DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC MAP OF PRE-TERTIARY ROCKS OF THE PARADISE RANGE AND SOUTHERN LODI HILLS WEST-CENTRAL NEVADA

By

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Pamphlet to accompany Map MF-2062

DESCRIPTION OF MAP UNITS

Qu **Surficial deposits, undivided (Quaternary)**—Unconsolidated and consolidated alluvium, colluvium, slope wash, and playa deposits

Qa **Alluvium (Quaternary)**—Unconsolidated alluvial deposits along active drainages

Qoa **Older alluvium (Quaternary)**—Unconsolidated and consolidated sand and gravel

Tv **Volcanic rocks (Tertiary)**—Unit also includes minor amounts of interstratified sedimentary rocks

Td **Hypabyssal dike rocks (Tertiary)**—Rhyolite felsite and porphyries of intermediate composition

GRANITIC AND HYPABYSSAL INTRUSIVE ROCKS

Radiometric and relative intrusive ages for these units for the most part unknown; relatively unaltered undated granitic and hypabyssal bodies presumed to be Cretaceous in age, based on regional relations; metamorphosed and (or) foliated bodies could be as old as Jurassic

Granite—Quartz conspicuous; K-feldspar generally predominant over plagioclase. Granites generally lack penetrative structural fabrics

gr_5 **Granite south of Paradise Peak (Cretaceous)**—Medium- to coarse-grained biotite granite. Locally contains small (1-2 cm) K-feldspar megacrysts and conspicuous ovoid quartz phenocrysts. Contains about 5 percent biotite. Generally strongly sericitized and pyritized; locally cut by stockwork quartz $\pm$ pyrite $\pm$ chalcopyrite veins with muscovite selvages. Crops out in west front of Paradise Range south of Gabbs and at south end of range crest. Sericite alteration age of 74.2$\pm$1.9 Ma (John and McKee, 1987) from a green sericite-quartz-fluorite-pyrite pod collected approximately 2 km south of Paradise Peak

gr_4 **Granite of Germany Canyon (Cretaceous)**—Fine- to medium-grained, allotriomorphic, granular, biotite granite. Sparcely porphyritic with small plagioclase and K-feldspar phenocrysts. Plagioclase phenocrysts locally have K-feldspar overgrowths. Generally strongly sericitized; locally pyritized. Crops out on west side of Paradise Range south of Germany Canyon. Presumably Cretaceous in age because granite bodies that can be dated in area are Cretaceous

gr_3 **Granite of Ellsworth (Cretaceous)**—Medium-grained, coarsely porphyritic, biotite granite containing abundant, white to pink K-feldspar megacrysts as much as 10 cm long. Ovoid quartz phenocrysts as much as 1 cm in diameter. Contains about 3-5 percent fine-grained biotite. Crops out in Ellsworth district. Presumably Cretaceous in age because other granite bodies that can be dated in area are of this age

gr_2 **Biotite granite (Cretaceous)**—Fine-grained, aplitic, biotite granite containing from about 5 to 7 percent biotite; locally with small miarolitic cavities. Biotite commonly altered to sericite and chlorite. Outcrop pattern in south end of Lodi Hills adapted from Vitaliano and others (1957)

gr_1 **Illinois stock (Cretaceous)**—Medium- to coarse-grained, porphyritic to nearly equigranular biotite granite. Contains small (1-2 cm) K-feldspar megacrysts and about 5 percent biotite. Locally strongly foliated. Whole-rock Rb-Sr isochron of 102.4 ± 0.8 Ma (A.C. Robinson, written commun., 1985). Crops out in south end of Lodi Hills; also known as the Lodi Hills pluton. Joint measurements within outcrop area from Vitaliano and others (1957)

Granodiorite—Quartz conspicuous; plagioclase generally predominant over K-feldspar

gd_7 **Gabbs pluton (Cretaceous)**—Medium-grained, equigranular, hornblende-biotite granodiorite. Fresh and unfoliated. Color index (surface-area percentage of mafic minerals) about 25. Mafic minerals mostly fine-grained, subhedral biotite; mafic inclusions abundant. Forms Gabbs pluton (also known as the Cottonwood pluton) at and south of Gabbs magnesite mine; also occurs in scattered, partly dike-like bodies from Bell Canyon southward along east flank of Paradise Range; forms migmatite in structurally highest unit, gd_5, beneath unit Jmq in major syncline in Bell Canyon area. Considered to be Cretaceous in age because of lithologic resemblance to unit gd_6 of demonstrable Cretaceous age

gd_6 **Hornblende-biotite granodiorite (Cretaceous)**—Fine- to medium-grained, equigranular, hornblende-biotite granodiorite. Color index about 20. Mafic minerals consisting of subhedral biotite and hornblende in subequal amounts. Small, fine-grained dioritic inclusions abundant. Intrudes unit gr_1 at south end of Lodi Hills

