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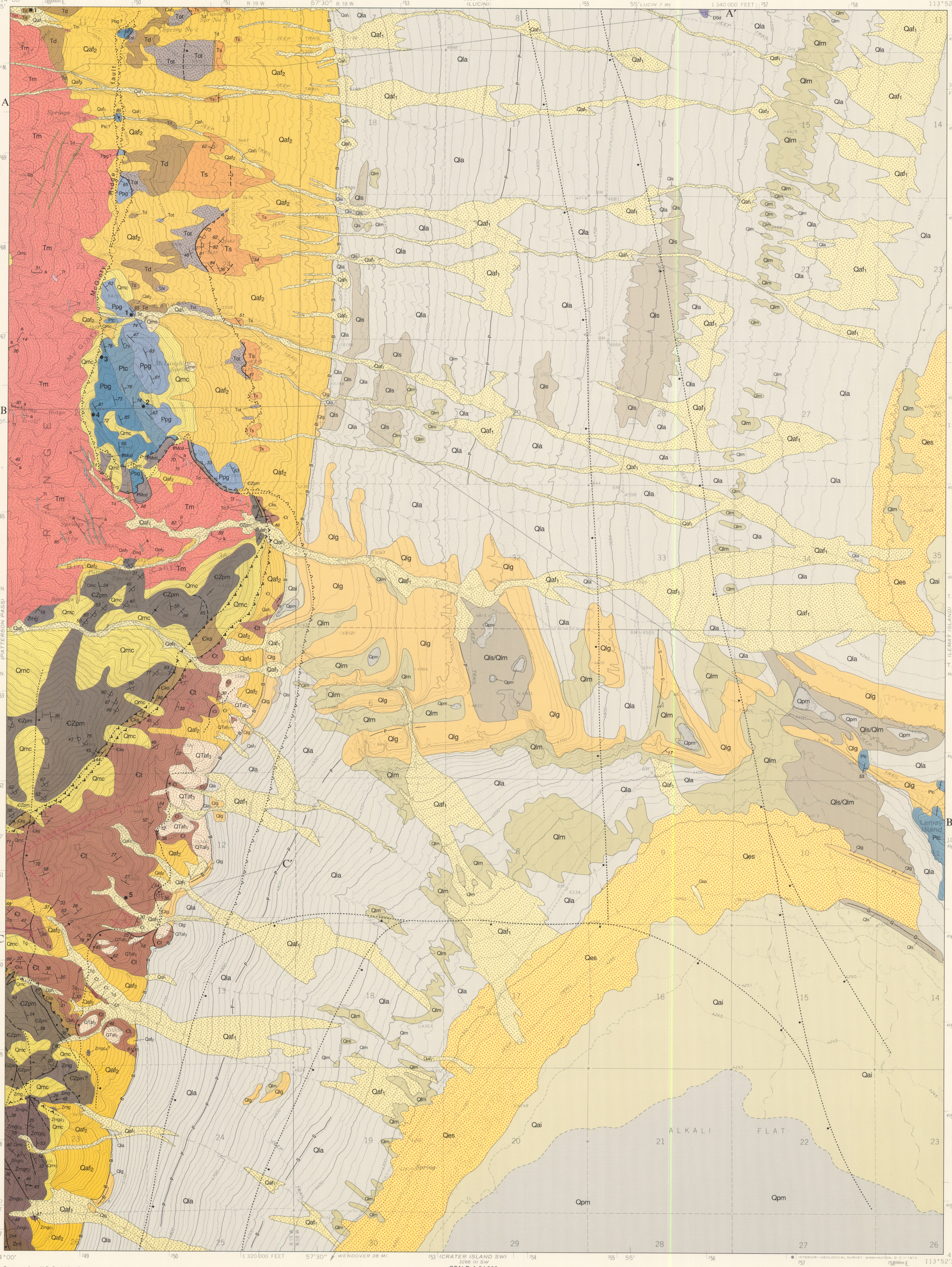


Base map from U.S. Geological Survey,
Crater Island NW 7.5′ Quadrangle, 1967

SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Cartography by J. Parker

MN
265 mils
14°55′ E

1993 MAGNETIC NORTH DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE CRATER ISLAND NW QUADRANGLE, BOX ELDER COUNTY, UTAH

by
David M. Miller
U.S. Geological Survey

1993

UTAH

QUADRANGLE LOCATION

DESCRIPTION OF MAP UNITS

Qmc Colluvium and talus (Holocene)--*Unconsolidated conglomerate, gravel, and sand slopewash deposits and blocky deposits on talus slopes.*

Qai Alluvial silt (Holocene)--*Thin sheets of unconsolidated, poorly sorted, brown silt with subordinate fine sand and clay. Deposited by streams and sheet floods along margins of Pilot Valley playa. Gradational into playa mud (Qpm), and interfingers with and is overlain by eolian sand (Qes).*

Qms Landslide deposits (Holocene)--*Displaced deposits of disaggregated rock and alluvium that form hummocky terranes.*

Qaf_1 Alluvial-fan deposits (Holocene and Pleistocene)--*Unconsolidated stream and fan deposits of poorly sorted gravel, sand, and silt. Deposited as alluvial cones at mouths of canyons and gullies, as alluvial floodplains bordering streams, and as sediments in stream channels. Slopewash included locally.*

Qes Eolian sand (Holocene and Pleistocene)--*Unconsolidated tan and light-brown fine sand and silt forming sheets and complexes of small dunes less than 1.5 m (5 ft) in height. Deposits are extensive along Pilot Valley playa, where they interfinger with lacustrine, alluvial, and playa deposits. Primarily consists of reworked regressive sandy marl deposits of Lake Bonneville. Most dunes stabilized by vegetation.*

Qpm Playa mud (Holocene)--*Unconsolidated, white, tan, and gray carbonate mud, oolitic sand, and gypsum and halite evaporite deposits (Lines, 1979) underlying Pilot Valley playa. Includes deposits of white to tan mud and silt on small playas behind Lake Bonneville barrier beaches.*

Qla Lacustrine and alluvial deposits, undivided (Holocene and Pleistocene)--*Varied, complexly interlayered, pale-colored deposits of lacustrine and alluvial origins including gravel, sand, and silt. In most places, unit consists of thin sheets of alluvium on poorly exposed lacustrine deposits.*

Qas Alluvial sand and silt (Pleistocene)--*Red sand and silt beds deposited on lacustrine marl (Qlm) and overlain by shoreline sand (too thin to be mapped) deposited by the Gilbert stage of Lake Bonneville.*

Qls/Qlm Lacustrine sand over lacustrine marl (Pleistocene)--*Well-sorted, fine sand that overlies silty white marl.*

Qls Lacustrine sand (Pleistocene)--*Unconsolidated brown sand in sheets as much as 3 m (10 ft) thick. Most deposits are just below Bonneville shoreline and between the Provo and Stansbury shorelines.*

Qlg Lacustrine gravel (Pleistocene)--*Moderately to well-sorted pebble, cobble, and sand deposits, with sand and silt matrix. Generally unconsolidated, but in places cemented by tufa. Interfingers with lacustrine sand (Qls). Locally includes poorly exposed underlying lacustrine sand or marl.*

Qlm Lacustrine marl (Pleistocene)--*White and buff, unconsolidated marl, clay, silt, and sand. In vicinity of gravel-bar complex extending from Pilot Range to Lemay Island, includes silty and sandy deltaic facies.*

Qaf_2 Older alluvial-fan deposits (Pleistocene)--*Unconsolidated, poorly sorted gravel and sand forming piedmont flanking Pilot Range. Mostly stream and fan deposits; slopewash included locally. Overlain by deposits of Lake Bonneville.*

$QTaf_3$ Oldest alluvial-fan deposits (Pleistocene and Pliocene?)--*Unconsolidated to partly consolidated, poorly sorted boulder, cobble, pebble, gravel, sand, and silt alluvial deposits forming raised terraces. Locally contains extensive pedogenic calcrete.*

Td Diabase (Pliocene?)--*Undivided reddish-brown, resistant diabase dikes and large nonresistant intrusive bodies that weather to soft, loose, brown soils. Generally fine-grained, hornblende-plagioclase mafic rock and pyroxene-plagioclase diabase. Diabase intrudes Miocene strata.*

Ts Sedimentary rocks (Miocene)--*Lithified, but generally nonresistant, green and brown fanglomerate; siliceous lake deposits such as conglomerate, sandstone, and siltstone; and limestone. Thin interbeds of white, altered, water-laid vitric tuff are included. Lake deposits are generally thin bedded and fine grained. Coarser rocks are mainly in lower part of section. Limestone is silty, dark brown, thin bedded. Marker unit of pebble conglomerate containing clasts of lineated metaquartzite indicated by dot-dashed line.*

Tf Felsite (Oligocene?)--*Light-gray felsite containing sparse phenocrysts of subhedral quartz, plagioclase, and alkali feldspar. Most outcrops are of north-striking, steeply dipping dikes.*

Tot Older tuff (Oligocene? and Eocene)--*White, altered tuff, possible rhyolite flows, and interbedded sedimentary and volcanic rocks. Tuff has phenocrysts of plagioclase, quartz, biotite, and hornblende in chalky, siliceous to clayey matrix. Rare flow-banding and rounded quartz grains are present in flows. Sedimentary rocks mostly are sandstone and siltstone, thinly interbedded with ash-flow tuffs and conglomerate consisting of reworked tuff.*

a Tm McGinty Monzogranite (Eocene)--*Coarse-grained, white to gray, porphyritic monzogranite to granodiorite. Phenocrysts of alkali feldspar are set in coarse-grained matrix of plagioclase, alkali feldspar, quartz, and biotite. Unit also includes pale-gray and cream-colored aplite dikes (a), commonly striking north and dipping steeply. Aplite in dikes commonly grades to pegmatite in borders or centers. The McGinty is considered latest Eocene in age.*

Tg Granodiorite dikes (Eocene)--*Light-gray, medium-grained, hornblende-biotite granodiorite with aphanitic to fine-grained matrix. Dikes vary in composition but are generally granodiorite.*

Ppg Grandeur Formation of the Park City Group (Permian)--*Interbedded light- and medium-gray, thin- to medium-bedded dolomite, chert, and sandstone. Quartz sandstone is fine grained, cemented by calcite, and commonly silicified and cherty; it typically weathers brown. Dolomite is sandy, well bedded, and rarely fossiliferous.*

Ptc Trapper Creek Formation (Permian)--*Thick-bedded, bioclastic limestone alternating with thin beds of silty limestone and dolomite, gray-brown dolomite, and clean gray limestone. Chert is sporadically present in limestone.*

Pbg Badger Gulch Formation (Permian)--*Laminated to thin-bedded, platy, dark-gray to black, silty limestone; less common laminae and thin beds of siltstone are browner than limestone. Some beds are bioclastic, typically containing crinoid fragments, spirifer brachiopods, and fusulinids.*

IPMcd Chainman Shale and Diamond Peak Formations, undivided (Pennsylvanian and Mississippian)--*Dark-gray shale, and dark-gray, dark-brown, and black sandstone and conglomerate with quartz, chert, and feldspar clasts.*

DSd Thick-bedded dolomite (Devonian and Silurian)--*Off-white, light- and medium-gray, faintly bedded to structureless dolomite and calcareous dolomite.*

Ꞓt Toano Limestone (Cambrian)--*Gray to tan, platy, laminated and thin-bedded limestone and phyllitic limestone with dolomite and siltstone partings. Lower part is dark gray, silt-rich, and gradational into the underlying Killian Springs Formation (Ꞓks).*

Ꞓks Killian Springs Formation (Cambrian)--*Dark-colored, graphitic phyllite. Lower part is homogeneous dark-gray, black, and dark-blue-gray graphitic phyllite, and upper part is dark-gray calcareous phyllite. Calcite content increases upward in upper part.*

ꞒZpm Prospect Mountain Quartzite (Cambrian and Late Proterozoic)-- *Light-colored, prominently bedded and cross-laminated quartzite forming massive cliffs.*

