STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND STRUCTURE OF THE TERTIARY UNITS IN THE NORTHERN PART OF THE FURNACE CREEK BASIN, DEATH VALLEY, CALIFORNIA

By

MARK EDWARD SAVOCA

Bachelor of Arts
S.U.N.Y. at Binghampton
Binghampton, New York
1978

Bachelor of Science
University of Washington
Seattle, Washington
1985

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1989

STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND STRUCTURE OF THE TERTIARY UNITS IN THE NORTHERN PART OF THE FURNACE CREEK BASIN, DEATH VALLEY, CALIFORNIA

Thesis Approved:

Ibrahim Cemen
Thesis Advisor

Zuhair al-Shaieb

Gary F. Stewart

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to express my sincere thanks to my thesis advisor, Dr. Ibrahim Cemen, for his patience, guidance, encouragement, and valuable suggestions. I would also like to thank my committee members Dr. Zuhair Al-Shaieb and Dr. Gary Stewart, whose contributions have served to improve this thesis.

I would like to thank Dr. James McAllister, whose work in the Furnace Creek Wash area provided an invaluable source of information. I thank Dr. Lauren Wright, Bennie Troxel, and Martin Miller for their contributions in the field, and for making my field season a memorable one.

I wish to express my gratitude to my fellow graduate students who have given friendship and support. I am fortunate to have shared so much, with so many excellent people.

This study was supported by an American Chemical Society-Petroleum Research Fund (ACS-PFR #18085-GB2) grant awarded to Dr. Ibrahim Cemen. I thank the donors of The Petroleum Research Fund for support of this research.

Partial support was also provided by a Death Valley Natural History Association research grant, and a Skinner Fellowship from the School of Geology, Oklahoma State University.

I would like to thank Death Valley National Monument for allowing this research to be conducted within the park, and for the logistical support provided during my field season.

I thank my parents, Jeanine and Joseph Savoca, for the lifetime of love, warmth, understanding, and encouragement. The acorn does not fall far from the tree.

Table Of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Research Objective

This study is concerned with the stratigraphy, sedimentology, and tectonic significance of Late Cenozoic rocks exposed in the northeastern part of Furnace Creek Wash, Death Valley, California (Fig. 1). These rocks record a period of deformation along a segment of the Furnace Creek strike-slip fault zone.

Location of Study Area

The Death Valley region, which is a part of the Basin and Range physiographic province of North America, is located in southeastern California (Fig. 1). The northwest trending Furnace Creek Wash lies to the east of central Death Valley and is bounded by the northern Black Mountains to the southwest and the central Funeral Mountains to the northeast (Fig. 1). Two areas within the northeastern part of the Furnace Creek Wash were studied (Fig. 1). The northern area lies within the U.S.G.S. Furnace Creek Quadrangle, Inyo County, California, between latitudes 36°30'and 36°24'10" north and longitudes 116°51'12" and 116°45'3" west and extends eastward from the northern Black

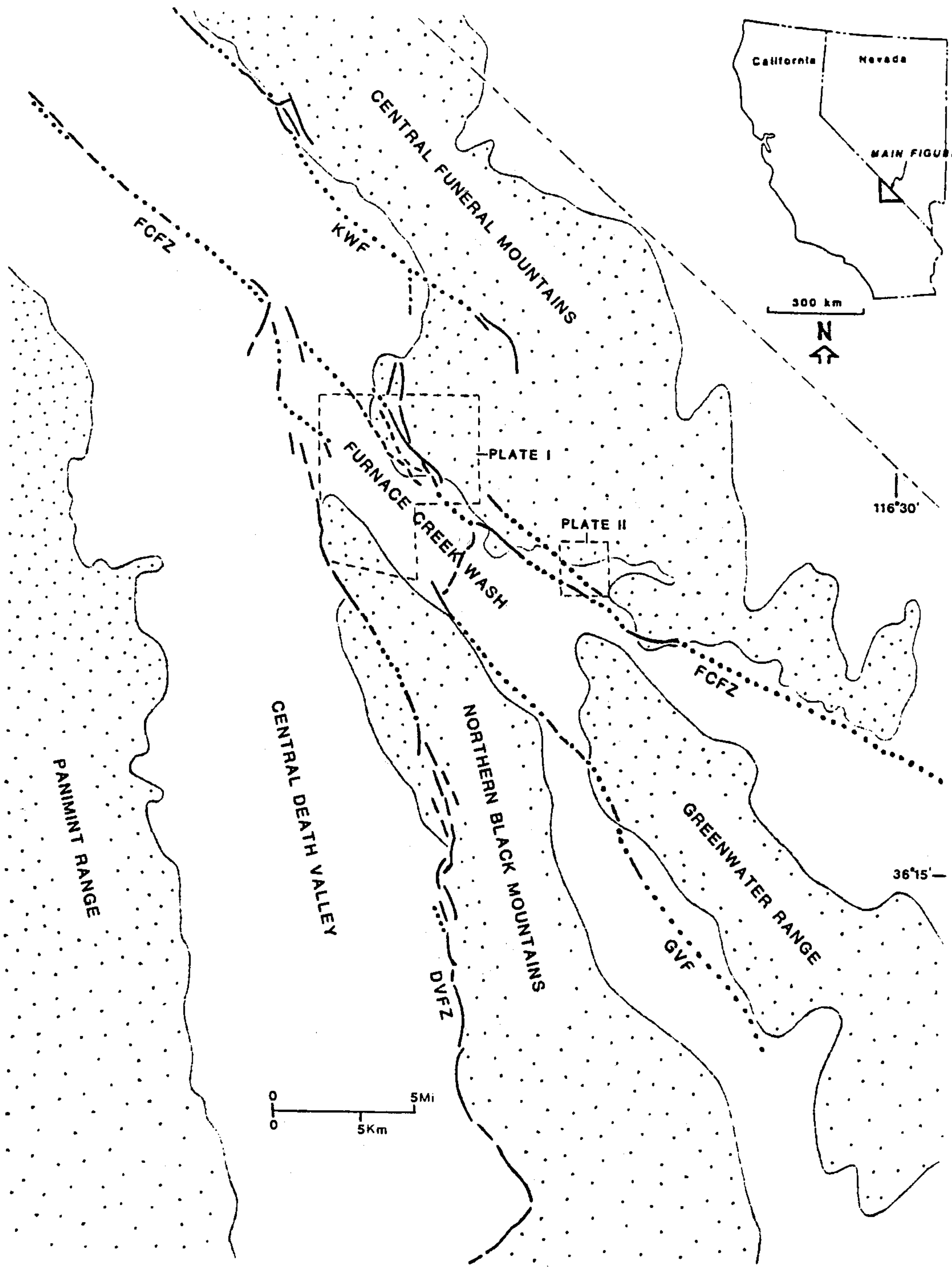


Figure 1. Index map of Death Valley region showing principal structural features and location of study area. Abbreviations: DVFZ. Death Valley fault zone; FCFZ. Furnace Creek fault zone; GVF. Grand View fault zone; KWF. Keene Wonder fault zone.

Mountains to the central Funeral Mountains (Fig. 1 and Pl.I). The southern study area lies within the U.S.G.S. Echo Canyon Quadrangle, Inyo County, California, between latitudes $36^{o}25'16"$ and $36^{o}23'4"$ north and longitudes $116^{o}42'4"$ and $116^{o}40'11"$ west along the western flanks of the central Funeral Mountains east of Hole in the Wall (Fig. 1 and Pl.II).

Methods of Study

The following tasks were performed during the course of this study:

1) Remapping of two areas in the northeastern part of Furnace Creek Wash (Pls. I,II), using a larger scale than McAllister (1970).
2) Mapping of portions of the western interior of the central Funeral Mountains (Pls. I,II).
3) Construction of structural cross-sections (Pl. III) based on McAllister's (1970) map, and geologic mapping performed during this investigation.
4) Measurement of a composite stratigraphic section of the lower conglomerate member of the Furnace Creek Formation (Fig. 11).
5) Measurement of clast imbrications in the lower conglomerate of the Furnace Creek Formation to infer paleocurrent directions (Fig. 12).
6) Petrographic analysis of 12 thin-sections from the

Furnace Creek Formation (Tables I, II, and III).

7) Interpretation of sedimentologic and petrographic data to determine the petrology, sediment source, and depositional environments of the Furnace Creek and Funeral Formations within the study area.
8) Measurement of strikes and dips of fault planes, and trends and plunges of fault striations.
9) Stereo-net analysis of fold data (Fig. 13).
10) Interpretation of structural data to determine the structural history of the prominent structural features exposed in the study area.

CHAPTER II

GEOLOGIC SETTING

Early Investigation in the Basin and Range

Systematic observations associated with the early geologic surveys of the 1860's and 70's led to the formulation of several models concerning the origin and age of mountain ranges within the Great Basin region of southeastern California and Utah. Gilbert (1875, in Nolan, 1943) suggested that the mountain blocks were bordered on both sides by major faults, and that vertical movements along these faults produced the present topographic relief. He observed linear range fronts that cut across rock structures and attributed these to faulting. King (1878, in Nolan, 1943) proposed that faulting had been preceded by intense folding.

Spurr (1901) observed that range-front faults are extremely rare in central and southern parts of the Great Basin, whereas other faults within mountain blocks do not effect topography. He also noted that along basin margins, unfaulted Tertiary strata unconformably overlie older rocks within the mountains. Based on these observations Spurr (1901) reasoned that erosion was the principle process responsible for the current pattern of basins and ranges.

Baker's (1913) observations in southern California, and southern Nevada suggested that some of the range-bounding faults were reverse faults produced by compression.

Louderback (1923, in Nolan, 1943) attributed the significant relief of the ranges to relatively recent tectonic activity which he later (Louderback, 1926, in Nolan, 1943) proposed as Pliocene or post-Pliocene. Ferguson (1926) proposed that block-faulting in west-central Nevada began before late Miocene, and suggested that block-faulting was not the result of a single event.

As research in the area continued, horizontal displacement was recognized as an important factor in the developement of Basin and Range structures. Gianella and Callaghan (1934) indicated a genetic relationship between faulting in the western Great Basin, and horizontal fault movement in the Sierra Nevada, and the San Andreas fault system. They suggested that future studies of Basin and Range structure should consider the effects of horizontal movements.

Death Valley Tectonics

The major Cenozoic structural elements of the Death Valley region include the northwest trending Furnace Creek fault zone (Fig. 1) which bounds the west side of the Funeral Mountains, the Death Valley fault zone (Fig. 1) which bounds the west side of the northern Black Mountains, and the southern Death Valley fault zone which bounds the west side of the central and southern Black Mountains. The kinematics and displacements associated with these faults will be addressed first, followed by discussions of the structural evolution and geometry of the Death Valley basin.

Kinematics

Curry (1938) attributed a large component of strike-slip movement to the en echelon faults of the Furnace Creek fault zone along the eastern margin of north central Death Valley. He observed offset alluvial fans and drainage channels, drag folds, horizontal fault striations, and sag ponds, and suggested a right-lateral strike-slip motion in which the amount of horizontal movement at least equals the vertical movement.

Noble (1941) recorded the presence of strike-slip and normal faults in the southern Black Mountains, and described the latter as surficial tension features associated with folding. He characterized the structure of southern Death Valley as a syncline, in which the eastern limb had been down-dropped by normal faulting.

Noble and Wright (1954) presented a model which described central Death Valley as a "fault trough...between the tilted Panamint Range block and the Black Mountains." In this model, the southern Death Valley fault zone was interpreted as a major strike-slip fault. Based on the orientation of fault striations, and the distribution of

Precambrian units across the fault zone, they concluded that the southern Death Valley fault zone had undergone right lateral, west side down movement, with greater horizontal than vertical displacement. The Furnace Creek fault zone, was characterized as having significant horizontal and vertical displacement, recurrent since the Late Mesozoic or Early Tertiary.

A genetic relationship between Basin and Range strcture, and strike-slip faults was suggested by Shawe (1965). He observed progressive change from dip-slip normal faulting in the northern part of the Churchill arc in west-central Nevada, to dominant strike-slip faulting near the southern end of the arc where it approaches the Walker Lane strike-slip fault zone. The contemporaneous development of these two different fault types led Shawe (1965) to the conclusion that both resulted from the same regional stress pattern.

Hill and Troxel (1966) suggested that right-lateral displacement along the Death Valley and Furnace Creek fault zones is the result of northeast-southwest directed crustal shortening and northwest-southeast relative extension, produced by a horizontal compressional force couple.

Burchfiel and Stewart (1966) related the development of central Death Valley as a pull-apart basin to tension and crustal extension resulting from strike-slip movement between the en echelon terminations of the southern Death Valley and Furnace Creek fault zones (Fig. 2).

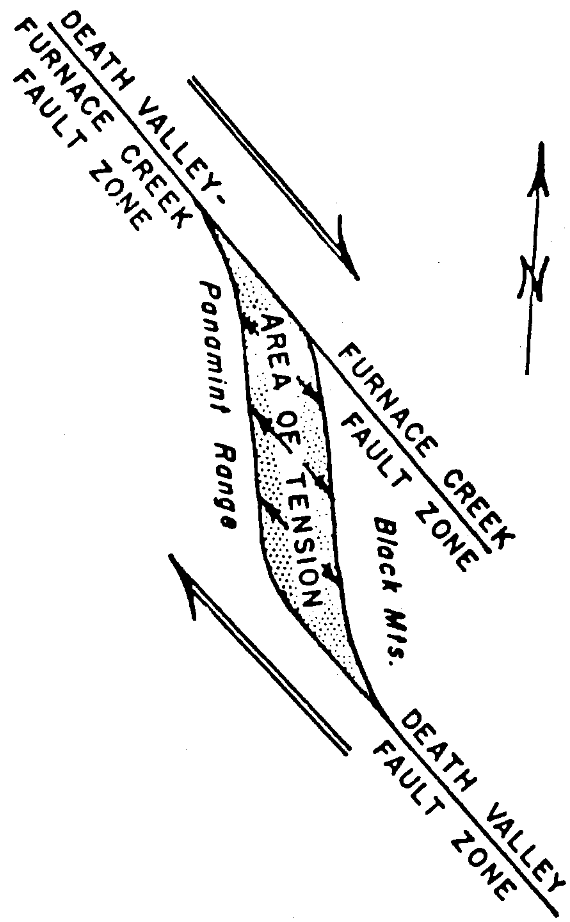


Figure 2. Diagramatic map showing strike-slip movement and "pull-apart" interpretation of central Death Valley (from Burchfiel and Stewart, 1966).

Displacement

Stewart (1967) reported abrupt changes in facies and thickness of upper Precambrian and lower Cambrian formations along the Death Valley and Furnace Creek fault zones. He proposed a right-lateral offset of approximately 50 miles for the Death Valley-Furnace Creek fault system (Fig. 3), and suggested that variation in the magnitude of offset within the fault system can be accommodated by large-scale structural bending (oroclinal flexure) adjacent to the fault zones. In this model large horizontal displacement could be accumulated as flexural rotation of the Black Mountain block (Fig. 3).

Wright and Troxel (1967, 1970) provided a different model in which maximum strike-slip displacements of 5 and 2 miles are proposed for the southern Death Valley fault zone and southern Death Valley-Furnace Creek fault zone respectively. Their interpretation is based on the displacement of stratigraphic features accross the major strike-slip fault zones in the region (Fig. 4). Wright, and Troxel (1967, 1970) also expressed concern with several aspects of the "large-displacement" model (Stewart, 1967; Stewart, Albers, and Poole, 1968). These are: 1) the validity of the assumption that crustal stability persisted during deposition of Late Precambrian and Paleozoic formations, and the use of sub-parallel, evenly spaced isopach lines to determine fault displacements. 2) Stewart's (1967) suggestion that thinner exposures of Late

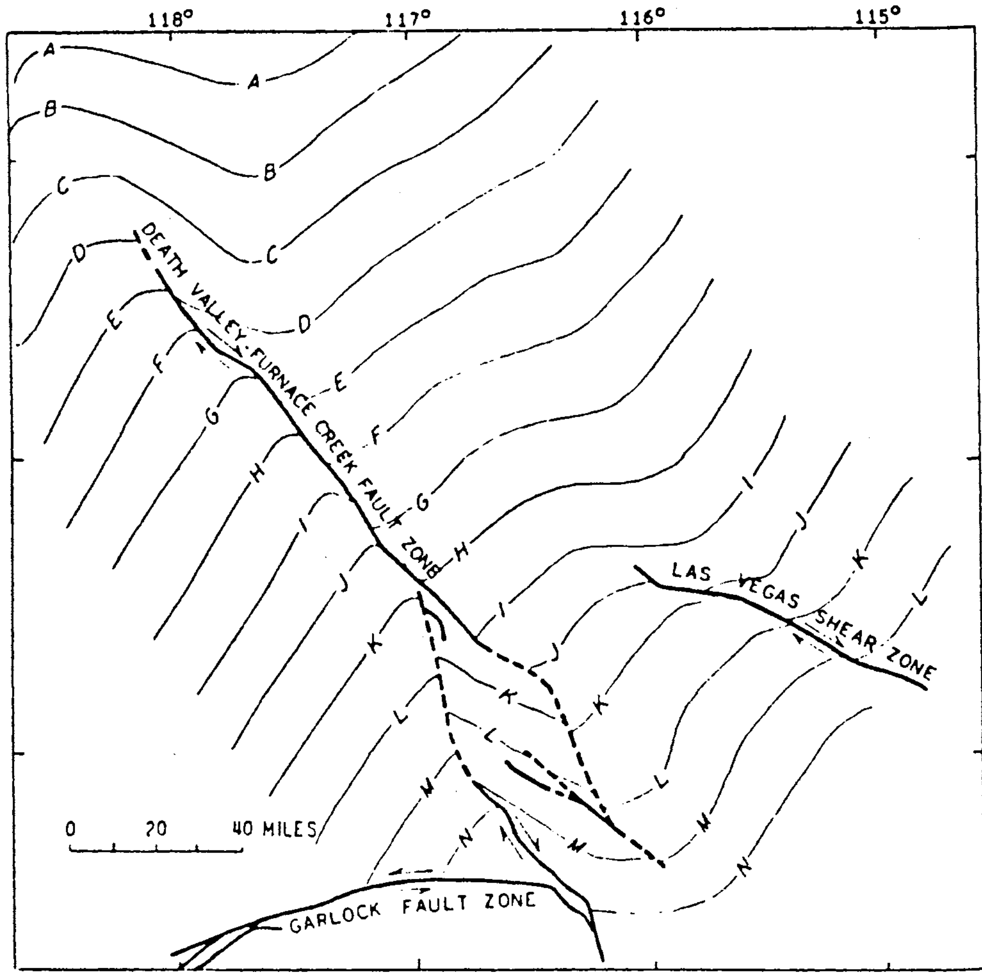


Figure 3. Interpretation of displacement of Upper Precambrian and Lower Cambrian hypothetical sedimentary trends across major fault zones in the Death Valley region (from Stewart, 1967).