gd_5 **Granodiorite of Baxter Spring (Cretaceous or Jurassic)**—Fine- to medium-grained, locally porphyritic, hornblende-biotite granodiorite. Color index varies from about 10 to 20 with sparce hornblende phenocrysts as much as 5 mm long that are pseudomorphed by fine-grained, green biotite. Also contains scattered, rounded, quartz phenocrysts as much as 7 mm in diameter and K-feldspar megacrysts as long as 2 cm. Plagioclase phenocrysts partially altered to epidote. Commonly metamorphosed; locally strongly foliated. Porphyry-like texture characteristic of dike-like bodies; some leucocratic dikes are nearly devoid of mafic minerals. Crops out from northwest side of Green Spring flat southward to east side of Paradise Range

gd_4 **Granodiorite of Big Chief Mine (Cretaceous or Jurassic)**—Fine- to medium-grained, biotite-granodiorite porphyry. Contains small phenocrysts of plagioclase and biotite in fine-grained matrix of quartz and feldspar. Strongly altered throughout, with sericite replacing feldspars, and chlorite and calcite replacing biotite; locally pyritized. Crops out in vicinity of Big Chief Mine and in low hills at south end of Lodi Valley

gd_3 **Granodiorite of Ottawa Canyon (Cretaceous or Jurassic)**—Fine- to medium-grained granodiorite porphyry. Scattered K-feldspar megacrysts as long as 1 cm. Biotite and hornblende phenocrysts pseudomorphed by fine-grained green biotite, which also occurs locally as patches in groundmass. Biotite commonly chloritized. Plagioclase phenocrysts, as much as 2 mm long, strongly sericitized. Very fine-grained groundmass of quartz and feldspar. Color index from about 5 to 15. Vicinity of Ottawa Canyon

gd_2 **Granodiorite porphyry (Cretaceous or Jurassic)**—Medium-grained, granodiorite porphyry. Seriate K-feldspar megacrysts as long as 4 cm; sparse, but characteristic, rounded phenocrysts of quartz. Locally highly sericitized, mostly well cleaved, fabric cataclastic in places. Represented mainly as fault blocks and slivers associated with lower Paleozoic(?) rocks in Lodi Hills; locally intrusive into both units Pzm and TRld, belonging respectively to the Quartz Mountain and Lodi allochthons

gd_1 **Fine-grained granodiorite (Cretaceous or Jurassic)**—Fine-grained granodiorite or quartz diorite. Intersertal, sericitized plagioclase laths and chloritized subeuhedral biotite with interstitial quartz and abundant opaque minerals. Intrudes only units Pza and Pzs of Quartz Mountain allochthon, west side of Paradise Range between Ottawa and Craig Canyons; also possibly in southeast Lodi Hills

Diorite—Mineral composition generally limited to plagioclase and mafic minerals

di_3 **Diorite of Lodi Hills (Cretaceous)**—Fine-grained, equigranular diorite or quartz diorite. Color index about 20; mafic minerals consisting of hornblende and sparce biotite. Fresh and unfoliated. Intrusive into unit gr_1 and intruded by unit gd_6 in south end of Lodi Hills. Outcrop pattern and joint measurements adapted from Vitaliano and others (1957)

di_2 **Diorite of Big Spring (Cretaceous or Jurassic)**—Medium-grained hornblende diorite in vicinity of Big Spring

di_1 **Diorite of Green Spring Flat (Cretaceous or Jurassic)**—Fine-grained, porphyritic diorite. Color index about 30, with fine-grained biotite pseudomorphing hornblende and occurring as patches in groundmass. Altered plagioclase phenocrysts as much as 3 mm long; no K-feldspar. Areally associated with unit gd_5 in hills southwest of Green Spring flat

Hypabyssal intrusive rocks

hpm **Porphyry of Menter Canyon (Cretaceous)**—Fine- to medium-grained, hornblende-biotite, granodiorite porphyry grading locally to porphyritic granodiorite. Porphyry contains small plagioclase, biotite, and hornblende phenocrysts; scattered phenocrysts of rounded quartz and megacrysts of K-feldspar as long as 1 cm; small phenocrysts of clinopyroxene present locally. Porphyry groundmass of very fine-grained quartz, feldspar, and green biotite. Mafic phenocrysts generally pseudomorphed by fine-grained green-brown biotite and magnetite. Crops out from Craig Canyon south to Bell Canyon; texture is most granitic in Topier Canyon and most volcanic in northeasternmost exposures. Age uncertain but considered to be Cretaceous because unit generally lacks structural fabrics shown by all pre-Tertiary strata and by older granitic intrusive rocks

hd **Dike rocks (Cretaceous or Jurassic)**—Miscellaneous dike rocks of mappable extent; generally of intermediate composition

ha **Meta-andesite porphyry and metadiorite (Cretaceous or Jurassic)**—Fine-grained meta-andesite porphyry to fine-grained porphyritic metadiorite. Tectonically interslivered with lower Paleozoic(?) rocks of Quartz Mountain allochthon in low hills at southeast end of Lodi Hills

hf **Felsic or intermediate hypabyssal rocks (Cretaceous or Jurassic)**—Various felsitic or intermediate hypabyssal rocks in Lodi Hills occurring as separately mappable intrusions, especially within unit ha, and as fault-bounded tectonic breccia, commonly including fragments of lower Paleozoic(?) quartzite and dolomite. Tectonically interslivered with units gd_2, ha, and lower Paleozoic(?) rocks of Quartz Mountain allochthon. Includes rocks identified in field as feldspar porphyry, aplite, and fine-grained meta-granodiorite

