DCS

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES (CNWRA)
Washington Office

TRIP REPORT

February 17, 1994

SUBJECT: Tectonics Research Project Field Reconnaissance in the Black Mountains Area of the Death Valley Extended Terrain — A Potential Deep Structural Analog for Yucca Mountain (20-5704-164)

DATE and PLACE: November 30 - December 10, 1993
Death Valley Region Extended Terrain, California and Nevada

AUTHOR: Gerry L. Stirewalt

DISTRIBUTION:

CNWRA	NRC-HLW	NRC-RES
W. Patrick	M. Knapp	B. Morris
J. Latz	S. Fortuna	F. Costanzi
B. Sagar	B. Stiltenpole	M. Silberberg
Directors	B. Meehan	J. Randall
Element Managers	J. Linehan	B. Ott
C. Connor	R. Ballard	G. Birchard
B. Hill	K. McConnell	L. Kovach
D. Ferrill	D. Brooks	
S. Young	J. Trapp	

SwRI	NMSS Site Rep
S. Rowe (Contracts)	P. Justus

9406300170 940225
PDR WASTE
WM-11 PDR

426.1
WM-11
NH15

delete all distributions except: CF, PDR + NRDOCS full text

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES (CNWRA)
Washington Office

TRIP REPORT

February 17, 1994

SUBJECT: Tectonics Research Project Field Reconnaissance in the Black Mountains Area of the Death Valley Extended Terrain – A Potential Deep Structural Analog for Yucca Mountain (20-5704-164)

DATE and PLACE: November 30 - December 10, 1993
Death Valley Region Extended Terrain, California and Nevada

AUTHOR: Gerry L. Stirewalt

PERSONS PRESENT:

Consultants/Others

A. Morris (University of Texas San Antonio – December 2 & 5)
K. Spivey (Graduate Student of A. Morris – December 2 & 5)
B. Wernicke (California Institute of Technology – December 2 & 3)

BACKGROUND AND PURPOSE:

The favorable and potentially adverse conditions (FCs and PACs) specified in 10 CFR Part 60 under 60.122(b)(1), 60.122(c)(11), and 60.122(c)(15) reflect regulatory concerns about the existence of Quaternary deformation and igneous activity within the controlled area of the potential high-level radioactive waste disposal site at Yucca Mountain and the projected (future) effects of these geologic processes. The gravity of these concerns to staff of the Nuclear Regulatory Commission (NRC) is reflected in the following key technical uncertainties (KTUs) defined in the License Application Review Plan (LARP) of the NRC (NRC, 1993):

- 60.122(c)(11) – The PAC is "structural deformation such as uplift, subsidence, folding, and faulting during the Quaternary Period." The related KTU in LARP section 3.2.1.5 (NRC, 1993) is "development and use of conceptual tectonic models for structural deformation."

- 60.122(c)(15) – The PAC is "evidence of igneous activity since the start of the Quaternary Period." The KTU in LARP section 3.2.1.9 (NRC, 1993) is "development and use of conceptual models as related to igneous activity."

Therefore, it will likely be necessary for NRC and CNWRA staff to undertake independent development of alternative models of tectonic and volcanic processes for the Yucca Mountain region during prelicensing and licensing review of models provided by the Department of Energy (DOE) for assessing likelihood and consequences of tectonic and volcanic activity. These alternative models will need to take into account Quaternary and pre-Quaternary history in order to establish a geologic framework in which past and contemporary deformation and igneous activity can be understood and potential future effects of these geologic processes can be assessed.

Potential field studies organized to support development and assessment of alternative regional tectonic models and structural models of faulting and associated deformation and igneous activity at Yucca Mountain are a primary objective of Task 4 of the project plan for research on tectonic processes in the central Basin and Range (Young and Stirewalt, 1993). Specifically stated, the objective is to identify and describe areas potentially useful as structural and tectonic analogs of the proposed Yucca Mountain site for supporting development and assessment of alternative tectonic models. This objective provided the impetus for the subject reconnaissance trip (the identification phase of the objective) as a precursor to possible field work in the Black Mountains area of the Death Valley region extended terrain (the description phase of the objective).

Investigation of geologic analogs has been acknowledged as a potentially useful approach for reducing KTUs related to tectonics and igneous activity (Kovach and Young, 1993). It is anticipated that the KTUs specified above can possibly be addressed through field efforts in the Black Mountains by considering the area as a geological analog for subsurface deformation at Yucca Mountain and igneous activity in Crater Flat. The potential for use of this area to investigate analogous tectonic and igneous features has been previously recognized (Stirewalt and others, 1992; Connor and Hill, 1993; Kovach and Young, 1993; Young and Stirewalt, 1993). It should provide information important for development and assessment of alternative tectonic models and conceptual models of igneous activity for the Yucca Mountain region because of the occurrence of a detachment-listric fault system and basaltic dykes, flows, and sills in the vicinity of the Black Mountains – an area tectonically similar to Yucca Mountain but more extended and tilted so that features initially formed at depth are now exposed at the surface. Consequently, this reconnaissance trip was undertaken to determine if the area could provide opportunities to observe features related to deformation and igneous activity which initially developed at depth in a region tectonically similar to Yucca Mountain.

SUMMARY OF PERTINENT POINTS AND ACTIVITIES:

General Tectonic Setting

Based on correlation of offset pre-Tertiary (Mesozoic) structures, Wernicke and others (1988) have suggested the region including Death Valley has experienced about 150km of Neogene (i.e., Late Tertiary between 23.7 and 1.6 my) extension. An average extension rate between the Black and Panamint Mountains of 6.4 to 2.7 mm/yr over the past 9 million years has been proposed by McKenna and Hodges (1990). As Miller (1991) pointed out, while there are differing opinions on the amount of extension which took place in Death Valley specifically, large-scale extension in the Death Valley region is not precluded by any of the current interpretations. The central segment of Death Valley has been classified as a

pull-apart basin which developed between the northwest-striking, right-lateral Furnace Creek and Southern Death Valley fault zones (Burchfiel and Stewart, 1966), with the Black Mountains bounding the eastern margin of the basin. Carr (1990) has interpreted Crater Flat as part of a pull-apart basin as well, so suggestion of strong tectonic similarity between Death Valley extended terrain and the Yucca Mountain area adds credence to its use as a reasonable structural analog. Uplift and tilting of the Black Mountains block during Tertiary extension has resulted in what is interpreted by Holm and Wernicke (1990) as a crustal block initially formed at "pre-extension" depths between 10km (based on geobarometry) and 30km (based on structural configuration) now being exposed at the surface. They essentially consider the block to have been emplaced by extensional tectonism and uplifted along a major detachment zone, with the crustal section then exposed by Neogene tectonic denudation along west-directed normal faults. Consequently, the Black Mountains block appears to represent one of the deepest exposed examples of structures associated with detachment faulting of the type proposed to underlie Yucca Mountain (Scott, 1990; Young and others, 1992), so style of associated deformation can be observed and described for characterization of a detachment-listric fault model for structures beneath Yucca Mountain.

