Text and references accompanying Nevada Bureau of Mines and Geology Map 188

Geologic Map of the Gordon Creek Quadrangle, Elko County, Nevada

by

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ABSTRACT

The map units in the Gordon Creek quadrangle range from Holocene to Neoproterozoic in age. The map area exposes a partial crustal cross section from mid-crustal rocks (sillimanite-muscovite-zone rocks, ~5.5 kb and ~630 ºC [based on garnet + aluminum silicate + plagioclase + quartz thermobarometry]) in the north to allochthonous, unmetamorphosed upper-crustal rocks in the south. The deepest exposed rocks are migmatitic, upper-amphibolite facies metasedimentary rocks correlated with the Neoproterozoic McCoy Creek Group (Zmc_m). Evidence of partial melting is widespread, and an isopleth was mapped, delineating an area of rocks that contain greater than 67% granitic rocks (early Oligocene to Cretaceous). Tertiary biotite monzogranite (Tmg) and abundant Tertiary–Cretaceous pegmatitic leucogranite (TKlg) form massive bodies, sheets, and dikes. Structurally above this migmatitic zone is a composite unit consisting of Cambrian–Neoproterozoic metamorphosed Prospect Mountain Quartzite and McCoy Creek Group rocks intruded by sheets of deformed mafic to silicic igneous rocks (€Zpmi). Isolated distinct bodies of massive pegmatitic leucogranite (TKlg) as well as abundant segregations of leucosome (crystallized leucogranitic melt) occur in these metasedimentary rocks. Overlying these units is another composite unit consisting of Ordovician to Cambrian impure calcite marble and calc-silicate rocks, intruded by a variety of igneous rocks (O€mi) ranging from pegmatitic leucogranite (TKlg) to mafic to felsic rocks. The Tertiary intrusive rocks occur as numerous sheets, many reaching 50+ m in thickness. These Tertiary intrusive rocks range from gabbro/quartz diorite (Trqd) to leucogranite (Twg) in composition, and two of the units have yielded U-Pb zircon radiometric ages of middle Eocene. A U-Pb monazite age of ~84 Ma in the southern Gordon Creek quadrangle suggests that at least part of the TKlg is Late Cretaceous. However, cross-cutting field relationships of pegmatitic leucogranite at various localities in the quadrangle indicate that some of the unit is Tertiary, perhaps as young as early Oligocene. The marble of Verdi Peak (O€m), exposed in the southern part of the quadrangle, includes the same metasedimentary rocks as O€mi but lacks the middle Eocene mafic to silicic igneous rocks. However, many small intrusive bodies of TKlg are common in the O€m unit as well as several sheets, reaching about 250 m in thickness. Also, a metapelite with the following assemblage: quartz + plagioclase + biotite + muscovite + kyanite + garnet + rutile has been found at two localities indicating upper-amphibolite facies metamorphism (>7 kb, ~600+ ºC) throughout much of the metamorphic sequence in the Gordon Creek quadrangle.

Subsequent to regional metamorphism in the Late Cretaceous was the development of a km-scale, west-rooted, normal-sense mylonitic shear zone during Oligocene time. At the southern end of the quadrangle, a normal-sense brittle detachment fault separates the O€m unit from an upper structural level of chiefly unmetamorphosed, brittlely attenuated stratified rocks ranging in age from late Paleozoic through middle Eocene (Arizona Spring quadrangle). One sample of Pennsylvanian Ely Limestone yielded conodonts with an elevated conodont alteration index (CAI) (5–7). Some exposures of Ely Limestone exhibit recrystallization and plastic flowage indicating weak metamorphic effects are present in the upper plate of the detachment-fault system. This metamorphism may be related to hot fluids derived from the subjacent metamorphic and igneous footwall. Between the upper-crustal rocks and the mid-crustal rocks are greenschist/lower-amphibolite facies rocks, consisting of Eureka Quartzite (Oe), a metadolomite unit (DOd), and graphitic calcite marble (Dg). The protolith ages of these rocks range from Upper Devonian to Ordovician. These metasedimentary rocks are typically preserved as fault slivers in the detachment-fault zone. These lithologic units are also exposed as low outcrops surrounded by Quaternary

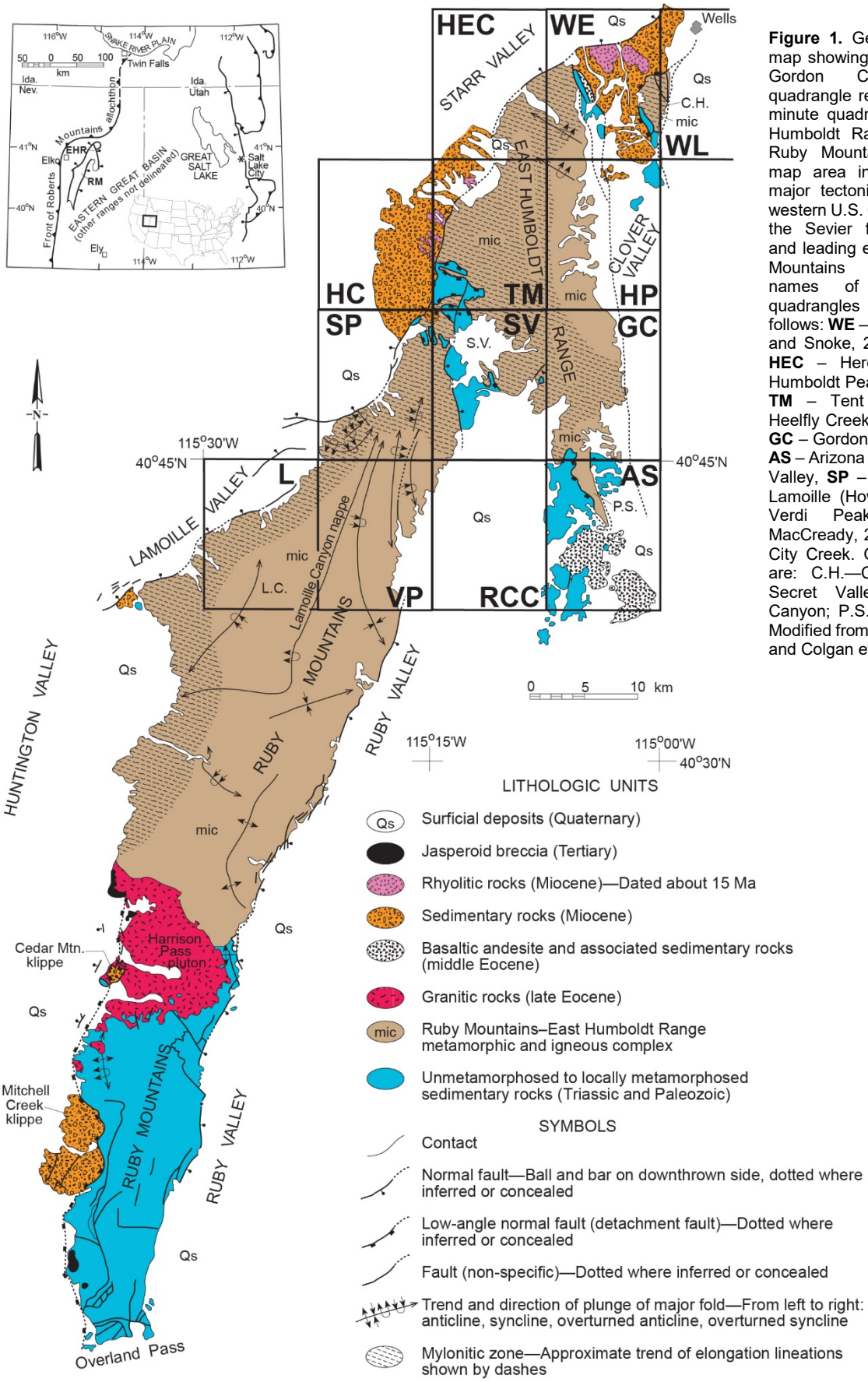

Figure 1. Generalized geologic map showing the location of the Gordon Creek 7.5-minute quadrangle relative to other 7.5-minute quadrangles in the East Humboldt Range and northern Ruby Mountains. Inset shows map area in relation to other major tectonic elements of the western U.S. Cordillera, including the Sevier fold-and-thrust belt and leading edge of the Roberts Mountains allochthon. The names of the 7.5-minute quadrangles are abbreviated as follows: **WE** – Welcome (McGrew and Snoke, 2015), **WL** – Wells, **HEC** – Herder Creek, **HP** – Humboldt Peak (McGrew, 2018), **TM** – Tent Mountain, **HC** – Heelfly Creek (Dee et al., 2015), **GC** – Gordon Creek (this report), **AS** – Arizona Spring, **SV** – Secret Valley, **SP** – Soldier Peak, **L** – Lamoille (Howard, 2000), **VP** – Verdi Peak (Howard and MacCready, 2004), **RCC** – Ruby City Creek. Other abbreviations are: C.H.—Clover Hill; S.V.—Secret Valley; L.C.—Lamoille Canyon; P.S.—Polar Star Mine. Modified from Snoke et al. (1997) and Colgan et al. (2010).

deposits east of normal faults related to the range-front system.

The youngest rock units in the quadrangle are a complex suite of Quaternary deposits, which include youngest to oldest(1) youngest alluvium (Qy), (2) landslide deposits (Qls), (3) colluvium (Qc), (4) younger alluvium (Qya), (5) megabreccia (Qmb), (6) older alluvium (Qoa), (7) glacial deposits (Qg), and (8) pluvial lake deposits (Qp). The eastern flank of the southeastern East Humboldt Range is bounded by a system of normal faults, which were active in the Quaternary.

INTRODUCTION

The Gordon Creek 7.5-minute quadrangle is situated in the southeastern East Humboldt Range, about 32 km south-southwest of Wells, Nevada (fig. 1). This area is important in the developmental history of the Ruby Mountains–East Humboldt Range (RM-EHR) core complex (Howard, 1980; Snoke, 1980; Snoke et al., 1990; Snoke et al., 1997), because it exposes a partial crustal cross section from mid-crustal rocks (at least ~5–6 kb) in the north to unmetamorphosed upper-crustal rocks in the south, which in turn continue south into the Arizona Spring 7.5-minute quadrangle (fig. 1; Taylor, 1984; Thorman and Brooks, 1994).

The rock units in the Gordon Creek quadrangle can broadly be divided into four distinct groups: (1) Quaternary deposits, ranging from pluvial lake deposits (Qp) and glacial deposits (Qg) to upper Holocene youngest alluvium (Qy); (2) unmetamorphosed to very low-grade late Paleozoic sedimentary rocks (Permian and Pennsylvanian, respectively); (3) metamorphosed sedimentary rocks (Upper Devonian to Neoproterozoic); and (4) numerous intrusive rocks that range in age from early Oligocene–middle Eocene to Late Cretaceous.

The rocks of the study area range in metamorphic grade from upper-amphibolite facies (sillimanite-muscovite zone) in the north to lower-greenschist facies in the south. Since the geologic mapping was completed, two kyanite-bearing metapelite localities were found in the Ordovician–Cambrian marble unit (O€m) in the southern part of the quadrangle (see geologic map for localities marked ‘K’). Subsequent to regional metamorphism in the Late Cretaceous (McGrew et al., 2000; Hallett, 2012; Hallett and Spear, 2011, 2014, 2015) was the development of a km-scale, west-rooted, normal-sense mylonitic shear zone during the early Oligocene (Wright and Snoke, 1993). At the southern end of the Gordon Creek quadrangle, a low-angle detachment-fault system is the dominant structural feature. This extensional allochthon is extensively exposed farther to the south in the Arizona Spring quadrangle (Taylor, 1984; Thorman and Brooks, 1994). The rocks in the hanging wall of this detachment-fault system are chiefly unmetamorphosed, brittlely attenuated stratified rocks, ranging in age from late Paleozoic through middle Eocene (Taylor, 1984; Brooks et al., 1995a, b; Snoke et al., 1997). In the Gordon Creek quadrangle, a late Cenozoic high-angle normal-fault system bounds the southeastern East Humboldt Range on its east side (Dohrenwend et al., 1991).

An Appendix is included with this report that is a field trip guide to key geologic localities in the Gordon Creek 7.5-minute quadrangle, northeastern Nevada.

PREVIOUS WORK

The earliest systematic reports of the geology of the East Humboldt Range date from the 40th Parallel Survey led by Clarence King (1878). It was also the focus of early studies on Basin-and-Range structure and geomorphology (Sharp, 1939, 1940). Prior to our study, the general geology of the East Humboldt Range was mapped by Snelson (1957), who recognized a low-angle fault at the southern end of the southeastern East Humboldt Range. Snelson (1957) interpreted this fault as an east-directed thrust fault (i.e., his Secret Creek thrust), which separated unmetamorphosed Lower Triassic and Upper Paleozoic rocks from a subjacent metamorphosed footwall. Snelson (1957) subdivided the metamorphic rocks into the Angel Lake and Snow Water units, based on differences in rock types, metamorphism, mylonization, and migmatization. In part, he also interpreted the contact between the overlying Snow Water unit and subjacent Angel Lake unit as a thrust fault. In the southeastern East Humboldt Range, Snelson (1957) delineated an undivided Devonian to Ordovician(?) sequence, which he mapped from the Polar Star Mine area to the south-southeast near where Nevada State Route 229 crosses the southeastern end of the East Humboldt Range. He described these rocks as recrystallized and contorted and interpreted them to be a thrust slice sandwiched between the subjacent Snow Water unit and overlying Triassic to Upper Paleozoic hanging wall of the Secret Creek thrust.

R.A. Hope (1970) did reconnaissance mapping in the Gordon Creek and Arizona Spring 7.5-minute quadrangles. He also recognized an Upper Devonian to Ordovician metasedimentary sequence in the southeastern East Humboldt Range. This sequence in part includes part of the Snow Water unit as well as the undivided Devonian to Ordovician sequence that Snelson (1957) discussed in his dissertation. This metasedimentary sequence is very similar to the metamorphosed Devonian to Cambrian strata that Thorman (1970) originally recognized in the Wood Hills and northern Pequop Mountains. The geologic mapping of Hope is included on plate 1 of the report by Coats (1987).

STRUCTURAL GEOLOGY

The metasedimentary rocks are extensively intruded by pegmatitic leucogranite sheets and dikes (TKlg) as well as mid-Tertiary tabular bodies, ranging in composition from quartz diorite/quartz gabbro to leucogranite. The cross sections highlight the sheet-like form of these intrusions, which can reach ~250+ meters in thickness (TKlg). Smaller intrusions (<1–5 m in thickness, too small to show on the geologic map) are interpreted as dismembered dikes that were probably feeders to the sheet-like bodies.

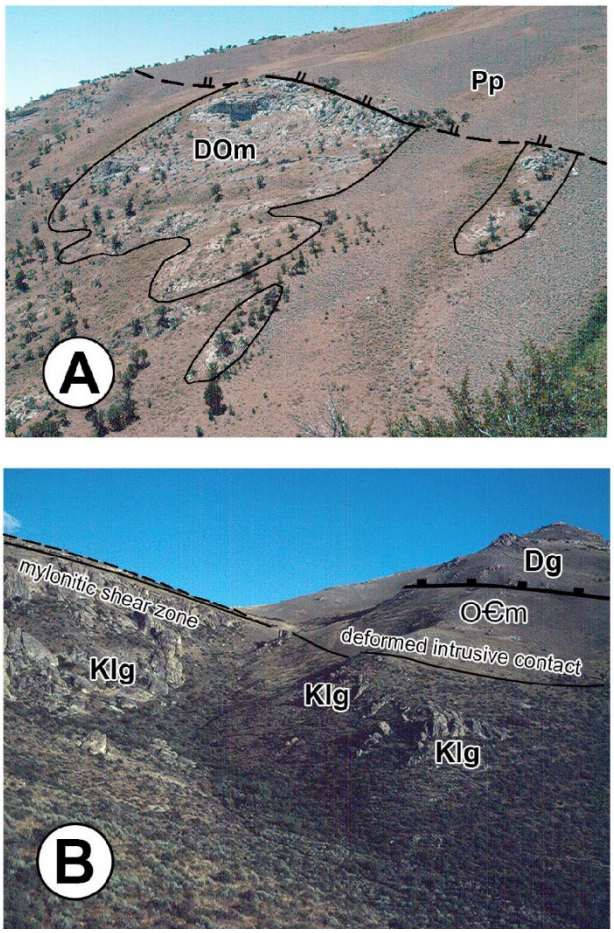

Figure 2. (A) View of the brittle, low-angle detachment fault in the southern part of the Gordon Creek quadrangle where Permian Pequop Formation (Pp) is above metamorphosed Guilmette Formation and dolomitic marble (labeled DOm in photograph). (B) Mylonitic shear zone-detachment-fault system exposed in the southern part of the Gordon Creek quadrangle (STOP 10). Exposures of metamorphosed Guilmette Formation (Dg) are above the O€m unit separated by ductile-to-brittle fault. The lower boundary of the O€m unit is a deformed intrusive contact overprinted by a mylonitic shear zone. Klg = Cretaceous pegmatitic leucogranite.

