Text and references to accompany Nevada Bureau of Mines and Geology Map 147

GEOLOGY OF THE VERDI PEAK QUADRANGLE

ELKO COUNTY, NEVADA

by

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The Ruby Mountains and adjoining East Humboldt Range form one of more than a score of North American Cordilleran metamorphic core complexes (Crittenden and others, 1980). The Verdi Peak Quadrangle spans much of the width of part of the northern Ruby Mountains and the exposed metamorphic core complex. The southwest corner of the quadrangle includes a paved road in Lamoille Canyon where the Ruby Mountains are accessible by car, described in several field guides (Snoke and Howard, 1984; Howard, 1987; Snoke and others, 1997). The east part of the quadrangle in Ruby Valley is also accessible by paved road. The quadrangle lies within the area of a geologic map of the Ruby Mountains (Howard and others, 1979, scale 1:125,000). Geologic maps of adjacent areas are in Howard (1966, 2000, scale 1:24,000) and MacCready and others (1997, scale about 1:45,600).

The core complex in the quadrangle exposes Neoproterozoic and lower Paleozoic miogeoclinal strata that exhibit a record of thrust-faulting, deep burial, upper-amphibolite-facies metamorphism, recumbent folding, and pervasive intrusion by Cretaceous, Eocene, and Oligocene granitoids. A metamorphic infrastructure of sillimanite-grade, coarsely crystallized strata and granitoids in the east part of the quadrangle exhibits large recumbent and upright folds. In the northwest part of the quadrangle and locally in the northeast corner, the infrastructure grades structurally upward into a mylonitic carapace a few hundred meters thick. This carapace is interpreted to record ductile tectonic thinning along an extensional shear zone during Cenozoic tectonic extension. Normal-sense, top-to-west shear along this zone and along brittle successors led to tectonic exhumation of the footwall. Quaternary normal faults control the present east and west range fronts. Glacial deposits in the mountains and pluvial-lake deposits in Ruby Valley help record the Pleistocene environment.

METAMORPHIC AND INTRUSIVE ROCKS

The Ruby Mountains metamorphic core complex comprises the pre-Quaternary rock units within the quadrangle. Metamorphosed sedimentary rocks consist largely of marble and quartzite and subordinate schist, and are correlated on the basis of gross lithologic sequence to unmetamorphosed Neoproterozoic to Ordovician strata of the Cordilleran miogeocline in nearby mountain ranges (Howard, 1971). Structural thicknesses of the stratigraphic units and their comparison to original stratigraphic thicknesses resemble those tabulated for the adjacent Lamoille Quadrangle (Howard, 2000). Granite intrusions intricately invade the metamorphic rocks, but the metamorphosed strata retain ghost stratigraphy and large coherent structures even where granitic rocks dominate.

The Paleozoic strata and some granitoids are metamorphosed to amphibolite facies. Diopside is a ubiquitous metamorphic mineral in calc-silicate rocks, and sillimanite is common in quartzofeldspathic rocks in most of the quadrangle. A mapped west-dipping sillimanite isograd is defined as the limit of sillimanite presence in muscovite-K-feldspar-bearing metaquartzite. The isograd roughly coincides with the gradational base of the mylonitic carapace, and may represent a downward limit of retrogressive metamorphism in mylonitized rocks. Geobarometry studies of contiguous metamorphic and intrusive rocks from nearby areas to the north and south by several authors suggest crystallization at depths >20 km (summarized in Howard, 2003).

Migmatitic networks of Late Cretaceous to Oligocene granite form half of the rock volume within the Ruby Mountains in the quadrangle, and intimately inject the relict framework of metamorphosed strata (Howard and others, 1979; Wright and Snoke, 1993; MacCready and others, 1997). Pegmatitic granite intrusions assigned a Late Cretaceous age ("PG" unit described by Lee and others, 2003 from just south and west of the quadrangle) are the most abundant; they consist of sills, dikes, and irregular bodies as thick as 100 m. Overprint patterns on the mapped metasedimentary units indicate the proportion of granite in the resulting migmatite; most is the pegmatitic granite, but also present (unmapped) are small amounts of medium-grained biotite granite gneiss and two-mica granite gneiss that probably correlate to the slightly older "EG" unit of

Lee and others (2003). The pegmatitic granite becomes proportionally more voluminous toward structurally deep levels, and is mapped separately where metasedimentary relics are absent along parts of the east flank of the Ruby Mountains. Lee and others (2003) concluded that their "EG" granite gneiss was derived from melting of metagraywacke, and that the much more voluminous pegmatitic granite was derived by melting of metapelitic rocks at shallower depths, <35 km.