ROCKS OF UNCERTAIN ALLOCHTHON ASSIGNMENT IN SOUTHERN PART OF PARADISE RANGE

MzPzg **Greenstone (lower Mesozoic and (or) upper Paleozoic)**—In low hills southwest of Paradise Range; relation to units TrPzdv and TrPzp unknown. More southerly exposures in sec. 31, T.11 N., R.36 E. and sec. 36, T.11 N., R.35 E. mainly metavolcaniclastic rocks including massive or graded volcanic- and chert-clast sandstone and grit, dark tuffaceous argillite, and minor conglomerate. Clasts in conglomerate mostly volcanic porphyries and granitic rocks as much as 0.5 m in diameter; rare clasts of white or silty brown-weathering marble. Southwesternmost exposures noticeably hornfelsed and with veins and large clots of epidote. More northerly exposures in and around sec. 30, T.11 N., R.36 E. mostly meta-andesite breccia and metadiorite; minor fine-grained volcaniclastic rocks, marble, and laminated, thin-bedded chert. Shell cross sections and silicified spines preserved in foliated marble suggest late Paleozoic brachiopods

MzPzp **Greenstone of Paradise Spring (lower Mesozoic and (or) upper Paleozoic)**—Mainly metamorphosed gabbro, gabbroic mafic segregates, and basalt; minor, but conspicuous, dikes of white felsite. Mostly lacks penetrative structural fabric; locally, where within anastomosing internal shear zones, strongly foliated and resembling unit TrPzdv. Restricted to upper plate of South fault. Unit is most likely part of basement of Lodi allochthon, but could represent a distinct allochthon

LODI ALLOCHTHON

Sedimentary rocks of McGery Canyon (Middle? and Lower Jurassic)—Correlative in part with the Dunlap Formation, as recognized elsewhere in the Paradise subterrane of the Walker Lake terrane (Silberling and others, 1987) in which the Dunlap Formation forms part of the Berlin allochthon and of the so-called Luning assemblage and Pamlico assemblage of Oldow (1984)

Jmq **Quartzite (Middle? and Lower Jurassic)**—Massive, white to light-brown, orthoquartzitic metaquartzite with local large-scale eolian cross lamination having foreset surfaces traceable for as much as 10 m; gradational into white, quartzose, calc-silicate rock formed from calcareous quartz sandstone; includes some dolomitic marble

Jmm **Marble (Middle? and Lower Jurassic)**—Foliated, coarsely crystalline, white or pale-yellow brown, dolomitic in part

Jms **Sandstone (Lower Jurassic)**—Gray-green or brown, hornfelsed. Mostly massive; lamination, where present, mostly planar; local scour and ripple-drift cross bedding. Minor pebbly sandstone and fine-grained conglomerate containing igneous clasts. Some laminated hornfels representing original pelitic rocks

Jms_2 **Upper part**—About 50 m thick; recognized where superposition is clear

Jms_1 **Lower part**—About 200 m thick; separated from unit Jms_2 by approximately 200 m of unit Jmm

Volcano Peak Group of Taylor and others (1983) (Lower Jurassic and Upper Triassic)—Typically consists of the Sunrise and Gabbs Formations, whose mutual boundary is lithologically unrecognizable in the Paradise Range

Jvb **Marble of Baxter Spring (Lower Jurassic)**—Gray, calcitic, mostly foliated. Some original, fine-grained, siliciclastic impurity, but less than that in unit JTrvl. Rare stringers of matrix-supported grit near Downeyville. Rhynchonellid brachiopod marker bed at or near stratigraphic top of unit and conspicuous at map localities 1-10

JTrvl **Limestone and calcareous clastic rocks (Lower Jurassic and Upper Triassic)**—Impure limestone and calcareous, fine-grained, terrigenous-clastic rocks; metamorphically recrystallized and hornfelsed; locally well foliated; commonly represented by brown siliciclastic hornfels occurring as diffuse, irregular, medium-thick interbeds in gray metalimestone. Conspicuous metacrysts of dark polyaugite locally abundant, locally replacing most of rock near Downeyville. Large, thick-shelled pectenacid bivalves of the genus *Weyla* and (or) arietitid ammonites of Early Jurassic (Sinemurian to Pliensbachian) age at map localities 11-16

Gabbs Formation (Upper Triassic)

Trvgn **Nun Mine Member of Taylor and others (1983)**—Thin- to medium-bedded, black, recrystallized limestone interbedded with black argillite; characteristically weathers reddish gray. Limestone locally well foliated; argillite hornfelsed. Some argillite with regularly spaced, thin, light-colored, silty laminae exhibiting micro-cross lamination and load casts. Mapped separately only in Lodi Hills and low hills at south end of Lodi Valley; locally recognizable farther south on west flank of Paradise Range but mapped there as part of unit JTrvl. Contains ammonites of the upper Upper Triassic (middle upper Norian) Amoenum Zone at map localities 17 and 18. Equivalent to lower member of Muller and Ferguson (1939)

