Text and references to accompany NBMG Field Studies Map 22

GEOLOGY OF THE COVE QUADRANGLE, NEVADA AND UTAH

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INTRODUCTION

The Snake Range, in eastern White Pine County, Nevada, is a 150-km-long, north-trending mountain range in the northern Basin and Range province (fig. 1). Sacramento Pass divides the range into two main parts, the northern and southern Snake Range. The Cove Quadrangle is one of twelve 7.5' quadrangles that cover the northern Snake Range and is situated along the southeastern most flank of the range, bordering Snake Valley to the east. It includes two of the main drainages in the range, Hendry's Creek and Hampton Creek (fig. 2). Main access into the part of the northern Snake Range covered by this quadrangle is via northern Snake Valley road, a well-maintained gravel road that heads north from the intersection of U.S. Highway 50 and State Route 487 in Nevada to Trout Creek in Utah. Several secondary dirt tracks provide access to the southeastern most flank of the range. Access to Hendry's Creek and Hampton Creek drainages is by maintained gravel roads to a trailhead at the mouth of Hendry's Creek canyon and a trailhead at 8,000 feet (2,400 m) elevation in Hampton Creek.

The northern Snake Range includes the Mount Moriah Wilderness Area, which was established in 1989. The steep-walled canyons and rugged ridge crests of the northern Snake Range provide access to The Table at about 11,000 feet (3,300 m) and Mount Moriah at 12,067 feet (3,678 m), forming some of the most scenic hiking country in the Basin and Range province. The broad, arch-like physiography of the northern Snake Range is shaped by its geology, which is unique compared to other mountain ranges in the region. The northern Snake Range is now considered a classic example of a Cenozoic metamorphic core complex (for example, Coney, 1979). The most prominent structural feature of the range is the northern Snake Range décollement (NSRD), a low-angle fault that juxtaposes an upper plate of complexly normal-faulted Paleozoic and Tertiary strata against a lower plate of ductilely attenuated metasedimentary and igneous rocks (figs. 2 and 3). The NSRD defines a north-trending asymmetric dome with about 5,000 feet (1.5 km) of structural relief (fig. 4). The age, origin, and tectonic significance of the NSRD have been topics of continuing debate since the fault was first described by Hazzard and others (1953) and Misch (1960). Although the origin of the NSRD and core complex detachment faults in general remain controversial, there is common agree-

Figure 1. Index map of east-central Nevada and west-central Utah showing location of the Snake Range with respect to surrounding mountain ranges in the northern Basin and Range province, western United States.

Figure 2. Index map of the northern Snake Range showing simplified geology and location of mapped 7.5-minute quadrangles.

Figure 3. Representative stratigraphic column for the Snake Range and environs. Representative structural thicknesses for upper plate and lower plate rocks after normal faulting and ductile thinning.

Figure 4. Structure contour map of the northern Snake Range décollement (from Lee, 1990).

ment that these complexes provide excellent exposure of both brittle and ductile structures formed as a result of large-magnitude crustal extension.

GEOLOGIC SETTING AND PREVIOUS WORK

Both the northern and southern Snake Range are underlain primarily by Late Proterozoic to Permian miogeoclinal shelf strata deposited along the subsiding continental margin of western North America (fig. 3) Miogeoclinal strata in the footwall of the NSRD range in age from late Proterozoic to Ordovician and generally define a broad, north-trending antiform. These rock units are relatively unfaulted but record a polyphase history of ductile deformation, metamorphism, and intrusion. The hanging wall or upper plate of the NSRD includes Middle Cambrian to Permian miogeoclinal rocks, as well as Tertiary sedimentary and volcanic rocks. In striking contrast to the lower plate, these rocks are little metamorphosed but highly faulted and tilted by multiple generations of normal faults (fig. 3).