McCoy Creek Group of Misch and Hazzard, 1962 (Late Proterozoic)--*Alternating phyllite and quartzite units. In this area, consists of:*

Unit G--Divided into:

Zmg Upper subunit--*Dark phyllite and metasiltstone with interbedded marble and quartzite.*

Conglomerate subunit--Divided into:

$Zmgc_4$ ---Interval 4--*Dark-gray to black conglomerate and coarse-grained quartzite.*

$Zmgc_3$ ---Interval 3--*Dark-brown, rhythmically bedded phyllite and metasiltstone forming gentle slopes.*

$Zmgc_2$ ---Interval 2--*Light-gray, coarse-grained to conglomeratic quartzite forming steep cliffs; generally medium to thick bedded and cross laminated, brown weathering, and micaceous.*

$Zmgc_1$ ---Interval 1--*Dark-brown, quartzose phyllite with interbeds of coarse quartzite and conglomerate. Quartzite is dark gray, brown, and light gray, impure and poorly size sorted. Conglomerate is polymict and contains phyllite rip-up wedges. Forms slopes with small cliffs.*

Zmf Unit F--*Gray, well-bedded and cross-laminated, cliff-forming quartzite. Lenticular conglomerate at top contains rip-up clasts of phyllite, boulders and cobbles of quartzite, and rare jasperoid clasts.*

UNITS SHOWN ONLY IN CROSS SECTION

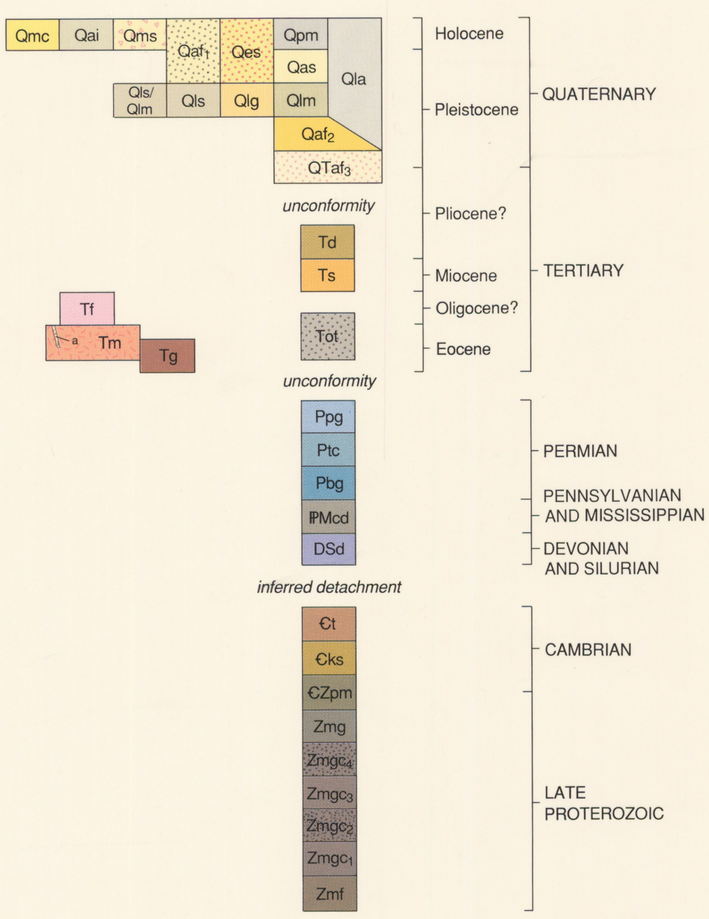
Ptf Third Fork Formation (Permian)--*Calcareous, platy sandstone and arkose, and silty limestone.*

Oes Ely Springs Dolomite (Ordovician)--*Dark-gray to black, poorly bedded, fractured calcareous dolomite.*

Oe Eureka Quartzite (Ordovician)--*White and light-gray orthoquartzite.*

Ogc Garden City Formation (Ordovician)--*Thinly interbedded blue-gray limestone, gray and brown silty limestone, and brown calcareous siltstone.*

CORRELATION OF MAP UNITS



MAP SYMBOLS

CONTACT--*Dotted where covered, dashed where gradational*

MARKER UNIT-- *Distinctive bed or unit within a map unit*

54 HIGH-ANGLE FAULT--*Dashed where location inferred, dotted where concealed; bar and ball on downthrown side; dip indicated*

BEDDING-PLANE FAULT--*Dashed where location inferred, dotted where concealed; barbs on hanging wall*

54 LOW-ANGLE NORMAL FAULT--*Dashed where location inferred, dotted where concealed; barbs on hanging wall; dip indicated*

GRAVITY-SLIDE BLOCK--*Dotted where concealed*

ORIENTATION OF BEDDING

12 Inclined

Vertical

74 Overturned

ORIENTATION OF FOLIATION

18 Inclined

Vertical

54 32 ORIENTATION OF FOLIATION AND BEDDING AT SAME OUTCROP

27 LINEATION--*Showing trend and plunge*

TRACE OF AXIAL SURFACE OF ANTICLINE

TRACE OF AXIAL SURFACE OF SYNCLINE --*Showing plunge*

45 a STRIKE AND DIP OF IGNEOUS FEATURES--*a, aplite; p, pegmatite dike*

● 4 LOCATION OF PALEONTOLOGY SAMPLE

■ 1 LOCATION OF GEOCHRONOLOGY SAMPLE

B—B BONNEVILLE SHORELINE

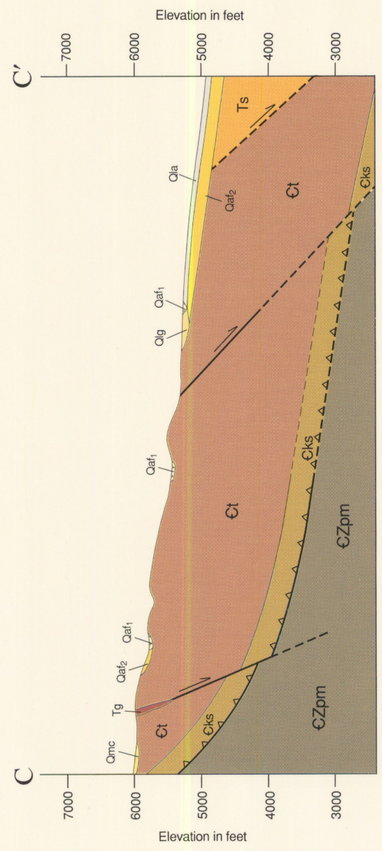
P—P PROVO SHORELINE

S—S STANSBURY SHORELINE

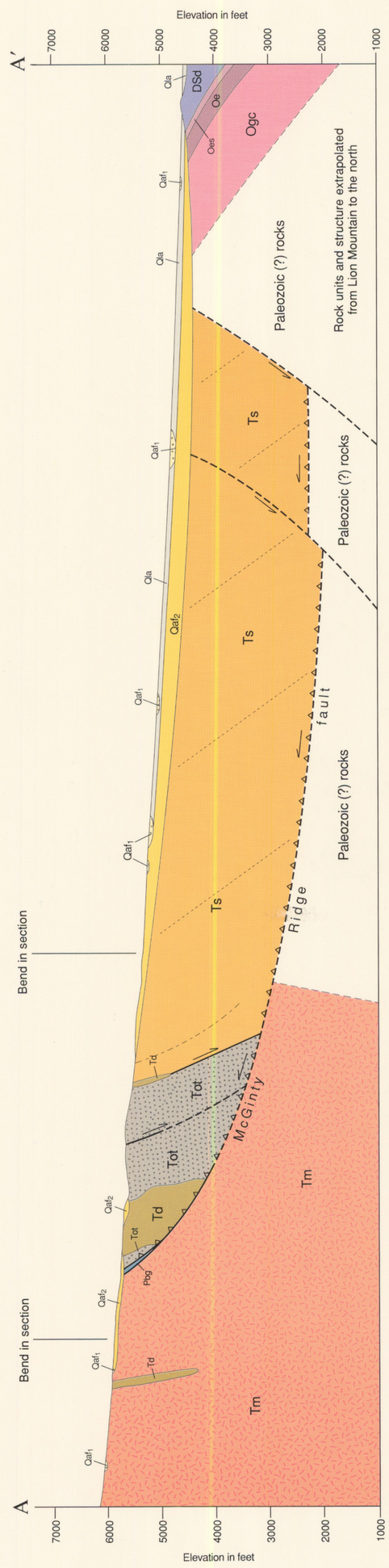
PV—PV PILOT VALLEY SHORELINE

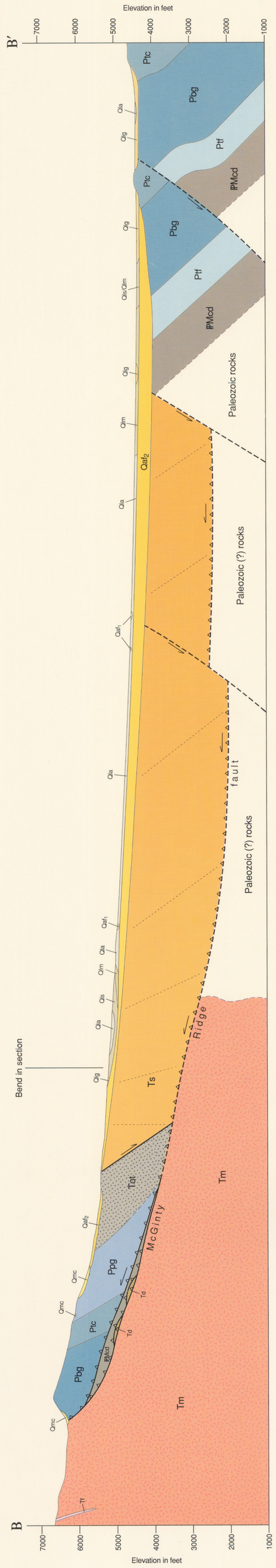
G—G GILBERT SHORELINE

FORMATION	SYMBOL	THICKNESS feet (meters)	LITHOLOGY
sedimentary rocks	Ts	3300 (1000)	
older tuff	Tot	1970 (600)	
Grandeur Formation	Ppg	1610 (490)	
Trapper Creek Formation	Ptc	660 (200)	
Badger Gulch Formation	Pbg	2400 (730)	
Chainman Shale and Diamond Peak Formations, undivided	IPMcd	65 (20)	
Thick-bedded dolomite	DSd	1400 (425)	
Toano Limestone	Ꞓt	1970 (600)	
Killian Springs Formation	Ꞓks	330 (100)	
Prospect Mountain Quartzite	ꞒZpm	2840 (865)	
McCoy Creek Group, Unit G, upper subunit	Zmg	1725 (525)	
McCoy Creek Group, Unit G, conglomerate subunit, interval 4	$Zmgc_4$	65 (20)	
McCoy Creek Group, Unit G, conglomerate subunit, interval 3	$Zmgc_3$	165 (50)	
McCoy Creek Group, Unit G, conglomerate subunit, interval 2	$Zmgc_2$	475 (145)	
McCoy Creek Group, Unit G, conglomerate subunit, interval 1	$Zmgc_1$	1310 (400)	
McCoy Creek Group, Unit F	Zmf	1400 (425)	



