Large-scale Geologic Mapping in Great Basin National Park, Nevada

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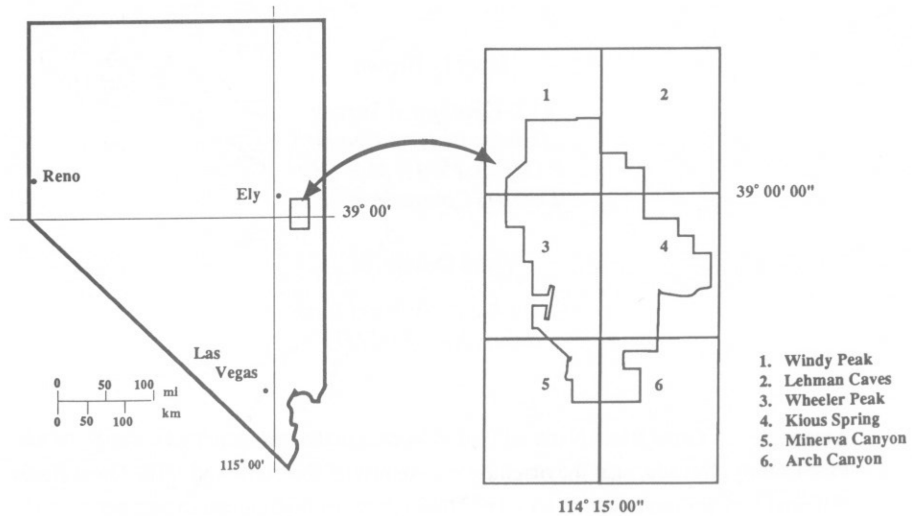
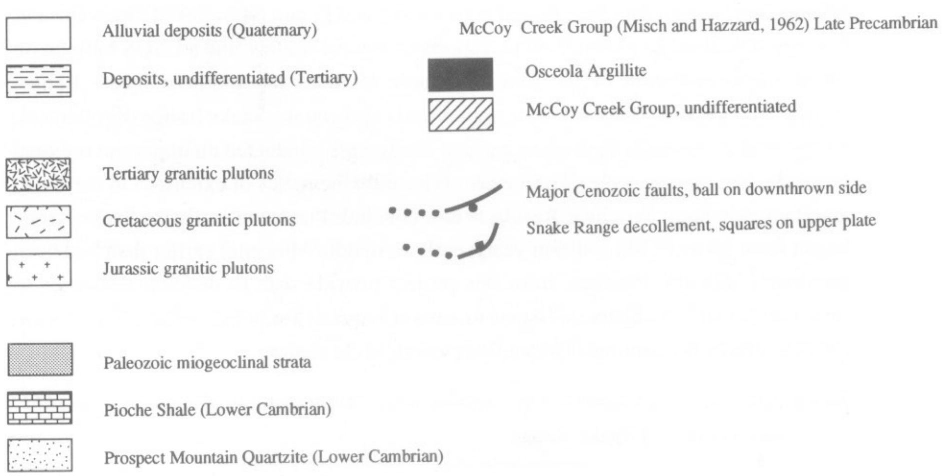
Abstract. Great Basin National Park is located in the southern Snake Range, White Pine County, Nevada, near the ranching community of Baker, Nevada. The Great Basin National Park project began in June 1992 through an interagency agreement between the U.S. Geological Survey (USGS) and the National Park Service (NPS) and was completed in March 1995. The project delivers large-scale geologic maps of the park, a Geographic Information System data base shared between the USGS and NPS, USGS Open-file and Geologic Quadrangle geologic maps, reports on topical studies, and a USGS bulletin on the geologic evolution of the park. The park includes the southern Snake Range, recognized as a metamorphic core complex and exposing the Snake Range decollement, a large-scale, low-angle fault plane surface. Studies are conducted on important regional problems like the age, time of initiation, style, and kinematics of extension in the Basin and Range Geologic Province. Results to date conclude that extension in the Snake Range began from 20 to 15 Ma (million years; early to middle Miocene) earlier than had been previously thought. Products from this project provide data to develop responses to preservation and management issues, to answer requests for public information, and to provide a basis for continued scientific research in the region.

Key words: Extension tectonics, geographic information systems, Snake Range decollement, southern Snake Range.

