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GEOLOGIC MAP OF PALEOZOIC ROCKS IN THE CALICO HILLS, NEVADA TEST SITE, SOUTHERN NEVADA

By

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ABSTRACT

The Calico Hills area in the southwestern part of the Nevada Test Site, Nye County, Nevada, exposes a core of pre-Tertiary rocks surrounded by middle Miocene volcanic strata. This map portrays the very complex relationships among the pre-Tertiary stratigraphic units of the region. The Devonian and Mississippian rocks of the Calico Hills are distinct from age-equivalent carbonate-shelf or submarine-fan strata in other parts of the Nevada Test Site. The Calico Hills strata are interpreted to have been deposited beyond the continental shelf edge from alternating silicic and carbonate clastic sources.

Structures of the Calico Hills area record the compounded effects of: 1) eastward-directed, foreland-vergent thrusting; 2) younger folds, kink zones, and thrusts formed by hinterland-vergent deformation toward northwesterly and northerly directions; and 3) low-angle normal faults that displaced blocks of Middle Paleozoic carbonate strata across the contractionally deformed terrane. All of these structures are older than any of the middle Miocene volcanic rocks that were erupted across the Calico Hills.

INTRODUCTION

Brightly colored, altered middle Miocene volcanic rocks exposed in the highland north of Jackass Flats (fig. 1) are the namesake for the Calico Hills in the southwestern Nevada Test Site. Bedding in these volcanic rocks defines an elliptical half-dome that is presumed to have formed during late Miocene intrusion and uplift of the dome core (Maldonado and others, 1979). Subsequent erosion through the volcanic cover has exposed Devonian and Mississippian strata that are the focus of this report. The central Calico Hills, covering a little more than 12 sq. km, show detailed features of a stratigraphic sequence that is unique in the Nevada Test Site area, and display extremely complicated structures formed during several stages of contractional and extensional deformation. The Calico Hills area contains some of the best evidence for the style and timing of major deformational events in this part of southern Nevada.

The first detailed geologic mapping in this area was completed by McKay and Williams (1964) in the southern Calico Hills, and by Orkild and O'Connor (1970) in the northern Calico Hills. These mappers recognized that the mixed carbonate and siliciclastic strata exposed here, identified as Devonian and Mississippian from limited macrofossil data, were distinct from more typical southern Nevada sections exposed farther east and south and did not correlate them with other Nevada Test Site area units. Dominantly shaley units in the eastern Calico Hills were correlated by McKay and Williams (1964) with the upper part of the Mississippian Eleana Formation (Poole and others, 1961) on the basis of lithologic similarities. Orkild and O'Connor (1970) extended the correlation with the Eleana Formation to more diverse sandstone-siltstone units and to bedded chert and argillite that crop out in the northern Calico Hills. In both early maps, all contacts between the dominantly carbonate units and the dominantly siliciclastic units were portrayed as faults.