Detachment-related deformation in the Black Mountains was first mapped and described by Noble (1941) who referred to it as the "Amargosa Chaos" because of the observed character of the deformation. (Style of deformation in the chaos is described in this report under the discussion for December 2.) Although he initially attributed the deformation to thrust faulting, subsequent workers have realized the deformation is associated with detachment faulting (e.g., Burchfiel and Wernicke, 1989). Listric normal faults which merge with gently west-dipping detachment faults have also been described in the vicinity of the Mormon Point turtleback on the west side of the Black Mountains in southern Death Valley (Troxel, 1986) and may provide a model of the intersection of listric faults with the associated detachment surface. This fault geometry association has been proposed at depth for the normal fault system exposed in the vicinity of Yucca Mountain (Scott, 1990; Young and others, 1992).

Field Reconnaissance Descriptions

Figure 1 (see next page) is an index map which shows locations of stops and traverses taken in Death Valley National Monument in connection with this reconnaissance trip.

November 30 (Tuesday) – Observation of Detachment Faulting, Brittle Deformation, and Mafic Dykes along the Fault-Controlled Western Front of the Black Mountains, Eastern Side of Death Valley, California

Prior to measuring orientations of any geologic features of interest, the Brunton compass was set for a magnetic declination of 14.5 degrees east based on information from 1986 USGS 1:100,000 topographic sheet 36116-A1-TM-100. This declination is the same as that used during the GPS survey conducted by B. Wernicke for the NRC between October 15-20, 1993. The survey was discussed in a trip report by G. Stirewalt dated November 5, 1993.

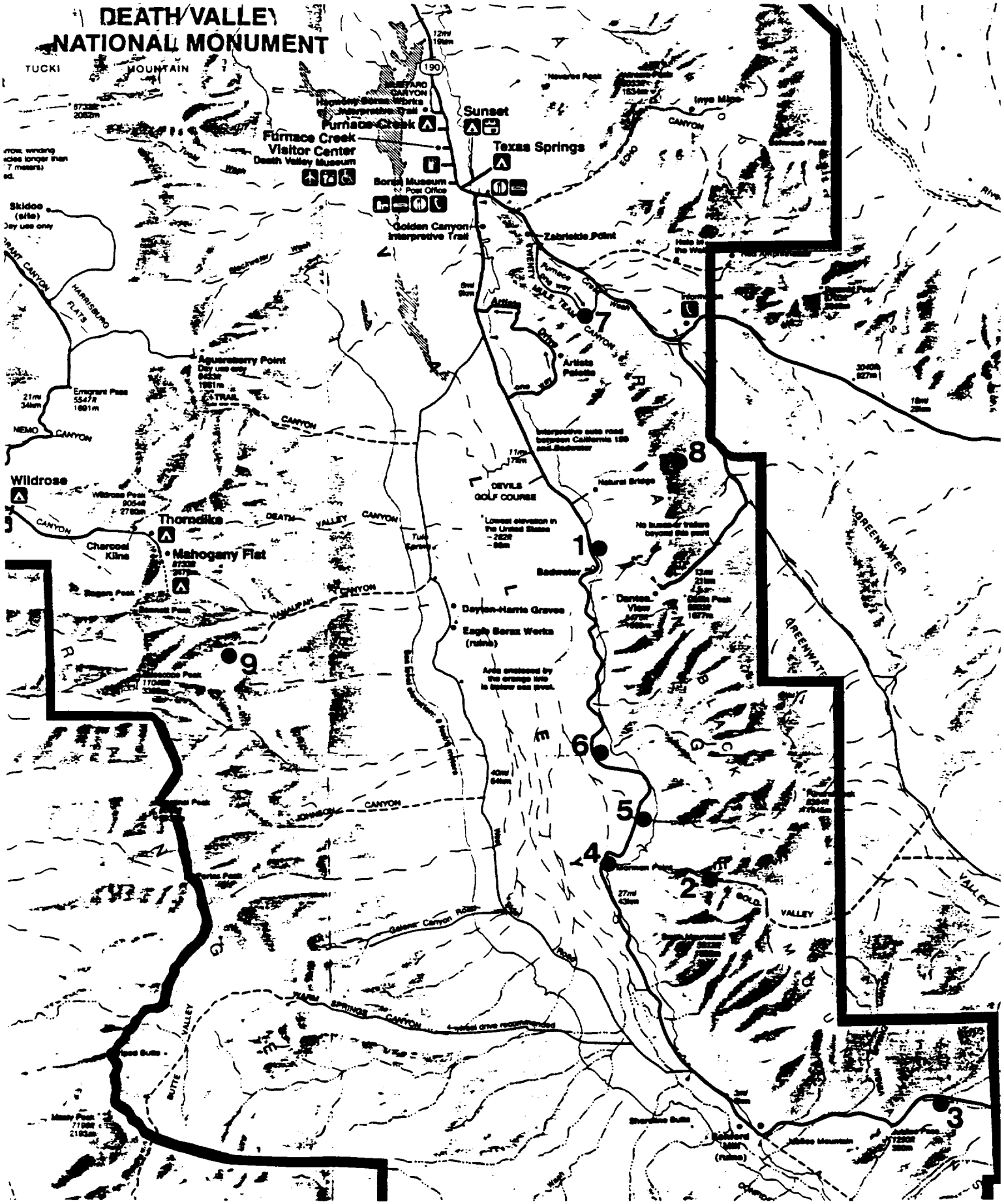

Figure 1. Location map for field reconnaissance in the Black Mountains area of Death Valley National Monument. See text for descriptions of Stops 1 - 9. (Base is National Park Service map at an approximate scale of 0.2 in. = 1 mi.)

California Highway 178 follows the Black Mountain front along the eastern side of the Death Valley pull-apart basin for about 65km (40 mi) and provides numerous opportunities to observe classic geomorphic and geologic features which mark the front as a recent fault scarp. There are excellent views along the highway of three turtlebacks (i.e., Badwater, Copper Canyon, and Mormon Point), features related to detachment faulting and normal faulting, and mafic dykes. The highway traverse was undertaken to determine whether locations along it could be used for studying deformation related to detachment faulting, association of normal faulting with the detachment, and association of mafic dykes and faulting. Near Stop 15 of Wright and others (1991), located adjacent to the Badwater turtleback 2.4km (1.5 mi) south of the intersection of Highway 178 and the gravel road to Natural Bridge (Stop 1 of Figure 1), a mafic dyke which is exposed low on the turtleback trends about N23E, 90. Farther up the southwestern slope of the turtleback, additional mafic dykes were observed. However, they were not readily accessible on foot due to the steepness of the slopes on which they were exposed so their orientations were not measured. Wright and others (1991) report numerous mafic dykes (at least one of which is clearly syntectonic according to their description but which was not observed by this writer) and high-angle normal faults here. The "turtleback fault" (i.e., the detachment) dips about 30W and separates upper plate Cenozoic fanglomerate from rocks of the lower plate, comprised mainly of mylonitized metasedimentary carbonate and gneiss. The carbonate is intensely fractured at this location. Differences of opinion exist on whether the Badwater turtleback fault can be interpreted as a single fault that is part of a regional detachment surface, as Wright and others (1991) believe. For example, Miller (1991) suggests this turtleback fault consists of at least three generations of initially high-angle, nearly planar faults that are temporally and spatially distinct. The controversy about the genesis of these turtleback fault surfaces was not an issue for resolution during the reconnaissance trip, however.

