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Bridget R. Wyatt
San Jose State University

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**PLIO-PLEISTOCENE DEFORMATION AT ALVORD MOUNTAIN
CENTRAL MOJAVE DESERT, CALIFORNIA**

A Thesis

Presented to

The Faculty of the Department of Geology

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Bridget R. Wyatt

December 2005

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APPROVED FOR THE DEPARTMENT OF GEOLOGY

Dr. Jonathan S. Miller

Dr. Paula Messina

Dr. David M. Miller, United States Geological Survey

APPROVED FOR THE UNIVERSITY

11/16/05

ABSTRACT

PLIO-PLEISTOCENE DEFORMATION AT ALVORD MOUNTAIN CENTRAL MOJAVE DESERT, CALIFORNIA

By Bridget R. Wyatt

This thesis focuses on Plio-Pleistocene faulting and associated deformation. The main structure is a 6 km northeast-striking fault named the Clews Ridge Fault, which shows a southwest to northeast increase in slip along its trace. Kinematic analysis and geologic mapping shows that it has accommodated normal and strike-slip deformation. Small domains of transtensional shear between the Clews Ridge Fault and adjacent faults and between major splays of the Clews Ridge Fault appear to have rotated several hundred meter scale blocks about vertical axes from 20°-55° clockwise. An open northwest-plunging anticline that folds Pleistocene and older strata is cut by the Clews Ridge Fault and other northeast-striking normal and/or strike-slip faults at Alvord Mountain. These major structures may be the result of wrenching and associated clockwise vertical axis rotation between the east-striking sinistral Coyote Lake Fault that bounds Alvord Mountain to the north and the east-striking sinistral Afton Fault to the south.

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around the campfire, and in the office, which was very helpful to the interpretations made in this manuscript.

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INTRODUCTION

The Mojave Desert region of southern California is an area of complex Late-Cenozoic to Recent deformation that is related to the relative motion between the Pacific and North American plates (Atwater, 1970). Most of the slip is taken up along the San Andreas Fault System, but ~15% of the slip over the last 6-10 Ma is taken up to the east in the Mojave Desert Block (Dokka and Travis, 1990 a, b), a wedge-shaped region that is bounded by the San Andreas Fault Zone to the south and the Garlock Fault to the north (Figure 1). Historic and recent seismicity in the Mojave Block (including 2 events with $M_w > 7.0$) have renewed interest in better understanding how, where, and at what rate deformation is distributed on faults and fault-related structures in this area, and how geodetically-determined strain rates compare and contrast to geologic slip rates along faults (e.g., Dixon et al., 2003; Oskin and Iriondo, 2004).

Two different structural domains are recognized in the Mojave Block, one containing northwest-striking dextral faults that parallel the San Andreas Fault and the other containing east-striking sinistral faults that parallel the Garlock Fault. In general, east-striking sinistral strike-slip faults predominate in the north-central Mojave Block, whereas northwest-striking dextral faults predominate in the rest of the region. Faults in both domains bound sub-blocks that are approximately 10-20 km wide and 50 km long (Figure 2), some of which are inferred to have been rotated clockwise about vertical axes

Fig. 1. Regional map showing elevation, faults (only a few are labeled), and geographic markers (freeways and cities) in the region. Modified map obtained from Southern California Earthquake Data Center (<http://www.data.scec.org/>). The Mojave Block is defined as an area bounded to the south by the San Andreas Fault and to the north by the Garlock Fault. The study area at Alvord Mountain is also indicated.

by as much as 60° according to paleomagnetic studies (Ross et al., 1989; Ron and Nur, 1996; Schermer et al., 1996; Miller et al., 2002; Glazner et al., 2002).

Previous Work

The amount, timing and distribution of strain on faults and folds in the Mojave Block, and particularly the importance and distribution of vertical axis rotation of fault blocks, is controversial. Total dextral slip across the Mojave Block since the early Miocene is estimated by Glazner et al. (2002) to be 44-72 km. This value is similar to ~65 km of dextral shear estimated by Dokka and Travis (1990), although the details of how that shear is distributed vary considerably. Provided below is a very basic review of these models as they pertain to the area of study.

Dokka and Travis (1990) proposed that sub-blocks in the central and north-central Mojave have rotated clockwise about vertical axes between 20° and 67° after the inception of the Eastern California Shear Zone (ECSZ) in the late Miocene (between 6-10 Ma) due to large-scale transtension, forming dilatational holes at domain boundaries as the province extended east-west. Glazner et al. (2002) argue that dextral and associated sinistral slip on east-striking faults is accommodating some vertical axis clockwise rotation of domain-specific fault blocks anywhere from 20° to 60°, which are domain specific (Figure 2), and based on documented slip on faults, geologic field relations and paleomagnetic data. Bartley et al. (1990) argue that in addition to the north-south shortening and vertical axis rotation of fault blocks a component of shortening within small-scale blocks is also being accommodated in the Mojave Block. They include

Fig. 2. Geologic map showing faults divided into kinematic domains through the Mojave Block of southeastern California, modified from Glazner et al. (2002). Zones 1 and 3 have verified lack of block rotation between major block-bounding faults post 23 Ma. Zones 2a and 2b have relatively well-constrained clockwise vertical axis rotation post-23 Ma of 22° and 23° respectively (see discussion in text and in Glazner et al., 2002).

Alvord Mountain in their study, which they argue created the anticlinal fold found there. They also interpret the dilatational holes of Dokka and Travis (1990) as depressions caused by thrust loading.

Research in the Fort Irwin area (domain 2a in Figure 2) north of Alvord Mountain has shown that east-striking sinistral faults have produced a minimum displacement between 3-5 km on block-bounding faults (Schermer et al., 1996). This is documented geologic slip that would be consistent with models by Schermer et al. (1996) which allow for 23° of clockwise vertical axis rotation related to dextral shear of 22 km, given 5 km of sinistral slip on these faults (Figure 3B). An additional 15° of clockwise vertical axis rotation can occur giving an additional 11 km of dextral slip, with no additional left slip occurring on sinistral faults (Figure 3C). This would allow clockwise rotations due to slip on east-striking sinistral block-bounding faults to be as high as 38°. However, paleomagnetic results indicate that rotation is as high as ~60°. This discrepancy may be explained by the clockwise bent ends of faults where paleomagnetic data were collected (Schermer et al., 1996). Miller and Yount (2002) explain this discrepancy by showing that strain within many of the fault-bounded blocks is partitioned into numerous smaller strike-slip faults, thrust faults and folds, and normal faults, with cumulative displacements possibly as great as 50% of displacement on block-bounding faults.