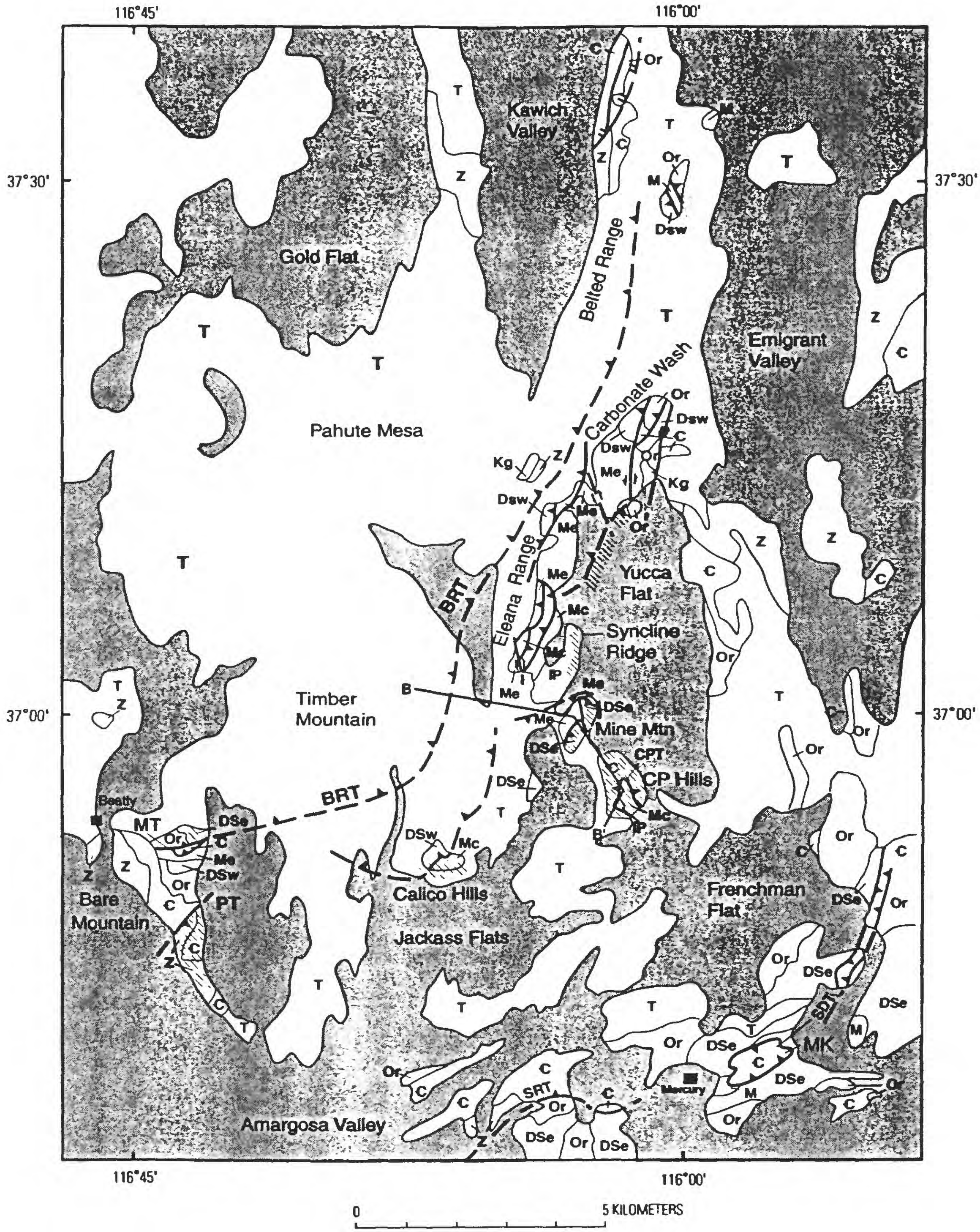


Figure 1.-- Sketch map of pre-Tertiary rocks in the Nevada Test Site region showing location of the Calico Hills area in relation to major contractional structures: BRT = Belted Range thrust; MT = Meiklejohn thrust; PT = Panama thrust; SDT = Spotted Range thrust; SRT = Specter Range thrust. Locations: BM = Bare Mountain; CPH = CP Hills; ER = Eleana Range. Map symbols: T = Tertiary rocks; Kg = Cretaceous granite; IP = Pennsylvanian; Mc = Mississippian Chainman Shale; Me = Mississippian Eleana Formation; M = other Mississippian rocks; DSe = eastern-facies Devonian and Silurian; DSw = western-facies Devonian and Silurian; Or = Ordovician; C = Cambrian; Z = Late Proterozoic; diagonal-rule pattern shows areas of hinterland-vergent deformation (from Cole and Cashman, 1997b).

Simonds and Scott (written commun., 1994) remapped parts of the Calico Hills area to examine the Tertiary history of faulting and hydrothermal alteration. They studied the Tertiary-Paleozoic contact in particular to evaluate whether it was a tectonic element of an hypothesized regional low-angle extensional fault complex (Scott, 1990). They did not resolve the stratigraphic nomenclature or correlation of the Devonian and Mississippian rocks between the Calico Hills and other localities, but did recognize several distinctive units within the carbonate section and mapped their distribution at 1:12,000-scale. Simonds and Scott (written commun., 1994) concluded that the Tertiary-Paleozoic contact is an erosional unconformity marked by a widespread gravel conglomerate deposit, and that the Paleozoic core of the Calico Hills was not greatly affected by Tertiary normal faults that displace the volcanic rocks. However, they noted large masses of strongly brecciated dolomite in structural positions above less-brecciated carbonate strata and beneath the Tertiary volcanic rocks. They interpreted these breccia lenses to have formed as near-surface landslides or debris flows prior to deposition of the Miocene gravel conglomerate that underlies the volcanic strata (Simonds and Scott, written commun., 1994).

Our initial reconnaissance in the Calico Hills in late 1994 convinced us that the Paleozoic rocks of the Calico Hills displayed a consistent, mappable, internal stratigraphy. Further, it was apparent that structures preserved in these rocks contained considerable information about timing and style of deformation not seen elsewhere in the Nevada Test Site vicinity. We identify ten informal stratigraphic units in this report within the assemblage of previously uncorrelated Middle Paleozoic strata. In addition, we present considerable new biostratigraphic data that allow these units to be compared with formally recognized units of similar age in southern Nevada.

Our detailed mapping (1:6,000-scale) shows that the principal pre-Tertiary structural element is an east-vergent thrust that emplaced the informal Devonian-Mississippian units eastward over the Chainman Shale in the direction of the foreland (Cole, 1997; Cole and Cashman, 1998). This thrust and the related folds in the hangingwall block are in turn overprinted by kink bands and large-scale overturned folds that verge toward the northwest and north in the direction of the hinterland (Cashman and Cole, 1996). Most contacts between stratigraphic units in the Calico Hills are depositional, rather than structural, but the overprinted deformations produce widespread brecciation in some units. This brecciation can be difficult to interpret without the broader structural context of the area. Our work shows that more than four-fifths of the carbonate breccias mapped by Simonds and Scott (written commun., 1994) as landslide or debris-flow deposits are instead internal breccias caused by folding of a particularly rigid Lower Devonian dolomite unit. We conclude that the other one-fifth of the dolomite breccias probably formed above local extensional normal faults, as described below.

Stratigraphic synthesis and regional paleogeographic analysis for the Paleozoic rocks in this area are contained in Trexler and others (1996) and Trexler and Cashman (1997) and summarized in Cole and others (1994). The structural context of the Calico Hills 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 (1998) and in Cole (1997).

STRATIGRAPHIC NOTES

The oldest rocks exposed in the Calico Hills consist of a Lower and Middle Devonian sequence of dolomite and limestone that is informally designated in this report as the Rocks of Calico Mines. Pre-existing biostratigraphic data and several new conodont identifications (table 1) show that this sequence is Lower and Middle Devonian. The Rocks of Calico Mines are therefore broadly contemporaneous with the upper Sevy Dolomite and lower Simonson Dolomite that were deposited farther east on the continental shelf (Johnson and others, 1988). In contrast to the Sevy-Simonson, the Rocks of Calico Mines contain common debris-flow beds, especially in the upper alternating unit Dc4, that indicate deposition in deeper water outboard of the continental shelf edge. In terms of lithology and sedimentological character, the Rocks of Calico Mines sequence is similar to the Rocks of Tarantula Canyon (Monsen and others, 1992) in the Bare Mountain area 30 km to the west, and to unnamed strata in the Carbonate Wash area 60 km to the north-northeast (fig. 1; Trexler and others, 1996).