Great Basin National Park (GBNP) in east-central Nevada is in the southern Snake Range, White Pine County, part of the northern Basin and Range Geologic Province (Figure). The park headquarters and the entrance to the





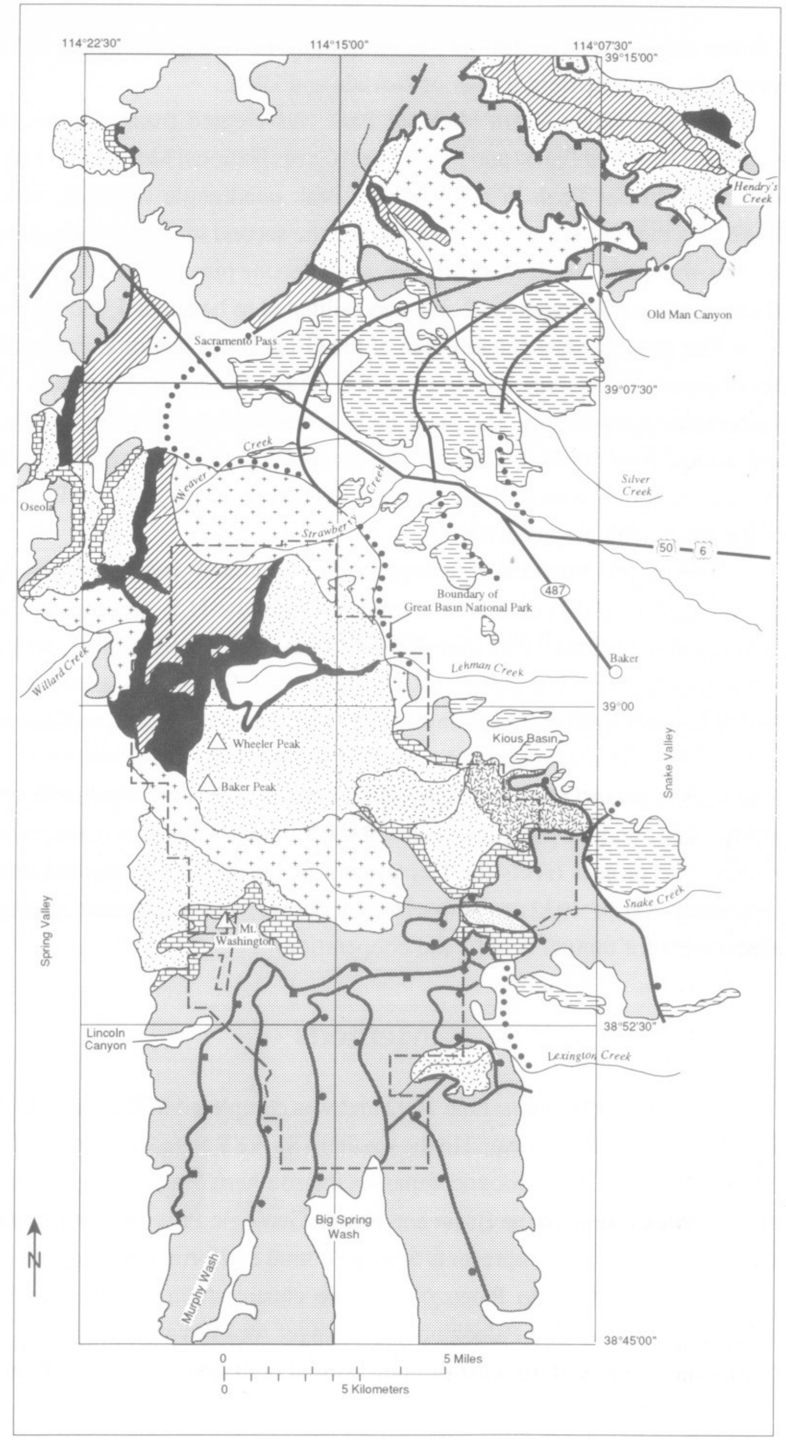


Figure. Generalized geologic map of the central Snake Range, Nevada. Map emphasizes the distribution of variably metamorphosed upper Precambrian and Cambrian miogeoclinal strata and the various plutons that intrude these rocks. Geologic map modified after Miller et al. (1988). Small index map shows boundary of Great Basin National Park and the six 7.5′ topographic quadrangles encompassing the park.