December 1 (Wednesday) – Gold Valley Traverse, Eastern Flank of the Black Mountains, California (Figure 1, Stop 2)

This traverse was undertaken to investigate the possibility of considering the Gold Valley area of the Black Mountains for studying associations between mafic dykes and faulting and gaining a better understanding of detachment-related deformation. The area is reached by a dirt access road which intersects the graded road running the length of Greenwater Valley on the eastern side of the Black Mountains at a point about 16.9km (10.5 mi) from the junction of the graded road with California Highway 178. The dirt access road stops at Willow Spring at the upper reaches of Gold Valley, and the area is generally described in Stops 6 and 7 of Wright and others (1991).

The 11.7 Ma (Wright and others, 1991) gabbroic Willow Spring Pluton is well-exposed in the Gold Valley area, where it is commonly intruded by silicic dykes. The writer observed that mafic dykes both cross-cut and parallel the silicic dykes, but appear less numerous than those of silicic composition. The orientation of one mafic dyke was N69W, 73S. Associations of mafic dykes and faulting were not obvious in the Gold Valley area. The Amargosa Chaos which Wright and others (1991) report to occur here has been persistently intruded by silicic igneous bodies so that the detachment fault is not preserved at this location. Consequently, it is not possible to directly observe the detachment surface and describe the adjacent deformation as can be done at other locations investigated by Noble (1941). However, brittle deformation appears to generally

prevail in the chaos at this location as well, where the most readily identifiable rock units are cliff-forming masses of grey dolomite. These units are either the Bonanza King Formation or dolomitic members of the Carrara Formation of Middle Cambrian and Early to Middle Cambrian age, respectively (Wright and others, 1991). Tertiary (Miocene) volcanic rocks (i.e., the Shoshone Volcanics) overlying the chaos units in the Gold Valley area have yielded a radiometric age estimate of 6.5 to 8.0 Ma (Fleck, 1970).

Based upon this field reconnaissance, it is not anticipated this location would provide useful information on the relationships between dykes and faulting. Therefore, no additional field efforts are recommended in the Gold Valley area.

December 2 (Thursday) – Regional Overview Trip with B. Wernicke in the Death Valley Region Extended Terrain, California

During this one-day traverse that passed from the Black Mountains on the east side of Death Valley and westward across Panamint Valley onto the Darwin Plateau, considerable information was presented by B. Wernicke. This detailed information can only be summarized in a condensed form in this report since it drew on nearly ten years of field experience in this region by B. Wernicke.

1. Tertiary/Quaternary volcanic rocks of the central Death Valley volcanic field include:

Valley Basalts – 1.7 Ma (sparse Pliocene-Pleistocene lavas, cinder cones, and agglutinate of central Death Valley; Split Cone on floor of Death Valley included here)

Funeral Formation Lavas – 4 to 4.8 Ma (basalts and andesites intercalated with conglomerates/fanglomerates, of which one basalt flow occurs on Funeral Peak in Black Mountains; thickest flows occur east of Black Mountains in Ryan area of Northern Greenwater Range, where they cap the Greenwater Volcanics; flat-lying to moderately tilted to about 20 degrees; overlie Tertiary strata of Furnace Creek Formation)

Greenwater Volcanics – 5 to 7 Ma (predominately dacitic lava flows with subordinate basalts, andesites, rhyolites, and ash-flow tuffs; tilted and unconformably overlie Shoshone Volcanics and Furnace Creek Formation)

Shoshone Volcanics – 7.5 to 8.5 Ma (rhyolitic lava flows and tuffs tilted about 30 degrees, often highly faulted, and unconformably overlie pre-Shoshone units and Amargosa Chaos; most aerially extensive volcanic sequence in Black Mountains area)

Sheepshead Andesite – Age uncertain, but possibly 9 to 10 Ma (laharic breccias, flows, and flow breccias)

Rhodes Tuff – 9 to 10 Ma (a lithic, rhyolitic, ash-flow tuff tilted about 45 degrees)

These units, defined by Wright and others (1991) and Wernicke (personal communication, 1993), are the volcanic units found in the Black Mountains area.

2. The southern Black Mountains of the Central Death Valley region are comprised by a series of tilted fault blocks with older Proterozoic units consisting mainly of granitic gneiss about 1700 Ma in age overlain by the later Proterozoic Pahrump Group. The base of the Pahrump is about 1000 Ma in age, and the Group includes the Crystal Spring Formation, Beck Springs Dolomite, and Kingston Peak Formation). The Pahrump Group is overlain in turn by Late Proterozoic-Paleozoic miogeoclinal sedimentary rocks (e.g., Proterozoic Noonday Dolomite, Johnnie Formation, Stirling Quartzite, and Wood Canyon Formation followed by Early Cambrian Zabriskie Quartzite and Carrara Formation and Middle Cambrian Bonanza King Formation). In most exposures of the later Proterozoic and Cambrian rock units, Noble (1941) observed severe brittle attenuation and noted the units were in fault contact with the older Proterozoic gneissic complex, forming the type locality of his "Virgin Spring Phase" (after exposures in the Virgin Spring area of the Black Mountains) of the Amargosa Chaos. Although he initially labeled this regionally important fault the "Amargosa thrust", he essentially recognized and defined the feature to which the label "detachment fault" is now commonly applied in this extended terrain!

A generalized columnar section of the PreCambrian to Middle Cambrian units mentioned above follows (after Wright and others, 1991):

PALEOZOIC

Middle Cambrian Bonanza King Formation (1100m – dolomite)

Early to Middle Cambrian Carrara Formation (500m – dolomite)

Early Cambrian Zabriskie Quartzite (240m)

PROTEROZOIC

Wood Canyon Formation (1200m – quartzite, siltstone, dolomite)

Stirling Quartzite (1450m)

Johnnie Formation (300m – quartzite, clastic dolomite, siltstone, conglomerate)

Noonday Dolomite (250m)

Pahrump Group (2300m – sandstone, siltstone, shale, dolomite, limestone, minor conglomerate with base about 1000 Ma)

Kingston Peak Formation of Pahrump Group
Beck Springs Dolomite of Pahrump Group
Crystal Spring Formation of Pahrump Group

Older Proterozoic gneissic complex (about 1700 Ma)

