Tertiary extensional features, Death Valley region, eastern California

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INTRODUCTION

The southeastern part of the Death Valley region (Fig. 1) displays two remarkable structural features: turtlebacks (Curry, 1938) and the Amargosa chaos (Noble, 1941). The changing ideas during the past half-century about the origin of these features reflect the growth of understanding of the major aspects of Basin and Range tectonics.

Although these features were initially believed to be related to thrust faulting, a consensus now exists that they are different aspects of widespread Tertiary extension associated with the development of the Basin and Range province. The evidence upon which this historical debate is based is discussed in the site descriptions presented herein.

SITE 27. AMARGOSA CHAOS

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LOCATION AND ACCESS

From Shoshone, California, a small community at the intersection of California 127 and 178, follow California 127/178 north one mile; then turn west on California 178 about 15 mi (18 km) to the edge of the area of concern, hereafter called the Virgin Spring area. All stops are on California 178 (Fig. 2). Shoshone is about 60 mi (96 km) north of Baker, California, a community situated on I-15 between Las Vegas and Los Angeles.

This text is abstracted from Wright and Troxel(l984). It, as well as sections of two guidebooks (Troxel, 1974 and 1982, various pages), are useful supplements to this guide.

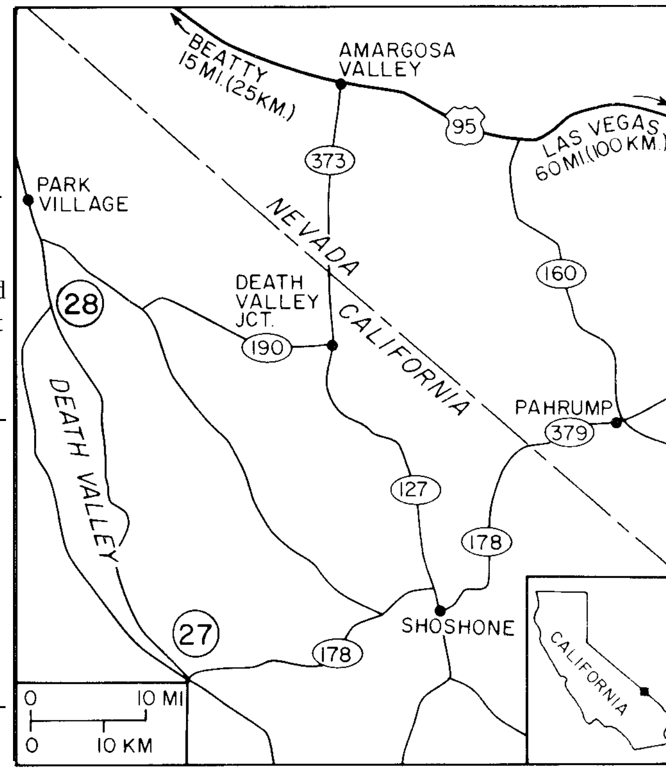


Figure 1. Map showing access to Amargosa chaos (Site 27) and turtlebacks (Site 28), Death Valley, southeastern California.

SIGNIFICANCE

Noble (1941) observed a style of faulting in the subject area so intricate and complex that he referred to the faulted rock units as “chaos.” He referred to these, as well as other similarly faulted terranes in the Death Valley region, as the “Amargosa chaos.” He selected the Virgin Spring area in the west-central part of the Black Mountains (Fig. 1) as the type locality for the Amargosa chaos.

Noble (1941) interpreted the terrane of the Virgin Spring area as broadly divisible into three lithologic-structural units (Fig. 2): (1) an autochthonous, relatively intact basement complex composed mostly of Precambrian quartzo-feldspathic metamorphic rocks and containing subordinate intrusive bodies variously of Precambrian, Mesozoic(?), and Tertiary age; (1) a composite allochthonous plate, comprising the various elements of the Amargosa chaos, much more deformed than the underlying complex, and composed largely of nested fault blocks of later Precambrian sedimentary rocks and diabase, Cambrian sedimentary rocks, and Tertiary volcanic, plutonic, and sedimentary rocks; and (3) an autochthonous cover of Late Cenozoic fanglomerate, basalt, and alluvium.