Research to the south of Fort Irwin has shown that the east-striking sinistral Afton and Manix Faults (Figure 2), which bound a sub-block 50 km long and 7 km wide have each separately produced 5 km of sinistral shear (Meek and Battles, 1990; Walker, personal communication, 2004). The slip may have produced approximately 22° of clockwise

(A)

Before Deformation (~10 Ma)

(B)

After 23° rotation,
5 km of left slip on faults
within domain
Total dextral shear, 22 km

(C)

Present
Additional rotation of 15°
No additional left slip
Total dextral shear, 33 km

Fig. 3. Figure showing rotations related to dextral slip over the last 10 Ma in the northern part of the Mojave Block, California directly north of Alvord Mountain from Schermer et al. (1996).

vertical axis rotation in the vicinity of Alvord Mountain (Glazner et al., 2002) in agreement with the minimum estimate of rotation in the Fort Irwin area (Schermer et al., 1996). On the basis of paleomagnetic data Ross et al. (1989) suggests that up to 50° of clockwise vertical axis rotation occurred sometime after the early Miocene at Alvord Mountain and that up to 27° occurred after 16 Ma. These numbers still leave a discrepancy between paleomagnetic results and documented slip in the region. Ron and Nur (1996) attempt to substantiate the paleomagnetic data collected by Ross (1989) and concluded that 50° of vertical axis clockwise rotation occurred at Alvord Mountain and three other localities in the Mojave Block, by comparing orientation of Independence dikes north of the Garlock Fault with dikes at these four Mojave Block localities. Miller and Walker (2002) determined that the dikes used to infer rotation at Alvord Mountain are actually late Cretaceous in age and not correlative to the late Jurassic Independence dikes north of the Garlock Fault thus casting doubt on this evidence for rotation.

Hopson et al. (2005) compare declinations from previous studies on the Independence dikes to the azimuths of 3600 dikes from 45 domains throughout the same dike swarm. A quarter of these dike orientations varied widely from the mean which indicate large deviations from the main trend of the swarm. Hopson et al. (2005) therefore concluded that dike orientations may be only a limited guide to late Cenozoic (post-23 Ma) vertical axis rotations.

Purpose of Study

As seen from the previous work done in this region, there is much discrepancy between vertical clockwise rotation amounts seen in paleomagnetic data and what would be predicted by amounts of documented slip on faults. This study therefore focuses on the significance of late-Cenozoic deformation at Alvord Mountain in order to gain a better understanding of kinematics of faulting and associated block rotation in the study area and within the Mojave Block as a whole. This study adds additional data that shed light on the discrepancies observed in previous studies at Alvord Mountain and surrounding the study area.

ROCK UNITS

Introduction

The rock descriptions of stratigraphy at Alvord Mountain (Figure 4) come from a combination of work done by Byers (1960), Fillmore (1993), Miller and Yount (2002) and observations in the study area by the author and Jennifer Strona.

Pre-Tertiary Rocks

Plutonic Rocks (b)

A mid-Jurassic pluton is exposed at only a few localities in the study area and is expressed as small (usually < 500 m² area) knolls to the west of the study area. The pluton is widespread and comprises the main basement unit at Alvord Mountain (Miller and Walker, 2002).

Tertiary Rocks

Clews Formation (Tr)

This formation consists of three stratigraphic units at its type locality: a lower unit composed of fine-grained tuffaceous sediments which is 12 meters (40 feet) thick; a middle unit of ridge-forming reddish brown fanglomerate composed mostly of local quartz monzonite with clasts as large as 3 meters (10 feet) in diameter that is 135 meters (445 feet) thick; and an upper unit of sandstone with included tuff beds that is 21 meters

Fig. 4. Generalized stratigraphic column of rock units at Alvord Mountain.

(70 feet) thick (Byers, 1960; Fillmore, 1993). The Clews Formation is in conformable contact with the younger Spanish Canyon Formation where exposed (Figure 5).

Alvord Peak Andesite (Tv1)

Formerly known as the Alvord Peak basalt (Byers, 1960), geochemical analysis by Strona and Miller (2002) has shown this unit is a silicic andesite (Figure 6). In hand sample, the rock is a dark gray to grayish-black nearly aphyric andesite. The andesite ranges in thickness from 120 meters (~400 feet) near its type locality at Alvord Peak, and thins out to the east, where it completely disappears just west of Clews Ridge. Near the study area in Spanish Canyon, its thickness is approximately 110 meters (~350 feet).

Spanish Canyon Formation (Tsc)

The Spanish Canyon Formation (Byers, 1960) is exposed throughout the study area (Plate 1) and is underlain by Clews Formation in the north and by the Alvord Peak Andesite in the south. The lower part of the Formation consists of lenticular white and olive-gray tuffs interbedded with sandstone and granitic boulder conglomerate (Figure 7). In the most complete exposures, two tuff units are each overlain by two sandstone and conglomerate units. The lower tuff unit is the thicker of the two. The upper part of the formation consists of two grayish-black hogback-forming olivine basalt flows, which provide reliable markers in the study area. Thicknesses range from 6 to 18 meters (20-60 feet) and where the unit is thicker, are separated by 6 to 18 meters (20 to 80 feet) of sandstone or boulder conglomerate.

Fig. 5. Image showing Clews Formation (Tr) in conformable contact with Spanish Canyon Formation (Tsc).

Fig. 6. Image of Alvord Peak Andesite (Tv1) in the foreground and Spanish Canyon Formation (Tsc) in the background. Although the Alvord Peak Andesite is a cliff former generally, in the southern edge of the study area shown here it typically forms low-relief hills cut by narrow gullies and small canyons. This is the approximate location of a measured cross-section A-A' on Plate 1 in the southern part of the study area.

Fig. 7. Image of tuff unit within the Spanish Canyon Formation (Tsc) in southern part of study area.

Barstow Formation

Lower Member (Tal)

The lower member of the Barstow Formation attains a maximum thickness of approximately 275 meters (~900 feet) and consists of 150 to 180 meters (~500 to 600 feet) of interbedded sandstone and pebble conglomerate, overlain by 60 to 90 meters (~200 to 300 feet) of tuff, tuffaceous sandstone, siltstone, and volcanic pebble conglomerate. The conglomerate beds in the lower 150 to 180 meters (~500 to 600 feet) contain conspicuous rectangular fragments of banded siliceous pre-Tertiary argillite, are well indurated, and form resistant red beds in the study area (Figure 8). The upper 60 to 90 meters (~200 to 300 feet) of the lower member contains two or three white vitric ashy tuff beds overlain by conglomerates with extremely well-rounded, light gray and grayish red-purple porphyritic andesite pebbles and cobbles.

Middle Member (Tam)

The tuffaceous middle member of the Barstow Formation comprises two or three, rarely more, friable white granular tuff beds and intervening clastic beds. The member varies greatly in thickness, depending mainly on the amount of clastic material between tuff beds. The total thickness of the tuff beds is approximately 3 meters (~10 feet). The tuff beds are frangible, poorly consolidated, granular, and pumiceous (Figure 9). Many of the white pumice

Fig. 8. Image of lower member of the Barstow Formation (Tal) in the south part of the study area.