Lehman Caves are located about 8 km west of the ranching community of Baker, Nevada, near the eastern border of Nevada and Utah.

In 1986, Great Basin National Park was created from portions of the Humboldt National Forest and the Lehman Caves National Monument. The park includes Wheeler Peak in the Wheeler Peak quadrangle (Figure), which at 3,982 m is the highest peak in the park and the second highest peak in Nevada. In 1964, the world's oldest known tree, a bristlecone pine (*Pinus longaeva*), was discovered near Wheeler Peak and was estimated to be about 4,950 years old.

The general management plan of the Great Basin National Park calls for development in several locations in the Kious Spring and Lehman Caves topographic quadrangles. The plans include a new visitor's center, parking lot, and access road located south of the present location and require geologic evaluation before construction. Therefore, current, large-scale geologic maps of the entire park are needed.

The project provides a geologic survey of GBNP and a Geologic Information System (GIS) data base shared between the U.S. Geological Survey (USGS) and National Park Service (NPS) as well as with local, state, and national data users. The project also provides USGS Open-file geologic maps, formal USGS Geologic Quadrangle (GQ) maps, topical studies, and associated reports. The GIS data set provides a powerful and cost-effective tool to develop responses to preservation and management issues, to answer requests for public information, and to provide a basis for continued scientific research in the region. The project meets the Department of the Interior's national mandate (Economy Act of 1932) to authorize, encourage, and implement interagency agreements for mutual benefit and cooperation.

Methods

The project began in June 1992 and was completed in March 1995. Great Basin National Park is located in the southern Snake Range, White Pine County, Nevada (Figure). The park encompasses the southern Snake Range, a structurally complex region in the Basin and Range Geologic Province. In general, the southern Snake Range represents a gentle domal antiform, uplifting and exposing late Precambrian to Paleozoic marine clastic strata that are themselves complexly faulted. The Paleozoic and younger rocks overlie the Snake Range decollement, a low angle, east-dipping normal fault system on the eastern flank

of the range. The uplifted strata are variably metamorphosed and intruded by plutons of Jurassic, Cretaceous, and Tertiary age. The Lehman Caves are developed in the Middle Cambrian Pole Canyon Limestone. The modern landscape was further sculpted by Pleistocene glaciations, and the most dramatic glacial features in the central Great Basin are preserved on the north flank of Wheeler Peak.

Because no large-scale geologic mapping of the study site existed, new mapping was needed in the area. The park includes six large-scale (1:24,000) topographic quadrangles: Windy Peak, Lehman Caves, Wheeler Peak, Kious Spring, Minerva Canyon, and Arch Canyon. J. L. Brown served as project chief—functions included collaboration with Park Service personnel, management of schedules and products for mapping and topical studies, and coordination and production of GIS products.

The first summer field season (1992) involved geologic mapping and field examination in three quadrangles: Windy Peak, Lehman Caves, and Kious Spring. The second summer field season (1993) involved geologic mapping and field examination in Arch Canyon and Wheeler Peak quadrangles. The final summer field season (1994) involved mapping in Minerva Canyon and Arch Canyon.

The quadrangles are prioritized according to complexity. Published and unpublished geologic data are compiled onto registered stable base greenline topographic mylars. The greenlines are required base material for further map publishing processes and digitizing. Digital elevation models of the topography were acquired for the six quadrangles at 1:24,000 scale. New data were compiled from recent aerial photography of the park using the Kern computerized photogrammetric mapper (PG-2). The compilations served as working drafts for the actual on-the-ground field work and were finalized after field mapping was completed. The field work follows standard geologic field mapping methods as described in Compton (1962). The geologic map is first published as an author-prepared, black and white, USGS Open-file Map and Report, which is quickly available to the NPS and the geologic community. The final product is a full-color USGS GQ map. All six quadrangles in Great Basin National Park will be published in the GQ format.

Ten samples for age dates were collected from selected plutons and flows and were analyzed by fission track and 40 Ar/39 Ar methods in laboratories at Stanford University and at the University of California at Santa Barbara. Fission track dating methods determine the age of a rock from microscopic paths of radiation damage caused by uranium fission. Dating methods (40 Ar/39 Ar) determine the age of a rock from the known radioactive decay rates of argon isotopes.