Noble (1941) interpreted a faulted contact between the basement rocks and the overlying Amargosa chaos as a regional thrust fault and the dominant structural feature of the Virgin Spring area. He named it the “Amargosa thrust” (Fig. 2). As Tertiary volcanic and sedimentary rocks are invo!ved in the chaos, he held that most or all of the movement on the proposed thrust occurred in Tertiary time. Noble later questioned the regional thrust concept.

SITE INFORMATION

Noble (1941) recognized three phases of the Amargosa chaos and named them the Virgin Spring, Calico, and Jubilee phases (Fig. 2). The Virgin Spring phase is composed almost entirely of units of the Pahrump Group (Fig. 3) and of the overlying latest Precambrian and Cambrian units. The Calico phase consists mostly of Tertiary volcanic units. The Jubilee phase comprises Tertiary conglomerate, finer-grained strata, and bodies of mono!ithologic breccia. He visualized the Virgin Spring phase as emplaced first and the Calico and Jubilee phases as moving over the Virgin Spring phase and semi-independently of it. Noble (1941) noted that much of the Calico phase "is intricately broken up by faulting, but not entirely chaotic" (p. 970) and that the Jubilee phase "presents a more confused picture than the other two phases" (p. 972).

The contact between the basement complex and the overlying Virgin Spring phase of the Amargosa chaos dips southwestward in some places and northeastward in others, delineating southwest-plunging antiforms and synforms. The largest antiform is termed the "Desert Hound anticline." The Malpais Hill syncline, Graham anticline, and Rhodes anticline appear in the eastern third of Noble's mapped area (Fig. 2). Noble cited these foldlike features as evidence that the Amargosa thrust was folded after most or all of the thrusting had ceased.

Since then, various persons have expressed views on the origin of the Amargosa chaos. Some have supported Noble's initial (regional thrust) interpretation; others have held that the constituent rock units of the chaos have remained close to their original sites of deposition.

Curry (1954) considered the turtleback surfaces of the Black Mountain front as marking northern extensions of the Amargosa thrust. Hunt and Mabey (1966) concurred with Noble (1941) that the dominant structural features of the Panamint Range, west of Death Valley, may be an anticline in a thrust plate like the Amargosa chaos. Hunt and Mabey suggested that the Amargosa chaos is a gravity-propelled detachment feature that began to move westward in Mesozoic time, was later folded, and then broken up by late Cenozoic normal faults.

Sears (1953) proposed that bodies of Tertiary granite and the various anticlines and synclines formed simultaneously, being effects of vertical forces related to rising magma, and that the chaos formed by gravity sliding off the flanks of the anticlines.

Bucher (1956) suspected that the Virgin Spring phase was caused by gravity sliding, but he related the sliding to a violent disruption. Drewes (1963), like Noble and Wright (1954), was inclined to limit the chaos to the vicinity of the Black Mountain block east of Death Valley and to attribute it to "repeated adjustments to large movements on the steep faults that bound the block." As alternate possibilities he suggested "near-surface bifurcation of a thrust fault" and "gravity sliding off a rising structural block."

ln our mapping of the chaos (Wright and Troxel, 1984), the following features of the Virgin Spring and Calico phases became obvious:

(1) Nearly all of the faults that feature the internal structure of the chaos are either normal or strike-slip; rarely do older rocks rest upon younger; (2) Where traceable downdip, the normal faults flatten with depth; some of them join along detachment surfaces within the chaos; others join along fault contacts between the Precambrian basement complex and the overlying later Precambrian units. Still others offset the contact and penetrate the complex; (3) The Virgin Spring phase is most chaotic within several tens of meters of the contact with the underlying complex.

We thus interpreted the chaos as an extensional feature, which formed on the underside of rotated fault blocks (Wright and Troxel, 1969) and also in the vicinity of low-angle detachment surfaces where normal faults flatten and join at shallow depths (Wright and Troxel, 1973). We also suggested that, in some areas, the crustal extension was accommodated by normal faulting in the basement, and by the emplacement of dikes and plutons (Wright and Troxel, 1973).

The basement complex is involved in the chaos and chaos-related faulting to a greater degree than Noble (1941) implied. Basement involvement is particularly obvious on the southwestern flank of the Desert Hound anticline (Fig. 2). The fault surface extends beyond the most westerly exposures of the Pahrump Group (Fig. 3) and splays into the complex. Southwest of the fault, the basal strata of the Crystal Spring Formation rest depositionally upon the complex. Many low-angle normal faults cut the crystalline complex (Wright and Troxel, 1984). The existence of these are important to a consideration of the origin of the chaos, as such faults permit extension of the basement concurrently with the formation of the chaos, and unaccompanied by the intrusion of bodies of igneous rock.