In many ways, the evolution of ideas concerning the origin of the NSRD charts the progress of our understanding of the extensional history of the Cenozoic Basin and Range province as a whole. Until the early 1970s, most low-angle faults like the NSRD in the western United States were mapped as thrust faults. The Snake Range décollement was first described by Hazzard and others (1953). A more detailed study of the geology of the northern Snake Range by Misch (1960) and Misch and Hazzard (1962) followed as part of a regional survey of the geology of eastern Nevada. They noted that the major structure in the northern Snake Range was a low-angle "décollement" that separated an autochthon of strongly metamorphosed rocks from an allochthon of faulted and folded, but largely unmetamorphosed, carbonate rocks. Nelson (1966, 1969) mapped the northern end of the range as part of a regional mapping project that included the Kern Mountains and southern Deep Creek Range. He mapped the décollement of Misch (1960) and identified lower-plate schists and marbles as metamorphosed equivalents of Proterozoic and Cambrian-Ordovician miogeoclinal units and upper plate rocks as Cambrian to Permian carbonate rocks and younger Tertiary rocks. Nelson proposed that rocks in the lower plate (his "autochthon") recorded three deformational events, the youngest of which involved the generation of mylonites and formation of folds that he assigned to the Mesozoic. He believed that these structures were associated with east-directed thrusting along the décollement horizon. The position of the Snake Range in the hinterland of the Cretaceous Sevier orogenic belt (fig. 1) led these and later workers to relate the low-angle "décollement faulting" in the northern Snake Range to Mesozoic thin-skinned thrust faulting further east, where the NSRD represented the basal shearing-off plane for these thrusts (Misch, 1960; Miller, 1966). However, Hose and Danes (1973) and Hintze (1978) recognized that the deformation in the upper plate was dominated by normal faulting and attenuation of the stratigraphic section rather than by shortening and thickening of the rock column. This led them to propose a model wherein the Snake Range and environs represented an uplifted hinterland, where extension was linked to coeval shortening in the foreland via a basal detachment fault now exposed as the NSRD. Armstrong (1972) was the first to suggest that many of these faults might be Tertiary rather than Mesozoic in age, and therefore unrelated to Mesozoic thrust faulting. Armstrong specifically cited geochronologic and stratigraphic relations from the southern Snake Range as some of his principal evidence for a Cenozoic age for the Snake Range décollement. Coney (1974) suggested that at least some of the lower plate deformation in the northern Snake Range might be related to the Snake Range décollement. He studied folds in marble mylonite beneath the NSRD and proposed "quaquaversal" or radial sliding of upper plate rocks off the northern Snake Range.

Hose and Blake (1976) compiled a 1:250,000-scale geologic map of White Pine County which included the first compiled geologic map of the northern Snake Range based largely on reconnaissance mapping by Hose. They mapped the low-angle NSRD in its entirety, which they described as separating a lower plate of undifferentiated Lower Cambrian quartzites and pelites and Middle Cambrian marbles from an upper plate of complexly faulted Middle Cambrian to Permian carbonate rocks. Hose and Blake (1976) proposed that two metamorphic and deformational events were recorded in lower plate rocks, a post-mid-Jurassic to pre-early Eocene intrusive and high-grade metamorphic event followed closely by a low-grade metamorphic event associated with the development of a strong penetrative foliation and west-northwest-trending mineral elongation lineation. This was followed by post-early Eocene movement along the NSRD and associated faulting in the upper plate. As part of the Wilderness RARE II study, additional mapping of the southern part of the northern Snake Range was carried out at a scale of 1:62,500 (Hose, 1981). This publication pointed out the magnitude of structural thinning of upper plate units by normal faulting. In an influential paper by Wernicke (1981) on the geometry and kinematic significance of extensional detachment faults, the Snake Range décollement was cited as a key example of a large-displacement, eastward-rooting low-angle normal fault.

Studies in the northern Snake Range by geologists based at Stanford University began in 1981 and are still ongoing. Miller and others (1983) and Gans and Miller (1983) suggested that the basic structural relationships in the northern Snake Range were best explained as

extensional in origin and Cenozoic in age. For the first time, the Late Proterozoic lower plate units in the central and southern part of the range were identified and correlated, bringing to light the incredible tectonic stretching or attenuation of these rock units by ductile deformational processes. The upper plate units were shown to have been affected by multiple generations of predominantly east-dipping normal faults, and it was pointed out that over much of the range there appeared to be near stratigraphic continuity between the oldest units present above and youngest units present below the décollement. These and other relations led Miller and others (1983) to question the need for significant displacement on the décollement and to propose instead that the NSRD originated as a subhorizontal ductile-brittle transition zone between a brittlely extending upper plate and a ductilely stretching lower plate. This interpretation was challenged by Bartley and Wernicke (1984), who specifically proposed that the NSRD represented a low-angle normal fault or shear zone with 60 km or more displacement that brought lower plate rocks up and out from under a thrust plate in the Sevier belt to the east. In their model, the near continuity or lack of stratal omission between upper and lower plate rock units cited by Miller and others (1983) was strictly fortuitous. Gans and Miller (1985) responded to this alternative interpretation by citing additional regional stratigraphic and structural relations that created difficulties with Bartley and Wernicke's proposed model.

