John C. Fremont in 1845. The Mormon pioneers reached the valley of the Great Salt Lake in 1847; by 1849 a cattle ranch had been established on the island and a ranch house built by Fielding Garr. This house, which still stands, was continuously occupied from 1849 until 1979 during which time the island was used for grazing cattle and for limited farming purposes. Metallic and non-metallic mineral resources were discovered and sporadic attempts were made to develop them.

Currently, the island is owned by the State of Utah and is administered by the Department of Natural Resources through the Division of State Parks and Recreation as Ante-

lope Island State Park. The park is a showcase for Archean metamorphic rocks, Proterozoic metasedimentary rocks, Basin and Range features, Lake Bonneville shorelines, and deformation features resulting from the Sevier orogeny. In addition to its geology, Antelope Island is a haven for wildlife, supporting populations of mule deer, coyotes, badgers, bobcats, and a herd of buffalo. It is regularly visited by migrating birds and provides habitat for waterfowl, eagles, hawks, owls, and the rare peregrine falcon.

The Utah Geological and Mineral Survey conducted geologic mapping and studies of the island during the latter half of 1987 to provide geologic information to the Division of Parks and Recreation in developing a master plan for Antelope Island State Park. The geology, mineral resources, geologic hazards, engineering geology, and ground-water resources were emphasized for this study.

### PREVIOUS WORK

Three geologic expeditions visited the island in the late 1800s: Stansbury (1855) in 1849-1850; Beckwith (1855) in 1855; and King (1878). However, the first detailed geologic map was not prepared until Willard Larsen completed his doctoral work at the University of Utah in 1957.

Larsen (1957) called metamorphic rocks on the island the Farmington Canyon Complex, which he divided into three "stratigraphic" units and identified the overlying metasedimentary rocks as Mineral Fork Tillite and Mutual Formation. He recognized Tertiary rocks on the island but did not divide them on his map. Larsen described his lower Farmington Canyon Complex unit, which includes the Red Rocks area on the west side of the island, as quartzo-feldspathic schist with relatively thin, intercalated amphibolite beds. His middle unit generally coincides with the major shear zone of the island and includes most of the rocks in the highest part of the island and in the Buffalo Scaffold Canyon area. It consists "predominantly of microline schist containing interbedded quartzo-feldspathic schists, mica schists, and amphibolite" with many intermediate rock types. Larsen's upper unit is migmatitic, quartzo-feldspathic gneiss with lesser amounts of amphibolite, quartz schist, pegmatite, and metaquartzite. He mapped this unit over most of the east side and all of the southern part of the island.

Bryant and Graff (1980) and Bryant (1988) conducted a reconnaissance of the Farmington Canyon Complex on the island and recognized the three basic subdivisions of Larsen (1957), but interpreted them differently. They identified Larsen's lower unit as a "nonlayered, rather uniform-appearing granite gneiss." They interpreted Larsen's middle unit as a well-developed zone of shearing and retrogressive metamorphism, and identified sillimanite in some of the less-sheared parts of this zone. In Larsen's upper unit, which underlies much of the east part of the island, they identified a mixture of granite gneiss similar to that in the lower unit but that contains less K-feldspar, migmatite, garnet-bearing gneiss, and numerous pegmatites. They concluded that gneissic parts of the Farmington Canyon Complex were derived predominantly from a metasedimentary sequence and that

sedimentary protoliths were derived from continental crust as old as 3600 million years. However, they noted that much of the island, primarily the lower unit, was of metagneous origin. Amphibolites were probably derived from basaltic intrusions. They also concluded that most of the shearing and retrograde metamorphism that dominates the middle unit occurred before deposition of the Mineral Fork and Kelley Canyon Formations, a conclusion with which we disagree.

Until the present, Larsen (1957) was the only one to have described the structure of the island. However, several workers have discussed or mapped the structure of the region. Notable publications are those by Crittenden (1963), Smith and Bruhn (1984), Bryant (1984; 1988), Crittenden and Sorensen (1985a; 1985b), Sorensen and Crittenden (1979), Viveiros (1986), and Yonkee and others, (1989).

### ROCK UNITS

Rocks on Antelope Island can be divided into seven groups, all of which are separated by unconformities: 1) Archean and Lower Proterozoic high-grade metamorphic rocks of the Farmington Canyon Complex, 2) Upper Proterozoic, low-grade-metamorphosed diamictite of the Mineral Fork Formation, 3) Upper Proterozoic, low-grade-metamorphosed Kelley Canyon Formation, 4) Cambrian Tintic Quartzite, 5) conglomerate, mudstone, and dolomite of an Eocene or younger conglomeratic unit, 6) tuffaceous sandstone, volcanic air-fall tuff, conglomerate, and other rocks of the Miocene-Pliocene Salt Lake Formation, and 7) unconsolidated and partially consolidated Quaternary surficial deposits (figure 1; plate 2, lithologic column).

The thickness of the highly metamorphosed rocks of the Farmington Canyon Complex cannot be measured directly, but many thousands of feet are exposed. The Mineral Fork Formation ranges from 0 to 200 feet (0-60 m) thick, and the Kelley Canyon Formation ranges from 70 to 280 feet (20-85 m). The upper contact of the overlying Tintic Quartzite is not exposed on the island, but the Tintic is at least 800 feet (245 m) thick. The Tertiary conglomeratic unit, exposed only on the east side of the island, has a maximum thickness of about 900 feet (270 m). The Salt Lake Formation, presumed to overlie the conglomeratic unit unconformably, may be as thick as 1800 feet (550 m), but it is so poorly exposed that even the structural relationships are unclear. Surficial deposits, dissected by recent erosion and exposed in gravel pits, are less than 50 feet (15 m) thick in most areas (plate 2, lithologic column). There are great gaps in the rock record preserved on Antelope Island; much of this history is represented by the more complete rock succession found in the Wasatch Range to the east.

### PRECAMBRIAN-ARCHEAN AND EARLY PROTEROZOIC Farmington Canyon Complex

The Farmington Canyon Complex is exposed in only three areas of northern Utah: a north-south belt along the west part of the Wasatch Range, at Durst Mountain north of Morgan, and on Antelope Island (figure 2) (it may also be exposed in a

### TIMING OF MAJOR EVENTS AFFECTING ROCKS ON ANTELOPE ISLAND (AGES ARE APPROXIMATE)

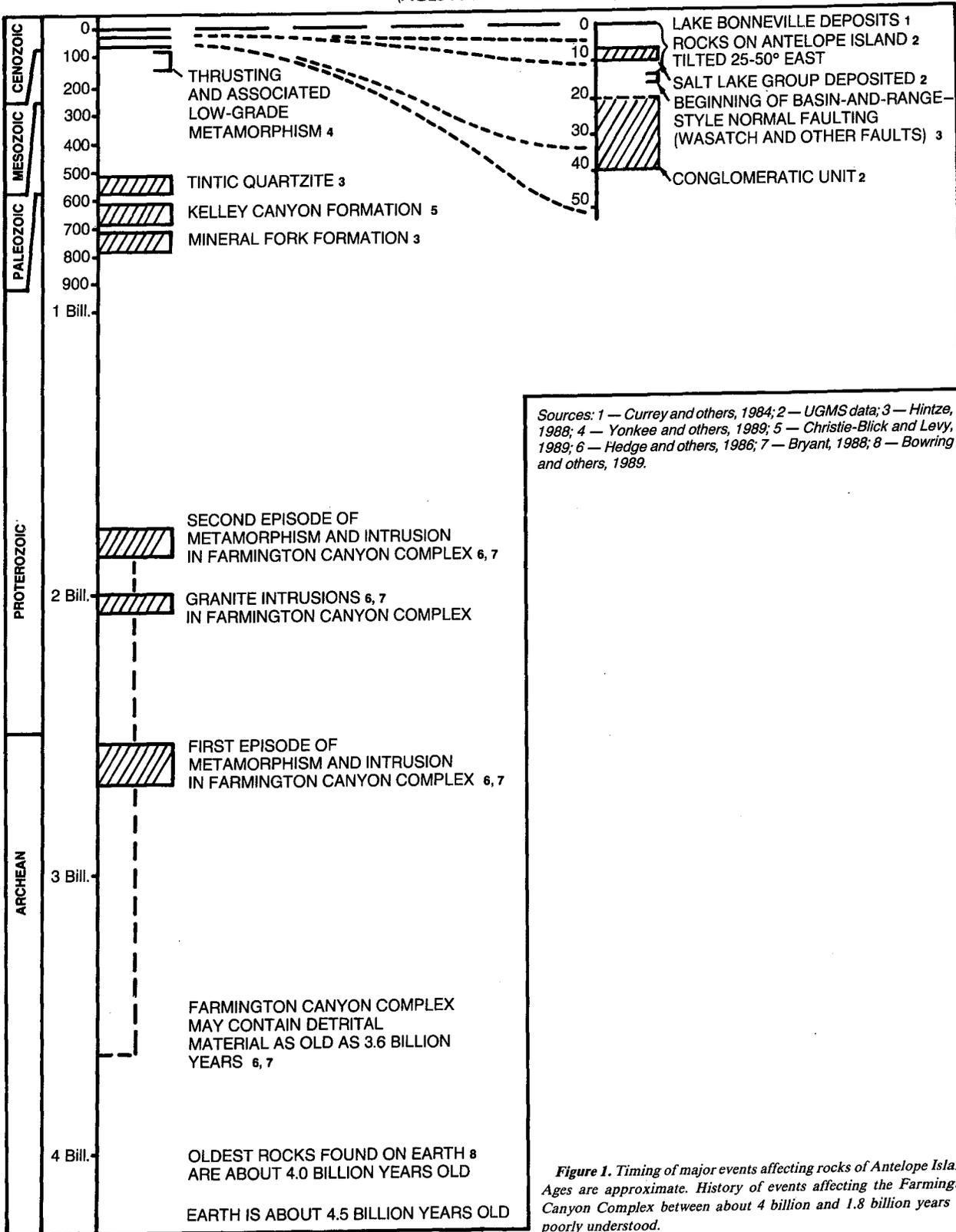
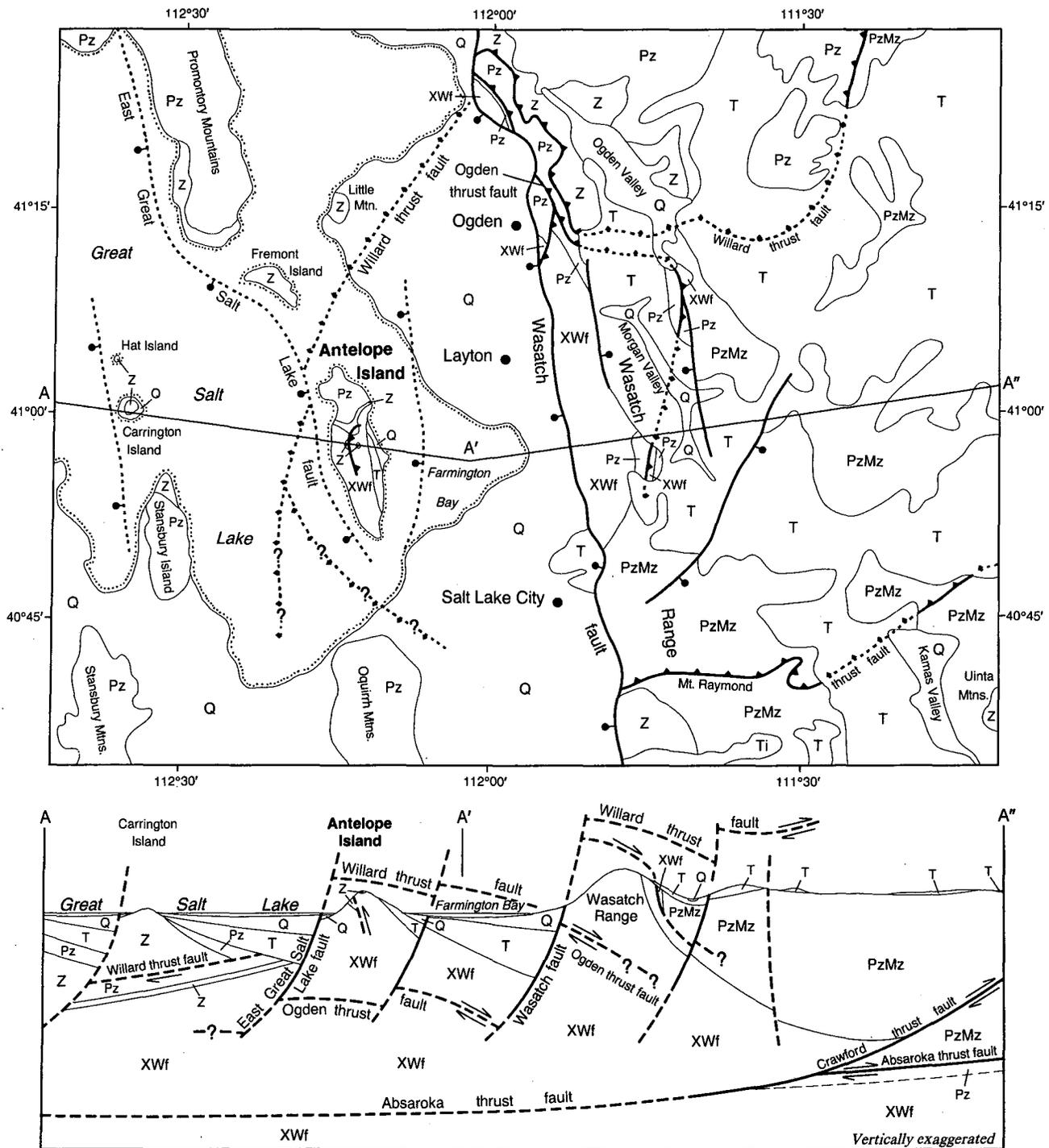


Figure 1. Timing of major events affecting rocks of Antelope Island. Ages are approximate. History of events affecting the Farmington Canyon Complex between about 4 billion and 1.8 billion years are poorly understood.