Another observation from geologic mapping and cross section preparation is distinct depth variation in the composition of the tabular intrusive bodies. At the high structural level of the igneous-metamorphic terrane in the southern part of the quadrangle, large tabular bodies (see cross section B–B′) of TKlg form an interconnected intrusive complex with pendants and interdigitated contacts of the Ordovician–Cambrian marble of Verdi Peak (O€m). Skarn zones (chiefly diopside and/or tremolite) are common along the contacts between the metacarbonate rocks and the intrusive pegmatitic leucogranite. With increasing structural depth (northward) sheets of the quartz diorite of Rattlesnake Canyon (Trqd, middle Eocene), biotite granodiorite–monzogranite orthogneiss of Horse Creek (Thg, middle Eocene?), and muscovite leucogranite orthogneiss of Woods Creek (Twg, middle Eocene?) are widespread in the central part of the quadrangle. Discontinuous bodies of pegmatitic leucogranite (TKlg) also occur in this part of the quadrangle

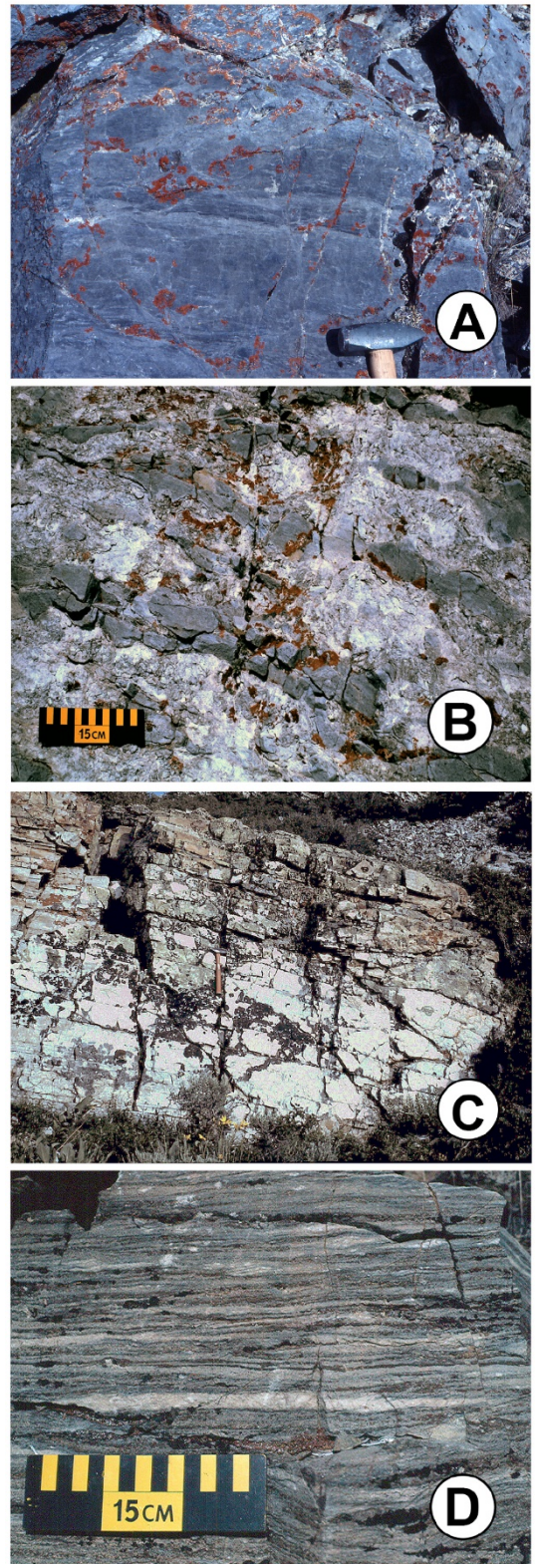

Figure 3. Metamorphic stratigraphy (Dg–O€m). (A) Blue-gray-weathering (gray black on fresh surface), color-banded graphitic calcite ± dolomite marble (Dg–metamorphosed Guilmette Formation). (B) Metadolomite (DOd) with coarse-grained layers of tremolite-rich rock. (C) Mylonitic, metamorphosed Eureka Quartzite (Oe). Hammer for scale is in the center of the photograph. (D) Laminated, color-banded (alternating gray and white layers), graphite-muscovite calcite marble (O€m).

but are distinctly subordinate to the middle Eocene intrusive rocks. Farther to the north beyond the >67% granite isopleth boundary, pegmatitic leucogranite (TKlg) is again very abundant and occurs as sheets and large bodies in migmatitic McCoy Creek Group metasedimentary rocks (Zmu_m). The other characteristic intrusive rocks at this structural level are sheets and dikes of biotite monzogranite (Tmg), which were also mapped by McGrew (2018) in the Humboldt Peak quadrangle to the north.

The dominant structural feature in the southern part of the quadrangle is a subhorizontal detachment-fault system (figs. 2A, B) that emplaced unmetamorphosed to weakly metamorphosed late Paleozoic rocks (Permian and Pennsylvanian stratigraphic units) onto metamorphosed sedimentary rocks ranging from the Upper Devonian Guilmette Formation to the O€m unit. Normal faults in the upper plate of the detachment fault end at the low-angle fault boundary. Tectonic slivers of metamorphosed Guilmette Formation (Dg, fig. 3A), Devonian–Ordovician dolomite marble (DOd, fig. 3B), and metamorphosed Eureka Quartzite (Oe, fig. 3C) occur along the brittle detachment fault, whereas the boundaries between the fault-bounded slivers suggest a plastic mode of deformation-related attenuation and boudinage of the original stratigraphy. This deformation mechanism has been depicted on the geologic map as plastic-to-brittle low-angle faults and is considered part of the detachment-fault zone.

Geologic mapping in the Arizona Spring quadrangle (Taylor 1984) indicate that the Dg, DOd, Oe, and O€m units gradually thicken and form a coherent sequence beneath the detachment fault. Also, small outcrops of metamorphosed Mississippian Pilot Shale, a crenulated phyllite, occur above Dg and immediately below the detachment fault in the Polar Star Mine area (Taylor, 1984). The Mississippian Chainman and Pennsylvanian–Mississippian Diamond Peak Formations are missing in the hanging wall of the detachment fault.

Numerous structural measurements were taken during the geologic mapping of the Gordon Creek quadrangle, and these data are summarized in a series of equal-area, lower-hemisphere projections (figs. 4A–F). A basic conclusion from these compilations is that the foliation in the metamorphic rocks is quite variable but is characterized by moderate to low dips southwestward (figs. 4A–C). Elongation lineations (figs. 4D–F) are characterized by shallow plunges and trend WNW–ESE to NW–SE. These lineations are especially characteristic of rocks in the mylonitic shear zone, although similarly oriented lineations occur in structurally deeper rocks, which have not undergone significant mylonitic deformation (e.g., Zmu_m). An interesting observation is that elongation lineations in Oe commonly trend NW–SE rather than the more typical WNW–ESE trend. This variation in lineation trend may be related to post-mylonitic folding of Oe. Fold mullions are also found in Oe.

Lineations are scarce in the O€m as well as in the TKlg

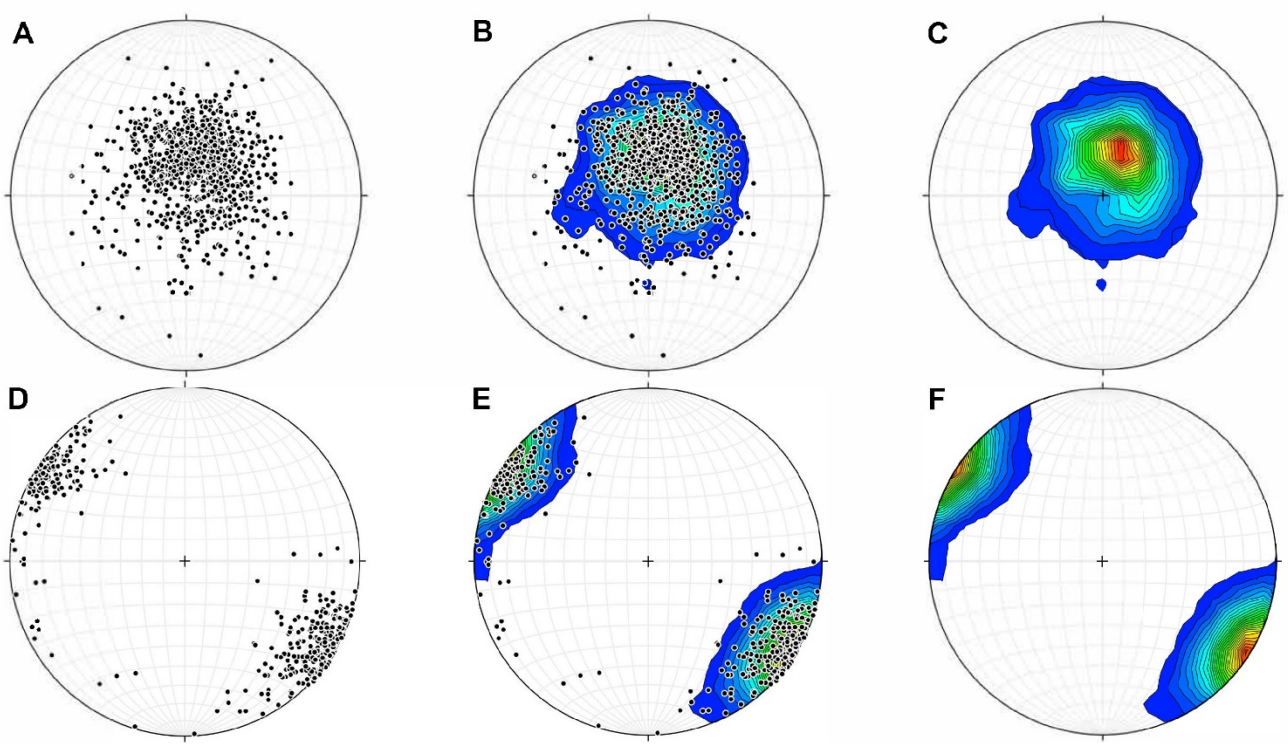

Figure 4. Equal-area, lower hemisphere projections of structural data from the Gordon Creek quadrangle. Kamb contours are at intervals of 2σ for all plots. (A) Poles (black filled circles) to foliation (N = 957) in the igneous and metamorphic terrain of the Gordon Creek quadrangle. (B) Poles to foliation and contoured by the Kamb technique. (C) Kamb contoured plot of poles to foliation. (D) Lineations (black filled circles, N = 394) in the igneous and metamorphic terrain of the Gordon Creek quadrangle. (E) Lineations and contoured by the Kamb technique. (F) Kamb contoured plot of lineations. All stereonet analyses were performed using the program Stereonet 9.5 made available by R.W. Allmendinger of Cornell University (Allmendinger et al., 2012).

in the southern part of the Gordon Creek quadrangle, although the metacarbonate rocks have commonly experienced strong deformation (O€m, fig. 2D). A scatter of lineations plot in the southwest quadrant of the stereonets (figs. 4D, E). These lineations are interpreted as an earlier fabric in the metasedimentary rocks, which are down-dropped along the Jerry Crab Spring normal fault and exposed as low outcrops at southern end of the quadrangle. These lineations are chiefly developed in Oe.

The age of the mylonitic shear zone is clearly Tertiary, based on its development in the middle Eocene intrusive suite (Trqd, Thg, and Twg) (Wright and Snoke, 1993). In the central part of the quadrangle, mylonization is extensive in O€mi and €Zpmi and increases to the west where it is pervasive in the Secret Valley quadrangle (fig. 1). There are a variety of sense-of-shear indicators in these rocks (figs. 5A–D). These kinematic indicators chiefly yield top-to-the-west-northwest, which is characteristic of the mylonitic shear zone throughout the northern Ruby Mountains (Snoke et al., 1997). The mylonitic shear zone is estimated as ~1.25-km thick based on the west–east cross section (A–A′) where it is roughly bounded by the RM-EHR detachment fault and by the 67% granite isopleth of the migmatitic McCoy Creek Group terrain (Zmu_m), where evidence of mylonitization is not widespread. In the south–north cross section (B–B′) structurally above the mylonitic shear zone is plastically deformed O€m intruded by sheets of TKlg which reach ~250+ m in thickness. An interesting exception to this observation is the presence a hectometer-scale mylonitic shear zone in the southern part of the Gordon Creek quadrangle (Snoke, 1998; figs. 6A, B) that overprints massive pegmatitic muscovite leucogranite and is close proximity to the RM-EHR detachment fault (fig. 2B) (Appendix, STOP 10, field trip guide).

The other large-scale structural features, which are prominent in the west–east cross section (A–A′), are high-angle normal faults and fracture zones that brittlely fractured the range. The largest displacement normal fault in this transect is the north-striking, range-bounding Gordon Creek fault, which down-dropped the extensive basin east of the range, manifested by Clover Valley. An exposure of Dg on

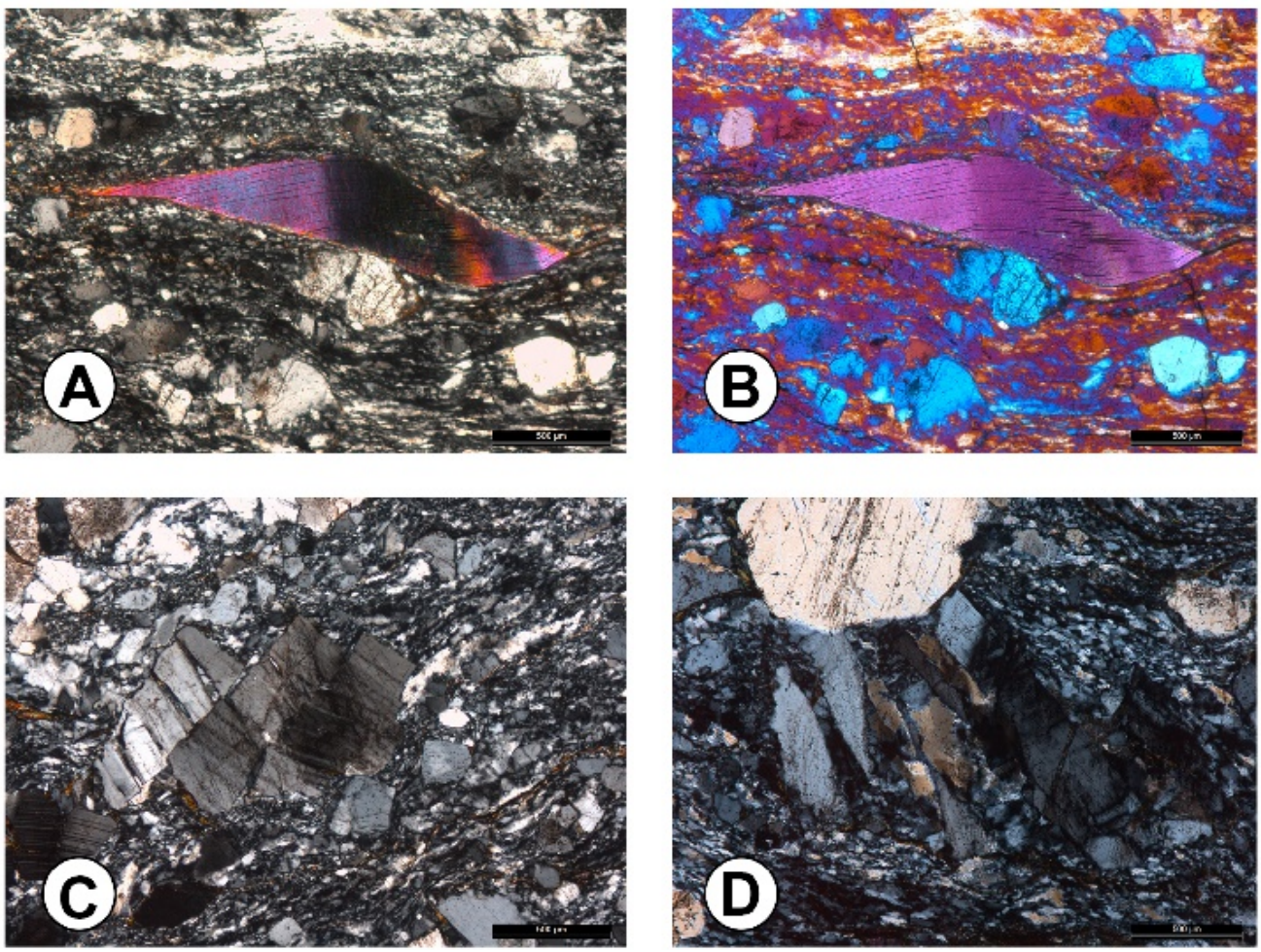

Figure 5. (A) Asymmetric porphyroclast of muscovite ('mica fish') in mylonitic muscovite leucogranite orthogneiss of Woods Creek, XP (crossed polars). The sense-of-shear is sinistral. (B) Same view as in (A), but with the first-order plate inserted to emphasize the detailed textural character of the muscovite porphyroclast with regard to surrounding grains, XP. (C) Domino-type, fragmented plagioclase grain in mylonitic muscovite leucogranite orthogneiss of Woods Creek, XP. Sense-of-shear is dextral. (D) Domino-type, fragmented plagioclase grain in mylonitic muscovite leucogranite orthogneiss of Woods Creek, XP. Note quartz grains, larger than matrix grains, between the fragments of feldspar. Sense-of-shear is sinistral. The scale in the lower right corner of each photomicrograph is 500 μm.

