U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE MINE MOUNTAIN AREA, NEVADA TEST SITE, SOUTHERN NEVADA

By

James C. Cole and Patricia H. Cashman

Open-File Report 97-697

Prepared in cooperation with the
Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-96NV11967)

1997

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Company names are for descriptive purposes only and do not constitute endorsement by the U.S. Geological Survey

GEOLOGIC MAP OF THE MINE MOUNTAIN AREA, NEVADA TEST SITE, SOUTHERN NEVADA

By

James C. Cole and Patricia H. Cashman

TABLE OF CONTENTS

Abstract 1

Introduction 1

Stratigraphic notes 2

Foreland-vergent structure 3

Hinterland-vergent structure 4

Extensional normal faults 5

Acknowledgments 5

References cited 6

ILLUSTRATIONS

Figure 1.-- Sketch map of pre-Tertiary rocks in the Yucca Flat region .... [on plate 1]

Plate 1.-- Geologic map of the Mine Mountain area, Nevada Test Site, southern Nevada .... [in pocket]

ABSTRACT

The Mine Mountain area is a small range of hills on the west side of the central Yucca Flat basin on the Nevada Test Site, Nye County, Nevada. This map portrays the very complex relationships among the pre-Tertiary stratigraphic units of the region. Rocks and structures of the Mine Mountain area record the compounded effects of: 1) eastward-directed, foreland-vergent thrusting; 2) younger folds and thrusts formed by hinterland vergence in a general westerly direction; and 3) low-angle normal faulting formed by extension along a northeast-southwest trend. All of these structures are older than the oldest middle Miocene volcanic rocks that were deposited on the flanks of the Mine Mountain terrane. High-angle faults that post-date these volcanic rocks locally show displacements of several hundred meters, but do not strongly affect patterns in the pre-Tertiary rocks.

INTRODUCTION

The low range of hills in west-central Yucca Flat known as Mine Mountain exposes a significant structure designated the Mine Mountain thrust. This fault is most conspicuous in the northern Mine Mountain area where, as viewed from Yucca Flat on the east, it is marked by a prominent subhorizontal contact between red-brown clastic rocks of the Eleana Formation and overlying light gray carbonate rocks of the Sevy and Laketown Dolomites. Johnson and Hibbard (1957) recognized the stratigraphic inversion represented by Devonian strata on top of Mississippian clastic rocks, and interpreted the Mine Mountain thrust fault as part of a zone of east-vergent thrusts noted in several localities along the western margin of the Yucca Flat basin (fig. 1).

More detailed geologic mapping by Orkild (1963, 1968) supported the same interpretation that the Devonian carbonates were emplaced toward the east, as summarized in Barnes and others (1963) and Barnes and Poole (1968). Carr (1974, 1984) interpreted the Mine Mountain structure as a folded relic of the east-vergent thrust system to account for his evidence that still-older rocks lay eastward of the Mine Mountain area in the subsurface of Yucca Flat. Robinson (1985) concluded that thrusting was relatively minor, based on a regional analysis of patterns in the pre-Tertiary rocks, and that most of the structural relations could be explained by broad folding followed by displacement of fragments of fold limbs by low-angle extensional normal faults. Caskey's study of the CP Hills south of Mine Mountain (fig. 1; Caskey and Schweickert, 1992) confirmed the inference of McKeown and others (1976) that the principal thrusting there was toward the west, rather than toward the east. Caskey emphasized that the major overturning in the footwall Pennsylvanian strata indicated significant contractional strain.

Our initial mapping, along with reconnaissance work by Guth (1981, 1990) and detailed fault-kinematic studies by M.R. Hudson (Hudson and Cole, 1993; Cole and others, 1989, 1994) showed that extension on low-angle normal faults was a significant part of the overall strain signature in the pre-Tertiary rocks of the Mine Mountain area. The nature and scope of the earlier thrusting was indecipherable, however, until detailed biostratigraphic analyses and sedimentological study showed that the middle Paleozoic rocks in this area belonged to different facies assemblages and could not all have been emplaced in the same thrust sheet from a single direction (Trexler and others, 1996; Cole and Cashman, 1997). Additional field work and detailed analyses of small-scale folds and bed-facing directions, documented in this map, show that the complex relations at Mine Mountain result from the combined effects of major foreland-vergent deformation related to the Belted Range thrust, and substantial folding and faulting due to later hinterland-vergent contraction in the CP thrust system (fig. 1; Cole and Cashman, 1997). The extensional normal faulting, although undeniably present, does not appear to have a significant effect on the present-day locations of major tectonic pieces of the Mine Mountain puzzle.