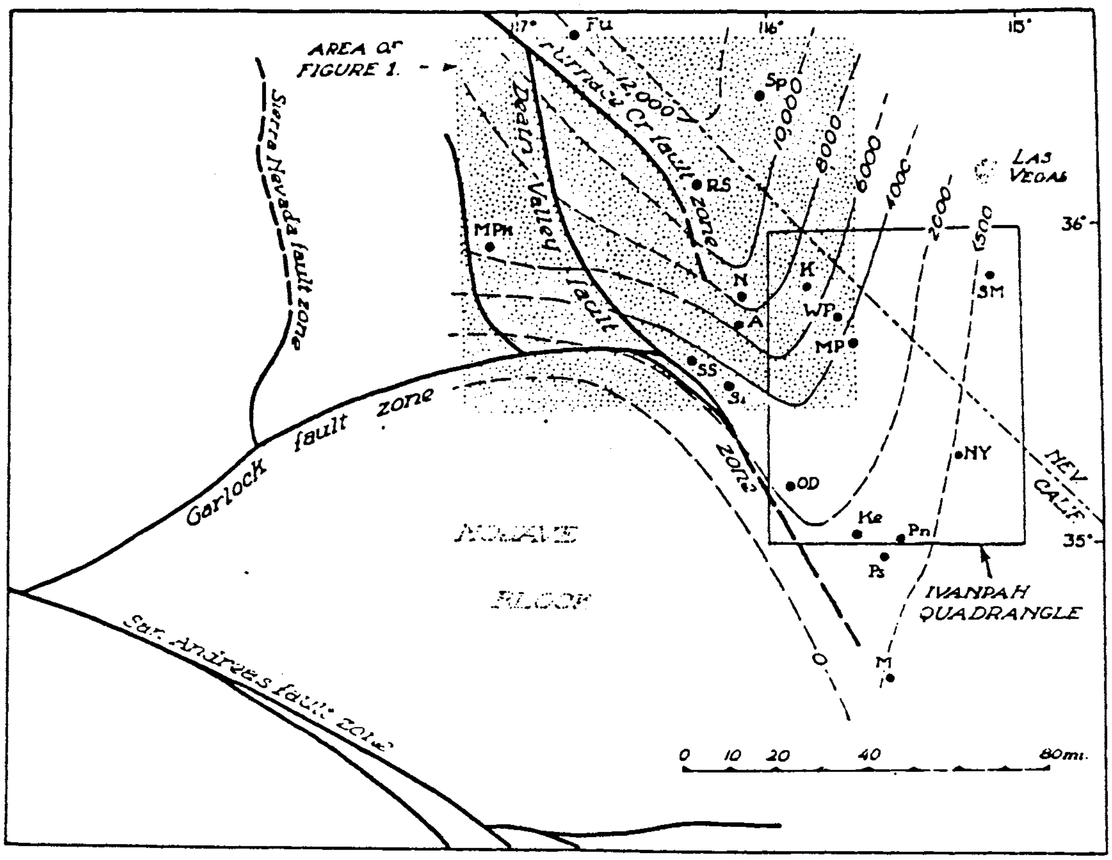


Figure 4. Isopachous contours of Late Precambrian-Cambrian strata and major faults of the Mojave Desert-Death Valley region (from Wright and Troxel, 1966).

Precambrian formations in the Panamint Range require significant right-lateral displacement. 3) The lack of correlation between Stewart's (1967) inferred oroclinal rotation of the Black Mountains, and observed orientations of planar features such as foliations, bedding planes, and fault planes within the Precambrian and Paleozoic formations in the Black Mountains and adjacent ranges.

In response to Wright and Troxel (1967, 1970), proponents of the "large displacement model" (Stewart, Albers, and Poole, 1968; Stewart, 1970a) have made the following points: 1) The lack of offset of Precambrian and Paleozoic geological lines may be accounted for by absorption of strike-slip displacement by oroclinal flexure (clockwise rotation) of the Black Mountain fault block. 2) An early oroclinal flexure (late Jurassic) may be present which predates and therefore does not effect subsequent Cenozoic faulting. 3) The northwestern trends of the Precambrian formations in western Death Valley (Wright and Troxel, 1967), may instead trend northeastward, and be results of major right-lateral offset. 4) The general northerly trend and easterly dip of planar features in the Black Mountains (Wright and Troxel, 1970), do not agree with the northwest trends of foliations, and bedding associated with turtleback surfaces exposed on the western flank of the Black Mountains.

Variable amounts of displacement have been proposed for the northern Death Valley-Furnace Creek fault zone.

Wright and Troxel (1970) described north- to northeast-trending "master normal faults" on the southwest side of the fault zone. Similar structures were not found northeast of the fault zone. Therefore they concluded that crust on the southwest side of the fault zone has undergone greater northwestward extension than crust on the northeast side (Fig. 5). Cemen, et al. (1985) agree with this conclusion based on the occurrence of igneous activity, and the presence of Furnace Creek Basin sediments southwest of the Furnace Creek fault zone.

Wright and Troxel (1970) suggested that differential extension along a 100-mile segment of the Furnace Creek fault zone is possible. They documented a zero displacement point in the northern Resting Spring Range (Fig. 5). From there displacement along the Death Valley-Furnace Creek fault zone progressively increases northwestward to as much as 20 miles in the vicinity of the Last Chance Range (Fig. 5). Northwestward increase in strike-slip displacement along the Furnace Creek fault zone has also been indicated by Cemen, et al. (1985) based on the increasing number of extensional features northwestward along the southwest side of the fault zone.

Basin Evolution

Stewart (1983) proposed a model of Death Valley evolution which requires approximately 80 km of west-directed Late Cenozoic extension along a single or system

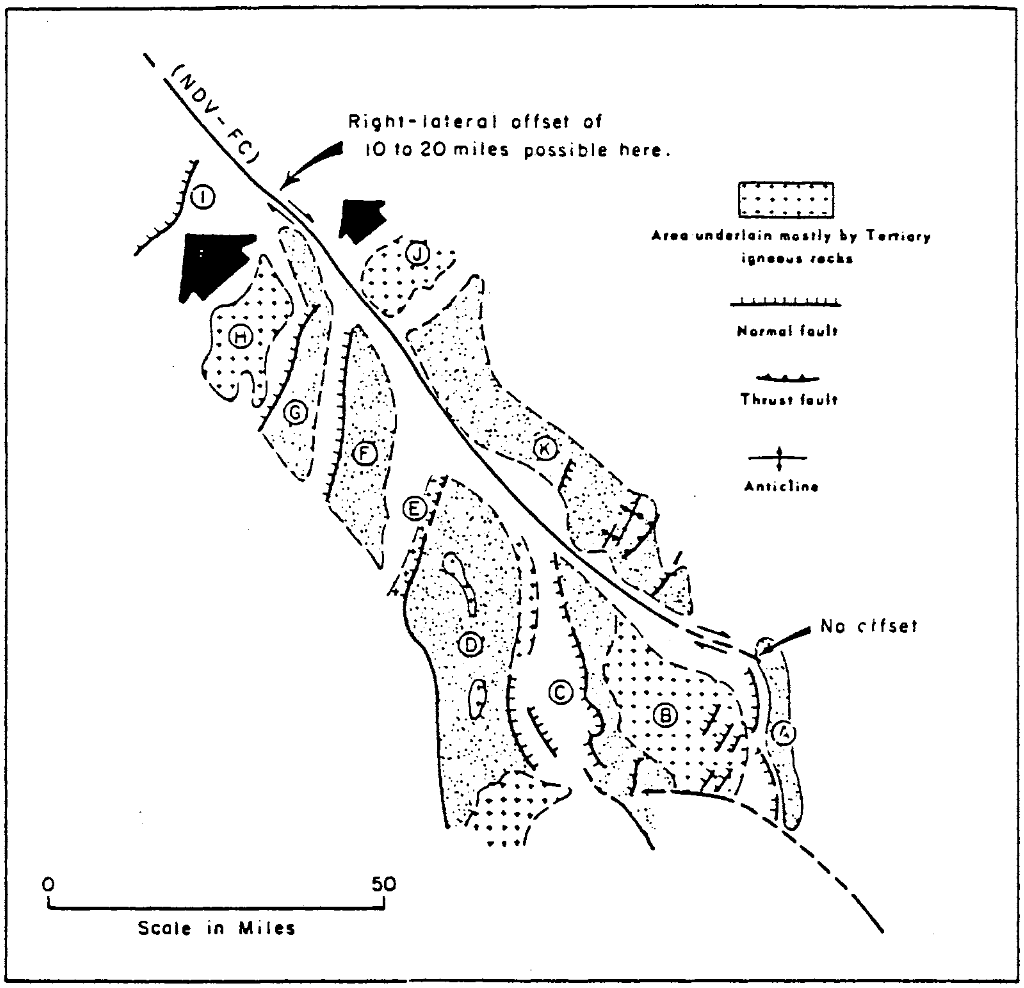


Figure 5. Map showing contrasting features on opposite sides of the northern Death Valley-Furnace Creek fault zone (NDV-FC) (Wright and Troxel, 1970).

of low-angle, westward-dipping detachment faults. In this model the Panamint Range, and Black Mountain structural blocks were transported northwestward (Fig. 6). In support of this interpretation Stewart (1983) cited the following: 1) The absence in the Black Mountains, and the Greenwater Range, of the thick Precambrian and Paleozoic section that is exposed in adjacent ranges. 2) The apparent offset of trends in thickness and facies of Precambrian units across the Furnace Creek fault zone. 3) The presence of minor, if any, right-lateral offset along the Death Valley fault zone. 4) Turtleback surfaces exposed on the western flanks of the Black Mountains contain striations and extension fractures that are consistent with northwestward extension.

Cemen, et al. (1985) provided a different model of Death Valley evolution, in which the Tertiary Artist Drive Formation was for the most part deposited upon a basement of Cambrian rocks. They concluded that "... the bedrock beneath the Artist Drive could not have been tectonically denuded of these formations by the westward transport of the Panamint Mountain block ...." In support of this interpretation Cemen, et al. (1985) cited the following: 1) The Cambrian Bonanza King Formation underlies Tertiary sediments in the Desolation Canyon (northern Black Mountains), Billie Mine (Furnace Creek Wash), and Eagle Mountain (southeast end of Furnace Creek Wash) areas. 2) Discontinuous exposures of the Paleozoic section, which overlies the Precambrian basement complex at the turtleback

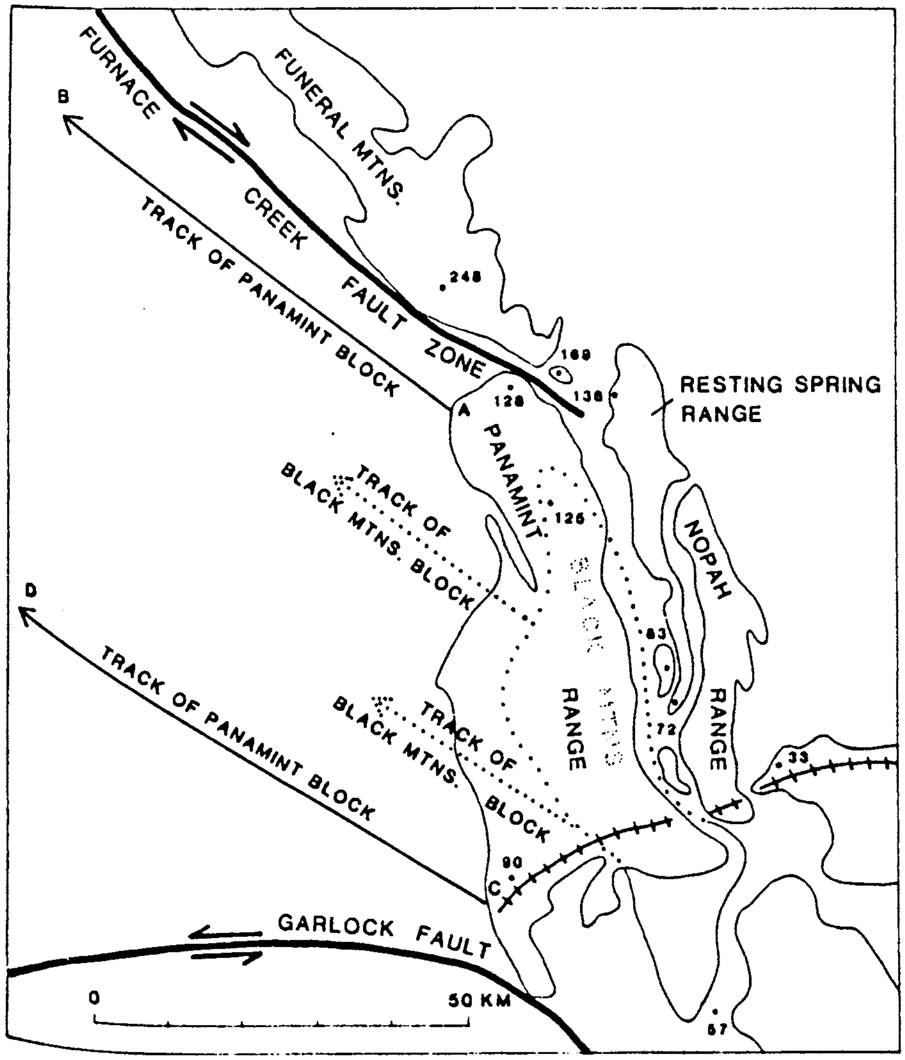


Figure 6. Reconstruction of Death Valley area prior to proposed detachment faulting. Dotted pattern indicates prefaulting position of Black Mountain block below Panamint Range block. B and D indicate present position of areas that were at A and C, respectively, prior to detachment faulting (from Stewart, 1983).

surfaces along the western front of the Black Mountains. 3) Composition of Artist Drive alluvial fan and stream deposits, which reflect the exposure of Upper Precambrian and Paleozoic rock units in the area of the Black Mountains and Greenwater Range during the deposition of the Artist Drive Formation (14 to 7.5 Ma). Therefore, Cemen, et al. (1985) proposed that the absence of thick Precambrian and Paleozoic rocks in the Black Mountains and Greenwater Range is due to sedimentary processes which transported these sediments northeastward and deposited them near the southern end of the Funeral Mountains (Cemen, et. al., 1982) and in the Furnace Creek Basin.

Basin Geometry

Wright and Troxel (1973) acknowledged the wide range of potential dips and depths of master faults in the Basin and Range province, but suggested a shallow-fault model for the southwestern Great Basin. In this model 1) rotated bedding is related to dip-slip along listric faults, 2) master faults cut the basement and flatten to horizontal at depths of 3 to 5 miles, and 3) smaller normal faults with less displacement end near the basement-sedimentary cover contact. Complex half-grabens such as Death Valley are associated with this tectonic style (Fig. 7).

Wernicke (1981) presented a tectonic model in which low-angle normal or "basal" faults "root" into the crust or possibly into the mantle to produce narrow zones of

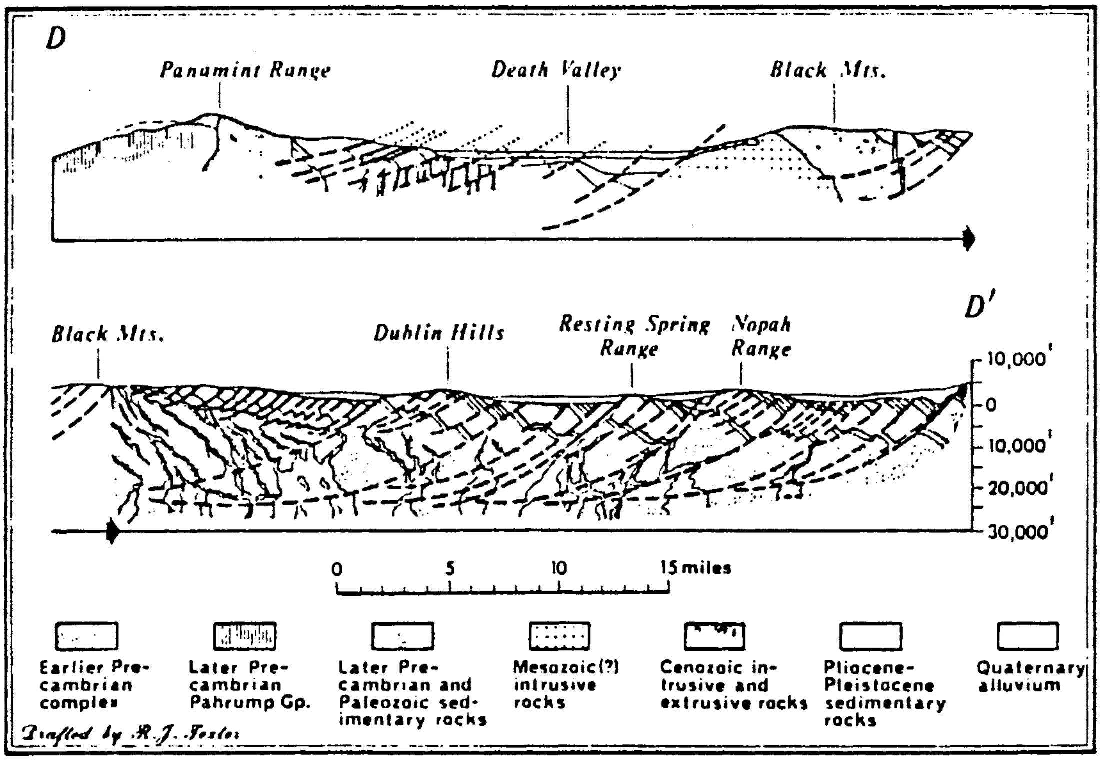


Figure 7. Geologic cross-section across the central Death Valley region (from Wright and Troxel, 1973).

decoupling (Fig. 8). Extensional faulting within the upper plate decreases down-dip along the "basal" surface as deformation changes from brittle to ductile. As a result, extension of the lower plate may occur at a significant distance and greater depth. Stewart (1983) and Jones (1987) have proposed low-angle, deep rooted normal faulting in the Death Valley region.

