Text and references to accompany Nevada Bureau of Mines and Geology Map 129

GEOLOGY OF THE LIME MOUNTAIN QUADRANGLE

LINCOLN COUNTY, NEVADA

by

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STRUCTURAL GEOLOGY

The Lime Mountain Quadrangle lies within an area of considerable structural complexity resulting from two contrasting deformation regimes, the earlier resulted from regional contraction, which was followed much later by regional extension (fig. 1, on plate). Flat-lying, mostly marine Paleozoic and Mesozoic strata were first folded and thrust southeastward 80 to 100 million years ago in late Cretaceous time as part of the Sevier orogenic contractional episode that produced thrusts in a belt that extends from southern Nevada to western Wyoming. These contractional structures were overprinted by major extensional structures beginning in this area about 24 million years ago in late Oligocene or early Miocene time (Carpenter and others, 1989; Bohannon and others, 1993; Carpenter and Carpenter, 1994). Regional extension caused the development of high-angle and low-angle normal faults, many with large displacement. The high-angle fault with the largest displacement is the Virgin-Beaver Dam Mountains fault that bounds the east side of the Mesquite deep basin. Basin subsidence attracted deposition of the Horse Spring and Muddy Creek clastics and provided low terrain toward which detached slide blocks migrated. The Castle Cliff detachments are conspicuous examples, but the down-to-the-south faults in the Dodge Spring Quadrangle (figs. 1 and 2) may also be evidence of extensional movement towards the basins that developed at that time.

Gravity observations (Blank and Kucks, 1989) show the Mesquite deep basin (fig. 1) with one of the largest negative gravity anomalies in southern Nevada confirming seismic and drilling data that show it filled with low-gravity sediments (Carpenter and Carpenter, 1994). On the west side of cross section B–B' (fig. 1) the Tule Desert basin has only small gravity relief because low-gravity valley-filling sediments are only a thin cover over higher gravity consolidated Tertiary volcanic and Paleozoic-Mesozoic sedimentary rocks. The Tule Springs Hills and Jumbled Mountain represent an east-tilted horst (Tschanz and Pampeyan, 1970) bounded by the East Tule Desert fault and the East Tule Springs Hills and Gourd Spring faults.

Structures Within the Lime Mountain Quadrangle

Tule Springs Hills Thrust

Axen's (1991, 1993) maps show a remarkably constant relationship between the overthrust Cambrian Bonanza King Formation and parautochthonous Jurassic Kayenta Formation as exposed in the southern part of the quadrangle for 5 miles (8 km) between Jones Spring Point and Middle Pond. A few slivers of Permian Kaibab-Toroweap and Triassic Moenkopi-Chinle are sandwiched between the overriding Cambrian and the parautochthonous Kayenta Formation. This sandwich relationship is shown in several other localities in the quadrangle and was first noted by Olmore (1971) on maps of adjacent quadrangles.

Axen (1991, 1993) interpreted that the many small to moderate displacement normal faults (generally <1 km normal separation) that cut the Paleozoic strata of the allochthon, as well as the roughly bedding-parallel attenuation faults that cut out significant sections of strata locally, were produced by Neogene reactivation of the Mesozoic thrust surface as a low-angle normal fault. He based this, among other arguments, on (1) the local involvement in this normal faulting of Ts at many sites in the allochthon, and (2) the fact that these normal faults cut the Neogene Mormon Peak detachment in the western Tule Springs Hills (Axen and others, 1990; Axen 1991, 1993).

Axen (1991) also mapped duplex faults within the allochthon in the Tule Springs Hills where part of the Cambrian Bonanza King Formation is imbricately repeated. Axen's (1991) cross section through the area is given in reduced and simplified form as our section D–D'. Dips on our geologic map indicate an anticline, here called the Jones Spring anticline, whose axis is shown on the map and cross section D–D'. Most normal faults on the west limb of the anticline are down-to-the-east, and most on the east limb are down-to-the-west, suggesting collapse of the anticline during extension. Axen (1991) identified several locations where he interpreted Tertiary sediments and/or

volcanic rocks to be found beneath older strata. None of his critical localities lies within the Lime Mountain Quadrangle. Some of Axen's localities in the adjacent Tule Spring Quadrangle were examined by the senior author who concluded that, because of alluvial/colluvial cover, structural relationships at some locations were uncertain, and in other locations the relationships seen could be explained by local gravity sliding of older rocks over younger. Given the steep topography and the regional history of basin-range faulting, tremors of which continue to occur today, the likelihood of downsliding of fault-riddled Paleozoic rocks over a substrate of Mesozoic strata and, locally, Tertiary of variable coherence, must be considerable in this area. Anders and others (1998) concluded that gravity sliding was the mechanism that produced large slide blocks in the nearby central Mormon Mountains and at Sheephorn Knoll in the Beaver Dam Mountains. Anderson and Barnhard (1993) also disagreed with Axen's interpretation.