Detailed stratigraphic documentation, regional paleogeographic analysis, and stratigraphic synthesis are contained in Trexler and others (1996) and Trexler and Cashman (1997) and summarized in Cole and others (1994). The structural context of the Mine Mountain area is shown schematically in fig. 1. Discussion of the regional structural interpretation and evidence for timing and direction of emplacement of principal thrust plates is contained in Cole and Cashman (1997) and in Cole and others (1997) and Cole (1997).

The excavations for which Mine Mountain is named consist of four shallow shafts and four adits that explore parallel silicified sheared zones in quartzites in the Devonian carbonate rocks (Cornwall, 1972; Quade and others, 1983). Barite, quartz, and very minor sulfide minerals are noted in the dumps. Microprobe analyses and assays indicate the presence of lead, silver, zinc, antimony, arsenic, and mercury (Quade and others, 1983). A well preserved mercury retort sits on the northeast slope of the Mine Mountain ridge next to the road, but there is on record of mercury production from this area (Quade and others, 1983).

STRATIGRAPHIC NOTES

The Eleana Formation at Mine Mountain differs from other documented sections in the region by being consistently finer grained and by having a younger base (Trexler and others, 1996). The underlying Guilmette Formation is also anomalous in the region because it is thin and because it contains thick quartzite beds in its upper part that show internal brecciation, which we interpret was formed by collapse into karst sinkholes (Trexler and others, 1996). Evidence for a similar history of non-deposition and karst dissolution is even better displayed along strike to the southwest at Shoshone Mountain (fig. 1). Limestone beds in the lower 25 m of the Eleana at both Mine Mountain and Shoshone Mountain contain late Kinderhookian to early Osagean conodonts. These data indicate deposition began in these localities about 10 m.y. later than in the type section of the Eleana north of Yucca Flat (fig. 1; Trexler and others, 1996). The biostratigraphic data also confirm that the Guilmette-Eleana contact southeast of Mine Mountain Pass is largely stratigraphic and not a thrust, as previously mapped by Johnson and Hibbard (1957) and by Orkild (1968). The unusually thin Guilmette is attributed to non-deposition or erosion coincident with the karst formation (Trexler and others, 1996).

Clastic rocks in the head of Slick Draw consist of uniform, dark green-brown and red-brown shale, along with sparse folded and dismembered beds of bioclastic limestone, impure quartzite, and a few beds of chert-granule conglomerate. Outcrop is poor, but bedding attitudes and stratigraphic facing directions suggest that this lithic assemblage lies conformably on top of Eleana unit Mei, which crops out west of the head of the Draw. We show this unit as Chainman Shale based on its distinctive association of shale, quartzite, and bioclastic limestone (Trexler and others, 1996). If correct, our interpretation would indicate the Chainman lithotype was deposited over the Eleana lithotype in this area (shown in cross- section A-A'), whereas the two units are time-equivalent but mutually exclusive in all other southern Nevada localities (Trexler and others, 1996). The presence of chert-lithic conglomerate, typical of Eleana clastic source-areas, in this Slick Draw section may indicate local co-mingling of sources during late Chesterian time. Due to the extreme structural complications in this area, however, we cannot preclude the possibility that the Chainman in Slick Draw was emplaced from the east during hinterland-vergent thrusting as a tectonic slice derived from the pre-existing Chainman footwall of a foreland-vergent Belted Range thrust element beneath the Eleana (see cross-section A-A').

FORELAND-VERGENT STRUCTURE

The principal evidence for foreland-vergent thrusting is implied by map relations indicated in fig. 1 and by regional stratigraphic arguments. The Eleana Formation at Mine Mountain was originally deposited west of the Chainman Shale preserved in the Syncline Ridge area (Trexler and others, 1996). Its present location east and south of the Syncline Ridge area requires east-vergent emplacement. Drill hole UE-1m, located on the northeast flank of Mine Mountain north of the 1-6C jeep trail, penetrated about 177 ft of steeply-dipping Eleana before entering 337 ft of flat-lying Chainman Shale (Cole and others, 1997). We interpret these relations to indicate UE-1m penetrated an east-vergent thrust in the subsurface (cross section A-A'). The broad arch of the Mine Mountain anticline and the diffuse anticline in the Eleana near UE-1m are both thought to have formed during east-vergent deformation (along with the Syncline Ridge fold), but both folds have been modified by younger deformation. As a result, bedding does not statistically define asymmetric fold limbs or an inclined hinge surface that would clarify the vergence direction during folding.