COCORP (1986) deep seismic reflection profiles across south central Death Valley indicate the presence of a midcrustal (15Km depth) tabular magma body, which may have been implaced along a zone of decoupling. The magma body does not appear to be cut by normal faults within the upper crust and no faults were detected below the body, indicating it may separate brittle upper crust from a more ductile lower crust. COCORP (1986) reflection data do not show evidence for the shallow, regionally continuous detachment beneath the Panamint Range proposed by Stewart (1983). The geometry of shallow and mid-crustal reflectors in the central Death Valley region support the shallow-fault model of Wright and Troxel (1973).

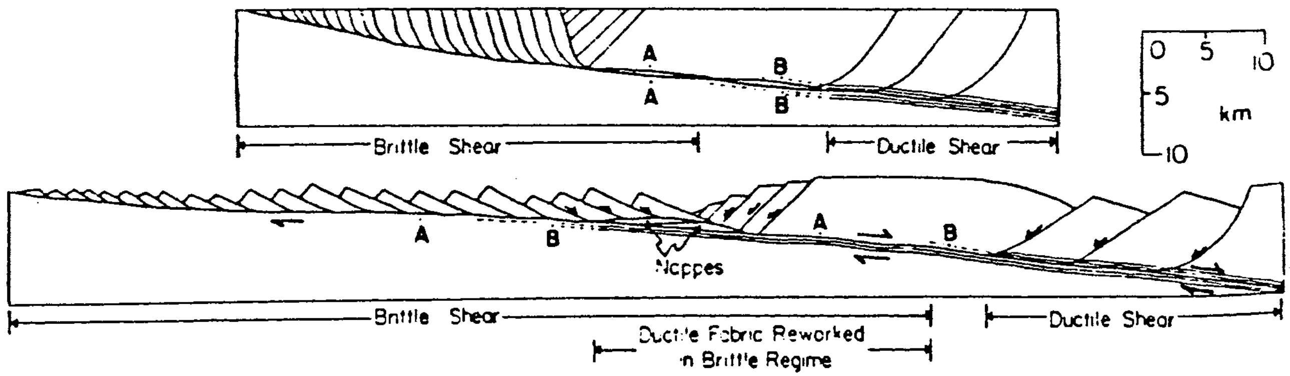


Figure 8. Idealized geologic cross-sections showing major features associated with the rooted, low-angle normal fault model (from Wernicke, 1981).

CHAPTER III

STRATIGRAPHY

Precambrian and Paleozoic

The oldest rocks in the study area are exposed in the Funeral Mountains, and record Late Precambrian to Devonian deposition in marine environments (Fig. 9). In the central Funeral Mountains the sequence is approximately 23,700 feet thick (Stewart, 1970b; McAllister, 1974). Detailed descriptions of these formations were provided by Hazzard (1937), Hunt and Mabey (1966), Stewart (1970b), and McAllister (1974).

The Precambrian Stirling Quartzite (Fig. 9) is composed of white to light gray, cliff-forming, massive to cross-bedded quartzite, and minor amounts of slope-forming siltstone, and carbonate rocks (Hunt and Mabey, 1966; Stewart, 1970b). Stewart (1970b) reported 4,800 feet of Sterling Quartzite in the central and southern Funeral Mountains.

The Precambrian and Early Cambrian Wood Canyon Formation (Fig. 9) is divided into three informal members by Stewart (1970b); lower and upper members of slope-forming interbeds of siltstone, shale, fine-grained quartzite, and distinctive brown-weathering carbonates; and

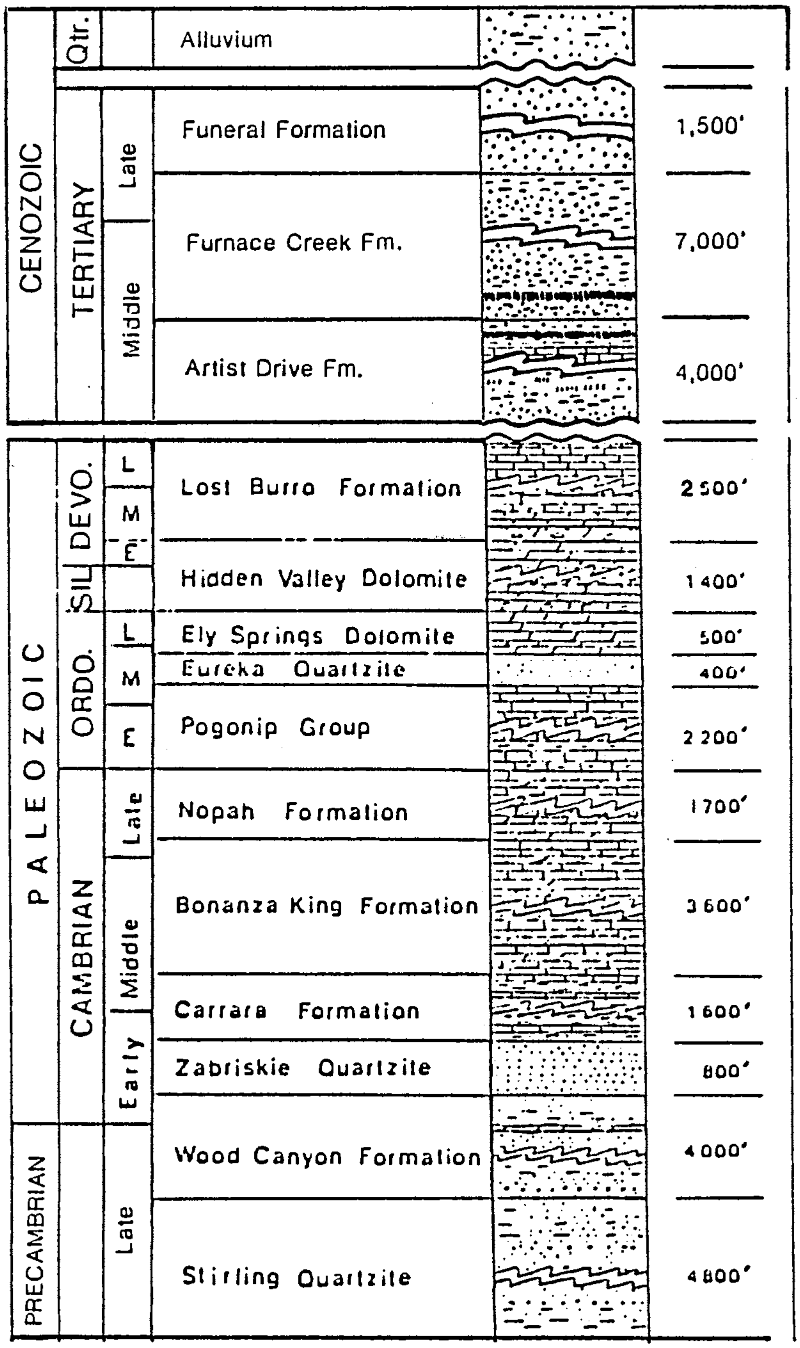


Figure 9. Generalized columnar section of stratigraphic units exposed in the central Funeral Mountains and northern Furnace Creek Wash area (modified from Cemen, et al., 1982).

a middle member of cliff-forming fine to medium grained quartzite, with minor amounts of conglomerate and siltstone (Stewart, 1970b; McAllister, 1970). Stewart (1970b) reported 4,000 feet of Wood Canyon Formation in the central and southern Funeral Mountains.

The Early Cambrian Zabriskie Quartzite (Fig. 9) consists of pale red to vitrually white, fine to medium grained, massive quartzite with sporadic small-scale crossbeds. It forms rough steep slopes and occasional cliffs, and weathers from pale orange to brown (Hunt and Mabey, 1966; Stewart, 1970b; McAllister, 1970). This unit is commonly fractured. McAllister (1974) reported 800 feet of Zabriskie Quartzite in the central and southern Funeral Mountains.

The Early and Middle Cambrian Carrara Formation (Fig. 9) records the transition from deposition of predominantly siliceous clastic material to deposition of relatively clean carbonate sediments. The lower part consists of interbedded pale red to white quartzite and greenish gray siltstone and shale; the upper part contains three prominent beds of gray and yellowish brown silty limestone, separated by shaly and silty beds (Stewart, 1970b; McAllister, 1970). McAllister (1974) reported 1,600 feet of Carrara Formation in the central and southern Funeral Mountains.

The Middle and Late Cambrian Bonanza King Formation (Palmer and Hazzard, 1956) (Fig. 9) was divided into two formal members by McAllister (1970). The Papoose Lake Member consists of thick-bedded dark gray dolomite and limestone; the overling Banded Mountain Member contains light and dark gray limestone and dolomite interbeds. The base of the Banded Mountain Member is marked by prominant brown-weathering clastic beds (Hunt and Mabey, 1966; McAllister, 1970). The Bonanza King Formation reaches a thickness of 3,600 feet in the central and southern Funeral Mountains (McAllister, 1974).

The Late Cambrian Nopah Formation (Fig. 9) consists of a basal clastic bed of brown-weathering, fossiliferous shale and silty limestone, overlain by alternating light gray and dark gray layers of dolomite that resemble the underlying Banded Mountain Member (Hunt and Mabey, 1966; McAllister, 1970). The Nopah Formation reaches a thickness of 1,700 feet in the central and southern Funeral Mountains (McAllister, 1974).

The Early and Middle Ordovician Pogonip Group (Hunt and Mabey, 1966) (Fig. 9) consists of distinctive combinations of carbonate and clastic rocks that at other places are designated formations. In the Funeral Mountains, McAllister (1970) informally divided the Pogonip Group into three parts: a thinly bedded carbonate lower part, which contains a zone of light brownish orange siltstone and shale; a middle part containing thicker silt and shale zones interbedded with brown siliceous clastic rocks and gray limestone or dolomite; and an upper part consisting of thickly-bedded cliff-forming gray limestone or dolomite. The Pogonip Group reaches a thickness of 2,200 feet in the central and southern Funeral Mountains (McAllister, 1974).

The Middle Ordovician Eureka Quartzite (Fig. 9) consists of a brown-weathering quartzite and thinly interbedded shale lower part, and a white, massive quartzite upper part (Hunt and Mabey, 1966; McAllister, 1970). This unit commonly is fractured. The Eureka Quartzite reaches a thickness of 400 feet in the central and southern Funeral Mountains (McAllister, 1974).

The Middle and Late Ordovician Ely Springs Dolomite (Fig. 9) consists of cliff-forming, thick bedded, dark gray, cherty dolomite, capped by lighter gray dolomite (Hunt and Mabey, 1966; McAllister, 1970). McAllister (1974) reported 500 feet of Ely Springs Dolomite in the central and southern Funeral Mountains.

The Silurian and Early Devonian Hidden Valley Dolomite (Fig. 9) consists of a medium to dark gray, well bedded dolomitic lower part, that contains chert, and abundant Silurian fossils, and an upper part of light gray, massive dolomite (Hunt and Mabey, 1966; McAllister, 1970; 1974). McAllister (1974) reported 1,400 feet of Hidden Valley Dolomite in the central and southern Funeral Mountains.

The Middle and Late Devonian Lost Burro Formation (Fig. 9) consists of a light gray and dark gray striped dolomitic lower part, and a similarly colored limestone upper part. The base and top of the formation are marked by brown-weathering sandy and quartzitic beds (Hunt and Mabey, 1966; McAllister, 1974). The Lost Burro Formation reaches a thickness of 2,500 feet in the central and southern Funeral Mountains (McAllister, 1974).

Cenozoic

Previous Investigations

Sedimentary and volcanic rocks exposed within the Furnace Creek Wash and along the adjacent Funeral and Black Mountains were first described by Thayer (cited by Noble, 1941). Thayer's Tertiary section, based on mapping in the Northern Black Mountains and Greenwater Range, was summarized by Noble (1941) as follows:

Quaternary Deposits
    Unconformity
Tertiary Rocks
  Funeral fanglomerate(Pliocene ?) ....3000'
    Unconformity
  Greenwater volcanics(Pliocene ?) ....2500'
    Unconformity
  Furnace Creek formation(Upper Miocene or Pliocene) .2500'
    Unconformity
  Artist Drive formation(Oligocene or Miocene) ....5000'
    Unconformity
Paleozoic rocks

Additional lithologic descriptions of the Tertiary section in the Furnace Creek Wash area were provided by Noble (1941), and Hunt and Mabey (1966). Generalized geologic mapping of the Tertiary section in the Furnace Creek area appeared in Noble and Wright (1954); and Hunt and Mabey (1966). The Furnace Creek Wash area was mapped in detail by McAllister (1970). Based on structure sections, McAllister (1970) obtained a total thickness of approximately 7,000 feet for the Furnace Creek Formation, and between 1,000 and 1,500 feet for the sedimentary part of the Funeral Formation. It should be noted that McAllister's (1970) map was used extensively during the course of this study, and proved to be of great help.

Cemen et al. (1985) delineated the Furnace Creek Basin; a northwest trending, fault-controlled trough that coincides with the Furnace Creek Wash. The basin is bounded by the Furnace Creek fault zone to the northeast, and includes the northern portions of the Black Mountains and Greenwater Range (Fig. 1). It contains from oldest to youngest the Artist Drive, Furnace Creek, and Funeral Formations

Initial dating of the Tertiary section was conducted by Axelrod (1940). He assigned an Early Pliocene age to the upper part of the Furnace Creek Formation in the lower Furnace Creek Wash based on fossil leaf remains. Lohman (cited by McAllister, 1970) proposed an Early Pliocene age for the lower part of the Furnace Creek Formation and a Middle Pliocene age for the uppermost part, based on diatoms collected in the northern Black Mountains. Radiometric dates reported by Cemen et al. (1985) bracket the age of the Furnace Creek Formation in the Furnace Creek Basin area between 6.4 $\pm$.3 Ma (age of the upper part of the Artist Drive Formation) and 4.03 $\pm$.12 Ma (age of basalt in the Funeral Formation).

Furnace Creek Formation

The Furnace Creek Formation consists of interbedded conglomerate, sandstone, and pumaceous siltstone and mudstone (Fig 10). Alluvial fan conglomerates are restricted to the margins of the Furnace Creek Wash, and reflect short transport and rapid sediment deposition in areas of substantial topographic relief. These conglomerates are composed of material derived from source areas in the Funeral Mountains to the northeast and the Black Mountains to the south. Fluvial sandstone, and lacustrian siltstone and mudstone occupy the central part of the Furnace Creek Wash area and intertongue with conglomeratic beds.

Along the western flanks of the Funeral Mountains, the base of the Furnace Creek Formation either unconformably overlies the Paleozoic section, or more commonly is in fault contact with the Paleozoic section (Pls. I,II). Within the northern part of the Black Mountains the Furnace Creek Formation conformably overlies the volcanic and sedimentary sequences of the Artist Drive Formation (Pl. I). The Furnace Creek Formation is conformably overlain by the Funeral Formation within the study area. McAllister (1970) noted a gradual southeastward increase in the angularity of this contact.

During this study the lower (Tfc) and upper (Tfcu)

Figure 10. Photograph of Furnace Creek Formation outcrop, Furnace Creek Wash area.

conglomerate members of the Furnace Creek Formation, informally defined by McAllister (1970), are further divided into several informal submembers, based on systematic variations in the composition of detrital constituents. In this informal usage, submembers are understood to contain distinctly similar beds.

The main part of the Furnace Creek Formation (Tf) is defined by McAllister (1970) as predominantly lacustrine mudstone and siltstone, and minor undifferentiated limestone, conglomeratic, and gypsiferous beds. It occurs as interbeds within the upper conglomerate member of the Furnace Creek Formation, and separates the upper and lower conglomerate members of the Furnace Creek Formation. The main part of the Furnace Creek Formation is informally designated here as undifferentiated Furnace Creek Formation (Tf).

Lower Conglomerate Member

The lower conglomerate member is the stratigraphically lowest unit in the Furnace Creek Formation. Within the study area the thickest and lithologically most diverse exposures of lower conglomerate occur along the western flanks of the Funeral Mountains, south of Nevares Peak (Pl. I). At this location lower (Tfc1) middle (Tfc2) and upper (Tfc3) submembers of the lower conglomerate member are recognized. Siltstone and mudstone interbeds are present in the lower and upper submembers (Fig. 11).