At an isolated erosional remnant of the chaos adjacent to Highway 178 near Rhodes Wash (Stop at Point "a" of Wright and Troxel, 1984; Stop at Point "a" of Troxel and Wright, 1987; Stop 5-5 of Burchfiel and Wernicke, 1989; Stop 9 of Wright and others, 1991), the features Noble (1941) described in his "Virgin Spring Phase" of the Amargosa Chaos are strikingly displayed on the north face of a hill approximately 90m high (Figure 1, Stop 3). The lower part of the face is

comprised by strongly sheared, autochthonous, older Proterozoic gneisses (gray-weathering and locally red-stained crystalline basement) lying beneath a sub-horizontal fault contact with the overlying chaos. This fault is the detachment surface and the deformation related to the detachment clearly defines a wide zone. Noble (1941) surmised that present-day thickness of the Amargosa Chaos did not exceed about 610m (2000 ft) in the Virgin Spring area of the Black Mountains, but was uncertain whether the initial thickness may have been greater because the chaos is overlain by the Funeral fanglomerate in an erosional unconformity. The lower part of the overlying chaos sequence is comprised by fault-bounded lenses of arkosic sandstone (pale gray) and shale (lavender mudstones and siltstones) of the lower Crystal Spring Formation, the oldest of the three formations of the Proterozoic Pahrump Group. Dark green lenses higher on the face are slices of diabase sill that regionally separate the lower clastic members of the Crystal Spring from its higher carbonate member, represented by dark reddish-brown lenses of dolomite. The crest of the hill is held up by yellowish-gray Noonday dolomite, the oldest post-Pahrump unit in the Proterozoic miogeoclinal sequence. Like the Crystal Spring, the Noonday also occurs as fault-bounded lenses in the chaos. The Crystal Spring is ordinarily between 750m and 1200m thick (Troxel and Wright, 1987), but at this location has been attenuated to a thickness of no more than about 60m. All carbonate units have responded by brittle deformation. In spite of the attenuation and fracturing of the units, the exposed lenticular slices retain the proper stratigraphic position of younger over older. Figure 2 (see next page) is a copy of an illustration from Noble (1941) which clearly shows the fault-bounded lenses of the chaos. It is not clear exactly what factors may have governed development of thick zones of fracturing adjacent to the detachment surface.

From his original observations, Noble (1941) stated "every contact between blocks throughout the chaos is a fault" and "blocks in the chaos are so intensely and minutely fractured ... that uncracked pieces of rock over 2 inches in diameter are exceptional." His descriptions suggest potential hydrologic concerns for brittle units adjacent to a detachment surface and a possible need for characterizing and modeling these fracture systems. The thickness he suggested for the chaos (i.e., possibly greater than 600m) may produce a zone of fracturing extensive enough that it should be hydrologically considered in any subsurface model of detachment-related deformation at Yucca Mountain. He also described faults that "diverge upward from the generally flat Amargosa thrust, with the dip steepening away from the direction of movement" — a description which appears related to the occurrence of listric normal faults associated with the detachment.

3. At the Mormon Point turtleback along California Highway 178 (Figure 1, Stop 4), faulted Quaternary gravels were observed to overlie the turtleback (detachment) surface, below which lies Proterozoic Noonday Dolomite. Brittle failure associated with detachment faulting was characteristic of the deformation style of the metamorphosed Noonday, and an earlier(?) ductile fabric also exists in the dolomite. Some of the normal faults in the gravels exhibit a listric geometry above the detachment.

4. At Sheep Canyon along California Highway 178 (Figure 1, Stop 5), boulders derived from the Willow Spring Pluton found in flood materials atop an alluvial fan had mylonitic and gneissic fabric. A date on the fabric (hornblendes) gave 8.7 Ma (B. Wernicke, personal communication, 1993) and this mylonitic fabric has been observed at the base of the pluton to indicate a top to the northwest transport direction. B. Wernicke (personal communication, 1993) speculated that

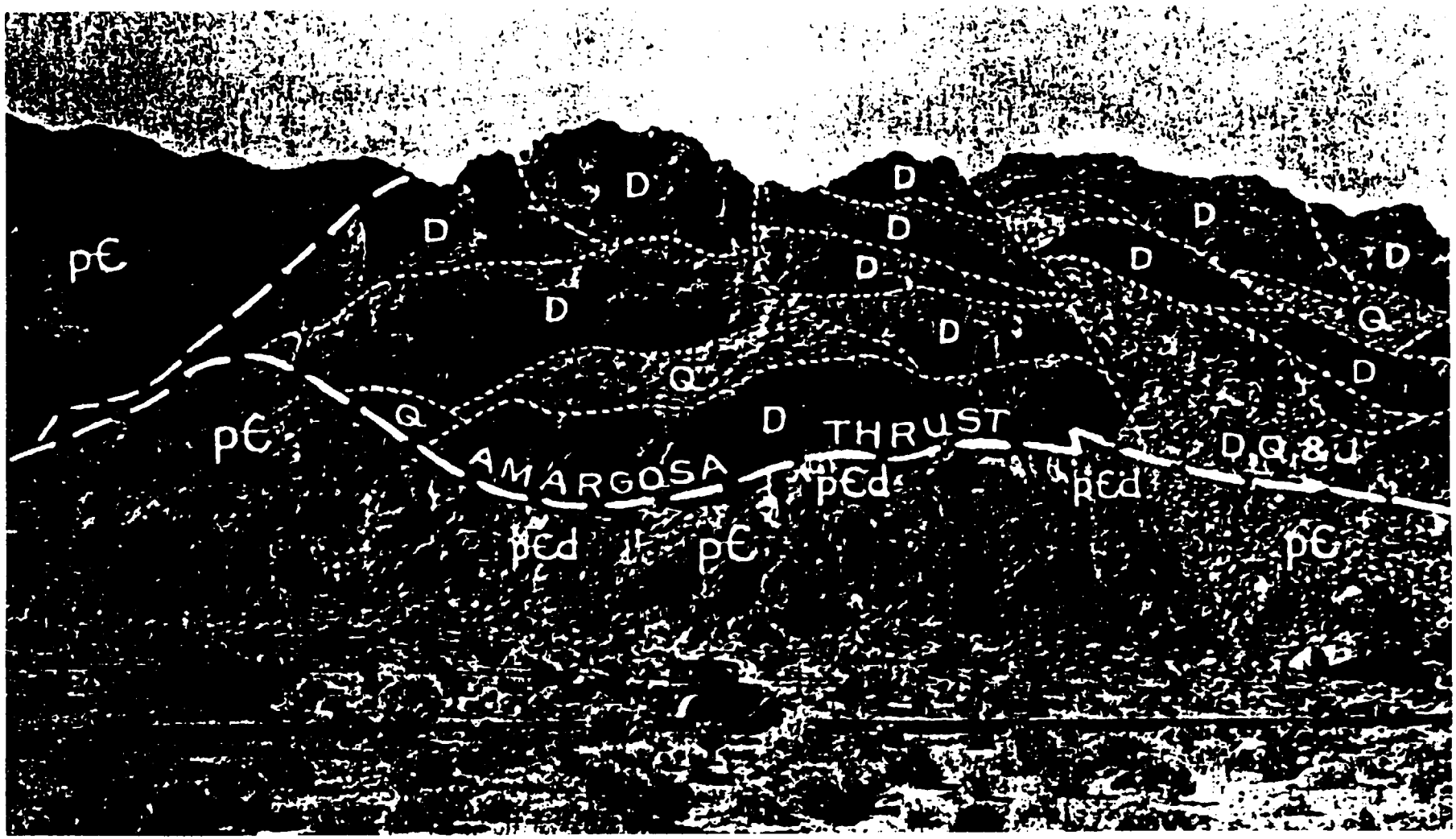

Figure 2. Exposure of "Amargosa Chaos" of Noble (1941) in Rhodes Wash, southern Black Mountains. Lenticular, fault-bounded blocks in the chaos are Cambrian or late pre-Cambrian dolomite (D), quartzite (Q), and jasperoid (J). The "Amargosa thrust" is the detachment fault, below which pC = pre-Cambrian gneiss and pCd = disintegrated pre-Cambrian gneiss (from Noble, 1941, Plate 10).