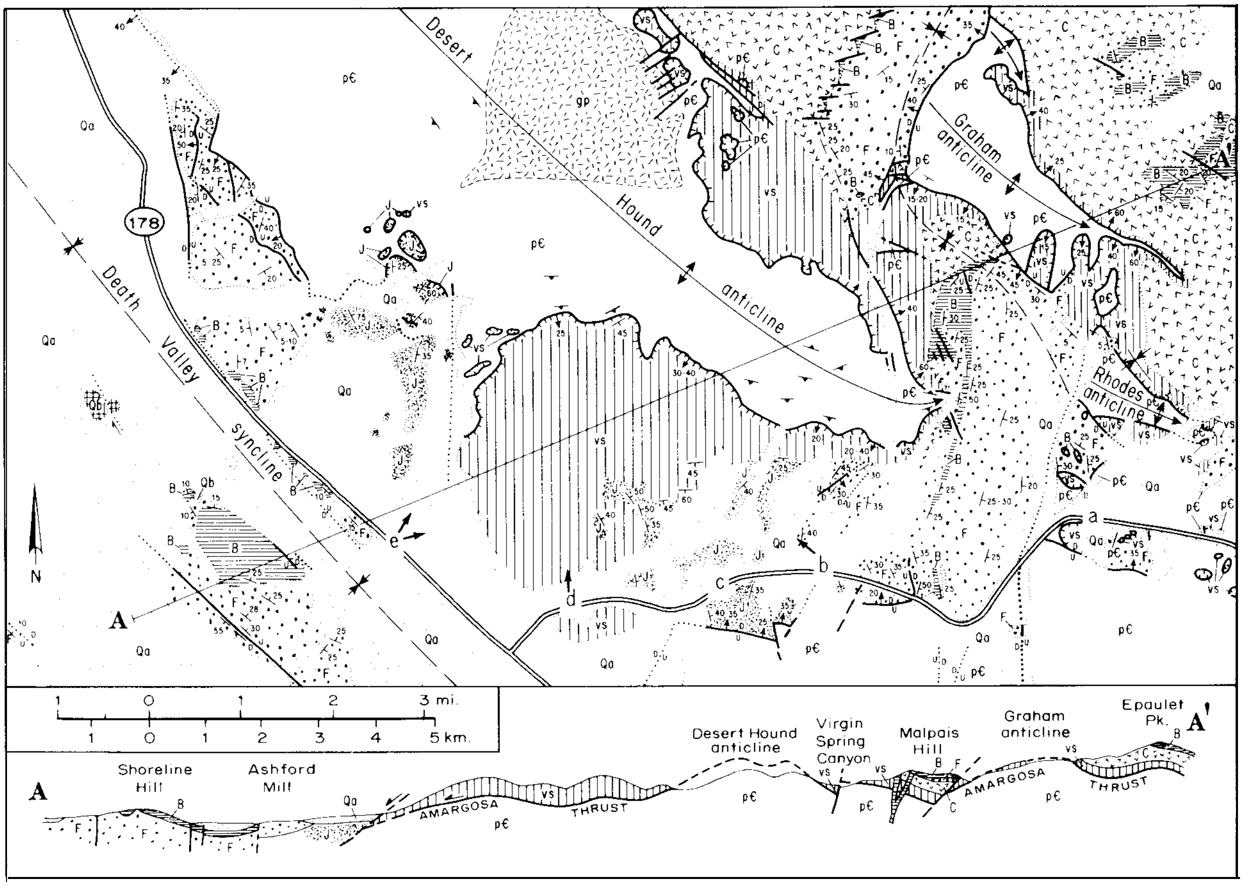
High-angle faults of relatively small displacement, apparently lateral, and commonly closely spaced, were mapped at several localities in the Virgin Spring chaos. Some lie entirely within the chaos; others offset the contact between the chaos and the underlying complex. All contribute to the disordered appearance of the chaos, but we interpret them as being superimposed upon the characteristic fault patterns of the chaos.