Luning Formation (Upper Triassic)

TRld — **Dolomite member**—Neomorphosed, dolomicritic, algal-laminate, "primary" (in the sense of Nichols and Silberling, 1980) dolomite; dark gray, weathering light gray. Grades into schistose, laminate, dolomite marble over much of Lodi allochthon. Characteristic exposures of unit in Milton Canyon area of Shoshone Mountains

TRldu — **Upper part**—Massive, gray, partly bioclastic, sugary, secondary dolomite; few tens of meters thick. Mapped separately only where stratigraphically below, and clearly in depositional contact with, the Volcano Peak Group in Lodi Hills and at south end of Lodi Valley

TRll — **Limestone and secondary dolomite member**—Dark-gray, massive, originally micritic, sparcely bioclastic or fossiliferous, recrystallized limestone. In Lodi allochthon, extensively replaced by eogenetic and mesogenetic (Nichols and Silberling, 1980) secondary dolomite and by hydrothermal secondary dolomite, mostly in upper part of unit; limestone in lower part of unit locally replaced by white, coarsely crystalline marble; replacement by magnesite widespread at Gabbs magnesite mine. Cross sections of large, thick-shelled, megalodontid bivalves, partly in growth position, abundant at map localities 19-22. Characteristic exposures of unit in Union Canyon area in Shoshone Mountains

Clastic, carbonate, and meta-igneous rocks of Downeyville (Triassic and upper Paleozoic?)—Restricted to Lodi allochthon; believed to be correlative, at least in part, with lower part of the Luning Formation in Berlin allochthon; may be partly a lateral equivalent of the Pamlico Formation of Oldow (1978)

TRdc — **Clastic rocks (Upper Triassic)**—Black, siliceous argillite with subordinate thin to thick interbeds of volcaniclastic sandstone and conglomerate. Mapped only on west side of Lodi Hills where thickness is about 120 m and upper and lower contacts appear depositional. Largely cut out by faulting in Downeyville area and farther south in Paradise Range, where limited exposures are mapped as part of unit TRdl

TRdl — **Metalimestone (Upper Triassic)**—Regularly thin- to medium-bedded; originally argillaceous, in part with regular, diffuse, hornfelsed, fine-grained, siliciclastic interbeds. Origmal lithologic character of unit best preserved in Lodi Hills where it superficially resembles unit JTRvl. From position in stratigraphic succession, unit is regarded as probable equivalent of unit TRli in Berlin allochthon. Includes phyllite and chlorite-muscovite schist along southwest flank of Paradise Range, where unit TRdc is included

TRPzdv — **Metavolcanic rocks (Triassic and upper Paleozoic?)**—Greenstone. Origmal fabrics largely destroyed by metamorphism, but volcanic breccia and conglomerate locally recognizable; probably includes massive, mafic, volcanic flows and (or) comagmatic intrusive rocks. In part, strongly foliated and lineated. Upper part regarded as Late Triassic in age because of stratigraphic position; lower part of unit, beneath unit TRdvm, could be as old as late Paleozoic

TRdvm — **Marble (Triassic)**—Mostly light-colored, coarsely crystalline. Forms conspicuous unit having a structural thickness of a few tens of meters within upper part of unit TRPzdv on west side of Lodi Hills

QUARTZ MOUNTAIN ALLOCHTHON

Sedimentary rocks (lower Paleozoic?)—Complexly intruded and (or) tectonically interslivered with intrusive rocks in northern and eastern Lodi Hills and separating the Lodi and Berlin allochthons between Ottawa and Craig Canyons in Paradise Range. Provisionally dated as early Paleozoic(?) in age because of lithic similarity to rocks of this age in Toquima Range (for example, as described by Shawe, 1981) and generally different character from nearby Jurassic quartzitic rocks of Lodi allochthon in Paradise Range and of Berlin allochthon in Shoshone Mountains

Pzs **Sandstone, argillite, and phyllite**—Light-olive-gray, gray-green, or light-yellow-gray; sandstone either quartzitic or feldspathic; bedding mostly disrupted

Pzm **Dolomitic marble**—Yellow-orange or buff; massive and sugary textured but locally preserving disrupted internal lamination. In Lodi Hills associated with and forming tectonic breccia with light and dark orthoquartzite; includes some isolated exposures composed entirely of orthoquartzite

Pza **Argillite, phyllite, and orthoquartzite**—Black; bedding disrupted

BERLIN ALLOCHTHON

Luning Formation (Upper Triassic)

TRll **Limestone and secondary dolomite member**—See unit description in Lodi allochthon section. Mostly sugary, black, secondary dolomite above massive, gray, partly bioclastic limestone where unit forms youngest preserved part of Berlin allochthon stratigraphic section in and near Germany Canyon

TRlc **Phyllite, grit, and conglomerate member**—Either dark greenish-gray or dark grayish-purple, with interbedded layers of chert grit and fine-grained, flattened- and stretched-pebble chert conglomerate. Recognized only in Berlin allochthon, where structural thickness is generally less than several tens of meters