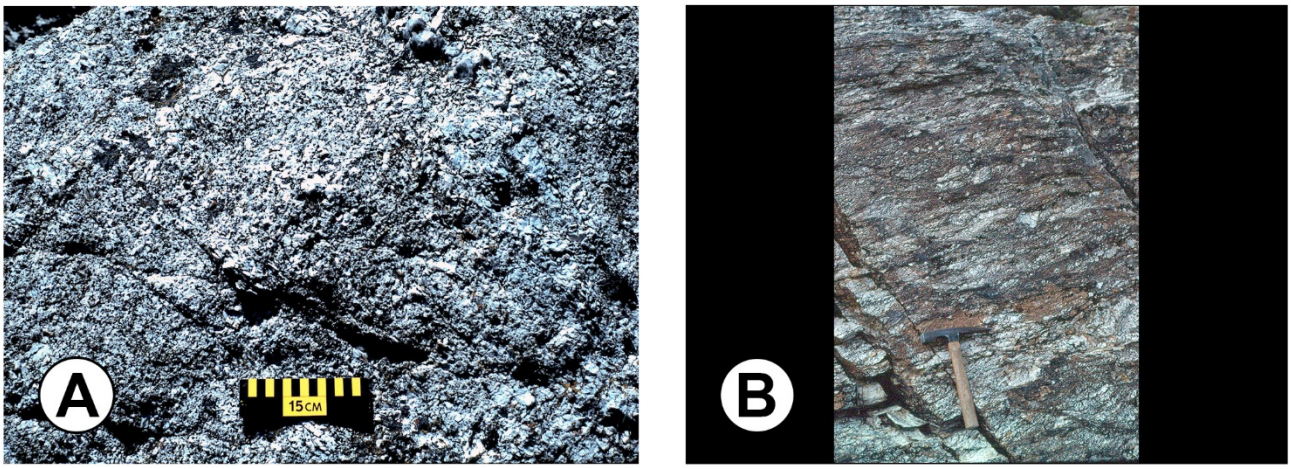

Figure 6. (A) Undeformed pegmatitic muscovite leucogranite (TKlg). Note the heterogeneous texture due in large part to scattered coarse-grained feldspar. (B) Mylonitic leucogranite showing heterogeneous strain manifested by variable grain size and foliation development (STOP 10).

the hanging wall of this major normal fault (Appendix, STOP 11, field trip guide) provides key evidence to the rock sequence that underlies Quaternary older alluvium (Qoa) along the western edge of Clover Valley (see cross section A–A′). An estimate of the throw of this range-bounding normal fault is at least ~915 m at Gordon Creek. However, the throw progressively increases to the north (Sharp, 1939). In the Welcome quadrangle at the northern end of the East Humboldt Range, McGrew and Snoke (2015) estimated the normal-sense dip separation of the ranging-bounding fault to be approximately 3000–4000 m. Another important normal fault is the curviplanar Jerry Crab Spring fault which down-dropped a metasedimentary sequence ranging from O€m through Dg, which has a metamorphic grade and structural fabric similar to the metasedimentary sequence exposed in the Wood Hills (Thorman, 1970; Camilleri, 2010b). This fault has minimum throw of ~458 m, based on equivalent Paleozoic metasedimentary rocks exposed at the top of the range. This estimate is only a rough approximation because the metasedimentary rocks at the higher level are brittlely and ductilely deformed due to their proximity to the low-angle detachment-fault system. Other normal faults and fracture zones have fewer specific markers of offset. However, these faults are considered to be part of a broad zone (~3-km wide) of normal faults and fracture zones (mapped as lineaments on the geologic map) related to the large range-bounding fault. Buried under the basin fill are probably other hidden faults, especially associated with springs on the geologic map (e.g., the north–south-striking Warm Springs fault). A subsurface Tertiary basin is postulated east of the Warm Springs fault. This interpretation is based on Tertiary sedimentary rocks (middle–late Miocene Humboldt Formation?) exposed in the southern part of Clover Valley (Hope, 1972) and the presence of a thick section of Tertiary sedimentary rocks at the northern end of Clover Valley (McGrew and Snoke, 2015).

CONDITIONS OF METAMORPHISM

The regional metamorphic grade in the southeastern East Humboldt Range varies from upper-amphibolite facies (sillimanite-muscovite zone) in the northern part of the Gordon Creek quadrangle (e.g., Honeyman Creek area, see sample localities on the geologic map) to lower-greenschist facies in the southern part of the range. Phyllitic crenulated schist is characteristic of the Mississippian Pilot Shale in the Polar Star Mine area of the Arizona Spring quadrangle (Taylor, 1984). In the Gordon Creek quadrangle, color alteration index (CAI) from the Ely Limestone reach 5 to 7 suggesting temperatures of ~300–450 ºC (Anita Harris, U.S. Geological Survey). CAI determinations from the metamorphosed Upper Devonian Guilmette Formation are 6–7 indicating temperatures of ~400 ºC (Anita Harris, U.S. Geological Survey). These elevated CAIs are interpreted to be related to hot fluids generated from the metamorphic and igneous footwall of the detachment-fault system.

Three metapelitic schists from the Honeyman Creek–Wiseman Creek area (Sicard, 2012), which contain the GASP subassemblage (garnet + aluminum silicate[sillimanite] + plagioclase + quartz), were studied using the University of Wyoming JEOL JXA-8900 microprobe. Natural and synthetic minerals were used as standards and analytical conditions were 15 kV, 75 s counting time, 20 nA specimen current, and 1 µm beam diameter. The metapelitic schists from the Honeyman Creek–Wiseman Creek area are correlated with McCoy Creek Group ‘G’ unit of Misch and Hazzard (1962). The prograde mineral assemblage of these schists is: quartz + biotite + muscovite + plagioclase + sillimanite + garnet + graphite + zircon (fig. 7A). Thermobarometric data using GASP assemblages and the TWQ program (Berman, 1991, 2007) indicate *P–T* conditions of ~5.5 kb and ~630 ºC. These results are not interpreted as indicating peak metamorphic conditions. Rather they are interpreted to capture *P–T* conditions of the cooling path during Cretaceous–Tertiary

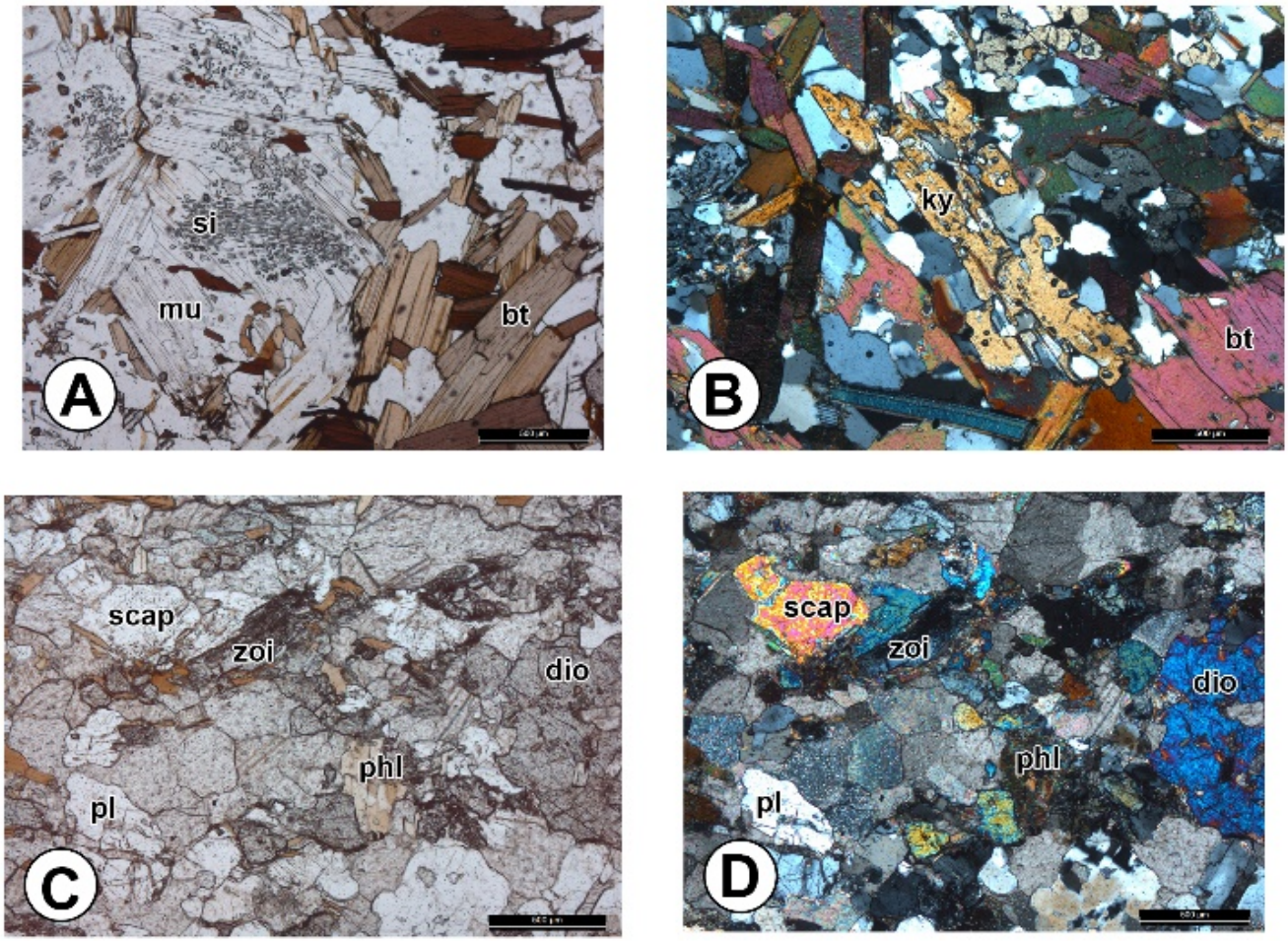

Figure 7. (A) Photomicrograph of quartz-plagioclase-muscovite-biotite-sillimanite-garnet (not visible in view) pelitic schist (Zmu_m), sillimanite needles and grains occur within muscovite. PPL; si = sillimanite, mu = muscovite, bi = biotite. (B) Photomicrograph of quartz-plagioclase-biotite-muscovite-kyanite-garnet (not visible in view) metapelite (O€m), XP; ky = kyanite, bt = biotite (C) Photomicrograph of calc-silicate paragneiss (O€m), PPL; scap = scapolite, zoi = zoisite, pl = plagioclase, dio = diopside, phl = phlogopite. (D) Photomicrograph of calc-silicate paragneiss, XP; scap = scapolite, zoi = zoisite, pl = plagioclase, dio = diopside, phl = phlogopite. The scale in the lower right corner of each photomicrograph is 500 μm.

exhumation. To the north, in Lizzies Basin (Humboldt Peak 7.5-minute quadrangle), Hallett and Spear (2014, 2015) determined *P–T* conditions in metapelites as ~7 kb and >720 ºC with continued heating in the migmatite zone (>67% leucogranite) to ~760 ºC.

Two kyanite-bearing localities (labeled 'K' on the geologic map) were discovered in the southern part of the Gordon Creek quadrangle after the above thermobarometric studies were completed. A metapelite sample collected at UTM coordinates (North American Datum 1983[NAD 83]) = 661941 E, 4515506 N contains the following metamorphic assemblage: quartz + plagioclase + biotite + muscovite + kyanite + garnet + zircon + tourmaline + rutile (scarce) (fig. 7B). A similar metapelite was discovered by Allen McGrew at UTM coordinates (NAD 83) = 661325 E, 4517737 N (McGrew et al., 2018). This metamorphic assemblage indicates that the O€m unit reached upper-amphibolite facies throughout its exposure in the southeastern East Humboldt Range. These metapelites are correlated with the Upper Cambrian Dunderberg Shale reported by Thorman, 1970; Hodges et al., 1992; and Camilleri, 2010b in the Wood Hills, immediately east of the northern East Humboldt Range. Although quantitative thermobarometry has not yet been done on these kyanite-bearing metapelites in the Gordon Creek quadrangle, the metamorphic assemblage is similar to the Wood Hills locality where Wills (2014) completed a detailed study of the metamorphosed Dunderberg Shale. Her thermobarometric results indicated *P–T* conditions of 6.8–7.1 kb and 610–630 ºC. Also, the timing of garnet growth using the Lu-Hf method yielded an age of 82.8± 1.1 Ma. The localities in the Gordon Creek quadrangle as well as in the Wood Hills show no evidence of partial melting as typical of the metapelites of the McCoy Creek Group at deeper crustal levels (McGrew, 2018; this study).

As a separate comparative study, three metapelitic schists, correlated with the McCoy Creek Group 'G' Unit, from Clover Hill (Welcome 7.5-minute quadrangle, McGrew and Snoke, 2015) were also studied using the GASP (garnet + aluminum silicate + quartz + plagioclase)

thermobarometer (Sicard et al., 2011, Sicard, 2012). These pelitic schists are characterized by a GRAIL metamorphic mineral assemblage: quartz + plagioclase + muscovite + biotite + garnet + kyanite + sillimanite + rutile + ilmenite (Hodges et al., 1992, Snoke, 1992). Thermobarometric data using GASP assemblages and the TWQ program (Berman, 1991, 2007) indicate *P–T* conditions of ~7.2 kb and ~735 ºC—consistent with the GRAIL assemblage. The metamorphic textures in the kyanite-bearing pelitic schists in the Welcome quadrangle support at least two metamorphic/structural overprints: (1) fibrolitic sillimanite grew as a late, minor mineral phase on large kyanite porphyroblasts, and (2) kyanite porphyroblasts were significantly kinked, interpreted as mechanical deformation during mid-Tertiary mylonitization.

Pressure and temperature (*P–T*) estimates calculated for metapelitic rocks from Honeyman Creek–Wiseman Creek area indicate that the southeastern East Humboldt Range experienced significant tectonic burial during the Sevier orogeny. The new results presented in this report are in accord with the decompression paths of McGrew et al. (2000) and McGrew and Snoke (2015). The higher *P–T* conditions (~7.2 kb, ~735 ºC) from the Clover Hill in metapelitic schists indicate that this area experienced even greater burial than the southeastern East Humboldt Range and support previous conclusions about significant tectonic burial in the northern East Humboldt Range (Hodges et al., 1992; McGrew et al., 2000; Camilleri and Chamberlain, 1997; Hallet and Spear, 2014). Based on rough estimates of about 3–4 km for every 1 kb, the southeastern East Humboldt Range could have been buried from ~16–22 km deep. However, these depths are probably minimum estimates based on the presence of quartz + plagioclase + biotite + muscovite + kyanite + garnet + rutile metapelite in the O€m unit to the south. This mineral assemblage indicates that the O€m unit reached upper-amphibolite facies (>7 kb and >600+ ºC) throughout its exposure in the southeastern East Humboldt Range. Calc-silicate paragneiss mineral assemblages with abundant diopside (Figs. 7C, D) support an upper-amphibolite facies metamorphism throughout the O€m unit. The nature of the Late Cretaceous overthickening in the East Humboldt Range is problematic but may be related to a phantom thrust sheet as part of the Sevier orogeny in the Cordilleran hinterland (Camilleri and Chamberlain, 1997; Camilleri, 1998).

DESCRIPTION OF MAP UNITS

Quaternary Surficial Deposits

Qy Youngest alluvium (upper Holocene) Unconsolidated silt, sand, and gravel of fluvial origin filling active stream channels and adjacent flood plains, mostly inset into alluvial fans on the east flank of the East Humboldt Range. Clasts include a wide variety of rock types from the mountains to the west. Thickness is estimated ~5 m.

Qls Landslide deposit (Holocene) Coarse, unconsolidated debris mostly composed of local bedrock, forms hummocky topography.

Qc Colluvium (Holocene) Poorly sorted silt, sand, gravel, and locally some talus mantling steep slopes with enough fine matrix to support grassy or brushy vegetation.

Qya Younger alluvium (Holocene and Pleistocene) Unconsolidated silt, sand, and gravel of fluvial origin older than active stream channels and adjacent flood plains. This unit exists both as small alluvial fans overlapping the older fans (Qoa) on the flanks of the East Humboldt Range, and as terraces above the present stream grade (Qy). Clasts include a wide sampling of rock types recognizable from the adjacent mountains. Thickness is estimated ~8 m.

Qmb Megabreccia composed of Upper Devonian metamorphosed Guilmette Formation (Pleistocene) – This body of rock is totally brecciated and veined by calcite, and there is no evidence of bedding. The megabreccia is surrounded by Ooa, and thus may be a large slide block within the Qoa unit.

Qoa Older alluvium (Pleistocene) Weakly consolidated or unconsolidated silt, sand, and gravel mantling alluvial-fan surfaces away from or above active stream channels. Clasts include a wide sampling of rock types recognizable from the adjacent mountains. The thickness of this unit is ~75 m.