Further studies in the northern Snake Range expanded our geologic mapping and utilized structural and kinematic analyses, seismic reflection profiling, metamorphic petrology, and extensive geochronology and thermochronology in order to help resolve issues as to the amount of displacement and initial angle of the NSRD, as well as the age of lower plate deformation and its geometric and kinematic relationship to the evolving NSRD (Rowles, 1982; Gans and Miller, 1983; Grier, 1983, 1984; Miller and others, 1983, 1987, 1988, 1989; Gans and others, 1985, 1989; Geving, 1987; Lee and others, 1987; Huggins, 1990; Lee, 1990, 1995; Lee and Sutter, 1991). Our geologic mapping at scales of 1:12,000 and 1:24,000 over a 12-year period (1981-92) was the first detailed mapping to be completed in the range. During the first half of this project, mapping was carried out on 1:16,000 black and white and 1:24,000 color aerial photographs and compiled upon orthophotoquadrangles because topographic maps were not yet available for the region.

Our studies have shown that lower plate rocks consist of metamorphosed Late Proterozoic to Lower Cambrian quartzites and pelites and Middle Cambrian to Ordovician marbles that correlate in a straightforward fashion to less deformed and metamorphosed sections in the adjacent Schell Creek, Deep Creek, and southern Snake Ranges. Jurassic and Cretaceous granitic plutons and Tertiary dike swarms intrude lower plate units. Lower plate rocks record at least three metamorphic and deformational events. The first metamorphic event, of Jurassic age, is best preserved along the southern flank of the northern Snake Range. Here, Late Proterozoic and Lower Cambrian quartzites and metapelites have been intruded and contact metamorphosed by a mid-Jurassic plutonic complex (fig. 2). Structural fabrics associated with this event are strongly overprinted by superimposed Cretaceous and Cenozoic fabrics.

The second metamorphic event, of Late Cretaceous age, affected a much broader region of the lower plate. A series of mineral-in isograds mapped along the eastern side of the range indicates that the grade of metamorphism increases from greenschist to amphibolite facies from south to north and with structural depth in the succession (Geving, 1987; Huggins, 1990). A Late Cretaceous pegmatite and aplite dike swarm was intruded during this metamorphic event, which has been dated at about 82 to 78 Ma (Huggins and Wright, 1989; Huggins, 1990). Structural fabrics associated with this metamorphic event have also been strongly overprinted by Cenozoic fabrics, making their analysis and interpretation difficult. However, on the northwestern flank of the range, Tertiary strain decreases and eventually dies out. Here, west-dipping foliations, minor thrust faults, and a map-scale fold now inferred to be of Cretaceous age are preserved (Lee, 1990; P. B. Gans, 1992, unpub. data). Lower to upper greenschist-facies metamorphism of Eocene to Miocene age (Lee and Sutter, 1991; Lee, 1995) strongly affected much of the lower plate, causing retrogression of older mid-Jurassic and Late Cretaceous metamorphic assemblages. The Tertiary metamorphic event was accompanied by vertical thinning and horizontal stretching, resulting in a subhorizontal, bedding-parallel mylonitic foliation and west-northwest-trending stretching lineation. This foliation is axial planar to isoclinal, recumbent folds in the northern half of the range. A strong gradient in the amount of deformation or strain of lower plate rock units developed during this youngest event. Strain increases dramatically from west to east across the range. Mesoscopic, microstructural, and petrofabric studies on lower plate rocks were utilized by Lee and others (1987) to modify the in-situ pure shear model proposed by Miller and others (1983). Lee and others (1987) proposed a strain path whereby pure and simple shear (top to the east) acted in unison and in sequence in the lower plate and that this strain was intimately tied to the evolution of the NSRD, ultimately leading to slip along this surface in the brittle regime. Structural studies by Gaudemier and Tapponnier (1987) were used to promote a model whereby lower plate deformation occurred entirely by simple shear. As pointed out by Lee and others (1987), the question of

