
# *Some relationships among folds, faults and mid-Tertiary igneous rocks near Gallup, northwestern New Mexico*

Marvin L. Milgate, 1989, pp. 123-125

*in:*

*Southeastern Colorado Plateau*, Anderson, O. J.; Lucas, S. G.; Love, D. W.; Cather, S. M.; [eds.], New Mexico Geological Society 40th Annual Fall Field Conference Guidebook, 345 p.

*This page is intentionally left blank to maintain order of facing pages.*

# SOME RELATIONSHIPS AMONG FOLDS, FAULTS AND MID-TERTIARY IGNEOUS ROCKS NEAR GALLUP, NORTHWESTERN NEW MEXICO

M. L. MILLGATE
U.S. Geological Survey, Denver, Colorado 80225

**Abstract**—Field relationships of folds, faults and intrusive igneous rocks near Gallup, New Mexico suggest a mid-Oligocene (about 31 my ago), northeasterly structural trend that might prove useful in analyzing structural and tectonic elements of the southeastern Colorado Plateau. The trend consists of extensional features, an assemblage of faults and minette dikes and plugs imposed across northwest-trending folds of ostensible Laramide age (about 75 to 40 my). A mid-Oligocene stress field containing a northwest-southeast minimum principal stress direction is indicated. A diatreme discovered south of known minette outcrops is tentatively included in the Twin Cones volcanic field (Hackman and Olson, 1977), within the minette province of Shoemaker (1956). Assuming age compatibility, the diatreme occurrence extends the volcanic field about 3.6 km to the southeast.

## INTRODUCTION

The Torrivio anticline, faults, minette dikes and plugs and breccia are well exposed about 12 km southwest of the city of Gallup, New Mexico. The Twin Buttes intrusion (Fig. 1), which forms a prominent topographic feature rising about 146 m above an alluvial plain, is about 760 m south of Interstate 40 (not shown on Fig. 1) and is readily visible from the highway. Farther southwest along the highway, the cliff-forming sandstone beds of the Gallup Sandstone visibly define the Torrivio anticline.

The previous work of Sears (1925), Beaumont et al. (1956), O'Sullivan and Beaumont (1957), Molenaar (1973, 1983) and Hackman and Olson (1977) set forth the stratigraphic relations and general structural grain of the area. In the course of local geologic investigation south and west of Gallup, additional outcrops of igneous rock and breccia were mapped, and several faults not previously recorded were found. In the preparation of the structure contour map (Fig. 1), several control points mapped by O. J. Anderson (unpublished map for New Mexico Bureau of Mines and Mineral Resources, 1988) were included, but the writer is responsible for the structural portrayal.