The contact between the Rocks of Calico Mines and the overlying Rocks of North Pass is an unconformity. The contact is marked by conglomerate-filled channel deposits in a few localities (for example, south of Origami Peak), and this basal contact locally truncates individual beds in the Rocks of Calico Mines sequence. Biostratigraphic data (table 1) show that the base of this sequence is upper Famennian (uppermost Devonian; Johnson and others, 1991), and thus most of the Famennian and Frasnian stages are missing across the unconformity.

Coincidentally, this hiatus between the two sequences includes the time of the Alamo impact event, an hypothesized bolide impact on the carbonate shelf approximately 110 km northeast of the Calico Hills (Warme and Sandberg, 1996). The duration of the depositional hiatus at Calico Hills indicates the gap was more likely caused by tectonic and eustatic factors and not by a singular impact event.

The overlying Rocks of North Pass sequence contains six informal sub-units, which consist largely of fine-grained siliciclastic deposits with locally prominent limestone intervals. The dominantly siliceous nature of the lower part of this sequence contrasts markedly with the underlying carbonate rocks, and indicates a significant change in clastic source areas following the hiatus.

The lowermost brown siltstone unit Dn1 of the Rocks of North Pass consists of thin-bedded quartzose siltstone, with local discrete lenses of quartz arenite. The brown siltstone unit is abruptly overlain by a black argillite and chert unit MDn2 that is characterized by very even bedding and monotonous uniformity. Both of these lower units appear to have accumulated in quiet water under balanced conditions of sediment influx and rate of deposition, most likely in fairly deep water.

Units Mn3, Mn5, and Mn6 of the Rocks of North Pass contain substantial limestone. These limestones are generally similar to each other and are fine- to medium-grained packstones that contain sparse macrofossils (calcareous spicules and spherules, sparse small brachiopods, and minor crinoid fragments). Well rounded quartz sand lag deposits are conspicuous on local bedding surfaces. Intraformational breccia beds are locally present in the limestone units of the Rocks of North Pass and indicate debris-flow transport from shallower-water source areas.

The red siltstone and sandstone unit (Mn4) is the only unit in the Rocks of North Pass that contains conspicuous detrital chert. The chert occurs as grains and pebbles in sandstone beds, pebbly mudstone beds, and in rare conglomerate with cobbles as large as 10 cm in diameter. The presence of chert clasts indicates some sedimentary influx from western and northern source areas where debris was transported from the Antler orogenic belt into foreland basins (Trexler and others, 1996). Otherwise, most of the Rocks of North Pass contain quartzose and calcareous detritus that probably came from more eastern source areas on the continental shelf.

The Rocks of North Pass are distinct from most other Famennian and Kinderhookian sections in the region (Trexler and others, 1996), but share some features with rocks designated as Eleana Formation north of Tarantula Canyon at Bare Mountain, 30 km west of the Calico Hills (fig. 1). The siliciclastic sequence at Tarantula Canyon consists of flaggy siltstone (Famennian) above much older debris-flow dolomite (Eifelian). This siltstone is overlain by monotonous black bedded chert and siliceous argillite. The chert and argillite are in turn overlain by interbedded limestone and chert-lithic conglomerate that are at least as old as Osagean (Trexler and others, 1996).

A fault-bounded block of heterogeneous strata at the summit of Raggedy Hill is mapped as Eleana Formation on the basis of its lithic assemblage, although we are not confident this correlation is correct. The truncated section in this isolated block contains coarse chert-pebble conglomerate, thin beds of black chert, orange-weathering bioclastic limestone, and red siltstone. This assemblage has conspicuously coarser clastic beds and more diverse rock types than in any of the other units exposed in the Calico Hills, but is similar to many parts of the Eleana Formation in the Yucca Flat area, 30 km to the northeast (Trexler and others, 1996; Trexler and Cashman, 1997). Because the Eleana was deposited in more westerly, offshore settings in the axial trough of the Antler foreland basin, the Eleana correlation for this block on Raggedy Hill implies significant lateral transport by foreland-vergent thrusting. However, we cannot rule out that this block may have been derived from an unusually heterogeneous part of the red sandstone and siltstone unit (Mn4) in the Calico Hills.

We correlate the uniform shale in the southern Calico Hills with the Chainman Shale of the Nevada Test Site region (Trexler and others, 1996; Cole, 1997). It is similar to the Chainman in the CP Hills to the east and with the Chainman in the Syncline Ridge area to the northeast in that it contains thin lenses of cross-bedded fine litharenite, carbonate debris-flow beds with abundant macrofossil fragments and grains of rounded chert, and local beds of impure quartzite. Biostratigraphic data from outcrop samples (table 1) indicate deposition during the Osagean through Chesterian stages, but these results cannot be placed in stratigraphic context because the outcrop quality is poor and because bedding attitudes are quite variable.

Drillhole UE-25a-3 in the southern Calico Hills produced about 770 m (2530 ft) of continuous core, as described by Maldonado and others (1979). The upper 720 m (2364 ft) of core consists of monotonous shale; several tens of meters of interbedded limestone and shale pass into continuous limestone (recrystallized to marble by contact metamorphism around Miocene intrusions; Maldonado and others, 1979) down to the bottom of the hole. Detailed logging by D. Herring (written commun., 1994), including petrographic and X-ray study, indicates the section penetrated in the well is probably continuous and shows no sign of major replication. Bioclastic limestone beds that crop out near the UE-25-a3 drillsite contain lower to middle Chesterian microfossils (table 1). Two samples of the bottom-hole carbonate rock were processed for conodonts for this study but both were barren. We would nevertheless expect that these limestones were deposited in Frasnian time (Late Devonian), similar to limestone immediately beneath the Chainman at CP Hills (Trexler and others, 1996).