Clear film blackline copies of the completed geologic greenlines are scanned on a Textronix drum scanner and the data converted into ARC INFO coverage. The ARC INFO coverage is edited to eliminate errors and other features attributed with elevations. A triangulated irregular network (TIN) is created to facilitate edge mapping and mosaicking of the six completed quadrangles into a geologic map of the whole park.

Study Site

The southern Snake Range, as part of the Basin and Range Geologic Province, represents the transition between the unextended Confusion Range structural block to the east and the more highly extended region encompassing the Snake, Schell Creek, and Egan ranges to the west (Gans and Miller 1983; Dumitru et al. 1993; Miller et al. 1993). The Snake Range decollement (Drewes and Palmer 1957; Misch and Hazzard 1962; Whitebread 1969; McGrew 1993) is exposed in the park and is recognized as a large-scale, low-angle, fault plane surface. In addition, the central portion of the southern Snake Range is recognized as a metamorphic core complex from mineralogical and microstructural fabric in the rocks (Misch and Hazzard 1962; Miller et al. 1989). Controversy abounds about the direction of movement (compressional or extensional) on the Snake Range decollement (Coward et al. 1987; Lee et al. 1987; McGrew 1993) and on the origin of metamorphic core complexes in general (Crittenden et al. 1980; Armstrong 1982; Coney and Harms 1984).

Following the development of plate tectonic theory and Atwater's (1970) reconstruction of the evolution of western North America using plate tectonic motion, most geologists have interpreted Basin and Range Geologic Province evolution within the context of plate tectonics. Subduction along the continental margin during the time of the Sevier orogeny (middle Cretaceous) in Nevada caused compression, eastward thrusting, and overthickening of the crust along a narrow welt bordering the eastern edge of the miogeocline. In Nevada, the location of the overthickened crustal welt approximated the Nevada–Utah state line and later became the locus for the development of metamorphic core complexes. The core complexes are unique mid-Tertiary features that represent

rare glimpses of continental crustal rocks that have been deformed and metamorphosed by stretching, extension, doming, and denudation. Structural and metamorphic relics of both the compressional and extensional phases of core complexes are preserved but are not easily interpreted.

The Snake Range decollement and its associated metamorphic core complex, together with recent seismic reflection profiles, suggest a regional crustal extension model at mid-Tertiary time (Wernicke 1981; Miller et al. 1983; Bartley and Wernicke 1984; McGrew 1993). In addition, extension in the eastern Basin and Range Geologic Province was preceded by a flux of magmatism into the crust and then was followed by low-angle, core-complex-style (extension) faulting (Gans et al. 1989). In the study area, extension began in the early Oligocene and resulted in approximately 95 km of west-northwest and east-southeast directed crustal stretching (Gans and Miller 1983). Because extension terrains appear to be compartmentalized and alternated with areas of much less deformation along the welt, they are not related in a simple way to plate-boundary forces. Therefore, the ultimate cause and regional tectonic setting of the park remains poorly understood.

The southern Snake Range is underlain by upper Precambrian to Triassic (540 to 240 Ma [million years ago]) sandstones, shales, and carbonates with cumulative thicknesses possibly greater than 15 km. They form part of a shallow-marine, miogeoclinal sequence deposited on the subsiding margin of North America. In the park, this sequence is represented by the Late Proterozoic and Lower Cambrian Prospect Mountain quartzite (Hague 1892), the Lower and Middle Cambrian pioche shale (Walcott 1908), and the Middle Cambrian Pole Canyon Limestone (Misch and Hazzard 1962). Spectacular exposures of the miogeoclinal strata are seen in the head wall of the Wheeler Peak cirque and at the north face of Mount Washington. Formational designations, thicknesses, and regional facies variations have been described by Drewes and Palmer (1957), Whitebread (1969), Hose and Blake (1976), and Stewart (1980). This sequence was intruded by granitic to dioritic plutons during Jurassic (160–155 Ma), mid-Cretaceous (110–90 Ma), and Late Cretaceous (90–70 Ma) time (Miller et al. 1983, 1988, 1990; Lee et al. 1986). The intrusion of the plutons caused deformation and metamorphism of the shallow marine shelf sequence.