**Figure 2.** Simplified diagrammatic geologic map and cross section of Antelope Island and vicinity showing the relationship of major thrust faults, normal faults, and geologic units. Rocks exposed on Antelope Island are sandwiched between the Ogden and Willard thrusts and are affected by intense faulting, shearing, and chlorite-grade metamorphism associated with movement along these thrust faults. The island is bounded by listric Basin and Range-type normal faults which are down to the west in stair-step fashion. Map units are XWf—Farmington Canyon Complex; Z—Upper Proterozoic metasedimentary rocks; Pz—Paleozoic rocks; PzMz—undivided Paleozoic and Mesozoic rocks; T—Tertiary sedimentary and volcanic rocks; Ti—Tertiary intrusive rocks; Q—Quaternary deposits. Thrust faults are shown by triangles, normal faults by heavy lines (offset shown by the ball and bar), faults are dotted or isolated triangles where covered or inferred. Sources of data: UGMS data; Smith and Bruhn, 1984; Bryant, 1988; Crittenden, 1972; Wilson and others, 1986; Viveiros, 1986; and Hintze, 1980.

small outcrop near Spanish Fork in central Utah). The rocks in these areas are similar. Bryant (1980; 1984), working primarily along the Wasatch Front, divided the complex into four major units: 1) quartz-monzonite gneiss; 2) migmatite, gneiss, and schist; 3) gneiss and schist; and 4) quartzite gneiss and schist. The quartz-monzonite gneiss is not recognized on Antelope Island. Although mineral assemblages in both areas indicate amphibolite-facies metamorphism, greenschist-facies retrogressive metamorphism is locally dominant. Hedge and others (1983) identified coexisting sillimanite, muscovite, and microcline, which indicates conditions favorable for incipient melting, as attested to by extensive migmatitic gneiss. An earlier event of granulite-facies metamorphism is indicated locally by relict orthopyroxenes. Zones of intense shearing are present in both the Wasatch Front and on Antelope Island. Front and on Antelope Island.

The Farmington Canyon Complex is equivalent in part to the oldest metamorphic rocks in the Raft River Range and the Uinta Mountains of Utah, to the oldest rocks of the Teton, Wind River, and other ranges of Wyoming, and to rocks of the Superior Province of the Canadian Shield (Hedge and others, 1986). It is part of the Wyoming Province of Condie (1969) and is considered to be the southwesternmost known exposure of the ancient continental core of North America. The Complex is significantly older than high-grade metamorphic rocks exposed in the Uncompahgre area of east-central Utah and Colorado and in the Grand Canyon area of Arizona and Nevada (Hedge and others, 1986).

The Farmington Canyon Complex was divided into eleven map units for this study. Some of the units are composed of a single rock type; others are groupings of rock types. One unit is differentiated on the basis of the effects of retrograde metamorphism that altered the original rocks. Single rock-type units generally have sharp boundaries, while the others have gradational contacts. Several of the units differ only slightly in composition and probably represent the same metamorphic history. They were differentiated only to assist the map user in identifying areas of slightly different lithologies. In the following descriptions, modifying mineral names are given in order of abundance, the most abundant first.

**Mixed amphibolite, gneiss, and granite (XWfh)** — The mixed amphibolite, gneiss, and granite unit consists primarily of light-pink to white pegmatitic granite and granodiorite, but it is distinguished by the presence of abundant gray to black hornblende-plagioclase gneiss and dark greenish-gray to black amphibolite, and by the lack of significant amounts of migmatitic gneiss or schist. The rock types are complexly intercalated, but the pegmatitic rocks appear to be younger, as they intrude the other rocks and are generally less foliated. The unit has a strongly defined compositional layering that generally strikes northeast, the same as the dominant trend of foliation on the island. The unit is exposed east of Daddy Stump Ridge in the central part of the island, where it weathers to low, jagged knobs and discontinuous ledges. It is locally chloritized. Contacts with adjacent units are gradational to interlayered over a narrow interval.

Minerals found in the amphibolite and hornblende-plagioclase gneiss include hornblende (30-40%), plagioclase (5-45%),

quartz (0-15%), sericite, chlorite, and a small percentage of opaque minerals. Sericite and chlorite probably formed at the expense of plagioclase and hornblende. Pegmatitic granite is composed mostly of quartz (30-40%), alkali feldspar (10-30%), and plagioclase (25-65%). Sericite is generally present in amounts less than 5 percent.

**Quartz-plagioclase gneiss (XWfq)** — The quartz-plagioclase gneiss unit has been mapped in small areas in the southern part of the island. Elsewhere, a few outcrops too small to be mapped are interlayered with other units. The unit consists entirely of quartz-plagioclase gneiss and occurs in layers of variable thickness. The high quartz content gives outcrops a milky, light-gray to greenish-gray "quartzite" appearance, and outcrops are often stained by hematite in shades of red. Foliation is expressed by the non-quartz minerals, which are widely separated. The rock is strongly jointed and exposed surfaces appear sharp and unweathered. The unit is resistant to erosion and forms sharp, jagged ridges. Contacts with adjacent units are usually sharp and well defined.

The quartz-plagioclase gneiss unit is composed of more than 90 percent quartz with the remainder consisting of plagioclase and opaque minerals, including magnetite and hematite. The ratio of plagioclase to dark minerals varies from outcrop to outcrop. The quartz grains range in size from about 0.004 to 0.2 inches (0.1-5.0 mm), are interlocking, and are strained and shattered in many samples. The plagioclase and opaque minerals, which are usually euhedral, are aligned parallel to the foliation exhibited by neighboring rocks. Much of the plagioclase has been altered to sericite.

**Layered gneiss (XWfl)** — The layered gneiss unit is composed of well-layered gneiss, migmatitic gneiss, schist, amphibolite, and pegmatitic granite. Exposures are limited to the east side of Daddy Stump Ridge in the central part of the island. Outcrops of the unit are similar in appearance to the mixed gneiss, amphibolite, granite, and schist unit (XWfb) described below, but they are distinguished by a strong layering habit reminiscent of bedding. Some of the individual layers, which are usually 2 to 6 feet (0.6-1.8 m) thick, can be traced 300 feet (90 m) or more along outcrops. The layering probably is of metamorphic origin, however, a sedimentary origin is also possible. Most of the layers are resistant and form cliffs and ridges. Overall, outcrops are generally darker in color than other units. Contacts with most adjacent units are gradational, although the contact with the chloritized and hematitized gneiss, mylonite and phyllonite unit (XWfg), described below, is a shear zone. In thin section these rocks are mineralogically variable. They contain quartz (15-40%), plagioclase (15-30%), and opaque minerals (0-15%). A few samples contain small amounts of hornblende, biotite, and muscovite. Some of the samples are highly altered, with as much as 20 to 30 percent sericite replacing plagioclase, and from 5 to 35 percent chlorite replacing mafic minerals.

**Amphibolite and gneiss (XWfa)** — Dike and sill-like masses of dark-green to black, foliated amphibolite and hornblende-plagioclase gneiss occur in most units, but only the largest outcrops are mapped separately. Most of the outcrops vary in thickness from a few feet to a few tens of feet, though locally they are as much as 100 feet (30 m) thick. They are generally

less resistant to erosion than are adjacent rocks and [therefore] form swales or saddles between ridges. The thicker masses are generally interlayered with coarse-grained gneiss and are intruded by pegmatite. The contact with surrounding units is sharp.

The amphibolite and hornblende-plagioclase gneiss unit consists of hornblende (35-55%) and plagioclase (0-35%). As much as 15 percent quartz, 5 percent orthoclase, 5 percent biotite, and 35 percent opaque minerals may also be present. Sericite is commonly abundant (as much as 45 percent), usually replacing plagioclase. As much as 5 percent chlorite has been observed in thin sections.

**Mixed gneiss, amphibolite, granite, and schist (XWfb)** — The mixed gneiss, amphibolite, granite, and schist unit is widespread in the southern half of the island. It consists of migmatitic gneiss that is interlayered with amphibolite, hornblende-plagioclase gneiss, plagioclase-biotite schist, and is intruded by pegmatitic granite (figures 3 and 4). Dominance and persistence of individual rock types is highly variable throughout the unit. The largest and most continuous outcrops of amphibolite and hornblende-plagioclase gneiss are mapped separately as map unit XWfa, and the pegmatitic granite as map unit XWfp. The migmatitic gneiss in this unit is similar to that in the migmatitic gneiss unit (XWfm), however, in this unit outcrops are not as continuous. Resistance to erosion varies from one area to another and depends on the dominant rock type. The gneiss and granite are generally resistant and form ridges while the amphibolite and schist are easily eroded. Contacts are generally gradational or interlayered because of the mixed nature of this unit.

**Migmatitic granitic gneiss (XWfm)** — The migmatitic granitic gneiss unit consists primarily of yellowish-gray, light-gray, or pink migmatitic gneiss. On fresh surfaces the color is gray to pale gray to brownish-gray. Locally it contains concordant and discordant pegmatite, interlayered amphibolite, and schist. This unit is characterized by a uniform orangish-gray appearance at outcrop scale. The unit is commonly massive and is cut by widely spaced joints, producing an angular, blocky weathering habit.

At a smaller scale, the migmatitic gneiss is characterized by alternating, discontinuous layers of darker, more mafic, and lighter, more sialic rock (frontispiece; figure 4). The darker layers are finer grained and the lighter layers have coarser, more uniform grain size. Each layer usually ranges in thickness from 0.25 to 3 inches (5-75 mm). There is commonly a concentration of mafic minerals along the margins of the lighter layers. The layers are lenticular to planar and commonly grade into one another. The foliation and layering are poorly to well developed and vary from planar to contorted. Ptygmatic folding is common. Though locally contorted, the foliation has a dominant strike and dip, generally the same as adjacent units.

The unit locally is cut by pegmatite dikes and sills, though the dikes are less common than in the other map units. They are generally 1 to 3 inches (25-75 mm) wide but locally bloom into pods several feet thick. The migmatitic gneiss consists of quartz (25-35%), orthoclase (5-25%), plagioclase (10-30%), hornblende (5-40%), opaque minerals (5-15%), sericite (10-20%), and chlorite (1-5%). The lighter layers are generally richer in feldspar and the darker layers are richer in hornblende and quartz.



*Figure 3. Amphibolite or hornblende-plagioclase gneiss invaded by coarse pegmatitic granite shows the intensity of the high-grade metamorphism that affected Farmington Canyon Complex rocks. Photograph is of a fallen block of the mixed gneiss, amphibolite, granite, and schist unit (XWfb) just west of Daddy Stump Ridge in the south-central part of Antelope Island.*



Figure 4. Coarse pegmatite dikes intruded into migmatitic gneiss, probably emplaced during the high-grade metamorphic event that occurred 1700 to 1800 million years ago. Photograph of a fallen block of the mixed gneiss, amphibolite, granite, and schist unit (XWfb) just west of Daddy Stump Ridge in the south-central part of Antelope Island.

**Red granitic gneiss (XWfr)** — The red granitic gneiss unit, which forms the Red Rocks area on the west side of the island, consists of red to light-brown, fine- to medium-grained granitic gneiss, with minor interlayered amphibolite and migmatitic gneiss. It is homogeneous and layering is rare. Hedge and others (1983) interpreted this unit and the adjacent rocks that are mapped as migmatitic gneiss (XWfm) as a pluton, emplaced about 2020 million years ago. The contact of the red granitic gneiss with the surrounding migmatitic gneiss (XWfm) is gradational through a distance of several tens of feet. Foliation in the red granitic gneiss unit defines a roughly circular pattern that deviates from the northeast-trending pattern of the rest of the island and may be subparallel to the original igneous structure. It is the most massive unit of the Farmington Canyon Complex and is cut by widely spaced, well-developed joints. It weathers into large blocks, forming jagged cliffs and ridges.

Average composition of the red granite gneiss unit is: quartz (30%), plagioclase (25%), orthoclase (15%), sericite (10%), microcline (5%), hornblende (5%), opaque minerals (5%), with minor amounts of accessory minerals. The rock is holocrystalline and generally equigranular, grains ranging in size from 0.002 to 0.28 inches (0.5-7 mm).