the fabric was produced in connection with flow during extension, so in this interpretation the ductile fabric is detachment-related.

5. At the Copper Canyon turtleback north of Mormon Point along California Highway 178 (Figure 1, Stop 6), an overview stop afforded a view of a profile of the turtleback and the overlying Tertiary sedimentary and volcanic rocks which Troxel and Wright (1987) report have been transported northwest over the turtleback surface.

6. B. Wernicke (personal communication, 1993) indicated a single age estimate had been acquired on one dyke within the mafic swarm observed on the south side of the Badwater turtleback – 6.3 Ma. Therefore, this dyke can be considered to be the correct age for acting as a feeder to the basaltic flows and sills found in the Furnace Creek Formation (about 5.5-6.5 Ma in age) of the Furnace Creek Basin north of the Badwater turtleback. Geochemistry and additional geochronology would be needed to determine if this dyke swarm could have fed the igneous materials existing in the sedimentary units of the Furnace Creek Basin.

December 3 (Friday) – Continuation of Regional Overview Trip with B. Wernicke in the Death Valley Region Extended Terrain, California

1. A traverse up 20-Mule Team Canyon (Figure 1, Stop 7) was undertaken to investigate associations between sediments of the Furnace Creek Formation in the Furnace Creek Basin of eastern Death Valley and basaltic flows and sills intercalated with the sediments, and to see if any feeder dykes for the flows and sills were exposed. [Numerous basaltic sills and flows also were observable in the Furnace Creek Formation on the road to Dante's View. The Lemonade Spring traverse of December 6 (Figure 1, Stop 8) went into this area.]

A generalized columnar section of the three dominantly sedimentary (Tertiary) formations of the Furnace Creek Basin is as follows (McAllister, 1974; Wright and others, 1991; B. Wernicke, personal communication, 1993):

Funeral Formation (conglomerates and intercalated basaltic lavas between 4-4.8 Ma)

Furnace Creek Formation (intercalated conglomerate, lacustrine mudstone, sandstone, tuff with basalt flows and sills between 5.5-6.5 Ma. Middle Pliocene is suggested age for the upper sedimentary units. Contains a time-transgressive basal conglomerate. Estimates of total thickness of sedimentary units range between 2130-3050m.)

Artists Drive Formation (lacustrine mudstone, sandstone, conglomerate with felsic and basaltic flows, sills, and dykes. Total thickness greater than 1220m with two massive pyroclastic members separating three well-stratified sedimentary units.)

Upper sedimentary member – about 245m thick
Upper pyroclastic member – 6.3 Ma and about 105m thick
Middle sedimentary member – about 185m thick
Lower pyroclastic member – 8.0 Ma and about 155m thick
Lower sedimentary member – 50% of total formation thickness; contains tuffs dated at 12.7 and 13.7 Ma and basal megabreccia of Bonanza King Formation

The Furnace Creek Formation represents a time-transgressive pulse of relatively rapid sedimentation. B. Wernicke (personal communication, 1993) speculates this formation was deposited in about 1 million years, indicating an increase in sedimentation rate over that for the thinner Artists Drive Formation. The presence of possibly hyaloclastic textures in some flows suggests they were extruded underwater or into water-saturated sediments, not a surprising fact for the lacustrine environment indicated by the sedimentary units of the Furnace Creek. Both basaltic flows and sills were observed to occur in the Furnace Creek Formation, but no dykes were found even though they have been reported by McAllister (1974). A gypsum "vein" about 0.5m wide trended along an approximate orientation of N70W for an estimated distance of about 50m.

The sediments and basaltic units of the Furnace Creek Basin – the Furnace Creek Formation specifically – may be a reasonable analog for the sedimentary and basaltic units found in Crater Flat. If the mafic dykes on the south side of the Badwater turtleback, one of which has been dated at 6.3 Ma (B. Wernicke, personal communication, 1993), could be shown to possibly be feeders for the igneous system as discussed for December 2 in this trip report, then field investigations in this location may provide information for construction of a model for flows and intrusions of basaltic rocks in the Crater Flat area of Yucca Mountain. Geochemistry and additional geochronology would be needed to determine if this dyke swarm could have fed the basaltic flows and sills in the Furnace Creek Formation.

2. A drive from Death Valley across Panamint Valley to the Darwin Plateau provided an excellent regional overview of the southern Basin and Range extended terrain. This plateau is essentially a homoclinal structure which rolls into Panamint Valley. East of the homoclinal hinge line, extreme extension has occurred in the region between the Colorado Plateau and Panamint Valley; west of it toward the Sierra Nevadas and beyond, there has been no extension. Panamint Valley itself is less than 3 Ma old (B. Wernicke, personal communication, 1993), indicating regional "younging" of extension from the Yucca Mountain area westward. At Father Crowley overlook above Rainbow Canyon in the Darwin Plateau, a cross-section of a reddish-colored basaltic cinder cone exposed in a high and unreachable cliff face showed feeder dykes extending up the cliff face to the cone, as well as smaller dykes feeding thin layer-parallel intrusions on the flanks of the cinder cone itself. Although the exposure does show the character of the cone and its associated dykes and small sills, because the exposure occurs in a vertical face at least 250m high, it would not be possible to investigate in detail the associations between this cone and its feeder system.

December 5 (Sunday) – Trip into the Bullfrog Hills near Beatty, Nevada, with A. Morris and K. Spivey

This trip into the Bullfrog Hills was in connection with the geochronology sampling program being undertaken by K. Spivey, under the direction of A. Morris at the University of Texas San Antonio, for possible investigation of deformation related to core complexes including uplift history based on application of fission track dating. It permitted a close look at the area mapped by Maldonado (1990) where he interpreted an upper and a lower detachment surface to occur, and a chance to compare style of deformation adjacent to these two detachment surfaces with observations on detachment-related deformation in the area of Amargosa Chaos.