Fig. 9. Image of middle member of the Barstow Formation (Tam) in the north part of the study area.

fragments in the tuff are near-lapilli or pea sized. The matrix includes glass shards and a minor amount of light yellowish-gray silt or fine sand. The lowermost tuff does not contain as much biotite as the other two beds. Most of the glass is pumice.

Upper Member (Tau)

The upper member of the Barstow Formation varies from about 30 to 120 meters (~100 to 400 feet) thick (Byers, 1960) and is unconformable with the overlying granitic fanglomerate in the northern part of the study area (Figure 10). An andesite cobble conglomerate, as much as 30 meters (~100 feet) thick, overlies the middle member of the Barstow Formation. Above the basal 30 meters (100 feet), the upper member consists of pebble conglomerate and interbedded sandstone with characteristic grayish-orange (salmon) color.

Basalt Flows (Tav)

Isolated outcrops of basalt mapped as Barstow volcanic units appear in the southernmost portion of the study area. These isolated exposures are surrounded by alluvium and are surrounded by exposed Barstow Formation in nearby areas.

Late Tertiary and Early Quaternary Rocks

Granitic Fanglomerate (QTcg)

Granitic fanglomerate is exposed extensively throughout the inward-facing

Fig. 10. Image of an angular unconformity between the upper member of the Barstow Formation (Tau) and Quaternary – Tertiary gravels (QTcg) in the north part of the study area.

Fig. 11. Image showing ridge of Quaternary-Tertiary gravels (QTcg) in the northern part of the study area faulted up against the upper member of the Barstow Formation (Tau), in foreground.

escarpment and low hills that flank the northern part of the study area (Figure 11). The thickness of the granitic fanglomerate reaches a maximum of about 300 meters (~1,000 feet) and lies unconformably above the Barstow Formation (Figure 11). The granitic fanglomerate is composed of well-sorted boulder beds with minor interbedded pebbly sandstone. The granitic fanglomerate is less indurated than the Barstow Formation, but is somewhat more indurated than the Quaternary gravels.

Quaternary Deposits

Windblown Sand (Qs)

Dissected cross-bedded sands, apparently dune deposits, occur in the northern portion of the study area and are well-sorted.

Alluvium (Qa)

The recent alluvium in the study area contains gravel and sand deposits of active and abandoned washes. Material is derived mostly from the Pre-Tertiary and Tertiary materials found in Alvord Mountain.

METHODS

Fieldwork

Geologic mapping was conducted with a topographic base at an overall scale of 1:12,000 feet (Plate 1). Geologic mapping was also done at a 1:6,000 scale in the north part of the study area and is shown on Plate 1. Mapping was conducted primarily using standard geologic mapping techniques with assistance from air photos and a Trimble Global Positioning System data logger. Bedding orientations, fault orientations and slip directions were collected. Particular emphasis was placed on fault contact relations to determine timing of faulting. Two weeks of reconnaissance work at Alvord Mountain were completed with the help of Jennifer Strona and Dr. Jonathan Miller of San Jose State University and Dr. David Miller of the United States Geological Survey during the winter/spring of 2001. Seven weeks of fieldwork were completed in the winter/spring of 2002 and 2003.

Structural Analysis

Stereonet analysis was completed using GEORient software version 9.2 (Holcombe, 2005). GEORient was used to plot slickenline orientation data from faults, and bedding planes in an equal area stereonet using ASCII text exported from the Environmental Systems Research Institute (ESRI) ArcView 3.2 database. Plots included the following: poles to faults and bedding planes; trend and plunge of slickenlines, and orientation of principal stress axes.

Kinematic analysis of fault slip data follows Marrett et al. (1990) methodology and requires the graphical construction of the principal incremental shortening and extension axes for a given population of faults. Each pair of axes lies on a movement plane containing the slip vector and the normal vector to the fault plane, and are at angles of 45° with each of the vectors (Figure 12). To calculate these axes, fault plane and slickenline orientation data were plotted on a stereonet using GEORient 9.2 software (Holcombe, 2005). The pole to the fault plane and slickenline orientation lie on the movement plane in which the shortening and extension axes lie 45° away from the fault plane. The measure of slip determines where along the movement plane these axes are plotted. This type of plot depicts areas of maximum extension and maximum shortening, to help better explain fault kinematics.

Measured structure sections were created using a 1:12,000 and a 1:6,000 scale topographic base with no vertical exaggeration to determine amounts of offset along faults in the region. These sections are located on Plate 1.

Geographic Information System Database

ESRI ArcView GIS 3.2 software was used to store and manipulate geological information. Stratigraphic units were mapped as polygons, fault contacts as lines, and kinematic information of faults and bedding orientations as points. This database represents a compilation of geologic mapping completed primarily by B. Wyatt, with additional input from J. Strona, J.S. Miller, D. Miller, R. Miller, D. Walker, and F.M. Byers.

Fig. 12. Geometry of fault-slip kinematics in lower-hemisphere, equal area stereographic projection by Marrett et al. (1990). The kinematic axes, slip direction and pole to fault lie in a common plane, with each of the kinematic axes forming angles of 45° with both the slip direction and the pole to the fault.

The attributes included in this geologic database have been used to extrapolate the geologic structure of the Alvord Mountain region, including fault kinematics and bedding orientations.

RESULTS

The most obvious map-scale deformational features in the study area at Alvord Mountain are the broad northwest-plunging anticline that folds Tertiary-Quaternary gravels and older units, and a set of northeast-striking transtensional brittle faults that cut nearly all units of the anticline. The mapping and analysis focused primarily on the southernmost major northeast-striking fault at Alvord Mountain in an attempt to better understand how this fault and fault-related deformation are linked to broader scale deformation in the northern Mojave Desert. This fault is identified here and on Plate 1 as the Clews Ridge Fault, and has been divided into a southern segment and a northern segment for the purposes of this discussion. This division is located at "The Gap," shown on Plate 1, where alluvium is largely covering the exposure of the Clews Ridge Fault.

Clews Ridge Fault (Southern Segment)

The exposed main trace of the southern segment of the Clews Ridge Fault is ~2 km long and juxtaposes the Alvord Peak Andesite (Tv1) and well-indurated sandstone of the lower Barstow Formation (Tal, Figure 13). The Alvord Peak Andesite on the northwest side of the fault exhibits a well defined damage zone characterized by closely-spaced fractures about 3-5 centimeters apart. This pattern is exhibited several meters to the northwest away from the fault contact (Figure 14). Minor amounts of calcite mineralization are also apparent intermittently along many fault traces and fractures. The

Fig. 13 Image showing contact between a stratigraphically-younger Barstow Formation sandstone (Tal) against older Alvord Peak andesite (Tv1). Note arrow pointing out backpack for scale.