**Coarse-grained granite (XWfc)** — Two intrusive plugs of pink, coarse-grained granite crop out on Garr Knolls, near the south end of the island (sections 33 and 34, T. 2 N., R. 3 W.). The forceful intrusion of the coarse-grained granite is indicated by the contorted nature of the surrounding unit. The outcrops are massive with large (4 to 8 feet or 1 to 2.5 m in diameter) blocks defined by prominent joints. The

rock grades from a true granitic texture to a crudely foliated texture. Schlieren or clots of micaceous material locally indicate foliation. The color of the granite is probably due to the pink orthoclase, although local alteration of magnetite to hematite imparts a darker color to the rock. In areas where magnetite is abundant, rust-colored solution fronts are evident. Locally, the coarse-grained granite is intruded by white pegmatite. Large xenoliths of the surrounding rocks are found at the edges of the coarse-granite intrusions. The contacts are sharp, but undulating, and there appears to be no chilled zone, although the neighboring rock is silicified.

The coarse-grained granite contains quartz (35-55%), plagioclase (10-40%), microcline (5-10%), sericite (5-20%), and opaque minerals (2-15%). Some specimens contain perthite, muscovite, and biotite. Crystals average 0.4 to 1 inches (10 to 25 mm) in width.

**Pegmatitic granite (XWfp)** — Pegmatitic granite is widespread in the Farmington Canyon Complex but is shown on the geologic map only where the outcrop areas are large enough to be mapped. Most outcrops are on the east side of the island and near Frary Peak. The unit occurs as large, irregular bodies and as dikes and sills. Outcrops are white to light gray and pink. Foliation is usually absent and contacts indicate the unit is younger than units it intrudes. In some areas, wall rock protrudes into the igneous mass and in other areas the unit contains xenoliths of the wall rock. The unit was intruded at a late stage in the history of the Farmington Canyon Complex, as shown by its relative lack of foliation. The outcrops are generally resistant and form protruding knolls. The rock is coarse grained, with individual crystals locally in excess of

7 inches (180 mm) in diameter. Contacts, where observable, are generally sharp.

This unit consists of quartz (30-40%), plagioclase (25-45%), and microcline (10-30%). Locally, perthite, muscovite, garnet, chlorite, and opaque minerals are abundant. Sericite, replacing plagioclase, ranges to as much as 20 percent.

**Silicified cataclastic gneiss (XWfs)** — Many Farmington Canyon Complex outcrops on Antelope Island are strongly silicified. One large area on the northern part of Daddy Stump Ridge is continuous enough to map separately. The unit consists of intensely brecciated, strongly silicified gneiss and other metamorphic rocks, and is probably similar to the mixed gneiss, amphibolite, granite, and schist unit (XWfb). It is dominantly red to reddish-gray. The rocks are hard, brittle, and form sharp, resistant ledges and knolls that weather into blocky, angular fragments. Most of the rocks are moderately chloritized. The contact with the adjacent chloritized and hematitized gneiss, mylonite, and phyllonite unit (XWfg) is gradational. The Mineral Fork Formation unconformably overlies this unit.

The silicification of these rocks apparently occurred after the main episode of metamorphism but before deposition of the unconformably overlying Mineral Fork as clasts of silicified rock occur in the overlying diamictite adjacent to the silicified unit. The original gneissic fabric can still be seen in the silicified rocks where the silicification is less intense. In some places these rocks were chloritized, apparently at a much later time.

**Chloritized and hematitized gneiss, mylonite, and phyllonite (XWfg)** — Rocks of other Farmington Canyon units that have been intensely chloritized and sheared, and retrogressively metamorphosed or altered to the lower greenschist facies, were mapped as the chloritized and hematitized gneiss, mylonite, and phyllonite unit. Outcrops of similarly altered rocks occur locally in the remainder of the Farmington Canyon Complex (as well as in the Mineral Fork and Kelly Canyon Formations) but were not mapped separately. In outcrop, the chloritized and hematitized rocks are easily differentiated from unaltered rocks by their dark-green color, in spite of the diversity of rock types affected. In general, the altered rocks are highly shattered, granulated, semi-brittle to plastically deformed, and have strongly developed cleavage. Locally, they are phyllonitized, intensely sheared, schistose, and are cut by numerous quartz veins (figure 5). In places the rocks are also hematitized, imparting a dark-red color. Commonly the rocks are resistant, forming ridges and sharp ribs. Contacts with adjacent units are generally gradational over a distance of a few feet to a few tens of feet, but sharper contacts occur along shear-zone boundaries.

As most of the rock types found in the rest of the Farmington Canyon Complex are represented in this unit, the mineralogy is similar to that described for the other units. However, there is a much greater percentage of chlorite in the altered rocks, as much as 50 percent in some samples, formed at the expense of mafic minerals. Biotite, muscovite, and sericite are also present in greater amounts.



*Figure 5. Quartz veins cutting highly brecciated, mylonitized, and chloritized rocks in a sheared zone in the chloritized and hematitized gneiss, mylonite, and phyllonite (XWfg) unit (SW ¼ section 21, T. 2 N., R. 3 W.). In some areas veins have been affected by shearing, while in others, veins postdate the shearing. Quartz is common in sheared zones and is probably related to shearing during the Sevier orogeny.*

In many areas, the retrograde metamorphism has destroyed original fabrics and minerals so that identification of the original rock type is not possible. In other areas, the parent rock types can still be recognized despite the alteration. Isolated remnants of undeformed or only slightly deformed rocks are included within this unit.

Although these rocks could be classified on the basis of their "pre-retrograde metamorphic" rock type, we felt that the effects of the retrograde metamorphism and associated deformation are important enough to warrant differentiation. Though the alteration and deformation apparently are associated with the Mesozoic Sevier orogeny, we use the Precambrian rather than Cretaceous designation to better indicate the origin of the rocks.

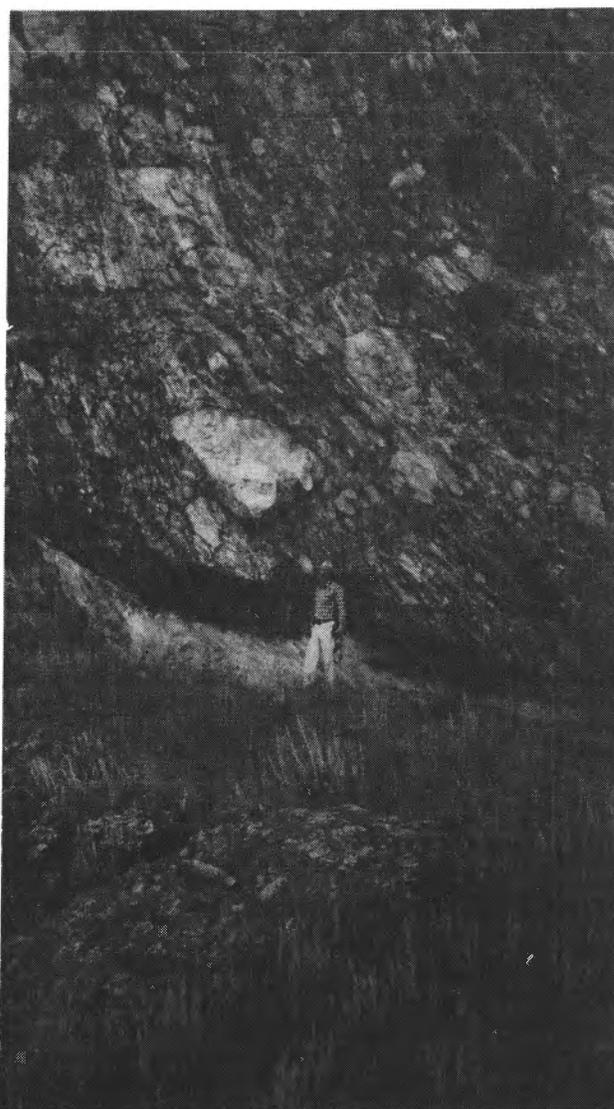
### PRECAMBRIAN—LATE PROTEROZOIC

Late Proterozoic rocks on Antelope Island occur in two formations. The lower is the Mineral Fork Formation which is separated from the Farmington Canyon Complex by an unconformity representing over a billion years. The term "Mineral Fork Tillite" was first applied by Crittenden and others (1952) to rocks in the Wasatch Range mountains but "formation" is now generally preferred since "tillite" implies direct deposition by a glacier, which is not the case for all of the rocks in the unit (Christie-Blick, 1983). The upper Kelley Canyon Formation is separated from the Mineral Fork by an unconformity or sequence boundary (Christie-Blick and others, 1988), however, bedding between the two units is parallel. The term "Kelley Canyon" was first applied by Crittenden and others (1971) to exposures in the Huntsville area of northern Utah. The Mineral Fork Formation is considered correlative with the Maple Canyon Formation, which directly underlies the Kelley Canyon in the Huntsville area (Paul K. Link, written communication, 1989). The Kelley Canyon is correlative with the Pocatello Formation of southern Idaho. The Mineral Fork is probably 770 to 720 million years old. The age of the Kelley Canyon is even less well constrained but is Late Proterozoic and younger than the Mineral Fork (Christie-Blick and Levy, 1989). The thickness of Late Proterozoic rocks on Antelope Island ranges from 70 to 480 feet (20 to 145 m). Basalt, including pillow lava, has been recognized in Late Proterozoic rocks elsewhere in northern Utah (Crittenden and others, 1971; Christie-Blick, 1985), but none was found on Antelope Island.

#### Mineral Fork Formation (Zmf)

The Mineral Fork Formation consists of dark-brownish-black, extremely poorly-sorted, matrix-supported diamictite. Clasts vary in size from sand to boulders in excess of seven feet (2 m) in length and are angular to rounded (figure 6). The matrix consists of mud, silt, and sand and constitutes 30 to 60 percent of the unit. The unit generally is slope forming but locally is cliff forming. It nonconformably overlies the Farm-

ington Canyon Complex along a sharp contact. It averages 10 to 20 feet (3-6 m) thick, but varies from 0 to 200 feet (0-60 m), reflecting paleotopographic relief. Bedding is not usually present, but a few lenses of fine-grained material exhibit horizontal bedding and a well-bedded conglomerate is present in one area near the upper contact. It is locally chloritized and structurally deformed.



*Figure 6. The Mineral Fork Formation is well exposed near Elephant Head on Antelope Island (SE ¼, SE ¼, section 18, T. 3 N., R. 3 W.). In this view diamictite in the Mineral Fork rests unconformably on light-colored Farmington Canyon Complex rocks. The nearly horizontal contact is at the man's waistline. Both units have been affected by deformation which occurred during Cretaceous thrust-faulting. The deformation imparted a strong shear fabric and cleavage that dips steeply to the right, and that stretched the less competent lithic clasts but deflected around the more competent quartzite clasts.*

Three distinct kinds of clasts are recognized in the diamictite: 1) metamorphic and metaigneous rocks; 2) well-rounded quartzite clasts; and 3) subangular quartzite boulders. The first group is composed of Farmington Canyon Complex rocks, including migmatite, gneiss, pegmatite, and amphibolite. These clasts are weathered, altered and are generally angular. Many are deformed with gradational and rounded boundaries. They were particularly affected by later deformation which has drawn them out into long, slender bodies and smeared their boundaries with the matrix. In some places near the base of the unit the clasts reflect the lithology of the immediately underlying Farmington Canyon Complex.

The second group of clasts consists primarily of well-rounded, abraded quartzite cobbles. Most are white to pale gray, but lavender and vivid green clasts are also present. These clasts are randomly distributed throughout the unit. They are generally much less deformed than the clasts in the first group. Quartzite clasts weather out in relief whereas all other clasts weather similar to the matrix.

The largest clasts in the diamictite are subangular quartzite boulders which compose the third group. They are present only in a few areas, mostly near Elephant Head (figure 6). They are randomly mixed among the other clasts, and some show slickensides and other shearing features.

#### Kelley Canyon Formation

**Dolomite member (Zkd)** — The dolomite member of the Kelley Canyon Formation is composed of light-pink to pinkish-gray, brittle, cliff-forming dolomite that weathers to

light-pinkish-brown to tan. The light-colored outcrops contrast sharply with the darker units above and below. Weathering produces hackly, meringue surfaces with many tiny fractures. The dolomite is generally massive, but thin bedding is present in some areas. It is finely crystalline and moderately marbled. It appears to have been relatively unaffected by deformation in most areas, but complex folds and recrystallized breccia are locally developed. The unit maintains a uniform thickness of 20 to 30 feet (6-9 m) and forms a resistant ledge. Interbedded slate similar to the overlying slate member is present in a few places. A sandstone dike intrudes the unit on Elephant Head and breccia dikes with clasts of lavender slate are present in a few localities. In places, the unit is cut by thin veins of calcite and quartz. The lower contact is generally sharp, but shows a few feet of relief.

**Slate member (Zks)** — The slate member of the Kelley Canyon Formation consists primarily of purple, lavender, reddish-brown, grayish-green, greenish-brown, and yellowish-orange slate (figure 7). Purple hues generally dominate in the upper half of the unit. Bedding is continuous, and thinly laminated to thin bedded, but the color does not always parallel bedding. Particle sizes range from clay to fine-grained sand. Thin lenses of reddish, hematite-enriched slate as much as 0.25 inches (6.4 mm) thick and 2 inches (50 mm) long occur in some horizons. Strong slaty cleavage is usually at low angles to bedding but locally deviates up to 90 degrees. Some parting surfaces have a sparkling sheen due to the presence of sericite. The contact with the underlying dolomite is gradational and conformable, with thin dolomite beds interfingering with the lower half of the slate unit. The unit usually forms



Figure 7. Exposure of slate of the Proterozoic Kelley Canyon Formation east of Mormon Rocks (SE ¼, section 19, T.3 N., R. 3 W.). Early attempts were made to exploit the platy rock as roofing stone or flagstone.

smooth covered slopes but is well exposed locally. The slate unit is between 50 and 250 feet (15 and 75 m) thick, with the variation probably due to structural deformation. Deformation has locally intensely affected the unit, forming sinuous patterns, "fishscale" surfaces, cleavage, tight complex folds, and small-scale faults.