FORELAND-VERGENT STRUCTURES OF THE CALICO THRUST

The principal structure in the Calico Hills related to foreland-vergent deformation is the Calico thrust. This prominent fault is more-or-less continuously exposed across the central part of the area and places various units of the Devonian-Mississippian sequence from southwest to northeast over the Mississippian Chainman Shale (cross-section A-A'). The upper plate of the Calico thrust displays a well exposed hangingwall anticline just west of the Gray Knobs, where bedding in the eastern (leading) limb is overturned eastward (fig. 2). Farther north toward Discovery Hill, local warps and kinks show eastward-overturning in upper plate beds near the trace of the Calico thrust.

The footwall Chainman Shale is locally folded into an eastward-overturned syncline immediately adjacent to the Calico thrust, for example, immediately west of the Gray Knobs and south of Blackledge Hill. The Chainman is poorly exposed in general and evidence for facing direction can only be obtained from grading in bioclastic limestone beds or from cross-stratification in quartzite beds. Nonetheless, sufficient measurements of clearly overturned beds were obtained to confirm the presence of east-vergent folding near the thrust in many locations.

West of the leading edge of the Calico thrust, several major folds within the upper plate are interpreted to have formed during thrust emplacement. The most conspicuous of these structures is the syncline outlined by the lower units of the Rocks of North Pass in the area north of Origami Peak (fig. 3a). These folds trend generally northward between

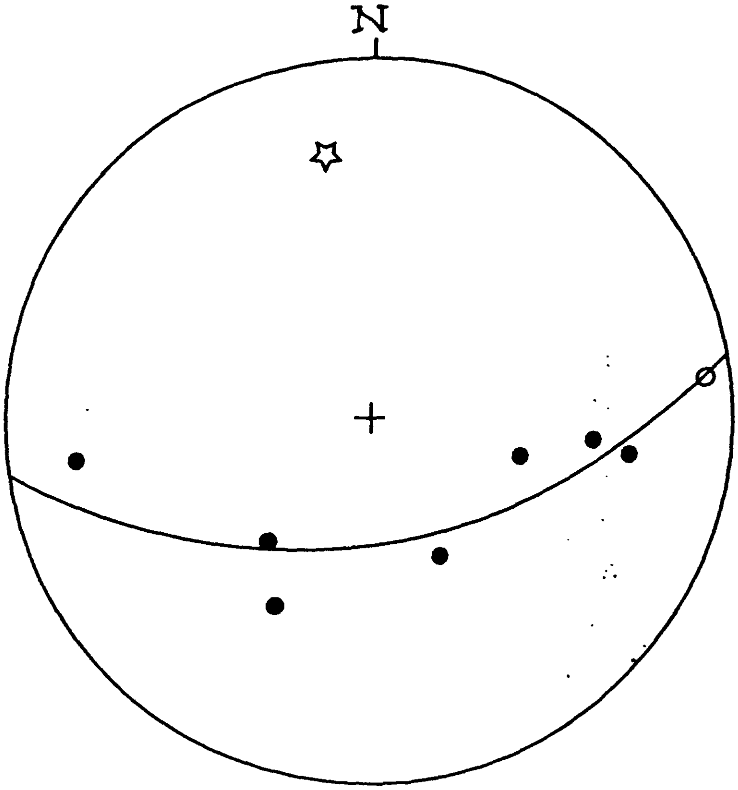


Fig. 2 -- Stereogram of bedding orientations in an overturned anticline in the upper plate of the Calico thrust, west of Gray Knobs. Filled circle = pole to upright bedding; open circle = pole to overturned bedding; star = fold axis (based on best-fit great circle)

Raggedy Hill and Discovery Hill, parallel to the leading edge of the thrust, and preserve eastward-vergent asymmetry or overturning (except where modified by younger deformation). Northwest-trending, relatively upright folds in the lower alternating dolomite unit of the Rocks of Calico Mines (Dc1) at Corduroy Hill are interpreted to belong to this generation of folding. We interpret the somewhat irregular trend and form of these folds to result from the brittle, massive nature of the thick-bedded dolomites in this unit and to the fact that folding was accompanied by widespread internal brecciation.

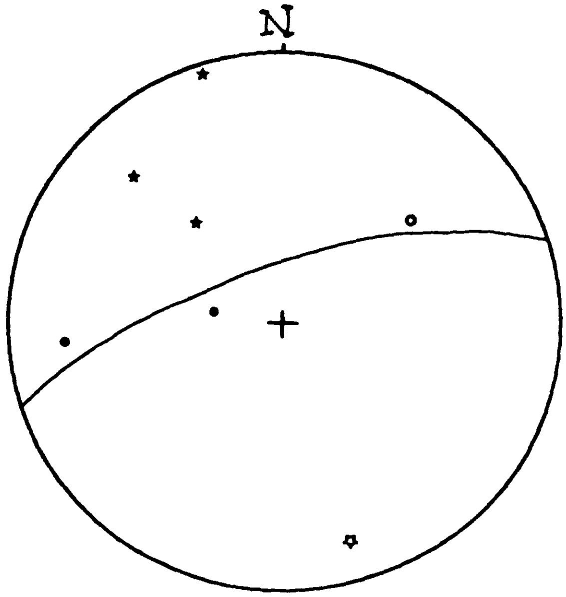
NORTHWEST-DIRECTED HINTERLAND-VERGENT STRUCTURES

Map patterns and structural trends in the Calico Hills are greatly complicated by the superimposed effects of contractional deformation that post-dates the east-vergent Calico thrust. The most conspicuous younger structures record vergence toward the northwest, as described in this section. These folds and kinks are well displayed in a broad northeast-trending zone that traverses the Calico Hills from approximately Origami Peak to Discovery Hill..