Fig. 14. Image showing Clews Ridge Fault contact close-up and extensive brecciation and damage of both Tal and Tv1. Note coffee mug in center of photo for scale.

lower member of the Barstow Formation, southeast of the Clews Ridge Fault, is also highly damaged, and has many small, well-exposed, minor fault traces parallel to the main structure which are several centimeters to 10s of meters long. These parallel fault surfaces are located meters to a few 10s of meters away from the main trace, with many of these surfaces exhibiting well preserved slickenstriae along well-polished fault planes (Figure 15). Each of the fault planes measured in this area showed only one clearly identifiable slickenline orientation.

The orientations of fault surfaces and associated slickenlines have been analyzed using equal area stereonet projections. These kinematic indicators were collected primarily along small faults parallel to and along the main trace of the Clews Ridge Fault. Stereonet analysis reveals that the Clews Ridge Fault exhibits a mean principal azimuthal orientation of 55° with a southeast dip of 72° (Figure 16a). The trend and plunge of slickenlines show a mean principal trend of 95° with a plunge of 55° to the east-southeast (Figure 16b). Fault plane slip indicators (e.g., drag, Riedel shears) on small fault surfaces were observed in only a few fault exposures, but (in the instances where slip could be determined) are consistent with inferred slip, based on stratigraphically determined slip along the main trace. A projection of m-poles for all slickenline data obtained along the southern segment of the Clews Ridge Fault show the trend and plunge of both the incremental extension and shortening axes (Figure 16c). This analysis indicates oblique normal slip with movement primarily to the east-southeast on this segment of the Clews Ridge Fault. A small graben is inferred to have formed between the Clews Ridge Fault

Fig. 15. Image showing well-polished striated fault planes exposed in the Barstow Formation near the southern segment of the Clews Ridge Fault. Pen shown for scale is oriented in the direction of slickenlines.

Fig. 16. Stereonet plots showing orientation data on fault traces parallel to and along the southern segment of the Clews Ridge Fault: a. poles to fault planes (mean 55° , 72° SE); b. fault planes plotted with trend and plunge of slickenlines (mean 55° SE, 95°) where arrow points in the direction of hanging wall slip towards the incremental extension axis (T-axis); c. the orientations of the principal stress axes where dark squares indicate sigma-1 and open squares indicate sigma-3, based on kinematic analysis of faults.

and the fault to the south based on map relations (see cross-section A-A' on Plate 1).

The amount of offset measured along the southern part of the Clews Ridge Fault is difficult to determine by direct field observations because of a lack of obvious piercing points. Slickenlines show that the last slip along the fault is oblique, and primarily down-dip. Determination of offset has therefore been calculated using geologic relations both in map and cross-section view (Plate 1) and the estimated slip direction based on the mean slickenline orientation. This calculation assumes that the fault has slipped consistently throughout its history. With these assumptions, 275-300 meters (900-1000 feet) of calculated normal slip has occurred along a transect crossing Wild Dog Ridge (Plate 1), although this is likely to be a minimum, since an additional component of lateral slip can be accounted for. Amounts of lateral offset is unconstrained due to poor exposure.

Clews Ridge Fault (Northern Segment)

This northern segment of the fault begins just east of "The Gap" (Plate 1) and is approximately 4 km long. No obvious fault surfaces are exposed within the Clews Formation along strike until the fault brings Mesozoic basement in contact with the Spanish Canyon Formation approximately 1.5 km (1 mile) to the northeast of "The Gap." Here, the Clews Ridge Fault changes orientation to the north-northeast, striking approximately 30° (Plate 1) and has been named "Splay A" for the purposes of this discussion. Approximately 1 km to the northeast the fault splays into two distinct segments. These have been named "Splay B" and "Splay C" (Plate 1). Fault surfaces are most apparent in the middle and upper members of the Barstow Formation and have well-

polished surfaces (Figure 17). Some fault planes in this area exhibit multiple orientations of slickenstriae on the same fault plane, probably indicating a complicated movement history for many of these small faults. As in the southern segment of the Clews Ridge Fault, sense of slip indicators are generally rare but where observed were consistent with inferred fault motion based on map relations.

Stereonet analysis has the Clews Ridge Fault along the northern segment exhibiting two mean principal azimuthal orientations of 43° with a southeast dip of 71° , and 226° with a northwest dip of 53° (Figure 18a). The trend and plunge of slickenline data show a mean principal trend of 72° with a plunge of 78° to the northeast (Figure 18b), which is somewhat steeper than the southern segment of the Clews Ridge Fault (i.e., greater down-dip component). A projection of m-poles for all slickenline data obtained on faults show the trend and plunge of both the incremental extension and shortening axes (Figure 18c). These kinematic data are consistent with data observed along the southern segment of the Clews Ridge Fault, although along the northern segment, the data are more dispersed.

The amount of offset measured along the northern part of the Clews Ridge Fault is difficult to determine by direct field observations because as in the southern segment, no piercing points were identified. Minimum determination of offset has been calculated using geologic relations in map view. A minimum of 1.5 km (5000 feet) of horizontal offset has occurred along the northern segment of the Clews Ridge Fault. This has been determined using lateral offset of the middle member of the Barstow Formation (Tam)

Fig. 17. Image showing: a.) Near-horizontal slickenline striae on a north-northeast striking fault; b.) Surface exposure of the same north-northeast striking fault.

Fig. 18. Stereonet plots showing orientation data on fault traces parallel to and along the northern segment of the Clews Ridge Fault: a. poles to fault planes (mean for NW quadrant cluster, 43° , 71° SE; mean for SE cluster, 226° , 53° NW); b. fault planes plotted with trend and plunge of slickenlines (mean is 75° SE, 71° where arrow points in the direction of hanging wall slip towards the incremental extension axis (T-axis); c. the orientations of the principal stress axes where dark squares indicate sigma-1 and open squares indicate sigma-3, based on kinematic analysis of faults.

along “Splay B,” and using lateral offset of the Spanish Canyon Formation basalts (Tv1) along “Splay C” (Figure 19). Lack of reliable stratigraphic indicators makes it difficult to determine the dip-slip component of offset in this domain, although slickenline striae suggest such movement. This would allow perhaps for a significant amount more of net offset across the northern segment of the Clews Ridge Fault. Offset amounts are very small where “Splay B” cuts Quaternary-Tertiary gravels. This relation shows that this fault was active before deposition of QTcg.

There is another small population of pervasive faults (Figure 20) exposed primarily in the upper member Barstow Formation between “Splays A” and “B” of the Clews Ridge Fault. These faults are oriented NNE ($\sim 20\text{-}25^\circ$) and have vertical dips (Figure 20a). Slickenline striae were collected (Figure 20b) but sense of motion was unobtainable.

Bedding Orientations

Bedding orientations of Tertiary rock units and Tertiary-Quaternary gravels across Alvord Mountain define a large anticlinal fold. The study area traverses across the southern portion of this anticline. Regions south of “The Gap” (Plate 1) in the study area sit west of the fold axis of this anticline, and the northern portion of the study area sits east of the fold axis. These beds have dips that, broadly speaking, are related to their proximity to the fold hinge. Dips range from a few degrees to as much as 41° (Figure 21). All the major high- angle faults cut this fold with east-northeast strikes, and beds tend to incline at steeper angles near faults. Quaternary-Tertiary gravels are also folded, although their dip angles are much shallower than older Tertiary units below (Figure 10).