The most recent faulting in the area took place about 12 to 5 Ma ago (late Miocene) and served to block out the mountains and flat valleys (horst and graben structure) distinctive of today's Basin and Range Geologic Province topography. Examples of tilt blocks formed from faulting and tilting of the northern and southern Snake Range and the Sacramento Pass strata (Grier 1983, 1984) during the late Miocene are visible looking north from the Wheeler Peak park road. Modern landforms such as fault bounded escarpments, triangular facets on mountain spurs, linear mountain fronts of high relief, and narrow V-shaped valleys suggest continuing active vertical uplift in the park in response to ongoing Basin and Range Geologic Province mountain-building (Dohrenwend 1987).

Results

Six geologic maps were prepared and digitized: Lehman Caves, Windy Peak, Kious Spring, Garrison, Wheeler Peak, and Minerva Canyon. The Lehman Caves quadrangle was published as USGS Open-file report 93-209 (Brown 1993) and is also available as a USGS Geologic Quadrangle (GQ-1758; Brown 1994a). Windy Peak was published as USGS Open-file report 94-687 (Brown 1994b); Kious Spring and Garrison quadrangles were published as USGS Open-file report 95-010 (Brown 1995). Mapping in Arch Canyon, Wheeler Peak, and Minerva Canyon quadrangles was completed in summer 1994. Because of the structural complexity, mapping of Arch Canyon and Minerva Canyon was the most challenging part of the project. The Great Basin National Park research project has resulted in other papers and abstracts (Brown et al. 1993; Dumitru et al. 1993; McGrew 1993; Miller et al. 1993).

Through GIS applications, we have produced colored geologic maps and three-dimensional, aerial perspective maps of the south Snake Range showing the geologic formations draped over the topography. These posters are on display at Stanford University, at the Visitor's Center of Great Basin National Park, and at the USGS National Center in Reston, Virginia. The digitized geologic maps are archived with the USGS National Mapping geologic data base and with the Nevada Bureau of Mines and Geology in Reno.

Discussion

Our purpose is to provide basic geologic mapping, GIS data sets, and results of geologic research to the newly established Great Basin National Park in the southern Snake Range, Nevada. The results help NPS develop responses to preservation and management issues and provide a basis for continued

scientific research in the region. In addition, published products that interpret research allow visitors to explore the value of parks as laboratories for natural resource studies.

We provide new data on the late Precambrian and Paleozoic depositional history of the region; illustrate the Mesozoic and Cenozoic structural, metamorphic, and intrusive history of rocks in the southern Snake Range; and detail the geometry and history of the fault systems that evolved during the formation of the southern Snake Range. Previous mapping provided information on stratigraphic succession, regional extents, and correlations of specific units at a small scale. Because much of the early mapping was done before the dissemination of modern petrologic concepts, structural and geochemical analyses and details of the correlation, ages, and compositions of geologic units were not well known.

Mapping objectives included providing greater detail on certain critical geologic relations, exploration for additional structures, and relating local fundamental deformational features to a regional scheme. This included determination of amounts of extension in the southern Snake Range; time of emplacement, composition, and source of plutons; nature and timing of movement on the Snake Range decollement; and interpreting the ultimate cause of thrusting.

Results of new apatite fission track dates from our study, supplemented by other information, point to significant extension and uplift from 20 to 15 Ma (early to middle Miocene) in the southern Snake Range, which was earlier than previously thought (Dumitru et al. 1993). New age dates are anticipated from the analyses of 10 samples collected in summer 1992 in the southern two quadrangles (Arch Canyon and Minerva Canyon) and will provide more detail on the timing of this extension event.

Previous work on the intrusive rocks in the southern Snake Range revealed three types of distinctive granitoids clustered in a small area, an association different from the rest of the Great Basin (Lee et al. 1986). Three of these plutons (Willard Creek, Osceola, and Snake Creek–Williams Canyon) are oldest (Middle Jurassic) and are derived from the deepest source. Two plutons (Pole Canyon–Young Canyon and Lexington Creek) are Late Cretaceous in age and are derived from shallower depth. The youngest pluton (Young Canyon–Kious Basin) is 37 Ma in age (Eocene) and is emplaced at the shallowest depth. Latest movement on the southern Snake Range decollement is believed to be younger than Eocene because the Young Canyon–Kious Basin and Lexington plutons were affected. In addition, pluton emplacement migrated from northwest to southeast, and migration was accompanied by shallowing of the magmatic source. A conclusion drawn from our studies to date shows that recent movement on the southern Snake Range decollement is extensional and was initiated after middle Miocene time.