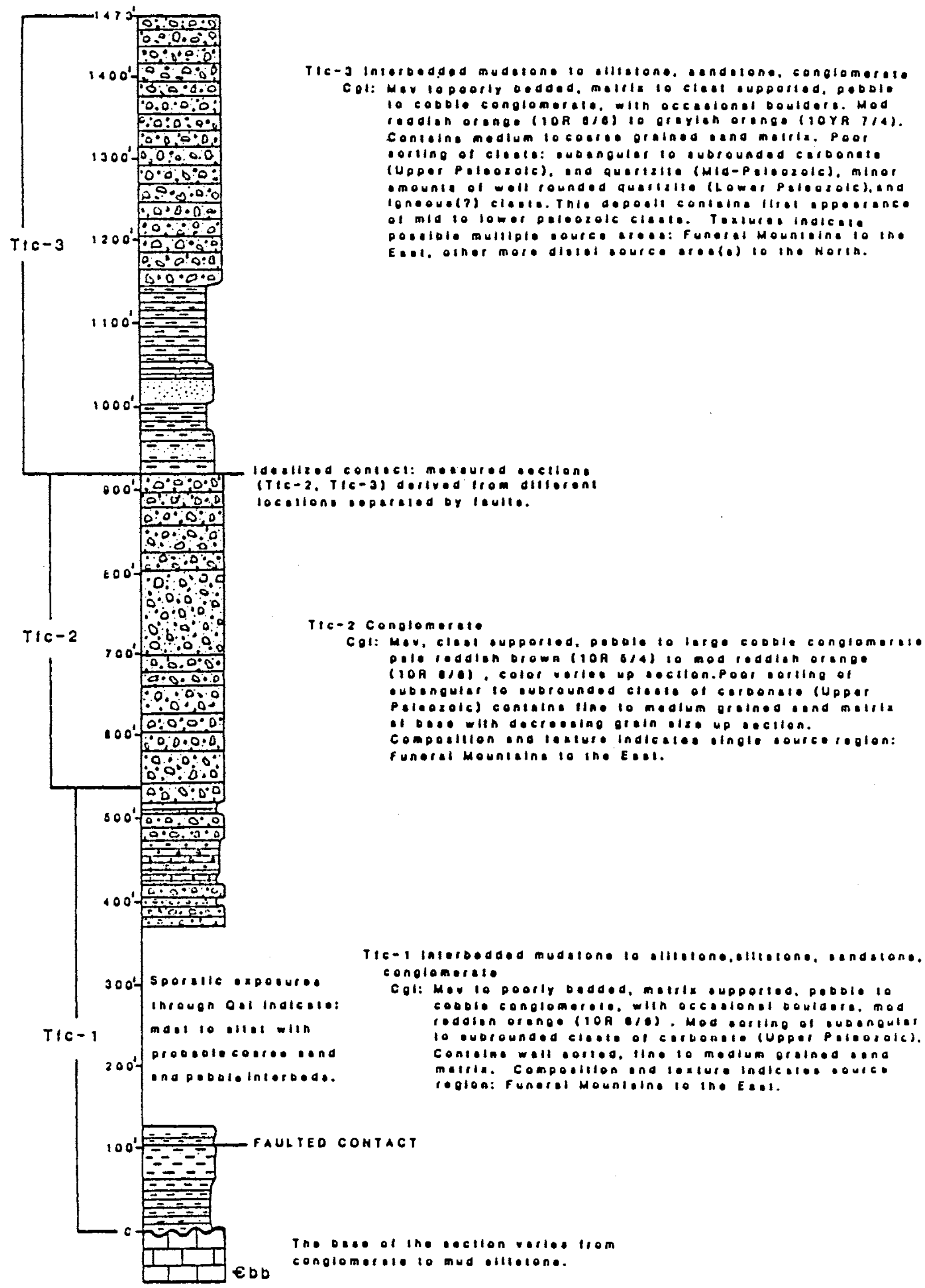


Figure 11. Composite measured section of the lower conglomerate member of the Furnace Creek Formation from the northern part of Furnace Creek Wash.

Thinner, less diverse exposures of the lower conglomerate member occur east of Hole in the Wall along the western flanks of the Funeral Mountains (Pl. II), and within the northern Black Mountains (Pl. I). Siltstone and mudstone interbeds are not present at these locations.

Lower Conglomerate Member: Funeral Mountains

Lower Submember

The base of the lower submember (Tfc1) consists of massive to poorly bedded pumaceous mudstone to siltstone, and interbedded well laminated siltstone and fine to medium grained, pumaceous, lithic arkose sandstone. Minor amounts of subangular to subrounded pebble size clasts of carbonate, siltstone, quartz, and lithic fragments were recorded. Notable features include: an up-section increase in the occurrence of sand, and pebble size clasts; and the development of a compaction foliation within the pumaceous siltstone.

Thin section analysis of a pebble rich sandstone from the lower part of the submember is shown in Table I-A. The detrital grains are poorly sorted, and subangular to subrounded, with the exception of euhedral muscovite, and biotite, which commonly show a subparallel long axis orientation. A pyroclastic origin is indicated by the abundance of glassy matrix and volcanic rock fragments, and the presence of foliated, euhedral muscovite and biotite (Table I-A). The occurrence of plutonic grains

TABLE I

Composition of samples from the
Lower conglomerate member of the Furnace Creek Formation.

	DETRITAL									DIAGENETIC			
SAMPLE	QUARTZ	FELDSPAR	carbonate R.F.	volcanic R.F.	silicilastic R.F.	plutonic R.F.	chert R.F.	MICAS	MATRIX	CEMENTS	CLAYS	POROSITY	ZEOLITE
A	15.5	6		13		T		T	48	16	1.5	T	T
B	10	4.5	45			T	1	T	12	7	.5	20	
C			58						12	22.5	2	5.5	
D	13	14.5		4				3	57	2	4.5		2

Siliciclastics include: Quartzite, Siltstone, Shale. Cements include: Calcite, Hematite, Pyrite, Feldspar and Quartz overgrowts, Clays include: Illite Smectite, sericite. Zeolite is Clinoptilolite. R.F. indicates rock fragment. T indicates trace amounts.

which are not represented in local outcrops indicates a distal sediment source area.

The upper part of the lower submember (Tfc1) is a matrix supported, massive to crudely bedded, pebble to cobble conglomerate, containing occasional boulders up to two feet in diameter, in a reddish orange, fine to medium grained sand matrix. The clasts are subangular to subrounded, moderately sorted, and composed of carbonate fragments possibly derived from the Ordovician Ely Springs Dolomite, and the Silurian to Early Devonian Hidden Valley Dolomite.

Interbedded within the conglomerate are fine to medium grained, cross-bedded sandstone with scoured bases; and massive, matrix supported, pebble conglomerate with well sorted, subangular to subrounded carbonate clasts, in a fine to medium grained sand matrix.

Thin section analysis of a conglomerate from the upper part of the submember is shown in Table I-B. The detrital grains are poorly sorted, and subangular to subrounded with the exception of euhedral muscovite, and hornblende. The abundance of detrital carbonate reflects the exposure, and erosion of Paleozoic carbonate units within the Funeral Mountains to the east.

A composite measured section of the lower submember (Tfc1) from the western flanks of the Funeral Mountains resulted in a thickness of 537 feet (Fig. 11). This figure represents a minimum thickness due to uncertainties concerning the nature, and location of the base of the submember, which is obscured by younger alluvium in measured section. Both faulted, and unconformable contacts occur betwee the lower submember (Tfc1) and the underlying Paleozoic basemen The lower submember appears to represent a coarsening upward sequence, in which mudstones and siltstones are successively overlain by sandstone, and conglomerate.

Middle Submember

The middle submember (Tfc2) rests conformably above the lower submember (Tfc1), and consists of a clast (lower part) to matrix (upper part) supported, massive, pebble to large cobble conglomerate, in a variable matrix. The clasts are angular to subrounded, poorly to moderately sorted, and composed of carbonate fragments probably derived from the underlying Ordovician Ely Springs Dolomite, and the Silurian to Early Devonian Hidden Valley Dolomite. The matrix varies from pale reddish brown, fine to coarse sand to carbonate granules at the base of the subunit, to grayish orange, silt to fine sand near the top.

Thin section analysis of the conglomerate from the middle submember (Tfc2) is shown in Table I-C. The detrital grains are very poorly sorted, subangular to angular, and derived from Paleozoic units within the Funeral Mountains to the east.

A measured section of the middle submember (Tfc2) from the western flanks of the Funeral Mountains resulted in a thickness of 385 feet (Fig. 11). This figure represents a minimum thickness due to erosion of the upper part of the outcrop.

Upper Submember

The upper submember (Tfc3) is typically in fault contact with the Paleozoic basement, or with the underlying submembers (Tfc1, and Tfc2). It consists of massive to laminated, pumaceous mudstone to siltstone, and interbeds of cross-bedded, medium to coarse grained lithic arkosic sandstone. The development of bedding, and the occurrence of pebble sized clasts increase up-section. Minor amounts of subangular to subrounded pebble sized clasts of carbonate, quartzite, shale, and siltstone of Paleozoic origin were noted. Rounded to well rounded pebble sized clasts composed of quartzite, and igneous rock fragments also occur.

Thin section analysis of the pyroclastic lake sediment from the base of the upper submember is shown in Table I-D. Detrital grains are moderately to well sorted, and angular to subrounded. Euhedral biotite grains commonly show a subparallel long axis orientation. The presence of volcanic rock fragments, and foliated biotite in a glassy matrix indicate pyroclastic deposition. Secondary porosity resulting from the dissolution of calcite cement, framework grains, and matrix is commonly filled by Zeolites (Clinoptilolite). Petrographic analysis of the coarse sandstone from the lower part of the upper submember is shown in Table I-E. Subangular to subrounded detrital grains are poorly to moderately sorted.

The upper part of the upper submember (Tfc3) consists of a matrix to clast supported, massive to crudely bedded, pebble to cobble conglomerate, containing occasional boulders up to four feet in diameter, and a variable matrix. The clasts show a bimodal texture in which both angular to subrounded carbonate and silisiclastics, and rounded to well rounded quartzites and igneous rock fragments occur. The clasts are poorly to moderately sorted, with best sorting, and imbrication development in clast supported fabrics. A general southward decrease in the relative amount of quartzite, and silisiclastics; and an increase in carbonate clasts was recorded. Matrix varies from silt to fine sand within clast supported sequences, to medium to coarse sand within matrix supported sequences. Matrix color varies from moderate reddish orange to grayish orange. Crude bedding results from the interbedding of clast supported and matrix supported conglomerates. Bed contacts appear to be non-erosive.

Thin section analysis of the conglomerate from the upper part of the submember is shown in Table II-F. Subangular to subrounded sedimentary and volcaic detrital grains are poorly sorted.

The first occurrence of Paleozoic siliciclastic material, and changes in carbonate lithologies reflect the

TABLE II

Composition of samples from the
Lower conglomerate member of the Furnace Creek Formation.

DETRITAL										DIAGENETIC		
SAMPLE	QUARTZ	FELDSPAR	carbonate R.F.	volcanic R.F.	siliciclastic R.F.	plutonic R.F.	chert R.F.	MICAS	MATRIX	CEMENTS	CLAYS	POROSITY
F	8.5	3	39	.5	11		3		4	19.5	1.5	10
G	3		21		11.5		T		14	44.5	2	4
H			46						10	38		6
I	9.5	4	2.5	15	1.5	8	T	1.5	33	22	2	1

Siliciclastics include: Quartzite, Siltstone, Shale. Cements include: Calcite, Hematite, Pyrite, Feldspar and Quartz overgrowts, Clays include: Illite Smectite, sericite. R.F. indicates rock fragment. T indicates trace amounts.

exposure, and erosion of successively older Precambrian, and Paleozoic units within the Funeral Mountains. Sediment sources for the upper submember (Tfc3) include the Late Precambrian Stirling Quartzite; Precambrian to Early Cambrian Wood Canyon Formation; Early Cambrian Zabriskie Quartzite; Early to Middle Cambrian Carrara Formation; Middle to Late Cambrian Bonanza King Formation; Late Cambrian Nopah Formation; Early to Middle Ordovician Pogonip Group; and Middle Ordovician Eureka Quartzite. Petrographic data indicate sediment input from a nearby volcanic source area.

Subordinate to the angular, locally derived clasts, the upper submember contains rounded to well rounded clasts composed of quartzite and igneous rock fragments. The occurrence of igneous clasts that are not represented in local outcrops, and the bimodal texture of clasts suggests the presence of a second, more distal sediment source area.

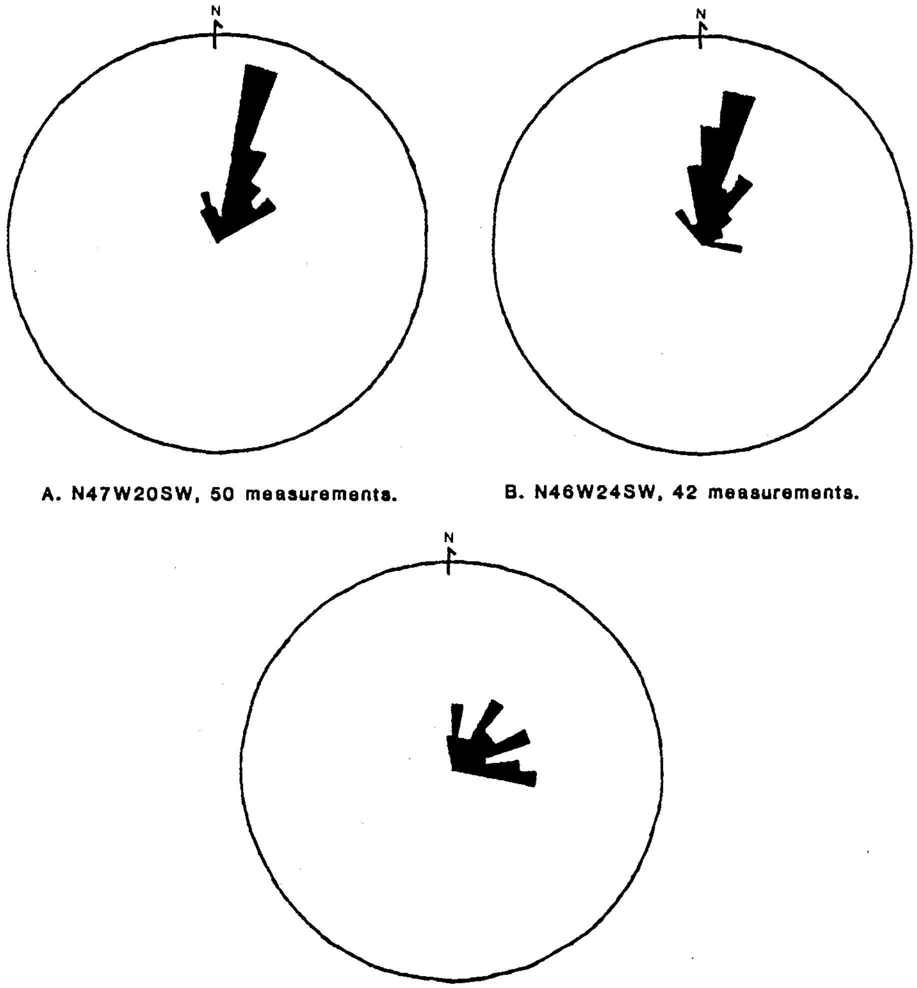
Reynolds (1969) observed well rounded, quartzite, and igneous clasts within conglomeratic exposures of the Oligocene to Miocene(?), Titus Canyon Formation, west of the mouth of Boundary Canyon, and along the flanks of the Grapevine Mountains. It is possible that well rounded quartzite and igneous clasts within the upper submember (Tfc3) were derived from exposures of the Titus Canyon Formation to the north. This would require a minimum sediment transport of 15 miles. It seems unlikely that these clasts represent locally derived, reworked clasts of older conglomerates, due to the absence of quartzite, and igneous clasts in the middle (Tfc2), and lower (Tfc1) submembers of the Furnace Creek Formation.

Estimates of paleocurrent direction, derived from clast imbrication measurements in the upper submember (Tfc3) indicate a bimodal northerly, and easterly source area (Fig. 12,A,B,C).

A measured section of the upper submember (Tfc3), from the western flanks of the Funeral Mountains resulted in a thickness of 551 feet (Fig. 11). This figure may represent a minimum thickness as both the base, and top of the measured section were obscured by younger alluvium.

Textural variability in the lower conglomerate member may be the product of several depositional facies. Matrix supported, massive conglomerates containing poorly sorted, angular to subangular clasts derived from adjacent underlying units indicate alluvial fan deposition. Their textural immaturity suggests a lack of clast-to-clast contact during short transport, and an inability of the transporting medium to winnow fines, and sort clasts. These features are characteristic of sediment laiden debris flows on alluvial fans. The development of clast supported, crudely bedded conglomerates containing moderately sorted, subangular to subrounded, imbricated clasts may be the result of lower viscosity debris flow and fluvial deposition.

Matrix supported, subrounded to subangular pebble



A. N47W20SW, 50 measurements.

B. N46W24SW, 42 measurements.

C. N45W29SW, 50 measurements.

Figure 12. Rose diagrams of imbricated clast dip directions from three outcrop localities (A,B,C) of the lower submember of the lower conglomerate member, Furnace Creek Formation.

conglomerates, and trough cross-bedded, coarse grained sandstone indicate a distal alluvial fan to proximal braided stream depositional facies. Massive to laminated siltstones and mudstones are interpreted as lake deposits.

Lower Conglomerate Member: Hole in the Wall area

A second exposure of the lower conglomerate occurs along the western flanks of the Funeral Mountains, approximately one mile east of Hole in the Wall (Pl. II). Here, the conglomerate unconformably overlies the Upper Paleozoic section, and is inturn conformably overlain, or in fault contact with younger strata of the Funeral Formation.

In this area the lower conglomerate consists of both matrix and clast supported conglomerate. Matrix supported conglomerates are massive, poorly sorted, and contain angular to subangular, pebble to cobble size clasts, and boulders up to four feet in diameter. Clast supported conglomerates are crudely bedded, moderately sorted, and contain angular to subrounded, pebble to small cobble size clasts, and sporatic boulders up to two feet in diameter.

In the northern part of the area (Pl. II), the majority of clasts are composed of carbonate that contain a distinctive brown weathering quartzite derived from the underlying Early to Middle Ordovician Pogonip Group, and minor amounts of quartzite derived from Middle Ordovician Eureka Quartzite. Thin section analysis of this conglomerate is shown in Table II-G. The detrital grains are poorly sorted, subangular to subrounded, and are derived from the underlying Paleozoic units within the Funeral Mountains. The matrix consists of pale reddish brown to grayish orange, silt rich mud to fine sand. Calcite cement may occasionally account for more than half of the interstitial matrix.