Small metamorphosed gabbro bodies are present locally, in areas shown by an overprint pattern in the mapped marble of Verdi Peak. The distinctive granite gneiss of Thorpe Creek (dated late Eocene) forms a sill that cores the Lamoille Canyon fold nappe, mimicking the shape of the nappe. In the east part of the quadrangle, a small body of hornblende-biotite diorite and small unmapped bodies of medium-grained hornblende-biotite quartz diorite to granodiorite gneiss, intruded into the marble of Verdi Peak and the metamorphosed Prospect Mountain Quartzite and McCoy Creek Group, may correlate with quartz diorite gneiss and granodiorite gneiss intrusions that Wright and Snoke (1993) dated at about 35 to 40 Ma (late Eocene) in the East Humboldt Range. Another variety of granitoid present in unmapped small bodies is mylonitic medium-grained biotite granite gneiss, common within the mapped marble of Verdi Peak in the west part of the map area. Younger intrusions in the quadrangle are small mapped and unmapped bodies of biotite monzogranite, which closely resembles rocks dated by Wright and Snoke (1993) and MacCready and others (1997) as 29±0.5 Ma (late Oligocene), and pegmatite dikes (late Oligocene?). The youngest intrusive rock (middle Miocene) forms basalt dikes that exhibit chilled margins against their wall rocks; similar dikes elsewhere in the Ruby Mountains contain amygdules indicative of intrusion at shallow depths after uplift and denudation of the core complex.

STRUCTURE

The Paleozoic strata and some granitoids in this migmatitic terrain are tectonically layered as a result of thrust faulting and later recumbent folding. An infrastructure of ductilely folded rocks in the eastern and central parts of the quadrangle grades upward into a mylonitic carapace, exposed in the northwest and locally the northeast parts of the quadrangle.

The oldest deformational structure recognizable is the pre-metamorphic, now recumbently folded Ogilvie thrust fault (Smith and Howard, 1977). This thrust stacks a stratigraphic sequence of the metamorphosed Prospect Mountain Quartzite and the marble of Verdi Peak atop a similar sequence, doubling it. As seen in this and adjacent quadrangles, the thrust-repeated sequence is folded into a recumbent anticline, the Lamoille Canyon fold nappe. The recumbently folded, already-stacked sequence thus forms multiples layers of alternating Prospect Mountain Quartzite and the marble of Verdi Peak. The thrust fault surface lacks recognizable cataclastic rocks or outcrop-scale discordance, an absence that can be attributed to post-thrusting metamorphism and deformation. Thrust faulting predates recumbent folding and emplacement of Late Cretaceous pegmatitic granite. Continuous lower Paleozoic to Triassic marine sections present in nearby areas suggest that the thrust faulting was of younger Mesozoic age. Unfolding yields a east-rooted thrust-fault geometry (see Snoke and Howard, 1984, fig. 10), so the thrust faulting may relate to west-verging folds and west-moved thrust plates that were assigned a Jurassic or Early Cretaceous age by Ketner and Smith (1974) and Smith and Ketner (1977) 50 km to the west in the Piñon Range area.

The Lamoille Canyon fold nappe, younger than the Ogilvie thrust fault, has an overturned limb at least 3 km long in the direction of east-southeastward vergence. The limb is 5–10 km long where more fully exposed in adjacent areas to the west and southwest (Howard and others, 1979; Howard, 2000). The nappe plunges gently north-northeastward, and hinge lines can be tracked for 20 km through this and adjacent quadrangles (Howard and others, 1979). The nappe at least partly predates Cretaceous pegmatitic granite, based on greater abundance of the pegmatitic granite on the lower limbs, suggesting that the granite is not folded around the nappe. The map units that describe the Lamoille Canyon nappe are mapped here (and can be interpreted on air photos) as continuous layers even where imperfectly exposed and greatly attenuated. In an alternate interpretation the second author mapped the marble of Verdi Peak as discontinuous beneath the gneiss of Thorpe Creek on the nappe's inverted limb (MacCready and others, 1997).

Eastward from the nappe are, in succession, a synclinal complex, the Hidden Lakes uplift, an upright syncline, and finally the root zone for the west-vergent, structurally higher Soldier Creek nappe (Howard, 1980). The Lamoille Canyon fold nappe, synclinal complex, and Hidden Lakes uplift all plunge northward under the west-vergent Soldier Creek nappe a few kilometers north of the quadrangle (Howard, 1980; Snoke, 1980). The opposite vergences of the overlapping Lamoille Canyon and Soldier Creek nappes exemplify an extraordinary variety in fold-nappe facing directions in the Ruby Mountains (Howard and others, 1979; Howard, 1980). West vergence of the Soldier Creek nappe is interpreted here as accentuated due to Tertiary extensional shearing.