Figure 5. Schematic diagram illustrating two generations of normal faults and attendant rotation that may be responsible for the observed attenuation of the stratigraphic section shown in figure 3 (modified from Miller and others, 1983).

simple versus pure shear remains controversial, as most structural and petrographic observations used to resolve these questions do not yield unique interpretations. In sum, important questions still remain regarding the exact age of development of lower plate fabrics, whether they are developed as a consequence of pure and/or simple shear, and what the exact kinematic relation is between these fabrics and the evolving NSRD.

In the overlying upper plate, unmetamorphosed to weakly metamorphosed Middle Cambrian to Permian carbonate rocks have in general been attenuated by at least two sets of imbricate normal faults. This resulted in successive northwestward tilting about a common axis in response to WNW-ESE extension, parallel to that recorded by the ductile deformational fabrics in the lower plate (Miller and others, 1983). However, the amount of strain indicated by these faults and the amount of rotation related to faulting varies across the range, as does the direction of tilting or rotation. Despite the extremely complex map pattern of upper plate normal faults, this generally systematic structural style is evident upon close inspection. Structural sections of Middle Cambrian to Permian (and locally Tertiary) strata that "young" to the west are repeated eastward on east-dipping normal faults that merge with, but do not offset the NSRD. These faults are labeled as "second-generation" faults on the cross sections on the map sheet. Within these tilted sections, older, gently west-dipping faults omit units as well, and are interpreted as originating as steep, down-to-the-east normal faults that once shallowed into the NSRD. These older faults (labeled as "first-generation" faults on the cross sections) rotated to low angles as they moved until cut by younger faults, which rotated them past horizontal and into their present westward dips. Macroscopically ductile deformation such as warping, normal drag, folding and complex arrays of smaller faults and their splays helped alleviate space problems at the toes of normal faults as they merged with the NSRD. Figure 5 schematically illustrates how this faulting history operated. Regardless of the details and the exact geometry of the faults themselves, it is clear that the process of faulting led to tremendous attenuation of the stratigraphic sequence which once formed the hanging wall or upper plate of the NSRD (figs. 3 and 5). Normal-sense movement along the NSRD during the time span of upper plate faulting is indicated, as only a few mapped faults actually cut and offset the NSRD. Motion along the NSRD is believed to have been down-to-the east and resulted in the juxtaposition of the less metamorphosed and mostly younger upper plate rocks down upon the more highly metamorphosed and generally older lower plate rocks. An important exception to this occurs in the northern part of the range where Middle Cambrian and younger rocks of the upper plate routinely overlie Late Cambrian and locally Ordovician strata in a lower plate position.

We previously postulated that most of the movement on the NSRD was Oligocene to early Miocene in age (for example, Gans and Miller, 1983; Miller and others, 1983; Gans and others, 1985; Lee and Sutter, 1991). However, new thermochronologic and geologic data suggest that movement along the NSRD was likely episodic. Multiple diffusion domain analyses of potassium feldspar Arrhenius data and $^{40}Ar/^{39}Ar$ age spectra together with apatite fission-track studies show three rapid cooling events: 1) middle Eocene (48-41 Ma), 2) late Oligocene (30-26 Ma) and 3) early to middle Miocene (20-15 Ma) (Miller and others, 1989, 1990; Lee, 1995). These cooling events may indicate diachronous exhumation of footwall rocks from beneath the NSRD. The spatial and temporal distribution of these cooling events suggest that the NSRD is a composite structure; the NSRD along the west flank of the range moved during the Eocene and Oligocene (Lee, 1995), and the NSRD along the east flank of the range moved during the Early to Middle Miocene (Miller and others, 1989, 1990). Field relations indicate that Miocene or younger sedimentary sequences along the northern, eastern and southern flanks of the range are cut and tilted by a set of normal faults that we infer either to cut or to sole into the NSRD in the subsurface, supporting the inferred Early to Middle Miocene episode of movement along at least these parts of the NSRD (Gans and others, 1989; Miller and others, 1989, 1990).