No vertical exaggeration





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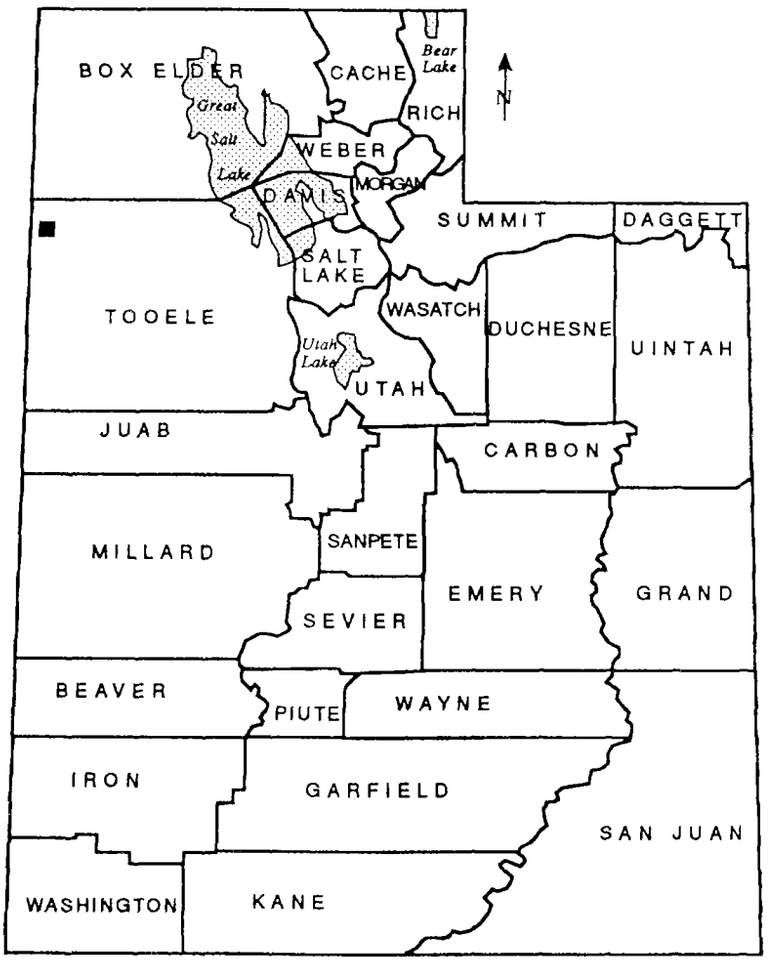
by

David M. Miller
U. S. Geological Survey



Map 145 **1993**
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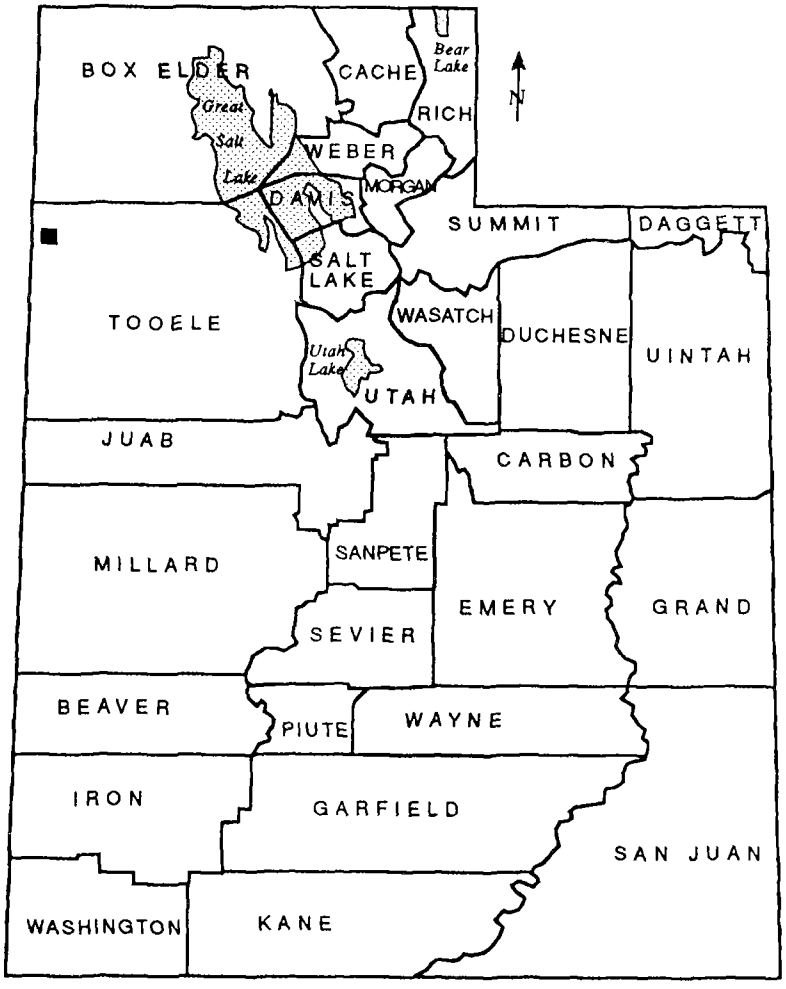

Map 145 **1993**
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GEOLOGIC MAP OF THE CRATER ISLAND NW QUADRANGLE, BOX ELDER COUNTY, UTAH

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ABSTRACT

The Crater Island NW quadrangle lies in northwestern Utah and includes part of the central Pilot Range and a broad, east-sloping piedmont. Late Proterozoic and Cambrian rocks are exposed in the Pilot Range in the southwest part of the quadrangle. These rocks were metamorphosed and folded during the Mesozoic and intruded by a large, latest Eocene granitoid pluton that underlies much of the northwestern part of the quadrangle. Faulted above the granitoid pluton and underlying much of the eastern part of the quadrangle is a sequence of Eocene to Miocene volcanic and sedimentary rocks. Widespread alluvial-fan deposits unconformably overlie the Tertiary and older rocks. During late Pleistocene time, Lake Bonneville inundated much of the quadrangle; shorelines cut into older alluvial aprons and lacustrine deposits indicate that the lake surface reached a maximum altitude of about 1,590 m (5,217 ft), including later isostatic rebound.

INTRODUCTION

The Crater Island NW quadrangle lies in northwestern Utah near the western border with Nevada and includes part of the central Pilot Range (figure 1). The north-trending crest of the Pilot Range passes a few kilometers west of the quadrangle, and the east side of the range and a broad, east-sloping piedmont east of the range lie within the quadrangle. The mountains are as high as 2,353 m (7,720 ft) south of Birch Canyon, 2,025 m (6,645 ft) at McGinty Ridge, and 2,048 m (6,720 ft) farther north. The

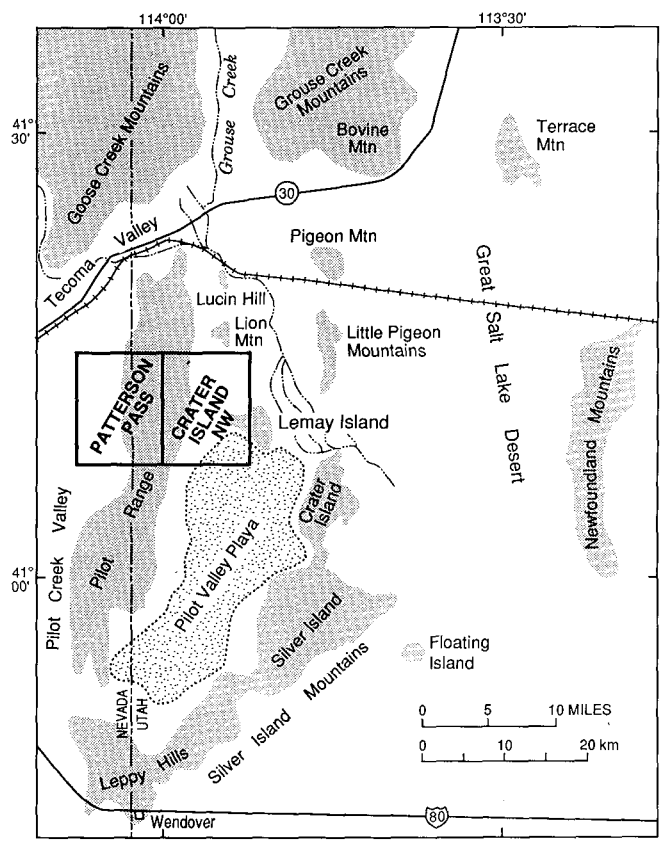

Figure 1. Location of physiographic features in the vicinity of the Crater Island NW quadrangle, northwestern Utah and northeastern Nevada.

piedmont comprising much of the eastern part of the quadrangle is divided into northern and southern parts by a prominent south-facing escarpment, the Birch Canyon-Lemay Island escarpment (plate 1). The northern piedmont ranges from about 1,829 m (6,000 ft) to 1,303 m (4,275 ft) in altitude. The southern piedmont consists of steeper, short alluvial fans that slope east from the Pilot Range to the Pilot Valley playa, about 1,294 m (4,245 ft).

The Pilot Range and nearby mountains are north-trending fault blocks (figure 1), typical of the northern Basin and Range Province. This part of the eastern Great Basin was part of the subsiding continental margin during Late Proterozoic and Paleozoic time, and great thicknesses of sedimentary rock accumulated (Miller, 1984; Hintze, 1988). The Pilot Range region was the site of igneous intrusion, metamorphism, folding, and low-angle faulting during the Jurassic, possibly continuing into the Cretaceous (Miller and others, 1987), and later was in the hinterland of the Cordilleran fold and thrust belt. During the Cenozoic, the region was tectonically extended. High- and low-angle normal faults, plutons and volcanic rocks, and deep sedimentary basins are characteristic of the Cenozoic. During Pleistocene time, Lake Bonneville inundated the northwestern Utah area. Shorelines cut into older alluvial aprons and lacustrine beach deposits at about 1,590 m (5,217 ft) indicate the maximum altitude of the surface of the lake along this flank of the Pilot Range, plus subsequent isostatic rebound.

Within the central Pilot Range two lithotectonic domains are separated by an Eocene granitoid pluton in the Birch Canyon area, and a third domain flanks the range (Miller and others, 1993). In the Crater Island NW quadrangle, two of these domains are present. In the domain south of the pluton, Mesozoic ductile deformation and metamorphism affected Late Proterozoic and Cambrian rocks that are continuous with those described in the Pilot Peak quadrangle (Miller and Lush, 1981) and the Patterson Pass quadrangle (Miller and others, 1993). North of the pluton and west of the Crater Island NW quadrangle are generally unmetamorphosed Paleozoic carbonate strata ranging from Ordovician to Permian in age. Flanking much of the Pilot Range and occupying most of the Crater Island NW quadrangle are Eocene and Miocene volcanic and sedimentary rocks, which form the third, structurally highest, lithotectonic domain.

The Pilot Range was mapped as part of a project to understand the Mesozoic and Cenozoic tectonics of northwestern Utah, a project that has yielded many geologic maps in the area (figure 2). This mapping of the Pilot Range uncovered structural, stratigraphic, and metamorphic relations that were not apparent in earlier studies by Blue (1960) and O'Neill (1968). This report and a companion report on the Patterson Pass quadrangle (Miller and others, 1993) provide new information and interpretations that supercede a preliminary geologic map of the Patterson Pass and Crater Island NW quadrangles (Miller and others, 1982).