Fig. 20. Stereonet plots showing kinematic data for a second smaller population of faults between splay A and splay B of the northern segment of the Clews Ridge Fault: a. Stereonet plot showing the poles to fault planes; b. Stereonet plot showing trend and plunge of slickenstriae.

Fig 21. Figure showing overall bedding orientations of rock units and Tertiary-Quaternary gravels (QTcg) in study area: a.) Poles to bedding in entire study area; b.) Poles to bedding west of the gap; c.) Poles to bedding east of the gap. Most of the south study area is west of the fold axis of a regional anticline, while most of the north study area is east of the fold axis. Steeper dips represent beds closer to faults.

Regional bedding orientations related directly to the overall orientation of the anticline in areas south of "The Gap" and west of the fold axis show a mean azimuthal orientation of 169° , 7° . The mean azimuthal orientation of all beds in the south part of the study area is 145° , 8° (Figure 21). The strikes of beds change orientation from southwest to northeast in the south part of the study area. In the southwest portion of the southern study area, the mean strike orientation as plotted on a rose diagram (Figure 22) is 45° - 225° . Towards the northwest quadrant of the south study area, the mean strike orientation as plotted on a rose diagram is 100° - 280° .

In the north part of the study area, beds north of "Splay A" are in the same orientation as regional beds along the east limb of the anticline. Beds north of "Splay A" show a mean strike orientation of 162° - 342° as plotted on a rose diagram (Figure 23). Beds between the "Splays A" and "B" of the Clews Ridge Fault show a mean strike orientation as plotted on a rose diagram as being 25° - 205° . Beds here strike at highly variable orientations and show dips anywhere from 6° to 41° . Beds south of Splay C of the Clews Ridge Fault show a mean strike orientation of 8° - 188° .

Fig 22. Figure showing change in orientation of bedding from the southwest to the northeast in the southern part of the study area: a.) Stereonet showing bedding orientations in southwest portion of study area; b.) Rose diagram showing a mean strike of 45° for beds in the southwest portion of the south study area; c.) Stereonet showing bedding orientations in the northeast portion of study area; d.) Rose diagram showing a mean strike of 100° for beds in the northeast portion of the south study area.

Fig 23. Figure showing stereonet and rose diagrams of bedding in north study area. Stars indicate mean: a.) Bedding north of the upper splay of the Clews Ridge Fault that also represents the regional strike of beds for the east limb of the anticline; Rose Diagram shows a mean strike of 162° ; b.) Bedding between the upper and lower splays of the Clews Ridge Fault. Rose diagram shows a mean strike of 025° ; c.) Bedding north of the upper splay of the Clews Ridge Fault. Rose diagram shows a mean strike of 008° .

DISCUSSION

The deformation at Alvord Mountain is complex and involves superimposed structures formed by local compression, extension, and strike-slip deformation. The main purposes for this discussion are to: (1) compare styles of deformation along the Clews Ridge Fault; (2) compare and contrast kinematics and slip along the fault, and (3) place the deformation in a regional context.

Clews Ridge Fault (Southern Segment)

The southern segment of the Clews Ridge Fault has had a complex deformational history. Its most recent motion has been recorded by slickenline data, offset rock units, and drag folding, as evidenced by variance in strike and steepening of beds along the fault trace. Analysis of these data suggest that the Clews Ridge Fault is a northeast-striking transtensional fault with motion down to the east-southeast (Figure 16, Plate 1).

Immediately to the southeast of the Clews Ridge Fault, two parallel fault segments have been mapped or inferred by the author (Plate 1), and these appear to parallel the Clews Ridge Fault. These parallel fault splays change orientation on approach to the Clews Ridge Fault where they go from an easterly strike to a southwesterly strike parallel to the Clews Ridge Fault (Plate 1, Figure 24 and 25). A measured cross-section along a northwest line A-A' has been completed across the Clews Ridge Fault and the proposed Afton Fault (Plate 1) in the study area. Faulting geometries and the order of lithologic

Fig. 24. Image showing the inferred trace of the Afton Fault, looking towards the east, as it bends from an easterly to a southwesterly direction. Note the graben between the two ridges. Map view of this photo shown in Figure 25.

Fig. 25. Illustration showing possible clockwise vertical axis rotation between splays of the proposed Afton Fault in the southern part of the study area from Plate 1.

units suggest that a small graben has formed between these two faults (Figures 24 and 25), which would be consistent with transtension in this region as shown by the Clews Ridge Fault.

The Afton Fault, an east-striking sinistral fault, has been mapped by Walker (personal communication, 2004) in the Cronese Hills ~7 km to the east of Alvord Mountain. Granite in the Cronese Hills has been offset left-laterally by 5 km (Walker, personal communication, 2004). This fault, when projected to the west, potentially merges with the southern segment of the Clews Ridge Fault (Plate 1), so these faults possibly are the westernmost exposures of the Afton Fault. However, the magnitude of strike-slip motion on the Afton Fault to the east (5 km) is difficult to reconcile with the estimated slip on these faults and Clews Ridge Fault (a few hundred meters).

Clews Ridge Fault (Northern Segment)

Observations and measurements for the northern segment of the Clews Ridge Fault and related sub-parallel faults are also consistent with a northeast-striking transtensional system with motion down to the east-southeast, although in detail the data are not as coherent as they are along the southern segment. This may be due to different responses of the rocks to deformation in the north part of the study area (e.g., well-indurated sandstone and basalt in the south vs. less well-indurated sandstone and tuffaceous sediments along the northern segment), a change in the behavior of the fault itself (i.e., change in the stress field along strike) or a combination of both factors together over the time the fault was active.

As shown in Figure 19 and Plate 1, the main trace of the Clews Ridge Fault splays into three main traces to the northeast of "The Gap." "Splay A" shows little apparent horizontal offset in comparison to "Splay B" and "Splay C", but it separates beds striking 342° north of the fault (parallel and east of the axial plane of the regional anticlinal fold) from beds striking primarily 25° south of this splay (Figure 19). The middle and lower splays (Figure 19, Plate 1) both show equivalent but relatively large amounts of lateral offset (1.5 km) when compared to the upper splay (0.2 km). Cross-cutting relations show that some normal faults have been laterally offset, and have probably been rotated by these splays by varying amounts (Figure 19). The offset along these normal faults is not large, and shows evidence of a few to 10s of meters of offset and drag folding. One or more of these faults are also probably responsible for locally cutting out the Spanish Canyon Formation between "Splays B" and "C". A measured cross-section along a northwest line B-B' across these rotated marker beds (Tam) shows this relationship (Plate 1).