Some folds are Mesozoic or Early Tertiary in age, formed concurrently with the Desert Hound anticline and strongly modified by movement along the principal fault and by innumerable smaller faults.

ORIGIN OF THE AMARGOSA CHAOS

The geologic features of the Virgin Spring area record four major deformational events. The first, occurring as early as 1,700 Ma, accompanied and followed the metamorphism of the crystalline complex. It contributed to the angular discordance between planar and linear features in the complex and bedding planes in the overlying later Precambrian sedimentary units.

The second began with the deposition of the arkosic-conglomeratic strata low in the Crystal Spring Formation and continued through Noonday time (Fig. 3), spanning a poorly bracketed interval of time that probably lasted about 400 m.y. This event was accompanied by vertical crustal shifts (Wright and Troxel, 1984) causing facies changes in the Pahrump Group and Noonday Dolomite, and the angular unconformity beneath



Explanation	Structural units	Age of component material	Character of material	Symbols
Qa Alluviall deposits		Quaternary	Sand, qravel, silt and clay, rock salt in Death Volley	Strike and dip of beds
Qb Basaltic ash		Quaternary	Dissected cinder cone and stratified ash	Strike and dip of schistosity in Precambrian rocks
~UNCONFORMITY~				
F Fanglomerate B Interbedded basalt flows	Funeral fanglomerate	Pliocene ?	Interlayered basalt, breccia, and fanglomerate.	Amargosa thrust, hachures on over-thrust side (dotted where concealed)
-UNCONFORMITY				
J	Jubilee phase	Precambrian to Tertiary	Sedimentary and volcanic rocks and breccias of granitic, sedimentary, and metamorphic rocks	Klippe Fenster
C Amargosa chaos	Calico phase	Almost wholly Tertiary	Rhyolitic lava and tuff	POST--THRUST STRUCTURES
vs Amargosa overthrust	Virgin Spring phase	Almost wholly Cambrian and later precambrian	Dolomite, limestone, sandstone, quartzite, shale, and slate	Normal fault, U,upthrown, D, downthrown; arrow Indicates relative direction of horizontal component (dotted where concealed)
p€ gp Metamorphosed rocks Granite and granite porphyry Intrusive	Autochthonous block	Precambrian metamorphic rocks, intruded by granite and granite porphyry of Tertiary ? age	Granitic gneiss and greenstone sills	Axis of anticline and direction of plunge Axis of syncline

Figure 2. Noble's (1941) original map and cross section of the Virgin Spring area, redrafted and slightly modified for reduction and black and white reproduction. Small letters identify vantage points along paved road discussed in text.

the Noonday. These features, as expressed in the Virgin Spring area, indicate the presence of a major Precambrian discontinuity.

We interpret foldlike features preserved in the later Precambrian and Cambrian sedimentary rocks as actual folds forming before intricate faulting that produced the chaotic appearance of the Pahrump and younger units. We suggest that this folding occurred in Mesozoic or Early Tertiary time.

We continue to attribute the formation of the Virgin Spring and Calico phases of the chaos, the fourth deformational event, to faulting related to crustal extension in Cenozoic time. When the Death Valley region was deeply eroded, within the late Mesozoic-early Cenozoic interval, and then severely extended in later Cenozoic time, the resulting pattern of faulting led to the illusion of a single Cenozoic dislocation surface, originally planar and later folded.

To our earlier interpretations that related the telescoping of the later Precambrian and Cambrian strata in the chaos largely or wholly to movement on normal faults, and that involve the underlying crystalline complex in the chaos-related faulting (Wright and Troxel, 1973), we add the following interpretations. (1) The complex and younger cover rocks have responded differently to severe crustal extension, thus creating the appearance of a single Tertiary thrust fault bringing the younger units over the complex without involving the complex. The complex has been broken and extended by normal faults. (2) The chaos-forming event has consisted of a continuum featured by normal faulting accompanied by intervals of erosion, basinal sedimentation, and volcanism, Thus, the Virgin Spring phase of the chaos is more intricately faulted than the Calico phase and the Calico phase more so than the Funeral Formation. (3) The high-angle faults of apparent lateral slip we interpret as genetically and temporally related to the normal faults.

SUGGESTED FIELD EXCURSION

Depart from Shoshone, travel one mile (1.2 km) north, then turn west on California 178. Five stops are shown on Figure 2 and discussed below. General features of the geology from Shoshone into Death Valley are described by Troxel (1974, p. 2-16 and 1982, p. 37-42, 71-74).