Small-scale folds and overturned beds in Eleana unit Mei south and west of Slick Draw indicate eastward vergence. These structures may be subsidiary folds on the east limb of the Mine Mountain anticline, or they may have formed during emplacement of a higher thrust plate. The slab of Sevy and Laketown Dolomite between Slick Draw and Gray Hill may be a relic of such a plate. Bedding in the dolomites generally dips westward, as does the fault contact with Eleana on the east, and this is the geometry that is displayed by foreland-vergent thrust-duplex blocks farther north in the Eleana Range (fig. 1; Cole and Cashman, 1997). This interpretation is illustrated in cross-section A-A'.

HINTERLAND-VERGENT STRUCTURE

The eastern side of the Mine Mountain area exhibits numerous thrust faults and folds at various scales that all record the effects of hinterland-vergent deformation, which is generally toward the west and northwest in this part of the Nevada Test Site. This deformation regionally overprints the foreland-vergent structures of the Belted Range thrust system and is referred to as the CP thrust system. Several CP-thrust plates and overturned folds are stacked up along Eureka Ridge, and both South and North Knobs and the area from Four Quad Hill to Slick Draw expose hinterland-vergent thrust plates (fig. 1).

Westward-vergent folding is also well displayed along the Guilmette-Eleana contact parallel to the Mine Mountain crest, at several locations within the Eleana Formation (for example, along Red Ridge), and beneath the dolomite breccia in upper Slick Draw. We believe, however, that these structures are within thrust plates that were originally emplaced toward the east over the Chainman Shale, and thus lie in the footwall of the CP thrust system.

The structure of Eureka Ridge is displayed in cross-section C-C'. Three thin thrust plates each carry overturned folds toward the northwest over progressively younger units. The combined effect of these slices is to distribute the total stratigraphic offset between the Cambrian Nopah Formation and the Mississippian Eleana Formation into imbricate thrust sheets. At the west end of the ridge, all structural elements bend toward the south and progressively verge toward the west. This change of trend is interpreted to have formed concurrent with folding and thrusting and is consistent with the irregular and local nature of the CP thrust structures on a regional basis (Cole and Cashman, 1997).

South Knob largely consists of an overturned flap of the Devonian carbonate section that was emplaced generally westward over the Mississippian Eleana Formation, as illustrated in cross-section B-B'. The direction of overturning in this upper plate, and in the footwall Eleana, shows that this flap is a very local feature because it verges toward the northwest, toward the west, toward the southwest, and toward the south along its lateral margins. These geometric characteristics (similar to glacial or extrusive flow forms) suggest the South Knob flap was extruded upward and outward toward the west and that it flattened and spread over the Eleana wherever resistance was least. A similar structural style is inferred north of the Mine Mountain Road at North Knob and Four Quad Hill from the arcuate trends of bedding and overturning directions in the Devonian carbonates, but the leading edges of these local thrust plates have been displaced by a younger high-angle fault.

Chainman Shale in the upper part of Slick Draw contains beds of bioclastic limestone and chert-granule conglomerate that are overturned toward the west, as indicated by inverted graded beds. We interpret these relations to indicate the overlying dolomites, which were originally emplaced toward the east as part of the Belted Range thrusting, have been displaced westward by a younger CP thrust that propagated through the older thrust stack (shown in cross-section A-A').

EXTENSIONAL NORMAL FAULTS

Dolomites and quartzites in structural blocks above the Eleana Formation locally preserve small-scale kinematic features on fractures that consistently indicate the latest slip occurred under dilational stress conditions (Cole and others, 1989; Hudson and Cole, 1993). The extension direction determined from numerous fault-slip measurements at each of 25 widely scattered localities is N55E-S55W, regardless of the dip direction of the local fault surface between Eleana and the overlying thrust plate (Hudson and Cole, 1993; figs. 6 and 7 in Cole and others, 1994). For example, the exceptionally well preserved imbricate, mullioned fault surfaces in Slick Draw have small-scale slip-sense indicators that reflect top-to-the-northeast displacement on east-dipping surfaces. In contrast, two measurement sites along the easternmost trace of the Mine Mountain thrust, located less than one km to the east, consistently show top-to-the-southwest displacements on the west-dipping thrust (Cole and others, 1994). Thus, these results from opposite sides of a local-scale dolomite thrust plate both show extension along the same trend but in opposite senses, leading to the conclusion that the dolomite was extended "in place" over the Eleana (Hudson and Cole, 1993; Cole and others, 1994, p. 73). Stated alternatively, the Eleana may have been extended (extruded) outward from beneath the overlying dolomite plate.