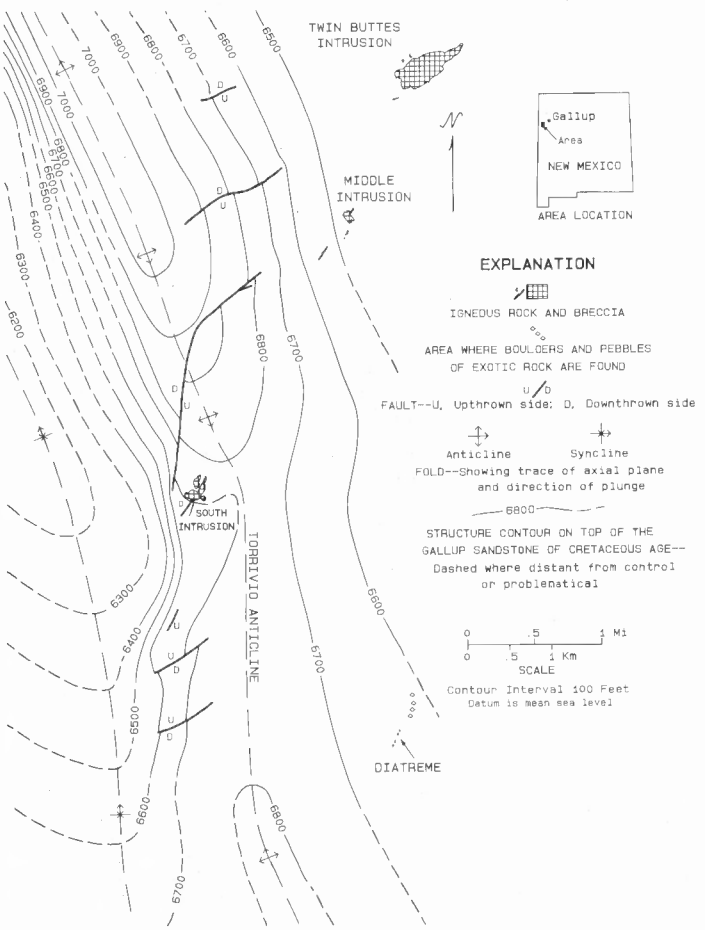


FIGURE 1. Structure-contour map of the southern part of the Torrivio anticline near Gallup, McKinley County, New Mexico.

## GENERAL GEOLOGY

Rocks in the mapped area consist, from oldest to youngest, of the uppermost beds of the Upper Cretaceous Mancos Shale, Gallup Sandstone and the lower members (mostly sandstone, mudstone and coal) of the Crevasse Canyon Formation; igneous rock and breccia of probably mid-Oligocene age; and landslide debris (toreva blocks), colluvium and alluvium of Quaternary age. The Torrivio anticline and adjacent syncline to the west are north- to northwest-trending, asymmetrical, open folds. Like many of the numerous folds in the region, the anticline has domes and saddles along its axis (Fig. 1). Synclines have similar reversals of plunge along axes (Hackman and Olson, 1977, sheet 2; Anderson, 1987, sheet 1). The anticline extends northwest of the mapped area (Fig. 1) about 10 km and 10.3 km southeast, but is not known to be associated with igneous rock or extensive faulting beyond the mapped area, although reversals of plunge occur along the anticline north of the mapped area.

Igneous rock (minette) and breccia intrude lower formations and extend upward into the Crevasse Canyon Formation. The Twin Buttes intrusion penetrates at least 100 m into the Bartlett Barren Member of the Crevasse Canyon Formation, and other intrusions are found well up in the underlying Dilco Coal Member, the lowermost member of the formation. The uneroded tops of minette intrusions are not known, and the roots are not exposed. Although there are no associated extrusive igneous rocks to show that the intrusions near Gallup erupted at land surface, many authors (Shoemaker, 1956; Hackman and Olson, 1977) regard the minette intrusions as evidence of volcanic events. This opinion is substantiated about 50 km north of Twin Buttes where minette intrusions and diatremes are associated with extrusive breccia, tuff and flows in the Chuska Mountains and the Defiance Plateau.

Contacts of igneous dikes and plugs with the sedimentary host rock are high-angle (most are near vertical) and crosscutting. Conformable or sill-like strutures were not observed. Breccia, consisting mostly of minette and sandstone fragments in a clay-like matrix of pulverized rock, tends to occur near the periphyry of intrusions and in places encases the resistant, dark-green, fine-grained minette. Very sparse, subrounded cobbles and pebbles of granitic rocks, schist and gneiss occur in the breccia at Twin Buttes. Several exposures of altered rock (not shown in Fig. 1) are adjacent to and in contact with the minette of the middle and south intrusions. These exposures contain large (tens of meters in long dimension) blocks of sandstone visibly tilted and

displaced upward against unlike sandstones and mudstones of overlying strata. All sandstone blocks displaced are in contact with minette. At Twin Buttes, a few of these large blocks are entirely within the igneous mass.

High-angle, normal faults crosscut the sedimentary rocks but do not transect minette, breccia or altered sandstone. Most faults have vertical or near vertical dips to the northwest, but the two northernmost faults dip about 60° northwest. The northernmost fault is likely the exposed northeastern extension of a slip surface along which large toreva blocks have recently slipped downward and northward to lower elevations. The 60° dip along this fault reflects the outcrop of a cylindrical slip surface well below its point of initial propagation near the edge of an erosional escarpment. The slip surfaces mapped by Sears (1925), O'Sullivan and Beaumont (1957) and Hackman and Olson (1977) are not shown (Fig. 1) because, although present, they are younger (probably as young as Quaternary) than other faults, and the mode of origin of these surfaces is essentially unlike and unrelated to that of the normal faults in the area.