### CAMBRIAN Tintic Quartzite (Ct)

The Tintic Quartzite consists of tan to pale-gray to greenish-gray, dense, coarse- to very coarse-grained quartzite and metaconglomerate. The quartzite is dominant, constituting at least 90 percent of the unit. The metaconglomerate contains moderately well-sorted clasts ranging from 0.5 to 2 inches (13-50 mm) in diameter. Bedding is medium to massive and can be recognized where conglomerate beds are present. The unit commonly forms ledgy slopes and small blocky cliffs. Due to complex structure, a complete section could not be measured on the island, but the unit is estimated to be at least 800 to 1000 feet ([at least] 245-305 m) thick. Locally, deformation has elongated and flattened clasts to an axial ratio of as much as 5:1, commonly oblique to bedding (figure 8). In thin section, the quartz grains are plastically deformed, elongated, recrystallized, and shattered.

The contact with the underlying slate member of the Kelley Canyon Formation is sharp and wavy with local relief as much as one foot (0.3 m), and it is often marked by a basal conglomerate. The Tintic Quartzite is exposed on the northern third of the island and as isolated remnants on Daddy Stump Ridge.

### CRETACEOUS (?) Quartz veins and bodies (Kq)

Quartz veins are widespread in all of the Precambrian and Cambrian rocks on the island. A particularly large body of quartz is present in rocks on Elephant Head. Only the largest and most discrete veins and bodies were mapped separately. The veins and body consist of white, pale-yellowish-white, or pale-greenish-white, coarsely- to finely-crystalline quartz. They are composed of 99 percent quartz with trace amounts of muscovite and opaque minerals. In thin section, some of the quartz shows intense strain effects.

Although the veins generally are less than ten feet (3 m) thick, some can be traced for over 1000 feet (305 m). The veins are more resistant than the host rock and form small protruding ledges. Blocks of older rocks are incorporated into the quartz body on Elephant Head where the largest amount of quartz occurs.

Most quartz veins and the quartz body apparently formed contemporaneously with Cretaceous thrust faulting, though some of the veins could be older or younger. Quartz veins are most common in the Precambrian and Cambrian rocks near zones of deformation but are not present in the overlying Tertiary sediments. Sericite in similar veins near the Willard and Ogden thrust faults in the Wasatch Range yielded  $^{40}\text{Ar}/^{39}\text{Ar}$  ages between 110 and 140 Ma (Early Cretaceous) (Yonkee and others, 1989).



Figure 8. Stretched and shattered pebbles in Tintic Quartzite near the north end of Antelope Island (NW ¼, section 31, T. 4 N., R. 3 W.). The shearing and stretching features displayed on the island likely formed during the Cretaceous Sevier orogeny.

## TERTIARY

Eocene to Miocene(?) unnamed conglomerate and Miocene-Pliocene Salt Lake Formation comprise the Tertiary section on Antelope Island and have an estimated combined thickness of over 3000 feet (900 m). On most of the island the Tertiary rocks overlie the older rocks unconformably, although the contact is rarely seen. This unconformity represents a gap in the rock record of more than 500 million years. Except locally, exposures are poor and are generally covered by Lake Bonneville deposits. Descriptions of units were obtained from the few available outcrops and [therefore] may be skewed in favor of the more resistant rock types.



**Figure 9.** Poorly sorted and crudely stratified lower member of the Eocene to Miocene conglomeratic unit on the east side of the island (section 9, T. 2 N., R. 3 W.). The clasts are derived primarily from Paleozoic rocks, mostly of Cambrian age. A few fossiliferous Mississippian clasts are also present. In places, the clasts are matrix-supported while in others they are clast-supported. The largest clasts (not seen in this photo) have diameters of 10 feet (3 m) or more.

Tertiary rocks crop out in two areas on Antelope Island. The largest area is a 6-mile (10 km) band of outcrops in the southeastern part of the island where Lake Bonneville sediments were excavated from two connected pits for road fill. The best natural exposures in this area occur along the western margin of the outcrop band (figure 9). The strike of these Tertiary beds ranges from N. 15° W. to N. 15° E. and the dips range from 20° to 45° to the east, averaging 35°.

The other, much smaller area of Tertiary outcrops occurs at the northern tip of the island, on Ladyfinger (figure 10). These outcrops were exposed when Lake Bonneville gravel deposits were removed to construct a causeway to the north end of the island. This exposure is about 1200 feet (365 m) long and 50 feet (15 m) wide; the rocks are strongly faulted and brecciated.



**Figure 10.** Exposure of faulted upper Tertiary volcanic ash and breccia along the Ladyfinger at the north end of Antelope Island (SW ¼, section 19, T. 4 N., R. 3 W.). These strata are steeply tilted. The breccia is composed of angular fragments of olive-green Paleozoic shale, Tertiary volcanic ash, and brown sandstone. The exposure is tentatively assigned to the Salt Lake Formation.

### Conglomeratic Unit

Exposures of the "conglomeratic unit" on Antelope Island can be divided into two informal units dominated by coarse conglomerate and limited to the large area on the southeastern side of the island. The poorly sorted deposits were shed from an ancient, nearby mountain range as alluvial-fan material made up of mud flows or debris flows. Deposition of the coarsest conglomerate beds was probably localized close to the canyon mouths; the parts of the formation that are covered or poorly exposed may represent interfluvial and lacustrine deposition. Biotite from a volcanically derived, gray-green claystone in the upper part of the lower conglomeratic unit yielded a K-Ar age of  $42.9 \pm 1.7$  Ma (table 1). Clasts of welded tuff collected nearby yielded K-Ar ages of  $38.8 \pm 1.5$  Ma and  $49.2 \pm$  Ma, confirming an Eocene age for the source material. Since the dated material was from reworked sedimentary deposits, the actual age of deposition is younger, but probably still Eocene. The lower part of the lower unit is late Paleocene to late Eocene, and the upper unit is latest Eocene to Miocene in age.

**Lower member of the conglomeratic unit (Tul)** — The lower member is best exposed in sections 4, 9, 16 and 27, T. 2 N., R. 3 W. It consists of a gray to reddish-gray boulder conglomerate with clasts up to 11 feet (3.3 m) in diameter, dark red conglomerate and breccia, and variegated grayish-green, purple, and reddish-gray bentonitic mudstone and claystone. The boulder conglomerate overlies the Farmington Canyon Complex in the northern exposures. Clasts are mostly dolomite, limestone and quartzite, with a few metamorphic rocks. The largest clasts are all dolomite and quartzite. Much of the matrix is derived from metamorphic rock.

The red conglomerate and breccia overlies the boulder conglomerate beds in the northern outcrops but directly overlies the Farmington Canyon Complex in southern exposures where the boulder conglomerate is not present. The red conglomerate and breccia is both clast and matrix supported and is crudely stratified. The clasts are angular to subangular metamorphic rocks derived from the Farmington Canyon Complex. The beds are poorly sorted; clasts range from coarse sand to boulders more than 4 feet (1.3 m) in diameter. Most clasts are 1 to 6 inches (25 to 150 mm) in diameter and the matrix is coarse sandstone. The outcrops are stained dark red by hematitic iron oxide that gives the rock its characteristic color. The resistant layers of conglomerate project through overlying Quaternary lacustrine beds and are 1 to 3 feet (0.3 to 1 m) thick. The rock between the resistant horizons probably is either less well cemented or finer grained.

The mudstone and claystone beds are poorly exposed in small washes in the excavated pit. They are thin to medium bedded, bentonitic, and are volcanically derived. Claystone from which the age determination was obtained is a grayish-red to light-olive-gray, thin-bedded, silty biotitic bentonitic clay. The upper contact is placed where the conglomerate becomes dominantly gray in color and contains volcanic clasts. The contact between the lower and upper members is

probably conformable and the beds may intertongue. The lower member is up to 400 feet (120 m) in thickness.

**Upper member of the conglomeratic unit (Tuu)** — Like the lower member, the upper member of the conglomeratic unit is poorly exposed; its best exposures are found in sections 9 and 27, T. 2 N., R. 3 W. The upper member is a medium-gray, clast-supported conglomerate composed of poorly sorted, subrounded to angular Paleozoic sedimentary, Precambrian metamorphic, and Tertiary volcanic clasts.

The matrix is coarse sandstone or gritstone cemented with calcite and reddish iron oxides. In the south pit area the upper member contains tuffaceous sandstone and abundant volcanic clasts that are not present in outcrops farther north.

Most of the Paleozoic clasts of the lower and upper members of the conglomeratic unit are Cambrian in age, some were derived from the Tintic Quartzite or an equivalent quartzite. Other clasts are Middle and Late Cambrian, gray to black dolomite and limestone. Fossiliferous limestone clasts of Mississippian age that contain brachiopods, corals, bryozoans, and crinoid stems are also present. These boulders were probably eroded from Paleozoic strata once present on the island that formed part of the lower plate of the Willard thrust fault.

In part of the upper member, some beds of conglomerate are cemented by, and interbedded with, pink, lacustrine limestone that weathers nearly white. Clasts in this unit are similar to those in the remainder of the upper member but rarely exceed one foot in diameter. The calcareous cement contains no iron oxide, and the conglomerate is cement supported. The most resistant part of this pink conglomerate forms a slight ridge traceable for at least 2 miles (3.2 km). It has not been seen in direct contact with the poorly sorted, gray, clast-supported conglomerate below or the Salt Lake Formation sediments above. Less well-cemented or fine-grained sediments probably both underlie and overlie it.

The upper member of the conglomeratic unit may be as much as 500 feet (150 m) thick. The Salt Lake Formation may overlie the conglomeratic unit disconformably.

### Salt Lake Formation (Tsl)

The Salt Lake Formation is very poorly exposed in the southeastern band of Tertiary outcrops. Gray, tuffaceous sandstone crops out in small patches throughout the excavated pit area. The outcrops shown on the map have been exaggerated to make them visible, and groups of outcrops have been combined. Fresh surfaces of the tuffaceous sandstone are light to medium gray, weathering to a lighter gray. It is very fine grained, noncalcareous, porous, moderately indurated, well bedded, laminated to medium bedded, and locally exhibits crossbedding. In places it is speckled black with small bits of iron oxide that mimic grains of biotite.

In the south pit, white, highly calcareous conglomerate containing subangular to subrounded quartzite and limestone cobbles that rarely exceed 3 inches (75 mm) in diameter is interbedded with tuffaceous sandstone. The quartzite cobbles, derived from Proterozoic sources, are purple, green, and white. Smaller percentages of clasts of Farmington Canyon Complex rocks, black chert, shale, and sandstone are also present; no volcanic clasts were found. The conglomerate is both clast and matrix supported. The crude stratification varies by horizon; some horizons are coarser, others are finer. Some conglomerate is cemented with tuffaceous sandstone and some with calcite.

In the northern part of the eastern band of Tertiary outcrops (NW ¼, NW ¼, NW ¼, section 3, T. 2 N., R. 3 W.) is a well-exposed lens of volcanic ash at least five feet thick (1.5 m) that consists of glass shards. The exposure is very light gray, fine grained, noncalcareous, porous, moderately indurated, and well bedded. It is bounded by fine-grained sediments; the ash was probably deposited in a lake.

The tuffaceous sandstone, volcanic ash, and conglomerate beds of the Salt Lake Formation are the more resistant horizons of the unit. The unexposed parts of the formation may be poorly cemented sandstone.

The top of the Salt Lake Formation is not exposed on the island, so an exact thickness cannot be measured. Assuming no structural complexities and a uniform strike and dip, it is estimated that the Salt Lake Formation is at least 1800 feet (550 m) thick. Correlation is tentatively made on the basis of stratigraphic position and lithologic affinities to surrounding northern Utah areas.

The Tertiary outcrop at the north end of Ladyfinger consists of gray volcanic ash and brown sedimentary breccia and sandstone (figure 10). The narrow outcrop belt, approximately 1200 by 75 feet (365 by 25 m), extends along an east-west shoreline and may be faulted against brecciated Tintic Quartzite to the east. The contact is indicated by a 1-foot-thick (0.3 m), brown, well-cemented breccia of mostly Tintic Quartzite that strikes N. 69° E. and dips 67° SE. Unfortunately, the outcrop is so shattered that structural relationships cannot be ascertained. Strike of the Tertiary beds ranges from N. 57 to 69° E. and the dip ranges from 20° NW. to vertical to 67° SE. No other Tertiary exposures occur on Ladyfinger.

The volcanic ash in the Ladyfinger outcrops is medium gray, laminated, and massive. It consists almost entirely of glass shards, although it contains a few suspended angular clasts of quartzite, shale, and black obsidian. The contact between the brown clastic rocks and the ash varies from very sharp to gradational. Coarse material occurs as clots, stringers, and irregular bodies in the sandstone and in the reworked volcanic ash matrix. The sedimentary breccia is very poorly sorted with individual clasts as large as one foot (0.3 m) in diameter. The clasts consist of very angular, olive-green shale, Paleozoic limestone and quartzite, Precambrian schist, slate, graywacke, and argillaceous sandstone. The shale is the dominant clast lithology.