Approximately half a mile to the east, the majority of clasts consist of carbonate lithologies most likely derived from the Middle to Late Ordovician Ely Springs Dolomite, and Silurian to Early Devonian Hidden Valley Dolomite. Also present are minor amounts of Eureka Quartzite, and Pogonip Group carbonates, and quartzite, and lenses of subangular to subrounded sandstone clasts of probable Tertiary age. The absence of lacal outcrops of similar sandstone suggest the presence of a second more distal sediment source. Thin section analysis of the conglomerate exposed in the eastern part of the area is shown in Table II-H. The detrital grains are poorly to very poorly sorted, subangular, and are derived from the underlying Paleozoic units exposed in the Funeral Mountains. The matrix consists of reddish orange to gray, carbonate cemented, mud rich silt.

Petrologic differences between the northern and eastern exposures of the lower conglomerate member most likely reflect differences in source area, however it is unclear whether the two exposures are time equivalents.

Within the Hole in the Wall area the presence of matrix supported, massive conglomerate, containing poorly sorted, angular to subangular clasts derived from adjacent underlying units suggest debris flow deposition on an alluvial fan. Clast supported, moderately bedded conglomerate containing moderately sorted, angular to subrounded clasts may result from lower viscosity debris flow, and fluvial deposition.

Lower Conglomerate Member: Northern Black Mountains

A third exposure of the lower conglomerate occurs within the northern part of the Black Mountains (Pl. I). There it conformably overlies the upper sedimentary member of the Artist Drive Formation, and is conformably overlain by younger units of the Furnace Creek Formation. Northeast of the mouth of Gower Gulch, the lower conglomerate member consists of a matrix to clast supported, massive to crudely bedded, pebble to cobble conglomerate, with boulders up to two feet in diameter, and a tan, silt rich mud to fine sand matrix. More than half of the clasts are composed of rounded to subangular, Paleozoic carbonate fragments. Lesser amounts of angular to subrounded, multicolored, Teriary volcanic rock fragments (rhyolite, pumice, and vesiculate, porphyritic basalt), and minor amounts of rounded to well rounded Tertiary granite, and subangular quartzite. Thin section analysis of this conglomerate is shown in table II-I. Subangular to subrounded detrital grains are poorly sorted.

Angular to subrounded Tertiary volcanic clasts are interpreted as being derived from exposures of the Artist Drive Formation in the northern Black Mountains. Rounded to subrounded clasts of Paleozoic carbonates, and subangular Paleozoic quartzite indicate a more distal source area, most likely derived from Paleozoic exposures within the Black Mountains to the south. It is also possible that rounded Paleozoic clasts represent reworked clasts of the Artist Drive Formation, derived from the Black Mountains to the south. The occurrence of rounded to well rounded granitic clasts indicate an additional distal source area most likely derived from Tertiary granites exposures in the Greenwater Range to the southeast (I.Cemen, Perso. Comm., 1988).

West of Twenty Mule Team Canyon (Pl. I), exposures of the lower conglomerate member conformably overlie the upper sedimentary member of the Artist Drive Formation, and are concordantly overlain by the basalts of the Furnace Creek Formation. The conglomerate consists of a clast to matrix supported, crude to well bedded, pebble to cobble conglomerate, with boulders up to two feet in diameter, and a tan to red, fine to coarse sand matrix. Thin sand interbeds are common. More than half of the clasts are composed of rounded Paleozoic carbonates. Lesser amounts of subangular to rounded, multicolored, Tertiary volcanic rock fragments (rhyolite, pumice, and porphyritic basalt), and rounded granitic clasts were noted, as well as minor amounts of subangular quartzite. Clast sorting, and imbrication are best developed within finer grained pebble beds. Bedding is a function of changes in clast size, sorting, and the relative abundance of matrix. Bed thickness ranges from several feet to several inches.

Variations in clast lithologies, and texture, suggest a multiple source origin for the lower conglomerate member. Subangular to rounded, Tertiary volcanic clasts are interpreted as being derived from exposures of the Artist Drive Formation in the northern Black Mountains. Rounded Paleozoic carbonates, and subangular Paleozoic quartzite indicate a more distal source area, most likely derived from Paleozoic exposures in the Black Mountains to the south. It is also possible that rounded Paleozoic clasts represent reworked fragments of the Artist Drive conglomerate. The presence of rounded granitic clasts suggest input from an additional distal source, most likely from Tertiary granites exposed to the southeast in the Greenwater Range.

Petrologic variation within the lower conglomerate indicates the presence of several depositional facies. Northeast of the mouth of Gower Gulch, matrix to clast supported, massive to crudely bedded conglomerates, in part composed of angular to subrounded clasts derived from underlying units suggest debris flow and fluvial deposition in an alluvial fan-distal fan environment. West of Twenty Mule Team Canyon, clast to matrix supported, crude to well bedded conglomerates, containing sand interbeds, and sporadically imbricated, rounded to subangular clasts, indicate lower viscosity debris flow, and fluvial deposition in an distal alluvial fan environment. The relative textural maturity of these deposits is attributed to signficant clast to clast contact during transport, and the ability of the transporting medium to winnow fines and sort clasts.

Upper Conglomerate Member

The upper conglomerate member overlies a thick section of undifferentiated Furnace Creek Formation (Tf) which separates it from the lower conglomerate member (Pl. I). The upper conglomerate member is commonly overlain by lake sediments and minor sands and conglomerates of the upper member of the Furnace Creek Formation (Tfu). Within the study area the thickest and petrologically most diverse exposures of the upper conglomerate member occur along the western flanks of the Funeral Mountains, south of Nevares Peak, and within the northern Black Mountains (Pl. I), where they intertongue with undifferentiated Furnace Creek Formation (Tf) . In these areas lower (Tfcu1) and upper (Tfcu2) submembers are recognized. Less diverse exposures of the upper conglomerate member occur east of Hole in the Wall along the western front of the Funeral Mountains (Pl. II).

Lower Submember: Funeral Mountains

Along the western flanks of the Funeral Mountains, the lower submember (Tfcu1) either conformably overlies undifferentiated Furnace Creek Formation (Tf), or more commonly is in fault contact with it. The lower submember consists of a matrix supported, massive to crudely bedded, pebble to cobble conglomerate, that contains boulders up to four feet in diameter, and a silty clay matrix. It also contains minor sand interbeds. The clasts are poorly to moderately sorted, and show a bimodal texture. The majority of clasts consist of subangular to subrounded, shale, siltstone, quartzite, and carbonate. Thin section analysis of this conglomerate (Table III-J) substantiates outcrop observations. The clasts are derived from the Precambrian to Early Cambrian Wood Canyon Formation, Early Cambrian Zabriskie Quartzite, Early to Middle Cambrian Carrara Formation, and Middle to Late Cambrian Bonanza King Formation. All of these formations are exposed in the Funeral Mountains to the east.

A general southward decrease in the relative amount of shale, and an increase in carbonate clasts were observed. This pattern reflects the present distribution of siliciclastic and carbonate rocks within the Funeral Mountains to the east. Carbonate fragments no longer constitute the majority of clasts in exposures of the lower submember in this area. This trend reflects the continued exposure of successively older Precambrian, and Paleozoic

TABLE III

Composition of samples from the
Upper conglomerate member of the Furnace Creek Formation.

DETRITAL										DIAGENETIC		
SAMPLE	QUARTZ	FELDSPAR	carbonate R.F.	volcanic R.F.	silicilastic R.F.	plutonic R.F.	chert R.F.	MICAS	MATRIX	CEMENTS	CLAYS	POROSITY
J	3		5.5	T	55				17	9.5	.5	9.5
K	2	12.5	2.5	35	9	1	T	.5	12	22	.5	3
L	7	4	14.5	6	37				20	7	.5	4

Siliciclastics include: Quartzite, Siltstone, Shale. Cements include: Calcite, Hematite, Pyrite, Silica overgrowth. Clays include: Illite/Smectite, Kaolinite. R.F. indicates rock fragment. T indicates trace amounts.

units containing abundant siliciclastics. The occurrence of lesser amounts of subangular igneous rock fragments, and minor amounts of rounded quartzite suggest the continued presence of a more distal northerly(?) sediment source area, first noted in the upper submember (Tfc3) of the lower conglomerate member.

Lower Submember: Northern Black Mountains

Within the northern part of the Black Mountains, the lower submember (Tfcu1) either conformably overlies undifferentiated Furnace Creek Formation (Tf) or is in fault contact with it. The lower submember (Tfcu1) is a clast to matrix supported, moderate to well bedded, poorly to moderately sorted, pebble to cobble conglomerate. It contains boulders up to one foot in diameter, and a silty mud to fine sand matrix. Lenses of laminated, medium to coarse sand are common. Petrographic analysis of this conglomerate is shown in Table III-K; detrital grains are poorly to very poorly sorted, and are subangular to subrounded with the exception of euhedral biotite, and hornblende.

The majority of clasts are angular to subrounded, multicolored, Tertiary volcanics (rhyolite, pumice, and vesiculate porphyritic basalt), derived from exposures of the Artist Drive Formation in the northern Black Mountains. A pyroclastic component is indicated by glassy matrix in thin section (Table III-K). Lesser amounts of subrounded, Paleozoic carbonates, and siliciclastics either originated from Paleozoic exposures within the Black Mountains to the south, or represent reworked clasts of the Artist Drive Formation. Minor amounts of subrounded to rounded granitic rock fragments, absent in local outcrops, probably originated from Tertiary granite exposures in the Greenwater Range to the southeast (I. Cemen, Perso. Comm., 1988). Clasts occasionaly show a crude imbrication.

Upper Submember: Funeral Mountains

The upper submember (Tfcu2) either conformably overlies undifferentiated Furnace Creek Formation (Tf), or is in fault contact with the lower submember (Tfcu1). A thick section of lake sediments (Tf) appears to separate the lower and upper beds. The upper submember (Tfcu2) consists of a matrix supported, massive to crudely bedded, moderately to poorly sorted, pebble to cobble conglomerate, with boulders up to four feet in diameter. Sand interbeds are common. The tan to orange, rarely green matrix varies from silty mud and fine sand, to medium and coarse sand. Thin section analysis of this conglomerate is shown in Table III-L; subangular to subrounded detrital grains are poorly sorted.

The clasts are moderately to poorly sorted, and composed of angular to subrounded quartzite, shale, and carbonate, derived from the Late Precambrian, and Paleozoic units exposed in the Funeral Mountains to the east. Lesser amounts of rounded to well rounded quartzite, and igneous clasts, derived from a more distal source area to the north (?) are also present.

The presence of a matrix supported, massive to crudely bedded conglomerate, containing poorly to moderately sorted, angular to subrounded clasts derived from adjacent units, in a fine grained matrix suggests debris flow deposition in an alluvial fan environment. Minor sand interbeds suggest lower energy fluvial deposition.

Upper Submember: Northern Black Mountains

The upper submember (Tfcu2) conformably overlies a thick section of undifferentiated Furnace Creek Formation (Tf), which separates it from the lower submember (Tfcu1). This contact is locally offset by faults. The upper submember (Tfcu2) is a clast to matrix supported, moderate to well bedded, pebble to cobble conglomerate. It contains sporadic boulders up to three feet in diameter, and a reddish tan to green, silty mud to coarse sand matrix. Silty mud, and fine to medium sand interbeds developed on sharp, non-scoured contacts are common. The clasts are poorly to moderately sorted, and composed of subrounded to sub angular Paleozoic carbonate, lesser amounts of porphyritic basalt, quartzite, conglomerate, and minor shale. Clasts occassionaly show a crude imbrication.

Paleozoic carbonates, and siliciclastics reflect the persistence of a more distal source area within the Black

Mountains to the south, previously noted in the lower submember (Tfcu1) in this area. Tertiary basalts are interpreted as derived from the Artist Drive Formation in the northern Black Mountains. The clasts of conglomerate closely resemble the Artist Drive Conglomerates exposed at the Billie Mine area 12 miles to the southeast (I.Cemen Perso. Comm. 1988). Their presence suggests a south to southeasterly source area. The clasts of conglomerate also closely resemble the lower submember (Tfc1) of the lower conglomerate, exposed along the eastern flanks of the Funeral Mountains (Pl. I). A source area in the Funeral Mountains would require a coalescing of alluvial sediments from the Funeral Mountains with those of the Black Mountains. Similar conglomerate clasts were not observed in exposures of the upper submember (Tfcu2) along the western flanks of the Funeral Mountains, suggesting that this is not a likely source area.

The presence of a clast to matrix supported, moderate to well bedded, poorly to moderately sorted conglomerate, containing sand lenses, and imbricated angular to subrounded clasts derived from underlying units indicate lower viscosity debris flow, and fluvial deposition in an alluvial fan environment. The relative textural maturity of these deposits is attributed to clast to clast contacts during transport, and the ability of the transporting medium to sort clasts, and winnow fines.

Upper Conglomerate Member: Hole in the Wall area

Approximately one mile east of Hole in the Wall, along the western flanks of the Funeral Mountains, exposures of the upper conglomerate member (Tfcu) are in fault contact with the underlying undifferentiated Furnace Creek Formation (Tf) (Pl. I). The conglomerate is clast to matrix supported, and massive to moderately bedded. It contains sporadic boulders up to two feet in diameter, and a brown orange, silty mud to fine sand matrix. Bedding results from changes in clast fabric, and matrix content. The conglomerate contains 1) clast supported, well sorted, moderately bedded conglomerate, containing crudely imbricated, pebble sized clasts, in a fine sand matrix; and 2) matrix supported, poorly sorted, massive to crudely bedded conglomerate, containing pebble to cobble sized clasts, with sporadic boulders up to two feet in diameter, and a silty mud to fine sand matrix. The first conglomerate type indicates lower viscosity debris flow, and fluvial deposition in an alluvial fan environment. The second conglomerate type suggests debris flow deposition on an alluvial fan.

The majority of clasts are composed of subangular to subrounded, Paleozoic carbonate, and quartzite derived from the Funeral Mountains to the east, and subangular, calcite cemented Tertiary(?) sandstone of unknown origin. Clasts of the lower conglomerate member derived from the Funeral Mountains to the east, and volcanic rock fragments of uncertain origin were recorded in minor amounts.

Funeral Formation

The Funeral Formation conformably overlies the Furnace Creek Formation within the study area. McAllister (1970) recorded a gradual southeastward increase in the angularity of this contact. The Funeral Formation is unconformably overlain by Quaternary alluvium. Within the study area, exposures of the Funeral Formation occur throughout the interior of the Furnace Creek Wash (Pls. I,II), and consist of upper (QTf), and lower (QTfl) sedimentary members, previously defined by McAllister (1970). A thickness of between 1,000 and 1,500 feet for the sedimentary part of the Funeral Formation was reported by McAllister (1970). Within the northern part of the Greenwater Range, the Funeral Formation contains basalt dated as $4.03 \pm .12$ Ma old (McAllister, 1973).

Petrologic description of the Funeral Formation will be limited to exposures of the upper sedimentary member (QTf) along the northeastern margin of Furnace Creek Wash (Pl. I), where it either conformably overlies the lake sediments (Tf), and upper conglomerate member of the Furnace Creek Formation, or is in fault contact with the same units.

Upper Sedimentary Member: Furnace Creek Basin

The upper sedimentary member is a clast to matrix supported, massive to moderately bedded, pebble to cobble conglomerate, with sporadic boulders up to three feet in diameter, and a reddish orange to dark brown, mud to medium sand matrix. It is typically composed of multi-layered sequences of conglomerate, and minor sand interbeds. Moderately sorted, crudely imbricated, pebble dominated beds indicate lower viscosity debris flow, and fluvial deposition in an alluvial fan environment. Poorly sorted, cobble to boulder dominated beds suggest debris flow deposition on an alluvial fan. Bed contacts are commonly non-distinctive, although distinct planar contacts were noted. The clasts are subangular to rounded, and composed of shale, siltstone, and quartzite, and lesser amounts of carbonate, derived from Precambrian, and Paleozoic exposures within the Funeral Mountains to the east. Minor clasts of conglomerate, which closely resemble the lower conglomerate member of the Furnace Creek Formation were also noted.

CHAPTER IV

STRUCTURE

The most prominent structural feature in the study area is the northwest trending Furnace Creek fault zone which lies along the northeastern margin of the Furnace Creek Wash, and bounds the southwestern side of the Funeral Mountains (Fig. 1; Pls. I,II). A segment of the northern Death Valley fault zone is also exposed within the study area, where it lies along the eastern margin of Death Valley, and bounds the west side of the northern Black Mountains (Fig. 1; Pl. I).

Precambrian and Paleozoic units in the Funeral Mountains contain large folds (Pls. I, III, cross-section A-A''), reverse faults, and high and lower angle normal faults (Pls. I,II). Cenozoic units within the Furnace Creek Wash have been folded (Pl. III, cross-section C-C') and faulted (Pls. I,II, and III); similar units exposed within the northern Black Mountains are uniformly tilted to the northeast (Pls. I,III, cross-section C-C'), and cut by high angle normal faults (Pls. I,III).

A comparison of structural features in the central Funeral, and northern Black Mountains shows a similar cross-cutting relationship between major range bounding fault zones and adjacent faults. In both areas, range bounding fault zones truncate range traversing faults at high angles (PL. I). The relative ages of the range traversing faults associated with these fault zones are not known. However, similar orientations, and sense of displacement suggest development in a common stress field. Quaternary activity on the northern Death Valley fault zone post-dates activity on the central part of the Furnace Creek fault zone (McAllister, 1970).

The folds within the Funeral Mountains will be discussed first, as they are probably the oldest structural features in the study area related to Mesozoic compressional events. The precise timing of these events is uncertain. However, Burchfiel et al. (1983) suggest a Mesozoic age for similar features in the Nopah and Resting Spring Ranges to the east. Field relationships in the Funeral Mountains indicate that folds predates all other structural features.