Qg Glacial deposits (Pleistocene) Chiefly includes morainal deposits. Lamoille and Angel Lake stages, undivided (Sharp, 1938; Wayne, 1984).

Qp Pluvial lake deposits (Pleistocene) Playa lake deposits include sand, clay, gravel, salt. Different lake levels are preserved based on concentric ancient shorelines (Qs1–5) seen throughout the entire basin surrounding Snow Water Lake, numbered 1–5, with 1 being the oldest and recording the largest pluvial lake.

Tertiary Rocks

Tj Jasperoid breccia (Neogene) Massive siliceous breccia, commonly re-cemented by quartz, associated with normal-sense fault zones, black or medium gray on a fresh surface. Interpreted as the result of hydrothermal replacement of an original host rock. Some small bodies of jasperoid are unmapped. The largest outcrop of jasperoid breccia is shown on the geologic map on the west side of the range (NE corner of section 32, T. 34 N., R. 61 E; UTM NAD 83 659648 E, 4517068 N.) adjacent to a buried normal fault.

Tls Landslide deposit (Neogene) Brecciated and silicified, blocks of late Paleozoic sedimentary rocks, including the Pennsylvanian Ely Limestone (ℙe) and Lower

Permian 'limestone and conglomerate' unit (Plc). Original bedding in the Ely Limestone is obscured. Anita G. Harris (U. S. Geological Survey, written commun., 1984) recovered many elements of conodonts from a limestone sample collected at locality 1. The conodont remains included: Adetognathus Lautus (Gunnell), Idiognathodus Delicatus (Gunnell), Neognathodus Medexultimus Merrill, and Neognathodus sp. indet. This conodont assemblage indicates a Middle Pennsylvanian age (Desmoinesian) consistent with the Ely Limestone. The color alteration index (CAI) is 4 1/2 to 5. Indicating that this limestone reached 250–300 ºC. The source of this inferred landslide deposit was probably the upper plate of the RM-EHR detachment fault.

Unmetamorphosed to Weakly Metamorphosed Sedimentary Rocks

Pk Kaibab Limestone (Permian) Light to dark gray, thick-bedded limestone, light gray to bluish gray massive dolomite with variable amounts of white, yellow to brownish nodular chert. Thin beds of yellow- to buff-colored, fine-grained sandstone are part of the unit. Chert-pebble conglomerate is also present in the lower part of the section. Dolomite is more abundant than limestone in the upper part of the section (Taylor, 1984).

Pp Pequop Formation (Lower Permian) Purplish-gray, platy silty limestone (slope-forming); massive thick-bedded, medium- to dark-gray, fine-grained limestone; locally fusulinid-rich coquina; and yellow-weathering, calcareous fine-grained sandstone. As described by Steel (1960).

Plc Limestone and conglomerate (Lower Permian) Massive-bedded, light- to dark-gray limestone with gray to black nodular to lenticular chert, massive limestone without chert; chert- and limestone-clast conglomerate and grit. Possible correlation with either the Ferguson Mountain Formation (Berge, 1960) or Riepe Spring Limestone (Steele 1960).

IPe Ely Limestone (Pennsylvanian) Light- to medium-gray resistant thick-bedded limestone with yellowish tan nodular or lenticular chert interlayered with slope-forming thin-bedded limestones, locally includes bioclastic limestone with brachiopod fauna, crinoid columnals, and other fossil fragments. In the Gordon Creek quadrangle, the Ely Limestone is commonly fractured and locally permeated by white calcite veinlets because of its proximity to the RM-EHR detachment fault. Some samples of the Ely Limestone exhibit granoblastic texture of calcite and plastic flowage yielding a sugary, foliated meta-limestone. These low-grade metamorphic effects indicate that local metamorphism of late Paleozoic rocks occur in the upper plate of the detachment-fault system. Pennsylvanian (late Morrowan to Desmoinesian) conodonts were recovered by Anita G. Harris (U. S. Geological Survey, written commun., 1983) from a meta-limestone sample collected at locality 2. The conodont elements include: Adetognathus Lautus (Gunnell), Adetognathus sp. indet., Idiognathodus cf. I. Delicatus (Gunnell), Neognathodus cf. N. Bassleri (Harris and Hollingsworth), and Neognathodus cf. N. Medadultimus Merrill or N. Medexultimus Merrill. This conodont assemblage is consistent with the Pennsylvanian Ely Limestone. The CAI is 5 to 7, indicating that this limestone reached 300–450 ºC. This low-grade metamorphism and deformation may be related to the juxtaposition of the Ely Limestone to the hot footwall of the RM-EHR detachment fault.

Metamorphosed Sedimentary Rocks

Dg Metamorphosed Guilmette Formation (Upper Devonian) Color-banded calcite ± dolomite marble to dark gray to black meta-limestone, commonly graphitic (fig. 3A). Recrystallized crinoid plates are recognizable in some calcite-rich layers. Less deformed areas have relict forms of stromatoporoids. Conodont fragments were recovered by Anita G. Harris (U. S. Geological Survey) from a meta-limestone sample collected at locality 3. The determined CAI is 6 to 7, indicating that this meta-limestone reached ~400 ºC. Low-grade metamorphic limestone is commonly massively bedded and highly veined by calcite. Equivalent to the "marble of Snell Creek" of Howard (1971, 2000).

DOd Dolomitic marble (Devonian to Ordovician, undivided) White to dark gray, medium-grained, massive dolomitic marble with subordinate dolomitic meta-sandstone and calc-silicate rock (fig. 3B). Pegmatitic leucogranite locally intrudes the DOd unit. This undivided unit is correlated with the Upper Devonian Simonson Dolomite, Lower Devonian Sevy Dolomite, Silurian Laketown Dolomite, and Upper Ordovician Fish Haven Dolomite. In the Gordon Creek quadrangle, the DOd unit as well as the overlying Upper Devonian Guilmette Formation and underlying Ordovician Eureka Quartzite are locally attenuated to zero thickness below the detachment fault, which emplaced unmetamorphosed to very low-grade late Paleozoic sedimentary rocks (Permian and Pennsylvanian, respectively) above the metamorphosed Upper Devonian to Ordovician sedimentary sequence. Some exposures of DOd are infolded into metamorphosed Eureka Quartzite (Oe) and marble of Verdi Peak with deformed igneous intrusions (O€mi).

Oe Metamorphosed Eureka Quartzite (Ordovician) Mylonitic (foliated and lineated), white vitreous metaquartzite (fig. 3C) commonly free of impurities except trace amounts of graphite, muscovite, and/or feldspar; gray (graphitic-bearing) metaquartzite may be interlayered with the white metaquartzite. Scarce calc-silicate-bearing metaquartzite. Ductile attenuation of the Oe unit in the Gordon Creek quadrangle is extreme; structural thickness varies from ~30 m to zero.

Throughout the western part of the Gordon Creek

quadrangle, the Oe unit forms sloping, resistant layers that are fault-bounded with the underlying marble of Verdi Peak (O€m) or O€mi units and Tertiary intrusions (usually the mid-Tertiary Horse Creek granodiorite/monzogranite orthogneiss [Thg] or Woods Creek leucogranite orthogneiss [Twg]). These plates of Oe are interpreted as klippen associated with the RM-EHR detachment-fault system. Some exposures of Oe are infolded into the O€mi unit.

O€m Marble of Verdi Peak (Ordovician to Cambrian, undivided) Light-gray to yellow to tan-weathering micaeous calcite marble and white calcite marble (fig. 3D). Common accessory minerals are phlogopite, muscovite, graphite, plagioclase, and/or quartz. Original cherty protoliths are characterized by impure calcite marble and siliceous lenses. Calc-silicate-bearing (chiefly tremolite or diopside), phlogopite calcite marble, and calc-silicate paragneiss (figs. 3A, B) are locally common. A typical mineral assemblage in the calc-silicate paragneiss is calcite-plagioclase-diopside-phlogopitic biotite-scapolite-titanite ± zoisite. Local skarn development occurs along intrusive contacts with coarse-grained to pegmatitic muscovite leucogranite (TKlg). Metapelitic rocks and white metaquartzite (possibly quartzite of the Kanosh Formation) are scarce components of the unit. A metapelite sample collected at UTM coordinates (NAD 83) = 4515507 N, 661942 E contained the following metamorphic assemblage: quartz + plagioclase + biotite + muscovite + kyanite + garnet + zircon + tourmaline + rutile (scarce) (fig. 7B, see 'K' on geologic map). A similar metapelite was discovered by Allen McGrew at UTM coordinates (NAD 83) = 4517738 N, 661326 E (McGrew et al., 2018). This metamorphic assemblage indicates that the O€m unit reached upper-amphibolite facies throughout its exposure in the southeastern East Humboldt Range. The metapelite is correlated with the Upper Cambrian Dunderberg Shale—a metapelite also recognized in the metamorphic sequence in the Wood Hills (Thorman, 1970; Camilleri, 2010b).

The Ordovician to Cambrian marble of Verdi Peak (O€m) is a sequence of impure metacarbonate rocks that were originally defined and named by K.A. Howard (Howard, 1966; 1971; 1980; 2000) in the northern Ruby Mountains. In the Lamoille Canyon area (northern Ruby Mountains), this mappable unit consists of calcite marble, siliceous calcite marble, graphitic calcite marble, calc-silicate rocks, and minor sillimanite-mica schist, paragneiss, and amphibolite. This unit is correlated to the Ordovician Pogonip Group and various Cambrian shale and limestone formations. In the Gordon Creek quadrangle, the structural thickness of this highly deformed unit is ~500 m, including thick sheets of pegmatitic leucogranite (see cross section B–B′).

O€mi Marble of Verdi Peak (Ordovician to Cambrian, undivided) with deformed igneous intrusions (mappable intrusive bodies have been delineated) Metasedimentary rocks (Ordovician to Cambrian) intruded by mid-Tertiary quartz dioritic to granitic rocks and Tertiary to Cretaceous pegmatitic leucogranite (TKlg), undivided. Platy gray to white graphite-bearing calcite marble, calc-schist, calc-silicate paragneiss, dolomitic-calcite marble, metadolomite, white metaquartzite (possibly quartzite of the Kanosh Formation), pegmatitic leucogranite (Tertiary[?] to Cretaceous), and locally abundant intrusive mafic to felsic orthogneiss (middle Eocene) that forms sheet-like to lenticular bodies. Mylonitic textures, including S-C fabric and elongation (stretching) lineation, are common in the igneous rocks except the pegmatitic leucogranite. The metasedimentary rocks are correlated with the marble of Verdi Peak (Howard, 1971, 2000). In the Gordon Creek quadrangle, this composite, highly deformed unit has a structural thickness of ~400 m, including many intrusive bodies of a wide range in composition.

€Zpmi Metamorphosed Prospect Mountain Quartzite (Cambrian and Neoproterozoic protolith age) and McCoy Creek Group quartzite and schist (Neoproterozoic protolith age), undivided and with deformed igneous intrusions (mappable intrusive bodies have been delineated) Tan- or pale brown-weathering, medium- to coarse-grained, micaeous feldspathic metaquartzite with interlayered pelitic schist, commonly migmatitic with pelitic rocks hosting a higher percentage of leucosome than quartzitic layers. These rocks are strongly foliated (flaggy) and lineated in the mylonitic shear zone. Sillimanite and garnet are present in some samples of the pelitic schist. This unit commonly includes abundant pegmatitic leucogranite (TKlg), ranging in scale from leucosome segregations to lenticular massive intrusive bodies. Other intrusive rocks include deformed mafic to granitic rocks in dikes, thin sheets (m-scale), and irregular masses.

Zmm McCoy Creek Group marble (Neoproterozoic) Coarse-grained, white graphitic calcite marble and calc-silicate rock lenses or discontinuous layers in the €Zpmi and Zmu_m units interpreted as original carbonate rock or impure calcareous stratigraphic layers dismembered during deformation and metamorphism. These rocks are correlated with metacarbonate rocks in the Neoproterozoic McCoy Creek Group (Unit G) of Misch and Hazzard (1962), Woodward (1967), and Miller (1983). In the Humboldt Peak quadrangle, the calcite marble layers yield high $\delta^{13}C$ values, which is interpreted to indicate a Neoproterozoic protolith age (Wickham and Peters, 1993).

Zmu_m McCoy Creek Group paragneiss, undivided, migmatitic phase (Neoproterozoic protolith age) Muscovite-biotite quartzofeldspathic paragneiss, migmatitic quartz + plagioclase + biotite + muscovite + graphite ± sillimanite ± garnet pelitic schist (figs. 7A; 8A, B), and coarse- to medium-grained micaceous feldspathic metaquartzite; calcite marble and calc-silicate rock (Zmm); and scarce amphibolite ± garnet. This unit contains >67% leucosome as well as mappable bodies of pegmatitic

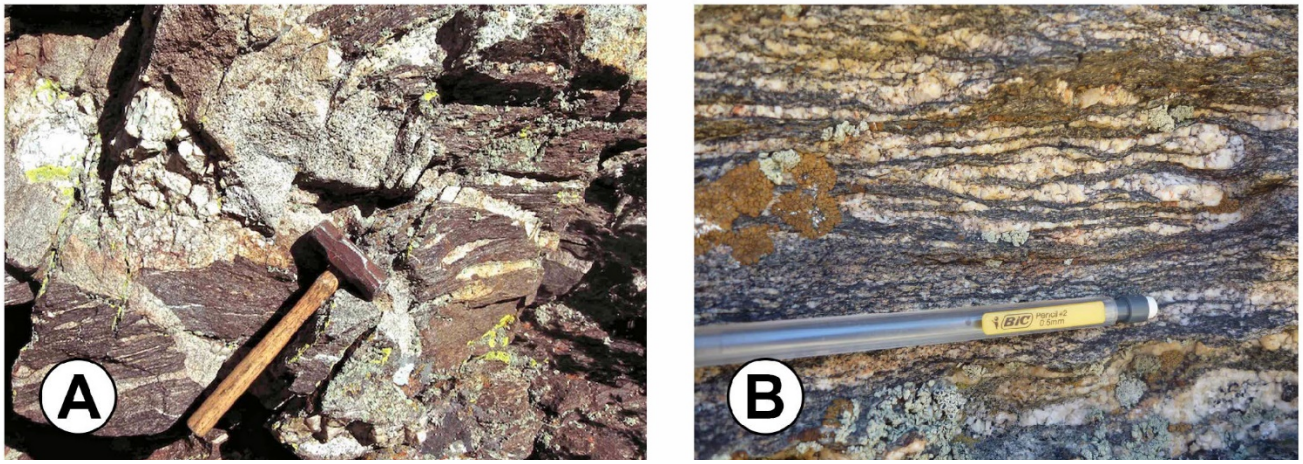

Figure 8. Variations in the Neoproterozoic McCoy Creek Group paragneiss migmatitic phase (Zmu_m). (A) Multiple intrusive relationships where host rock paragneiss contains thin leucosome segregations, pegmatitic leucogranite (TKlg), and crosscutting biotite monzogranite (Tmg) (UTM 661736 E, 4525677 N) (STOP 2). (B) Thin, isoclinally folded leucosome segregation in pelitic schist. The metamorphic grade of this rock is upper-amphibolite facies (sillimanite-muscovite zone).

leucogranite (TKlg) and biotite monzogranite (Tmg). The widespread pegmatitic leucogranite forms massive, lenticular layers, interpreted as intrusive bodies. In some exposures, thin leucogranite segregations suggest in situ partial melting of pelitic schist host rock (McGrew, 1992) (fig. 8B). Howard et al. (2011), using SHRIMP-RG U-Pb dating, documented Late Cretaceous and Paleogene leucogranite intrusions in the Lamoille Canyon area in the northern Ruby Mountains.

In the Humboldt Peak quadrangle, located immediately north of the Gordon Creek quadrangle, A.J. McGrew recognized a highly migmatitic paragneiss unit, which he called the "McCoy Creek paragneiss, migmatitic phase" (McGrew, 2018). That unit continues into the northern part of the Gordon Creek quadrangle. Misch and Hazzard (1962) described the McCoy Creek Group as consisting chiefly of metapsammitic to metapelitic rocks with subsidiary marble and sparse amphibolite. The rocks of the McCoy Creek Group are the oldest stratigraphic unit in the Cordilleran miogeoclinal sequence and are widely exposed throughout the eastern Great Basin (Woodward, 1963, 1967; Miller, 1983; Rodgers, 1984). The base of the McCoy Creek Group is typically not exposed. However, geologic mapping and SHRIMP-RG U-Pb dating of detrital zircon populations suggest that the base of this thick stratigraphic unit may be preserved in the Winchell Lake fold-nappe (Premo et al., 2008; McGrew and Snoke, 2010; Premo et al., 2010, 2014, McGrew and Snoke, 2015).

