Text and references to accompany NBMG Field Studies Map 18

GEOLOGY OF THE SPRING MOUNTAIN QUADRANGLE, NEVADA AND UTAH

by

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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 Spring Mountain Quadrangle is one of twelve 7.5' quadrangles that cover the northern Snake Range. It is located in the extreme northeastern corner of the range (fig. 2). Access into this portion of the range is via various dirt roads and tracks from the north Snake Valley road, a graded road that turns off U.S. Highway 50 in the vicinity of the "Y" and runs northward along the western side of Snake Valley.

The northern Snake Range includes the Mount Moriah Wilderness Area, which was established in 1989, and lies north of the Great Basin National Park. The steep-walled canyons and rugged ridgecrests of the northern Snake Range provide access to The Table, an unusually extensive plateau at 11,000 feet (3,350 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 remain controversial, there is general agreement that these complexes provide excellent exposure of both brittle and ductile structures formed as a result of large-magnitude crustal extension.

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).

GEOLOGIC SETTING AND PREVIOUS WORK

Both the northern and southern Snake Range are underlain primarily by late Precambrian to Permian miogeoclinal shelf strata deposited along the subsiding western continental margin of North America. Miogeoclinal strata in the footwall of the NSRD range in age from late Precambrian 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 schist and marble as metamorphosed equivalents of Precambrian 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 farther 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 for the Snake Range and environs, where uplift and extension in the hinterland 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 down the flanks of the dome.

Hose and Blake (1976) compiled a 1:250,000 scale geologic map of White Pine County which included the first published geologic map of all of the northern Snake Range, based on their reconnaissance mapping. 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 marble 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. Wernicke (1981), in an influential paper on the tectonic significance of detachment faults, cited the Snake Range décollement 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. 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 large amount of strain 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 proposed instead that the NSRD represented a low-angle normal fault or shear zone with 60 km or more displacement that brought lower plate rocks up from a deeper thrust plate in the Sevier belt to the east. In their model, the 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 their proposed model.

Further studies in the northern Snake Range expanded our geologic mapping and used structural and kinematic analyses, seismic reflection profiling, metamorphic petrology, and extensive geochronology and thermochronology in order to help place constraints on 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; Miller and others, 1983; Gans and others, 1985; Geving, 1987; Lee and others, 1987; Miller and others, 1987; Miller and others, 1988; Miller and others, 1989; Gans and others, 1989; Huggins, 1990; Lee, 1990; Lee and Sutter, 1991; Lee, 1995). Our geologic mapping at scales of 1:12,000 and 1:24,000 over a 12-year period (1981-1992) 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 on 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 marble 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 quartzite and metapelite have been intruded and contact metamorphosed by a mid-Jurassic plutonic complex (Miller and others, 1988). 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 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 (Lee, 1990; P. B. Gans, 1992, unpub. data) are preserved. 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. Strain associated with this younger event increases dramatically from west to east across the range. Mesoscopic, microstructural, and petrofabric studies on lower plate rocks were used by Lee and others (1987) to modify the 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 (see also Gans and others, 1985). Structural studies by Gaudemer and Tapponnier (1987) were used to promote a model whereby lower plate deformation occurred entirely by simple shear. The question of simple versus pure shear remains controversial (Lee and others, 1987), as most structural and petrographic observations used to resolve these questions do not yield unique interpretations. 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 been attenuated by at least two

sets of imbricate normal faults whose exact ages remain poorly constrained but are at least in part Eocene(?)-Miocene in age. In the Sacramento Pass area and at the northern end of the northern Snake Range, Tertiary fanglomerate, lacustrine deposits, and volcanic rocks are cut by normal faults that merge along strike with the NSRD, demonstrating a Tertiary age for much if not all of the extensional faulting (Gans and others, 1989). Parts of the upper plate of the NSRD are characterized by a systematic history of east-directed normal faulting that 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. Movement along the NSRD during the time span of upper plate faulting is geometrically required, as none of the upper plate faults actually cut and offset the NSRD. Motion along the NSRD is believed to have been top-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 Upper 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 may have been episodic and occurred during the Eocene to middle Miocene. Multiple diffusion domain analyses of potassium feldspar Arrhenius data and $^{40}Ar/^{39}Ar$ age spectra, and apatite fission-track studies suggest 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 are interpreted to indicate diachronous exhumation of footwall rocks from beneath the NSRD. The spatial 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, and the NSRD along the east flank of the range moved during the early to middle Miocene (Miller and others, 1989, 1990; Lee, 1995). Field relations showing 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 exhumation event (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. The high-strain rocks and mylonites of the lower plate may also represent more than one Tertiary event, but our studies have not been able to demonstrate this. Limiting factors include the resolution of available geochronologic techniques, 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 exhumation of ductile extensional fabrics in the range. More sophisticated studies and modeling of existing data are necessary to fully understand the kinematic history and mechanics of deformation and faulting.