Carpenter and others (1989) and Carpenter and Carpenter (1994) have shown that the paleogeography during Tertiary development of the Mesquite Deep Basin (fig. 1) precludes widespread activation of a single Tertiary extensional glide plane on the same surface as the older Tule Springs Hills thrust.

Lime Mountain Thrust

Exposure of the Lime Mountain thrust can be walked its entire distance around the upper flanks of Lime Mountain where it dips gently eastward (cross section A–A') and places Cambrian Bonanza King Formation on Mississippian Monte Cristo Limestone. Tertiary normal faults drop the allochthon down on the southeast flank of Lime Mountain where Ordovician, Silurian, and Devonian strata make up part of the overthrust rocks.

The Lime Mountain thrust is unique in that it is the only place in the quadrangle where overthrust rocks rest on a unit as old as Mississippian. The Lime Mountain block is a horst, bounded on north, east, and west sides by high-angle normal faults of large displacement. Relationships at the south end of Lime Mountain are covered by alluvium which probably conceals additional faults.

The Cambrian-on-Mississippian structural relationship of Lime Mountain is particularly significant considering that it appears directly adjacent to the more usual Cambrian-on-Mesozoic relationship in the southeastern part of the Jacks Mountain Quadrangle (figs. 1 and 2), and most other places in the area shown on figure 1. The Cambrian-over-Mississippian thrust relation is similar to that mapped by Wernicke (Wernicke and others, 1985) in the Mormon Mountains about 24 miles (39 km) southwest of Lime Mountain. If the thrusting was directed to the southeast, Lime Mountain lies approximately along the strike of the ramp on which the thrust moved to the higher level (Cambrian-over-Jurassic) shown over most of the rest of the Lime Mountain Quadrangle. Some southeastward strike-slip faulting of the rocks now exposed in the Lime Mountain block would be required to juxtapose the two different thrust relationships in the same quadrangle. Another unique thrust relationship in the area is seen in the Motoqua Quadrangle (figs. 1 and 2), where the Square Top Mountain thrust places Permian strata across folded Mesozoic strata (Hintze and others, 1994).

Joshua and Related Faults

The Joshua fault, which cuts east-southeast for 3 miles (4.8 km) through the central part of the quadrangle, is believed to be representative of other faults of similar trend and character. All appear to be vertical, or nearly so, and some, like the Joshua fault, juxtapose strata of differing attitudes. Although we have not found slickensides or other minor features to support our interpretation, we believe that the Joshua and related faults are primarily strike-slip faults.

In section 35, T8½S,R70E, the block of rocks on the northeast side of the S35 strike-slip fault carried lower Miocene volcanic and sedimentary rocks southeastward. The volcanic rocks appear to rest uncomformably on the underlying lower Paleozoic strata and both moved together on the block. Strike-slip transport on the S35 fault occurred sometime after 22 Ma, the age of the Harmony Hills Tuff, the youngest dated rock involved.

A sliver of upper Paleozoic carbonate lies in the S35 fault zone in a relationship similar to exotic blocks along strike-slip fault zones in other places on this quadrangle, most conspicuously in section 3, T9S,R70E.

U.S. Geological Survey geologist R.E. Anderson's unpublished map of the Jacks Mountain 7.5-minute Quadrangle, from which the reduced simplification on figure 1 was derived, shows three southeast-striking faults northwest of Lime Mountain. The middle one shown on figure 1, which might properly be called a tear fault because it offsets the main thrust fault, could have first moved in Late Cretaceous time, but the parallel fault just north of it appears to offset Tertiary volcanic rocks and be of an age similar to the S35 and Joshua faults.

It is intriguing to speculate that the entire Lime Mountain fault block may have been transported in Tertiary time some distance from the northwest. As mentioned above, under the discussion of the Lime Mountain thrust, the Cambrian-over-Mississippian thrust relationship is typical of exposures some miles to the west.

Tectonic Melanges

Units Jkm, Pkt, and O€m are mixtures of breccia and broken fragments of formations, pieces of which are too small to be shown separately at the 1:24,000 scale. Unit Jkm is a melange of upper autochthon units; unit Pkt is a mixture of upper Paleozoic units that lie structurally above the Mesozoic units of the autochthon, and structurally beneath lower Paleozoic units of the allochthon; unit O€m is a melange of units of the overthrust plate. Coherence ranges from complete recementation in carbonate units, to little reconsolidation in sandstone and siltstone units. The melanges are believed to have formed in association with Late Cretaceous thrust faulting, possibly modified by late Tertiary high- or low-angle extensional faulting.

In section 35, T8½S,R70E., and adjoining section 2, T9S, R70E. a large area labeled PIPb? shares some structural characteristics with other melange units. Its internal structure is much less chaotic than most, but it is a block that lies above a melange of Jkm and beneath an overthrust sheet of Cambrian carbonate. It is a large mass of upper Paleozoic strata transported between the main sheet of Cambrian rocks over a disrupted terrane of parautochthonous Mesozoic rocks. The PIPb? mass is, itself, parautochthonous as are similar upper Paleozoic fragments elsewhere on the maps.