Mesozoic Structural Features

Folds

South of Nevares Peak, along the western flanks of the Funeral Mountains, Precambrian, and Paleozoic units dip to the southwest (Pl. I). To the west, the same units within the Furnace Creek fault zone dip steeply southwest, or are overturned in that direction. To the east, Precambrian, and Paleozoic units dip to the southeast.

Stereonet analysis of dip data defines a southeast plunging overturned anticline (Fig. 13A). The plunge of the fold is reflected in the southward exposure of progressively younger Precambrian, and Paleozoic units (Pl. I).

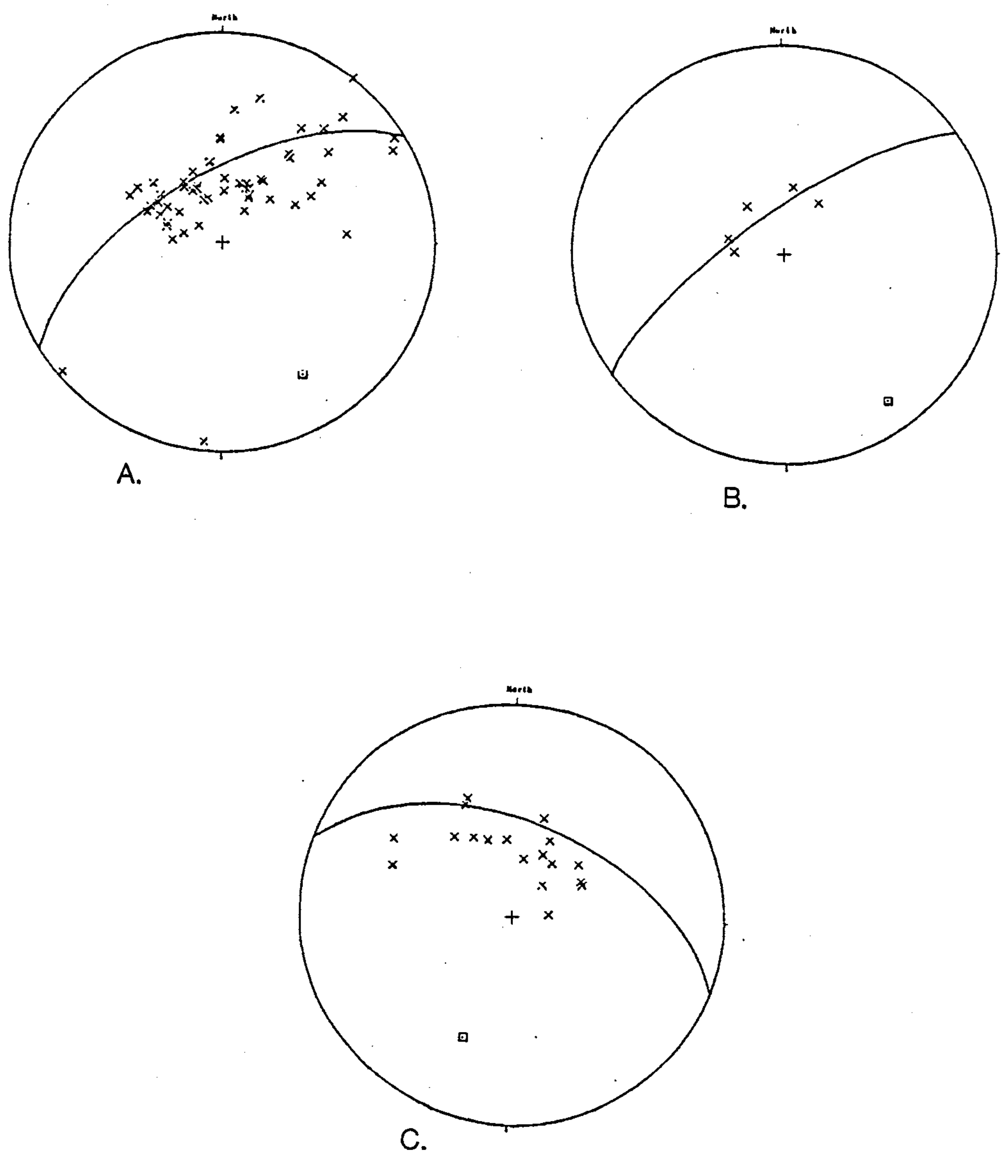
Along the eastern limb of this anticline, Paleozoic units begin to dip back to the southwest. Stereonet analysis of related dip data defines a southeast plunging overturned syncline (Fig. 13B).

Approximately one mile east up Echo Canyon, Paleozoic units change dip direction from southwest to southeast (Pl. I). Stereonet analysis of dip data defines a southwest plunging, overturned anticline (Fig. 13C). This anticline probably plunges to the northwest as it is not observed between the anticline and syncline to the north (Pl. I).

The subparallel orientation of fold axial planes, and the general southward plunge of fold axis suggests a common origin for these structures. The folds are most likely related to a Mesozoic compressional event. This interpretation is based on the lack of compatable folding within Tertiary units adjacent to the Funeral Mountains, and the modification of folded units by the Furnace Creek fault zone, and other Tertiary faults within the Funeral Mountains.

Reverse Faults

Folded Precambrian, and Paleozoic units within the Funeral Mountains are cut by numerous faults of varying



A. B. C.

Figure 13. Equal area stereo-net projections (A,B,C) of folded units within the central Funeral Mountains.

orientation, and displacement. Features associated with these structures include exposed fault planes containing slickensides, striations, zones of gouge, and fault breccia.

A north-south striking reverse fault, dipping 64° to 67° westward displaces the Early Cambrian Upper Wood Canyon Formation, and Zabriskie Quartzite against the Early to Middle Cambrian Carrara Formation in the northeastern part of the study area, west of hill 4213 (Pl. I). This fault, is offset, and truncated by a series of northeast trending faults. A second reverse fault, striking to the northeast, and dipping 70° SE displaces the Middle Cambrian Papoose Lake Member of the Bonanza King Formation against the Middle to Late Cambrian Banded Mountain Member, north of Echo Canyon (Pl. I). This fault is truncated by a low angle normal fault to the north, and an east-west trending fault to the south.

Reverse separation of aproximately 50, and 150 feet for the northern and southern reverse faults respectively, are infered in cross-sections A'-A''(Pl. III), and E-E'(Pl. III). The strike of the reverse faults are subparallel to the strike of axial planes of Mesozoic folds in the central Funeral Mountains. The reverse faults are interpreted as a result of Mesozoic compression.

Cenozoic Structural Features

Folds

Cenozoic sediments within Furnace Creek Wash are folded (Pls. I, and III, cross-section C-C'). McAllister (1970) mapped several northwest, and southeast plunging folds in the northern part of the Wash, and attributed their development to fault drag. Several folds occur within the interior of the Wash (Pl. III, cross-section C-C') in areas most likely not effected by fault drag associated with range bounding faults. This suggests that other deformational stresses in addition to fault drag have contributed to the development of folds in the northern Furnace Creek Wash area. These folds may have developed as extensional folds in response to the northwest directed Late Cenozoic extension which produced the strike-slip displacement along the Furnace Creek-Death Valley fault system (I. Cemen, Perso. Comm., 1988).

East of Hole in the Wall, a single southeast plunging syncline developed within the undifferentiated Furnace Creek Formation (Tf) of the Furnace Creek Formation was mapped adjacent to the Furnace Creek fault zone (Pl. II). The subparallel allignment of the fold axis, and fault zone and their proximity to one another suggest that the fold is the result of fault drag. Paleozoic units in this area consistantly dip to the east-northeast, and do not appear to be folded (Pl. III, cross-section F-F').

Furnace Creek fault zone: Central Funeral Mountains

The northwest trending Furnace Creek fault zone bounds the west side of the Funeral Mountains, down-dropping Cenozoic sediments to the southwest against Paleozoic units to the northeast (Pls. I,II). Northeast of Texas Springs (Pl. I), the fault zone contains a series of subparallel, northwest trending faults (Pl. III, cross-sections A-A', B-B', and C'-C''). Fault planes dip 48° to 88° SW, with the exception of two faults southwest of Nevares Peak, which dip 67° NE, and 75° SE (Pl. III, cross-section A-A'), and appear to be overturned to the west.

In the northern part of the study area, along the eastern edge of the Furnace Creek fault zone, the Banded Mountain member of the Bonanza King Formation is faulted against the Lower member of the Wood Canyon Formation (Pl. I). An apparent normal-separation of approximately 7,000 feet is indicated for this fault in cross-section A-A'(Pl. III). About a mile to the south a separation of similar magnitude is indicated in cross-section B-B'(Pl. III) for a fault along the eastern edge of the Furnace Creek fault zone.

Based on minimum thicknesses for Tertiary units (Fig. 11), normal-separations of 800 to 1,500 feet are indicated in cross-sections A-A', and B-B'(Pl. III) for faults separating Tertiary and Paleozoic units within the Furnace Creek fault zone. North of the mouth of Echo Canyon (Pl. I) the upper conglomerate member of the Furnace Creek

Formation is faulted against rocks of the Pogonip Group (Pl. III, cross-section E-E'). Although the total thickness of the Tertiary section is not known at this location, a maximum normal-separation of several thousand feet is likely.

Individual faults are commonly composed of several closely spaced, discrete slip surfaces, containing slickensides, striations, and zones of gauge, and breccia. Abundant calcite cementation along the faults of the Furnace Creek fault zone indicate preferential fluid migration along zones of relatively higher permeability associated with fault fractured sediments. As a result, faults often form erosionally resistant ridges of greater relief than their surroundings. Along the eastern edge of the Furnace Creek fault zone prominent scarps mark faults which cut Tertiary units (Fig. 14).

Striations developed on fault plane surfaces, or within layers of fault breccia, often show a variety of orientations ranging from horizontal to oblique to vertical. It appears that net displacements on individual faults within the Furnace Creek fault zone result from the episodic accumulation of oblique-slip, dip-slip, and strike-slip movements.

Tertiary sediments within the Furnace Creek fault zone generally dip to the southwest. This orientation most likely reflects the initial depositional dip of alluvial fan sediments originating from a northeasterly source in

Figure 14. Photograph of prominent fault scarp of the Furnace Creek fault zone. Undifferentiated Furnace Creek Formation in the western (right) block has been down-dropped next to lower conglomerate member in the eastern (left) block.

the Funeral Mountains, the rotation of bedding planes resulting from southwest block down displacement along the Furnace Creek fault zone.

Within the eastern edge of the Furnace Creek fault zone, there are several faults at moderate to high angles to the major northwest trending faults (Pl. I). These faults displace both Paleozoic, and older Tertiary units, and are consistantly truncated by major northwest trending faults. Cross-cutting, and sratigraphic relationships suggest that these structures predate the development of the Furnace Creek fault system.

Furnace Creek fault zone: Hole in the Wall area

Southeast of Hole in the Wall, the Furnace Creek fault zone bounds the west side of the Funeral Mountains, and is often concealed by Quaternary alluvium (Pls. II, and III, cross-section F-F'). Late Cenozoic sedimentary units are cut by the fault zone to the southwest. The deformation of beds within the undifferentiated Furnace Creek Formation (Tf) suggest oblique movement on the easternmost trace of the Furnace Creek fault zone (Pl. II). Changes in bed orientation on the northeastern block show a clockwise rotation, and an increase in dip in the direction of the fault. Beds on the southwestern block show a clockwise rotation, and a decrease in dip in the direction of the fault (Fig. 15). This deformation is attributed to fault drag, and is compatible with right-lateral, southwest block

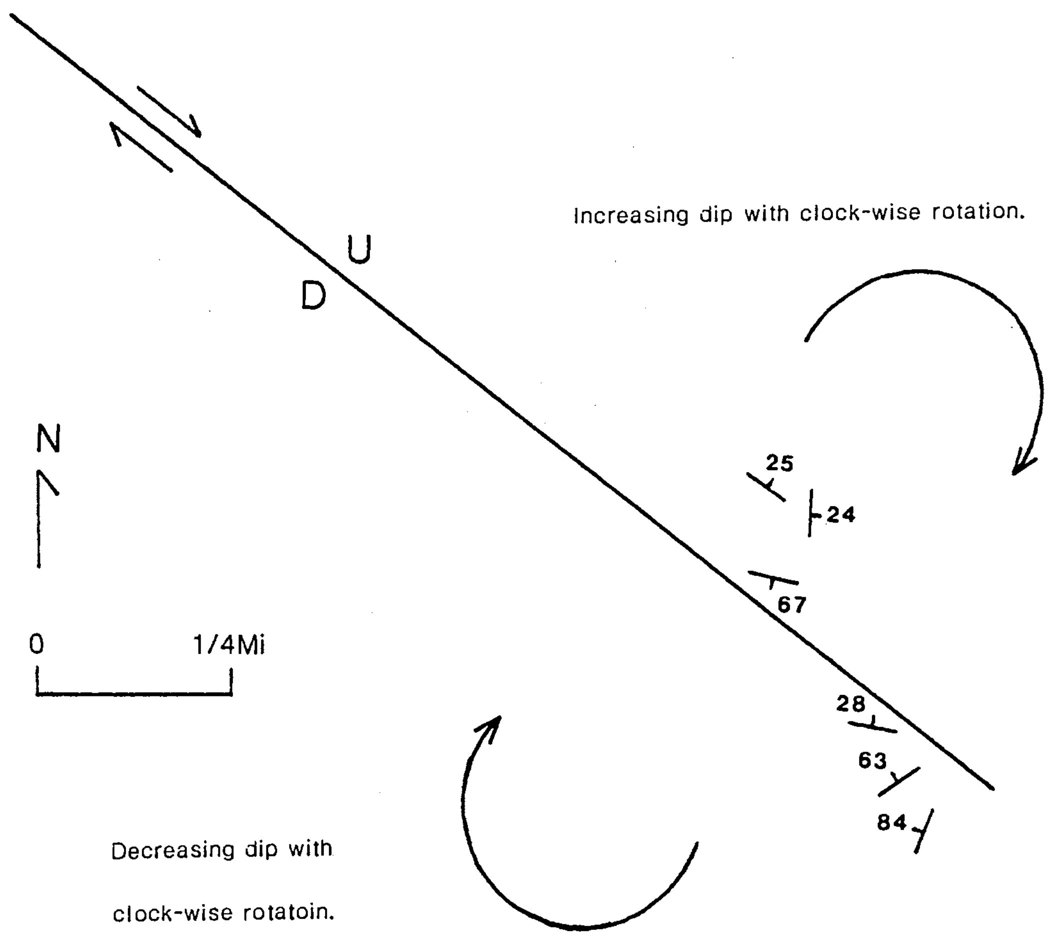


Figure 15. Schematic map showing rock deformation resulting from right-lateral, southwest block down movement on the Furnace Creek fault zone, Hole in the Wall area.

down movement.

Death Valley fault zone: Northern Black Mountains

The northern Black Mountains are bounded to the west by the Death Valley fault zone, which lies concealed beneath Quaternary alluvium (Pls. I, and III, cross-section C-C'). Discontinuously exposed fault scarps developed within Quaternary alluvium along the western flanks of the Black Mountains reflect recent activity on the fault zone. McAllister (1970) concludes that movements on the Death Valley fault zone postdate movements on the Furnace Creek fault zone, which is overlain by Quaternary alluvium. Faults within the northern Black Mountains appear to be truncated by the Death Valley fault zone (Pl. I).

Normal Faults: Central Funeral Mountains

The most pervasive structures in the central Funeral Mountains are normal faults which strike northeast to northwest (Pl. I). In the northeastern part of the study area, Paleozoic units are cut by a series of subparallel, east-northeast trending, north dipping, high angle normal faults. A southward increase in normal separation from 100 to 300 feet is indicated in cross-section A'-A''(PL. III).

In the northwestern part of the central Funeral Mountains (PL. I), Precambrian and Paleozoic units are cut by faults whose trend varies from west-northwest to east-northeast. Stratigraphic separation, and fault plane geometry indicate normal separation for several of these faults. Within the central and southern parts of the central Funeral Mountains (Pl. I), Paleozoic units are cut by predominantly east-west trending faults. Stratigraphic separation, and fault plane orientation indicate that the majority of these faults are high angle normal faults, dipping 64° to 87° to the north and south.

Structures within the Funeral Mountains are truncated by the Furnace Creek fault zone, and are interpreted as predating the development of the fault zone (Pl. I).

North of hill 3647, in the central part of the Funeral Mountains, Paleozoic units are cut by a normal fault which is about 5 Km in extent (Pl. I). The fault has a southeast trending segment and a southwest trending segment, and is informally named the Echo Canyon fault. The southeast trending segment of the fault dips 44° to 53° SW, displacing Middle to Late Cambrian Bonanza King Formation against the Early Cambrian Zabriskie Quartzite and the Early to Middle Cambrian Carrara Formation (Pl. III, cross-section E-E'). South of Echo Canyon, zones of calcite filled fractures occur in the hanging wall, as well as thick layers of fault gauge and breccia along the fault plane. The southeastern limit of this structure lies outside the study area. As much as 2,200 feet of normal separation may have accumulated on this fault surface (Pl. III, cross-section E-E').

The southwest trending segment of this fault dips 85°

to 89^{o} NW, and brings the Middle Cambrian Papoose Lake Member of the Bonanza King Formation against Early and Middle Cambrian Carrara Formation (Pl. III, cross-section D-D'). At it's southwestern end the fault is truncated by the Furnace Creek fault zone. A cross-section accross this fault (Pl. III, cross-section D-D') indicates 1,250 feet of vertical, normal separation.

Two faults northwest and northeast of hill 3647 (Pl. I) show a similar map pattern and sense of displacement to the Echo Canyon fault. Cross-cutting relationships (Pl. I) suggest that these three faults postdate all other structural features in the central Funeral Mountains. Prior to truncation, the southwest trending segment of the Echo Canyon fault appears to truncate part of the Furnace Creek fault zone, indicating continued activity during the development of the fault zone. These structures are interpreted as fault bounded landslide features probably resulting from slope instability associated with the uplift of the central Funeral Mountains.