GEOLOGY AND STRUCTURAL HISTORY OF THE SPRING MOUNTAIN QUADRANGLE

The bedrock geology of the Spring Mountain Quadrangle includes isolated remnants, or klippen, of the upper plate of the NSRD and a small portion of the lower plate. These rocks record the polyphase deformational-metamorphic-igneous history typical of rocks elsewhere in the northern Snake Range, which in the upper plate includes at least two generations of normal faults, and in the lower plate includes both Cretaceous and Tertiary metamorphism and ductile deformation. The NSRD dips gently northeastward off this flank of the range along the western edge of the quadrangle and is inferred to lie in the shallow subsurface beneath the remainder of the quadrangle. Much of the quadrangle is underlain by a broad, gently east-dipping pediment surface of Quaternary alluvium (Qol) that slopes down and merges with the highest Lake Bonneville beach terraces (Qbs). This pediment is deeply incised (up to 40 m) by modern drainages (for example, Marble Wash and Swan Creek), reflecting the progressive drop in base level for the Quaternary catchment basin.

Lower Plate Rocks

Middle and Upper Cambrian rocks of the lower plate are exposed at low elevations in the southwestern and western portions of the quadrangle. They include

calcite marble, dolomitic marble, and calc-schist. Metamorphic minerals present include high-Mg biotite + phlogopite + muscovite + quartz + calcite + dolomite ± plagioclase ± tremolite/actinolite ± clinozoisite ± sphene. In the calc-schists, a common assemblage is phlogopite or biotite ± muscovite ± quartz ± clinozoisite ± plagioclase ± calcite. These minerals and the absence of index minerals such as diopside, wollastonite, garnet, and scapolite suggest that the rocks last equilibrated at upper greenschist facies conditions. The age of the peak metamorphism in this area has not been dated directly but is thought to be Late Cretaceous based on U-Pb monazite ages of high-grade pelites farther south in the range (Lee and Fischer, 1985, Huggins and Wright, 1989). Rare sill-like bodies of diorite also occur in the lower plate.

The lower plate units are generally right side up and in correct stratigraphic order but are now intensely deformed tectonite with a predominant gently east-dipping mylonitic foliation and a well-developed east-southeast-trending mineral elongation lineation. The penetrative strain has attenuated the stratigraphic section to a small fraction of its original thickness, such that complete sections of Dunderberg Shale are often only a few meters thick, as opposed to an original stratigraphic thickness of 60 to 100 m. Elsewhere along the eastern flank of the range, complete sections of lower plate units are commonly thinned to about 10% of their original thickness, largely by plastic flow (Miller and others, 1983; Lee and others, 1987). In detail, the character, orientation, and magnitude of lower plate fabrics in this quadrangle are highly variable and complex, a consequence of both heterogeneous strain and a polyphase history. Intraformational folding on scales ranging from centimeters to hundreds of meters is widespread, particularly in lower plate marble. These folds are mainly isoclinal recumbent folds with hinge lines that parallel the mineral elongation lineation, but other orientations and more open varieties also exist. Boudinage of more resistant layers (mafic sills, dolomitic marble, calc-schist) on scales ranging from centimeters to hundreds of meters is spectacularly developed and ubiquitous (Gaudemer and Tapponnier, 1987; Lee, 1990). Stunning examples of such boudinage can be observed on the walls of canyons in the lower plate. Here, low-strain lozenges of dolomitic marble, calc-schist, and diorite are set in a swirly, banded matrix of blue and white calcite marble mylonite. Indeed, much of the complexity to lower plate structural fabrics, including variations in fold geometry and orientation, multiple foliations, and conflicting shear sense indicators, appears to be a direct consequence of the heterogeneous strain and quasi-turbulent flow field around more resistant blocks. For example, shear bands, trains of asymmetric folds, and multiple transposition foliations within the banded marble mylonites are best developed on the flanks of large (10-100 m) lenticular bodies of dolomite and calc-schist and typically verge in opposite directions on either side of the same boudin.