## QUATERNARY

Quaternary deposits on Antelope Island consist mostly of lacustrine sediments deposited by Late Pleistocene Lake Bonneville and Holocene Great Salt Lake. Sand and gravel beach deposits of Lake Bonneville are found more than 1000 feet (305 m) above the present Great Salt Lake shoreline and are concentrated along four prominent and several intermediate shorelines which represent stillstands of the rising and falling lake. Fine-grained deposits are locally exposed in wave-sheltered Lake Bonneville coves, in Holocene lagoons, and around modern springs. Alluvial, eolian, and mass-wasting processes have been active in post-Bonneville time, producing deposits that locally cover the bedrock and lacustrine deposits. Mining and other human activities have disturbed deposits in some areas on the island.

**Lacustrine sand, silt, and clay deposits (Q1f)** — Fine-grained sediments deposited below wave base in Lake Bonneville are buried beneath various thicknesses of regressive shoreline deposits. Layers of fine sand, silt, and clay occur at or near the surface in wave-sheltered areas on the north sides of several, mainly west-facing, embayments. Elsewhere, local areas of fines that grade into coarser grained deposits are small or poorly exposed and have not been differentiated. Lacustrine fine-grained deposits exposed in stream cuts above White Rock Bay are finely laminated and are stratified into a lower greenish, silty and clayey sand facies and an upper "cleaner" white, sand facies. The lower deposits contain reworked marl with ostracods.

**Lacustrine sand and gravel deposits (Q1g)** — Sand and gravel deposits of Lake Bonneville and Great Salt Lake cover much of Antelope Island. The sediments, derived from local bedrock and colluvium, were deposited on or near shore at various levels of the lake. Abandoned shorelines are a striking geomorphic feature of the island and are expressed as boulder concentrations, beach ridges, wave-built terraces, and wave-cut benches. Coarse-grained lacustrine deposits typically vary in grain size and sorting from relatively well-sorted sand or fine gravel to stratified mixtures of gravel and sand.

**Lacustrine boulder deposits (Q1b)** — Boulders are a notable component of some shore-zone deposits, representing high-energy erosion of bedrock knobs and headlands. Extensive accumulations of Tintic Quartzite boulders form strandlines on hillsides at the north end of the island.

**Lacustrine oolitic sand deposits (Q1o)** — Ooids, accretionary grains of calcium carbonate, occur in varying amounts in Holocene beach deposits but are most abundant along the west side of the island. A large supply of fine-grained quartz sand at the north end of the island, derived from Tintic Quartzite, provides nuclei for precipitation of calcium carbonate in wave-agitated water. The ooids are generally spherical, medium-sand-sized, and have a polished luster.

**Lacustrine lagoonal deposits (Q1l)** — Organic-rich sand, silt, and clay deposits are localized in lagoons behind Holocene beach ridges and spits on the gently sloping east side of the island.

**Marsh deposits associated with springs (Qsm)** — Organic-rich sand, silt, and clay deposits occur in wet areas surrounding modern springs. Spring-fed marshes are most abundant and extensive on the east side of the island, where they commonly occur in old gravel pits and behind beach ridges near the Great Salt Lake.

**Colluvial deposits (Qc)** — Colluvium occurs commonly as a thin deposit on the flanks of ridges above the Bonneville shoreline. Only larger, thicker, and more discrete deposits of colluvium and talus (including rock-fall debris) are mapped. These accumulations occur normally below steep slopes, mainly along portions of the Bonneville shoreline platform and within some drainages.

**Landslide deposits (Qms)** — Slumps and larger, complex rotational and translational landslides are found in coarse-grained lacustrine deposits and in colluvium above the Bonneville shoreline. The largest slope failure, above White Rock Bay, occurred in Provo shore-zone deposits sometime after Lake Bonneville receded below the level of the landslide. Recent small slumps have occurred in colluvial slopes and in wave-cut slopes along the modern shore.

**Alluvial-fan deposits (Qaf)** — Alluvial fans, common in open, low-gradient areas on both sides of the island, are developed below the Bonneville shoreline and post-date regression of the lake. Most fans bury, and therefore are also younger than, the Gilbert shoreline. The alluvium is dominantly coarse-grained (sand and gravel) debris-flow and flash-flood deposits, largely derived from lacustrine deposits and colluvium.

**Stream channel alluvial deposits (Qal)** — Channelized alluvium generally occurs along ephemeral drainages cut into lacustrine deposits and is continuous with alluvium deposited in fans. Channel alluvium is dominantly coarse-grained (sand and gravel) debris-flow and flash-flood deposits, largely derived from lacustrine deposits and colluvium.

**Siliceous wind-blown sand deposits (Qes)** — Dunes and thin sheets of siliceous wind-blown sand extend landward from Gilbert-level and lower beach deposits at the north end of the island above Bridger and White Rock Bays, where Tintic Quartzite-derived sand is abundant. Siliceous wind-blown deposits are older, morphologically more subdued, and finer grained than the oolitic dunes (Qeo) developed adjacent to the Great Salt Lake.

**Oolitic wind-blown sand deposits (Qeo)** — Sparsely vegetated, active sand dunes comprised dominantly of ooids extend landward from Holocene beach deposits at the north end of the island above Bridger and White Rock Bays.

**Disturbed ground (Qfd)** — Sand and gravel mining has removed lacustrine and alluvial deposits from extensive areas along the southeast side of the island, exposing underlying bedrock, and from excavations on the north part of the island. In some of the excavations, especially in the large pits on the southeast part of the island, reclamation contouring has redistributed overburden and soil materials.

**Artificial fill (Qf)** — Artificial-fill deposits consist of broken rock, sand, and gravel spoil from mining and drilling operations. Only larger spoil areas have been mapped.

## STRUCTURAL GEOLOGY HIGH-GRADE METAMORPHIC STRUCTURES

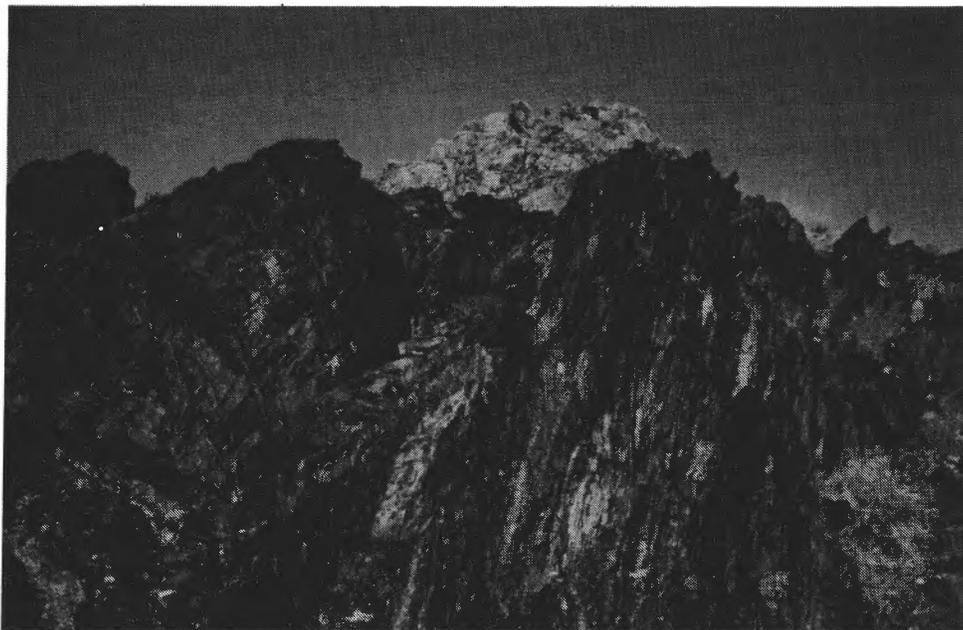
The bedrock core of Antelope Island is composed of highly metamorphosed rocks of the Precambrian Farmington Canyon Complex (frontispiece; figure 3 and 4; plate 2, lithologic column). Most of these rocks are layered gneiss, migmatitic gneiss, and schist. Except where overprinted by later events, they are in the amphibolite metamorphic facies. Hedge and others (1983) reported sillimanite, an indicator of metamorphic intensity, on the island. Rocks of the Farmington Canyon Complex have a strong foliation that strikes northeast and dips steeply to the southeast. The rocks exhibit extensive ductile deformation, including complexly contorted folds, gneissic layering and foliation, mineral and stretching lineations, and boudinage lenses. Locally, intrusions have penetrated the foliated rocks, most notably in the Red Rocks area on the west side of the island and in the Dairy Springs area on the east side. The intrusion on the west side of the island is crudely concentrically foliated, whereas the pegmatitic granite on the east side is nonfoliated. A few smaller plugs show evidence of forceful intrusion; the surrounding foliated rocks are contorted and shattered.

## LOW-GRADE METAMORPHIC STRUCTURES

On the north half of the island, the Farmington Canyon Complex rocks are unconformably overlain by Proterozoic and Cambrian metasedimentary rocks which, in general, dip to the north. These rocks are only slightly metamorphosed; they show bedding, ripple marks, and other sedimentary features. This metamorphism is correlative with the retrograde metamorphism described below.

## SHEARING AND RETROGRADE METAMORPHIC STRUCTURES

In numerous areas on the island, the high-grade metamorphic rocks of the Farmington Canyon Complex have been retrogressively metamorphosed to the lower greenschist facies and exhibit shear features, faults, vein arrays, and cleavage (figure 11). Retrograde metamorphism and shearing are commonly associated but do not always occur together. Similar lower greenschist-facies features are present in varying degrees in the Late Proterozoic and Cambrian rocks. All the Precambrian and Cambrian rocks are cut by numerous shear zones which usually trend northeast, although some trend north or northwest. The shear zones range in width from a few feet to nearly a mile (1.6 km), and one can be traced for nearly five miles (8 km). Only the most well-defined shear zones were mapped separately. The shear zones show semi-brittle deformation and are characterized by intense phyllonitic cleavage and low-grade alteration. The cleavage is defined by parallel mica grains and stretched quartz grains, and often cuts gneissic foliation. Slickensides occur on shear surfaces in phyllonite. Tension gashes and Riedel shears are also associated with the shear zones and low-grade metamorphism. In many places, the shear zones parallel the gneissic foliation, taking advantage of weaker zones in the foliated rock.



**Figure 11.** Strong cleavage (right side of photograph) and weak cleavage (left side) along a shear zone continue upward from the Farmington Canyon Complex into the Mineral Fork Formation. The cleavage and associated alteration formed during the Cretaceous Sevier orogeny. The contact between the Farmington Canyon Complex and the Mineral Fork Formation is near the top of the darker rocks, but it is difficult to see because of the intense chloritization and deformation. The lighter rocks at the top of the photograph are the dolomite member of the Kelley Canyon Formation. Outcrop is located near the Daddy Stump Ridge fault in NW¼, section 29, T. 3 N., R. 3 W.

#### Antelope Island shear zone

A particularly broad shear zone, the largest on the island, is herein named the Antelope Island shear zone. It extends north 20° to 25° east from section 19, T. 2 N., R. 3 W. to section 29, T. 3 N., R. 3 W. It may extend northerly into section 9 but is less developed in that area. It dips steeply northwest, cutting the dominant southeast-dipping foliation in the Farmington Canyon Complex rocks. The maximum width observed is about 3000 feet (915 m), although the average width is about 1500 feet (455 m). It is easily identifiable by intensely dark-green chloritization. The most intense shearing is near the sharply delineated west edge of the zone. Shearing features diminish gradually toward the east within the zone.