1. Ordovician carbonate of the middle plate lying between the two detachment surfaces mapped by Maldonado (1990) near the Old (original) Bullfrog Mine is seen brecciated, but apparently not with the intensity and scale of brecciation of carbonate layers noted in the Amargosa Chaos region of the Black Mountains. Ductile cataclastic textures were noted in float of the Ordovician carbonate unit. Carbonates of the middle plate adjacent to the Old Bullfrog Mine location do not appear to be as fractured as the carbonate units at the mine itself, based on exposures observed. Slickensides were noted in Tertiary volcanic units overlying the carbonate of the middle plate.

2. At the Old Bullfrog Mine, the exposed upper detachment fault separates highly attenuated lower and middle Paleozoic clastic and carbonate rocks of the middle plate from an overlying upper plate sequence of faulted and tilted Tertiary (Miocene) volcanic, volcaniclastic, and sedimentary rocks (McKague and others, 1989). The lower detachment, not exposed at this stop, separates the middle plate from a lower plate of core complex, Proterozoic, amphibolite grade metamorphic rocks which are tentatively correlated with the Johnnie Formation (McKague and others, 1989) and exposed about 1.6km southwest of the Old Bullfrog Mine. The Tertiary volcanic units are strongly brecciated and contain a stockwork of quartz veining, at least some of which show chalcedony banding to suggest pulses of (low-temperature?) fluid movement rather than single-shot hydrothermal (high-temperature) pegmatite intrusions. Brecciation is intense; even the quartz veins show evidence of intense brecciation at a fine scale. This "mini-chaos" appears similar in deformational behavior to the brittle carbonate observed in the Amargosa Chaos. A difference at this location is that permeation of the fractured mass by silica-rich solutions was ubiquitous, while no similar veining was noted in the observed exposures of Amargosa Chaos. It is worth noting that the Old Bullfrog Mine was also an area "saturated" with disseminated gold above and below the upper detachment surface, which is also an indication of movement of mineralized solutions at this locale. These associations suggest the system was fractured intensely enough to allow permeation of available fluids into the rocks, even though the system now must be at least partially "healed" by the veining. Effects on groundwater flow systems may have occurred because of increased pathways due to detachment-related fracturing. Detachment-related fracturing may be extensive enough to require consideration of potential effects on regional and local hydrology when hydrologic models are being constructed. Extension-related detachment faulting has already been proposed as a viable alternative tectonic model for subsurface fault geometry at Yucca Mountain (Scott, 1990; Young and others, 1992).

3. Traversing south of the Old Bullfrog Mine, two stops were made to observe Proterozoic lower plate metamorphic core complex rocks. Exposures are sparse, and we covered essentially the entire area where the core complex occurs based on Maldonado's (1990) map. The gneisses contain pegmatitic quartz veins, and a single reading on the foliation surface gave N31W, 47NE for its orientation. A mineral lineation on the foliation surface had a rake angle of 40E. The Bullfrog Hills area does not appear to be the best location for analyzing deformation related to metamorphic core complexes as A. Morris and K. Spivey had hoped, because the complex itself is so very poorly exposed.

December 6 (Monday) – Lemonade Spring Traverse, Northeastern Flank of the Black Mountains, California (Figure 1, Stop 8)

This traverse was undertaken to visit another area (i.e., in addition to the 20-Mule Team Canyon traverse of December 3) to attempt to locate possible feeder dykes associated with the basaltic flows and sills in the Furnace Creek Formation. (As an interesting aside, Lemonade Spring was modified by early miners in a fashion which now allows the sheep to drink at a grassy oasis. The National Park Service set up a solar-powered camera to monitor the movement of mountain sheep at this spring.)

The spring issues from what appears to be a volcanic ash unit at an elevation of about 1125m, and was the end of the traverse up the canyon. Below this elevation along the canyon, basalt flows, volcanic breccias, and lacustrine sediments occurred. Basaltic dykes were not observed in the traverse, but relationships between flows and sediments were noted as were wet-sediment deformation features (slump folds) in the mudstones. An open, chalcedony-lined fracture trending N7E was partly filled by a clastic dyke and surrounded by chalcedony-cemented breccia composed of igneous (probably basaltic) fragments. This feature may mark the location of a "fossil" spring where low-temperature fluids percolated through the breccia.

December 7 (Tuesday) – Hanaupah Canyon (South Fork) Traverse, Eastern Flank of Panamint Mountains, California (Figure 1, Stop 9)

This traverse was undertaken to investigate the relationship between a felsic dyke swarm and faulting in an area east of Telescope Peak in the Panamint Mountains and to consider what light may be shed (by possible field studies at this location) on the association between faulting and dyke formation. As described by McDowell (1974), the north-striking rhyolite porphyry dyke swarm was intruded along a west-dipping fault system produced by initial doming and extension of the roof rocks over the Little Chief Stock (a granite porphyry).

Access to Hanaupah Canyon is from the unpaved West Side Road in Death Valley, a route not open in the summer season because it requires traversing the central part of Death Valley. The foot traverse began at 13.4km (8.3 mi) up the road to Hanaupah Canyon from West Side Road since washout of the canyon roadway by water flowing from Hanaupah Spring farther up the canyon made driving impossible (even with 4-wheel drive). The traverse up the south fork of Hanaupah Canyon to Hanaupah Spring at an elevation of about 1220m was through thick growth of wild grape, willow, and rushes. Lower in the traverse, faulting was noted in the canyon wall but without associated dykes. I walked above the spring to an estimated elevation of 1340m on the north side of the canyon, the site of an old adit which appeared to be located in the Proterozoic Noonday Dolomite (based on mapping by Albee and others, 1981). The formation was intensely fractured and possibly faulted at this location, although no specific fault planes were observed. The main dyke swarm described by McDowell (1974) and shown on the map of Albee and others (1981) was not reached by this traverse up the canyon. From the vantage point reached, however, it appeared that a ridgetop traverse on the south side of the south fork of Hanaupah Canyon to reach elevations between 1585-1700m would be best for observation of the dyke swarm and faults.

December 8 (Wednesday) – Overview Trip to Northern Death Valley

This trip was taken to investigate the general distribution of basaltic rocks in northern Death Valley. In the vicinity of Ubehebe Crater, from a distance there appears to be basaltic cones or flows above the valley floor on the west side of Death Valley and possibly north of Ubehebe Crater also. It would be interesting to consider distribution of the cones and flows to determine what, if any, relationship they bear to major faulting in the area – particularly in light of the suggestions of strong tectonic similarities between the Death Valley and Yucca Mountain areas with respect to development of parts of both areas as pull-apart basins (see discussion under General Tectonics Setting).

December 9 (Thursday) – Hanaupah Canyon (South Fork) Ridgetop Traverse, Eastern Flank of Panamint Mountains, California (Figure 1, Stop 9)

This second traverse up Hanaupah Canyon was undertaken with the express purpose of a ridgetop traverse to elevations above 1585m along the ridge on the south side of the south fork of Hanaupah Canyon to investigate any associations between faulting and dyke formation which may be considered for detailed field studies at this location. Realizing the rhyolite porphyry dyke swarm was intruded along a west-dipping fault system related to initial doming and extension of the roof rocks over a granite porphyry stock (McDowell, 1974), it is clear that the stress regime for faulting and dyke formation in this setting (i.e., a localized stress field) is different from that imposed by regional extension. It is also clear that the felsic dykes are related to development of the stock, a genesis which is very different from that of basaltic dykes derived from a deeper-seated origin. Notwithstanding the fact that the dykes did intrude along the faults in this case, these two factors may render this field example a poor analog for analyzing associations between (basaltic) dykes and faulting in regionally extended terrains.