The best single panorama of chaos exposures available from the highway is provided at a point in Bradbury Wash 3.5 mi (about 5.5 km) west of Salsberry Pass and 0.5 mi (about 0.8 km) east of the east boundary of Death Valley National Monument (Fig. 4).

The first ridge toward the viewer from the Panamint Range exposes the major features of Noble's (1941) Desert Hound anticline. The central part of the anticline is marked by exposures of the gray crystalline complex beneath Desert Hound Peak. Its limbs are identifiable by exposures of the varicolored, younger Precambrian and Cambrian units that compose the Virgin Spring phase of the chaos.

The near low ridge is underlain by east-tilted conglomerate and basalt of the late Cenozoic Funeral Formation. They are

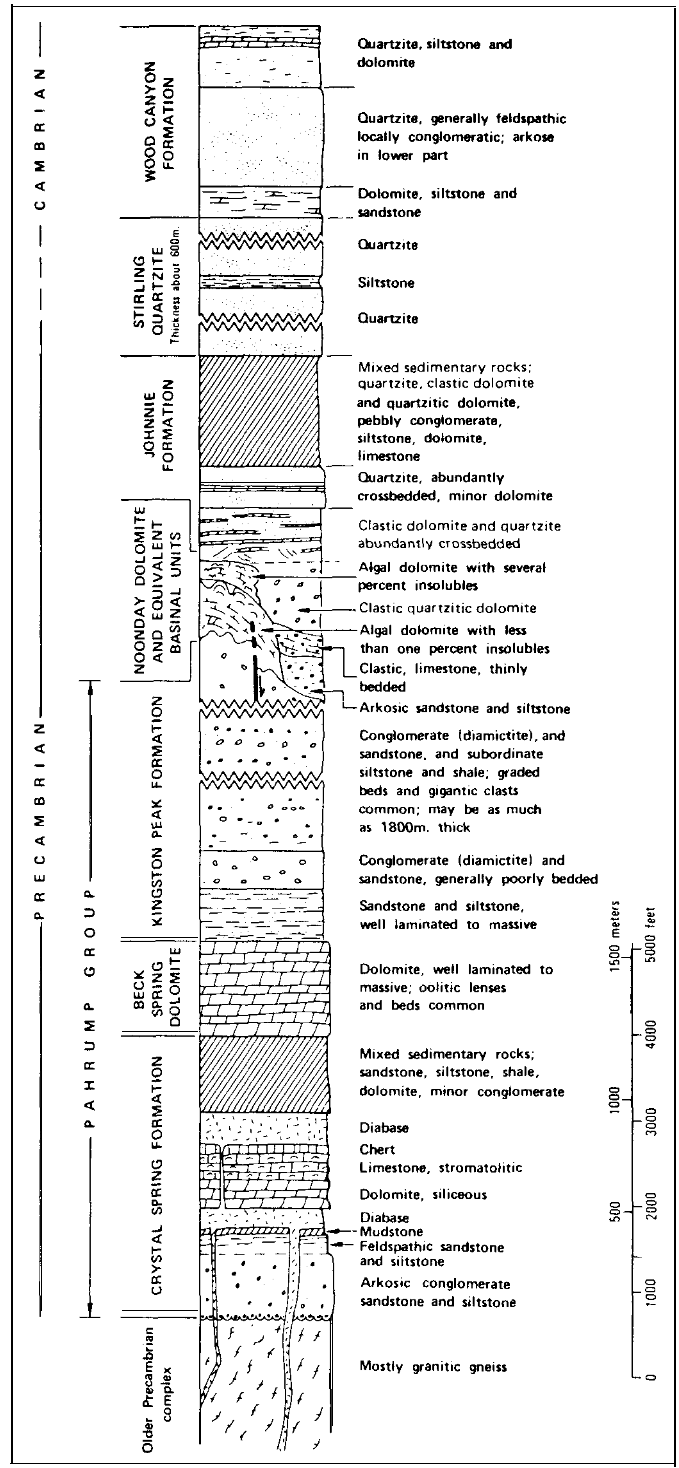


Figure 3. Generalized columnar section of Precambrian to Lower Cambrian strata, Death Valley region. Equivalent basinal units of Noonday Dolomite are now known as the Ibex Formation. From Wright and others (1974).

much less deformed than the rock units of the chaos and thus postdate the formation of the chaos.