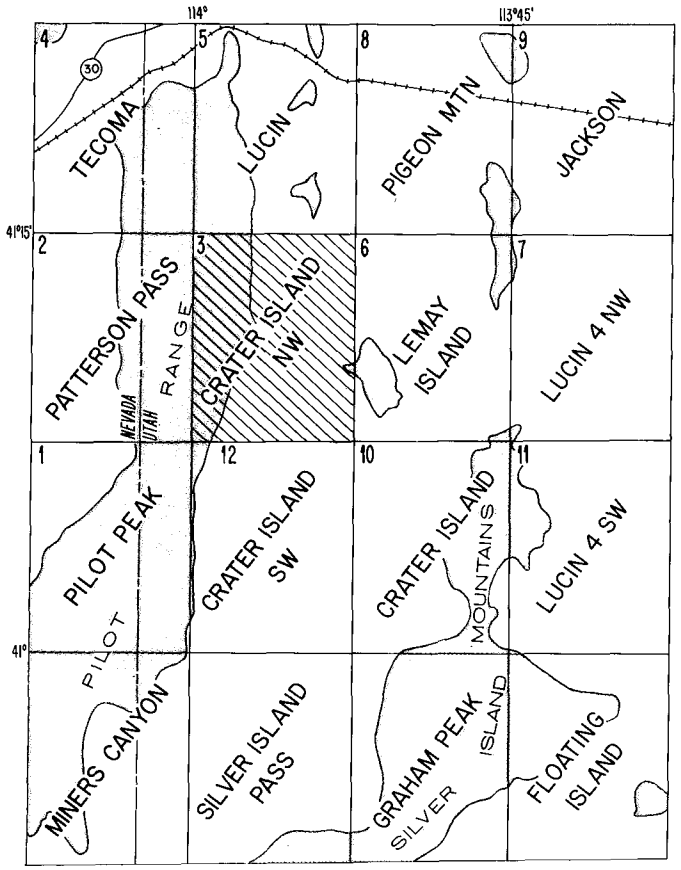

Figure 2. Quadrangle map index for Crater Island NW and nearby quadrangles. Numbers indicate published 1:24,000-scale geologic maps (1) Miller and Lush, 1981; (2) Miller, Lush, and Schneyer, 1993; (3) this report; (4) Miller and Schneyer, 1985; (5) Miller, 1985; (6) Miller and Glick, 1986; (7) Glick and Miller, 1986; (8) Glick and Miller, 1987; (9) Miller and Glick, 1987; (10) Miller and others, 1990; (11) Miller, 1990b; (12) Miller, 1990a.

DESCRIPTION OF ROCK UNITS

The rock units within the Crater Island NW quadrangle include Late Proterozoic and Paleozoic strata of the Cordilleran miogeocline, Cenozoic intrusive igneous rocks, Cenozoic sedimentary and volcanic deposits, and Quaternary deposits. Detailed descriptions of these rock units, discussions of problematical aspects, and interrelations between units are included in this section. Most Paleozoic rock units in the quadrangle were geographically extended to the Pilot Range and Lemay Island by Miller and Schneyer (1985) and Miller and Glick (1986), some igneous rocks were named and described by Miller and others (1987), and Late Proterozoic and Cambrian strata were extended to the Pilot Range (and in some cases named) by Woodward (1967), Miller (1983), and McCollum and Miller (1991).

LATE PROTEROZOIC

McCoy Creek Group

The McCoy Creek Group of Misch and Hazzard (1962) was defined for a thick sequence of alternating phyllite and quartzite units underlying the Late Proterozoic and Cambrian (restricted) Prospect Mountain Quartzite in the Schell Creek Range, east-central Nevada. This nomenclature was extended to the Pilot Range by Woodward (1967), O'Neill (1968), Miller and Lush (1981), and Miller (1983). Miller (1983) followed Stewart (1974) by including the uppermost unit of Misch and Hazzard's (1962) McCoy Creek Group, unit H, within the lower part of the Prospect Mountain Quartzite because the two units are indistinguishable in most locations. This modified sequence of the

McCoy Creek Group extends from unit G at the top to unit A at the base.

In the Crater Island NW quadrangle, only units G and F of the McCoy Creek Group crop out south of Birch Canyon. Unit G in the central Pilot Range differs from the unit in the southern Pilot Range and in the Schell Creek Range by the addition of thick conglomerate and phyllite intervals within its lower part (Miller, 1983). Detailed descriptions of units G and F are given by Miller (1983).

McCoy Creek Group, Unit F

Unit F is composed of gray, well-bedded, cross-laminated quartzite that forms steep cliffs. The thick beds of quartzite typically display tabular, wedge, and trough cross-laminations. Bed surfaces bounding the cross sets locally carry scattered white vein quartz pebbles. The basal 40 m (130 ft) or so of the unit (exposed in the adjacent Pilot Peak quadrangle) is composed of poorly bedded, gray quartzite containing feldspar fragments and rare beds of conglomerate. The uppermost part of the unit, as much as 20 m (65 ft) thick, contains lenticular channels and beds of massive conglomerate separated by quartzite and rare mica schist beds. Rip-up wedges of phyllite (originally shale), boulders and cobbles of quartzite, feldspar grains, and rare jasperoid clasts are common throughout this conglomeratic upper part of the unit. Only the upper part of unit F, about 425 m (1,400 ft) thick in this part of the Pilot Range (Miller, 1983), is exposed in the Crater Island NW quadrangle.

McCoy Creek Group, Unit G

Miller (1983) divided unit G of the McCoy Creek Group into two subunits, the upper subunit and the (lower) conglomerate subunit. The upper subunit consists mainly of phyllite and metasiltstone, whereas the conglomerate subunit consists of alternating coarse conglomerate and phyllite intervals.

Conglomerate subunit - The (lower) conglomerate subunit consists of four alternating intervals of phyllite and conglomerate, designated intervals 1 through 4 in ascending order. Phyllite in this subunit was metamorphosed to biotite-epidote-plagioclase assemblages. At the southernmost outcrops, however, andalusite, staurolite, muscovite, garnet and tourmaline are present in addition to biotite; epidote is not present.

Interval 1. This interval is composed of dark-brown, quartzose phyllite and silvery schist, and interbedded coarse-grained quartzite and conglomerate. Phyllite and quartzite are interbedded on a scale of 10 to 25 m (30 to 80 ft). Phyllite zones weather dark brown and consist of micaceous quartzite, slate, green phyllite, and schist. Quartzite beds are dark gray, brown, and light gray, and are impure and poorly size sorted. Conglomerate is polymict, containing feldspar and phyllite rip-up wedges. Interval 1 is about 400 m (1,310 ft) thick.

Interval 2. This interval is composed of light-gray, coarse-grained to conglomeratic quartzite forming steep cliffs. It is generally medium to thick bedded, brown weathering, and micaceous with tabular cross-laminations. Quartzite beds are coarse grained, impure, and poorly size sorted. Locally, beds contain as much as 20 percent detrital feldspar. The upper 105 m (345 ft) of the interval is polymict conglomerate. Interval 2 is about 145 m (475 ft) thick.

Interval 3. This interval is composed of dark-brown, rhythmically bedded phyllite and metasiltstone forming gentle slopes. It is about 50 m (165 ft) thick and at the top and bottom is interbedded with adjacent units.

Interval 4. This interval is composed of cliff-forming, impure, black to gray quartzite that is generally poorly size sorted; it contains feldspar and mica. Conglomerate interbedded with the quartzite is polymict; it is similar to, but darker in color than, the conglomerate in interval 2. Clasts in the conglomerate consist of quartzite of various colors, jasper, and slate, and the clasts vary considerably in size, shape, and roundness. Interval 4 is greater than 20 m (65 ft) thick and structurally truncated at top.

Upper subunit - The upper subunit consists of micaceous, fine-grained quartzite, dark phyllite, light-colored marble, and metasiltstone. The upper subunit is about 525 m (1,725 ft) thick in the adjacent Patterson Pass quadrangle about 1 km (0.6 mi) to the west, but only thin structural slices and a pendant(?) in the McGinty Monzogranite are present in this quadrangle.

LATE PROTEROZOIC AND CAMBRIAN

Prospect Mountain Quartzite

The Prospect Mountain Quartzite is a prominent, thick, cliff-forming unit primarily composed of thick-bedded, distinctly cross-laminated quartzite. Three subdivisions of the Prospect Mountain can be discerned in locations where it is well exposed (Miller, 1983): a lower white, vitreous, pure quartzite; a middle blue-gray quartzite containing as much as 30 percent feldspar fragments; and an upper gray, thick-bedded, distinctly cross-laminated quartzite. The upper interval makes up most of the Prospect Mountain. It ranges in grain size from medium sand size to pebble, but for the most part is coarse. The quartzite generally consists of quartz grains with minor amounts of mica and feldspar. Cross sets are commonly tabular or wedge shaped although festoons were noted in several localities. Beds typically have gravel layers at their base, perhaps representing lag deposits. Distinctive color and grain size mark the uppermost 70 m (230 ft) of the Prospect Mountain Quartzite. Many quartzite beds in this part are dark gray due to the presence of iron oxide minerals, and conglomerate beds as much as 4 m (13 ft) thick are present locally. Thick conglomerate sections contain phyllite beds and rip-up wedges of phyllite (originally shale). The Prospect Mountain is at least 865 m (2,840 ft) thick in a faulted section west of the Crater Island quadrangle, and is much thinner in this quadrangle. The Prospect Mountain Quartzite is herein used as defined by Misch and Hazzard (1962) and further modified by Woodward (1967), Stewart (1974), and Miller (1983). Following Stewart (1974), we consider the Prospect Mountain Quartzite to be mainly Late Proterozoic but it also contains Lower Cambrian beds in its upper part.

CAMBRIAN

Killian Springs Formation

The Killian Springs Formation is a dark-colored phyllite forming topographic benches, in great contrast to the underlying white, cliff-forming Prospect Mountain Quartzite. The lower part is mostly homogeneous dark phyllite and siltstone; rare, fine-grained sandstone layers outline bedding. The upper part

consists of slightly calcareous phyllite and siltstone that is interbedded with laminated and cross-laminated dark limestone in the uppermost 10 to 15 m (33 to 45 ft). The limestone beds typically are 2 to 10 cm (1 to 4 in) thick and interbedded phyllite is 10 to 30 cm (4 to 12 in) thick. The entire Killian Springs contains disseminated cubes of pyrite. The base of the Killian Springs is in sharp contact with thick-bedded quartzite of the Prospect Mountain Quartzite, and the top grades into clastic limestone of the lower part of the Toano Limestone. The Killian Springs is structurally thinned in every exposure in the quadrangle; its base is everywhere a bedding-plane fault and its top is in many places faulted. The Killian Springs is about 300 m (985 ft) thick at its type section in the Patterson Pass quadrangle, but is at most 100 m (330 ft) thick in the Crater Island NW quadrangle.

The Killian Springs Formation was formally named by McCollum and Miller (1991), revising the informal term "phyllite of Killian Springs" of Miller (1983) and Miller and others (1982). The new name was proposed to emphasize the contrast between graphitic black phyllite in the Pilot Range and the green siltstone, quartzite, and limestone of the broadly correlative Pioche Formation (Hintze and Robison, 1975), which overlies the Prospect Mountain Quartzite in much of eastern Nevada and western Utah. The Killian Springs also is exposed in the neighboring Silver Island Mountains, Utah, and Toano Range, Nevada (McCollum and Miller, 1991). Siliceous sponge spicules, abundant in the upper part, are suggestive of Middle Cambrian forms (McCollum and Miller, 1991). McCollum and Miller (1991) provisionally regarded the Killian Springs Formation to be Early and Middle Cambrian in age.

Toano Limestone

The Toano Limestone is composed mainly of slightly metamorphosed, thin-bedded to laminated, gray silty limestone. It occupies the core of the Cottonwood Springs syncline (plate 1) and is tightly folded and cleaved in most places. The base of the unit is drawn at the top of the uppermost dark calcareous phyllite bed of the underlying Killian Springs Formation. The lower part of the section is mainly medium-gray, laminated limestone with tan, dolomitic laminations and interbeds. Sparse calcareous quartzite beds also are present. The lower part grades upward into very thinly bedded, tan, silty limestone and fissile, gray, calcareous and graphitic phyllite of the upper part. The unit contains cubes of pyrite throughout. Primary soft-sediment structures such as folds caused by slumping, trough cross-stratification, and chaotic bedding are common. The thickness of the unit is estimated at about 600 m (1,970 ft), but no stratigraphic top is exposed. The unit is 850 m (2,790 ft) thick in the type section in the Toano Range (McCollum and Miller, 1991).

Middle Cambrian trilobites were recovered from the Toano Limestone (table 1, no. 5). In the Toano Range, 15 km (9 mi) to the southwest, the youngest fossils in the type Toano Limestone are late Middle Cambrian in age, thus the formation is considered to be Middle Cambrian in age (McCollum and Miller, 1991).

The Toano Limestone probably was deposited on a distally steepened carbonate ramp (McCollum and Miller, 1991). Sedimentary structures and graded bedding suggest that some sediment was emplaced as debris flows, and the cosmopolitan trilobite fauna indicates unrestricted open-marine conditions.