The results of these fault kinematic studies are based on measurements from the Mine Mountain thrust trace, from Eureka Ridge, from South Knob, from Slick Draw, from Breccia Ridge, and from several localities along the Mine Mountain crest. In several localities, it appears the extensional slip has cut down into the lower-plate Eleana because overturned folds in Eleana limestone (formed during thrusting) are beheaded or absent along parts of the Eleana-dolomite thrust contact. These observations formed the basis for conclusions stated by Cole and others (1989) that most of the low-angle faults between Paleozoic rock units in the Mine Mountain area were extensional normal faults, even though they recognized that prior thrusting must have occurred to produce the original stratigraphic inversion of units. The regional stratigraphic framework, and the biostratigraphic control on various units, had not been established at that time, and those conclusions were made in ignorance of the extent of overturned section and the importance of hinterland-vergent structures in the Mine Mountain area.

The broad picture of structure in the Mine Mountain area documented by this map, and the supporting studies, shows that the foreland- and hinterland-vergent thrusting are the major factors in the distribution of rock units. Extension is clearly recorded by the detailed fault-slip indicators, but the amount of slip does not appear to have translated major blocks of rock to significantly different positions.

ACKNOWLEDGMENTS

This map was prepared in cooperation with the U.S. Department of Energy under interagency agreement DE-AI08-96NV11967 and predecessor agreements. This work was conducted in support of DOE's nuclear-weapons testing program and the environmental restoration program to improve understanding of the structural and stratigraphic relations in the pre-Tertiary rocks of the Yucca Flat area.

The authors gratefully acknowledge the assistance lent by prior mapping in this area (Orkild, 1963, 1968; McKeown and others, 1976) and by unpublished reconnaissance mapping done by P.L. Guth at the start of this project. Details of the complex structure in the Mine Mountain area could only be worked out after sufficient biostratigraphic work had been completed. This additional work shows that the Eleana Formation here is markedly different from the Eleana elsewhere, and must have been tectonically transported to the Mine Mountain area from its place of origin. Biostratigraphic work by A. Harris, B. Skipp, A. Titus, G. Webster, M. Kurka, and others was essential to completing this map, as was our collaboration on the regional stratigraphic and paleoenvironmental analysis with J. Trexler (Trexler and others, 1996). Detailed fault-slip analysis by M. Hudson was critical to understanding the kinematics of fault movements in the Mine Mountain area and to evaluating the effects of extensional normal faulting in this area (Cole and others, 1989; Hudson and Cole, 1993).

REFERENCES CITED

Barnes, Harley, Hinrichs, E.N., McKeown, F.A., and Orkild, P.P., 1963, U.S. Geological Survey investigations of Yucca Flat, Nevada Test Site, Part A - Geology of the Yucca Flat area: U.S. Geological Survey Technical Letter NTS-45, Part A, 196 p.

Barnes, Harley, and Poole, F.G., 1968, Regional thrust-fault system in Nevada Test Site and vicinity, in Eckel, E.B., ed., Nevada Test Site: Geological Society of America Memoir 110, p. 233-238.

Byers, F.M., Jr., Barnes, Harley, Poole, F.G., and Ross, R.J., Jr., 1961, Revised subdivision of Ordovician System at the Nevada Test Site and vicinity, Nevada: U.S. Geological Survey Professional Paper 424-C, p. C106-C110.

Carr, W.J., 1974, Summary of tectonic and structural evidence for stress orientation at the Nevada Test Site: U.S. Geological Survey Open-File Report 74-176, 53 p.

Carr, W.J., 1984, Regional structural setting of Yucca Mountain, southwestern Nevada, and late Cenozoic rates of tectonic activity in part of the southwestern Great Basin, Nevada and California: U.S. Geological Survey Open-File Report 84-854, 109 p.

Caskey, S.J., and Schweickert, R.A., 1992, Mesozoic deformation in the Nevada Test Site and vicinity: implications for the structural framework of the Cordilleran fold and thrust belt and Tertiary extension north of Las Vegas Valley: Tectonics, vol. 11, p. 1314-1331.

Cole, J.C., 1997, Major structural controls on the distribution of pre-Tertiary rocks, Nevada Test Site vicinity, Nye County, Nevada: U.S. Geological Survey Open-File Report 97-533, 16 p., scale 1:100,000.

Cole, J.C., and Cashman, P.H., [in press 1998], Structural relationships of pre-Tertiary rocks in the Nevada Test Site region, southern Nevada: U.S. Geological Survey Professional Paper 1607, 40 proof p.

Cole, J.C., Harris, A.G., and Wahl, R.R., 1997, Sub-crop geologic map of pre-Tertiary rocks in the Yucca Flat and northern Frenchman Flat areas, Nevada Test Site, southern Nevada: U.S. Geological Survey Open-File Report 97-678, 24 p., scale 1:48,000.