Unsettled problems of Basin and Range Geologic Province extension include determining driving mechanisms of low-angle faulting; relating extension with plate-boundary forces; evaluating the role of magmatic intrusion as a possible driving mechanism for extension; understanding isostatic rebound, doming, and flattening of the footwalls of normal faults; evaluating the location, amount, and timing of extension; determining the significance of the flat mantle–crustal boundary (Moho) beneath basins and ranges; and detailing the significance of the association of decollement surfaces with metamorphic core complexes.

Acknowledgments

The 1992 collaboration between the U.S. Geological Survey and the National Park Service resulted in large-scale geologic mapping in Great Basin National Park. The research was funded by the National Park Service through an interagency agreement with the U.S. Geological Survey. We thank A. J. Hendricks and park staff for their expertise and support.

We thank participants of the field camp of Stanford University for preliminary geologic mapping supported by NSF grants from 1981 to 1986 in the Windy Peak and Lehman Caves quadrangles in the southern Snake Range.

Cited Literature

Armstrong, R. L. 1982. Cordilleran metamorphic core complexes—from Arizona to southern Canada. Annual Review of Earth and Planetary Sciences 10:129–154.

Atwater, T. 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. Geological Society of America Bulletin 81:3513–3536.

Bartley, J. M., and B. P. Wernicke. 1984. The Snake Range decollement interpreted as a major extensional shear zone. Tectonics 3:647–657.

Brown, J. L., compiler. 1993. Geologic map of Lehman Caves quadrangle, White Pine County, Nevada, by E. L. Miller and S. P. Grier. U.S. Geological Survey Open-file Report 93-209:14.

Brown, J. L., compiler. 1994. Geologic map of Lehman Caves quadrangle, White Pine County, Nevada, by E. L. Miller and S. P. Grier. U.S. Geological Survey Geologic Quadrangle Map GQ-1758. 14. 1 map, scale 1:24,000.

Brown, J. L., compiler. 1994. Geologic map of Windy Peak quadrangle, White Pine County, Nevada, by E. L. Miller, P. B. Gans, and S. P. Grier. U.S. Geological Survey Open-file report 94-687:30. 1 map, scale 1:24,000.

Brown, J. L., compiler. 1995. Geologic map of Kious Spring and Garrison quadrangles, White Pine County, Nevada, and Millard County, Utah, by A. J. McGrew and E. L. Miller. U.S. Geological Survey Open-file report 95-10:32. 2 maps, scale 1:24,000.

Brown, J. L., E. L. Miller, D. M. Miller, M. P. Crane, and P. T. McCarthy. 1993. Geographic information systems, mapping, and geology in Great Basin National Park, Nevada: cooperative interagency research. Geological Society of America Pacific Coast and Rocky Mountain Section Abstracts with Programs 25:14.

Compton, R. R. 1962. Manual of field geology. John Wiley & Sons, New York. 378 pp.

Coney, P. J., and T. A. Harms. 1984. Cordilleran metamorphic core complexes; Cenozoic extensional relics of Mesozoic compression. Geology 12:550–554.

Coward, M. P., J. F. Dewey, and P. L. Handcock, editors. 1987. Continental extensional tectonics. Geological Society of London Special Publication 28. 637 pp.

Crittenden, M. D., Jr., P. J. Coney, and G. H. Davis, editors. 1980. Cordilleran metamorphic core complexes. Geological Society of America Memoir 153. 490 pp.

Davis, G. H., and P. J. Coney. 1979. Geologic development of the Cordilleran metamorphic core complexes. Geology 7:120–124.

Dohrenwend, J. C. 1987. Basin and Range Geologic Province. Pages 303–342 *in* W. L. Graf, editor. Geomorphic systems of North America. Geological Society of America, Centennial Special 2:303–342.

Drewes, H., and A. R. Palmer. 1957. Cambrian rocks of the southern Snake Range, Nevada. American Association of Petroleum Geologists Bulletin 41:104–120.

Dumitru, T. A., E. L. Miller, and C. Savage. 1993. Fission track evidence for widespread early to middle Miocene extension in the northern Basin and Range Geologic Province. Geological Society of America Abstracts with Programs 25:33.

Gans, P. B., G. A. Mahood, and E. Schermer. 1989. Synextensional magmatism in the Basin and Range Province; a case study from the eastern Great Basin. Geological Society of America Special Paper 233. 53 pp.