TRli **Shaly limestone and calcareous shale member**—Foliated and recrystallized shaly limestone, calcareous shale, and limestone. Equivalent to the calcareous shale and shaly limestone members of the Luning Formation of Silberling (1959). Recognized only in Berlin allochthon; characteristic exposures of member in area of Berlin-Ichthyosaur Park in Shoshone Mountains

TRlr **Clastic rock member**—Metaquartzitic chert-pebble conglomerate and massive, featureless, hornfelsed, fine-grained, clastic rocks. Equivalent to the clastic member of the Luning Formation of Silberling (1959). Recognized only in Berlin allochthon; characteristic exposures of member in Richmond Hill area of Shoshone Mountains

Greenstone of Shamrock Canyon (Triassic and (or) upper Paleozoic)—Restricted to, and characteristic of, Berlin allochthon. Characteristic exposures in vicinity of Shamrock Canyon in Shoshone Mountains where these rocks were previously—and erroneously—mapped by Silberling (1959) as the Pablo Formation

Ŧ Pzsb **Meta-andesite breccia and tuff**—Andesitic greenstone breccia, tuff, and subordinate massive andesite greenstone; generally unstratified; includes comagmatic(?) diorite and (or) gabbro dikes. Conspicuously epidotized near contacts with unit gr_3. Equivalent in the Shoshone Mountains to the greenstone member of the Pablo Formation of Silberling (1959)

Ŧ Pzsm **Marble**—Mostly white to light-yellow-gray, coarsely crystalline, calcitic marble. Massive where not strongly foliated; some gray, megascopically recognizable bioclastic marble preserved near mouth of Marble Falls Canyon. Equivalent in the Shoshone Mountains to the limestone member of the Pablo Formation of Silberling (1959)

Ŧ Pzsc **Volcaniclastic rocks**—Volcaniclastic andesitic greenstone representing protolithic tuffaceous mudstone, volcaniclastic sandstone, conglomerate, sedimentary breccia, and minor coarse andesite breccia. For the most part, represents a shoaling-upward turbiditic sequence exhibiting graded bedding, cross bedding, and planar lamination, commonly in Bouma A-C-D sequences. Distinctive several-meter-thick unit of lapilli welded tuff near top; uppermost part may have been subaerially deposited. Black, gray, or white orthoquartzite clasts sparcely represented in conglomeratic beds throughout; rare granodiorite clasts in conglomerate near top of unit. Equivalent in Shoshone Mountains to the clastic member of the Pablo Formation of Silberling (1959)

Contact—Depositional or intrusive. Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed. Parallel arrows show relative horizontal displacement; perpendicular arrow shows direction of dip. Ball and bar on downthrown side

Low-angle extensional fault—Dashed where approximately located; dotted where concealed. Hachures on hanging wall

Thrust fault—Dashed where approximately located; dotted where concealed. Sawteeth on inferred upper plate

Overturned thrust fault

Fold

Axial trace, first-deformation fold

Axial trace, second-deformation fold. Dotted where concealed

Syncline, shown on first-deformation axial trace

Anticline, shown on first-deformation axial trace

Overturned syncline, shown on first-deformation axial trace

Overturned anticline, shown on first-deformation axial trace

Strike and dip of beds

Inferred upright

Inferred overturned

Vertical. Facing direction uncertain

Demonstrably upright, based on depositional features

Demonstrably overturned, based on depositional features

Vertical. Ball on side of facing direction, based on depositional features

Strike and dip of cleavage—Preferred parallel planar fracture; gradational into foliation

Inclined

Vertical

Strike and dip of foliation—Megascopic metamorphic mineral-growth fabric

Inclined

Vertical

Strike and dip of compaction foliation—In tuffaceous volcanic rocks of Tertiary age