In summary, we now think that the combined data on the deformational history of upper and lower plate rocks indicate that the NSRD is a composite structure rather than a single fault; thus it was never simultaneously active over its entire mapped extent. East-dipping normal faults along the eastern flank of the range were likely active in mid-Miocene and later times and perhaps originated as steep faults that have since been rotated to present low dips. Because the older parts of the NSRD were dragged into parallelism with this younger faulting, it is not obvious where the trace of the older fault ends and the younger begins. In The Cove Quadrangle, we would venture that the trace of the younger fault underlies the mapped klippen of upper plate rocks along the eastern flank of the range. We indicate this relationship in cross section A-A'. If the high-strain rocks and mylonites of the lower plate represent more than one Tertiary event as well, our studies to date have not unequivocally resolved these with confidence. Limiting factors include the resolution of available geochronologic techniques, given the complex thermal and deformational histories of the minerals available for dating, and the inability of structural studies to distinguish more than one superimposed event if these are developed at low angles to one another. Clearly, the NSRD represents the end result of an involved history of extensional strain at both ductile and brittle levels of the crust and that more than one episode of faulting is responsible for the relative uplift and exposure of ductile extensional fabrics in the range. However, more sophisticated studies and modeling of existing data are necessary in to fully understand the kinematic history and mechanics of deformation and faulting.

GEOLOGY AND STRUCTURAL HISTORY OF THE COVE QUADRANGLE

Bedrock is exposed only in the northwestern part of The Cove Quadrangle, which covers the southeastern-most corner of the northern Snake Range. Broad alluvial pediments slope gently away from the range toward northern Snake Valley, where they were reworked in a lacustrine environment during the existence of Lake Bonneville 10,000 to 32,000 years ago (Currey and James, 1982). The NSRD is the main structural feature in The Cove Quadrangle and underlies a series of prominent klippen of faulted, upper plate, Paleozoic strata along the eastern and southeastern flanks of the range. The dark, craggy klippen contrast sharply with the smooth, light-colored dip slopes of Cambrian and Late Proterozoic mylonitic quartzite and schist beneath the NSRD. The NSRD dips gently eastward about 15° beneath Snake Valley, where it has been imaged seismically (Allmendinger and others, 1983; McCarthy, 1986) and can be projected just above and parallel to the dip-slope ridge crests of quartzite to the exposures of the NSRD at higher elevations in the range. The Cove Quadrangle provides easy access to some of the best exposures of the NSRD and associated lower-plate mylonites in the range, making it an excellent place for field trip stops (for example, Gans and Miller, 1983; Miller and others, 1987).

In the southern part of the quadrangle, lower plate formations, including the Cambrian Prospect Mountain Quartzite, Pioche Shale, and Pole Canyon Limestone are intruded by a Jurassic plutonic complex described in more detail in the adjacent Old Mans Canyon Quadrangle (Miller and others, in press). In The Cove Quadrangle, there is easy access to excellent exposures of the mylonitized pluton and its deformed intrusive contact with the Cambrian Prospect Mountain Quartzite in the small drainage west of The Cove (a small basin in the central part of the quadrangle). Just above these outcrops are the white-gray cliffs of swirled and folded Middle Cambrian marble mylonite beneath the NSRD.

To the north, Hendry's Creek provides access to spectacular exposures of flaggy quartz mylonites and interbedded schist that display a wide variety of ductile-to-brittle mesoscopic and microscopic structures that are now considered typical of rocks having undergone

large amounts of (extensional) strain (Gans and Miller, 1983; Lee and others, 1987; Miller and others, 1987). All rocks in this drainage possess a very prominent foliation subparallel to bedding and a well-developed west-northwest-trending mineral elongation or stretching lineation. Lower plate rock units are so attenuated that their present thicknesses are less than one-tenth of their original stratigraphic thicknesses (fig. 3). The flaggy and conspicuously jointed mylonitic quartzites are quarried providing a uniquely aesthetic decorative stone of many uses.