Cole, J.C., Trexler, J.H., Jr., Cashman, P.H., and Hudson, M.R., 1994, Structural and stratigraphic relations of Mississippian rocks at the Nevada Test Site, in McGill, S.F., and Ross, T.M., eds., Geological Investigations of an Active Margin: Geological Society of America Cordilleran Section guidebook, San Bernardino, California, 1994, p. 66-75.

Cole, J.C., Wahl, R.R., and Hudson, M.R., 1989, Structural relations within the Paleozoic basement of the Mine Mountain block; implications for interpretations of gravity data in Yucca Flat, Nevada Test Site: Proceedings from Fifth Symposium on Containment of Underground Nuclear Explosions, Santa Barbara, California, Lawrence Livermore National Laboratory, CONF-8909163, vol. 2, p. 431-456.

Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 47 p.

Guth, P.L., 1981, Tertiary extension north of the Las Vegas Valley shear zone, Sheep and Desert Ranges, Clark County, Nevada: Geological Society of America Bulletin, vol. 92, p. 763-771.

Guth, P.L., 1990, Superposed Mesozoic and Cenozoic deformation, Indian Springs quadrangle, southern Nevada, in Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Boulder, Colorado, Geological Society of America Memoir 176, p. 237-249.

Hudson, M.R., and Cole, J.C., 1993, Kinematics of faulting in the Mine Mountain area of southern Nevada: Evidence for pre-middle Miocene extension: Geological Society of America Abstracts with Programs, vol. 25, no. 5, p. 55.

Hurtubise, D.O., and du Bray, E.A., 1992, Stratigraphy and structure of the Seaman Range and Fox Mountain, Lincoln and Nye Counties, Nevada: U.S. Geological Survey Bulletin 1988-B, p. B1-B31.

Johnson, J.G., Sandberg, C.A., and Poole, F.G., 1989, Early and Middle Devonian paleogeography of western United States, in McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World: Calgary, Canadian Society of Petroleum Geologists, Memoir 14, Volume 1, Regional Syntheses, p. 161-182.

Johnson, M.S., and Hibbard, D.E., 1957, Geology of the Atomic Energy Commission Nevada Proving Grounds area, Nevada; U.S. Geological Survey Bulletin 1021-K, p. K333-K384.

McKeown, F.A., Healey, D.L., and Miller, C.H., 1976, Geology of the Yucca Lake quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1327, scale 1:24,000.

Orkild, P.P., 1963, Geologic map of the Tippipah Spring quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-213, scale 1:24,000.

Orkild, P.P., 1968, Geologic map of the Mine Mountain quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-746, scale 1:24,000.

Poole, F.G., Houser, F.N., and Orkild, P.P., 1961, Eleana formation of Nevada Test Site and vicinity, Nye County, Nevada: U.S. Geological Survey Professional Paper 424-D, p. D104-D111.

Quade, Jack, Tingley, J.V., Bentz, J.L., and Smith, P.L., 1983, A mineral inventory of the Nevada Test Site and portions of Nellis Bombing and Gunnery Range, southern Nye County, Nevada: Nevada Bureau of Mines and Geology administrative report prepared for DOE Nevada Operations Office under contract DE-AS08-82NV10295, 65 p.

Robinson, G.D., 1985, Structure of pre-Cenozoic rocks in the vicinity of Yucca Mountain, Nye County, Nevada -- a potential nuclear-waste disposal site: U.S. Geological Survey Bulletin 1647, 22 p.

Trexler, J.H., Jr., and Cashman, P.H., 1997, A southern Antler foredeep submarine fan: the Mississippian Eleana Formation, Nevada Test Site: Journal of Sedimentary Research, vol. 67, no. 6, p. 1044-1059.

Trexler, J.H., Jr., Cole, J.C., and Cashman, P.H., 1996, Middle Devonian through Mississippian stratigraphy on and near the Nevada Test Site; implications for hydrocarbon potential: American Association of Petroleum Geologists Bulletin, vol. 80, p. 1736-1762.

Wahl, R.R., Sawyer, D.A., Carr, M.D., Minor, S.M., Cole, J.C., Swadley, WC, Laczniak, R.J., Warren, R.G., Green, K.S., and Engle, C.M., 1997, Digital geologic map database of the Nevada Test Site area, Nevada: U.S. Geological Survey Open-File Report 97-140, scale 1:100,000.

Warme, J.E., and Sandberg, C.A., 1996, Alamo megabreccia: Record of a Late Devonian impact in southern Nevada: GSA Today, vol. 6, no. 1, p. 1-7.