The traverse line was totally contained in Proterozoic sedimentary rocks – the Stirling Quartzite (youngest) low in the traverse passing downsection in the uphill ridgetop climb into the Johnnie Formation, the Noonday Dolomite, and possibly the Kingston Peak Formation (oldest). The dyke swarm has not been mapped in the Stirling Quartzite, but the other units in the traverse were cross-cut by the dyke swarm at elevations between 1585-1700m (Albee and others, 1981). Felsic dykes cross-cutting the sedimentary units were apparent in exposures on steep slopes of the canyon wall, but were more difficult to define in outcrops along the line of the traverse. Distinct faults with which the dykes were associated were not observed, partially because of the high relief and steep slopes in the areas where dykes were noted that hindered reconnaissance observation. The topographic and geologic maps being carried by the author did not show an old mine with copper mineralization which marked the end of the traverse at an elevation probably higher than 1700m. An old boiler remaining at the mine site showed a date of 1942.

Based upon this field reconnaissance, it is not anticipated this location would provide much useful information on the relationship of dykes and faulting without very detailed work tracing out individual dykes to determine if behavior of the dykes in the vicinity of faults could be ascertained. However, the general point drawn from the work of McDowell (1974) is that faults did control the pathways for dyke intrusion at this location. It is doubtful this area would provide the best analog for fault control of basaltic dykes in terrains subjected to regional

extension, and further work in Hanaupah Canyon does not appear warranted – but there certainly were spectacular views from the top of the ridge!

December 10 (Friday) – Return Trip to Las Vegas through Death Valley

On the drive back to Las Vegas from Beatty, additional photographs were taken from California Highway 178 in the vicinity of the Badwater turtleback (Figure 1, Stop 1) to better document the existence of mafic dykes at this location. Two other mafic dykes observed relatively low on the sloping turtleback surface near the location where the orientation of one dyke was measured on November 30 are probably reachable with minor scrambling up the slope and it may be possible to walk out most of their trace lengths along the slope.

A quick stop at the erosional remnant of the chaos exposure adjacent to Highway 178 (Figure 1, Stop 3) reaffirmed the extensive brittle failure response of the carbonate units adjacent to the detachment surface. Lighting conditions were poor, so no additional photographs were taken.

IMPRESSIONS/CONCLUSIONS:

1. It is concluded that the southern Black Mountains area can provide a reasonable structural analog for detachment-related deformation at depth at Yucca Mountain. B. Wernicke (personal communication, 1993) speculated that the original depth of formation of the detachment surface now exposed at the Rhodes Wash exposure was "a few kilometers." The view of a detachment fault developed during this reconnaissance trip is that of a zone of deformation characterized by extreme brittle failure of carbonate units within the zone (e.g., Rhodes Wash exposure and Bullfrog Hills) and associated listric normal faulting. Tertiary volcanic units also behaved in a brittle manner where they were observable adjacent to a detachment surface (e.g., Old Bullfrog Mine). The detachment-related fracturing has opened pathways for fluid migration which are sometimes filled by veining, as is the case at the Old Bullfrog Mine, and sometimes not, as is noted at the Rhodes Wash chaos exposure along California Highway 178. Noble (1941) reported that the thickness of the chaos (i.e., the zone of detachment-related fracturing) was at least 600m in the Amargosa Chaos area of the Black Mountains and aerially extensive. This fracturing may have an influence which should be considered in analysis of regional and site-specific hydrology at Yucca Mountain. It may also be possible to find exposures in the southern Black Mountains which show style of deformation occurring above ramps in the detachment to provide information on geometry of this deformation for consideration in modeling possible subsurface structures at Yucca Mountain.

   The significance of the possibly detachment-related(?) ductile fabric to hydrology appears non-problematical since this fabric is not thought to form a major flow pathway with the same concerns as for fractured carbonates and volcanic rocks. It appears of mainly academic interest whether the ductile fabric, if related to detachment faulting, was developed as a function of depth or strain rate factors.

2. It is concluded that the mafic dyke swarm which cuts the Badwater turtleback trending toward the flows and sills of the Furnace Creek Formation and the Furnace Creek Formation itself may provide an analog for the Crater Flat area of Yucca Mountain to help describe the associations between igneous

materials and the sedimentary fill in Crater Flat. Additional geochemistry and geochronology would be necessary to determine whether the Badwater dyke swarm could be feeders for the flows and sills in the Furnace Creek Formation. Whether relationships between dykes, faulting, and the flows and sills can be investigated in the northern Black Mountains is uncertain. Although dykes were not observed in the Furnace Creek Formation during this reconnaissance, McAllister (1974) reported their occurrence. Additional field work may reveal information on associations between dykes and faulting.

3. It is not recommended that Gold Valley or Hanaupah Canyon be considered for investigation of associations between dykes and faulting. Gold Valley does not have such associations well-exposed. Hanaupah Canyon does not appear to be an acceptable analog for fault control of mafic dykes in regionally-extended terrains since the dykes of felsic composition at that location were intruded along a fault system related to localized stresses from doming and extension over an intruding stock – an analogy more similar to that of development of faulting due to stresses occurring over a rising salt dome than a stress field associated with regional extension. Notwithstanding the observation of McDowell (1974) that there is exclusive fault control of this felsic dyke swarm, it does not appear to be the best area for investigation of because of the "special case" conditions under which the dykes and faults are related. That is, deep-seated or regional structural control on dyke intrusion is not shown at this location.

PROBLEMS ENCOUNTERED:

No problems were encountered during the reconnaissance survey.

PENDING ACTIONS:

Before detailed field investigations can be undertaken under Task 4 of the CNWRA tectonics research plan (Young and Stirewalt, 1993), it will be necessary to prepare auxiliary plans for any such anticipated efforts. These plans will only be prepared if it is decided by CNWRA that field work is warranted. Initiation of field work is subject to final approval by NRC Office of Research staff after their review and appraisal of the auxiliary plans. Since this area is located in Death Valley National Monument, it is necessary to remember any field investigations or sampling programs must be coordinated well in advance with representatives of the National Park Service.

RECOMMENDATIONS:

It is recommended that consideration be given to using the southern Black Mountains area as an analog for better understanding deep structures at Yucca Mountain in relation to a detachment fault model. Specific information can be obtained on fractures related to detachment faulting and the geometric relationships between the detachment surface and associated listric normal faults. Detachment-related fracturing and potential concerns for regional and site-specific hydrology relative to this fracturing can be considered. It may be possible to investigate ramp-related deformation above the detachment surface to provide for more realistic modeling of the geometry related to this deformation.