Mesozoic thrust faulting and recumbent folding probably resulted in deep tectonic burial. Hodges and others (1992) and McGrew and others (2000) found geobarometric evidence in metamorphic assemblages in the core complex north of the quadrangle that suggest burial to roughly 35 km depths in Jurassic or Cretaceous time. Hornblende barometry on intrusions related to the biotite monzogranite from upper Lamoille Canyon, barely southwest of this quadrangle, suggests that its intrusion into the marble of Verdi Peak in the Tertiary was at 20–25 km depth (Snoke and others, 1999). These depth estimates suggest that metamorphic rocks in the quadrangle experienced >10 km of tectonic burial by thrust faulting of the 12-km-thick miogeoclinal section, and were later exhumed.

The north-plunging Lamoille Canyon fold nappe and axes of other mapped major north-trending folds in the infrastructure are paralleled by mesoscopic folds, intersection lineations, and mineral-alignment lineations in metasedimentary rocks and pegmatitic granite. North-trending mesoscopic folds in quartzite in the Hidden Lakes uplift locally are coaxially refolded. North-trending lineations also are locally present in Eocene and Oligocene granitoids, from which MacCready and others (1997) concluded that some plastic flow in the infrastructure continued into Oligocene time.

The mylonitic carapace on the west flank of the Ruby Mountains is up to ~1 km thick. At its base, the mylonitic fabrics die out downward over a distance of 100–200 m. Both the upper and lower limbs of the Lamoille Canyon nappe are attenuated in this mylonitic zone. A top-to-the-west-northwest shear sense for the mylonitic fabric is indicated by (1) strong mineral-elongation lineations of this trend, (2) quartz fabrics (MacCready, 1996), (3) S-C fabrics measured in adjacent quadrangles (Lister and Snoke, 1984; Snoke and Lush, 1984), and (4) the azimuth of drag sense of diversely oriented disharmonic folds (Howard, 1968, 1980, 2000). Some unmapped bodies of the biotite monzogranite contain the mylonitic fabric with its west-trending lineation, indicating that mylonitization continued past 29 Ma (MacCready and others, 1997). A lower limit on age of the mylonitic deformation of about 20 Ma is suggested by biotite K-Ar and $^{40}Ar/^{39}Ar$ cooling ages (Kistler and others, 1981; Dallmeyer and others, 1986). Wright and Snoke (1993) concluded that mylonitization occurred about 29-23 Ma. The mylonitic zone is considered to represent a deep expression of middle Tertiary extensional shearing that led to unroofing of the middle crust (Snoke and Lush, 1984; Snoke and Howard, 1984; Howard, 1987). Patterns of Oligocene to middle Miocene cooling ages on the metamorphic and granitic rocks, from fission-track and biotite $^{40}Ar/^{39}Ar$ studies, suggest that much of the footwall was at elevated temperatures, typical of midcrustal levels, until it was rapidly cooled in the early Miocene (Kistler and others, 1981; Dokka and others, 1986; Dallmeyer and others, 1986). Stratigraphic evidence from surrounding areas (Sharp, 1939; Smith and Ketner, 1977) as well as the geochronologic and structural evidence supports a model that ascribes this cooling to extensional unroofing during progressive rise of the footwall.

Gently dipping, top-to-the-west, brittle extensional faults cut the mylonite carapace northeast of the quadrangle in Secret Pass (Snoke, 1980; Snoke and others, 1997). These faults are inferred to represent late stages of faulting and attenuation in the shear zone at progressively higher and cooler crustal levels as the rising footwall was denuded.

The consistent east-northeast strike of steep late Oligocene(?) pegmatite dikes indicates a regionally unusual north-northwest direction of inflation and minimum compressive stress during their intrusion. Younger middle Miocene basalt dikes on the other hand strike north, and record small east-west inflation after the metamorphic and granitic rocks had been largely denuded.

A Quaternary normal fault that is largely concealed by alluvium in this quadrangle bounds the east flank of the Ruby Mountains. A splay passes into the range as the Withington fault, the mapped trace of which, largely concealed but marked by down-to-east throw and a high east-facing fault-line scarp, indicates an east dip of about 45°. The Withington fault's throw is as much as 900 m, based on estimated down-to-east separation of the stratigraphic base of the marble of Verdi Peak in the Hidden Lakes uplift. High rugged peaks on the upthrown west side of the Withington fault overlook a moraine-veneered plateau on its east side that is occupied by Robinson and Soldier Lakes. This plateau perches hundreds of meters above Ruby Valley and may be the relic of a pre-faulting erosion surface.

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