Intrusive Igneous Rocks

Tmg Biotite monzogranite (early Oligocene to middle Eocene?) This intrusive unit consists of weakly to moderately foliated, medium-grained, equigranular biotite monzogranite, locally with small feldspar phenocrysts. The chief mineral phases are sodic plagioclase, alkali feldspar, quartz, biotite ± muscovite. Accessory minerals include myrmekitic intergrowths, epidote-allanite, apatite, zircon, monazite, and opaque oxides. Local deuteric alteration of biotite to chlorite and titanite is common. The biotite monzogranite occurs as roughly concordant sheets or discordant dikes. In the deformed samples of Tmg, dynamic recrystallization is indicated by grain-size reduction of quartz as well as undulatory extinction, subgrain development, and deformed neoblasts. A sample of biotite monzogranite orthogneiss collected from Angel Lake in the northern East Humboldt Range yielded a U-Pb zircon ID-

Figure 9. Inclusions of pegmatitic leucogranite (TKlg) in a dike of Tertiary biotite monzogranite (Tmg). These complex intrusive relationships may suggest local mingling of magmas during emplacement.

TIMS crystallization age of 29 ± 0.5 Ma (Wright and Snoke, 1993; their RM-5).

Near the northern border of the Gordon Creek quadrangle sheets of Tmg reach up to ~100+ m in thickness. These intrusive bodies occur as concordant layers that are subparallel to the foliation in €Zpmi and Zmu_m. These exposures of Tmg comprise most of the large cliffs north of Honeyman Creek. The Tmg unit also includes discordant layers of monzogranite that are interpreted as feeder dikes between the sheets. These bodies are commonly foliated and entrained in the overall deformational fabric. Complex intrusive relationships between pegmatitic leucogranite and Tertiary biotite monzogranite suggest the local mingling of magmas during emplacement (fig. 9).

Twg Muscovite leucogranite orthogneiss of Woods Creek (middle Eocene?) Fine-grained, equigranular muscovite leucogranite orthogneiss. Color index is <5 and locally hololeucocratic. The chief mineral phases are sodic plagioclase, alkali feldspar, quartz, and muscovite. Accessory minerals include garnet, biotite, apatite, zircon, and opaque oxides. Commonly pervasively foliated and lineated (mylonitic), characterized by dynamic recrystallization of quartz and muscovite. Asymmetric porphyroclasts of muscovite ('mica fish') (figs. 5A, B) and domino-type, fragmented feldspar porphyroclasts are also characteristic microstructures in these mylonitic orthogneisses (figs. 5C, D). The Twg occurs as lenticular sheets that range from <1–50+ m chiefly within the O€mi.

Thg Biotite granodiorite–monzogranite orthogneiss of Horse Creek (middle Eocene?) Sodic plagioclase, perthic alkali feldspar, quartz, and biotite are the chief primary minerals. Accessory minerals include muscovite, titanite, zircon, apatite, and opaque oxides. The feldspars constitute about 75% of this medium-grained orthogneiss with fine-grained recrystallized quartz (~15%) and biotite (~7%) in trails around the porphyroclasts. Biotite is locally altered to chlorite (~2%) and muscovite and accessory minerals make up the rest of the rock. Thg is typically strongly foliated and lineated (mylonitic), characterized by extensive syntectonic dynamic recrystallization of quartz

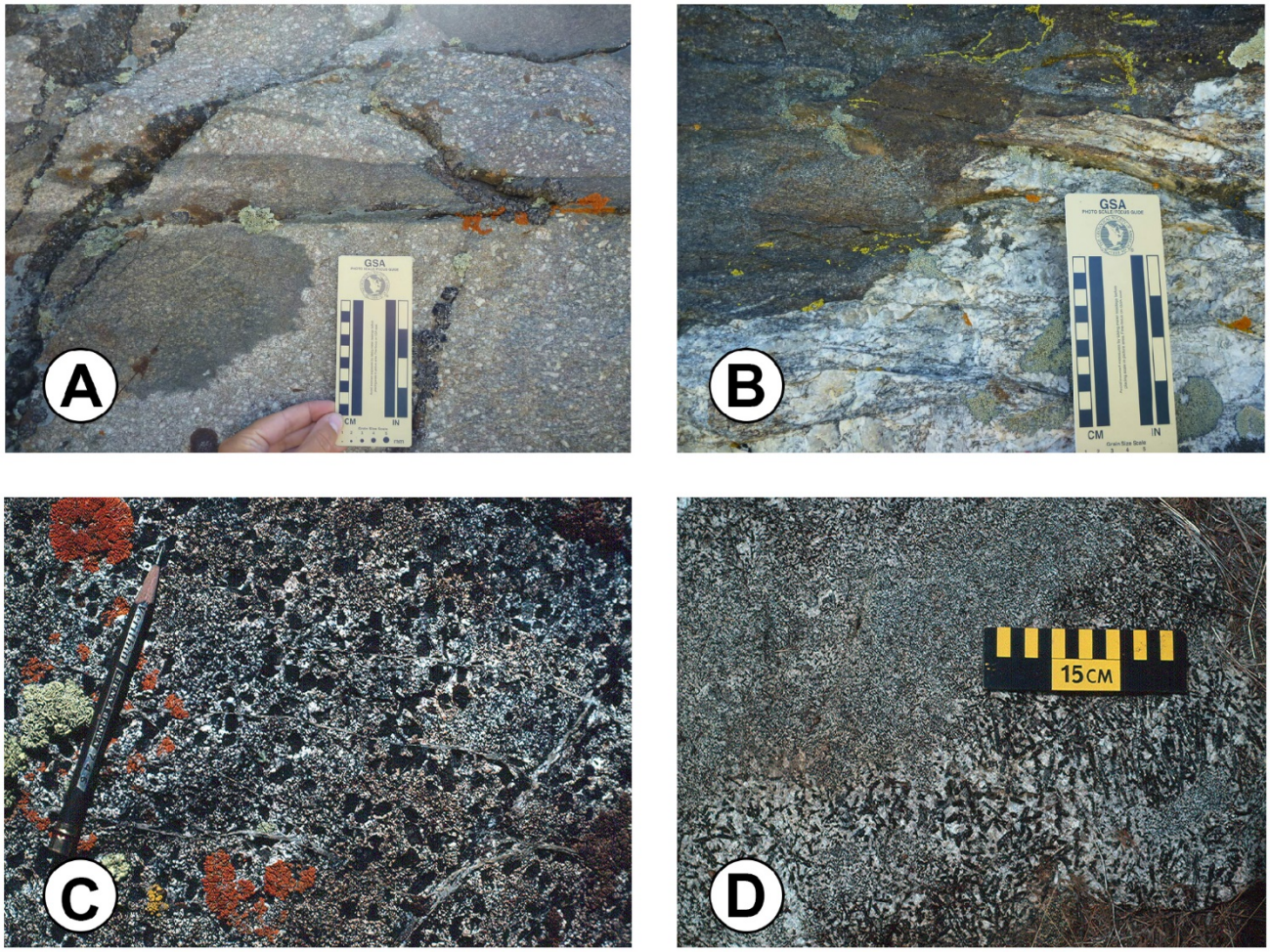

Figure 10. Field relationships and textural variations in the middle Eocene quartz diorite of Rattlesnake Canyon (Trqd). (A) Partially resorbed enclaves of quartz diorite (Trqd) intruded by Horse Creek augen granodiorite/monzogranite orthogneiss (Thg). These relationships suggest the mingling of magmas during emplacement during the middle Eocene. (B) Pegmatitic leucogranite (TKlg) dike crosscutting medium-grained quartz diorite (Trqd). (C) Porphyritic phase of Trqd characterized by blocky, subhedral hornblende crystals in a matrix of hornblende, plagioclase, and quartz. (D) Pegmatitic texture in a medium-grained hornblende gabbro/diorite (Trqd).

and biotite with porphyroclasts of feldspar. Plagioclase augen are chiefly brittlely deformed indicated by fractured, domino-type grains. Mylonitization is thus near the brittle-to-plastic transition for plagioclase feldspar. Mesoscopic S-C fabric is common in hand specimen. A sample of mylonitic biotite granodiorite-monzogranite orthogneiss collected from Horse Creek canyon (locality A) yielded a U-Pb ID-TIMS zircon crystallization age of ~35 ± 3 Ma (Wright and Snoke, 1993; RM-7).

The Horse Creek orthogneiss is commonly intruded by and intrudes pegmatitic granites (TKlg) suggesting overlap with Tertiary leucogranite pegmatites. The Thg occurs as lenticular sheets that range from <1–100 m chiefly in O€mi. This intrusive unit does not commonly occur low in the stratigraphic section with only scattered small bodies in €Zpmi. The rock type is distinguished in hand sample from the mid-Tertiary biotite monzogranite (Tmg), which overlaps compositionally (Sicard, 2012), by the larger grain size and presence of feldspar augen (porphyroclasts) in Thg.

Trqd Quartz diorite of Rattlesnake Canyon (middle Eocene) Massive to foliated quartz dioritic rocks consisting chiefly of plagioclase, hornblende, biotite, quartz, and opaque oxides. Accessory minerals include conspicuous titanite as well as epidote-allanite, apatite, and zircon. A relict igneous texture, including zoning of plagioclase grains, is commonly preserved despite weak to moderate deformation. Interstitial quartz patches have undergone partial recrystallization to micro-mosaic aggregates consisting of a mixture of new anhedral grains (neoblasts) and subgrains in older strained grains. Green hornblende grains commonly exhibit a late-magmatic, partial reaction to biotite. Some rocks within this unit are meladiorite and hornblende gabbro. These rock types are much subordinate to the quartz dioritic rocks. The ubiquitous presence of both hornblende and biotite suggest that the Trqd unit crystallized from a H_2O-saturated magma. Hornblende is commonly the most abundant mafic mineral in the quartz dioritic rocks, although in some varieties the modal biotite content is greater than hornblende.

A sample of weakly deformed biotite-hornblende quartz diorite collected from Rattlesnake Canyon (locality B) yielded a U-Pb ID-TIMS zircon crystallization age of ~38 ± 2 Ma (Wright and Snoke, 1993; their RM-13). Farther to the north in the Humboldt Peak quadrangle, a more deformed biotite-hornblende quartz diorite yielded an age of 40 ± 3 Ma (Wright and Snoke, 1993; their sample RM-19; McGrew, 2018).

The Trqd unit commonly occurs as sheet-like intrusions (<1–50+ m thick), which are boudinaged into discrete pods in areas of strong deformation. Thicker parts of a sheet are commonly coarser-grained than the marginal phases, are weakly foliated and lineated, and preserve the original igneous texture of a quartz diorite. Outcrop evidence of magmatic mingling between Trqd and other Tertiary intrusive rocks include pillows and numerous enclaves of quartz diorite associated with granitic rocks (fig. 10A). Pegmatitic leucogranite dikes also crosscut the Trqd unit (fig. 10B), indicating the presence of felsic magma during the emplacement of the Trqd unit.

The quartz diorite of Rattlesnake Canyon (Trqd) is characterized by great textural variation. Broadly there are five textural varieties: (1) equigranular, (2) an ocellar variety, (3) hypidiomorphic-granular, (4) porphyritic (fig. 10C), and (5) pegmatitic (fig. 10D).

1. Equigranular. This unit is typically characterized by a foliated, fine-grained biotite-hornblende quartz (mela)diorite, which has about equal amounts of subhedral to euhedral green hornblende (~25%) and biotite (~25%). The largest crystal in this rock type is hornblende (~2 mm), which is rarely altered to chlorite. The most abundant mineral is plagioclase (~40%), which displays albite, Carlsbad, combined Carlsbad-albite, and deformation twins. The quartz (~7%) is fine grained and exhibits undulose extinction, subgrain development, and recrystallized neoblasts. Opaque oxides (~2%), apatite, titanite, and zircon are present as accessory minerals.

A variant of this textural type is epidote-biotite quartz diorite (fig. 11). Epidote is associated with biotite, and large subhedral grains of allanite occur with epidote. Hornblende is typically a minor phase. In mylonitic rocks, plagioclase forms small augen in a fine-grained matrix of biotite and quartz.

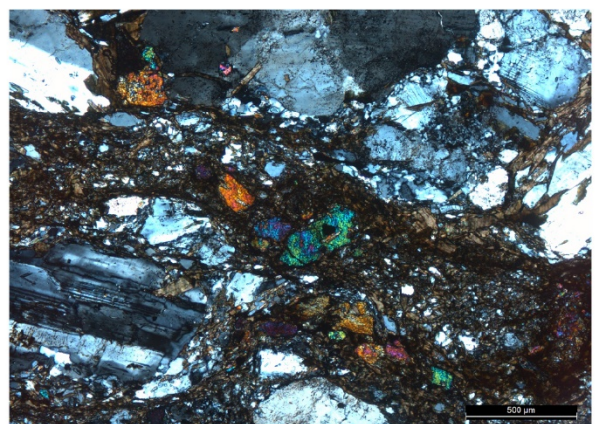

Figure 11. Photomicrograph of mylonitic epidote-biotite quartz diorite (Trqd). The epidote (high birefringent mineral) is non-magmatic and was formed during mylonitization based on its association with recrystallized aggregates of biotite. The scale in the lower right corner of the photomicrograph is 500 µm.

2. Ocellar-textured quartz diorite. The typical rock type is hornblende-biotite quartz-bearing diorite. Modal biotite is greater than hornblende. Biotite grains are bent, and local grain-size reduction is common. Quartz is interstitial and exhibits undulatory extinction, subgrain development, and neoblasts indicating solid-state deformation. Accessory minerals are titanite, epidote/allanite, and opaque oxides associated with biotite. A weak fabric defined by biotite grains is common.

The ocelli in this textural variety are a spherical aggregate of subhedral plagioclase crystals and interstitial quartz with skeletal titanite grains in the center (figs. 12A, B). In more deformed samples, the ocelli are flattened into oval shapes. This distinctive textural characteristic is an example of titanite-centered ocellar texture (Vegas et al., 2011). The origin and significance of ocellar texture in quartz dioritic rocks is controversial (cf., Vegas et al., 2011 and Gogoi et al., 2017). Given other outcrop-scale evidence of magmatic mingling (fig. 10A), the ocellar texture may be related to this phenomenon.

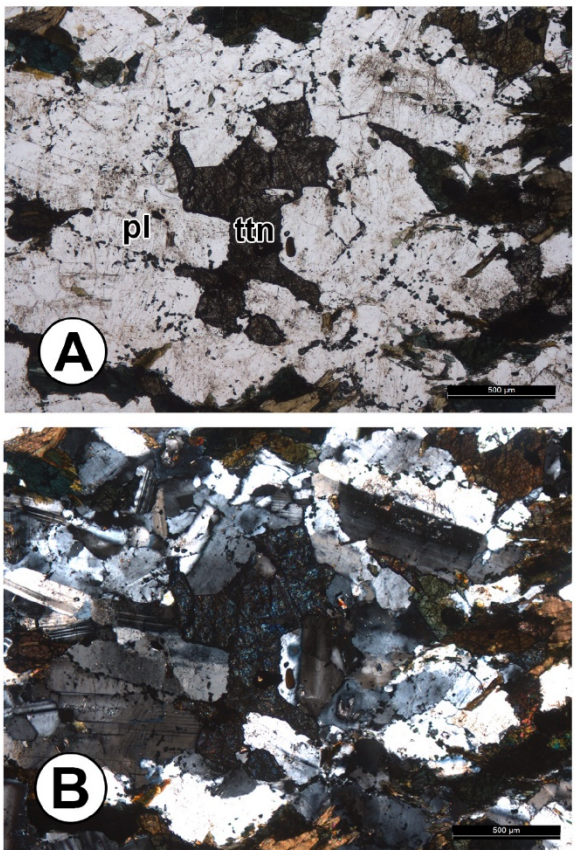

Figure 12. Photomicrograph of ocellar-textured quartz diorite (Trqd). (A) Skeletal titanite (ttn) grain occurs in the center of an oval aggregate of subhedral plagioclase (pl) and interstitial quartz, PPL. This distinctive texture is an example titanite-centered ocellar texture (Vegas et al., 2011). (B) Same view as (A) but XP. The scale in the lower right corner of each photomicrograph is 500 µm.

3. Hypidiomorphic-granular. This textural variety of the Trqd is a less deformed biotite-hornblende quartz-bearing diorite. A planar fabric is defined by tabular plagioclase and subhedral, prismatic hornblende grains (figs. 13A, B). The lithology consists of green hornblende (~23%), biotite (~10%), plagioclase (~60%), quartz (~5%), titanite (chief accessory mineral, ~1%), apatite, epidote-allanite, and opaque oxides. Biotite is chiefly associated with hornblende. Locally chlorite replaces biotite. Quartz is interstitial and exhibits undulatory extinction and subgrain development indicating weak late solid-state deformation superposed on an earlier magmatic fabric.