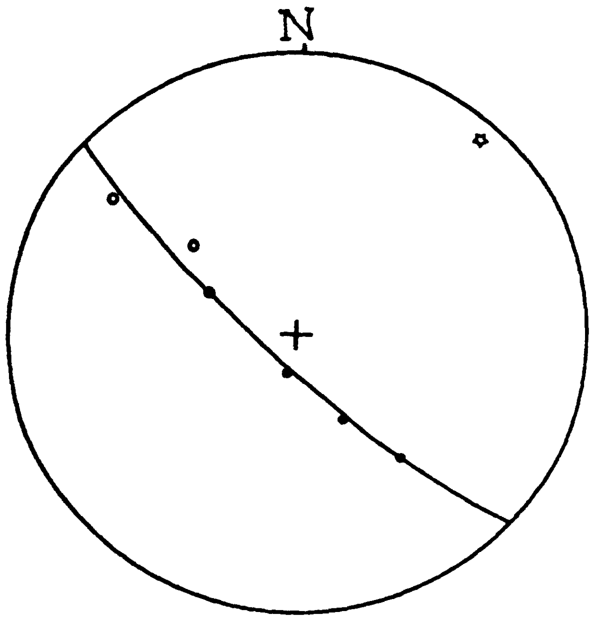
Hinterland-vergent folding with the northwestward sense of overturning deforms the Calico thrust and produces the conspicuous jog in the trace of the thrust in the central part of the Calico Hills. At Blackledge Hill, a prominent 4-m thick black dolomite debris-flow bed illustrates the sense and style of this folding. Along a traverse from west to east, north-dipping beds in the Rocks of Calico Mines strike progressively more northeastward as they steepen and eventually overturn toward the northwest to form an overturned syncline. Farther north-northwest along strike of the same beds, stratal orientation flips abruptly back to moderate northerly dips as the hinge surface of an overturned anticline is crossed. In detail, the folding takes place through a broad zone of distributed shear (see cross-section B-B') with numerous local dip reversals, but the net effect is represented by the overturned syncline-anticline pair.

This refolding also deforms the eastern limb of the large first-generation syncline in the Rocks of North Pass at Origami Peak (fig. 3). The brown siltstone unit Dn1 appears abnormally thick on this east limb because it is repeated by northwest-verging kinks and folds (cross-section B-B'). The geometry of small-scale refolded folds on the south side of Origami Peak shows that the younger set is the one that verges toward the northwest (fig. 3b). This locality contains the clearest outcrop-scale evidence for the sequence of folding in the Calico Hills and was named Origami Peak for its well preserved interference folds (Cashman and Cole, 1996).

Cross-section C-C' illustrates a fold in the Calico thrust. The Rocks of Calico Mines in the hangingwall map out a moderate-scale anticline that plunges gently northward and has a steep to overturned western limb. The trend of this fold is distorted by still younger deformation at Flip-Flop Peak (see below), but is interpreted to have initially formed during the northwest-verging hinterland-directed deformation.



(a). -- First-generation structures. Filled star = measured axis of mesoscopic first-generation fold that has been refolded in the second generation. Vergence is toward the northeast, as shown by the orientation of overturned bedding.



(b). -- Second-generation structures. Vergence is toward the northwest, as shown by the orientation of overturned bedding. Note that the cluster of refolded first-generation fold axes in (a) above plot near the axis of second-generation folding shown here.

Fig. 3 -- Stereogram of bedding orientations and other features south of Origami Peak, showing effects of northwest-directed refolding. Filled circle = pole to upright bedding; open circle = pole to overturned bedding; open star = fold axis (based on best-fit great circle);

Northwest-vergent folding is also evident in the area of the Calico mines where refolding of the original north-trending folds produces egg-crate outcrop patterns. Just east of Castle Bowl and between the two mine shafts, the brown siltstone unit Dn1 of the Rocks of North Pass is abnormally thin around the limbs of a bowl-shaped syncline that preserves a relic of the black argillite and chert unit Mdn2. Refolded folds within the brown siltstone unit on the southwest corner of this syncline show that the northwest-verging structures are the younger set.

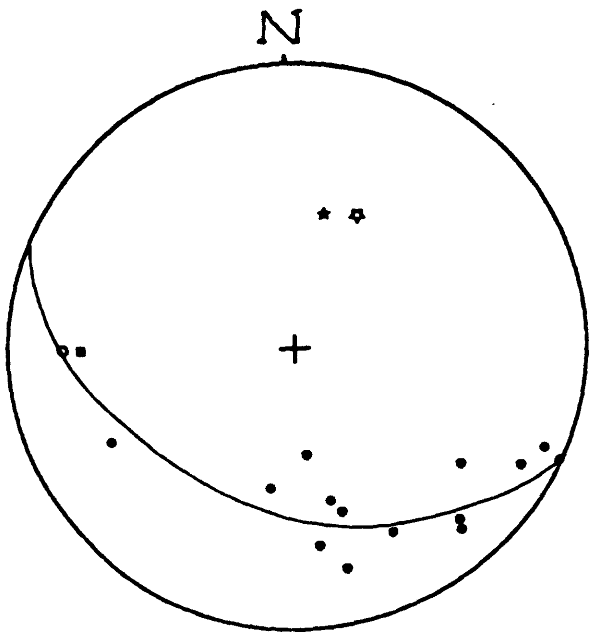
These map-scale folds that formed during the northwest-verging deformation are the most conspicuous indicators of the structural overprint on the Calico thrust structures. Outcrop-scale kinks and isolated folds that also formed during this phase are present in many locations in the central Calico Hills but they are too small to affect the trace of unit contacts. These younger structures are preferentially developed in beds that formed the west-facing limbs of the first generation folds.