There is another small population of pervasive north-striking faults (Figure 19) that is exposed primarily in the upper member of the Barstow Formation between "Splays A" and "B" of the Clews Ridge Fault. This group has a mean azimuthal orientation of 22° and a vertical dip (Figure 20). Map relations suggest that these faults are a newer generation of faults than the Clews Ridge Fault when looking at cross-cutting relations between the two distinct different orientations. Poor exposure between the two fault contacts and the small number of data points prevents further interpretation of the data.

Strain Incompatibility between the Afton Fault and Clews Ridge Fault

The Afton Fault in the Cronese Hills 7 km east of Alvord Mountain has been documented as having 5 km of sinistral offset along its trace (Walker, personal communication, 2004). The Clews Ridge Fault is documented in this study as having a minimum total of 1.5 km (4900 feet) of lateral offset along the northern segment. In addition, a minimum of 300 meters of left-lateral oblique slip took place on the southern segment of the Clews Ridge Fault has been measured. The minimum combined lateral slip across the Clews Ridge Fault would therefore be greater than 1.5 km and less than 1.8 km. This leaves a deficit of between 3.0 and 3.5 km left unaccounted for when considering motion along the Afton Fault. Available kinematic data allowed only for a minimum amount of offset along the Clews Ridge Fault.

There is a difference of observed and/or estimated slip between the northern and southern segments of the Clews Ridge Fault that needs to be addressed. One contributing factor for this difference may be that larger amounts of slip could be budgeted along the southern segment of the Clews Ridge Fault given better piercing points and exposure. Another possibility may be that slip is being transferred to other faults south of the Clews Ridge Fault. A large amount of alluvium conceals the Afton Fault between the Cronese Hills and Alvord Mountain, where deformation of bedrock is not visible, and a significant amount of slip could be concealed. The Afton Fault may also continue west and south of the Clews Ridge Fault, and could be concealed by alluvium. High ridges of Plio-Pleistocene sediments to the south of the Clews Ridge

Fault may possibly reflect deformation related to unexposed faults just south of the study area.

Regional Bedding Orientations and Localized Clockwise Vertical Axis Rotation

Bedding orientations of Tertiary rock units and Tertiary-Quaternary gravels in the south part of the study area change orientation significantly from the southwest to the northeast, and are not directly related to regional folding. Beds in the southwest portion of the study area change strike over a greater than 1 km map distance from northeast 45° parallel to the Clews Ridge to east-northeast 100° and parallel to the possible Afton Fault splays (Figure 25). If left slip occurred on these faults, then this suggests a clockwise rotation of beds between the Clews Ridge and Afton Faults of $\sim 55^{\circ}$ as one moves toward the northeast. This rotation is similar to that estimated by Hillhouse (1994) using paleomagnetic data collected from a thin exposure of Peach Springs Tuff in this same area, which gave 48° - 56° of clockwise vertical axis rotation with respect to an unrotated Miocene pole on the Colorado Plateau (Figure 25).

Rotation has probably affected beds along the northern segment as well. Regional bedding related to folding on the east side of the fold axis shows a mean azimuthal orientation of 348° , 22° , which is the azimuthal orientation of beds north of the upper splay of the Clews Ridge Fault. The structural complexities of the northern domain are primarily associated with rotation of blocks between "Splays A" and "C" of the Clews Ridge Fault (Figure 19). Relatively older normal faults and beds originally showing a northerly strike have been rotated clockwise about a vertical axis locally by the northern

segment of the Clews Ridge Fault as much as 20° - 45° due to shear, assuming the Barstow Formation Middle Member (Tam) is relatively undeformed approximately 1.5 km to the east, where beds are striking generally due north (Figure 19), and assuming these same bedding parallel faults were in the same orientation as these same undeformed Barstow middle member (Tam) units at inception. This is shown diagrammatically in Figure 26 as a series of block diagrams where north-striking, east-dipping Barstow Formation is cut by strike-parallel normal faults, which are then later rotated during left-lateral shear on the Clews Ridge Fault.

Timing of Regional Folding and Faulting

Bedding at Alvord Mountain is folded into a large north-northwest plunging anticline (Byers, 1960). All Tertiary rock units, including Quaternary-Tertiary gravels, have been folded, although there is evidence that folding may have partly been syntectonic with deposition of the Quaternary-Tertiary gravels. Evidence for this includes a significant angular unconformity between the gravels and the Tertiary Barstow Formation, (especially visible in the northern part of the field area [Figure 10]), and shallowing dips upwards in the Quaternary-Tertiary gravels, (seen best in drainages to the north of the field area [see also Byers, 1960]).

The Clews Ridge Fault and parallel faults to the north clearly cut the major fold and Quaternary-Tertiary gravels in the study area. In addition, there is no obvious evidence that the major faults, including the Clews Ridge Fault, have been folded. Thus regional folding and fold-related uplift appear to precede most of the major transtensional faulting

Fig. 26. Figure showing deformation of north study area: a.) Before deformation; b.) After normal faulting with a few to 10's of meters of offset; c.) After deformation related to the northern segment of the Clews Ridge Fault showing differential clockwise rotation between splays.

and block rotation documented here. Miller and Walker (2002) suggest the major anticlinal fold is younger than 3 Ma based on sedimentological observations in the region coupled with fission track data showing final cooling of uplifted igneous rocks in the late Miocene or early Pleistocene. This youthful upwarping is then superimposed by the Clews Ridge Fault and numerous other younger faults, including a ~4 km long northeast-striking normal fault parallel to the Clews Ridge Fault, approximately 2 km to the north (Figure 27). In addition, Pliocene ash within the Quaternary-Tertiary gravels (QTcg) is folded (D. Miller, personal communication, 2005). Reconnaissance along this fault suggests that motion is primarily down-dip with very little if any strike-slip motion, as indicated by both slickenstriae on fault planes and drag folding along its part of the fault.

Regional Deformation and Alvord Mountain

As mentioned previously, earlier work in the vicinity of Alvord Mountain has suggest that: (1) folding is due to transpression associated with regional N-S shortening (Bartley et al., 1990); (2) Alvord Mountain may have rotated about a vertical axis as large rigid blocks (Schermer et al., 1996); (3) a minimum of 20 km of regional dextral shear have been postulated to feed through to the Alvord Mountain region by some combination of sinistral slip and block rotation (Glazner et al., 2002).