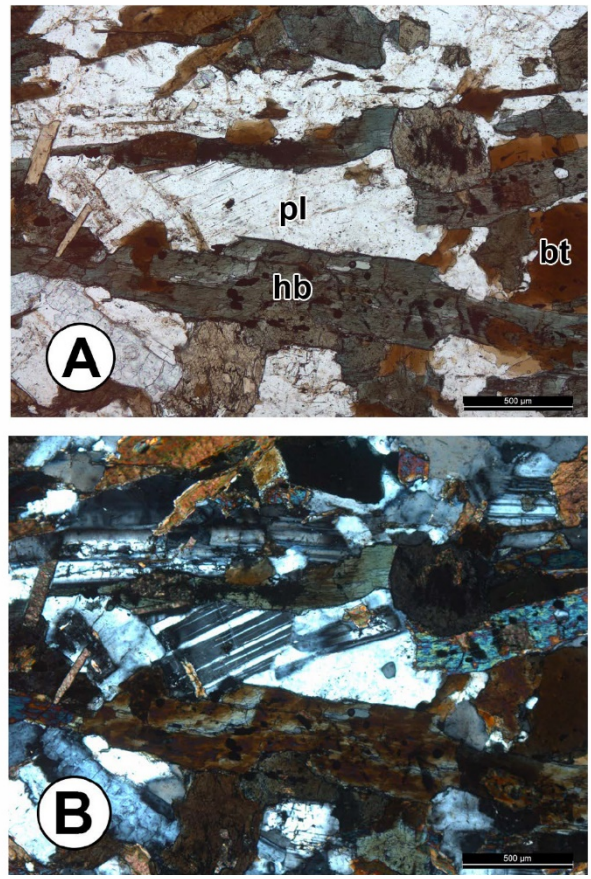

Figure 13. (A) Photomicrograph of hypidiomorphic-granular biotite-hornblende quartz-bearing diorite, PPL; hb = hornblende, bt = biotite, pl =plagioclase. (B) Same view as (A) but XP. The scale in the lower right corner of each photomicrograph is 500 µm.

4. Porphyritic. A very distinctive gabbroic phase in the Trqd unit is characterized by large (up to ~1 cm in maximum dimension), blocky, subhedral hornblende crystals in a matrix of plagioclase, hornblende, and quartz (fig. 10C). Biotite and accessory titanite and opaque oxides partly replace the large hornblende grains. Quartz exhibits undulatory extinction and subgrain development indicating late solid-state deformation superposed on an igneous texture. Accessory apatite is also present.

5. Pegmatitic. A rare textural variation in the Trqd unit is very coarse-grained to pegmatitic hornblende gabbro (fig. 10D) characterized by prismatic green hornblende, plagioclase, interstitial quartz, and accessory titanite and apatite. Biotite, titanite, and opaque oxides are associated with the hornblende prisms. The hornblende prisms are typically ~1–2 cm in length with some grains reaching ~3 cm. Plagioclase exhibits conspicuous zoning. Pegmatitic rocks occur as discrete segregations in coarse-grained biotite-hornblende quartz diorite.

TKlg Leucogranite (early Oligocene? to Cretaceous) Leucocratic muscovite ± biotite granite. Typical accessory minerals are garnet and monazite. Heterogeneous texture, coarse-grained to pegmatitic with scarce aplite, massive to weakly foliated (fig. 6A). A U-Pb ID-TIMS monazite age of ~84 Ma was obtained from a fine-grained garnet-muscovite leucogranite from this unit about 1.3 km southwest of Jerry Crab Spring area (locality C) (Wright and Snoke, 1993; RM-12, see their table 5). A syntectonic leucogranite collected from the hinge zone of the Winchell Lake fold-nappe in the northern East Humboldt Range yielded a U-Pb ID-TIMS zircon crystallization age of 84.8 ± 2.8 Ma (McGrew et al., 2000).

The pegmatitic leucogranite is a very leucocratic rock (color index typically <5) with a heterogeneous coarse texture consisting of alkali feldspar, sodic plagioclase, quartz, muscovite ± biotite, and trace garnet. Rarely relict sillimanite(?) is pseudomorphosed by plumose muscovite. This coarse-grained granitic rock typically does not exhibit foliation unless it has been deformed in a high-strain zone (fig. 6B). The rock unit also exhibits medium-grained and aplitic varieties. The pegmatitic leucogranite commonly occurs as thin (~1–2 m) layers within the O€m and O€mi units (figs. 14A, B). However, it also cuts across foliation at low angles. It is locally foliated but is generally weakly deformed to undeformed in the interior of the intrusive bodies, although boudinage is common on a large and small scale. The TKlg can become strongly lineated and foliated within the Tertiary mylonitic shear zone; elongated muscovite/biotite aggregates locally define a lineation (fig. 6B). Segregations of leucogranite (<5 cm) occur as layers in €Zpmi and Zmu_m and are commonly isoclinally folded (fig. 8B).

Large outcrops exposed on ridges are more resistant rock than the surrounding O€m unit (figs. 14C, D), but are hard to trace across valleys. The intrusions are sheet-like (up to ~250 m thick) and sometimes have dikes that connect these sheets. As a map unit, areas with greater than 75% pegmatitic leucogranite were mapped as the TKlg unit on the geologic map of the Gordon Creek quadrangle.

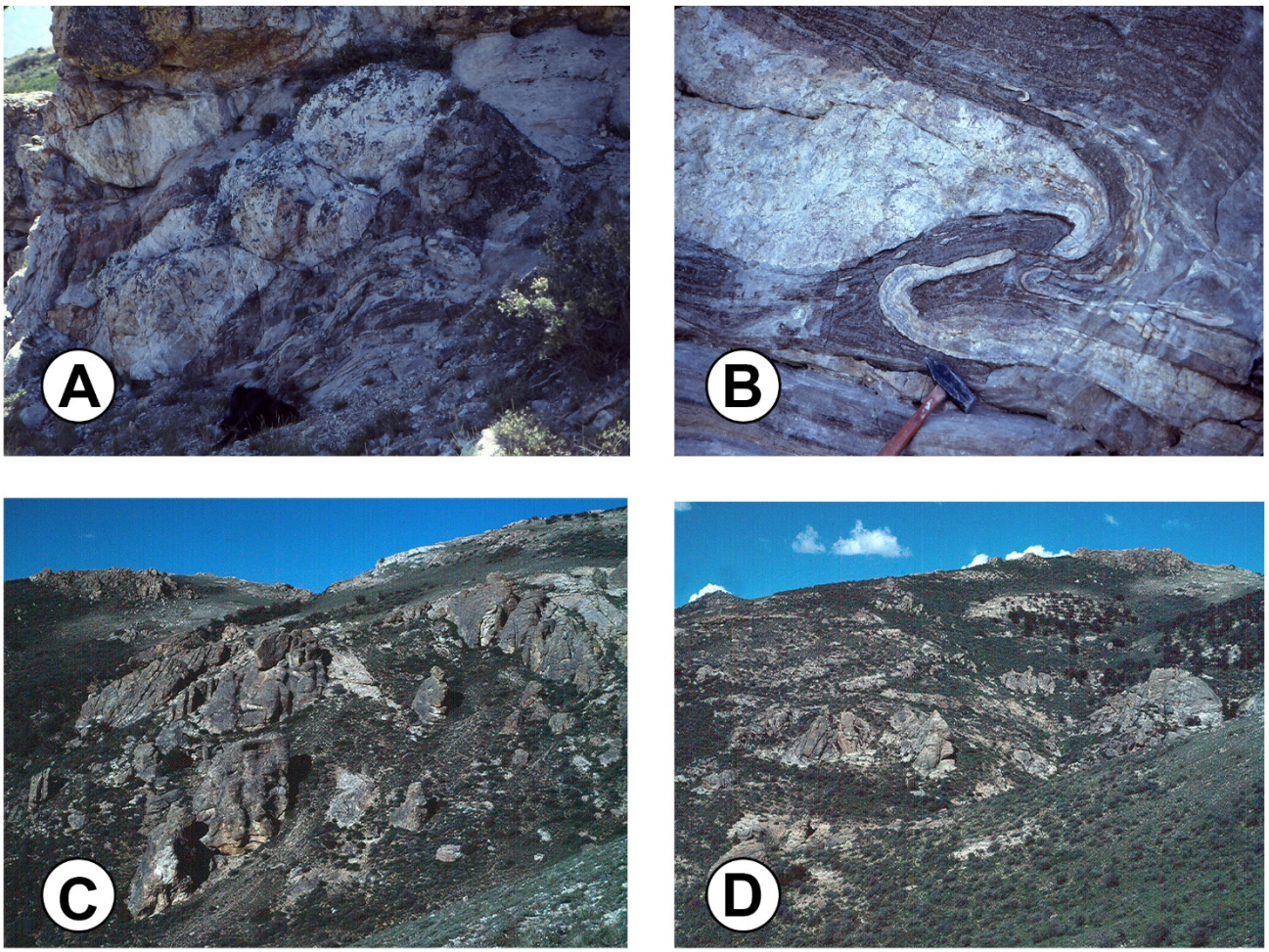

Figure 14. (A) Pods (boudinaged dikes) of pegmatitic leucogranite (TKlg) in highly deformed impure calcite marble with interlayered quartz-biotite metasiltstone. Hammer for scale is in the center of the photograph. (B) Boudinaged and folded layer of pegmatitic leucogranite (TKlg) in impure calcite marble. Mylonitic foliation is folded. (C) Rugged exposures of pegmatitic leucogranite (TKlg), which form large sheet-like masses in the southern part of the Gordon Creek quadrangle. (D) Exposures of pegmatitic leucogranite in the southern part of the Gordon Creek quadrangle. The tree-covered areas are underlain of large pendants of O€m.

Large intrusions of the TKlg in the southern part of the Gordon Creek quadrangle are probably chiefly Cretaceous, based on a U-Pb ID-TIMS monazite age the ~84 Ma (Wright and Snoke, 1993). Similar TKlg intrusions occur in the northern part of Gordon Creek quadrangle, especially well-exposed on the ridges above Wiseman Creek. SHRIMP dating of zircon from pegmatitic leucogranite from the northern Ruby Mountains yielded a broad spectrum of ages that range from 92 to 26 Ma, with peaks at 92, 68, 42, 37, and 29 Ma (Howard et al., 2011). As noted by Howard et al. (2011) the crystallization and emplacement history of the TKlg is commonly unclear and complicated by the chance that some zircon grains are likely inherited, or the history could have included metamorphic overprinting. While the leucogranites are not very deformed, the coarse grain size and pegmatitic nature may have impeded the large sheets and boudins from deforming internally during deformation. At some localities, pegmatitic leucogranite appears intruded by (and perhaps mingled with) biotite monzogranite of the Tmg unit at significant temperatures, indicating the genesis of Tertiary pegmatitic leucogranite during mid-Tertiary magmatism (fig. 9).

SUMMARY AND CONCLUSIONS

The Gordon Creek 7.5-minute quadrangle exposes a long stratigraphic record that ranges from the Quaternary to Neoproterozoic as well as a complex structural history. The following highlights are the fundamental conclusions derived from the geologic mapping of the Gordon Creek quadrangle.

1. In the Gordon Creek quadrangle, a partial crustal cross section is exposed, ranging from mid-crustal rocks (~5–6 kb) in the north to unmetamorphosed upper-crustal rocks in the south.

2. The oldest event preserved in the map area was the deposition of Neoproterozoic sedimentary rocks of the McCoy Creek Group. Although the base of this section is not exposed in the Gordon Creek quadrangle, it appears to be preserved in the Angel Lake area in the northern East Humboldt Range (McGrew and Snoke, 2010; Premo et al., 2010, 2014; McGrew and Snoke, 2015). In that area, the basement rocks are dated and interpreted as Paleoproterozoic and Neoarchean in age.

3. Deposited above the Neoproterozoic McCoy Creek Group is the remainder of the Cordilleran miogeoclinal sequence, ranging up into the Lower Triassic (and perhaps Upper Triassic) at the south end of southeastern East Humboldt Range (Taylor, 1984: Thorman and Brooks, 1994). In the map area, stratified rocks as young as Permian rocks (Pequop Formation) are exposed at the southern margin of the Gordon Creek quadrangle.

4. An isopleth of >67% granitic rocks delineates the deepest exposed rocks in the Gordon Creek quadrangle. The granitic rocks within this area are chiefly pegmatitic leucogranite (TKlg) and biotite monzogranite (Tmg).

5. Metasedimentary rocks within the area delineated by the isopleth include migmatitic, upper-amphibolite facies pelitic schists of the Neoproterozoic McCoy Creek Group. These rocks locally contain the mineral assemblage: quartz + biotite + muscovite + plagioclase + sillimanite + garnet + graphite + zircon, indicating the sillimanite-muscovite zone of upper-amphibolite facies metamorphism. GASP (garnet + aluminum silicate + plagioclase + quartz) thermobarometry indicates ~5.5 kb and ~630 ºC. These *P–T* conditions are interpreted to capture part of the cooling path during Cretaceous–Tertiary exhumation.

6. Structurally above the migmatitic zone is a composite unit of Cambrian–Neoproterozoic metamorphosed Prospect Mountain Quartzite and McCoy Creek Group (€Zpmi), including a distinctive, mappable Neoproterozoic calcite marble to calc-silicate rock unit (Zmm). €Zpmi is intruded by abundant igneous rocks, including Trqd, Thg, Twg, TKlg, and Tmg.

7. Overlying €Zpmi is another composite unit consisting of Ordovician to Cambrian impure calcite marble and calc-silicate rock (O€mi), which is intruded by TKlg and a variety of Tertiary igneous rocks (Trqd, Thg, and Twg). The Tertiary intrusive rocks occur as numerous sheets, some reaching tens of meters in thickness.

8. Middle Tertiary magmatism is widespread in the southeastern East Humboldt Range. The Rattlesnake Canyon biotite-hornblende quartz diorite (Trqd) has been dated at ~40–38 Ma (U-Pb, zircon; McGrew, 1992; Wright and Snoke, 1993). The Tertiary Horse Creek granodiorite/monzogranite orthogneisses has also been dated by U-Pb (zircon) techniques in the southeastern East Humboldt Range at ~35 Ma (Wright and Snoke, 1993). Tertiary biotite monzogranites similar to those in the southeastern East Humboldt Range have been dated at ~29 Ma (U-Pb zircon) in the Angel Lake area of the northern East Humboldt Range as well as in the northern Ruby Mountains (Wright and Snoke, 1986; 1993).

9. In the southern part of the Gordon Creek quadrangle, the marble of Verdi Peak (O€m) is extensively exposed, which is intruded by many small bodies of TKlg as well as several sheets, reaching about 250 m in thickness. In this area, the middle Tertiary igneous rocks are not present. Two localities of metapelite in O€m contain the mineral assemblage: quartz + plagioclase + biotite + muscovite + kyanite + garnet + rutile, indicating upper-amphibolite facies metamorphism (>7 kb, ~600+ ºC) throughout much of the metamorphic sequence in the Gordon Creek quadrangle.

10. The intrusive igneous rocks in €Zpmi and O€mi and surrounding metasedimentary rocks are deformed in a km-scale mylonitic shear zone and are pervasively foliated and lineated. It is estimated that ~170 ºC of cooling and 4 kb of decompression between ~85 and ~50 Ma, followed by another 450 ºC cooling and 4–5 kb decompression between ~50 and ~21 Ma were needed, producing ~30 km of exhumation accommodated by the west-dipping mylonitic shear zone and detachment fault of the RM-EHR core complex (Dallmeyer et al., 1986; Dokka et al., 1986; Hurlow et al., 1991, Hodges et al., 1992; McGrew and Snee, 1994; McGrew et al., 2000; Hallett and Spear, 2014; see fig. 6 in

McGrew and Snoke, 2015).

11. A normal-sense brittle low-angle detachment fault separates the metamorphic and igneous terrain from an upper structural level of unmetamorphosed, brittlely attenuated stratified rocks of late Paleozoic through middle Eocene age (Taylor, 1984). Elevated CAI (5–7) in a sample of Pennsylvanian Ely Limestone (ℙe) indicate weak metamorphic effects in the upper plate, probably related to hot fluids derived from the subjacent footwall of metasedimentary and igneous rocks.

12. Between the upper plate of the detachment-fault system and metasedimentary and igneous rocks of the footwall are fault slices of Oe, DOd, and Dg. The slices are bounded by plastic-to-brittle, low-angle faults that are interpreted as part of the detachment-fault system. These rock units have experienced greenschist to lower-amphibolite facies metamorphism.

13. The Quaternary history of the Gordon Creek quadrangle includes the development of a high-angle normal-fault system on the east side of range. The normal faults bounding the east side of the southeastern East Humboldt Range (e.g., Gordon Creek fault; see geologic map) form a series of faults and fracture zones that led to the steeper topographic front on the east side of the range. The normal-fault system includes buried faults under the west side of the adjacent basin, which includes Quaternary, Tertiary, and older rocks in the subsurface. The Warm Springs fault is interpreted as the western border of a middle–late Miocene sedimentary basin that underlies the central part of southern Clover Valley.

14. The quadrangle also exposes Pleistocene pluvial lake deposits (Lake Clover), glacial deposits, older alluvium, megabreccia, and younger alluvium. Colluvium, landslides and youngest alluvium are the most recent stratigraphic units exposed in the Gordon Creek quadrangle.

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The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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APPENDIX

Field trip guide to key geologic localities in the Gordon Creek 7.5-minute quadrangle, northeastern Nevada. Field trip stop locations are shown on the geologic map.