NORTH-SOUTH CONTRACTIONAL STRUCTURES

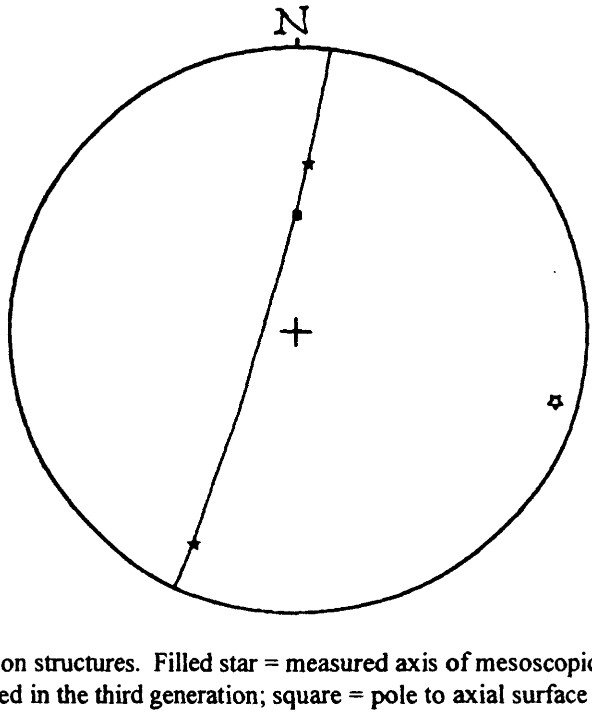
The very latest set of pre-Tertiary structures recorded in the Calico Hills formed in response to contraction oriented approximately north-south. Map-scale folding related to this event is only known in the southwestern Calico Hills between Whitetop Peak and Flip-Flop Peak and in the northern Calico Hills on the south slope of Pebbly Gulch. Small-scale kinks and warps that are also inferred to have formed during this last contraction were measured at widely scattered locations, but these do not affect map patterns of unit contacts.

The dramatic overturning at Flip-Flop Peak is illustrated on the western half of cross-section C-C'. Bedding in the upper plate of the Calico thrust in this locality can be traced westward from upright, gentle north dips to progressively steeper attitudes, and finally to attitudes that are strongly overturned toward the north (fig. 4). Most of the south slope of Flip-Flop Peak contains south-dipping beds that form the overturned upper limb of this nearly recumbent syncline. The hinge zone is not well exposed because the fold has a chevron profile, but the lower limb of the fold is defined by upright, north-dipping beds on the lower slopes of this Peak and in the canyon to the south. Refolded folds exposed locally on the north slope of Flip-Flop Peak show that this north-vergent folding deforms pre-existing northwest-vergent folds (fig. 4).

Geometrically similar folding is defined by bedding attitudes and the outcrop pattern of the Rocks of Calico Mines on the north face of Whitetop Peak. The north-verging overturned syncline there is most likely the same fold exposed at Flip-Flop Peak to the east, but it has been displaced downward by about 240 m (800 ft) across the prominent west-dipping normal fault (cross-section B-B').



(a). -- Second-generation structures. Square = pole to axial-plane cleavage; filled star = measured axis of mesoscopic second-generation fold. Vergence is toward the northwest, as shown by the orientation of overturned bedding.



(b). -- Third-generation structures. Filled star = measured axis of mesoscopic second-generation fold that has been refolded in the third generation; square = pole to axial surface of third-generation fold. Vergence is toward the north, as shown by the orientation of the axial surface.

Fig. 4 -- Stereogram of bedding orientations and other features at Flip-Flop Peak, showing effects of north-directed refolding. Filled circle = pole to upright bedding; open circle = pole to overturned bedding; open star = fold axis (based on best-fit great circle);

The small syncline on the south slope of peak VABM Calico also appears to have formed in response to north-south contraction. It is defined by defined by bedding attitudes and the outcrop pattern of the Dc4-Dn1 contact. Although its trend is highly irregular in detail, and northwesterly overall, small-scale flexures in the north-facing limb show consistent asymmetry toward the north.

The pre-Tertiary structure that is covered by Miocene volcanic rocks along Calico Crest appears to be fairly simple. The contact between Dn1 and MDn2 strikes east-west under Calico Crest and dips northward to form the south limb of a major syncline. The upper units Mn4, Mn5, and Mn6 of the Rocks of North Pass generally dip southward in the Pebbly Gulch area to form the north limb of the same syncline. The limestone beds in this north limb locally show mesoscopic folding that indicates south-vergent contraction as shown on the map, which we interpret to be due to the youngest deformation. The origin of the larger-scale syncline (covered beneath Calico Crest) is less clear. On the basis of scale alone, it would seem most likely that it originated with the foreland-vergent deformation, but its present east-west orientation may result from the youngest (north-south) contraction, or from modification of its original trend imposed during the northwest-vergent hinterland-directed folding.

STRIKE-SLIP FAULTS

One mapped fault and one inferred fault in the area of the Calico mines displace map units in a manner that indicates strike-slip offset. The trace of the Calico thrust east of the campsite (ruins) is not continuous with its expected position if projected from outcrop in the area of the Gray Knobs, for example. The displaced block is bounded by a mapped sinistral fault on the north and by a dextral fault that is buried by colluvium on the south near the Calico Mines. These two faults, in conjunction, appear to act as tear faults in the Calico thrust plate. Sinistral displacement is indicated on the mapped fault because it displaces both east- and west-dipping features in that sense. Displacement on the buried fault is inferred to be dextral from offsets of both east- and west-dipping features, and by the mismatch of fold-axial trends on either side of the fault. Horizontal slip on the order of 150 to 250 m is inferred for each of these tear faults.