SILURIAN AND DEVONIAN

Thick-bedded dolomite

A small exposure of generally light-colored, thick-bedded to structureless dolomite (DSd) at the northern edge of the quadrangle is continuous with larger exposures to the north in the Lucin quadrangle (Miller, 1985). The dolomite unit is unfossiliferous in most places, although crinoid fragments are present locally. The unit is greater than 425 m (1,400 ft) thick where it is better exposed to the north and west.

The thick-bedded dolomite unit is not assigned to formally named units recognized elsewhere in the eastern Great Basin because it appears to represent a transitional facies. To the east, the Laketown and Sevy Dolomites are widespread, and to the west the Roberts Mountains Formation and Lone Mountain Dolomite are widespread. Neither the distinctive tripartite division of the Laketown Dolomite nor the laminations characteristic of the Sevy Dolomite are present in the thick-bedded dolomite unit. In addition, platy limestone of the Roberts Mountains Formation is not present. Rocks in the upper part of the thick-bedded dolomite unit are similar to those in the Lone Mountain Dolomite, suggesting that the northern Pilot Range rocks are of closer affinity to the western-facies rocks than to the eastern-facies rocks.

The thick-bedded dolomite unit is Silurian and Early Devonian in age in the northern Pilot Range. The unit is mainly Silurian in age on the basis of fossil collections, with the uppermost part presumably earliest Devonian in age (Miller and others, 1993).

MISSISSIPPIAN AND PENNSYLVANIAN

Chainman Shale and Diamond Peak Formation, undivided

This unit is mainly quartzite, gray and black shale and siltstone, and polymict conglomerate exposed in outcrops along the south rim of McGinty Ridge. The conglomerate is silicified and resistant, containing clasts of chert, sandstone, calcareous sandstone, and jasperoid. Exposures of the unit, consisting mainly of shale and broken pieces of quartzite and conglomerate, form a tectonic slice as much as 20 m (65 ft) thick between low-angle faults underlying Permian strata in McGinty Ridge.

PERMIAN

Badger Gulch Formation

The Badger Gulch Formation is a thick unit composed of dark, platy, silty limestone. The upper part crops out on McGinty Ridge, where it typically forms scree slopes. Thickness estimated from cross sections is 730 m (2,400 ft), but the unit is strongly folded and fractured, and the lower part is cut out by faulting.

The Badger Gulch Formation is lithologically similar to the middle part of the Pequop(?) Formation as mapped by Miller (1985) and Miller and Schneyer (1985) farther north in the Pilot Range, and to the Badger Gulch in the Little Pigeon Mountains to the east (Miller and Glick, 1986). Bryozoans from near the base of the Badger Gulch Formation on McGinty Ridge yielded species limited to Lower Pennsylvanian to Upper Permian strata

(table 1, no. 4). A collection from near the top of the section contained Permian bryozoans and Early Permian schwagerinid fusulinids (table 1, no. 3). On the basis of age, stratigraphic position, and lithologic similarity, we correlate the Badger Gulch in McGinty Ridge with the Leonardian Badger Gulch Formation at the Leach Mountains (Miller and others, 1984) and Little Pigeon Mountains (Miller and Glick, 1986).

Trapper Creek Formation

The Trapper Creek Formation conformably overlies the Badger Gulch Formation at McGinty Ridge and also crops out at Lemay Island. It is composed of thin-bedded, sandy and silty limestone and thick, bioclastic limestone beds. It is locally cherty and dolomitic. Bioclastic beds contain fragments of brachiopods, crinoids, bryozoans, and fusulinids. The unit forms steep, brown-colored slopes. The Trapper Creek is about 200 m (660 ft) thick at McGinty Ridge. Thin-bedded, silty limestone at Lemay Island is similar to the Trapper Creek on McGinty Ridge but is generally less silty and is regularly bedded on the scale of 1 to 3 cm (0.4 to 1.2 in). It underlies the Grandeur Formation to the east (Miller and Glick, 1986).

The Trapper Creek Formation in the Crater Island NW quadrangle is lithologically similar to the unit in the nearby Leach Mountains (Miller and others, 1984) and the Little Pigeon Mountains (Miller and Glick, 1986). Pennsylvanian to Permian productid brachiopods were identified (table 1, no. 2) from a collection in the middle part of the Trapper Creek Formation at McGinty Ridge. On the basis of age, lithology, and stratigraphic position, the Trapper Creek Formation at McGinty Ridge is correlated with the Trapper Creek Formation exposed elsewhere in northwest Utah and with the upper part of the Pequop(?) Formation as mapped by Miller (1985) and Miller and Schneyer (1985) farther north in the Pilot Range.

Grandeur Formation (of the Park City Group)

The Grandeur Formation is composed mainly of resistant, cherty sandstone and dolomite. The unit is highly silicified, typically having a massive to bedded cherty aspect. The Grandeur Formation is highly fractured and gently folded, but it appears to gradationally overlie the Trapper Creek Formation. The base is defined by a change from thin-bedded, silty limestone of the Trapper Creek Formation to silicified, cherty sandstone and limestone of the Grandeur. About 10 m (33 ft) above the base the limestone gives way to dolomite typical of the remainder of the section. The approximate thickness of the unit estimated from cross sections is 490 m (1,610 ft), but the top of the Grandeur is not exposed.

The Grandeur Formation is Early Permian in age in the northern Pilot Range area (Miller and others, 1984; Miller, 1985; Miller and Glick, 1986). Diagnostic fossils are rare; those observed are crinoid fragments, rare silicified brachiopods(?), and silicified fusulinids. The Grandeur contains Early Permian (Leonardian) fusulinids at McGinty Ridge (table 1, no. 1), in accord with its age elsewhere in northwest Utah.

TERTIARY

Granodiorite dikes

Dikes of granodioritic composition crop out sparsely south of Birch Canyon. The dikes typically are fine to medium grained, subequigranular, and contain quartz, alkali feldspar, plagioclase, and biotite; some also contain hornblende. Many are slightly to highly sericitized. Granophyric textures are common. The dikes strike from northeast to east, and in several cases have intruded along small faults.

Lithologic similarity with the Bettridge Canyon Granodiorite in the Pilot Peak quadrangle (figure 2; Miller and Lush, 1981) and an increase in the number of dikes toward that pluton suggest that the dikes are about the same age as that pluton, 38.9 ± 0.9 Ma based on U-Pb zircon dating (Miller and others, 1987). The presence of abundant hornblende in some dikes indicates that the McGinty Monzogranite, which only has rare hornblende, is probably not the source for the dikes.

McGinty Monzogranite

The McGinty Monzogranite (Miller and others, 1987) is a porphyritic, coarse-grained pluton underlying much of the western part of the quadrangle. Previous workers termed the pluton "monzonite" (Blue, 1960; Doelling, 1980), "granodiorite" (Hoggatt and Miller, 1981), and "monzogranite of Patterson Pass" (Miller and others, 1982). Modal analyses indicate that the McGinty ranges from monzogranite to granodiorite (figure 3). Euhedral phenocrysts of alkali feldspar, as large as 5 cm (2 in) in maximum diameter, are set in a coarse-grained matrix of subhedral plagioclase and alkali feldspar (5-12 mm [0.2-0.5 in]), subhedral quartz (8-12 mm[0.3-0.5 in]), and biotite (5 mm [0.2 in]). Accessory minerals are hornblende, zircon, sphene, apatite, and xenotime(?). Biotite, generally 6-9 percent modally (figure 3), typically is partly altered to chlorite or, rarely, to sericite. Plagioclase grains commonly show sericitic alteration in their cores. Only one dike of the McGinty was noted in outcrops of the Prospect Mountain Quartzite south of Patterson Spring (not shown on plate 1). That dike strikes about N 30° W.

Inclusions are sparse throughout most of the pluton, but zones with abundant inclusions are present in several places. The two common inclusions are porphyritic, biotite-hornblende-pyroxene quartz monzonite to quartz monzodiorite and hornblende quartz diorite(?); the inclusions typically are 10 to 20 cm (4 to 8 in) in diameter. The quartz diorite(?) is also included within the biotite-hornblende quartz monzonite inclusions. Non-systematically oriented mafic schlieren and irregularly shaped zones of phenocryst-rich rock are common. Dikes of aplite and pegmatite, distinguished on the accompanying geologic map (plate 1), generally strike north-northwest. They are considered to be closely related to the main phase of the McGinty Monzogranite. The dikes consist of quartz, plagioclase, and alkali feldspar with accessory biotite and an iron oxide mineral, and commonly grade to quartz-feldspar pegmatite at their borders or centers.

Isotopic dating indicates that the McGinty Monzogranite is latest Eocene in age, a revision of the "Eocene or Oligocene" age of Miller and others (1987). Coats and others (1965) obtained a biotite K-Ar cooling age of 31 ± 6 Ma (recalculated with new decay constants in Miller and others, 1987), and Hoggatt and

TABLE 1. Paleontologic data for the Crater Island NW quadrangle.

Map no.	Field (USGS) no.	Rock unit	Fossil age	Date of report	Paleontologist	Faunal description	Latitude	Longitude
1	M82PR-04 (D435-PC)	Grandeur Formation	Early Permian (early Leonardian)	12/30/82	B.R. Wardlaw	Conodonts recovered were: *Neostreptognathodus ruzhencevi* Kozur *xaniognathus* sp. Age is Early Permian. *N. ruzhencevi* is found in the upper two-thirds of the Trapper Creek Formation and the lowermost part of the Grandeur Formation in the Leach Mountains. CAI=2.0	41°13'08"	113°59' 00"
2	M79PR-180	Trapper Creek Formation	Pennsylvanian or Permian	1/22/80	M. Gordon, Jr.	This collection contains small productid brachiopods belonging to a single highly-spinose marginiferid species. This brachiopod resembles several genera of the subfamily *Costispiniferinae*, which occur in Pennsylvanian and Permian rocks.	41°12'35"	113°59'20"
3	M79PR-177 (27625-PC)	Badger Gulch Formation	Permian	1/8/81	R.C. Douglass, O.L. Karklins	This sample contains advanced schwagerinids that indicate probable Early Permian age. Bryozoans include: *Cystodicty* (?) sp. *Dyscritella* (?) sp. Fenestelloids, indet. Rhabdomesids, indet. *Rhombopora lepidodendroides* Meek *Rhombotrypella* sp. *Streblotrypa* sp. *Tabulipora* sp. *Timanodictya* sp. Trepostome, indet. The bryozoan assemblage is typical of Pennsylvanian and Permian strata. The presence of *Timanodictya* indicates a Permian age.	41°12'46"	113°59'16"
4	M79PR-181 (27599-PC)	Badger Gulch Formation	Early Pennsylvanian to Late Permian	5/27/80	O.L. Karklins	This sample contains fragments from more than ten bryozoan colonies of a single species *Rhombopora lepidodendroides* Meek, which ranges in age from Early Pennsylvanian to Late Permian. The morphology of these specimens is suggestive of a Permian age.	41°12'32"	113°59'20"
5	M82 PR-64C (D-3420-CO)	Toano Limestone	Probably Middle Cambrian	11/83	A.R. Palmer	This sample contains very scrappy fragments of silicified trilobites. One slightly flattened cranidium suggests a ptychoparioid trilobite of "average aspect" (cf. *Elrathia*), with a wide rostral plate, which is a morphology that is characteristically Middle Cambrian in age.	41°09'38"	113°59'02"

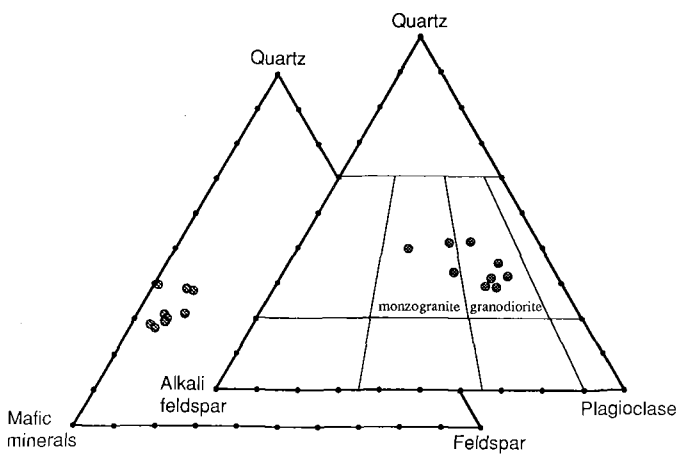

Figure 3. Modal compositions of the McGinty Monzogranite derived from point counts of stained slabs. Data include sample 63NC106 from Coats (1987). Results are biased somewhat by the difficulty of sampling the common coarser grained, phenocryst-rich phase of the pluton; as a result, granodiorite specimens are over-represented.