Rhodes Hill, in the near foreground north of the highway, is underlain by gray gneiss of the Precambrian complex. The overridden part of the complex is exposed on the crest of the low ridge that limits Bradbury Wash on the south. Jubilee Peak also is underlain by the Precambrian complex.

Epaulet Peak, identifiable by a capping and fringelike talus slopes of dark brown- to black-weathering basalt, dominates the skyline north of Bradbury Wash. The basalt and a thin, discontinuous, underlying layer of conglomerate apparently are correlative with the Funeral Formation.

Exposed over most of the southwest slope of Epaulet Peak are rhyolitic volcanic rocks, varicolored, but mostly in shades of yellow. These are the Shoshone Volcanics of Pliocene age. They are faulted considerably more than the overlying Funeral Formation, and form the principal exposures in the Virgin Spring area of Noble's Calico phase of the chaos.

Exposed in a belt still lower on the southwest slope of Epaulet Peak are highly faulted latest Precambrian and Cambrian units in an occurrence of the Virgin Spring phase of the chaos. Within the belt are fault-bounded segments of the Noonday Dolomite, Johnnie Formation, Stirling Quartzite, Wood Canyon Formation, and Zabriskie Quartzite. Viewed collectively, they are darker-mostly in shades of red-than the overlying volcanic units. They are more colorful and resistant and much more faulted than the gray underlying crystalline complex, which is barely in view from here. This contact is a segment of Noble's Amargosa thrust and marks the northeast limb of the Graham anticline (Fig. 2). He also interpreted the contact between the Virgin Spring and Calico phases of the chaos as a surface of movement, but less than the movement on the lower contact.

Exposures of the Virgin Spring phase of the Amargosa chaos in lower Bradbury Wash. Upon entering Death Valley Monument, and for the next 4 mi (about 6.5 km) westward, the road is close to exposures of the Virgin Spring phase of the chaos and its contact with the underlying complex. Here, as elsewhere, the contact is marked by an abrupt change from the gray of the complex to the brighter and more varied colors of the chaos. In this area, only isolated erosional remnants of the chaos remain, but they show features much like those that characterize larger bodies of the Virgin Spring phase. Of the chaos-forming units at this locality, the Noonday Dolomite is the easiest to identify. It is the yellowish gray, resistant unit that supports most of the knobs within 0.5 mi (0.8 km) of the highway. At numerous places, one can observe details of the faulted lower surfaces and the intensely fractured nature of the various overlying rock units.

The best exposure of the Virgin Spring chaos along California 178 lies adjacent to and south of the highway and west of the Monument boundary (point a, Fig. 2). There the chaos underlies the steep north face of a hill about 300 ft (90 m) high and displays most of the features that are commonly ascribed to the lower part of the chaos in general.

The lower part of this face is underlain by the gray-weathering, locally red-stained crystalline complex. Within it are sheared masses of dark green diabase dikes and nearly white granitic pegmatite dikes. All are thoroughly sheared and become progressively more so upward to the nearly horizontal contact with the overlying chaos. The strong evidence of dislocation along this contact, together with the deformation recorded in the chaos, impressed Noble to the extent that he identified it as an occurrence of his Amargosa thrust.

The pale gray to dark lavender, thin fault-bounded lenses at the base of the overlying chaos consist of arkosic sandstone and siltstone of the dominantly elastic lower part of the Crystal Spring. The dark green lenses higher on the face are slices of the diabase sill that, regionwide, separates the lower elastic members from the carbonate member. The latter, in turn, is represented by the still higher, dark reddish brown lenses. This hill, like other hills in the vicinity, is upheld by yellowish gray dolomite of the Noonday Dolomite. Strata of the Johnnie Formation are exposed on the south side of the hill crest. Both the Noonday and Johnnie, like the Crystal Spring, occur as fault-bounded lenses and thus also qualify as chaotic.