LOW-ANGLE NORMAL FAULTS

Numerous isolated blocks of strongly brecciated dolomite are bounded below by low-angle faults in several localities in the Calico Hills. The rocks in most of these blocks can be identified as either the lower alternating unit Dc1 or the upper alternating unit Dc4 of the Rocks of Calico Mines. Most blocks rest on Chainman Shale. The orientation of relict bedding in these blocks (difficult to determine due to the internal brecciation) does not appear to be systematically related to adjacent blocks or to the orientation of bedding in the Calico thrust plate. The blocks are thus not erosional remnants of a once-continuous fault block. The inferred slope directions of the bounding faults are irregular in detail but, taken together, seem to dip radially away from a position near the (present-day) Calico Crest. These geometric characteristics suggest the blocks moved largely independent of each other.

The very large block of displaced dolomite on Chainman Shale at Bald Hill is mapped as an extensional fault block for several reasons. Brecciation is noted in the lower part of the dolomite block, although it is inconspicuous on the east side of the hill due to Miocene recrystallization. Bedding in the dolomite is truncated by the fault contact against the Chainman, especially on the north side of the block. These two field relations are typical of extensional fault complexes noted in the Test Site area (Cole and others, 1989; 1994; Cole and Cashman, 1998). In addition, these relations are both inconsistent with observed characteristics in the upper plate of the Calico thrust as displayed nearby at Gray Knobs.

The extensional faulting at Calico Hills is only known to be older than the sedimentary breccia and conglomerate, which is slightly older than 13.0 Ma (Simonds and Scott, written commun., 1994; Wahl and others, 1997). Extensional fault blocks of similar character are exposed in the Mine Mountain area and the CP Hills, located east and northeast of the Calico Hills in the eastern Nevada Test Site (fig. 1). Detailed kinematic studies at Mine Mountain by Hudson (Cole and others, 1989, 1994; Hudson and Cole, 1993) show that the youngest slip sense in all cases was extensional, and Cole and Cashman (1997) conclude that the amount of displacement was not large. Extensional displacements on low-angle normal faults elsewhere in this region are known to predate Oligocene volcanic deposits in the Belted Range (Cole, 1997), and circumstantial evidence strongly suggests similar deformation near northern Yucca Flat is older than Late Cretaceous (Cole and others, 1993). The available evidence does not admit any further comparisons; all the low-angle normal faults in this diverse region may be old (pre-Cenozoic), or separate extensional events may have produced similar fault systems at different times.

ACKNOWLEDGMENTS

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The authors gratefully acknowledge the assistance lent by Bill Simonds in sharing his unpublished mapping in the area (Simonds and Scott, written commun., 1994). His identification and mapping of identifiable marker units in the Devonian and Mississippian section provided us a considerable head-start in evaluating our working model of the structure and in focusing our follow-up work. Biostratigraphic work by A. Harris, B. Skipp, M. Kurka, and others was essential to confirming the sense of stratigraphic facing in this highly deformed terrane, and was critical to establishing the regional context of the major structural blocks in the Calico Hills. These factors could only be comprehended as an outgrowth of our collaboration on the regional stratigraphic, sedimentologic, and paleoenvironmental analysis with J. Trexler (Trexler and others, 1996).

Logistical support for all our studies was provided by the staff of the USGS Core Library and Data Center in Mercury, Nevada, particularly Jerry Magner and Ron Martin. We also acknowledge the assistance of Jerry Woods of the DOE Operations Control Center at the Nevada Test Site for accommodating our access to the area during various exercises.

REFERENCES CITED

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.

Cashman, P.H., and Cole, J.C., 1996, Structure of Paleozoic rocks in the Calico Hills. Nevada Test Site: Implications for regional reconstructions: EOS, v. 77, no. 46, p. F641

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., 1997, Geologic map of the Mine Mountain area, Nevada Test Site, southern Nevada: U.S. Geological Survey Open-File Report 97-697, 8 p. 1 plate, scale 1:12,000.

Cole, J.C., and Cashman, P.H., [in press 1998], Structural relationships of the pre-Tertiary rocks of the Nevada Test Site region, southern Nevada: U.S. Geological Survey Professional Paper, 100 ms p.

Cole, J.C., Harris, A.G., Lanphere, M.A., Barker, C.E., and Warren, R.G., 1993, The case for pre-middle Cretaceous extensional faulting in northern Yucca Flat, southwestern Nevada: Geological Society of America Abstracts with Programs, v. 25, no. 5, p. 22

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.

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.

Johnson, J.G., Sandberg, C.A., and Poole, F.G., 1988, 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, J.G., Sandberg, C.A., and Poole, F.G., 1991, Devonian lithofacies of western United States, in Cooper, J.D., and Stevens, C.H., eds., Paleozoic paleogeography of the western United States II: Pacific Section, Society of Economic Paleontologists and Mineralogists, vol. 67, p. 83-105.

Maldonado, Florian, Muller, D.C., and Morrison, J.N., 1979, Preliminary geologic data of the UE-25a-3 exploratory drill hole, Nevada Test Site, Nevada: U.S. Geological Survey report USGS-1543-6, 47 p.

Mc Kay, E.J., and Williams, W.P., 1964, Geologic map of the Jackass Flats quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-368, scale 1:24,000.

Monsen, S.A., Carr, M.D., Reheis, M.C., and Orkild, P.P., 1992, Geologic map of Bare Mountain, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Map I-2201, scale 1:24,000.

Orkild, P.P., and O'Connor, J.T., 1970, Geologic map of the Topopah Spring quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-849, 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.

Scott, R.B., 1990, Tectonic setting of Yucca Mountain, southwest 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. 251-282.