### Diatreme and associated rocks

A diatreme occurs about 3.6 km south of the minette intrusions. A few small outcrops of breccia are found in the bottom of a dry wash in the NE¼ NW¼ sec. 27, T14N, R19W. Exposures of the sedimentary host rock occur both upstream and downstream from diatreme outcrops. The intrusion occurs in the lower sandstone and mudstone strata of the Dilco Coal Member of the Crevasse Canyon Formation. Contacts of breccia with sedimentary rocks in place were not identified.

Rounded to subrounded cobbles and pebbles of exotic rock are contained in fine-grained breccia that consists mostly of sandstone and mudstone fragments in a clay-like matrix. Angular pieces of exotic igneous and metamorphic rock were not identified in the smaller fragmental sizes but may be present. Rounded and subrounded xenoliths in the breccia range in composition from granite to kimberlite and include schist and gneiss. One pebble was identified (J. E. Fassett, written commun., 1971) as gabbro containing about 15% garnet. An outer shell of the exotic rock is commonly altered and may be friable in some specimens. Some pebbles are so deeply altered and weathered that they fragment when handled. Fine-grained rocks containing abundant quartz and feldspar are least altered. Rock types rich in olivine (and its alteration products), pyroxene, iron oxide and amphibole are most altered.

Above and north of the diatreme outcrops, numerous boulders, cobbles and pebbles of exotic rock are found along a north-trending ridge crest (Fig. 1). Sparse cobbles and pebbles also occur in dry washes and alluvium below and northeast of the ridge. On the crest are pink, rounded to subrounded, coarse-grained granite boulders up to 1 m in longest dimension. Smaller rocks, generally rounded to subrounded, include amphibolite(?), pyroxenite, mica schist, quartz-layered gneiss, feldspathic gneiss, altered gabbro(?) and some light-colored granitic rock. Small, angular fragments of sandstone are common. Again, the rocks rich in quartz and feldspar are least altered. The larger, pink granite boulders appear little weathered and unaltered. Minette was not identified among the exotic rocks along the ridge or in the breccia outcrops.

## AGE RELATIONSHIPS

The Torrivio anticline and adjacent syncline are ostensibly of Laramide age, the age of regional folding of the rocks of Upper Cretaceous age. The age of Laramide folding and faulting extends from about 75 to 40 my, depending somewhat on localities and authors (Rehrig and Heidrick, 1976, p. 212; Laughlin et al., 1983, p. 48). Hackman and Olson (1977, sheet 1) include the intrusions (Fig. 1) in the Twin Buttes volcanic field, a part of the minette province defined by Shoemaker (1956, p. 183), and assign a mid-Oligocene age (an absolute age on the order of 31 my) to these intrusions and related volcanic events. This age was obtained by Naeser (1971, p. 4980) from granite xenoliths from the diatreme matrix at Buell Park, Arizona about 52 km northwest of the Twin Buttes intrusion. The diatreme at Buell Park, intruded by minette dikes, is assigned to the Zilditloi volcanic field, minette province (Hackman and Olson, 1977, sheet 2). During emplacement of the minette intrusions (Fig. 1), the fold forms were distorted and thus provide evidence that the igneous rock and breccia are younger than folding.

The precise age of the diatreme (Fig. 1) is not known. The diatreme is somewhat isolated and poorly exposed, thus permitting only the observation that it is younger than rocks in the Dilco Coal Member (Upper Cretaceous) and older than alluvium of Quaternary age. The diatreme is thought to be part of the Twin Cones volcanic field and thus of similar age, although no evidence has been marshalled to support such assignment other than proximity to known intrusions. Fragments of mudstone and sandstone found associated with the diatreme are thought to be derived from the sedimentary host rock but are of unknown age. The larger, rounded exotic rocks found in breccia and as discrete occurrences near the diatreme outcrops are igneous and metamorphic, basement–rock types most likely of Precambrian age. For example, the coarse-grained granite boulders are similar to granite of Precambrian age in the Zuni Mountains (O. J. Anderson, oral commun., 1988) more than 49 km to the southeast. The faults (Fig. 1) crosscut the anticline. Thus, the faulting is later than folding or occurred late in a folding phase of deformation. No other evidence was noted that conclusively defines the relative or absolute age of faulting.