Strike and dip of joints

Inclined

Vertical

Plunge of lineation—Metamorphic mineral-growth fabric

Plunge of minor fold axes


Inclined


Subhorizontal


Folds of lineation

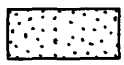

Anticline axis

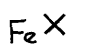

Syncline axis


Overturned anticline axis


Overturned syncline axis


Fold(s) and strike and dip of associated axial surface or cleavage


Hydrothermal alteration


Magnetite-replacement prospect—Two occurrences northwest of Alum Spring


Mine dump


Fossil locality number

LIST OF FOSSILS AND THEIR LOCALITIES

Map number	
1	Rhynchonellid brachiopods; hills near Downeyville
2	Do.
3	Do.
4	Rhynchonellid brachiopods; range crest north of Paradise Peak
5	Do.
6	Do.
7	Do.
8	Do.
9	Rhynchonellid brachiopods; east of Paradise Peak
10	Rhynchonellid brachiopods; west of B and C Spring
11	*Weyla* sp. of Sinemurian or Pliensbachian (Early Jurassic) age; Craig Canyon near Downeyville
12	*Weyla* sp. of Sinemurian or Pliensbachian (Early Jurassic) age; McGery Canyon-Tungsten Canyon divide
13	*Weyla* sp. of Sinemurian or Pliensbachian (Early Jurassic) age; vicinity of Paradise Peak
14	*Weyla* sp. and arietitid ammonites; east of Paradise Peak
15	Arietitid ammonites of Sinemurian or Pliensbachian age; Bell Canyon
16	Arietitid ammonites of Sinemurian or Pliensbachian age; Tungsten Canyon-Granite Canyon divide
17	*Cochloceras* sp., *Arcestes* sp., late Norian (Late Triassic) age; west side Lodi Hills (Quartz Mtn. 7.5' quadrangle)
18	*Cochloceras* sp., *Rhabdoceras* sp., late Norian (Late Triassic) age; low hills at south end of Lodi Valley
19	Megalodontid(?) bivalves of probable Norian (Late Triassic) age; west side Lodi Hills (Quartz Mtn. 7.5' quadrangle)
20	Do.
21	Megalodontid bivalves of probable Norian age; east of Downeyville
22	Megalodontid bivalves of probable Norian age; McGery Canyon-Tungsten Canyon divide
23	Conodonts including *Epigondolella* cf. *E. postera* identified by A.G. Harris (written commun., 1984) and representative of a Late Triassic morphotype no older than late Karnian in age; Ellsworth district

PRE-TERTIARY STRUCTURAL EVOLUTION

MESOZOIC ALLOCHTHONS

All of the pre-Tertiary stratified rocks in the Paradise Range and nearby Lodi Hills are thought to be allochthonous with respect to cratonic North America, and they belong to four or more tectonostratigraphically different allochthons having late Mesozoic displacement histories. At least three of these allochthons are composed of upper Paleozoic and (or) lower Mesozoic rocks of the Paradise subterrane of the Walker Lake terrane (Silberling and others, 1987).

The most extensive of these allochthons, as exposed in the map area, is composed mainly, or wholly, of lower Mesozoic rocks and is named here the Lodi allochthon (LOu and LOl on fig. 1). Strata of the Berlin allochthon (BE on fig. 1) are largely correlative with those of the Lodi allochthon and crop out to the northeast of it, in the Paradise Range, and also about 20 km farther east, in the Shoshone Mountains, outside of the map area. Uppermost Triassic and lowermost Jurassic strata of the Lodi and Berlin allochthons are very similar and can be assigned to the same lithologic units that form the upper part of the Luning Formation and the bulk of the overlying Volcano Peak Group of Taylor and others (1983). In their older and younger parts, however, the stratigraphic sections of the Lodi and Berlin allochthons are quite distinct. In the Lodi allochthon of the Paradise Range the sedimentary rocks of McGery Canyon (Jmq, Jmm, Jms) and the subjacent upper unit (Jvb) of the Volcano Peak Group form a stratigraphic sequence different from that of correlative upper Lower and Middle(?) Jurassic rocks of the Berlin allochthon in the Shoshone Mountains. Moreover, volcanic and volcaniclastic rocks, which characterize the older parts of both the Lodi and Berlin allochthons, occur at much higher levels within the Triassic section of the Lodi allochthon compared to the Berlin allochthon. Based on lithologic correlations, the youngest coarse volcanic debris in the Triassic section of the Lodi allochthon is of early Norian (middle Late Triassic) age, whereas in the Berlin allochthon it is Ladinian (late Middle Triassic) or older in age.

Rocks of the Lodi allochthon belong to both the Gabbs nappe and its lower plate. As strata of the Gabbs nappe are overturned for more than 25 km in the inferred transport direction, displacement between the nappe and its lower plate may have been sufficient to have juxtaposed somewhat different stratigraphic sections. However, the older parts of the section within the Gabbs nappe are not exposed in its lower plate, and conversely the upper part of the section in the lower plate of the nappe is younger than the stratigraphically highest of the overturned beds within the nappe that are truncated by the Gabbs thrust, the sole of the nappe. Thus, the parts of the sections in which lithologic contrast might be most expected, by analogy with the differentiation of the Lodi and Berlin allochthons, cannot be compared, so both the Gabbs nappe and its lower plate are included in the Lodi allochthon. Both the nappe and its lower plate contain some rocks that differ markedly from correlatives in the Berlin allochthon.

Another juxtaposed allochthon is probably represented by the isolated exposures of undated volcanogenic rocks (MzPzg) in the low hills southwest of the Paradise Range. These rocks, whose contact with the Lodi allochthon is buried beneath a broad tract of Tertiary volcanic rocks, manifest a different structural and metamorphic history than that of nearby parts of the Lodi allochthon. The rocks of unit MzPzg might belong to the extensive turbiditic, andesitic volcaniclastic unit of uncertain age that crops out as close as 20 km west of the Paradise Range and is included in the so-called "Sand Springs assemblage" of Oldow (1984), another allochthonous component of the Paradise tectonostratigraphic subterrane. Alternatively, they could represent a latest Paleozoic island-arc association akin to the Black Dyke Formation of Speed (1977), which forms a fault sliver between different allochthons of lower Mesozoic rocks about 50 km southwest of the Paradise Range, within the Paradise subterrane.