Miller (1981) obtained a biotite K-Ar cooling age of 36.6 ± 0.5 Ma. The McGinty Monzogranite is one of several granitoids forming generally small plutons and dikes throughout most of the Pilot Range. Many dikes have yielded K-Ar biotite ages similar to those for the McGinty, and the crystallization age of one pluton, the Bettridge Canyon Granodiorite (exposed about 5 km [3 mi] south of the Crater Island NW quadrangle), is firmly fixed by a U-Pb zircon age of 38.9 ± 0.9 Ma (Miller and others, 1987). The K-Ar age on biotite from the McGinty probably records the cessation of Ar diffusion after at least a few million years of cooling following crystallization of the pluton. The pluton therefore is probably about 38 or 39 million years old, roughly the same age as the Bettridge Canyon body.

Older Tuff

The older tuff unit (Tot) crops out in the northwestern part of the quadrangle. It consists primarily of altered felsic volcanic rocks in northern exposures and of interlayered sedimentary and volcanic rocks in southern exposures. The altered volcanic rocks in the north form massive white outcrops underlying rounded hills just south of the Tunnel Springs. These outcrops are vir-

tually continuous with wider exposures along strike northward in the Lucin quadrangle (Miller, 1985). Most outcrops are of massive, white, siliceous and clayey material, but less altered rocks contain (in order of abundance) plagioclase, quartz, biotite, sanidine, and hornblende. Rarely, white tuff breccia and light-gray, flow-banded welded tuff can be distinguished. Biotite from this rock unit to the north yielded a K-Ar age of 36.9 ± 1.1 Ma (W.C. Hillhouse, cited in Miller, 1985). The rocks apparently represent hydrothermally altered rhyolitic tuff that probably was close to extrusive vents.

Southward from the massive outcrops of white, altered rhyolitic tuff are piedmont exposures of interlayered volcanic rocks, alluvium, and thin-bedded sandstone and siltstone that are grouped within the older tuff unit. These rocks are distinguished from overlying Miocene sedimentary rocks by the abundance of coarse-grained volcanic rocks. Volcanic breccia, ash-flow tuff, and reworked tuff in conglomerate crudely grade upward to, and are interbedded with, thinly bedded sandstone and siltstone. The volcanic rocks are typically dark green and brown, are crudely bedded in 1- to 3-meter (3- to 10-ft) thick sets, and appear to be andesitic to rhyolitic in composition. Their highly altered, typically silicified and chloritized, condition makes identification difficult. Ash-flow tuff is moderately to strongly welded and contains coarse-grained potassium feldspar, plagioclase, and quartz phenocrysts in an altered matrix of silica and chlorite. Several flows carry abundant lithic clasts of chert and limestone. Between the ash flows are brown and green, silicified, medium- to fine-grained volcanic rocks that carry feldspar and quartz phenocrysts. Conglomerate is poorly sorted and crudely bedded, suggesting a debris-flow origin. Quartzite clasts, as large as 30 cm (12 in), and andesite clasts are most common; some conglomerate contains feldspar and chert clasts as well. Angular unconformities displaying minor truncation of beds are common at the bases of conglomeratic sequences. Sandstone is mainly coarse to medium grained and thin bedded.

Outcrops of the older tuff consistently lie west of, and structurally under, Miocene sedimentary rocks. The massive altered tuff, of late Eocene age (Miller, 1985), is separated from Miocene rocks by a diabase dike, but farther north the contact is a normal fault (Miller, 1985). Southward, the altered tuff apparently interfingers with or is overlain by interbedded volcanic and sedimentary rocks in the older tuff unit. The altered tuff and associated volcanic and sedimentary rocks strongly resemble the biotite tuff unit on the west side of the Pilot Range (Miller and others, 1993), which is considered to be Oligocene(?) and Eocene in age on the basis of K-Ar data. As a result, the older tuff unit is considered to be Oligocene(?) and Eocene in age.

Felsite

Dikes of light-gray felsite (Tf) crop out in the western part of the quadrangle. The felsite contains common rounded, embayed quartz phenocrysts of two types, dark-colored and clear (5-10 mm [0.2-0.4 in]), and less common anhedral plagioclase (5 mm [0.2 in]) and alkali feldspar phenocrysts. Feldspars in most dikes are altered to clays. The felsite dikes locally grade into brown, siliceous, flow-banded breccia; at these sites, the gray felsite contains inclusions of brown brecciated felsite. Felsite dikes cut the latest Eocene McGinty Monzogranite, and are in turn cut by diabase dikes. The felsite may be a late magmatic phase of the McGinty intrusive event or a distinctly younger intrusive event. Although felsite dikes are common within and near the McGinty Monzogranite, the dikes crop out much farther south than the McGinty (Miller and Lush, 1981), suggesting that the dikes are not related to the pluton. I regard the felsite to be of Oligocene(?) age.

Sedimentary rocks

The sedimentary rocks unit (Ts) consists mainly of fine-grained lake deposits such as silty limestone, siltstone, and sandstone. Sedimentary rocks typically are siliceous, and some contain recognizable reworked volcanic ash. The main rock type is thin-bedded, finely cross-laminated, and well-sorted tuffaceous sandstone and siltstone. Volcanic glass is the primary constituent of many rocks, but primary igneous minerals are rare, suggesting that the rocks represent thoroughly reworked felsic tuff. Beds of brown limestone, some fossiliferous, are present near Tunnel Spring No. 1 and in places farther south. A distinctive marker bed of coarse-grained sandstone is continuous to the north with coarse beach deposits containing lineated metaquartzite clasts (Miller, 1985). Claystone is a minor component of the unit, usually forming pale yellow and white, soft outcrops of papery fissile shale. Rocks in the unit generally fine upward; sedimentary structures in several places confirm that the rocks are younger to the east. The sedimentary rocks unit is greater than 1,000 m (3,300 ft) thick northeast of McGinty Ridge where it is steeply dipping to overturned, but exposures are poor and many unrecognized faults could be present in the piedmont. Its base is discordant to the underlying older tuff unit in several places, so that contact is interpreted as a fault.

Blue (1960) reported that late Miocene or earliest Pliocene mollusks were recovered from the upper part of the sedimentary rocks unit. The sedimentary rocks unit is continuous with similar rocks to the north in the Pilot Range (Miller, 1985). The unit there was considered by Miller (1985) to be Miocene in age because it is disconformably capped by approximately 8.7-million-year-old rhyolite and an approximately 12-million-year-old ignimbrite is contained within it (both ages K-Ar).

Diabase

The diabase unit (Td) crops out as narrow dikes composed of dark-brown diabase and as larger, deeply weathered bodies whose surface exposures are characterized primarily by dark-brown soils. Sparse outcrops of diabase in the weathered soils confirm that diabase underlies most of these areas. Diabase is consistently crystalline and massive, and displays no structures such as vugs and vesicularity, indicating that it represents intrusive rock. Rock types included within the diabase unit are fine- to coarse-grained hornblende-pyroxene-plagioclase rock and fine- to medium-grained pyroxene-plagioclase diabase with ophitic texture. An iron oxide mineral (probably ilmenite) is abundant. Many dikes contain alteration products such as talc, sericite, and carbonate minerals. The dikes generally strike north-northeastward.

Diabase dikes intruded Miocene sedimentary rocks and the dikes are unconformably overlain by Pliocene(?) and Pleistocene alluvium. The diabase is probably Pliocene(?) in age. A K-Ar age obtained for hornblende from the unit is 116.3 ± 5.8 Ma (table 2), an age inconsistent with field relations. Hornblende in the sample dated is intergrown with pyroxene,

TABLE 2. Geochronologic data for the Crater Island NW quadrangle .

Map no.	Sample no.	Sample site Lat.	Sample site Long.	Rock type	Mineral dated	Mean K_2O (wt pct)	$^{40}Ar_{rad}$ (pct)	$^{40}Ar_{rad}$ (10^{-10}mol/ g)	Age (Ma)
1	M81PR-117	41°14'58"	113°59'51"	Diabase	Hornblende	0.522	42.87	0.8628	111.4
							48.83	0.9061	116.8
							47.26	0.9370	120.7
								mean age =	116.3±5.8

Analyses by W.C. Hillhouse. Decay constants given by Steiger and Jäger (1977)

and the mineral separate was therefore probably not pure hornblende. The age is interpreted as resulting from retention of excess Ar.

TERTIARY AND QUATERNARY

Oldest alluvial-fan deposits

Consolidated to unconsolidated, coarse gravel deposits that cap several small hills and form small dissected terraces in the southwestern part of the quadrangle are assigned to the oldest alluvial-fan deposits (QTaf3). Clasts in the unit are derived from bedrock exposed in the Pilot Range, and the alluvial-fan morphology of the deposits and their position adjacent to bedrock at the range front indicate that they were derived from the range in approximately its current physiographic configuration. The deposits are not closely linked to current drainages and are dissected by current drainages, suggesting that base level was lowered between deposition of the oldest alluvium and Lake Bonneville time. Pedogenic, calcrete-bearing, thick laminae are common in the gravels. Similar pedogenic calcrete in a few gully exposures of gravels underlying the older alluvial-fan deposits unit (Qaf2) north and east of McGinty Ridge suggest that the oldest alluvial-fan deposits (QTaf3) widely underlie the older alluvial-fan deposits (Qaf2) (although they are not distinguished on the map or cross sections). The geomorphic relations are characteristic of "old alluvial-fan deposits" of Christenson and Purcell (1985), which they consider to be generally older than 500 thousand years. Thick laminae in pedogenic calcrete suggests a middle Pleistocene or older age (Machette, 1985). I consider the oldest alluvial-fan deposits to be late Pliocene(?) to middle Pleistocene in age.

Gravels in the unit are about 10 m (33 ft) thick along the range front in the southwestern part of the quadrangle. The isolated gravel caps define a gently east-dipping surface, suggesting that the deposits once were part of an alluvial-fan complex at the eastern base of the range. The fan complex was dissected, exposing underlying Paleozoic rocks that may have underlain a pediment. Most of the alluvium lies east of a moderately east-dipping fault, but it locally overlaps the fault. These relations probably indicate that the fault created a topographic step or range-front scarp at the time of or just prior to deposition of the oldest alluvial-fan deposits.

QUATERNARY

Quaternary deposits in the Crater Island NW quadrangle are primarily alluvial and lacustrine in origin, representing alluvial-fan complexes built eastward from the Pilot Range and deposits of Lake Bonneville. Restricted Quaternary deposits of eolian and mass-movement origin are also present in the quadrangle. A ridge extending from Birch Creek to Lemay Island forms a drainage divide across which many deposits change character. The south side of this ridge forms a steep escarpment that predated deposits of Lake Bonneville, but the escarpment was accentuated by beach deposits of the lake. In this report I refer to the escarpment as the Birch Canyon-Lemay Island escarpment. The late Pleistocene deposits of Lake Bonneville are well dated at about 30 to 10 thousand years (Scott and others, 1983; Currey and others, 1984), providing a convenient marker dividing Holocene deposits from Pleistocene and older deposits.