INTRODUCTION

The goal of this field trip guide is to provide the user with an overview of the structural and petrologic history of the southeastern East Humboldt Range, northeastern Nevada, by summarizing key geologic localities in the Gordon Creek 7.5-minute quadrangle. The center of the map area is roughly 20 mi (32 km) south-southwest of Wells, Nevada, a small town located along I-80. The field trip guide highlights important exposures of middle to upper crustal rocks and their field relations, including Cretaceous and Tertiary intrusive bodies, metasedimentary rocks that range in protolith age from Upper Devonian to Neoproterozoic, a crystal-plastic mylonitic shear zone, a Tertiary brittle detachment-fault system, a part of the range-front fault system, and representative pelitic schists used in thermobarometric studies. The localities (STOPS) are arranged generally from north-to-south in order for the user to progressively traverse across a southward tilted cross section ranging from a mid-crustal level (sillimanite-muscovite-zone rocks) to an upper-crustal level consisting of allochthonous, unmetamorphosed rocks (middle Eocene to Pennsylvanian in age) that compose the southeastern part of the East Humboldt core complex.

All UTM coordinates are based on the North American Datum 1983 (NAD 83), which is the same datum as the topographic base map for the Gordon Creek 7.5-minute quadrangle.

General Directions

Traveling west on I-80, use Exit 352A to reach Wells, Nevada, and U.S. Highway 93 (Great Basin Highway) to reach (STOPS 1–11) on the eastern flank of the East Humboldt Range). For accessing localities on the southwestern flank of the East Humboldt Range (STOPS 12–15) continue westward on I-80 until you reach Exit 321 and follow Nevada State Route 229 until you reach north Ruby Valley.

FIELD TRIP STOPS

AREA 1 – Honeyman Creek

Map Units: McCoy Creek paragneiss (migmatitic phase) (Zmu_m), calc-silicate rock (Zmm), Tertiary–Cretaceous leucogranite (TKlg), Tertiary biotite monzogranite (Tmg), and various Quaternary units.

Directions: Drive south from Wells, Nevada, on U.S. Highway 93. Go about 19 mi (~30.6 km) and turn right onto the southern entrance to Clover Valley Road. Take this road west until it turns north; continue north along the front of the range until the second ranch. There is a gate onto the ranch property just beyond the horse pen, about 800 ft (~245 m) past the ranch driveway. You must ask permission to enter through this gate. Drive up the gravel and grass track, through a gate (close it behind you), then continue straight until a track goes left into the trees and crosses Honeyman Creek. Follow this up to the right as it heads towards the mountain front. The road gets rough as it crosses the creek, then opens up into a field where there is a Forest Service boundary fence and gate (663134, 4526120). Go through the gate and continue to drive up the road. At 662801, 4526031 is exposed pelitic schist with sillimanite and scarce garnet, which is a common rock type in Zmu_m. Coarse-grained, non-mylonitic quartzite is also exposed in this area. When you reach a fork in the road (662763, 4526045) bear left and drive up the hill and park at the top (662759, 4526006). There are many outcrops of typical intrusive relations between various granitic rocks (TKlg and Tmg) and host rocks (Zmu_m) along the walk to STOP 1 as well as STOP 2.

This area highlights large intrusions of Tertiary biotite monzogranite (Tmg) that extend southward from the Humboldt Peak 7.5-minute quadrangle, located directly to the north and mapped by A.J. McGrew (2018). These monzogranite intrusions dominate the Honeyman Creek drainage but are significantly smaller and less abundant in the drainage to the south (Wiseman Creek, STOP 3).

STOP 1. UTM Coordinates: 662038, 4525778

Along the jeep trail, outcrops and float of coarse-grained calc-silicate rock are conspicuous. These skarns are characterized by ruby red calcareous garnet, quartz, and scarce green diopside and apparently occur within the migmatitic McCoy Creek Group (Zmu_m). The protolith was probably a calcareous layer in a quartzite-rich sequence, which experienced metasomatism during magmatic intrusion of adjacent granitic rocks. Skarns are common in various parts of the RM-EHR core complex, including Lamoille Canyon (Jeon, 1999) in the northern Ruby Mountains and Lizzies Basin in the Humboldt Peak quadrangle (McGrew, 2018). These skarns are typically associated with pegmatitic leucogranite intrusions (TKlg), suggesting the importance of hydrothermal fluids in the petrogenesis of these calc-silicate rocks (McGrew, 1992).

STOP 2. UTM Coordinates: 661667, 4525667

The outcrop just right (north) off the trail shows important relations between the country rock (i.e., pelitic schist and paragneiss of the McCoy Creek Group), dikes of deformed pegmatitic leucogranite (TKlg), and equigranular Tertiary biotite monzogranite (Tmg) (fig. 8A). The pelitic schist/paragneiss is characterized by many thin segregated layers of leucogranite (i.e., leucosome), inferred to indicate in situ partial melting related to deep burial, which the Neoproterozoic sedimentary rocks experienced in the Late Cretaceous (McGrew et al., 2000; Hallett and Spear, 2014). Biotite defines the foliation, and asymmetric folds in the leucogranite indicate a westward vergence. Some of the

folded leucogranite layers are cut by younger leucogranite dikes. The age of these dikes is uncertain. Some dikes may be Cretaceous in age (~84 Ma), based on U-Pb (monazite) radiometric dating near the Jerry Crab Spring area (Wright and Snoke, 1993; their RM-12, table 5) or they could be Tertiary in age (e.g., see Howard et al., 2011). If these dikes indicate multiple ages, Cretaceous and Tertiary, a significant deformation occurred between their intrusion into their host rocks. The pegmatitic leucogranite is characterized by large, blocky crystals of white feldspar, books of muscovite, and small (~1–3 mm) cinnamon-colored, Mn-rich garnets. The youngest dike at this locality crosscuts all the other rock types, and is oriented at 065°, 80° SE. Locally, medium-grained monzogranite dikes intrude and are intruded by leucogranite dikes. These crosscutting intrusive relationships are indicative of a complex intrusive history that apparently extended over a significant interval of geologic time.

The Tertiary biotite ± muscovite monzogranites, interpreted as sheets and dikes, are exposed in the cliffs to the north. The monzogranite sheets are connected by feeder dikes, which are commonly foliated and deformed. In some outcrops, Tertiary monzogranite apparently intruded pegmatitic leucogranite before the leucogranite had completely crystallized (fig. 9). These relationships suggest either the granitic rocks are coeval or perhaps just similar in age since Tertiary ages have been reported for some pegmatitic leucogranite intrusions (Howard et al., 2011). If you follow a walking trail westward, through the rock exposures, there is an example of spheroidal weathering, characterized by a rusty red/brown hue, in a Tertiary monzogranite (Tmg) body.

Layers of marble (Zmm), which have been mapped in the Humboldt Peak quadrangle (McGrew, 2018), are exposed near this area. These marble exposures occur as discontinuous lenses of coarse-grained calcite marble with accessory graphite grains (1–2 mm in size). The calcite marbles vary in degree of metamorphic fabric from a weak foliation to a high-strain tectonitic fabric. The larger bodies of marble can be traced as distinct layers in the Ꞓ̄Zpmi or Zmu_m units (see geologic map). In the Humboldt Peak quadrangle (McGrew, 2018), these marble layers yielded high $\delta^{13}C$ values, which are interpreted to indicate a Neoproterozoic protolith age (Wickham and Peters, 1993). Amphibolites (± garnet) is another rock type that occurs in the Zmu_m and are interpreted as original Neoproterozoic mafic dikes now strongly deformed into discontinuous lenses.

AREA 2 – Wiseman Creek

Map Units: McCoy Creek paragneiss (migmatitic phase) (Zmu_m), Prospect Mountain Quartzite-McCoy Creek Group and intrusive rocks (Ꞓ̄Zpmi), Tertiary–Cretaceous leucogranite (TKlg), and various Quaternary units.

Directions: Drive south from Wells, Nevada, on U.S. Highway 93. Go about 19 mi (~30.6 km) and turn right onto the southern entrance to the Clover Valley Road. Take this road west until it turns north; continue north along the front of the range until the first ranch. About 1200 ft (~366 m) north of the ranch there is a dirt road on the left that heads west into the range. You must ask permission at the ranch to drive along this two-track. Follow the two-track until you find a good parking spot on the north side of Wiseman Creek. Watch carefully for rattlesnakes in this area both in the sagebrush and sunning on the rocks. Hike from here to the creek and STOP 3 (UTM coordinates listed below). STOP 3 is on the south side of Wiseman Creek.

STOP 3. UTM Coordinates: 663697, 4524211 (see geologic map for thermobarometric sample locality 3)

This stop is an important locality because it exposes the oldest and most metamorphosed and migmatitic rocks in the map area (Zmu_m). The migmatitic phase of the Neoproterozoic McCoy Creek Group (Misch and Hazzard, 1962) locally contains the subassemblage: biotite-muscovite-garnet-sillimanite-plagioclase. This pelitic schist with distinctive index minerals is likely the McCoy Creek G unit of Misch and Hazzard (1962) because of the characteristic abundance of aluminum silicate group minerals in this horizon at other localities throughout the RM-EHR core complex (Hudec, 1992; Hodges et al., 1992; McGrew, 1992; Snoke, 1992; McGrew and Snoke, 2015; McGrew, 2018). Samples of pelitic schist were analyzed on the automated JEOL JXA-8900 electron-probe microanalyzer at the University of Wyoming. Garnet + Aluminum Silicate + Plagioclase + Quartz (GASP) thermobarometry was employed to determine pressure and temperature (*P–T*) conditions during upper-amphibolite facies metamorphism. The results of these analyses indicate metamorphic conditions at ~5.5 kb and ~630 ºC (Sicard, 2012). Based on other thermobarometric determinations in the East Humboldt Range (Hurlow et al., 1991; Hodges et al., 1992; McGrew et al., 2000; Sicard et al., 2011; Hallett and Spear, 2014), these results apparently do not represent peak metamorphic conditions in the southeastern East Humboldt Range. Rather, they are interpreted to capture *P–T* conditions of the cooling path during Cretaceous–Tertiary exhumation. This regional metamorphism is inferred to be Late Cretaceous (McGrew, 1992; Hallett and Spear, 2014). The thermobarometric data and regional relationships in the RM-EHR core complex indicate that significant crustal thickening was overprinted by high-temperature mylonitization during the early Oligocene and subsequently by brittle, low-angle to high-angle normal faulting in middle Miocene to Quaternary time.

At this locality, pegmatitic leucogranite is a conspicuous component within the Zmu_m unit. The leucogranite occurs at various scales from sheet and dike intrusive bodies to cm-scale, folded leucosome segregations, which suggest in situ partial melting (fig. 8B). Layers of quartzite, generally less than ~1-m-thick, are also present at this locality. However, much thicker cliff-forming layers crop up topographically higher in the Ꞓ̄Zpmi unit and are inferred to be part of the Prospect Mountain Quartzite, which is dominated by quartzite with only local interlayers of

pelitic schist. It is possible that the presence of schist higher up in the quartzite-dominated section indicates infolding of the McCoy Creek Group within the Prospect Mountain Quartzite. The folded, sheared, attenuated, and plastic nature of the rock units and the overprinting by the mylonitic shear zone (especially along the ridgeline) make it impossible to determine an intact stratigraphic sequence.

AREA 3 – Rattlesnake Canyon

Map Units: Middle Eocene biotite-hornblende quartz diorite of Rattlesnake Canyon (Trqd), Prospect Mountain Quartzite-McCoy Creek Group (ЄZpmi), metamorphosed Eureka Quartzite (Oe), Tertiary–Cretaceous pegmatitic leucogranite (TKlg), and various Quaternary units.

Directions: Drive south from Wells, Nevada, on U.S. Highway 93. Go about 23 mi (~37 km) and after a gravel pit on your left, turn right at a paved entrance (666346, 4515328) with a cattle guard (there is a mailbox on the left). Take this road, which becomes gravel, for ~2.1 mi (~3.4 km) until it comes to a T at a gate marked "Lone Pine Ranch." Do not go through this gate, but instead take a right turn onto a rough two-track road that parallels the fence line. Follow the fence line to a corner in the fence at 663203, 4517948. If you want to continue to drive from here, you should have 4WD. Walk or drive up a steep two-track with abundant float of metamorphosed Eureka Quartzite (Oe). When you reach the top of the hill turn left (663164, 4518421) and drive (walk) down into the gully of Rattlesnake Creek. Park where it is convenient and walk to STOP 4.

STOP 4. UTM Coordinates: 662454, 4518351 (lowest exposures of Trqd on ridge north of Rattlesnake Canyon)

At this locality (and farther up the ridge) is a texturally variable intrusion of the middle Eocene biotite-hornblende quartz diorite of Rattlesnake Canyon (Trqd) intruded into strongly foliated and lineated quartzite host rocks (662590, 4518429) of the Prospect Mountain Quartzite-McCoy Creek Group (ЄZpmi). The Trqd is typically medium-grained and hypidiomorphic-granular with ~20% hornblende and slightly less biotite, and a matrix of fine-grained hornblende, plagioclase, and quartz (figs. 13A, B). The quartz diorite has a fine-grained, foliated margin, whereas the internal part of the intrusion has a relict igneous texture characterized by crisscrossed hornblende prisms. This mafic unit also varies in the relative proportions of hornblende and biotite from outcrop to outcrop. A sample from this intrusive body was dated by U-Pb ID-TIMS (zircon) techniques as 38 ± 2 Ma (Wright and Snoke, 1993; their sample RM-13, see U-Pb sample locality B on the geologic map) indicating a middle Eocene emplacement. Further to the north in the Welcome and Humboldt Peak quadrangles (McGrew and Snoke, 2015; McGrew, 2018), a large-scale, sheet-like intrusion of biotite-hornblende quartz diorite yielded an age of 40 ± 3 Ma (Wright and Snoke, 1993, their sample RM-19). A pegmatitic variant of Trqd (UTM coordinates: 662514, 4518654), also occurs in this unit (fig. 10D). This rock type contains euhedral to subhedral prisms of green hornblende reaching up to ~3 cm. These grains are magmatically altered to biotite + opaque oxides. Plagioclase, titanite, and apatite are also components of this rock.

The presence of both hornblende and biotite as well as pegmatitic hornblende gabbro/diorite suggest a H_2O-rich mafic magma. Leucogranite, which locally intrudes the dioritic rocks (e.g., at 662520, 4518659) is interpreted as cogenetic. However, these very felsic rocks could represent either a late differentiate derived from a parent mafic magma or a partial melt generated by crustal melting during the intrusion of a mafic magma at depth. Quartz veins, fractured and boudinaged, occur in these outcrops.

AREA 4. Jerry Crab Spring area

Map Units: Marble of Verdi Peak (OЄm), metamorphosed Eureka Quartzite (Oe), dolomitic marble (DOd), metamorphosed Guilmette Formation (Dg), Ely Limestone (ℙe), Tertiary–Cretaceous leucogranite (TKlg), and various Quaternary units.

Directions: Drive south from Wells, Nevada, on U.S. Highway 93. Go about 23 mi (~37 km) and after a gravel pit on your left, turn right at a paved entrance (666346, 4515328) with a cattle guard (there is a mailbox on the left). Take this road, which becomes gravel, for ~2.1 mi (~3.4 km) until it comes to a T at a gate marked "Lone Pine Ranch". Turn left onto a two-track that follows the fence line. At about 0.3 mi (~0.5 km) bear left at a fork and at a road junction (0.1 mi [0.16 km]) turn right. Drive 0.3 mi (~0.5 km) to a two-track, turn left, and drive 0.1 mi (0.16 km) to a parking spot (663737, 4515509) on metamorphosed Eureka Quartzite.

STOP 5: UTM Coordinates: 663737, 4515509

At this locality, a sequence of metasedimentary rocks ranging from OЄm through Dg is exposed. This sequence is distinctive, because it lacks igneous intrusions that are common in the metasedimentary rocks of the Gordon Creek quadrangle. Walk to the northeast through exposures of vitreous white metaquartzite and a gray variety related to trace graphite in the metaquartzite. The metaquartzite is strongly lineated and foliated. Down slope from the metaquartzite exposures are scattered exposures of the marble of Verdi Peak (OЄm). After you have examined these rocks, return to the parking spot and walk westward crossing the contact between Oe and DOd. Although the actual contact is not exposed, it is interpreted as a relatively low-angle, plastic-to-brittle fault based on attitudes in the underlying Oe and OЄm, macroscopic boudinage of Oe, and brecciation in the Oe near the contact. Continue to walk westward crossing the main road and climbing slightly uphill to the contact with the overlying Dg (663418, 4515502). The Dg immediately above this contact exhibits spectacular plastic flowage with banding oriented 307º, 32º NE (663409, 4515496). The measured attitude is discordant to the mapped contact suggesting that the contact may be a fault. Farther uphill are many exposures of Dg, which have

steep to vertical attitudes of bedding. These interesting variations in Dg suggest complex folding and heterogeneous strain.

STOPS 6 to 10.

Directions: After you return to the parking spot, turn around and drive to the main road. At the junction turn to the left. Drive to the Jerry Crab Spring (small creek crosses the road and green watering troughs on the left, 662500, 451478). This spring and Davis Spring to the north lie on an east-dipping normal fault, which is part of the range-front fault system. This fault is responsible for the down-dropping of the metasedimentary rocks exposed at STOP 5. Continue along the road to a three-road intersection (662302, 4514556) and take the middle road and drive 0.6 mi (~1 km) to a parking spot (661386, 4514038).