Mafic greenstones of unit MzPzp form most of the hanging wall (SF on fig. 1), or upper plate, of the South fault at the south end of pre-Tertiary exposures in the Paradise Range. The nature of this fault, and thus the structural history of these rocks, is uncertain. The South fault could be either a Mesozoic thrust or a low-angle Tertiary normal fault that pre-dates the Sheep Canyon fault on which the Tertiary rocks in the southwest part of the Paradise Range are detached from the pre-Tertiary section. Because the hanging wall of the South fault is interpreted to include fault slivers of units Jvb, JTRvl, and TRld, in addition to unit MzPzp, and because unit MzPzp partly resembles unit TRPzdv, the rocks displaced by the South fault are most likely part of the Lodi allochthon. Nevertheless, unit MzPzp could represent a discrete allochthon.

Still another tectonostratigraphically distinct allochthon is characterized by a variety of quartzites, sandstones, argillites, phyllites, and dolomitic marbles (Pzs, Pza, Pzm) which on lithologic grounds are believed to be of Paleozoic(?), largely early Paleozoic(?), age. These rocks occur in a structurally disrupted mass between the Lodi and Berlin allochthons along the west side of the Paradise Range north of Craig Canyon, and they continue into the eastern and northern Lodi Hills where they are intricately intruded by and structurally brecciated and interslivered with igneous rocks (gd_2, ha, and hf). These disrupted sedimentary rocks are included in the Quartz Mountain allochthon (QM on figs. 1 and 2), named for Quartz Mountain where rocks of the allochthon are exposed about 5 km northwest of the map area. The areas in the Lodi Hills that are labelled QM on figures 1 and 2 include both rocks of the Quartz Mountain allochthon and the areally more extensive intrusive rocks of units gd_2, ha, and hf because their mutual distribution is too complex for portrayal at this scale. However, most of the faults that bound exposures of these intrusive rocks, along with those of the disrupted sedimentary rocks that characterize the Quartz Mountain allochthon, are thought to post-date the fault or faults on which the sedimentary rocks of the Quartz Mountain allochthon were originally emplaced.

DEFORMATION HISTORY

Rocks of the Lodi and Berlin allochthons in the Paradise Range and Lodi Hills have undergone polyphase deformation that generally fits the pattern described by Oldow (1984) for other parts of the Paradise subterrane. The earliest deformation, termed D1 (and equivalent to the regional "D2" of Oldow, 1984), caused major northwest-southeast tectonic shortening. Emplacement of the Gabbs nappe on the Gabbs thrust and development of the conspicuous west-northwest-trending, mineral-growth stretching lineation (domains C and D, fig. 1) in the rocks of the nappe is attributed to D1. Variable orientations of the axes of minor folds (domain C) within the plane of the D1 cleavage or foliation suggest rotation into parallelism with the D1 lineation. Minor, decimeter-scale, northeast-trending folds of D1 lineation, characteristic of the southwesternmost exposures of the Gabbs nappe, are regarded as a late phase of D1.

Subsequent polyphase deformation (D2), resulted from northeast-southwest shortening, the older phase(s) being southwest verging, and the younger phases of D2 being northeast verging. A northwest-trending D2 fold axis is described by folding of D1 cleavage or foliation in rocks of the Lodi allochthon, as in domain D, and especially in domain B, where an early, premetamorphic cleavage survived hornfelsic recrystallization in sandy beds of the Volcano Peak Group.

Bedding attitudes in a large and relatively well-exposed part of the Berlin allochthon (domain E) generally strike northwest and describe a shallow southeast-trending D2 fold axis. Just to the northwest of domain E, however, different fault blocks preserve both overturned and upright sequences of Berlin allochthon rocks that strike northeast and may relate to a large D1 fold (fig. 1). For comparison, bedding attitudes are also shown on figure 1 for rocks of the Berlin allochthon in the Grantsville Canyon area of the Shoshone Mountains (termed domain F), about 22 km southeast of domain E. Here the same southeast-trending D2 fold axis is again well defined by bedding orientations. At the south end of pre-Tertiary exposures in the Shoshone Mountains a large northeast-trending D1 syncline is folded around this D2 axis (Silberling, 1959, pl. 10).

The highly deformed sedimentary rocks in domain A, which belong to the Quartz Mountain allochthon, include rock types that originally might have been part of the middle Paleozoic Roberts Mountains allochthon. Thus they may have already been deformed in Paleozoic time, prior to being thrust into their present location. Orientation of cleavage and foliation surfaces among these rocks indicates refolding around the regional D2 fold-axis trend (fig. 2), but their fold history is undoubtedly much more complex.

ORIGIN OF MAJOR PRE-TERTIARY STRUCTURES

Major D1 structures within the map area include the Gabbs thrust, which is the sole of the Gabbs nappe; D1 folds in the lower plate of the nappe within rocks of the Lodi allochthon; and the possible large northeast-trending isoclinal anticline, mentioned above, in the northwesternmost exposures of the Berlin allochthon.

In the overturned sequence of the Gabbs nappe, the sheared-out depositional contact between units TRld and JTRvl forms the southern part of the feature mapped by Vitaliano and Callaghan (1963) as the Paradise thrust. Although shear strain is pronounced in the zone of this fault, and some stratigraphic section is cut out, it is not regarded as a major allochthon-bounding fault.