During late Miocene to at least Pleistocene time Alvord Mountain has clearly not behaved as a single coherent rotating rigid block as simple models of block rotation in the Mojave Desert region have concluded previously (e.g., Ross et al. 1989; Ron and Nur, 1996; Schermer et al., 1996). Faults parallel to the Clews Ridge Fault and the major

Fig. 27. Illustration showing deformation (faults and folds) between the Coyote Lake Fault and the Afton Fault at Alvard Mountain. Diagram in top right corner shows how deformation might progress in a pure wrench system due to simple shear (discussed in text). Faults are dashed where approximated, dotted where concealed. Most of the small NE-striking faults minor sinistral or dextral offset and an unconstrained but probably minor (< a few hundred meters) amount of normal offset. Folds are shown by lines representing axial planes and arrows representing anticlinal folds. Map modified from Byers (1960).

anticline collectively document significant out-of-the-plane deformation. However, the relations between folding and transtensional faulting at Alvord Mountain are complex and cannot be neatly incorporated into other regional models of deformation. For example, Bartley et al. (1990) propose that regional transpression is causing north-south contraction in the Mojave Block and may be responsible for the anticlinal fold at Alvord Mountain. However, the orientation of this fold would suggest east-west contraction. In addition, models of block rotation north of the Coyote Lake Fault by Schermer et al. (1996), which is the northern boundary of Alvord Mountain, suggest that the region has rotated clockwise about a vertical axis as a rigid block. These models however can account only for approximately 23° of vertical axis clockwise rotation (Figure 3) with 5 km of slip on east-striking sinistral faults. When applying this model to the Alvord Mountain block between the Afton and Coyote Lake Faults, this creates a discrepancy between paleomagnetic data and rotation allowed by shear of approximately 30° (Schermer et al., 1996).

Overall deformation at Alvord Mountain is likely coupled to the two large-scale east-striking sinistral faults that bound it to the north and to the south (Figure 27). The east-striking sinistral Afton Fault is the south block-bounding fault and has documented slip across it of 5 km (Glazner et al., 2002; Walker, pers. comm. 2004). Alvord Mountain is bounded to the north by the east-striking sinistral Coyote Lake Fault, which was identified by McCulloh (1960) who determined that there is a sharp step in depth to basement using topography and gravity data. Offset has not been determined because this fault is obscured along much of its length by alluvium (Schermer et al., 1996) but it

does truncate Pliocene and Quaternary deposits, generally producing a north-facing scarp in Pliocene gravel that is 10 to 50 m high. The Pliocene gravel is also deformed into folds along the fault with axes trending $\sim 20^\circ$, vertical axial planes, and limb dips of 20° (Miller and Yount, 2002).

The rotated domains observed at Alvord Mountain along the Clews Ridge Fault are small and highly localized, and the total amount of rotation in these smaller blocks are poorly constrained. These internal rotations appear to be related in large part to both interactions of the proposed Afton Fault and Clews Ridge Fault in the south, and by vertical axis rotation between differing splays of the Clews Ridge Fault in the north, related to internal deformation of the block rather than a large regional rigid body clockwise vertical axis rotation, as has been observed in similar blocks north of the study area (Schermer et al., 1996; Miller and Yount, 2002).

One model that might help explain deformation at Alvord Mountain is a wrench system caused by simple shear between the Afton and Coyote Lake Faults (Figure 27). Extension in this model would be accommodated primarily by transtensional northeast-striking faults, including the Clews Ridge Fault, and compression would be accommodated primarily by a north-northwest trending anticline. Both structures are in approximately the correct orientation for wrenching between these two major block-bounding faults. The problem with this model, however, are that normal faults at Alvord Mountain, particularly along the Clews Ridge Fault, are in transtension and they fail to exhibit pure dip-slip motion, as a simple shear wrench system would require. This model would also require that both the Afton Fault and the Coyote Lake Fault be continuous

throughout the south and north parts of the study area. This is not observed directly with either fault, although parts of the Afton and Coyote Lake Faults are concealed by alluvium in many locations.

Another model that can help explain deformation at Alvord Mountain is a contractional step-over between the Afton Fault and the Coyote Lake Fault. Evidence for this contraction is the north-northwest striking anticlinal fold between the Afton and Coyote Lake Faults. In addition, the Afton Fault strikes westward from the Cronese Hills into the southeast portion of the study area but direct evidence for the Afton Fault disappears west of the Clews Ridge Fault, although this may be explained by alluvium concealing the fault trace. This may also be explained however by the Coyote Lake Fault being the continuation of this contractional step over to the northwest of Alvord Mountain. The Coyote Lake Fault cuts through bedrock in the regions to the northwest of Alvord Mountain in the Fort Irwin area. However, there seems to be little direct evidence for the Coyote Lake Fault along strike to the east (Byers, 1960; Miller and Yount, 2002), although this may be explained by large amounts of alluvium covering the fault trace in this location as well.

CONCLUSIONS

Stratigraphic and structural data presented in the previous sections imply the following Plio-Pleistocene deformation for Alvord Mountain:

- (1) Between 1.5 and 1.8 km of combined minimum slip has been calculated for the Clews Ridge and related faults, and likely has had more.
- (2) Clockwise vertical axis rotation of between 20-50 degrees has occurred at Alvord Mountain in the study area which is due in part due to motion along the Clews Ridge and Afton faults to the south and motion along splays of the Clews Ridge Fault to the north.
- (3) Internal deformation between the Afton and Coyote Lake faults may be occurring as either: (a) a wrench system associated with simple shear between the Afton Fault and Coyote Lake Fault, or (b) a contractional step over between the Afton Fault and Coyote Lake Fault.

These results imply that Alvord Mountain cannot be treated purely as a rotating rigid crustal block. Deformation is accommodated not only laterally, but structures are observed that are compatible with both transpression (fold) and transtension as faults with a normal component of displacement. Detailed study of structures between block-bounding faults, such as at Alvord Mountain, have a complex strain history that is important to incorporate into regional shear zone models.

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APPENDIX: DIGITAL GEOLOGIC MAP DATABASE SPECIFICATIONS

Introduction

This geologic map database describes geologic materials and structural relations completed for Alvord Mountain, San Bernardino County, California. Geologic units in the area consists of Mesozoic igneous basement and Tertiary – Quaternary sedimentary, volcanic and alluvial deposits.

The data presented in this database is useful to understand and extrapolate from, physical geologic properties of the southeast Alvord Mountain region including properties of beds and bedding relations and kinematic information of faults.

Digital Compilation

The geologic map information was digitized in Environmental Systems Research Institute (ESRI) ArcView version 3.2. The projection of this data is in Universal Transverse Mercator and the datum is 1983, zone 11. The map compilation presents new polygon (geologic map unit contacts), line (faults) and point (structural attitude) vector data that was used to analyze structural data by location. Use of a Trimble GeoExplorer III Global Positioning System (GPS) receiver during field observations aided in determining positions and extents of geologic features while mapping in pencil on a paper topographic base map. The data were collected according to the accuracy standard of maintaining a maximum Position Dilution of Precision (PDOP) of 6, while tracking a

minimum of 4 satellites. These data were differentially corrected and have estimated accuracies in the X and Y direction of 0 to 5 meters, using the above standards while selective availability is set to zero.

Most areas were mapped at 1:12,000 with the exception of between “Splays A” and “B” of the northern segment of the Clews Ridge Fault (Plate 1), which were mapped at 1:6,000 scale. Lines, points and polygons were digitized using these base maps by standard ArcView 3.2 commands on a GUI interface.