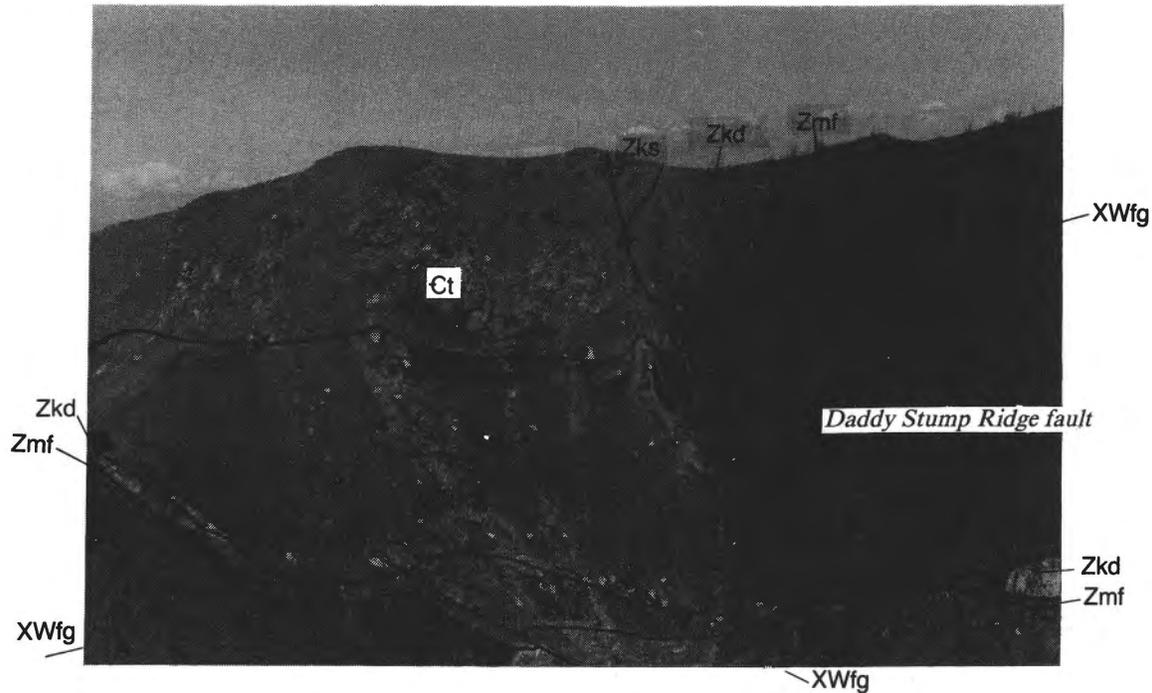
#### FAULTS

Several faults were mapped, mostly where they displace Proterozoic rocks. It is likely that additional faults cut the Farmington Canyon Complex and the Tintic Quartzite, but the lack of distinctive marker beds in these units prevented their recognition. In some areas, faults that displace Late Proterozoic rocks extend into the Farmington Canyon Complex as sheared and highly silicified zones. Most of the faults are high-angle faults that cut tilted Proterozoic rocks at the north end of Daddy Stump Ridge. Displacements on these faults are small, rarely exceeding 50 feet (15 m). Faults with major displacements are discussed separately. No major thrust faults are exposed on Antelope Island.

#### Daddy Stump Ridge fault

The major north-trending fault just west of Daddy Stump Ridge, herein named the Daddy Stump Ridge fault, can be traced for two miles (3.2 km). Along the southern trace of the fault the rocks on the east block are intensely sheared, more resistant, and are altered to dark greenish-black. In a few areas the rocks are silicified and locally are mineralized. The fault strikes N. 10° W. for most of its length; the north end curves sharply to the east (figure 12). This fault dips to nearly vertical in the southern half, but the dip decreases to about 60° easterly in the northern segment. The south end is covered by Lake Bonneville deposits, while the north end is concealed beneath a landslide. The Daddy Stump Ridge fault is a reverse fault that places older Farmington Canyon Complex rocks on younger Late Proterozoic rocks along its northern part. We interpret this fault to be a minor backthrust, probably related to movement along nearby major thrust faults (the Willard or Ogden thrusts) during the Cretaceous Sevier orogeny (figure 2). Near the sharp curve in the fault at the north end, Late Proterozoic and Cambrian rocks of the footwall are tightly folded. There (and elsewhere on the island) quartzite, which typically deforms in a brittle manner, has been deformed plastically. Near the curve the Tintic Quartzite is tightly folded along with the more ductile slate and diamictite rocks.

Late Proterozoic rocks near Stringham Peak have been offset a minimum of 800 feet (245 m), but actual slip may be much more. Offset appears to increase farther south, but it cannot be measured because Farmington Canyon Complex rocks are found on both sides of the fault.



**Figure 12.** View looking east toward Daddy Stump Ridge fault, near Stringham Peak (SW¼, section 29, T. 3 N., R. 3 W.). The Daddy Stump Ridge fault is marked by the labeled line, sawteeth on the upper plate. It is a northwest-to west-directed backthrust whose offset increases to the south (right) and that dies out behind the ridge in the left side of the photo. Rocks near the bend in the fault are tightly folded. In the footwall, the Tintic Quartzite forms a syncline. Labeled units are: XWfg-chloritized and hematitized gneiss, mylonite, and phyllonite, of the Farmington Canyon Complex; Zmf-Mineral Fork Formation; Zkd-dolomite member, and Zks-slate member of the Kelley Canyon Formation; and Ct-Tintic Quartzite.

### Stringham Peak faults

The western fault bounding a tilted block in which the Mineral Fork and Kelley Canyon Formations and the Tintic Quartzite are preserved at the north end of Daddy Stump Ridge is herein named the West Stringham Peak fault. Although it has the N. 10° W. trend of the Daddy Stump Ridge fault, it has normal displacement of no more than 100 feet (30 m) and has the downthrown block to the east. Although aligned, the two faults are not continuous. The East Stringham Peak fault also cuts the tilted block and has a sinuous trace. At its north end it parallels the west fault, but at its south end it trends east-west. The downthrown side is to the northeast and has displacement of as much as 250 feet (75 m). Near the curve at the southern end of the fault, the adjacent Late Proterozoic rocks are tightly formed into a recumbent fold.

### Elephant Head fault

The herein-named Elephant Head fault trends N. 60° W. and appears to be a normal fault whose downthrown block is to the northeast. It parallels the trend of Elephant Head ridge and is at least one mile (1.6 km) long. Where it cuts the Late Proterozoic rocks, the slate member is faulted against

the Mineral Fork Formation. The displacement is between 100 and 200 feet (30-60 m). Rocks on the northeast side of the Elephant Head fault generally dip northward about 30 degrees, whereas those on the southwest side dip more than 50 degrees to the north. Several branch faults with offsets less than 50 feet (15 m) extend northeast from the Elephant Head fault. Some are downthrown to the northwest, others to the southeast, and in one place a prominent graben is formed. They cannot be traced far into the Farmington Canyon Complex. In one place, a sharp flexure parallels these subsidiary faults. Here the brittle dolomite member of the Perry Canyon Formation is sharply folded rather than faulted. A large quartz body (Kq) straddles the Elephant Head fault, but its relationship to the fault is unclear.

### Mormon Rocks fault

The Mormon Rocks fault strikes east-west along the east end of Mormon Rocks ridge. It mostly cuts the Farmington Canyon Complex and is identifiable because foliation in the red granite unit (XWfr) on the south side of the fault is overprinted by retrograde metamorphism and cleavage. At the east end of the fault the red granite is brought against steeply tilted and attenuated Late Proterozoic rocks. Rocks near the east end of the fault trace are strongly silicified.

### Ladyfinger fault zone

A complex, east-west-trending fault zone is exposed in the Tertiary and Cambrian beds on the north tip of Ladyfinger. Its relationships are unclear because of poor exposures. It is late Tertiary or Quaternary in age since it cuts the Salt Lake Formation. The Tintic Quartzite is highly shattered in the fault area, and the Salt Lake Formation rocks are steeply tilted as well as displaced.

### Faults adjacent to Antelope Island

The East Great Salt Lake fault zone is located approximately one mile (1.6 km) west of the west shore of Antelope Island and is a major Basin and Range fault that has been active during Quaternary time (figure 2) (Cook and others, 1980; Viveiros, 1986; Pechmann and others, 1987). It is along this fault that the island has been elevated and tilted. Displacement is large, measured in thousands to tens of thousands of feet. A north-south branch of this fault may extend onto the island near Westside Spring on the southwest part of the island. Seismic and gravity evidence support the presence of this branch (D.R. Mabey, unpublished information), although it is poorly defined on the island. Geophysical evidence has defined the East Antelope Island fault block east of the island (Cook and others, 1966; Wilson and others, 1986), but no faults of this system appear to be present on the island.

### FOLDING AND TILTING

On a large scale, bedded rocks of Antelope Island are generally tilted rather than folded. Local folding is most pronounced in the vicinity of faults and may be related to movement on those faults (figure 12 and 13). The Late Proterozoic and Cambrian rocks are warped across broad tilted surfaces so that strikes and dips are variable, although dips are generally to the north.

Tertiary rocks on the east side of the island strike northerly and dip 20 to 45 degrees to the east toward the East Antelope Island fault.

### ISOSTATIC REBOUND

No evidence for significant structural deformation is known in the Quaternary sediments that mantle the island. Shoreline elevations on the island are higher than along the margins of the Bonneville topographic basin, indicating isostatic rebound following recession of Lake Bonneville (Crittenden, 1963; Currey, 1982). In addition, accurate surveying has revealed that some shorelines may be slightly deformed by regional tectonic processes (D.R. Currey, personal communication, 1987).



*Figure 13. Exposure of a remnant of the Kelley Canyon Formation and the Tintic Quartzite on Bamberger Hill, along Daddy Stump Ridge in the central part of the island (section 32, T. 3 N., R. 3 W.). The rocks are tightly folded and faulted. The light rocks to the left and along the base are Tintic Quartzite. The darkest rocks are mostly Upper Proterozoic slate, but the dolomite and diamictite are also present. All of these rest unconformably on the Farmington Canyon Complex. A small mine and dump with copper oxide minerals are present near the faulted contact between the light and dark rocks.*

## JOINTS

Joint sets are well developed in many Farmington Canyon Complex rocks. As many as five sets are present in one area. Joints probably developed from unloading caused by uplift and erosion.

## GEOLOGIC HISTORY

### PRECAMBRIAN DEFORMATION AND INTRUSION

#### Archean sedimentary and metamorphic history

The rocks of the Farmington Canyon Complex, though strongly overprinted by Proterozoic and Phanerozoic events, have a history extending into the Early Archean (Stacey and others, 1968; Compton and others, 1977; Hedge and others, 1983; Bryant, 1988). Hedge and others (1983) have established that the original rocks were sedimentary and may be as old as 3600 Ma. These were intruded by basalt and gabbro prior to a period of intense metamorphism that occurred about 2600 Ma. Condie (1969) assigned the oldest Farmington Canyon Complex rocks to the Wyoming province, and thus to the ancient protocontinent of North America. Little is known about the earliest events that affected these rocks.

#### Intrusion of granite

The migmatitic gneiss (XWfm) and the red granitic gneiss (XWfr) units were part of a granite body intruded prior to Proterozoic metamorphism. Hedge and others (1983), using U-Pb data from zircons, obtained results believed to date the original intrusion at about 2020 Ma. One sample was from the migmatitic gneiss unit (XWfm) on the west-central part of the island (plate 1), and another from a drill core obtained about a mile (1.6 km) west of the island. Their ages do not coincide with other recognized intrusive events (about 1700-1800 Ma) in the Rocky Mountain area.

#### Early Proterozoic high-grade metamorphic event

The Farmington Canyon Complex was intruded and overprinted by intense metamorphism about 1790 Ma when the Wyoming province was sutured to other parts of the Archean basement, enlarging the Proterozoic basement of the North American continent. During this event, recognized throughout much of North America, Farmington Canyon Complex rocks were more extensively overprinted than were nearby areas of Wyoming and Montana (Hedge and others, 1986). Most high-grade mineral assemblages and deformation features in the Farmington Canyon Complex of Antelope Island were formed during this event (Hedge and others, 1983; Bryant, 1988).

### LATE PRECAMBRIAN AND PALEOZOIC QUIESCENCE

Evidence from Antelope Island and surrounding areas indicates a long period of quiescence with no significant metamorphism or tectonic deformation from Late Precambrian to

early Mesozoic time. Outcrops of the Mineral Fork and Kelley Canyon Formations, and the Tintic Quartzite, are only slightly metamorphosed and show typical sedimentary features (figure 13). The slight metamorphism may be the result of deep burial and Mesozoic low-grade metamorphism.

The Late Precambrian and Early Cambrian units were deposited between 770 and 500 million years ago (Christie-Blick and Levy, 1989). The Mineral Fork is thought to represent deposition from an extensive glacial event into an ocean that covered parts of this region (Christie-Blick, 1983; Crittenden and others, 1983). The dolomite and slate members of the Kelley Canyon Formation may represent deposition in a shallow marine environment. The Tintic Quartzite, which disconformably overlies the Kelley Canyon Formation, represents the near-shore deposits of a transgressing Paleozoic ocean. No other Paleozoic or Mesozoic formations are preserved on Antelope Island, although they are well represented in surrounding ranges. Formations deposited during this interval, and preserved in nearby areas, are generally conformable and were deposited mostly in low-energy environments.

### SEVIER OROGENY

Roughly 140 to 65 million years ago, western North America was subjected to the mountain-building event known as the Sevier orogeny. During this event great "sheets" of rock were transported many miles eastward on nearly horizontal thrust faults. One or more such thrust faults cut the rocks beneath what is now Antelope Island, and others are known to have ridden over the rocks now exposed on the island (figure 2). During this time, the Antelope Island shear zone, the Daddy Stump Ridge fault, the Elephant Head fault, the Stringham Peak faults, and the other smaller faults, folds, cleavage, and shear zones in the Precambrian and Cambrian rocks probably formed. The rocks were also chloritized and quartz veins were emplaced. Silicification and hematitization may have also occurred. Few rocks on the island remained unaffected.

A comparison of the geology of the Precambrian and Cambrian rocks of Antelope Island with surrounding areas indicates that the rocks on the island are most similar to rocks in the lower plate of the Willard thrust exposed in the Ogden area along the Wasatch Front. There, the upper plate of the Willard thrust contains an extremely thick section of Proterozoic and Paleozoic rocks, and the lower plate contains a thin section of Paleozoic rocks and no Proterozoic rocks (Crittenden and Sorensen, 1985a; 1985b). The Willard thrust fault was probably positioned just a few hundred feet above the rocks now exposed on the island. The trace of the Willard thrust passes between Antelope and Fremont Islands, (located six miles or 9.7 km to the northwest); rocks on Fremont Island are believed to be part of the upper plate of the Willard thrust.