D1 structures in the lower plate of the Gabbs nappe, within the Lodi allochthon, consist of tightly to moderately appressed, northeast-trending segments of kilometer-scale folds, well displayed, for example, in Lower Jurassic strata along the southern range crest and southeast flank of the Paradise Range.

The oldest D2 structure is inferred to be the largely hypothetical Big Chief thrust fault, responsible for the emplacement of the Quartz Mountain allochthon. Most of the actual trace of the Big Chief fault has been obliterated by post-displacement intrusion and faulting. Sedimentary rocks of the Quartz Mountain allochthon lithologically resemble Paleozoic rocks exposed 60 km or more east of the Paradise Range, along and east of the $(^{87}Sr/^{86}Sr)_0 = 0.706$ isopleth (see index map), which is taken to mark the edge of sialic crust. It seems unlikely that these kinds of rocks could have been basement for either the Lodi or Berlin allochthon, the oldest exposed parts of which include deep-marine andesitic volcaniclastic rocks. Presumably, the Paradise subterrane, including the Lodi and Berlin allochthons, was first transported left laterally into position along the continental margin during D1 time (Oldow, 1984), and the original boundary between the Berlin and Lodi allochthons may have been a major left-lateral fault. At the beginning of D2 time, sedimentary rocks of the Quartz Mountain allochthon are then thought to have been carried over the Berlin and Lodi allochthons from the east on the hypothetical Big Chief fault, possibly as a southern continuation of the westward overthrusting attributed to the Toiyabe uplift zone of Speed and others (1988). Further deformation of the Quartz Mountain allochthon then resulted from infolding and imbrication of the Quartz Mountain with the Lodi and Berlin allochthons during southwest-directed thrusting of the Berlin allochthon over the Lodi allochthon. In figure 2, isoclinal overturning of the Big Chief fault and overriding of the Quartz Mountain allochthon by the Berlin allochthon on the Ottawa fault is hypothesized, although the actual structural relationships must be much more complex. Overturning of the Big Chief thrust—and the Quartz Mountain allochthon—is indicated by the small exposures of overturned Lodi allochthon rocks that appear to structurally overlie the Quartz Mountain allochthon in the northeast Lodi Hills (section A-A', fig. 2). In the Lodi Hills and northern Paradise Range, respectively, granodiorite porphyries of units gd_2 and gd_4 intrude the contact—presumably the Big Chief thrust—between the Quartz Mountain and Lodi allochthons. Thus the northeast-dipping faults in the Lodi Hills that separate the mixture of unit gd_2 and rocks of the Quartz Mountain allochthon on its southwest side from the Lodi allochthon are probably younger D2 structures that truncate the Big Chief fault at depth, as suggested on figure 2 (cross section A-A').

Other major southwest-verging D2 structures in the area are the Holly Well fault, which juxtaposes the Gabbs nappe and its lower plate in the Lodi allochthon, and the kilometer-scale north-northwest-trending folds that refold northeast-trending folds in the lower plate of the Gabbs nappe. The most conspicuous of these early D2 folds is the major, tightly appressed, upright syncline that is traceable from Lodi Valley southward to the east-central part of the Paradise Range. Foliation in unit gd_5, a porphyritic granodiorite possibly related to units gd_2 and gd_4, is folded around this syncline in the vicinity of the large exposure of unit Jmq that occupies the core of this fold.

Younger phases of the D2 event are northeast-verging and cause northeastward overturning of earlier structures within the Lodi allochthon, such as the northern parts of the Holly Well fault and the axial surface of the major syncline that parallels it farther east. Faults related to this phase of northeastward overturning include some that imbricate the Lodi allochthon along the west side of the Paradise Range and in the Lodi Hills. One such fault in the Lodi Hills (section A-A', figs. 1 and 2) apparently truncates an overturned segment of the Holly Well fault.

The latest D2 structures are noticeably less ductile than those of the earlier phases. Brittle late-phase deformation is responsible, for example, for the ubiquitous

steeply southwest-dipping spaced cleavage that affects a broad belt of rocks, which include parts of the Berlin and Quartz Mountain allochthons, unit gd_2, and adjacent parts of the Lodi allochthon in both the Lodi Hills and nearby parts of the Paradise Range. The complexly faulted boundary between the Lodi allochthon and the intricate mixture of unit gd_2 and rocks of the Quartz Mountain allochthon at the north end of the map area, in the Lodi Hills, involves a plethora of minor faults in a crudely defined pattern such that northeasterly traces tend to left-laterally offset northwesterly traces in an overall brittle system of northeast-southwest shortening.

AGE OF DEFORMATION

The youngest strata affected by convergent deformation are late Early Jurassic, or at the youngest, early Middle Jurassic in age. The more ductile phases of D2 predate the Illinois stock (gr_1), which has a reliable radiometric age of about 102 Ma (see description of map units). Unfortunately, radiometric ages are not available for any of the older plutonic rocks whose ages would narrow the Middle Jurassic to Early Cretaceous bracket for the initiation of D1 deformation. The brittle, late phase, D2 deformation displayed in the Lodi Hills could be Late Cretaceous, or even early Tertiary, in age.

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