It is also recommended that sediments and igneous materials of the Furnace Creek Formation in the Furnace Creek Basin near the northern Black Mountains area be considered as an analog for characterizing reasonable associations between sediments and included igneous material in Crater Flat. In addition, the dyke system which cuts the Badwater turtleback may prove to be a feeder system for the flows and sills in the Furnace Creek Formation and may reveal information on associations between mafic dykes and faulting which are useful analogs for more realistically modeling dyke emplacement history in areas of extensional faulting.

REFERENCES:

Albee, A.L., T.C. Labotka, M.A. Lanphere, and S.D. McDowell, 1981, Geologic map of the Telescope Peak Quadrangle, California: US Geological Survey Quadrangle Map GQ-1532 at 1:62,500.

Burchfiel, B.C. and J.H. Stewart, 1966, "Pull-apart" origin of the central segment of Death Valley, California. Geological Society of America Bulletin, 77, 439-441.

Burchfiel, B.C. and B.P. Wernicke, 1989, Day 5 - Spring Mountains breakaway zone, Amargosa Chaos, and the Death Valley pull-apart basin in Extensional Tectonics in the Basin and Range Province between the Southern Sierra Nevada and the Colorado Plateau. 28th International Geological Congress Field Trip Guidebook T138, American Geophysical Union, 39-45.

Carr, W.J., 1990, Styles of extension in the Nevada Test Site region, southern Walker Lane Belt - An integration of volcano-tectonic and detachment fault models in B.P. Wernicke, ed, Basin and Range Extensional Tectonics near the Latitude of Las Vegas, Nevada. Geological Society of America Memoir 176, 283-303.

Connor, C.B. and B.E. Hill, 1993, Project plan for field volcanism. CNWRA Project Plan, Rev 0, Change 5, 34p with appendix.

Fleck, R.J., 1970, Age and tectonic significance of volcanic rocks, Death Valley, California. Geological Society of America Bulletin, 81, 2807-2816.

Holm, D.K. and B.P. Wernicke, 1990, Black Mountains crustal section, Death Valley extended terrain, California. Geology, 18, 520-523.

Kovach, L.A. and S.R. Young, 1993, Volcanism/Tectonics Natural Analogs Working Group Summary in W.M. Murphy and L.A. Kovach, eds, The Role of Natural Analogs in Geologic Disposal of High-Level Nuclear Waste. CNWRA Report 93-020, 115-120.

Maldonado, F., 1990, Geologic map of the northwest quarter of the Bullfrog 15-minute Quadrangle, Nye County, Nevada: U.S. Geological Survey Misc. Investigations Series Map I-1985, scale 1:24,000.

McAllister, J.F., 1974, Geology of the Furnace Creek borate area, Death Valley, Inyo County, California: Guidebook - Death Valley Region, California and Nevada, GSA Cordilleran Section 70th Annual Meeting Field Trip, 84-86.

McDowell, S.D., 1974, Emplacement of the Little Chief Stock, Panamint Range, California: Geological Society of America Bulletin, 85, 1535-1546.

McKague, H.L, P.P. Orkild, and S.R. Mattson, 1989, The geology of the Nevada Test Site and surrounding area: Field Trip Guidebook T186, 28th International Geological Congress, American Geophysical Union, Washington, D.C., 31p.

McKenna, L.W. and K.V. Hodges, 1990, Constraints on the kinematics and timing of late Miocene-Recent extension between the Panamint and Black Mountains, southeastern California in B.P. Wernicke, ed, Basin and Range Extensional Tectonics near the Latitude of Las Vegas, Nevada. Geological Society of America Memoir 176, 363-376.

Miller, M.G., 1991, High-angle origin of the currently low-angle Badwater Turtleback fault, Death Valley, California. Geology, 19, 372-375.

Noble, L.F., 1941, Structural features of the Virgin Spring area, Death Valley, California. Geological Society of America Bulletin, 52, 941-999.

Scott, R.B., 1990, Tectonic setting of Yucca Mountain, southwest Nevada in B.P. Wernicke, ed, Basin and Range Extensional Tectonics near the Latitude of Las Vegas, Nevada. Geological Society of America Memoir 176, 251-282.

Stirewalt, G.L., Young, S.R., and K.D. Mahrer, 1992, A review of pertinent literature on volcanic-magmatic and tectonic history of the Basin and Range. CNWRA Report 92-025.

Troxel, B.W., 1986, Significance of Quaternary fault patterns, west side of the Mormon Point turtleback, southern Death Valley, California - A model of listric normal faults in B.W. Troxel, ed, Quaternary Tectonics of Southern Death Valley. Friends of the Pleistocene-Pacific Cell, Field Guide, 37-39.

Troxel, B.W. and L.A. Wright, 1987, Tertiary extensional features, Death Valley region, eastern California. Geological Society of America, Cordilleran Section Centennial Field Guide, 121-132.

U.S. Nuclear Regulatory Commission, 1993, Draft License Application Review Plan for review of license application for a geologic repository for spent nuclear fuel and high-level radioactive waste, Yucca Mountain site, Nevada. NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Radioactive Waste Management, NUREG-1323.

Wernicke, B.P., J.K. Snow, and J.D. Walker, 1988, Correlation of Early Mesozoic thrusts in the southern Great Basin and their possible indication of 250-300 km of Neogene crustal extension in D.L. Weide and M.L. Farber, eds, This Extended Land - Geological Journeys in the Southern Basin and Range. University of Nevada at Las Vegas Department of Geoscience Special Publication 2, 255-267.

Wright, L.A. and B.W. Troxel, 1984, Geology of the northern half of the Confidence Hills 15-minute Quadrangle, Death Valley region, eastern California - The area of Amargosa Chaos. California Department of Conservation, Division of Mines and Geology, Map Sheet 34, 31p plus geologic map.

Wright, L.A., T.L. Pavlis, M.A. Ellis, R.A. Thompson, E.H. DeWitt, M.G. Miller, B.W. Troxel, J.K. Otton, and L.F. Serpa, 1991, Cenozoic magmatic and tectonic evolution of east-central Death Valley Region, California in M.J. Walawender and B.B. Hanan, eds, Geologic Excursions in Southern California and Mexico. Geological Society of America, 1991 Annual Meeting Guidebook, San Diego, CA, 93-127.

Young, S.R. and G.L. Stirewalt, 1993, Project plan for research on tectonic processes in the central Basin and Range region. CNWRA Project Plan, Rev 0, Change 5, 36p with appendix.

Young, S.R., G.L. Stirewalt, and A.P. Morris, 1992, Geometric models of faulting at Yucca Mountain. CNWRA Report 92-008.

AUTHOR: DATE: 18 Feb '94

Gerry L. Stirewalt, Principal Geoscientist

CONCURRENCES: DATE: 2/23/94

H. Lawrence McKague, Manager, Geologic Setting Element

DATE: 2/25/94

Budhi Sagar, Technical Director