## SPATIAL RELATIONSHIPS

The form of the Torrivio anticline and the adjacent syncline (Fig. 1) was determined from the field mapping of Anderson (unpublished, 1988) and the writer as well as the previous work of Hackman and Olson (1977, sheet 2). In the absence of precise elevations for the datum plane, other configurations are possible. For example, the 6700–ft–contour line could cross the trace of the axial plane east and southeast of the south intrusion, thus showing that for a short distance along the axis the top of the Gallup Sandstone is lower than 6700 ft. However, the general fold form shown in Figure 1 would not be changed by alternative configurations.

The western limb of the anticline shows steepening southwest of the southern intrusion and a flattening in dip to the northeast and east. East of the southern intrusion, the trace of the axial plane of the anticline is convex to the east. These features are attributable to deformation of the sedimentary strata at the time of emplacement of the intrusion. Strata have been bent upward and outward around the intrusion. This bending compensates in part for the additional volume of rock intruded into the sedimentary host. Volume is also gained by vertical uplift of strata above the intrusion after failure of strata by brittle fracture, as evidenced by the displacement of the large blocks of altered sandstone and the breccia previously described. Similar bending of strata is not demonstrated at the middle and Twin Buttes intrusions, mostly because dependable stratigraphic horizons which could be mapped around and across the intrusions were not readily identifiable. Further, the outcrops at the middle intrusion and at Twin Buttes are partially disturbed and concealed by quarrying.

The intrusions are obviously aligned northeasterly. This alignment is defined by: (1) the alignment of intrusive centers of dikes and plugs, (2) the occurrence of dikes mostly southwest of plugs, (3) the long axis in plan of plugs and (4) the strike of dikes. The strike of dikes contributes to the perception of northeast trend, and each dike also is radial to its own individual intrusive center. Also contributing to the northeast trend are the strikes of faults. Faults mapped along the anticline strike northeast, in contrast to the northwest-trending fold axes. In places, fault strikes are nearly normal to fold axes, and most strikes are more nearly parallel to the trend of minette intrusions than the trend of folds. The longest fault is near the southern intrusion and has the largest throw seen on any of the faults, about 30 m. This throw contributes significantly to the uplift of strata near the south intrusion. The configuration of the diatreme (Fig. 1) reflects the meanders of the dry wash in which outcrops occur and does not indicate structural trend.

## STRUCTURAL IMPLICATIONS

The northeast structural trend defined by faults and intrusions near Gallup, New Mexico crosscuts the northwest-trending folds of Laramide age. The Laramide fold forms are modified by displacement of strata along faults and by bending, brittle fracture and displacement of strata by intrusion. Absolute ages of similar minette and other rock from intrusions elsewhere in the minette province provide the best estimate of absolute age of the intrusions near Gallup, a mid-Oligocene age of about 31 my. Thus, the faulting and intrusion occurred on the order of 10 my after the major phases of Laramide deformation.

The mid-Oligocene deformation is noticeable but not great. For example, there is no evidence to indicate that the plunge reversals along fold axes are other than Laramide in age. However, later deformation is sufficient to modify dip, anticlinal closure, fold plunge and location of fold axes and thus be of interest to those exploring for oil and gas in the southeastern Colorado Plateau. The mid-Oligocene structural trend suggests an attendant stress field prevalent at the time of faulting and intrusion. The intrusions define an extensional or tensional situation in which the minimum principal stress is oriented generally northwest-southeast, i.e., the intrusions were emplaced in passive tension fractures trending northeast. Tension is favored rather than compression because intrusive-sedimentary contacts are vertical or nearly so, and most of the normal faults are near vertical, the dips expected as a result of failure in response to tension.

The fact that most of the fault strikes are subparallel to the intrusions and that faults dip at a high angle may be the best evidence that faulting is more nearly related to the intrusive trend than to other structural elements, because the attitudes of intrusions and faults are compatible with respect to the same stress field. The possibility that fault and intrusive trends are the result of a northeast–oriented, lateral shear couple is dismissed because the writer is unable to demonstrate appreciable strike slip along faults, dikes or plugs. A review of the maps of Allen and Balk (1954), O'Sullivan and Beaumont (1957) and Hackman and Olson (1977) indicate that elsewhere in the minette province of Oligocene age some intrusions and faults have attitudes similar to those near Gallup. However, the degree of similarity is not readily decipherable from the levels of geologic detail portrayed.