Because the youngest deformation to affect the rocks in this area involves such large strain, any older fabrics (if they existed) have been effectively obliterated. Elsewhere in the northern Snake Range, at least two distinct fabrics are present, an older one associated with peak metamorphism and inferred to be Mesozoic and a younger high-strain, low greenschist facies fabric inferred to be Tertiary (Miller and others, 1983; Lee and others, 1987; Lee and Sutter, 1991). The high strain fabric in the lower plate of this quadrangle presumably correlates with the younger (S_2) fabric elsewhere in the range, as it clearly postdates peak metamorphism (metamorphic minerals are broken and pulled apart, with new growth of chlorite-white mica in pressure shadows) and occurred at temperatures where calcite and quartz were mainly behaving ductilely. However, it should be emphasized that the absolute age(s) of the high strain deformation remains poorly constrained. Miller and others (1983) inferred it to be largely Oligocene and synchronous with extensional faulting in the upper plate, which at the time was also thought to be mainly Oligocene (Gans and Miller, 1983). Lee and Sutter (1991) carried out an $^{40}Ar/^{39}Ar$ study of the lower plate and also concluded that the mylonitic deformation was largely Oligocene on the basis of approximately 37-Ma ages on rhyolite porphyry dikes that appeared to predate the deformation and 24 to 25 Ma ages of metamorphic micas interpreted to reflect post-deformational cooling of the lower plate. More recently, calculated thermal histories, based on multiple diffusion domain analyses of potassium feldspar $^{40}Ar/^{39}Ar$ age spectra, showed that lower plate rocks along the western part of the range did not drop below 300°C until 34 Ma, whereas lower plate rocks along the eastern flank did not drop below 300°C until 20 Ma (Lee, 1995). These results led Lee (1995) to conclude that 37-Ma undeformed rhyolite porphyry dikes along the western flank of the range postdated mylonitic deformation and that mylonitic deformation along the eastern flank was pre-20 Ma. However, given all of the uncertainties (for example, correlation of fabrics and temperatures during deformation) the only firm minimum and maximum age brackets are provided by the age of peak metamorphism (latest Cretaceous) and the final cooling and exhumation of the lower plate at about 20 to 15 Ma (Miller and others, 1990; Lee, 1995).

Upper Plate Rocks

Isolated hills and ridges of unmetamorphosed Middle Cambrian to Pennsylvanian sedimentary rocks and Tertiary volcanic rocks occur in the Spring Mountain Quadrangle as inselbergs that stand above the older alluvium pediment surface. These rocks are known or inferred to lie in the upper plate of the NSRD, as they sit above the subsurface projection of this fault and

exhibit the typical structural style of upper plate rocks elsewhere in the range. The upper plate units are all highly faulted and tilted by normal faults with a wide range of present day orientations. The faults portrayed on the geologic map are simply the larger and/or more clear-cut of these faults. In reality, there are many more faults, and they occur at scales ranging from centimeters to kilometers. The internal structure of the Middle Cambrian rocks is particularly oversimplified because these units are so thick and monotonous and lack distinctive marker beds that might allow refinement of the finer scale structure.

Upper plate rocks are exposed in the northwestern, northeastern, and southwestern corners of the quadrangle. In the northwestern area, Middle Cambrian to Ordovician units are in direct contact with lower plate rocks along the NSRD and form the southern tip of a bedrock ridge that is continuous northward with the eastern Kern Mountains. These rocks dip mainly to the west and are cut by older, gently west-dipping faults and younger, moderate- to high-angle, east-dipping normal faults. Stratigraphic throw on the mapped faults ranges from several hundred meters to more than a kilometer. A small exposure of hornblende dacite (Td) in this area appears to be a subvolcanic intrusion, but it is not clear whether it is in fault contact with the Middle Cambrian rocks or intrudes them. Farther north, similar hornblende dacite bodies have been dated at about 35 Ma and appear to postdate many of the upper plate faults but are cut by the NSRD (Gans and others, 1989).