Normal Faults: Hole in the Wall area

Northwest and northeast trending normal faults cut Middle to Upper Paleozoic and Tertiary units within the Funeral Mountains, southeast of Hole in the Wall (Pls. II, and III, cross-section F-F'). Based on limited exposures, northeast trending faults appear to truncate and therefore postdate northwest trending faults. Faults exposed within the Funeral Mountains are most likely truncated beneath Quaternary alluvial cover by the Furnace Creek fault zone to the west.

Normal Faults: Northern Black Mountains

In the northernmost part of the Black Mountains, northeast striking faults cut the upper members of the Furnace Creek Formation, down dropping blocks on the west side (Pls. I, and III, cross-section C-C'). To the south, these faults are truncated by younger(?), east striking faults which cut the lower members of the Furnace Creek Formation, and upper members of the Artist Drive Formation. The faults are mostly down-to-the north, but some faults are down-to-the south.

Tertiary units within the northern Black Mountains generally dip to the northeast. This orientation does not appear to be the result of fault drag along the Death Valley fault zone, or faults in the northern Black Mountains, but may be attributed to the northeast directed rotation of beds along west dipping listric normal faults.

CHAPTER V

CONCLUSIONS

Based on data collected during the course of this study two types of conclusions are reached; those pertaining to stratigraphic and sedimentologic aspects of the Furnace Creek Formation, and those pertaining to structural aspects of the Furnace Creek fault zone and adjacent structures.

Stratigraphy and Sedimentology

Along the western flanks of the central Funeral Mountains, the lower conglomerate member of the Furnace Creek Formation (McAllister, 1970) can be divided into lower (Tfc1), middle (Tfc2), and upper (Tfc3) submembers, based on changes in clast composition and matrix. These submembers record part of the uplift and erosional history of the central Funeral Mountains.

The lower conglomerate member is interpreted as a remnant of an alluvial fan based on a) angularity of rock fragments, derived from adjacent underlying units, b) poor degree of sorting, c) lack of internal stratification, and d) the presence of fine grained matrix. An east to northeasterly source is indicated by a westward thinning of the conglomerate, and by the presence of Precambrian and Paleozoic formations within the central Funeral Mountains to the east and northeast. An additional source area is indicated by the presence of rounded to well-rounded quartzite and igneous clasts, probably derived from exposures of the Oligocene to Miocene(?) Titus Canyon Formation, 15 miles to the north, in the southern Grapevine Mountains. Clast imbrications in the upper submember (Tfc3) indicate southerly and westerly paleocurrent directions.

Along the western flanks of the central Funeral Mountains an incomplete measured section of the lower conglomerate member of the Furnace Creek Formation resulted in a minimum thickness of 1,473 feet (Fig. 11). Interbedding angular conglomerates and lacustrine sediments may represent tectonic cyclothems as defined by Gloppen and Steel (1981), and reflect episodic tectonic activity along that segment of the Furnace Creek fault zone. Asymmetry within the lower conglomerate member of the Furnace Creek Formation along opposing margins of the Furnace Creek Basin may reflect the tectonic dominance of the northeastern margin during early deposition of the Furnace Creek Formation. Within the northern part of the Black Mountains, the lower conglomerate member of the Furnace Creek Formation is interpreted as a remnant of an alluvial fan-braided stream system based on a) the presence of rounded to subangular, locally imbricated clasts, b) crude to well developed bedding, c) clast to matrix support, d) a sandy matrix, and e) the presence of numerous sand interbeds. A southerly source area is indicated by the presence of Tertiary Artist Drive volcanics, and Paleozoic carbonates within the Black Mountains to the south. Rounded granitic clasts most likely originated from exposures of Tertiary granite in the Greenwater Range to the southeast.

Along the western flanks of the central Funeral Mountains and within the northern part of the Black Mountains, the upper conglomerate member (Tfcu) of the Furnace Creek Formation (McAllister, 1970), can be divided into lower (Tfcu1) and uppe (Tfcu2) submembers based on changes in clast composition and matrix.

Along the western flanks of the Funeral Mountains the lower submember (Tfcu1) is interpreted as a remnant of an alluvial fan based on a) angularity of rock fragments, b) massive to crude bedding, c) matrix support, and d) the presence of fine grained matrix. The upper submember (Tfcu2) is interpreted as a remnant of an alluvial fan-braided stream system based on a) the presence of moderately to poorly sorted, subangular to subrounded clasts, b) massive to crude bedding, c) fine to locally coarse matrix, and d) the presence of numerous sand interbeds.

An east to northeasterly source is indicated by a westward thinning of the conglmerate, and by the presence of Precambrian and Paleozoic formations within the central Funeral Mountains to the east and northeast. An additional source in the southern Grapevine mountains is also indicated.

Within the northern part of the Black Mountains, the lower (Tfcu1) and upper (Tfcu2) submembers of the Furnace Creek Formation are interpreted as remnants of distal alluvial fan-braided stream systems based on a) the presence of poorly to moderately sorted, locally imbricated, angular to subrounded clasts, derived from adjacent underlying units, b) moderate to well developed bedding, c) clast to matrix support, d) fine to medium grained matrix, and e) the presence of numerous, laminated sand interbeds.

A southerly source area is indicated by the Presence of Tertiary Artist Drive volcanics, and Paleozoic carbonates within the northern part of the Black Mountains to the south. A south to southeasterly source area is indicated by the presence of clasts of Tertiary conglomerate that closely resemble the Artist Drive conglomerates exposed at the Billie Mine area, 12 miles to the southeast. Granitic rock fragments, similar to those found in the lower conglomerate (Tfc) may be derived from exposures of Tertiary granite in the Greenwater Range to the southeast, or may represent locally reworked clasts from the lower conglomerate (Tfc).

Structure

Folds and reverse faults within Precambrian and Paleozoic units in the central Funeral Mountains (Pls. I, and III, cross-section A-A'') are attributed to Mesozoic compressional events.

East-northeast striking, high angle normal faults cut Precambrian and Paleozoic units in the central Funeral Mountains (Pls. I, and III, cross-section A-A''). These faults, which postdate Mesozoic compressional features, are truncated by the Furnace Creek fault zone, and are interpreted as early Cenozoic extensional features comparable to those documented by McAllister (1971) and Cemen, et al. (1985) near the southern end of the Funeral Mountains.

Based on the earliest Tertiary structural features, initial crustal fragmentation in the Death Vally region occurred along generally northeast striking, high angle normal faults, in response to Early Cenozoic northwest directed crustal extension.

Northeast to east-west striking faults in the northern Black Mountains and within the Furnace Creek fault zone are truncated by the Death Valley and Furnace Creek fault zones respectively (Pl. I). These faults are interpreted as 1) predating development of the Furnace Creek and Death Valley fault zones, and 2) probably contemporaneous with similarly oriented faults in the central Funeral Mountains.

Striations developed on individual faults of the

Furnace Creek fault zone indicate episodic strike-slip, oblique-slip, and dip-slip displacement compatable with northwest directed crustal extension. Fault drag associated with the faults of the eastern edge of the Furnace Creek fault zone (Pl. II, Fig. 17), and stratigrphic separations (Pls. I,III) indicate right-lateral, southwest block down net movement.

In the central Funeral Mountains, the southeast to southwesterly trending Echo Canyon fault and two other similar faults constitute a special kind of structure. The dip of the Echo Canyon fault decreases from near vertical along the southwestern segment to as low as 44^{o} SW along the southeastern segment. Down-dropping of the southern block has resulted in aproximately 2,200 feet of stratigraphic separation (Pl. 7). The structures bounded by the Echo Canyon fault to the east and the two other faults to the north are interpreted as fault bounded landslide features resulting from slope instability associated with the uplift of the central Funeral Mountains. Cross-cutting relationships indicate these features postdate Early Tertiary extensional faults, and predate latest activity along the Furnace Creek fault zone.

REFERENCES CITED

Axelrod, D.I., 1940, A record of Lyonothamnus in Death Valley: Jour. Geology, vol. 48, pp. 526-531.

Baker, C.L., 1913, The nature of the later deformation in certain ranges of the Great Basin: Jour. Geology, vol. 21, pp. 273-278.

Burchfiel, B.C., and Stewart, J.H., 1966, "Pull-apart" origin of the central segment of Death Valley, California: Geol. Soc. America Bull., v. 77, pp. 439-442.

Burchfiel, B.C., Hamill IV, G.S., and Wilhelms, D.E., 1983, Structural geology of the Montgomery Mountains and the northern half of the Nopah and Resting Spring Ranges, Nevada and California: Geol. Soc. America Bull., v. 94, pp. 1359-1376.

Cemen, I., Drake, R., and Wright, L.A., 1982, Stratigraphy and chronology of the Tertiary sedimentary and volcanic units at the southeastern end of the Funeral Mountains, Death Valley region, California, in Cooper, J.D., Troxel, B.W., and Wright, L.A., eds., Geology of selected areas in the San Bernardino Mountains, western Mojave Desert, and southern Great Basin, California: Guidebook, field trip no. 9, 78yh annual metting Cordilleran Section, Geol. Soc. America, pp. 77-86.

Cemen, I., Wright, L.A., Drake, R.E., and Johnson, F.C., 1985, Cenozoic sedimentation and sequence of deformational events at the southeastern end of the Furnace Creek strike-slip fault zone, Death Valley region, California, in Biddle, K.T., and Christie-Blick, N., eds., Strike-slip deformation, basin formation, and sedimention: The Society of Economic Paleontologists and Mineralogists, special publication no. 37, pp. 127-141.

COCORP, 1986, Death Valley bright spot: A midcrustal magma body in the southern Great Basin, California?: Geology, v. 14, pp. 64-67.

Curry, H.D., 1938, Strike-slip Faulting In Death Valley, California: (Abstract) Geol. Soc. America Bull., v. 49, no. 12, pp. 1874.

Ferguson, H.G., 1926, Late Tertiary and Pleistocene faulting in western Nevada: (Abstract) Geol. Soc. America Bull., v. 37, pp. 164.

Gianella, V.P., and Callaghan, E., 1934, The Earthquake of December 20, 1932, at Cedar Mountain, Nevada and it's bearing on the genesis of Basin-Range structure: Jour. Geology, v. 42, pp. 1-22.

Gloppen, T.G., and Steel, R.J., 1981, The deposits, internal strcture and geometry in six alluvial fan-fan delta bodies (Devonian-Norway)- A study in the significance of bedding sequence in conglomerates, in Ethridge, R.G., and Flores, R.M., eds., Recent and ancient non-marine depositional environments: models for exploration: Society of Economic Paleontologists and Mineralogists, special publication no. 31, pp. 49-69.

Hazzard, J.C., 1937, Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Jour. Mines and Geology, v. 33, pp. 273-339.

Hill, M.L., and Troxel, B.W., 1966, Tectonics of Death Valley region, California: Geol. Soc. America Bull., v. 77, pp. 435-438.

Hunt, C.B., and Mabey, D.R., 1966, Stratigraphy and structure Death Valley, California: Geol. Survey Prof. Paper 494-A, 162p.

Jones, C.H., 1987, Is extension in Death Valley accomodated by thinning of the mantle lithosphere beneath the Sierra Nevada, California?: Tectonics, v. 6, no. 4, pp. 449-473.

McAllister, J.F., 1970, Geology of the Furnace Creek borate area, Death Valley, Inyo County, California: California Div. Mines and Geology. Map Sheet 14, with text, 9 p.

__________, 1971, Preliminary geologic map of the Funeral Mountains in the Ryan quadrangle, Death Valley region, Inyo County, California: United States Geological Survey open file report, Scale 1:62500.

__________, 1973, Geological map and sections of the Amargosa Valley borate area, southeast continuation of the Furnace Creek area-Inyo County, California: Calif. Div. Mines and Geol., Misc. Geol. Invest. Map I-782.

__________, 1974, Silurian, Devonian, and Mississippian Formations of the Funeral Mountains in the Ryan quadrangle, Death Valley region, California: United States Geological Survey Bulletin, 1386, 35 p.

Noble, L.F., 1941, Structural features of the Virgin Spring area, Death Valley, California: Geol. Soc. America Bull., v. 52, pp. 941-1000.

Noble, L.F., and Wright L.A., 1954, Geology of central and southern Death Valley region, California, in Jahns, R.H., ed., Geology of southern California: Calif. Div. Mines Bull., 170, chapt. II, pp. 143-160.

Nolan, T.B., 1943, The Basin and Range Province in Utah, Nevada, and California: United States Geological Survey Prof. Paper 197-D, pp. 141-196.

Palmer, A.R., and Hazzard, J.C., 1956, Age and correlation of Cornfield Springs and Bonanza King Formations in southeastern California and Nevada: Am. Assoc. Petroleum GeologistsBull., v. 40, no. 10, pp. 2494-2499.

Reynolds, M.M., 1969, Stratigraphy and structural geology of the Titus and Titanothere Canyons area, Death Valley, California: unpublished PhD thesis, Berkeley University, California, 310 p.

Shawe, D.R., 1965, Strike-slip control of Basin-Range structure indicated by historic faults in western Nevada: Geol. Soc. America Bull., v. 76, pp. 1361-1378.

Spurr, J.E., 1901, Origin and structure of the basin ranges: Geol. Soc. America Bull., v. 12, pp. 217-270.

Stewart, J.H., 1967, Possible large right-lateral displacement along fault and shear zones in the Death Valley-Las Vegas area, California and Nevada: Geol. Soc. America Bull., v. 78, pp. 131-142.

__________, Albers, J.P., and Poole, F.G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: Geol. Soc. America Bull., v. 79, pp. 1407-1413.

__________, 1970a, Reply to discussion on summary of regional evidence for right-lateral displacement in western Great Basin: Geol. Soc. America Bull., v. 81, pp. 2175-2180.

__________, 1970b, Upper Precambrian and Lower Cambrian strata in the southern Great Basin, California and Nevada: U.S. Geol. Survey Prof. Paper 620, 206p.

__________, 1983, Extensional tectonics in the Death Valley area, California: Transport of the Panamint Range structural block 80 Km northwest: Geology, v. 11, pp. 153-157.

Wernicke, b., 1981, Low-angle normal faults in the Basin and Range province: Nappe tectonics in an extending orogen : Nature, v. 291, pp. 645-648.

Wright, L.A., and Troxel, B.W., 1967, Limitations on right-lateral, strike-slip displacement, Death Valley and Furnace Creek fault zones, California: Geol. Soc. America Bull., v. 78, pp. 933-950.

____,and ____, 1970, Discussion on summary of regional evidence for right-lateral displacement in the western Great Basin: Geol. Soc. America Bull., v. 81, pp. 2167-2174.

____,and ____, 1973, Shallow-fault interpretation of Basin and Range structure, southwest Great Basin, in Dejong, k., and Scholten, R., eds., Gravity and Tectonics: New York, John Wiley and Sons, pp. 397-407.

VITA

Mark Edward Savoca

Candidate for the Degree of

Master of Science

Thesis: STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND STRUCTURE OF THE TERTIARY UNITS IN THE NORTHERN PART OF THE FURNACE CREEK BASIN, DEATH VALLEY, CALIFORNIA

Major Field: Geology

Biographical:

Personal Data: Born in Pittsburgh, Pennsylvania, September 22, 1955, the son of Joseph and Jeanine Savoca.

Education: Graduated from Byram Hills High School, Armonk, New York, in may, 1974; received Bachelor of Arts Degree in Anthropology from S.U.N.Y.-Binghampton in May, 1978; recieved Bachelor of Science Degree in Geology from University of Washington in August, 1985; completed requirements for the Master of Science degree in Geology at Oklahoma State University in May, 1989.

Professional Experience: Research Assistant, School of Geology, Oklahoma State University, January, 1989 to May, 1989; Teaching Assistant, School of Geology, Oklahoma State University, August, 1986 to December, 1988; Geologist, United States Department of the Interior N.P.S.-Denver Service Center, July, 1987 to August, 1987-Death Valley National Monument, January, 1986 to August, 1986.