Simonds, F.W., and Scott, R.B., [1994 written commun.], Geology and hydrothermal alteration at the Calico Hills, Nye County, Nevada: U.S. Geological Survey unpublished Open-File Report, 93 ms. p., 1 plate, scale 1:12,000.

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, v. 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.A., 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.

le 1. -- BIOSTRATIGRAPHIC DATA for samples from the CALICO HILLS

P ID nple number	STRATIGRAPHIC SIGNIFICANCE	PHYSICAL DESCRIPTION	BIOSTRATIGRAPHY Source
ks of Calico Mines			
CH-25	Plotted from coordinates listed by F. Maldonado; area mapped as unit Dc3; USGS collection 9989 SD	Dolomitic limestone; time equivalent to uppermost Sevy Dolomite; conodont CAI = 3.5 to 4	Pol. gronbergi zone; middle Emsian; Harris, 1979
CH-26	Plotted from coordinates listed by F. Maldonado; area mapped as upper unit Dc4; USGS collection 9990 SD	Dolomitic limestone; time equivalent to silty-cherty unit between Simonson Dolomite and Sevy Dolomite; conodont CAI = 3 to 3.5	Pol. inversus zone; middle Emsian; Harris, 1979
CH-27	Plotted from coordinates listed by F. Maldonado; area mapped as unit Dc3; USGS collection 9991 SD	Dolomitic limestone; time equivalent to lower alternating member of Simonson Dolomite; conodont CAI = 3	T. kockelianus zone; late Eifelian; Harris, 1979
94PC 2182	Sample taken near top of unit Dc4, less than 10 m below stratigraphic base of Eleana Fm.	Dark gray, richly fossiliferous dolomite with common crinoid and coral fragments	Middle Devonian; middle Eifelian to early Givetian; Kurka, 1995
ks of North Pass			
95JC 718	Lower part of unit Dn1; calcareous interval only 1 to 2 m thick, about 18 m above stratigraphic base of unit	Well bedded gray silty limestone grainstone; fine-grained and black; lacks conspicuous macrofossils	Early Famennian; Kurka, 1996
JC10612	Upper part of unit Dn1; less than 15 m below top of unit	Micrite with common spherical globules and elongate calcareous spicules; slightly silty; no diagnostic macrofossils	Pa. g. expansa to Si. praesulcata zones; late Famennian; Kurka, 1995
94PC 2153	Middle part of unit Mn3	Well bedded gray limestone with thin silty-cherty beds and layers that contain lag concentrations of rounded brown quartz and crinoid columnals	Kinderhookian; Kurka, 1995
JC10678	Middle part of unit Mn5, approximately 15 m above stratigraphic base of unit	Gray well bedded slightly sandy limestone with common calcareous spicules; section locally shows debris-flow beds of redeposited micrite and sandy micrite; conodont CAI = 3	Upper crenulata - isosticha zone; late Kinderhookian with redeposited Famennian elements; Harris, 1995; Kurka, 1995
JC10739	Highest preserved part of unit Mn6, approximately 75 m above stratigraphic base of unit	Gray sandy-silty limestone that shows irregular globular chert masses on bedding planes; some beds contain crinoid columnals and brachiopod fragments	late Kinderhookian; Kurka, 1995

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ıle 1. -- **BIOSTRATIGRAPHIC DATA for samples from the CALICO HILLS (continued)**

ıP ID. ηple number	**STRATIGRAPHIC SIGNIFICANCE**	**PHYSICAL DESCRIPTION**	**BIOSTRATIGRAPHY** Source
ainman Shale			
JC10312 B	Chainman Shale; collected in outcrop west of UE-25a-3 drillhole	Poorly sorted pelmatazoan packstone; iron-rich matrix; barren of conodonts, but contains: Endothyra excellens?, Endothyra sp., stacheiid algae, Eostaffellina?; Archeodiscus sp., Neoarchaediscus, Paramillerella designata; Tetrataxis sp.	middle Chesterian; approximate foram zone 17-18; Skipp, 1995
JC10312 C	Chainman Shale; collected in outcrop west of UE-25a-3 drillhole	Non-sorted packstone-wackestone; barren of conodonts, but contains: Eostaffellina?, Paramillerella designata, Endothyra sp., Girvanella sp.	middle Chesterian; approximate foram zone 18; Skipp, 1995
94JTA 22	Chainman Shale; collected in outcrop west of UE-25a-3 drillhole	Unsorted crinoidal packstone; extensively reworked turbidite	early Chesterian; foram zone 16; MicroStrat, 1994
95JC848	Chainman Shale; isolated outcrop northeast of Raggedy Hill; sample taken just beneath thrust contact with Devonian Rocks of Calico Mines	Ocher-weathering bioclastic limestone with common, varicolored clasts of well rounded chert, some as large as 1 cm diameter	Chesterian; sparse conodonts; Kurka, 1995
2-89SN-722	Chainman Shale; collected beneath brecciated dolomite; south side of Raggedy Hill	Bioclastic limestone; conodont CAI=4	Gn. typicus zone; Early Osagean, MicroStrat, 1989

TES:

Letters next to sample numbers correspond to identifiers next to fossil locality symbols on map

Conodont CAI = color-alteration index value, which indicates maximum temperature imposed on the sample over geologic time (Epstein and others, 1977)

All sources are written communication. A. Harris, MicroStrat, Inc., and M. Kurka examined conodonts; B. Skipp examined foraminifera and other microfossils in thin section

Mississippian conodont zones and Mamet foraminiferan zones are based on Poole and Sandberg (1991); Upper Devonian conodont zonation from Sandberg and others (1982); Middle and Lower Devonian conodont zonation from Johnson and others (1989)