Spring Mountain (also called Gandy Peak) is underlain by Middle Cambrian to Lower Ordovician units that dip primarily to the east and are cut by four moderate-displacement normal faults, two older ones that dip gently northeastward at a small angle to bedding and omit minor amounts of section, and two younger ones that dip westward at high angles to bedding. The significance of the reversal from westward bedding dips in the west to eastward dips on the eastern side of the quadrangle is not clear. The eastern dips may persist in the subsurface across Snake Valley and become the east-dipping limb of the Confusion synclinorium of Hose (1977), or it may be a more local phenomenon. Across-strike dip reversals of this sort have been observed elsewhere in the Snake Range and often occur abruptly across a high-angle fault that approximately parallels bedding in the footwall but is at high angles to bedding in the hanging wall. The simplest explanation for this geometry is that the faults are cutting previously folded units, despite the fact that we have not been able to identify hinge regions for folds of this scale in the upper plate.

Poorly exposed Upper Devonian, Mississippian, and Pennsylvanian rocks, as well as minor amounts of Tertiary volcanic and sedimentary rocks, are exposed in the low hills just off the eastern flank of the range at the southern end of the quadrangle. These rocks are brecciated and pervasively faulted on a small scale; bedding attitudes are erratic though mainly west-dipping; and contacts between different units are either obscured or demonstrably faulted. It is not clear whether the Tertiary dacite in this area is a subvolcanic intrusion or lava flow and whether the contacts are intrusive, stratigraphic, or faulted. Rare exposures of gently tilted conglomerate and marl that are probably Miocene age occur in some of the more deeply incised washes beneath the Quaternary pediment surface. It is possible that this entire mass of Paleozoic and Tertiary rocks represents some sort of composite slide block into the now tilted Miocene sedimentary rocks. Such relations have been convincingly documented in the Sacramento Pass region to the south (Grier, 1983, 1984) and must be considered when dealing with apparent "bedrock" that is not in clear structural continuity with the main part of the range.

The broad, gently east-dipping pediment surface defined by the older alluvium is probably Pleistocene and developed before or during the last glaciation, as this surface slopes down to and is reworked by the highest Lake Bonneville beach terrace and back-beach lagoons. The deep incision of this pediment surface by the modern drainages is probably not a consequence of tectonic or fault-related uplift of the Snake Range, but rather reflects the progressive shrinking of Lake Bonneville and lowering of base level to the modern Snake Valley playa lake. Spring Mountain gets its name from a "warm" spring at the southern tip of the mountain. Water from the spring averages about 65 to 70°F—delightful on a hot day but somewhat uncomfortable as a late evening soak. The spring emerges from a series of caves in the Middle Cambrian limestone near its contact with older alluvium. Based on its temperature, it is probably not fed by a deeply circulating or fault-controlled hydrothermal system. Instead, shallow groundwater that drains the broad low area between the northern Snake Range and Kern Mountains apparently flows at or near the base of the older alluvium toward Snake Valley and is forced to the surface by the natural bedrock barrier of Spring Mountain.

Correlation of Upper and Lower Plate Rocks

Prior to Cenozoic faulting, Paleozoic strata in the Spring Mountain 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. In the Spring Mountain Quadrangle, Paleozoic rocks in the upper plate of the NSRD are complexly faulted and most sections are incomplete (fig. 3). Similarly, Middle and Upper 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. The lower plate units and their correlation are described in greater detail by Lee (1990).

At the scale of the northern Snake Range, unit descriptions and formational names are not always consistent, because of real geographic variations in the stratigraphy. We have attempted to handle most of these in our legend of map units and stratigraphic column (fig. 3). Specifically, unit descriptions for the 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 5.

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Figure 5. Stratigraphic nomenclature, unit designations, and correlations for Middle Cambrian upper and lower plate units across the northern Snake Range.

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