## SUMMARY AND CONCLUSIONS

Relationships among folds, faults, dikes and plugs near Gallup, New Mexico permit identification of a northeast–oriented, mid-Oligocene (about 31 my) structural trend of local significance. Relative ages gained in the field indicate that the trend is later than folding of Laramide age. However, an absolute age of 31 my depends upon the assignment of local minette intrusions to a volcanic field of the minette province, which has been dated by radiometric methods at Buell Park, Arizona. The structural trend is fairly clear and uncomplicated and may prove to be useful in structural and tectonic analysis elsewhere, especially in the southeastern Colorado Plateau.

The attitudes of faults and minette dikes and plugs suggest a mid-Tertiary (mid-Oligocene) stress field containing a northwest-southeast minimum principal stress direction. Field evidence indicates that the geologic features defining the structural trend originated in response to tension rather than compression. The modification of a fold form of Laramide age during emplacement of a minette plug of mid-Oligocene age indicates that the sedimentary host rocks underwent some bending, as well as failure by brittle fracture during Oligocene time. No evidence was found to indicate that plunge reversals along fold axes are of other than Laramide age, but the suggestion remains that the mid-Oligocene event significantly modified fold forms.

A localized occurrence of rounded to subrounded boulders, cobbles and pebbles of exotic rock in breccia and strewn along a nearby ridge and along dry washes identify a diatreme south of the minette intrusions. Except for abundant angular fragments of sandstone and mudstone of unknown affinity, the exotic rock consists of igneous and metamorphic types most likely of Precambrian age. The diatreme is tentatively assigned to the Twin Cones volcanic field, minette province, of mid-Oligocene age. However, minette was not found in the breccia or among the associated exotic rocks. Assuming concordant ages, this diatreme occurrence extends the Twin Cones volcanic field to the southeast.

## REFERENCES


Allen, J. E. and Balk, R., 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 36, 192 p.

Anderson, O. J., 1987, Geology and coal resources of Atarque Lake 1:50,000 quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Map GM-61, scale 1:50,000.

Beaumont, E. C., Dane, C. H. and Sears, J. D., 1956, Revised nomenclature of Mesaverde Group in San Juan Basin, New Mexico: American Association of Petroleum Geologists Bulletin, v. 40, p. 2149–2162.

Hackman, R. J. and Olson, A. B., 1977, Geology, structure, and uranium deposits of the Gallup 1°×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey, Miscellaneous Geological Investigations Map I-981, scale 1:125,000.

Laughlin, A. W., Aldrich, M. J. and Vaniman, D. T., 1983, Tectonic implications of mid-Tertiary dikes in west-central New Mexico: Geology, v. 11, p. 45–48.

Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico; *in* Fassett, J. E., ed., 1973, Cretaceous and Tertiary rocks of the southern Colorado Plateau: Durango, Four Corners Geological Society Memoir, p. 85–110.

Molenaar, C. M., 1983, Principal reference section and correlation of Gallup Sandstone, northwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 185, p. 29–40.

Naeser, C. W., 1971, Geochronology of the Navajo-Hopi diatremes, Four Corners area: Journal of Geophysical Research, v. 76, p. 4978–4985.

O'Sullivan, R. B. and Beaumont, E. C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-190, scale 1:125,000.

Rehrig, W. A. and Heidrick, T. L., 1976, Regional tectonic stress during Laramide and late Tertiary intrusive periods, Basin and Range province, Arizona: Arizona Geological Society Digest, v. 10, p. 205–228.

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U.S. Geological Survey, Bulletin 767, 53 p.

Shoemaker, E. M., 1956, Occurrence of uranium in diatremes on the Navajo and Hopi reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey, Professional Paper 300, p. 179–185.

Zuni Buttes looking E. Flaggy-bedded Rock Point Member of Chinle Formation (Upper Triassic) in foreground. Jurassic Zuni Sandstone forms flanks of buttes and is capped by thin, dark-colored Cretaceous Dakota Sandstone on tops of buttes. Feather Rock is vertical projection between buttes. Photograph taken 25 February 1989 by Paul L. Sealey.