Upon careful examination, it can be seen that the most obvious deformational fabrics in the schist and quartzite of Hendry's Creek postdate the growth of most metamorphic minerals in these rocks. This is evidenced by the conspicuous chlorite pressure shadows developed around garnets in a direction parallel to the stretching lineation, by pulled-apart, segmented staurolite and biotite porphyroblasts, and by well-developed sets of extensional crenulation cleavage in the schists that cut and rotate coarse-grained micas. From these observations it can be concluded that the strain that resulted in the extreme attenuation of lower plate units occurred at lower metamorphic grade, probably entirely at lower greenschist facies conditions (Gans and Miller, 1983; Lee and others, 1987). Although the high-strain mylonitic foliation in lower plate rocks in The Cove Quadrangle is generally developed subparallel to original bedding and unit contacts, an exception to this occurs in Hendry's Creek, where some of the deepest exposed levels of the lower plate are involved in a series of open to isoclinal recumbent folds whose axes trend parallel to the lower plate stretching direction. Similar folds in the Hampton Creek drainage to the north have been ascribed by Rowles (1982) to a component of constrictional strain operating during the overall attenuation and stretching of the units. The subhorizontal mylonitic foliation is axial planar to these folds. In quartzite units, original bedding is folded by these structures, but in the intervening schists, the planar surfaces that define the folds are an older schistosity that is generally tightly crenulated.

Peak metamorphism in the Hendry's Creek and Hampton Creek region resulted in the growth of coarse-grained garnet and staurolite in schist units of the Late Proterozoic McCoy Creek Group. This metamorphic event is responsible for a series of Barrovian mineral-in isograds mapped along the eastern side of the range; metamorphism increases northward and with depth in the stratigraphic succession (Geving, 1987; Huggins, 1990). The following progression is documented from south to north and with increasing metamorphic grade: chlorite-biotite-garnet-staurolite-in isograds. In addition, the Late Proterozoic Osceola Argillite develops coarse kyanite + biotite in the Hampton Creek region between the biotite-in and garnet-in isograds mapped in these same rocks (Rowles, 1982; Huggins, 1990), suggesting that the kyanite grew at low temperatures, below the aluminum-silicate triple junction (for example, Holdaway, 1971). The coarse-grained garnet-staurolite-bearing schists and kyanite-biotite schists of Hampton Creek are quite impressive and well worth the visit.

Deformational fabrics produced during the Cretaceous metamorphic event are strongly overprinted by Tertiary fabrics, thus cannot be measured and evaluated in detail. Because Tertiary strain that resulted in the extreme attenuation of lower plate units occurred at lower metamorphic grade, the older metamorphic isograds were collapsed and are now much closer together, suggesting abnormally high metamorphic field gradients (greater than 100°C/km) (Geving, 1987; Miller and others, 1988; Huggins, 1990).

Peak metamorphism in the Hampton Creek area (and Smith Creek area to the north) has been dated as Late Cretaceous in age (Lee and Fischer, 1985; Huggins and Wright, 1989; Huggins, 1990) between approximately 82 and 78 Ma. Dating the younger, superimposed mylonitic fabric has been more difficult because the younger deformation took place under greenschist-facies conditions and likely did not reset most of the older mineral ages. At the deepest levels of exposure in Hendry's Creek, new growth of biotite, rather than chlorite, occurs within the mylonitic foliation. Temperatures of deformation seem to increase northward as well as with depth, as evidenced by upper greenschist assemblages associated with the younger deformational event in the Smith Creek region (Huggins, 1990). $^{40}Ar/^{39}Ar$ thermochronology of metamorphic and igneous muscovite from Hendry's, Hampton, and Smith Creeks typically yield disturbed spectra with Oligocene-Miocene total gas ages, which may represent partially to significantly reset Cretaceous micas (Lee and Sutter, 1991). Calculated thermal histories, based on multiple diffusion domain analyses of potassium feldspar $^{40}Ar/^{39}Ar$ age spectra from the Smith Creek area, indicate that lower plate rocks along the eastern part of the range did not drop below 300°C until 20 Ma, providing a minimum age on mylonitic deformation (Lee, 1995).