Older alluvial-fan deposits

Unconsolidated, poorly sorted gravel and sand (Qaf2) forming thick alluvial fans along much of the piedmont flanking the Pilot Range were eroded by waves and are overlain by deposits of Lake Bonneville. Therefore, the fans are Pleistocene (or possibly older) in age. The older alluvial fans are most extensive north and east of McGinty Ridge, and are exposed in small remnants above the Bonneville shoreline south of Birch Canyon. About 1.5 km (1 mi) south of Birch Canyon the older alluvial-fan deposits are mainly composed of granitoid gravel derived from the McGinty Monzogranite. The canyon upslope to the west of this fan complex now is floored by metamorphic rocks, suggesting that it was beheaded by the Birch Canyon drainage during or after the deposition of the Pleistocene older alluvial-fan deposits.

Lacustrine and alluvial deposits, undivided

At altitudes below the Bonneville shoreline, interlayered deposits of lacustrine and alluvial origins are mapped as undivided (Qla). In most places, this unit consists of a thin sheet of lacustrine marl, sand, or gravel lying on the older alluvial-fan

deposits. In many places thin alluvium (Qaf_1) in turn lies on the lacustrine deposits. The rough alluvial topography above the Bonneville shoreline is in sharp contrast to the smoothly beveled topography below the shoreline, where the undivided lacustrine and alluvial deposits lie.

Lacustrine marl

The lacustrine marl unit (Qlm) is exposed as a relatively clean marl only south of the Birch Canyon-Lemay Island escarpment. At most other exposures, the unit contains a larger percentage of clay, silt, and sand because it was deposited either in the shorezone (nearshore environment) or was reworked during lake regression. Exceptionally thick and continuous exposures of the lacustrine marl unit along the south front of the Birch Canyon-Lemay Island escarpment are of a silty and sandy shorezone facies. This shorezone facies was successively deposited over transgressive gravel deposits (Qlg) as the lake rose; it drapes over gravel barriers and into depressions behind the barriers. However, along the front of the gravel barrier whose crest lies at 1,536 m (5,025 ft) (1.5 km [1 mi] southeast of the mouth of Birch Canyon), a thin gravel wedge overlaps the shorezone marl facies, which lies on the main gravel barrier at this locality. These relations probably indicate an oscillation in water depth. Another location along the Birch Canyon-Lemay Island escarpment where lacustrine gravel probably overlies the lacustrine marl unit is near the upper altitudinal limit of the Stansbury shorezone, at an altitude of about 1,377 m (4,520 ft). Here, the deep-water, clean facies of the lacustrine marl overlies a gravel barrier beach greater than 10 m (33 ft) thick. This gravel deposit is correlated with similar deposits in the Silver Island Mountains, about 15 km (9 mi) to the east, where the gravel is sandwiched between lacustrine marl deposits and therefore indicates a major oscillation during the transgression of the lake (Oviatt and others, 1990).

Sandy marl about 1,566 m (5,140 ft) altitude and about 3 km (2 mi) north of Birch Canyon lies above a fining-upward sequence grading from gravel to sand to sandy marl. The sequence is capped by poorly sorted gravel and sand. This section is interpreted as a transgressive sequence capped by a thinner regressive sequence, and the marl is sandy because it was deposited in shallow water proximal to the Bonneville shoreline. Similar, but sandier, marl lies stratigraphically between sand and gravel collectively mapped as the lacustrine sand unit (Qls) 1.5 km (1 mi) south of Birch Canyon and just below the Bonneville shoreline.

Lacustrine gravel

Prominent lacustrine gravel deposits (Qlg) extend discontinuously along the Birch Canyon-Lemay Island escarpment in the center of the quadrangle. These deposits represent several stands of Lake Bonneville. The altitudes of crests of prominent barrier beaches lie at about: a) 1,590 m (5,217 ft) (the Bonneville shoreline [-B-] of Gilbert, 1890); b) 1,568 m (5,145 ft); c) 1,561 m (5,120 ft); d) 1,533 m (5,030 ft); e) 1,513 m (4,965 ft); f) 1,493 m (4,900 ft); g) 1,475 m (4,840 ft) (upper Provo shoreline [-P-]); h) 1,471 m (4,825 ft) (lower Provo shoreline); i) 1,405 m (4,610 ft); j) 1,378 m (4,520 ft) (Stansbury shorezone [-S-] of Oviatt and others, 1990); k) 1,306 m (4,285 ft) (Pilot Valley shoreline [-PV-] of Miller, 1990b); and l) 1,299 m (4,262 ft) (Gilbert shoreline [-G-]). In addition to these prominent barrier beaches, a double-tombolo west of Lemay Island lies about 1,343 m (4,405 ft) altitude. The gravel deposits consist of moderately to well-sorted pebbles, cobbles, and sand, with a sand and silt matrix. Deposits at and slightly below the Bonneville shoreline interfinger with lacustrine sand (Qls). The deposits are generally unconsolidated, but many in places below the Provo shorelines are cemented by tufa. Gravel supply from lake currents and from alluvial and fluvial detritus must have been greatest east of Birch Canyon, where gravels are voluminous along the Birch Canyon-Lemay Island escarpment. The morphology of these gravel constructions, as well as distinctive clasts in them, indicate that lake currents were directed southward.

Most gravel beaches were formed during the transgression of Lake Bonneville, as indicated by marl, a deep-water deposit, overlying beach gravel. The earliest such beaches are widely developed about 1,306 m (4,285 ft) in this region and were informally named the Pilot Valley shoreline by Miller (1990b). Notable regressive beaches include the Provo beaches, which were partly constructed on transgressive beaches but mainly represent gravel deposited after a catastrophic decline in lake level, and the beach at the Gilbert shoreline, which formed during a latest Pleistocene minor transgression following the complete withdrawal of Lake Bonneville waters from this part of the basin (Currey, 1980; Scott and others, 1983; Currey and others, 1984).

Lacustrine sand

Well size-sorted sand deposits (Qls) lie near the Bonneville shoreline north and south of Birch Canyon and at lower altitudes, between the Provo and Stansbury shorelines, in the northeastern part of the quadrangle. Near the Bonneville shoreline, the sand deposits are as much as 3 m (10 ft) thick and form a part of a fining-upward transgressive sequence of gravel to sand to marl. This sequence is typically capped by thin, regressive gravel. The sand deposits near the Bonneville shoreline are found between 1,566 and 1,578 m (5,140 and 5,180 ft) altitude.

Extensive sheets of brown, lacustrine sand, locally reworked into small eolian dunes, are present below the Provo shoreline at altitudes of approximately 1,450 m (4,760 ft) and 1,400 m (4,600 ft). Exposures are too poor to allow determination of the stratigraphic position of the sand, although the high degree of sorting and homogeneity of these deposits indicate lacustrine deposition. The factors that led to deposition and preservation of these lower-altitude sand deposits are uncertain, although it seems likely that the deposits are regressive and represent nearshore environments. It also is possible that stream sediments were supplied from the northwestern part of the quadrangle and reworked during short stillstands or minor oscillations during the transgression of the lake. However, no gravel barrier bars or other records of large sediment input are preserved near the sand deposits.

Lacustrine sand over lacustrine marl

Fine, well-sorted sand overlies white marl (Qls/Qlm) over much of the double tombolo, about 1 km (0.6 mi) in length, lying west of Lemay Island. These deposits lie at altitudes below the Stansbury shoreline and in positions on the tombolo where sediments have been little disturbed by Holocene fluvial activity. Because the sand is better sorted than is typical of regressive sand

deposits at higher altitudes, I interpret it as a probable transgressive deposit of the Stansbury oscillation (Oviatt and others, 1990). By this interpretation, marl was deposited during the Stansbury highstand when the lake crested at somewhat above 1,377 m (4,520 ft) altitude, the water level fell, and during its later rise the sand was deposited. Alternatively, some or all of the sand may be regressive-phase, representing reworking of the Stansbury shorezone sand during the lake regression.

Alluvial sand and silt

Red beds of alluvial fine sand and silt (Qas) rest on lacustrine marl (not distinguished on plate 1) and are overlain by shoreline sand and sparsely pebbled platforms (too thin to be mapped) probably representing remnants of Gilbert shoreline deposits. The red beds were mapped in only one location in the southeastern part of the quadrangle, about 1,298 m (4,260 ft) altitude, although fragmentary exposures may be present elsewhere in the extensive eolian sand field bordering Pilot Valley playa. The red beds were interpreted by Currey and others (1988) as uppermost Pleistocene alluvial deposits.

Eolian sand

Thin sheets of tan, eolian, fine sand and silt (Qes), mostly derived from reworked sandy marl with smaller components derived from the nearby playa and alluvium, lie along the playa margin in the southeastern part of the quadrangle. Irregular mounds in these sand sheets are locally as much as 1.5 m (5 ft) thick. Eolian sand deposits interfinger with lacustrine, alluvial, and playa deposits and blanket much of the transitional zone between playa and alluvial-fan depositional sites.

Alluvial-fan deposits

Unconsolidated stream and fan deposits (Qaf_1) of poorly sorted gravel, sand, and silt postdate the development of the Bonneville and younger shorelines. These deposits are found as steep alluvial fans at mouths of canyons and gullies, as alluvial floodplains bordering streams, and as sediments in stream channels. Channels containing these "youngest" alluvial deposits have been cut into the older (Qaf_2) and oldest ($QTaf_3$) alluvial-fan deposits and into Lake Bonneville deposits, indicating that they are primarily Holocene in age but the oldest part of the deposits could be latest Pleistocene.

Landslide deposits

Disaggregated colluvium forms hummocky landslides at McLaughlin Spring and along the south side of McGinty Canyon. The landslides (Qms) appear to disrupt the older alluvial-fan deposits (Qaf_2), and therefore are probably Holocene in age. A gravity-slide block on the south side of McGinty Ridge represents mass movement on a much larger scale than those distinguished as landslide deposits. The slide has displaced the Badger Gulch Formation onto the McGinty Monzogranite.

Playa mud

Carbonate mud and silt (Qpm) deposited by a combination of alluvial and lacustrine processes underlie the broad playa in the southeastern part of the quadrangle. These mud deposits contain varying amounts of oolitic sand, and gypsum and halite evaporite deposits (Lines, 1979). Other deposits mapped as playa mud underlie depressions located behind Lake Bonneville beach ridges on the Birch Canyon-Lemay Island escarpment that contain standing water during periodic rainfall. These deposits consist of white to tan mud and silt.

Alluvial silt

Bordering the Pilot Valley playa are extensive thin sheets of alluvial silt with subordinate fine sand and clay (Qai). These deposits constitute a facies transitional between the coarse alluvial deposits (Qaf_1) of the piedmont and the fine playa deposits (Qpm). The alluvial silt was probably deposited both as low-gradient alluvial sheets and as delta-like deposits within the margins of standing water bodies. The deposits are bounded by gradational contacts with playa mud and they interfinger with and are overlain by eolian materials (Qes).

Colluvium and talus

Colluvium and talus (Qmc) deposits are common along many steep slopes in the Pilot Range. Particularly abundant deposits of blocky talus lie on slopes underlain by the Prospect Mountain Quartzite. Along the lower parts of talus slopes, such as those bordering the southern side of Birch Canyon, the talus deposits are gradational with colluvium consisting of conglomerate, gravel, and sand. Colluvium generally supports vegetation, whereas talus contains little fine material between blocks and supports little vegetation.

STRUCTURE

Pre-Quaternary rocks in the Crater Island NW quadrangle display diverse structures that can be conveniently divided into two lithotectonic domains based on age, metamorphism, and structural history. In the first lithotectonic domain, south of Birch Canyon, low-angle and high-angle faults, penetrative folds and cleavage, and a major fold deform metamorphic rocks. Many of these structures are known or inferred to be post-Middle Jurassic to pre-latest Eocene in age on the basis of relations with dated igneous bodies. In the second domain, north of Birch Canyon and throughout the eastern part of the quadrangle, low-angle and high-angle faults (many inferred on the basis of gravity anomalies) cut Neogene strata and igneous rocks.