Structure of Tertiary Volcanic and Sedimentary Rocks

Unit QTab covers the valley areas so completely that outcrops of units Tb, Ts, and Tmc are limited to only a few locations in this quadrangle. The largest exposures of Tb protrude above QTab in the east-central part of the map. In the stream washes that cut through the largest Tb outcrop a few feet of weakly cemented alluvium can be seen beneath the basalt. These cut-bank exposures are too small to show on the geologic map. Hill 4438, located 1.1 miles (1.8 km) northwest of Lime Mountain, is capped with the basalt which there overlies the red tuff, Trt, which has an age of about 13.9 Ma. Both the red tuff and the basalt are probably in their original site of deposition and rest on an older thrust melange. Tb is thus young enough to be about the same age as the Muddy Creek Formation. Tentative faults are shown cutting unit Tb southwest of Lime Mountain. They were drawn in order to explain the scattered Tb exposures which are believed to represent a single flow. Pervasive alluvial cover from weathering of unit QTab precluded actually tracing the faults across that unit.

The reason for mapping the Muddy Creek Formation, Tmc, separately from unit Ts is that Tmc exposures in this quadrangle generally have low dips whereas Ts is purposely titled "Alluvial sediment with steep dips," and is older than Tmc. The most extensive exposures of unit Ts is along the east-central quadrangle boundary where Ts overlies Miocene volcanic rocks that dip northeastward 50°–60° degrees. Axen (1991) mapped a small area of Ts in section 24, T9S,R70E, near the southeast corner of the quadrangle. Ts there also overlies Miocene volcanic rocks and both are shown as downdropped on normal faults into surrounding Paleozoic strata.

ACKNOWLEDGMENTS

The only previously published geologic map of the area covered by this quadrangle was by Tschanz and Pampeyan (1970) whose 1:250,000-scale map of Lincoln County only hinted at the complexities therein. Olmore (1971) pioneered 1:24,000-scale mapping in the nearby Mormon Mountains area and was followed by Axen's (1991) 1:12,000-scale mapping that included the southern quarter of the Lime Mountain Quadrangle where much-faulted allochthonous Paleozoic strata override Mesozoic strata.

Students in Brigham Young University Geology Department's field course roughed out the geology of the Lime Mountain Quadrangle in May 1986 under the direction of L.F. Hintze and graduate field assistant Becky Hammond. Hintze spent one or two weeks in each of the next eight years mapping the complex geology of the quadrangle on color aerial photographs during the course of which he consulted with R. Ernest Anderson and Myron G. Best regarding the identification of the variably altered volcanic rocks in the quadrangle. Gary Axen was particularly helpful in directing Hintze to the best places in the Tule Springs Hills to become familiar with his Paleozoic map units. In reducing Axen's (1991) 1:12,000-scale mapping to the 1:24,000 scale of our Lime Mountain Quadrangle map it was necessary to combine some of Axen's subdivisions of lower Paleozoic units and to eliminate some of his strikes and dips. In addition, Hintze remapped the upper Paleozoic and Mesozoic units along the north edge of Axen's map to better join with Hintze's mapping north of the overlap area. No major changes were necessary, only minor adjustments of contact and fault positions.

The text, map legend, cross sections, and other illustrations were completed by Hintze in August 1998 and submitted to the Nevada Bureau of Mines and Geology. Reviews of this material by Larry Garside, Christopher Henry, R. Ernest Anderson, and James and Daniel Carpenter resulted in the improved version presented herewith. A helpful field review in the quadrangle area was conducted in October 1999 by Christopher Henry of the Nevada Bureau of Mines and Geology and Peter Rowley of the U.S. Geological Survey. Myron G. Best examined critical exposures of volcanic rock in the quadrangle in March 2000 and made useful field observations and identifications.

We are grateful to all of the geologists mentioned above who have contributed to better understanding of this complex area. Because geologists who have published on structural aspects of the Mormon Mountains–Tule Springs Hills area have not reached a consensus on the identity and relative importance of its Mesozoic contractional and Cenozoic extensional structures, readers will recognize that the senior author is biased in interpreting Mesozoic contractional thrusting to have moved sheets of allochthonous Paleozoic strata distances measured in tens of kilometers, and interpreting that subsequent late Cenozoic extension resulted chiefly in block faulting and gravity gliding with maximum local horizontal displacement measured in a few kilometers at most. Cumulative extension across the large basin-range by this mechanism may have amounted to tens of kilometers but not as a coherent shallow sheet.

We thank the reviewers of this map and text and hope that they will find their suggestions fairly represented. Except for Axen's mapping, the senior author is responsible for the mapping and written interpretation of the geology of this quadrangle.

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