Upper plate units in The Cove Quadrangle include Cambrian (Pole Canyon Limestone) to Permian (Arcturus Formation) miogeoclinal sedimentary rocks and Miocene or younger conglomerates. As elsewhere in the Snake Range, these rocks are complexly normal-faulted, and not all units of the miogeoclinal succession are present. Formational contacts and bedding strike north-northeast and dip variably westward. At least three east-dipping normal faults repeat Paleozoic units. Within the repeated sections of the three fault-bounded blocks are a variety of older normal faults but they are too poorly exposed to make generalizations about their geometry and offset in this quadrangle. The

westernmost of the three east-dipping faults described above downdrops Ordovician-Silurian dolomite against the Cambrian Pole Canyon Limestone. The second downdrops units of the Ordovician Pogonip Group against the Cambrian Dunderberg Shale and lower plate marble tectonites of the Cambrian Pole Canyon Limestone. The third and eastern fault places Ordovician to Devonian units against the Cambrian Dunderberg Shale. These three faults merge with the NSRD and do not offset it. Miocene and younger conglomerate is involved in this faulting along the southwestern most edge of the quadrangle and south of Hendry's Creek and some of the highly brecciated and shattered portions of the upper plate along the easternmost flank of the range could in part include gravity slide or avalanche deposits. The relationship of the Tertiary deposits to the faulting history in this part of the Snake Range is described in greater detail in the adjacent quadrangle to the west (Grier, 1983; 1984).

The southernmost prong of the great Lake Bonneville occupied northern Spring Valley during the lake's highest stand and was referred to by Gilbert (1890) as "Snake Bay." Deposits related to this lacustrine system, which was in existence about 32,000 to 10,000 years ago (Currey and James, 1982), are developed along the edges and floor of Snake Valley. These include older sand and gravel alluvial deposits reworked by the lake, as well as finer-grained sediments deposited in the lake itself. The highest stand of this lake is believed to have been 16,000 to 15,000 years ago (Currey and Oviatt, 1985); oscillations in the level of the lake left a series of stranded or drowned shorelines characterized by sand and gravelly beach deposits. Locally, V-shaped sand and gravel spits, termed "V-bars," with back-beach lagoons are developed and are believed to have formed by changing wind and current directions.

Correlations of Upper and Lower Plate Rocks

Prior to Cenozoic faulting, Late Proterozoic to Paleozoic strata in The Cove Quadrangle formed part of a regionally extensive sequence of miogeoclinal strata deposited on the subsiding western continental shelf of North America (Gans and Miller, 1983). Formational designations, thicknesses, and regional facies variations have been described by Drewes and Palmer (1957), Whitebread (1969), Hose and Blake (1976), and Stewart (1980), among others (fig. 3)).

In The Cove Quadrangle, Paleozoic rocks in the upper plate of the NSRD are complexly faulted, and most sections are incomplete. Exceptions include the intact section of Ordovician to Devonian strata in the southeasternmost klippe of upper plate rocks in the quadrangle and a fairly intact section of Dunderberg Shale and conformably overlying Notch Peak Formation just to the northwest of this klippe. Similarly, Late Proterozoic and Lower Cambrian rocks in the lower plate of the NSRD are quite deformed and metamorphosed, and their present thicknesses are not representative of their original stratigraphic thicknesses. Description of the less metamorphosed and deformed counterparts of these units in the adjacent southern Snake Range can be found in Misch and Hazzard (1962) and in Miller and others (1993), where the rationale for a somewhat different nomenclature than that used by Misch and Hazzard (1962) is discussed.

At the scale of the northern Snake Range, unit designations and formational names occasionally vary. We have attempted to handle most of these in our legend of map units and stratigraphic column (fig. 3). Specifically, unit designations for Middle Cambrian units vary in different parts of the northern Snake Range so we have further clarified our unit designations and their equivalence in figure 6.

Upper plate, northern part of northern Snake Range	Upper plate, southern part of northern Snake Range
Cn Notch Peak Limestone	
Cd Dunderberg Shale	Cd Dunderberg Shale
Cm Middle Cambrian Limestone (undifferentiated)	Cl Lincoln Peak Formation
	Cpc Pole Canyon Limestone

Lower plate, northern part of northern Snake Range	Lower plate, southern part of northern Snake Range
Cd Dunderberg Shale	top not exposed
Cr Raiff Limestone	Pole Canyon Limestone
Cmn Monte Neva Formation	
Ce Eldorado Limestone	
Cpi Pioche Shale	Cpi Pioche Shale
Cpm Prospect Mountain Quartzite	Cpm Prospect Mountain Quartzite

Figure 6. Stratigraphic nomenclature, unit designations, and correlations for Middle Cambrian upper and lower plate units across the northern Snake Range.

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