Plate I Geologic Map of the Northern Furnace Creek Wash Area

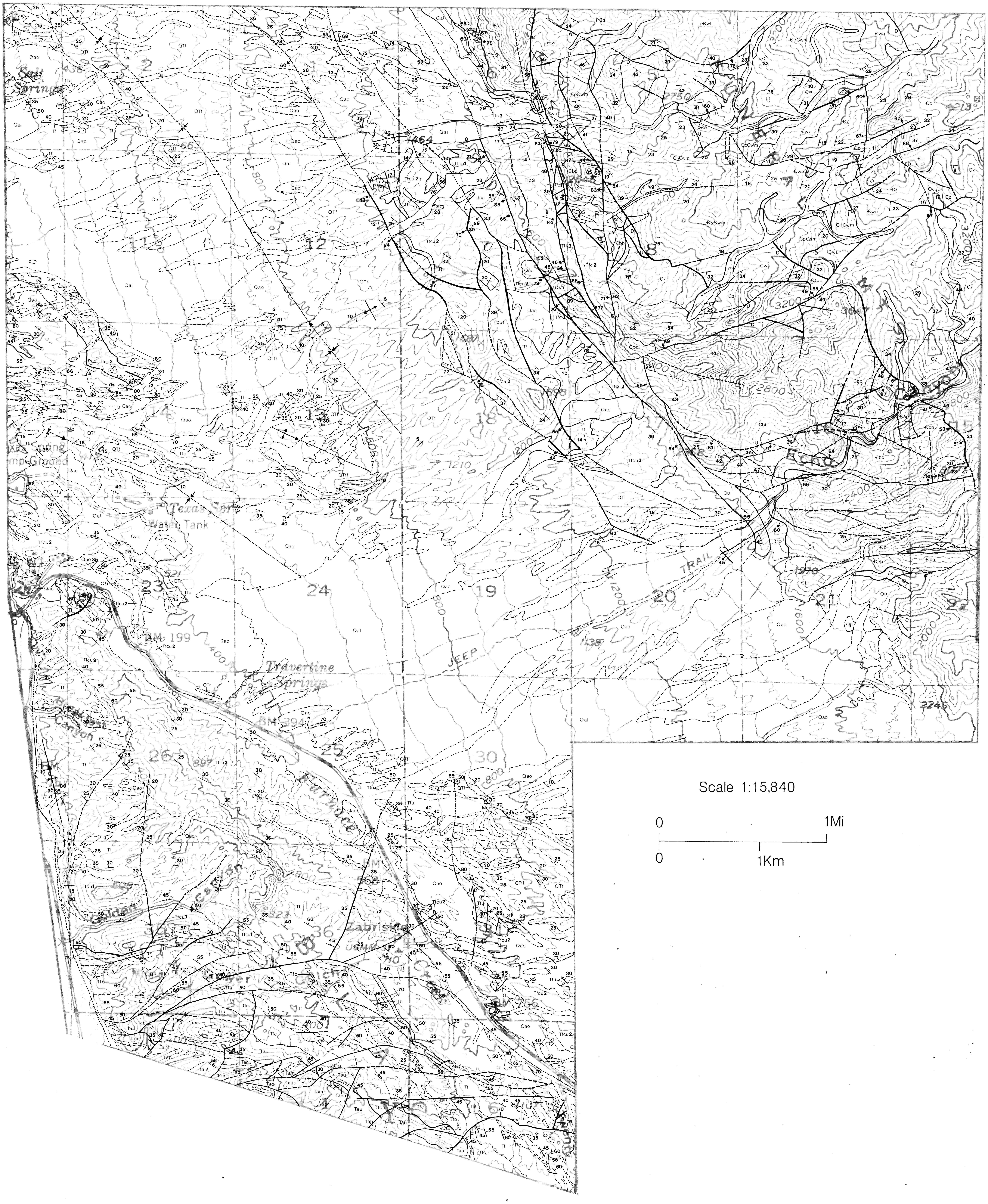


Plate II

Geologic Map of the Area East of Hole in the Wall

Scale 1:15,840

0 — 1Mi

0 — 1Km

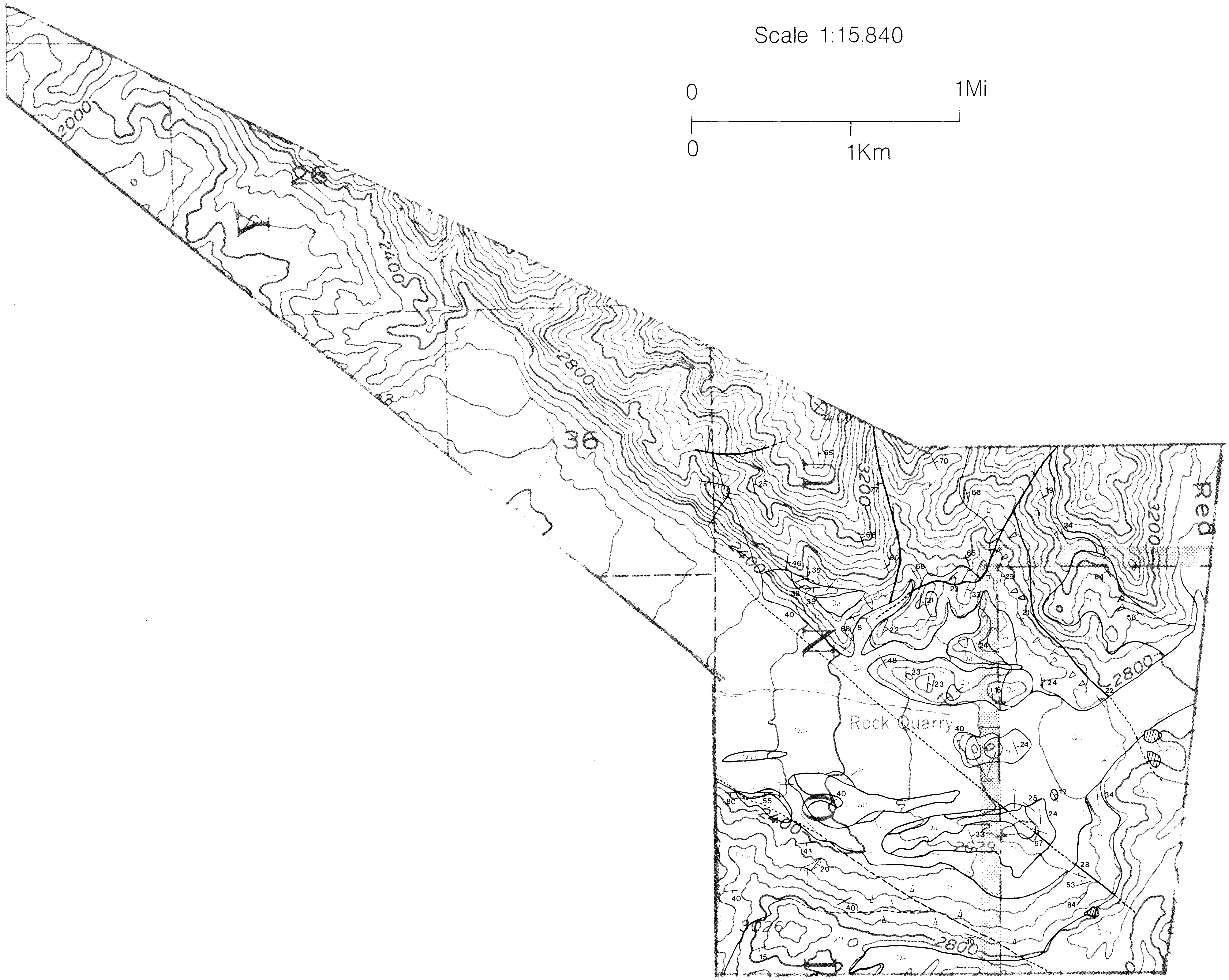
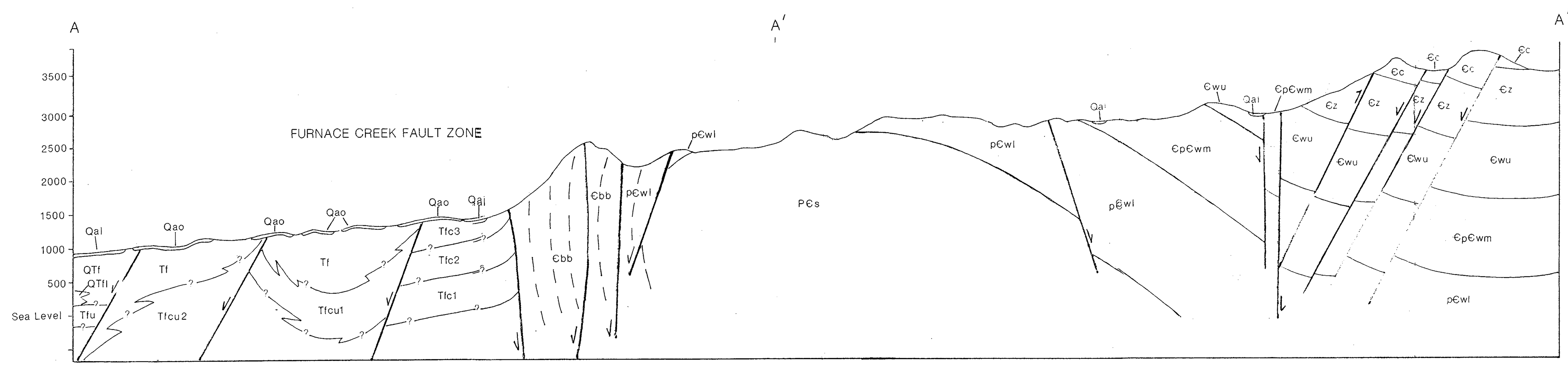
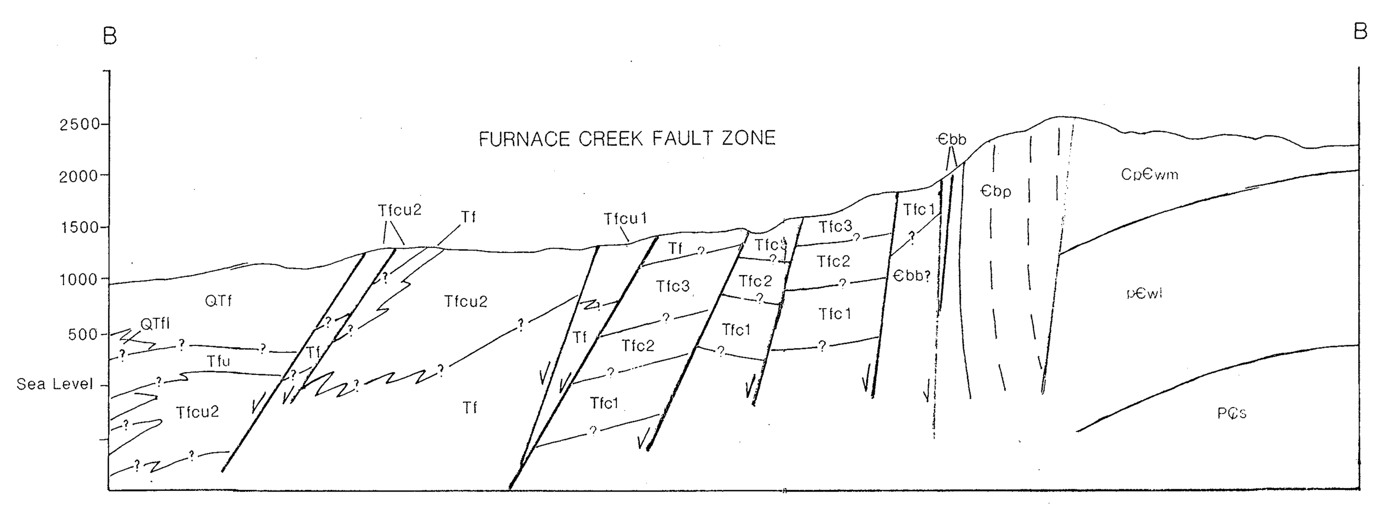
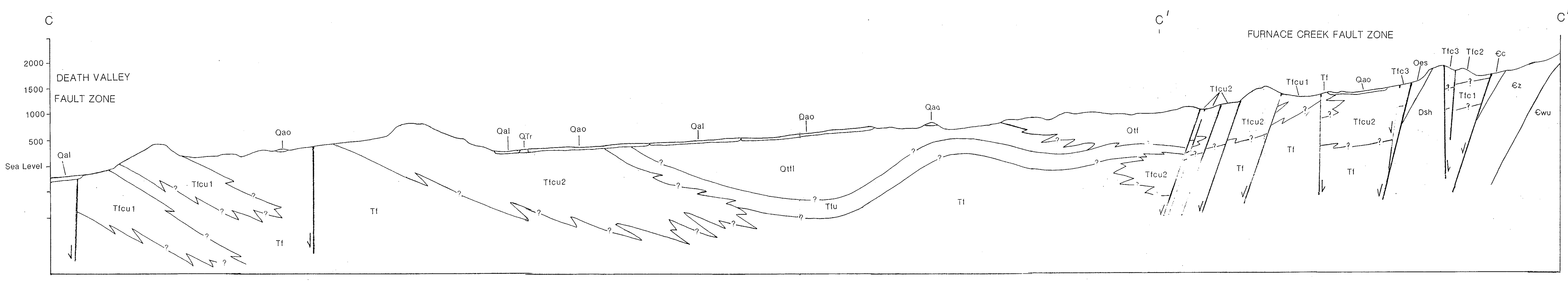
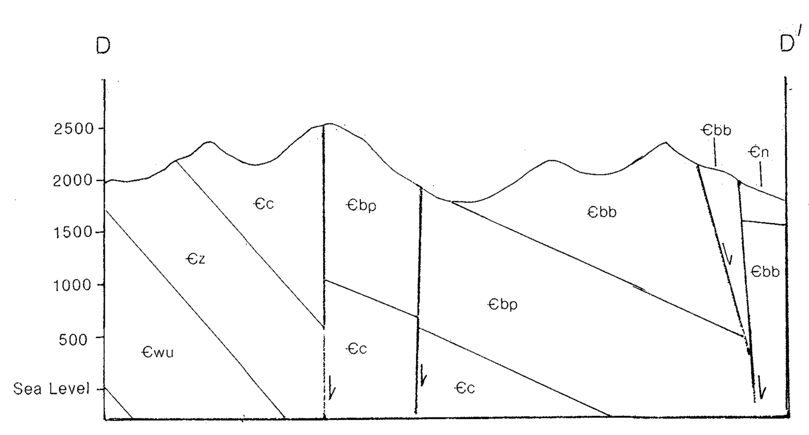


PLATE III CROSS-SECTIONS

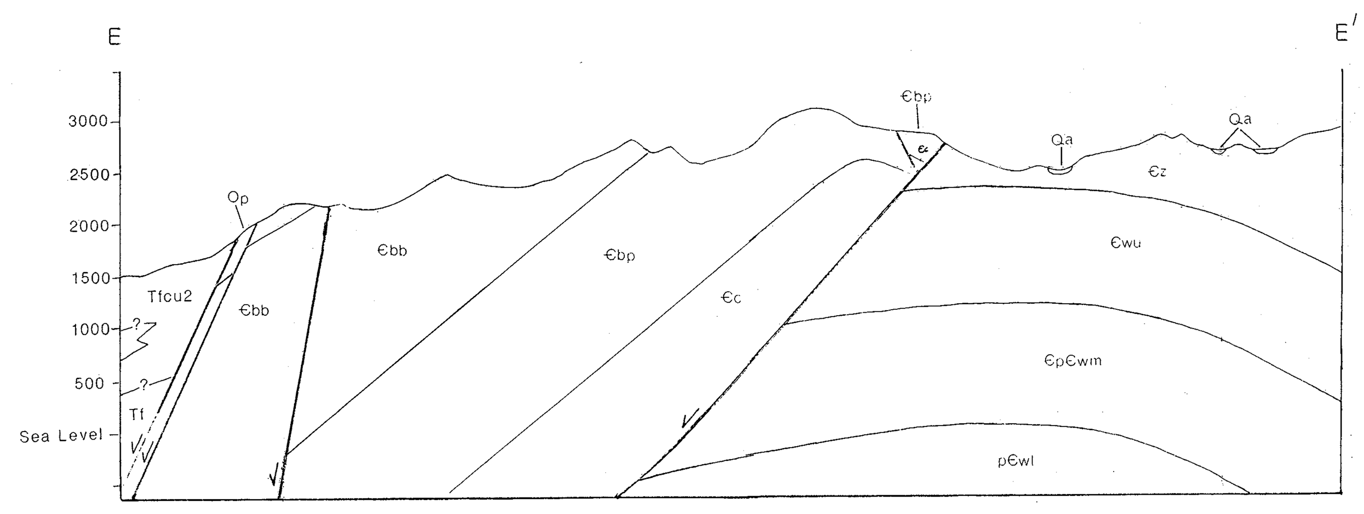


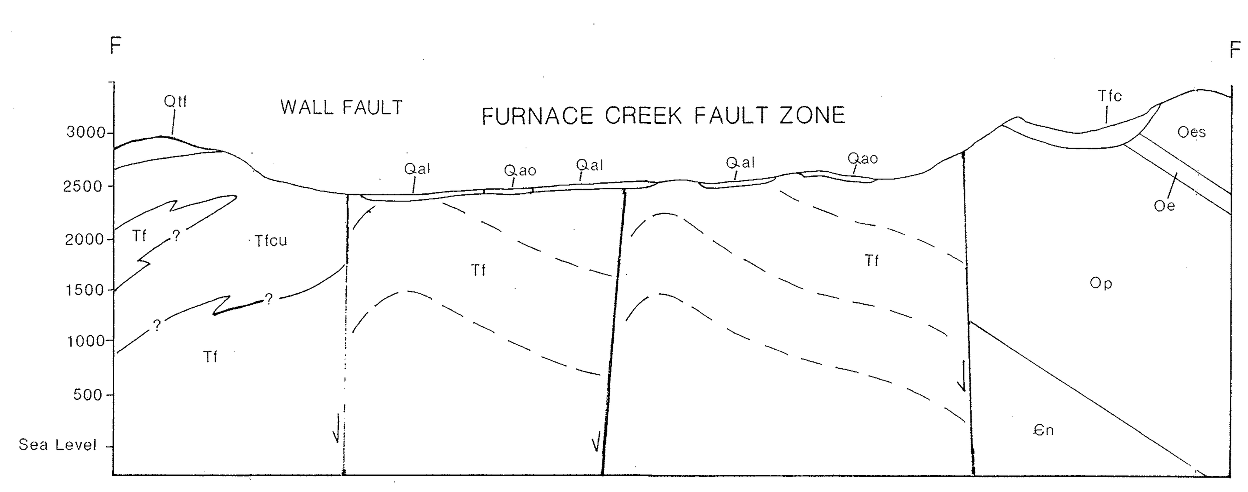






The angle between the line of cross-section and the strike of rock units decreases from D to D'.





Scale 1:15,840

0 — 1Mi
0 — 1Km

LEGEND

QUATERNARY
- Qal, Qao — Surficial deposits

UNCONFORMITY

- QTf, QTfl — Funeral Formation

TERTIARY (Late, Middle)
- Tfu, Tfcu2, Tf, Tfcu1, Tfc3, Tfc2, Tfc1 — Furnace Creek Formation

UNCONFORMITY

DEVO.
- Dl — Lost Burrow Formation

SIL.
- Dsh — Hidden Valley Dolomite

ORDOVICIAN
- Oes — Ely Springs Dolomite
- Oe — Eureka Quartzite
- Op — Pogonip Group

CAMBRIAN
- Cn — Nopah Formation
- Cbb, Cbp — Bonanza King Formation
- Cc — Carrara Formation
- Cz — Zabriskie Quartzite
- Cwu, CpCwm, Pcwl — Wood Canyon Formation

PRECAMBRIAN
- PCs — Sterling Quartzite