Gans, P. B., and E. L. Miller. 1983. Style of mid-Tertiary extension in east-central Nevada. Pages 107–160 *in* K. D. Gurgel, editor. Geologic excursions in the overthrust belt and metamorphic core complexes of the intermountain region, Nevada. Utah Geological and Mineral Survey Special Studies 59, Geological Society of America Field Trip Guidebook 1. Utah Geological Survey, Salt Lake City.

Grier, S. P. 1983. Tertiary stratigraphy and geologic history of the Sacramento Pass area. Pages 139–144 *in* K. D. Gurgel, editor. Geologic excursions in the overthrust belt and metamorphic core complexes of the intermountain region, Nevada. Utah Geological and Mineral Survey Special Studies 59, Geological Society of America Field Trip Guidebook 1. Utah Geological Survey, Salt Lake City.

Grier, S. P. 1984. Alluvial fan and lacustrine carbonate deposits in the Snake Range—a study of Tertiary sedimentation and associated tectonism. M.S. thesis, Stanford University, Stanford, Calif. 61 pp.

Hague, A. 1892. Geology of the Eureka district, Nevada. U.S. Geological Survey Monograph 20. 419 pp.

Hose, R. K., and M. C. Blake, Jr. 1976. Geology and mineral resources of White Pine County, Nevada—Part 1. Geology. Nevada Bureau of Mines and Geology Bulletin 85:1–35.

Lee, D. E., R. W. Kistler, and A. C. Robinson. 1986. The strontium isotope composition of granitoid rocks of the southern Snake Range, Nevada. U.S. Geological Survey Bulletin 1622:171–179.

Lee, J., E. L. Miller, and J. F. Sutter. 1987. Ductile strain and metamorphism in an extensional tectonic setting: a case study from the northern Snake Range, Nevada, USA. Pages 267–298 *in* M. P. Coward, J. F. Dewey, and P. L. Hancock, editors. Continental extensional tectonics. Geological Society of London Special Publication 28:267–298.

McGrew, A. J. 1993. The origin and evolution of the southern Snake Range decollement, east central Nevada. Tectonics 12:21–34.

Miller, E. L., P. B. Gans, R. W. Brown, and T. A. Dumitru. 1993. Apatite fission track evidence for Miocene extensional faulting, east-central Nevada, Northern Basin and Range Province. Geological Society of America Abstracts with Programs 25:121–122.

Miller, E. L., P. B. Gans, and J. Garing. 1983. The Snake Range decollement—an exhumed mid-Tertiary ductile–brittle transition. Tectonics 2:239–263.

Miller, E. L., P. B. Gans, and A. J. W. Gleadow. 1989. Uplift history of the Snake Range metamorphic core complex, Basin and Range Geologic Province, U.S.A., from apatite fission track data. EOS 70:1309.

Miller, E. L., P. B. Gans, J. Lee, and R. W. Brown. 1990. Geochronologic studies bearing on the origin and evolution of mylonites beneath normal fault systems, Basin and Range Geologic Province: Seventh International Conference on Geochronology, Cosmochronology and Isotope Geology, Canberra, Australia. Geological Society of Australia Abstracts 37.

Miller, E. L., P. B. Gans, J. E. Wright, and J. F. Sutter. 1988. Metamorphic history of the east-central basin and range province—tectonic setting and relationship to magmatism. Pages 650–682 *in* W. G. Ernst, editor. Metamorphism and crustal evolution of the western United States. Prentice-Hall, Englewood Cliffs, N.J.

Misch, P., and J. C. Hazzard. 1962. Stratigraphy and metamorphism of late Precambrian rocks in central northeastern Nevada and adjacent Utah. American Association of Petroleum Geologists Bulletin 46:289–343.

Stewart, J. H. 1980. Geology of Nevada—a discussion to accompany the geologic map of Nevada. Nevada Bureau of Mines and Geology Special Publication 4. 136 pp.

Walcott, C. D. 1908. Nomenclature of some Cambrian Cordilleran formations. Smithsonian Miscellaneous Collections 53:1–12.

Wernicke, B. 1981. Low-angle normal faults in the Basin and Range Province: nappe tectonics in an extending orogen. Nature 291:645–647.

Whitebread, D. H. 1969. Geologic map of the Wheeler Peak and Garrison quadrangles, Nevada and Utah. U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-578. 1 sheet, scale 1:48,000.