The full thickness of the Crystal Spring ordinarily ranges between 2,500 and 4,000 ft (750 and 1,200 m; Fig. 3). The fault-bounded slices of Crystal Spring exposed on the nearby vertical north face of the hill in the lower Bradbury Wash are limited to about a 200-ft-segment (60 m) of the face. The Beck Spring Dolomite and Kingston Peak Formation may have been eroded away from this location in Precambrian time before the Noonday Dolomite was deposited, but most of the Crystal Spring has been faulted out in the formation of the chaos. Each slice retains its proper stratigraphic position, younger over older.

View of the southwest limb of the Desert Hound anticline from the west side of Jubilee Pass. A point about 0.5 mi (0.8 km) west of Jubilee Pass (point b, Fig. 2) affords an excellent distant view of the crest and southwest limb of the Desert Hound anticline and of the southwestern body of the Virgin Spring chaos (Fig. 5). From Desert Hound Peak eastward is exposed the gray-weathering, earlier Precambrian crystalline complex. The dark green patches within it are exposures of parts of an anastomosing system of Precambrian diabase dikes; the lighter patches are exposures of prediabase pegmatite bodies and Tertiary acidic dikes.

The contact between the complex and the Virgin Spring phase of the chaos is about halfway down the slope southward and is identifiable by the characteristic change in color, from the gray of the complex to the warmer colors of the later Precambrian and Cambrian units. The dark green unit near the skyline is the sill of diabase in the Crystal Spring Formation. The lightest-colored rock, which tends to form topographic highs, is the yellowish gray dolomite of the Noonday Dolomite. The post-Noonday formations are more difficult to distinguish from one another. Of these, the most distinctive are the pale orange to pale lavender, well-layered units of the Johnnie Formation.

The contact between this body of Virgin Spring chaos and the underlying complex is everywhere strongly faulted, but is unbroken by later faults. It dips moderately to steeply southwest-

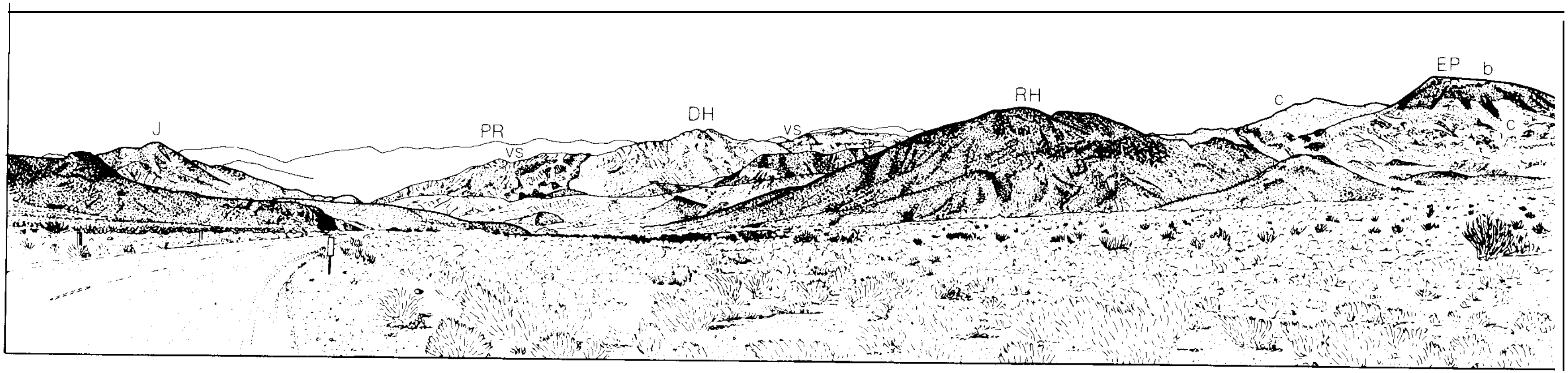


Figure 4.