STOPS 6 to 10 are reached by a foot traverse that is approximately 2.5 mi (~4 km) in round trip distance. This area provides the opportunity to explore a large body of pegmatitic leucogranite (TKlg), which forms prominent exposures in the southern part of the Gordon Creek quadrangle (figs. 14C, D). These intrusions form tabular masses connected by thick dikes, which cut across topography (see cross section B–B'). In this area, the pegmatitic leucogranite intrudes the Ordovician–Cambrian marble of Verdi Peak (O€m), interpreted as the metamorphosed equivalent of lower Paleozoic carbonate rocks of the Cordilleran miogeocline (Howard, 1971). This area also provides access to a low-dipping detachment-fault system characterized by a braided fault zone including attenuated slices of metamorphosed Upper Devonian to Ordovician metasedimentary rocks (Dg, DOd, and Oe) and overlying Pennsylvanian and Permian unmetamorphosed sedimentary rocks (ℙe, Plc, and Pp). These units lie structurally above the O€m unit, which contains many intrusive bodies of TKlg. The traverse ends at a well-exposed mylonitic shear zone located along the ridgeline in a prominent saddle (Snoke, 1998) (fig. 6B). This ductile shear zone is characterized by meter-scale boudins of pegmatitic leucogranite entrained in impure calcite marble. The shear zone passes down into non-mylonitic, continuous exposures of TKlg along the gullies and in prominent towers above the Jerry Crab Spring.

The traverse starts at a parking place (UTM coordinates: 661386, 4514038) along a two-track road that leads up a narrow canyon. At **STOP 6 (UTM coordinates: 661199, 4514012)** you can examine locality C (see geologic map) where a sample of medium-grained garnet-muscovite leucogranite was collected for U-Pb monazite geochronology. A U-Pb ID-TIMS monazite age of ~84 Ma was obtained from this sample (Wright and Snoke, 1993; RM-12, see their table 5). After examining the TKlg unit, traverse up the slope to the south eventually crossing into the Ordovician–Cambrian marble of Verdi Peak (O€m). The O€m unit is a heterogeneous unit, including impure calcite marble and calc-silicate paragneiss (figs. 3D, 7C, D). In this area, the rock unit is commonly a blue-gray to tan impure calcite marble characterized by color-banding and siliceous layers (metamorphosed chert). The marbles vary in grain size from fine- to coarse-grained and are commonly strongly foliated, but lineations are scarce. Pegmatitic leucogranite (TKlg) intrusive contacts are commonly discordant to the banding and/or foliation in the O€m, which suggests that the development of the tectonitic planar features predated the intrusion of the leucogranite bodies.

Continue upslope to an outcrop of white metadolomite (DOd) at **UTM coordinates: 660999, 4513410 (STOP 7).** At the base of this metadolomite exposure is gray metadolomite suggesting a protolith of Fish Haven and/or Laketown Dolomite. Below the metadolomite is thin fault slice (2–3 m thick) of metamorphosed Ordovician Eureka Quartzite (Oe) intruded by pegmatitic leucogranite (TKlg). The Oe is a bright white metaquartzite that is very pure with the exception of accessory muscovite and graphite. The metadolomite is also intruded by coarse-grained pegmatitic leucogranite. This metadolomite exposure is a fault slice along the RM-EHR detachment fault and is overlain by another fault-bounded slice of metamorphosed Guilmette Formation (Dg).

Continue to climb upward until you reach outcrops of Dg at **UTM coordinates: 660914, 4513387 (STOP 8).** At this location, recrystallized crinoid disks occur in the white layers of this unit. Less deformed exposures of Dg commonly contain relict forms of stromatoporoids. Note that granitic rocks do not intrude this rock unit, and the metamorphic grade is only greenschist facies rather than amphibolite facies characteristic of the stratigraphic units structurally below the Dg exposures. The Dg unit forms fault-bounded slice that occurs immediately below the brittle RM-EHR detachment fault. An important aspect of the deformation below the RM-EHR detachment fault is the extreme attenuation of the stratigraphic sequence (Dg–Oe). This attenuation is both related to ductile boudinage and brittle excisement. South of the Gordon Creek quadrangle, in the Arizona Spring quadrangle, the Dg–Oe stratigraphic section is progressively thicker. Near the Polar Star Mine in the Arizona Spring quadrangle metamorphosed Mississippian Pilot Shale occurs as a greenschist-facies crenulated phyllite.

Topographically above Dg locality are exposures of very weakly metamorphosed Pennsylvanian Ely Limestone (ℙe), which are part of the upper plate of the RM-EHR detachment fault. Contour through the Dg exposures to reach the ℙe locality **(UTM coordinates: 660431, 4513625) (STOP 9).** The limestone is fractured and permeated by a network of veinlets of calcite and quartz. Farther to the north along the ridge (660297, 4514034), bedding in the ℙe is low dipping (66º, 9º SE) to the southeast and appears to be subparallel to the inferred detachment surface. The detachment fault cuts out the Pennsylvanian–Mississippian Diamond Peak Formation, which is present in the adjacent Secret Valley 7.5-minute quadrangle (Snoke, unpublished data).

Pennsylvanian conodonts were recovered by Anita G. Harris (U. S. Geological Survey) from a limestone sample collected at locality 2 (see geologic map). The CAI is 5 to 7,

indicating that this limestone reached 300–450 ºC. In thin section, some samples of the limestone are totally recrystallized to a granoblastic aggregate of calcite. Once you have examined the lithology of the ℙe, chiefly a light- to medium-gray, thick-bedded meta-limestone with yellowish tan nodular or lenticular chert, walk downhill through the fault slice of Dg to a prominent saddle where the intrusive contact between TKlg and the O€m unit is exposed (fig. 2B). At this locality traverse northwest to UTM coordinates: 660302, 4514677 where a flaggy exposure of mylonitic leucogranite occurs in the TKlg **(STOP 10).** This high strain zone is part of a shear zone at the top of a large mass of undeformed pegmatitic leucogranite (fig. 6A). This shear zone is interpreted as Tertiary in age and the contact between the O€m unit and TKlg is a deformed intrusive contact.

Viewpoint: On your way between STOPS 9 and 10 you have the opportunity to see a variety of important geographic and geologic locations surrounding the general area of the southeastern East Humboldt Range. To the southeast and east is Spruce Mountain (10,262 ft [3128 m]) and Spruce Mountain Ridge, respectively (Hope, 1972, Pape et al., 2016). To the east in Clover Valley is Snow Water Lake, a large annually filled playa deriving water from snow melt in the East Humboldt Range. Snow Water Lake is a remnant of Lake Clover, a pluvial lake during the Pleistocene (Reheis et al., 2002; Munroe and Laabs, 2011). Snow Water Lake is surrounded by shorelines, which indicate the previous highstands of this ancient pluvial lake. To the northeast are the Wood Hills mapped by Thorman (1970) and Camilleri (2010b). Beyond the Wood Hills to the northeast and east are the Pequop Mountains (Thorman, 1970; Camilleri, 2010a). Both the Wood Hills and Pequop Mountains expose lower Paleozoic metasedimentary rocks similar to those exposed at STOP 5.

To the north is the east front of the East Humboldt Range and Clover Hill (McGrew and Snoke, 2015; McGrew, 2018). A Quaternary normal-fault system bounds the east flank of the East Humboldt Range as well as Clover Hill (Dohrenwend et al., 1991; McGrew and Snoke, 2015). Traces of Quaternary faults that are considered part of the range-front fault system are delineated on the geologic map of the Gordon Creek 7.5-minute quadrangle. These features include lineaments that are interpreted as fracture zones or small-slip fault zones. The Warm Springs fault is delineated in the subsurface east of the main range-front fault (Gordon Creek fault, see STOP 11) based on mapping in the Arizona Spring quadrangle (Taylor, 1984, Thorman and Brooks, 1994) and the alignment of springs.

On the trip back to the vehicle, the dominant rock is the pegmatitic leucogranite (TKlg), containing small 1–2 mm red garnets, which are common in this rock type. This area, and just north, exposes rugged outcrops of TKlg (figs. 14C, D), which form continuous, interconnected sheets intruded into the O€m host rock. Since the leucogranites generally appear in thick intrusions subparallel to the foliation, with smaller feeder dikes cutting across the foliation, they were probably injected as sheets that were subsequently deformed into large-scale boudins. North of the Jerry Crab Spring area discrete intrusive bodies of leucogranite are still common in O€m, but mappable bodies are less abundant in the central part of the quadrangle. In this area, the intrusions into O€mi are dominated by middle Eocene(?) Horse Creek granodiorite/monzogranite orthogneiss (Thg) and middle Eocene Rattlesnake Canyon biotite-hornblende quartz diorite (Trqd).

AREA 5 – Gordon Creek area

Map Units: Prospect Mountain Quartzite-McCoy Creek Group €Zpmi, metamorphosed Guilmette Formation Dg, and various Quaternary including a Dg megabreccia in Qoa.

Directions: Drive south from Wells, Nevada, on U.S. Highway 93. Go about 19 mi (~30.6 km) and drive pass the southern entrance to the Clover Valley Road. Continue on U.S. Highway 93 for about 1.1 mi (~1.8 km) and then turn right onto a two-track. Drive to the southwest until you reach a Y intersection (664889, 4517976) and turn hard right. Continue for 0.2 mi. and then turn left and drive to a fence line (end of the road) and park.

STOP 11.

The purpose of this STOP is to visit the Gordon Creek fault, which is an element in the range-front fault system. From the parking spot (664760, 4519062) follow the fence line, walking to the north until you reach the top of the ridge south of Gordon Creek. Cross the fence and walk eastward through €Zpmi until you reach the contact with Dg (665004, 4519372). This is the trace of the Gordon Creek fault. Continue to walk to the east until you reach good exposures of Dg at 665058, 4519397. At this locality, the Dg is a dark gray meta-limestone with bedding parallel to foliation, which strikes N 2º E and dips 45º E. Turn around and return to the parking spot. Near the parking spot visit brecciated and calcite-veined exposures of Dg apparently in Qoa (664810, 4519142). There is no evidence of bedding in these exposures, and they are interpreted as a Dg megabreccia (Qmb) formed during slip along the front-range fault system.

AREA 6 – Horse Creek Ridge

Map Units: Marble of Verdi Peak with abundant igneous intrusions (O€mi), Ordovician metamorphosed Eureka Quartzite (Oe), middle Eocene(?) muscovite leucogranite orthogneiss of Woods Creek (Twg), middle Eocene(?) granodiorite/monzogranite orthogneiss of Horse Creek (Thg), middle Eocene biotite-hornblende quartz diorite of Rattlesnake Canyon (Trqd), Tertiary–Cretaceous pegmatitic leucogranite (TKlg), and various Quaternary units.

Directions: Take Nevada State Route 229 south from I-80. After crossing Secret Pass take a left onto a dirt road that leads to north Ruby Valley. After you cross the Franklin River take a left onto a Forest Service road; i.e., the Horse Creek road. Drive along the Horse Creek road for about 2.0

mi (~3.2 km). Take a left at the first major fork (659782, 4520202) in an aspen grove, beyond a large clearing with a right turn into it. Drive along a steep and rough road up to the first open ridge (659481, 4520802) informally named 'Horse Creek Ridge'. STOPS 12 to 15 are reached by a foot traverse that is approximately 1.0 mi (~1.6 km) in round trip distance.

This area displays the intrusive relationships between the middle Eocene(?) Horse Creek granodiorite/monzogranite orthogneiss (Thg) and middle Eocene(?) Woods Creek leucogranite orthogneiss (Twg), as well as some textural variations in the middle Eocene Rattlesnake Canyon biotite-hornblende quartz diorite (Trqd). Farther west, down the ridge are klippen of the Ordovician metamorphosed Eureka Quartzite (Oe), which are associated with the RM-EHR detachment-fault system.

STOP 12. UTM Coordinates: 659520, 4520889

Walking north up the ridge to the given UTM coordinate, you first encounter an outcrop showing the typical "ocellar variety" of Trqd. The white ellipsoidal "spots" are composed of plagioclase with yellow titanite grains in the middle of the aggregate. The ellipsoidal aggregates are slightly flattened in the foliation. This distinctive texture is interpreted as an example of original titanite-centered ocellar texture (Vegas et al., 2011, Gogoi et al., 2017). This type of ocellar texture is an igneous texture characterized by a skeletal crystal of titanite at the center surrounded by plagioclase and minor quartz (figs. 12A, B). The significance of ocellar texture is controversial. One interpretation is that it indicates mingling of mafic and felsic magmas (see Gogoi et al., 2017 for a detailed petrogenetic model). There is also a significant amount of epidote in this unit, likely due to the amount of calcium and iron in this rock type (fig. 8). At this locality, this unit varies from a fine-grained, equigranular biotite-hornblende quartz diorite without ocelli to a medium-grained, hypidiomorphic-granular texture, similar to that found in Rattlesnake Canyon.

At this locality, the Trqd unit forms thin sheets (typically less than 4 m thick) within abundant country rock as well as other intrusive rocks. The sheets are inferred to be interconnected by thinner, dike-like bodies, and they commonly occur as dismembered boudins within a variety of host rocks.

Some of the textural variation in the Trqd unit perhaps relates to the crystallization history in the sheets. For example, the coarse-grained textural variations could represent crystallization near the center of a sheet. However, there is much variation in the distribution of coarse- and fine-grained varieties within the Trqd unit. Pegmatitic rocks in the Trqd unit are typically neither foliated nor lineated, suggesting that these very coarse-grained rocks were competent during penetrative deformation. At this locality, the Trqd unit is highly weathered, probably due to its high mafic mineral content. It typically appears as a resistant black rock from a distance. Also, at this locality the quartz diorite contains epidote veins interpreted as a manifestation of late-stage hydrothermal brittle fracturing.

STOP 13. UTM Coordinates: 659583, 4520897

While walking to the next outcrop, traverse north up the ridge from STOP 12, note the textural variations in the Trqd unit. Evidence for magma mingling relationships is present in these exposures. This interesting relict igneous feature occurs at numerous localities in the Trqd unit (fig. 10A). At this locality, enclaves of unusually mafic dioritic rocks of the Trqd unit are flattened and form irregular-shaped ellipsoids within the Thg unit. Some resorption is suggested along the irregular margins. In other places, the Trqd pillows occur within a more felsic quartz dioritic or granitic rock. This outcrop also shows an interesting relationship between intrusion and deformation indicated by a folded leucogranite dike that cuts across a foliated Trqd dike and thereby provides convincing evidence for Tertiary leucogranite magma in this system.

STOP 14. UTM Coordinates: 659831, 4521089

Farther north up the ridge the granodiorite/monzogranite orthogneiss of Horse Creek (Thg) becomes distinctly mylonitic. The rock is plastically deformed and extremely stretched in appearance with the tops of the outcrop showing a conspicuous stretching lineation defined by elongated quartz and feldspar. Shear-sense indicators in this rock indicate top-to-the-west-northwest, based on asymmetric mica fish, winged σ-type porphyroclasts, type I S-C fabric (Lister and Snoke, 1984). Dark-colored, biotite aggregates are elongated and indicate grain-size reduction.

This outcrop is similar to other localities where the middle Eocene(?) Horse Creek granodiorite/monzogranite orthogneiss (Thg) appears interlayered with the Woods Creek leucogranite orthogneiss (Twg). Geochemistry shows similar trace-element signatures of Thg and Twg where they are interdigitated, suggesting these rocks mingled before they were strongly deformed in the mylonitic shear zone (Sicard, 2012). Therefore, these two orthogneisses could be coeval based on mingling relationships, and the observation that they are usually associated with each other in the field. Twg is the dominant rock type farther up the outcrop and contains tilted muscovite porphyroclasts that indicate a sense-of-shear to the west-northwest. Typically, the Twg unit only contains a few percent biotite. However, where it is interdigitated with the Thg unit, the biotite is greater but still <10 percent.

Just west of this outcrop is a slight valley, interpreted as a Tertiary fault zone, based on the abrupt end of outcrops of Oe and Twg, as well as the predominance of shear fractures in these outcrops. The planes of these shear fractures are oriented ~N–S with near-vertical dips and oblique-trending slickenlines, suggesting oblique-slip displacement. There is also abundant scree in the valley, which could be from fault brecciation or landslide/mass movement. This evidence of possible faulting is compatible with local map relationships, which indicate larger brittle faults in this area that strike

nearly N–S. To reach STOP 15, cross the scree-filled, fault valley to the west.

STOP 15. UTM Coordinates: 659402, 4521323

Across this valley and past the small grove of aspen is a gently sloping plateau of Ordovician metamorphosed Eureka Quartzite (Oe) that is mapped as a low-angle fault contact on top of the Tertiary intrusions (some Thg is just below it to the west) and is inferred to be part of the detachment-fault system. The Oe unit is conspicuous here because of its bright white color. In detail, the Oe unit commonly contains trace graphite and muscovite. It has been metamorphosed and dynamically recrystallized during intense mylonization. The foliation agrees with the general foliation for the area, at 057º, 23º SE with faint muscovite and graphite lineations at 023º/162º. Variations in the typical SE-dipping foliation and ESE-trending lineation (~110º) are common in Oe. Shear fractures at the edge of this outcrop are oriented NNE–SSW, and dip near vertical, with slickenlines close to pure strike-slip, and defined by iron staining.