The Ogden thrust, which underlies the Willard thrust in the Ogden area, places rocks of the Farmington Canyon Complex on itself and on the Tintic Quartzite (Bryant, 1984; Crittenden and Sorensen, 1985a; 1985b). It appears likely that the Ogden thrust passes beneath the rocks now exposed on the island.

The shearing, retrograde metamorphism, the backthrust, and most of the other faults on the island were probably contemporaneous with movement on one or both of these major thrust faults.

### TERTIARY DEPOSITION

Mountains formed during the late Cretaceous to middle Tertiary shed coarse sediments as debris flows, mud flows, and channel deposits as alluvial fans. Coarser materials collected at the mouths of ancestral canyons, while finer materials were deposited in the more distal areas. Lacustrine deposits formed in the basins between alluvial fans and at the distal ends of the fans. Such rocks, probably deposited during the Eocene, now compose the conglomeratic unit (table 1). The mountains from which these sediments were eroded were composed of rocks of Paleozoic age. Incorporated volcanic materials, possibly derived from Eocene volcanics, indicate nearby volcanic activity.

The Salt Lake Formation is thought to have been deposited during Miocene and Pliocene time (about 18 to 1.5 million years ago) in basins formed by Basin and Range faulting. Volcanic activity occurred during this time and most deposits contain interbedded tuffaceous sandstone, volcanic ash, and other volcanically derived materials (Hintze, 1988).

### BASIN AND RANGE FAULTING

Antelope Island is part of a large structural block bounded on both sides by major high-angle, possibly listric, normal faults that formed during the Basin and Range episode of extension (figure 2). Between 17 and 14 million years ago, block faulting began to affect western Utah, forming the Basin and Range topography that characterizes the area today (Hintze, 1988, p. 74). This fault activity continues to the present. Antelope Island rose as a mountain range with basins on either side that filled with the detritus from this and surrounding ranges. The East Great Salt Lake fault zone is the principal Basin and Range fault along which Antelope Island has risen.

Probably as a direct result of faulting, Tertiary rocks on the east side of the island are tilted eastward from 20 to 45 degrees. This tilting must be taken into account in reconstructions of earlier events that affected the island.

### QUATERNARY HISTORY

Most of the Quaternary-age sediments on the island are of Lake Bonneville age and younger, ranging from about 23,000 years ago to the present (plate 2, time-lake level graph of Lake Bonneville). The extent of pre-Lake Bonneville sediments is unknown because they are mostly covered with younger deposits. Lake Bonneville, at its maximum extent, covered much of western Utah and the border areas of southeastern Idaho and northeastern Nevada. The many horizontal terraces and benches visible on hillsides around the island represent old shoreline levels of the lake as it rose and fell. The deepest part of Lake Bonneville was near the Grassy Mountains, 45 miles

(72 km) west of Antelope Island, where the water was more than 1000 feet (305 m) deep at its maximum. The land beneath Lake Bonneville has since risen, due to isostatic rebound, in proportion to the weight of the water column that was above it (Crittenden, 1963). Shoreline elevations in the central part of the basin, in the vicinity of Antelope Island, are therefore higher than at the borders of the basin.

The oldest prominent basin-wide shoreline, the Stansbury level, was constructed as the lake began to rise and submerge the existing landscape. It is discontinuous in the basin but locally well-developed on Antelope Island at elevations ranging from approximately 4430 feet to 4490 feet (1351-1369 m) (D.R. Currey, personal communication, 1988) approximately 300 feet (90 m) above the present level of Great Salt Lake. The shoreline is expressed as wave-abrasion platforms that are locally covered with laminated tufa and beachrock, or as low, gravel beach ridges containing boulders from nearby bedrock sources. Boulders are relatively common in Stansbury and other transgressive shoreline deposits because they were reworked from colluvium and weathered bedrock by the rising lake. Ages of Stansbury deposits range from 23,000 to 22,000 years old (Currey and others, 1984).

After Stansbury time, the lake fluctuated irregularly but gradually transgressed to its highest level, marked by the Bonneville shoreline, by about 16,000 years ago (Currey and others, 1984) (figure 14). The Bonneville level was controlled by a topographic threshold at an elevation of approximately 5090 feet (1550 m) at Zenda, Idaho (Red Rock Pass), where water spilled northward into the Snake River drainage. The lake oscillated near the threshold elevation, producing several different shorelines within a zone of 45 feet (14 m) (Currey, 1980). The dominant Bonneville shoreline on Antelope Island is at an elevation about 5250 feet (1600 m) and is marked by gravel and boulder beaches and wave-cut platforms around the highest peaks. Isostatic rebound of the island raised the shoreline approximately 150 feet (45 m) above the Zenda threshold.

Sometime between 14,500 and 13,500 years ago (Currey and others, 1984), the Zenda threshold was breached and the outlet eroded down to the level of a bedrock sill at Red Rock Pass, a few miles to the south. The ensuing catastrophic flood into the Snake River lowered the surface of Lake Bonneville approximately 360 feet (110 m) within a few months (Jarrett and Malde, 1987) to the Provo level. The Provo shoreline, at an elevation of 4850 to 4880 feet (1480-1490 m) on Antelope Island, is characterized by wave-cut platforms and gravel beaches, locally capped with beachrock. Many of the Provo beaches have extensive boulder deposits. As the climate became warmer and drier, Lake Bonneville receded and dropped below the Red Rock Pass threshold to elevations equal to historical lows of the Great Salt Lake by 12,000 to 11,000 years ago (Currey and others, 1984).

The late Pleistocene Gilbert shoreline, approximately 100 feet (33 m) above the Great Salt Lake, was produced by a small transgression of the lake about 11,000 to 10,000 years ago and represents the last stage of Lake Bonneville. The pre-Gilbert regression is represented by an unconformity over Bonneville-age lake-bottom sediments; the unconformity is overlain by Gil-



*Figure 14. View of a part of Antelope Island from the west, near Dry Canyon, showing etched shorelines and shoreline deposits of Lake Bonneville. The highest shoreline (along the distant ridge line) is the Bonneville level (about 5250 feet; 1600 m). The prominent shoreline in the middle distance is the Provo (about 4880 feet; 1487 m). The Gilbert shoreline occurs at the first prominent change in slope above the present shoreline. The prominent bench about halfway between the Gilbert and Provo shorelines is the Stansbury shoreline.*

bert-age transgressive deposits. This sequence has been exposed by erosion at the eastern tip of Sea Gull Point (W.E. Mulvey, oral communication, 1988). The Gilbert shoreline is displayed on Antelope Island at elevations of approximately 4260 to 4280 feet (1293-1305 m) as single and double beach ridges and, particularly on the east side, as bars and lagoons. On the north end of the island, winds reworked Gilbert beach sands. The dunes consist mainly of quartz sand, in contrast with the predominantly oolitic sand of dunes from Great Salt Lake shorelines in the same area.

The Holocene remnant of Lake Bonneville, the Great Salt Lake, fluctuated between the elevations of 4221 feet and 4180 feet (1287 and 1275 m) in the last 10,000 years, including historic highs of 4212 feet (1284 m) in 1873 and 1986-87, and a historic low in 1963 of 4191 feet (1278 m) (Currey and others, 1984). The highest Holocene storm berms on Antelope Island occur near an elevation of 4225 feet (1288 m). Holocene "coastal" deposits consist of oolitic beach sand, sand and gravel beaches, bars, and oolitic eolian "coastal" dunes.

Post-Bonneville alluvial fans, composed of debris-flow and debris-flood deposits, bury older lacustrine deposits and locally extend down to modern shorelines. Toes of these fans have undergone wave erosion during the recent rise of Great Salt Lake. Several post-Bonneville landslides have occurred in lacustrine deposits, and numerous small slumps in colluvium are believed to have occurred during the "wet period" of the early 1980s along the Wasatch Front. Rock-fall debris is found at or near the base of most steep outcrops.

## ECONOMIC GEOLOGY

The mineral resources of Antelope Island include construction materials, non-metallic resources, and metal occurrences. Construction materials and non-metallic resources include sand and gravel, road-base materials, roofing and flagstone slate, riprap, crushed stone, oolitic sand, and building stone. By far the most important use of geologic materials has been for construction purposes, mostly for causeway and highway construction. Known metallic mineralization is limited to occurrences of copper and iron.

### SAND AND GRAVEL AND ROAD BASE MATERIAL

In 1967, the Utah Department of Transportation (UDOT) investigated two potential sources of sand and gravel on the northern part of the island for use in constructing a causeway from Syracuse to Antelope Island. The first area was in the N  $\frac{1}{2}$ , section 32, T. 4 N., R. 3 W. (UDOT material site number 06069). Thirteen holes ranging in depth from 2 to 27 feet (0.6-8.2 m) were augered on the site. Granular material was present to at least a depth of 27 feet (8.2 m). Seven samples of material from several holes and depths were obtained; the gravel content averaged 31 percent, sand averaged 56 percent, and silt and clay averaged 13 percent. Liquid limits ranged from non-plastic to 26, plasticity indexes ranged from non-plastic to 7, and the gravel had a wear of 19.1 percent. Material from this deposit was subsequently used as fill on the causeway.

The second area was in the NW  $\frac{1}{4}$ , SE  $\frac{1}{4}$ , section 4, T. 3 N., R. 3 W. (UDOT material site number 06070). Five holes were augered that ranged in depth from 9 to 20 feet (2.7-6.1 m). Four samples taken in two of those holes revealed a gravel content of 38 percent, sand content of 57 percent, and 5 percent silt and clay content. All material was non-plastic and had a zero swell. Material from this site was never used.

In 1969, the UDOT opened a pit in SW  $\frac{1}{4}$ , section 31, T. 4 N., R. 3 W. (UDOT material site number 06068). The thickness of sand and gravel was 30 feet (9.1 m). Three cut-bank samples were obtained from different levels for testing. The gravel content averaged 60 percent, sand 31 percent, and silt and clay 9 percent. Liquid limits ranged from 18 to 29, plasticity indexes ranged from non-plastic to 6, the swell was zero on all samples, and the gravel wear averaged 38 percent. A large amount of material from this pit was used on the causeway. By the end of 1973, all the gravel lenses had been excavated and only sand and silt remained (A.K. Hunsaker, UDOT, written communication, 1987). The pit was later extended to the southeast and much of the material removed was used for maintenance of the causeway.

During 1975 and 1978, the UDOT investigated alluvial fans and beach-sand deposits on the southeast side of the island. A large quantity of embankment material was needed for the construction of Interstate Highway 80 from Saltair to Redwood Road in Salt Lake City. The areas investigated were parts of sections 15, 22, and 27, T. 2 N., R. 3 W. During the two years, 89 holes were augered and 20 holes were rotary drilled in these sections. The holes ranged in depth from 2 to 105 feet (0.6-32 m) and enough granular material was found to satisfy construction requirements. Sixty-one samples were tested; 31 were classed as A-1-b material (AASHO classification), 16 as A-2-4 material, and the remaining samples ranged from A-4(0) to A-7-6(12) material. In general, the gravel content was between 10 and 20 percent. The silt and clay percentages of the samples ranged from 7.3 to 95.9 percent, but sand was, by far, the largest volume of material. In 1979 and 1980 about 16 million cubic yards of material were excavated from this part of the island for highway construction (J.T. McCleary, UDOT, written communication, 1987). The material was carried by a 13-mile-long (21 km) conveyor belt to a stockpile and loading facility west of Salt Lake City near 5600 West and North Temple Streets. At that time, the conveyor belt system was the longest ever built in the world.

Many exposures, mostly in gullies, were examined in sand and gravel deposits around the perimeter of the island for this study. As indicated by the UDOT tests, gravel is not a large fraction in any of the deposits, and sand dominates.

### ROOFING AND FLAGSTONE SLATE

James Hall (1852, p. 126-128), with the 1850-51 Stansbury Survey of the Great Salt Lake, was probably the first to note the slate on the various Great Salt Lake islands. He reported:

"The specimens collected in the islands and shores of the Great Salt Lake are sufficient to give one a very good idea of the general geological features. The specimens are

of metamorphic rocks, consisting of talcose and mica slates, hornblende rocks, and a few specimens of granitic or syenitic character.

Some specimens of the latter description occur along the valley of Ogden's River, Antelope Island, Fremont Island, a part of Promontory Point, and Mud Island, on the east side of the lake, judging from the numerous specimens, consist principally of talcose and mica slates, with hornblende rock."

On Antelope Island, the slate is assigned to the upper member of the Kelley Canyon Formation. Several pits and small quarries investigating these slates have been opened along the ridge crests in sections 19 and 20, T. 3 N., R. 3 W. The largest is located in the NE  $\frac{1}{4}$ , NW  $\frac{1}{4}$ , section 20, T. 3 N., R. 3 W. and is about 40 feet (12 m) wide and 90 feet (27 m) long. About 25 feet (8 m) of thin-bedded, platy and laminated slate and hard shale are exposed. Early settlers apparently attempted to quarry the rock into large sheets or plates in some of the pits, but it was difficult to maintain size uniformity because the rock plates were too thin and broke easily. More recently, the rock was broken into small pieces to be used as roofing gravel or to be incorporated into asphalt roofing shingles or rolls. However, it appears that little, if any, was shipped from the island; the volume of the dumps around the pits compare well with the volume of material removed from the pits.