Spatial Resolution

Use of this digital geologic map database should not violate the spatial resolution of the data. Although the digital form of the data removes the constraints imposed by the scale of the paper map (Plate 1), the detail and accuracy inherent in the map scale are also present in the digital map. Plotting at scales larger than 1:12,000 (or at 1:6,000 scale between “Splays A” and “B” of the northern segments of the Clews Ridge Fault) will not yield greater accuracy, although it may reveal fine-scale irregularities above the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Database Specifics

General

The map database consists of ArcView format shapefiles, which are stored in Universal Transverse Mercator (UTM) projection (Table 1), and a series of data tables.

The content of the geologic database can be described in terms of feature classes that include lines (PolyLines), areas (Polygons), and points that compose the map.

Definitions of the database items are explained in Table 2.

Lines

Lines are recorded as strings of vectors and are described in the arc database file (Faultlines.dbf) described in Table 3. They define the mapped fault types in this digital database. The distinctions, including whether the location of the contact is certain, approximately located, or concealed are recorded in the Fault_type field according to the line types listed in Table 4.

Table 1 – Map Projection

Projection	Universal Transverse Mercator (UTM)
Datum	1983, zone 11
Zunits	Meters
Units	Meters
Spheroid	GRS 80
X shift	None
Y shift	None

Table 2 – Description of Database Items

Geologic Layer	Shapefile	Description
Contacts	<Geology.shp>	Polygon files of geologic units and boundary of study area.
Map Boundary	<Qal.shp> <Map_boundary.shp>	
Faults (Lines)	<Faultlines.shp>	Line/arc file of fault contacts.
Bedding (Points) Fault (Points)	<Bedding_attitudes.shp> <Fault_attitudes.shp>	Strike and dip of beds. Strike and dip of fault, kinematic data where known.
Base Map	<Alvord_east.tif>	Topographic base from 500 dpi scan of USGS Alvord Mountain East 7.5' quadrangle, 1986.

Table 3 – Description of Arc Database File <Faultlines.dbf> for Faultlines.shp

Shape	PolyLine
Id	Unique number
Fault_type	Description in Table 4

Table 4 – Line Types Recorded in the Fault_type field of the Arc Database File Faultlines.dbf for Shapefile Faultlines.shp

Normal_concealed	Normal fault, concealed
Normal_approximate	Normal fault, approximately located
Normal_certain	Normal fault, certain
unknown_conceal	Unknown fault type, concealed
unknown_approx	Unknown fault type, approximately located
unknown_certain	Unknown fault type, certain

Areas

Areas are described in the arc database file (Faultlines.dbf) described in Table 5.

They define the mapped rock units in this digital database. Map units are identified under Ptype by map label, and are listed in Table 6. Further descriptions of rock units listed are available in the Rock Units chapter of this manuscript.

Table 5 – Description of Polygon Database File <Geology.dbf> for Geology.shp

Shape	Polygon
Id	Unique number
Ptype	Description in Table 6

Table 6 – Map Units Recorded in the Ptype Field of Polygon Database File <Geology.dbf>

Ptype	Description
Qs	Quaternary sand
Qa	Quaternary alluvium
QTcg	Quaternary/Tertiary gravel
Tav	Barstow Formation Basalt
Tau	Barstow Formation Upper Member
Tam	Barstow Formation Middle Member
Tal	Barstow Formation Lower Member
Tsc	Spanish Canyon Formation
Tr	Clews Formation
b	Mesozoic Basement

Points

Data gathered at a single locality are described in two different arc database files. Arc database file Bedding_attitudes.dbf is described in Table 7 and arc database file Fault_attitudes.dbf is described in Table 8.

The identities of the points describing bedding planes taken are recorded in the Id field of the shapefile Bedding_attitudes.shp. Strike and dip values of the bedding planes are recorded in the Strike and Dip fields, respectively. The Strike_corr field can be used to rotate a strike and dip symbol to its proper orientation in the Legend Editor of ArcView3.2 by clicking on “Advanced” and selecting Strike_corr from the drop down menu. The unit field depicts the rock unit the bedding measurement was taken. See Table 6 for further description of rock units.

The identities of the points describing fault planes and kinematic indicators taken are recorded in the Id field of the shapefile Fault_attitudes.shp. Strike and dip values of the fault planes and trend and plunge of the slickenlines, are recorded in the Strike and Dip fields and Trend and Plunge fields respectively. Numerical values of “0” in the dip, trend and plunge fields indicate that data were not collected or available. The unit field depicts what rock unit the fault or bedding measurements were taken. See Table 6 for further description of rock units.

Table 7 – Description of Point Database File <Bedding_attitudes.dbf> for Bedding_attitudes.shp

Shape	Point
Id	Unique number
Strike	0° - 360°
Dip	0° - 90°
Strike_cor	Negative number 0° - 360°
Unit	See Table 6

Table 8 – Description of Point Database File <Fault_attitudes.dbf> for Fault_attitudes.shp

Shape	Point
Id	Unique number
Strike	0° - 360°
Dip	0° - 90°
Trend	0° - 360°
Plunge	0° - 90°
Fault_type	See Table 9
Unit	See Table 6

Table 9 - Fault Type Recorded in the Fault_type field of the Point Database File <Fault_attitudes.dbf>.

normal	Normal fault
reverse	Reverse fault
strike-slip	Strike-slip fault (unknown slip)
unknown	Unknown fault type

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI

Geologic Map

lap and Sections of t North-cen San Bernard B

of the Southeast Por -central Mojave Dese ardino County, Calif

By Bridget Wyatt

East Portion of Alvord Mesa Desert California

Alvord Mountain

116° 33.75'

Scale: 1:6,000

Rubic's Cube

1:6,000

s Cube

SE
B'

Quaternary

Qs

Qa

QTcg

T

Explanation

Quaternary

Qs

Windblown Sand

Qa

Alluvium

QTcg

Quaternary Tertiary Gravels

Tertiary

Local Angular Unconformity

Approximate Mean Declination
Declination, 1960

35° 3.25'

1,000 500

Scale 1:12,000

Contour Interval is 40 feet
Datum is mean sea level

Tertiary

Barstow F

Tam

Tal

Tsc

Tr

Pre-Tertiary

b

25

Local Angular Unconformity

Barstow Formation

- Basalt
- Upper Member
- Middle Member
- Lower Member

- Spanish Canyon Formation
- Alvord Peak Andesite
- Clews Formation

Regional Nonconformity

Pre-Tertiary

- Basement

----- Contact

Dashed where approximately located; dotted where concealed.

Fault, showing dip

Dashed where approximately located; dotted where concealed. U, upthrown side; D, downthrown side. Arrows indicate relative movement, where known. Line indicates trend and plunge of slickenline striae where known.

Strike and Dip of Beds

Horizontal Bedding