Structures south of Birch Canyon

South of Birch Canyon, moderately metamorphosed strata form a major northeast-trending syncline, the Cottonwood Springs syncline (plate 1). The strata are folded, cleaved, and cut by ductile bedding-plane faults in a consistent sequence of deformation. The oldest is bedding-parallel cleavage, followed by northeast-striking cleavage that is related to development of northeast-trending folds and bedding-plane faults. Both of these cleavage sets were accompanied by growth of muscovite and biotite. Miller and others (1987) demonstrated that metamorphic mineral growth took place during the Late Jurassic and

possibly also during the Cretaceous in similar metamorphic rocks south of and continuous with those in the Crater Island NW quadrangle. Later high-angle faults cut structures formed during ductile deformation, strike north, and are presumed to be Neogene in age.

Ductile structures appear to be related to the development of the Cottonwood Springs syncline. Penetrative cleavage oriented nearly parallel with bedding and containing rare east-trending mineral elongation lineation is deformed by steeply northwest-dipping penetrative cleavage that is axial planar to small folds with shallowly northeastward- plunging axes. The small folds are generally open to moderately tight, and they are similar in geometry and orientation to the major Cottonwood Springs syncline. Small-scale, northeast-trending folds are especially well developed within the Toano Limestone in the core of the syncline. In the adjacent Patterson Pass quadrangle, small-scale folds are probably related to bedding-plane faulting (Miller and others, 1993). Because bedding-plane faults near the base and top of the Prospect Mountain Quartzite appear to show greatest stratigraphic truncation along the steeply dipping limbs of the Cottonwood Springs syncline, they probably are related to development of the syncline. By this view, parasitic folding and bedding-plane faulting were caused by disharmonic folding on a grand scale as the major syncline formed.

Folds and bedding-plane faults south of Birch Canyon are latest Eocene or older in age, because the structures were intruded by the McGinty Monzogranite. Retrograde metamorphic minerals are present near the margin of the pluton, indicating that ductile deformation and regional metamorphism distinctly predated emplacement of the pluton. In the adjacent Pilot Peak quadrangle (Miller and Lush, 1981), folds and bedding-plane faults, interpreted as correlative with the structures in the Crater Island NW quadrangle, formed during regional metamorphism that predated 83 million years ago (Miller and others, 1987). Metamorphism, folding, and faulting in the Pilot Peak quadrangle postdated intrusion of muscovite granite, which has been dated at 155 to 165 Ma by U-Pb on zircon (Miller and others, 1987). Deformation in the Pilot Peak quadrangle is therefore constrained as Late Jurassic to Late Cretaceous in age; deformation south of Birch Canyon is interpreted as the same age because of physical continuity with structures in the Pilot Peak quadrangle.

Several moderately dipping normal faults cut the Cottonwood Springs syncline. West-dipping faults near the edge of the quadrangle show separations of a few tens of meters in most cases and are characterized by narrow breccia zones. They have orientations similar to Quaternary faults along the west margin of the range, and therefore are probably Neogene in age. An east-dipping fault that passes from near Birch Canyon southward to the range front also shows tens of meters of separation. Granodiorite appears to have intruded the fault, although exposures are poor and it is possible that the granodiorite is broken in the fault zone. The fault may be Eocene or older, as indicated by apparent intrusive relations with the granodiorite. Cutting the eastern exposures of the Toano Limestone is a shallowly to moderately dipping fault marked by brecciated dolomite and silicification. This east-dipping fault appears to be normal because it places what is presumably the Prospect Mountain Quartzite against the McCoy Creek Group of Misch and Hazzard (1962) at its south end. This fault marks a major topographic break at the foot of the range; east of it are fragments of pediment exposures that are locally capped by Pliocene(?) and Pleistocene alluvium. The fault probably is one of several in a broad zone that form a frontal fault system for the Pilot Range.

Structures cutting Tertiary strata

Low-angle faults located in the pediment north of Birch Canyon and inferred to lie in the central and eastern parts of the quadrangle cut Neogene strata and the latest Eocene McGinty Monzogranite. Most of the mapped faults in the pediment dip moderately to gently eastward and northeastward. Other faults apparently bound a shallow basin containing low-density Tertiary strata (Cook and others, 1964) north of the Birch Canyon-Lemay Island escarpment and a deeper basin south of that escarpment.

At McGinty Ridge, a low-angle fault slice enclosing the undivided Chainman Shale and Diamond Peak Formation rests on the McGinty Monzogranite. The monzogranite is brecciated and partly altered to epidote, chlorite, and sericite adjacent to the fault (the McGinty Ridge fault), indicating moderate temperatures during fault movement. Sandstone and shale of the Chainman-Diamond Peak unit is jumbled; bedding is rarely evident. Diabase is brecciated at the McGinty Ridge fault also. Faulted above the Chainman-Diamond Peak, and dipping steeply eastward into the McGinty Ridge fault, is a sequence of Permian strata that is structurally discordant with respect to underlying rocks. Eastward and northward from these Permian strata are similarly eastward-dipping Tertiary strata. The contact between Permian and Tertiary strata is not exposed, but in adjacent quadrangles to the north this contact is a fault (Miller, 1985).

The similar bedding orientations in the Permian and Tertiary strata suggest a common origin for tilting of the two sequences. Northward from McGinty Ridge, the trace of the McGinty Ridge fault placing Tertiary strata on the pluton is north trending, and the fault dips moderately eastward. Slices of Paleozoic carbonate rocks occur sporadically in the fault zone, always separating granitic rocks on the west from Tertiary strata on the east. Parallel faults lie to the east, but the orientations of these faults are not well known. Movement on the McGinty Ridge fault postdated deposition of Miocene sediments in the eastern block and intrusion of Pliocene(?) diabase, and predated Pleistocene gravel that covers the fault trace. In contrast, the fault separating Eocene from Miocene strata, in the hanging wall of the McGinty Ridge fault, appears to have been intruded by diabase and therefore is probably older than the McGinty Ridge fault. Miocene strata are truncated by this older fault, so it is probably Miocene in age. The rotation of bedding in Permian to Miocene strata to vertical and overturned in the hanging wall of the McGinty Ridge fault is most simply interpreted as due to down-to-the-west normal faulting. Continued rotation of the fault and strata along younger normal faults (at depth?) probably accounts for the steep bedding and the gentle eastward dip of the fault that originally probably dipped moderately west. Thus, the range front north of Birch Canyon is caused by different erosion rates in the tilted section of non-resistant Tertiary rocks and relatively resistant granite and Paleozoic rocks.

Faults inferred to underlie the eastern part of the quadrangle were located on the basis of gravity data (Cook and others, 1964). A Tertiary basin about 750 m (2,500 ft) thick was inferred by Cook and others (1964) to lie between the northern Pilot Range and small bedrock hills to the east (Lion Mountain in the Lucin quadrangle and Lemay Island; figure 1). The faults bounding

this basin apparently do not cut Pleistocene alluvium and they bound low-density blocks inferred by Cook and others (1964) to represent Tertiary sedimentary rocks. In places along the west side of this block, Miocene strata are cut by mapped faults nearly coincident with the gravity anomalies, suggesting that the basin is late Miocene or Pliocene in age. In contrast, a deeper basin containing about 1,200 m (4,000 ft) of low-density sedimentary rocks underlies the Pilot Valley playa (Cook and others, 1964). It may be that younger (Pliocene?) faulting created a deeper basin to the south of the Birch Canyon-Lemay Island escarpment by causing additional subsidence of the basin block along this part of the Pilot Range. The straight range front and the escarpment were probably caused by these younger faults, but no faults are exposed.

ECONOMIC GEOLOGY

Considerable mining activity took place in the Lucin district west and north of the Crater Island NW quadrangle during the late 1800s and early 1900s, but none is known within the quadrangle. Blue (1960) and Doelling (1980) summarized the history of the Lucin district, which included copper, lead, silver, and iron production. Mineralization was mainly by replacement of carbonate rock and in fracture fillings in middle Paleozoic carbonate strata; it appears to be spatially related to abundant small, altered intrusions of the McGinty Monzogranite. Although it seems unlikely that mineralization similar to that of the Lucin district is present within exposed rocks of the Crater Island NW quadrangle, the association of mineralization with the McGinty Monzogranite indicates that similar mineralization may be buried near the margins of the pluton.

Several features in the quadrangle have potential economic interest. (1) Sorted gravel deposits along the shores of ancient Lake Bonneville may be suitable for construction uses. (2) Felsite dikes (Tf) are locally altered and brecciated and in some cases carry casts after pyrite; they may have served as conduits for mineralizing fluids. (3) Siliceous Tertiary volcanic rocks may have potential for disseminated gold or other mineralization. (4) Concentrated minerals in brines within the saturated playas of Pilot Valley may be economically retrievable. Nolan (1927) described potash brines in the area, and Lines (1979) compared brines of Pilot Valley playa with those of Bonneville Salt Flats. (5) Black sands in the northern Pilot Range, apparently related to decomposed diabase bodies (Miller, 1985), were described by Doelling (1980) as ilmenite-rich and a possible titanium resource. Although the black sand locations shown by Doelling lie to the north of the Crater Island NW quadrangle, similar sands derived from deeply weathered diabase are widespread in the northwestern Crater Island NW quadrangle. (6) Vein quartz and jasperoid, locally associated with the fault zone in outcrops of the Toano Limestone and marking the range front, may be sources for disseminated gold or related mineralization. (7) A broad zone near the normal fault between Eocene volcanic rocks and Miocene strata is commonly silicified, and it may have potential for disseminated gold or other mineralization.

HYDROLOGY

Most streams in the Crater Island NW quadrangle are intermittent, but part of lower Birch Canyon, below Patterson Pass Spring, is perennial. The source of this spring is apparently ground water in granite gravel upslope that is forced to the surface where it passes over shallowly buried rocks of the McCoy Creek Group of Misch and Hazzard (1962). In many canyons in the piedmont in the northwestern part of the quadrangle, the ground water probably is located in the shallow subsurface because phreatophytes line the canyons. Small springs in this area were developed as a water source for the railroad village of Lucin to the northeast. No springs are known east of the Bonneville shoreline and north of the Birch Canyon-Lemay Island escarpment, and ranches developed in this area reportedly rely on water wells several hundred meters deep. In contrast, a few small springs lie near the margin of the Pilot Valley playa south of the Birch Canyon-Lemay Island escarpment. These springs are probably due to ground water in alluvial fans, derived from the Pilot Range, being forced to the surface above impermeable clays along the playa margin (Miller, 1990a).

GEOLOGIC HAZARDS

Although there is no evidence for young faulting in the Crater Island NW quadrangle, Pleistocene and Holocene faulting is indicated by rounded scarps, linear terraces, and well-developed linear arrays of springs in the Patterson Pass quadrangle to the west (Miller and others, 1993). These youthful faults could give rise to moderate or large earthquakes typical of other parts of the Basin and Range Province. Thus, groundshaking from earthquakes and related hazards, such as liquefaction of water-saturated sand, are potential hazards in this quadrangle. Additionally, landslides, gravity-slide blocks, and talus slopes in the Pilot Range potentially could be activated by earthquakes, excessive rainfall, or other destabilizing processes.

Alluvial fans bordering the Pilot Range and alluvial deposits in canyons were emplaced primarily by destructive debris flows, sheet washes, and overbank flooding. In many sites, alluvium is currently being deposited or erosion is taking place. There is great potential for destructive floods and debris flows, particularly close to the range front and within canyons. Shallow ground water is also a hazard in the southeastern part of the quadrangle, particularly during wet seasons.

Eolian sand rimming the Pilot Valley playa and local sand dunes developed at sites of lacustrine sand accumulation are subject to migration if the fragile vegetative cover is disturbed. Roads and other constructions, if located carefully, may avoid dangers of drifting sand dunes. The extensive clay-rich sediment in the quadrangle, including various lacustrine, playa, and eolian deposits, suggests that expansive soils could be present.

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