The slate has the sheen typical of micaceous slates, but close examination shows little mica to be present. The colors of the rock include purple, brownish-gray, grayish-purple, lavender, light-orange, light-greenish-gray, medium-brown, and yellow. The rock is irregularly thinly laminated to thin bedded so that little of the material would be of the right thickness for flagstone. The splittable material ranges from  $\frac{1}{4}$  to 3 inches (5-75 mm) in thickness.

### OOLITIC SAND

Oolitic sand beaches and dunes are found along the northern and western shores of Antelope Island. Ooids are sand-size particles of calcium carbonate deposited concentrically around a nucleus of quartz or a brine shrimp fecal pellet. The calcium carbonate is present in the ooid as the mineral aragonite.

Calcium carbonate, at least 92 per cent pure, can be used as smelter flux. Although oolitic sand along the southern shore of the Great Salt Lake has been used for such purposes from time to time, none of the material from Antelope Island is known to have been used. Larsen (1957) analyzed three samples which averaged only 81 percent calcium carbonate, but the sampling was too limited to disqualify all the deposits.

### RIPRAP AND CRUSHED STONE

The Tintic Quartzite has been quarried for riprap in the NW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , section 25, T. 4 N., R. 4 W. Large, durable blocks and slabs of the quartzite were used to protect the embank-

ments of the north causeway. Quartzite, abundant on the north end of the island, may be ideal for use as road metal when crushed. Aggregate may be mined from the terrace deposits of Lake Bonneville, however, none of this material would be suitable for concrete aggregate because the rocks commonly contain reactive minerals.

### BUILDING STONE

Farmington Canyon Complex rock has been used extensively to face homes and other buildings in the Davis County area. Attractively patterned, durable gneisses found on Antelope Island could be used for similar purposes. Gneisses with interesting patterns may provide desirable garden stones and other decorative uses. Larsen (1957, p. 126) suggested that the quartz-plagioclase gneiss, located in the center of SE  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , section 33, T. 2 N., R. 3 W., would serve well as a building stone because of its blocky and jointed habit.

### METALLIC MINERAL OCCURRENCES

Occurrences of copper and iron have been discovered in scattered, east-west-trending quartz veins in the higher central part of the island. The mineralized quartz veins range from 6 inches (150 mm) to more than 15 feet (5 m) thick, and are as much as a half mile (0.8 km) in length. Mineralization along the veins is neither uniform nor consistent. Where present, it is concentrated along the margins of the vein, spreading slightly into the country rock. Copper also occurs along the unconformity separating the Farmington Canyon Complex from the Mineral Fork Formation. However, the shows are less common and smaller than the vein occurrences.

The most obvious mineralization is that of the copper oxides, malachite and chrysocolla. Other copper minerals observed include azurite, chalcantinite, bornite, and chalcocopyrite. Iron minerals are also present, such as hematite, magnetite, limonite, jarosite, and pyrite. Bornite, chalcocopyrite, and pyrite commonly occur as small blebs in the quartz veins; the other listed minerals are found as crusts, coatings, and stains, especially on joint and fracture surfaces. Mineral occurrences rarely exceed 30 feet (9 m) in length and 15 feet (5 m) in width. The average copper content is estimated to not exceed 0.3 percent at each occurrence. The age of mineralization is unknown.

Workings consist of shallow shafts and inclines, pits, small diggings, and one adit that was cut to intersect quartz veins at depth. Most prospecting activity probably took place between 1900 and the end of World War II, with the greatest effort made during World War I. It is doubtful that anything more than a few test lots of ore were ever shipped. Prospectors probably were lured to the veins by the reddish hematitic gossans that usually surround the mineralized areas. Locally, these gossans show boxwork structures stained with limonite.

Rocks in the Farmington Canyon Complex locally are stained red with hematite. This staining is probably not related to the copper mineralization and also seems to be unrelated to the chloritic retrograde metamorphism of the

Sevier orogeny. Some of the pegmatitic gneisses contain primary magnetite and hematite crystals.

### OIL AND GAS

The potential for significant oil and gas discoveries beneath Antelope Island appears low because of the presence of metamorphic rocks which underlie the island; however, some industry workers believe unmetamorphosed Paleozoic and Mesozoic sedimentary rocks may occur beneath thrust faults underlying the island. The Anschutz Corporation obtained a permit in 1981 to drill a 20,000-foot (6096 m) exploration well on Antelope Island to test the thrust fault relationships, but the project was never completed. The well was only drilled to a depth of about 133 feet, and no information is available on the rocks drilled (F.C. Moulton, personal communication, 1989). This well is located on the northeast part of Antelope Island (SE  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , section 17, T. 3 N., R. 3 W.). No other wells for oil and gas have been drilled on Antelope Island.

Better potential appears to lie in fault-bounded basins filled with thick Cenozoic sediments east and west of the island. Amoco Production Company drilled an exploration well approximately 4 miles (6.4 km) west of Antelope Island. This well bottomed in Precambrian rock at 10,419 feet (3175 m) and had a show of oil (Bortz and others, 1985). They report that west of the well the basin contains up to 14,000 feet (4270 m) of Tertiary sediments.

### GROUND WATER

Unlike other islands in the Great Salt Lake, Antelope Island has numerous springs that flow from bedrock and surficial deposits. Many of these ground-water discharge points are at low elevations around the periphery of the island and are submerged during periods of high lake level.

The better quality springs are generally above an elevation of 4400 feet (1340 m) on the east side of the island. These springs are thought to be locally recharged by rain and snow infiltrating into lacustrine and alluvial deposits as well as highly fractured and jointed bedrock. The water quality of springs located at higher elevations is good, whereas those at lower elevations contain greater concentrations of dissolved salts. Comparison with water emanating from similar bedrock springs in the Wasatch Range shows that sodium and chloride ion concentrations are greater in the spring water of Antelope Island. This suggests that storms passing over the Great Salt Lake and the Great Salt Lake Desert provide precipitation charged with higher than normal concentrations of sodium and chloride ions.

### GEOLOGIC HAZARDS

Fifty miles (80 km) of coastline, proximity to major faults, and steep, rocky slopes combine with local geology to produce various geologic hazards on Antelope Island. The principal hazards are lake flooding and erosion, landslides, debris flows, rock falls, and earthquake-induced ground shaking.



*Figure 15. Geologic hazards such as landslides, migrating sand dunes, and debris flows pose potential problems on Antelope Island. The greatest problems are created by high-water storm waves which batter the shorelines and damage roads, beach facilities, and other construction. This photograph shows the road on the northeast end of the island near the end of the causeway (SW ¼, section 19, T. 4 N., R. 3 W.). The road was damaged by waves during the 1986 high stand of the Great Salt Lake.*

### LAKE-LEVEL RISES

Fluctuations in the level of the Great Salt Lake cause flooding and erosion in coastal areas (figure 15). The 1983-87 rise of the lake to 4212 feet (1284 m) destroyed road access to the island and inundated public beaches. However, such dramatic lake-level rises have been relatively infrequent. The last time the lake reached an elevation near 4212 feet (1284 m) was in 1873. This level probably has been equalled or exceeded only three other times during the past 700 years (McKenzie and Eberli, 1985). Postglacial Great Salt Lake may have reached its highest level (4221 feet; 1287 m) 2000 to 2500 years ago when it was about 10 feet (3 m) above the recent high (Currey and others, 1988). Recent efforts to control the level of the lake by pumping water to the Great Salt Lake Desert have helped to reduce lake flooding and erosion hazards.

### MASS MOVEMENTS

Mass movements include landslides, debris flows, rock falls, creep, and other gravity-induced rock or soil movement. Landslide hazards exist in areas of wave erosion along the modern shore, on and beneath abandoned wave-built lake terraces, and on colluvial slopes above the Bonneville shoreline. A large landslide on the northwest side of the island above White Rock Bay removed gravel from the outer edge of a

prominent Provo shore platform. The landslide deposit has hummocky morphology which has not been cut by lake shorelines. It is thus less than about 13,000 years old, but probably more than several hundred years old. Several smaller landslides, mostly slumps, have occurred elsewhere in Lake Bonneville and younger shore-zone deposits.

Weathering of bedrock above the Bonneville shoreline has produced locally thick mantles of colluvium on steep slopes. Numerous small, fresh slumps and tensional fractures in the colluvium probably date from the wet years of the early 1980s, when landslides and debris flows were common in similar colluvium in the Wasatch Range (Wieczorek and others, 1983). On Antelope Island, the wet conditions reactivated old slumps and part of a complex landslide.

Debris flows and rock falls are two other mass-movement hazards on the island. Debris flows and debris floods, likely originating in saturated colluvium, have built extensive alluvial fans during post-Bonneville time on both sides of the island. A few visible scars and fresh, unvegetated deposits are evidence that the hazard persists. Rock falls are associated with some beach deposits consisting of large boulders of Tintic Quartzite and with bedrock promontories on the island's west side. The hazard exists at the base of steep slopes beneath perched lacustrine boulders and outcrops of fractured bedrock.

## EARTHQUAKES

Nearby major fault zones present a significant earthquake hazard. The central portion of the Wasatch fault zone, with surface-rupture zones about ten miles (16 km) east of Antelope Island and potential earthquake epicenters much closer, has experienced numerous large earthquakes (magnitude 7.0-7.5) during the Holocene (Schwartz and Coppersmith, 1984). The East Great Salt Lake fault zone is concealed beneath the lake less than a mile (1.6 km) west of Antelope Island. This fault may have an average Quaternary rate of movement that is half the Holocene rate for segments of the Wasatch fault zone and may be similarly capable of generating large earthquakes (Pechmann and others, 1987). Only one surface-rupturing event has occurred in historical time in the region. This was the 1934 magnitude 6.4 earthquake about 50 miles (80 km) northwest of Antelope Island in Hansel Valley, Utah. The largest earthquakes since 1850 near Antelope Island occurred in 1910 and 1914. They had estimated magnitudes of 5.5 and were located near Salt Lake City and Ogden (Arabasz and others, 1980).

Antelope Island lies within Uniform Building Code seismic zone 3 and Utah Seismic Safety Advisory Council seismic zone U-4, the highest seismic hazard zones in Utah (Ward, 1979). Strong ground-shaking during earthquakes could initiate landslides and rock falls, generate large waves (seiches) in the Great Salt Lake, and cause liquefaction in saturated sandy and silty deposits around springs or near the lake shore.

## OTHER HAZARDS

Antelope Island currently has few buildings or paved roads, but several other geologic hazards present potential problems for future development. Blowing sand from sparsely vege-

tated dunes may accumulate on roads and near buildings. Sand may also be eroded from beneath buildings. Disturbance of vegetation may cause dunes to become more active.

Clayey and silty lacustrine deposits beneath surficial sand and gravel, and saturated or compressible organic soils in lowland and spring-fed areas, may create unstable ground conditions for foundations. Lacustrine deposits on steep slopes are easily eroded, as indicated by deep gullies along off-road vehicle trails.

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Table 1

*Analytical Data on Potassium-Argon Age Determinations*

Sample: AIGW-0102

Unit: conglomeratic unit

Location: 40°52'52" N., 112°10'25" W.

Material Analyzed: Biotite concentrate, -80/+200 mesh

Date Analyzed: Nov. 13, 1987

Age: 42.9±1.7

 $^{40}\text{Ar}/^{40}\text{K} = 0.002523$  $^{40}\text{Ar}$  (ppm) = 0.01991; 0.01983 Average = 0.01987 $^{40}\text{Ar}/\text{Total } ^{40}\text{Ar} = 0.575; 0.512$ 

%K = 6.549; 6.654 Average = 6.602

 $^{40}\text{K}$  (ppm) = 7.876

Sample: AITW-0930

Unit: conglomeratic unit

Location: 40°52'48" N., 112°10'22" W.

Material Analyzed: Phlogopite concentrate, -80/+200 mesh

Date Analyzed: Oct. 28, 1988

Age: 38.8±1.5

 $^{40}\text{Ar}/^{40}\text{K} = 0.002279$  $^{40}\text{Ar}$  (ppm) = 0.01966; 0.01906 Average = 0.01936 $^{40}\text{Ar}/\text{Total } ^{40}\text{Ar} = 0.586; 0.392$ 

%K = 7.094; 7.147 Average = 7.121

 $^{40}\text{K}$  (ppm) = 8.495

Sample: AIMJ-0101

Unit: conglomeratic unit

Location: 40°52'51" N., 112°10'28" W.

Material Analyzed: Biotite concentrate, -80/+200 mesh

Date Analyzed: Oct. 28, 1988

Age: 49.2 ±1.9

 $^{40}\text{Ar}/^{40}\text{K} = 0.002897$  $^{40}\text{Ar}$  (ppm) = 0.02014; 0.02024 Average = 0.02019 $^{40}\text{Ar}/\text{Total } ^{40}\text{Ar} = 0.434; 0.347$ 

%K = 5.879; 5.806 Average = 5.843

 $^{40}\text{K}$  (ppm) = 6.970

Constants Used:

 $\lambda\beta = 4.962 \times 10^{-10}/\text{year}$  $(\lambda_e + \lambda'_e) = 0.581 \times 10^{-10}/\text{year}$  $^{40}\text{K}/\text{K} = 1.193 \times 10^{-4}/\text{g/g}$ 

Laboratory: Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, MA