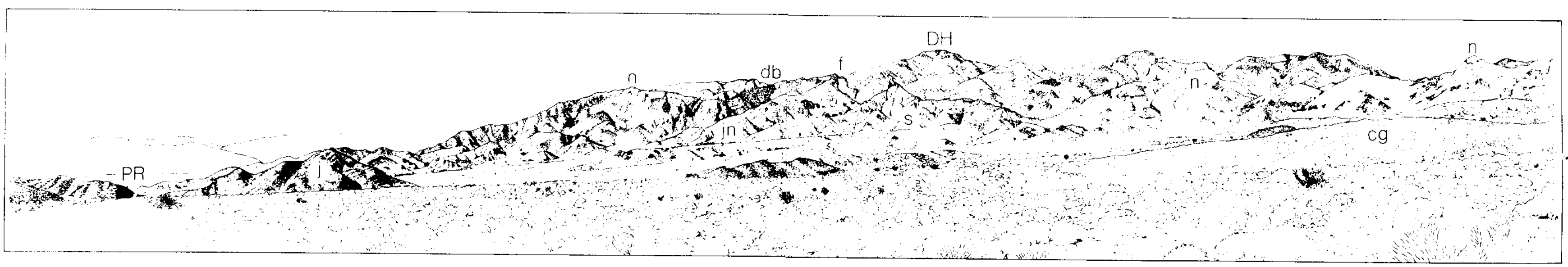


Figure 5.

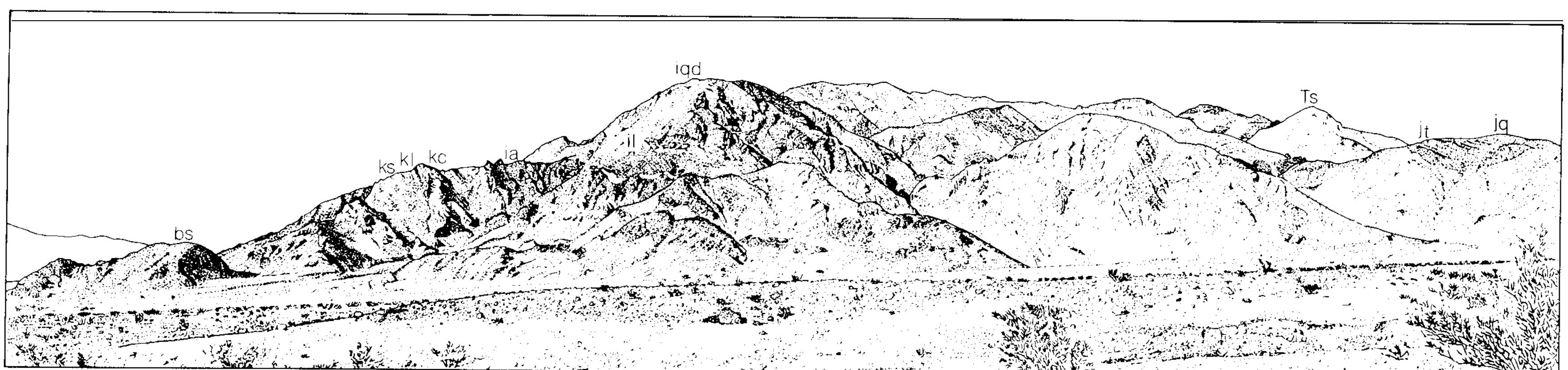


Figure 6.

ward and resembles in detail the contact and associated overlying and underlying rock units observed at point a along the highway in lower Bradbury Wash. This contact is the most continuously exposed segment of Noble's Amargosa thrust (Fig. 2). The overlying, younger units compose the thickest and most extensively exposed body of the Virgin Spring phase of the chaos in the map area. Most of the chaos in this body is much less intricately faulted than the chaos observed near the highway.

Jubilee phase of the Amargosa chaos exposed near Point of Rocks. The most accessible and some of the best examples of Noble's (1941) Jubilee phase of the Amargosa chaos underlie three hills just north of the highway and opposite Point of Rocks, about 2 mi (3.2 km) west of Jubilee Pass (point c, Fig. 2). Noble (1941) distinguished this phase from the other two phases because, unlike them, it contains abundant conglomerate and siltstone of Tertiary age, as well as bodies of Tertiary volcanic and granitic rock and various rock units of the Pahrump Group and latest Precambrian and Cambrian formations. In addition, many of the bodies of Tertiary volcanic and granitic rock and all of the bodies of the older units are truly breccia layers, which, although monolithologic, are interlayered with Tertiary conglomerate, siltstone, and tuff. Noble and Wright (1954) reinterpreted most or all of these bodies of breccia as sedimentary units

Figure 4. Sketch of westward view of the terrane of the Amargosa chaos from a point on California 178, 3.5 mi (5.6 km) west of Salsberry Pass and 0.5 mi (0.8 km) east of the eastern boundary of Death Valley National Monument. Topographic features are indicated by capital letters, geologic features by small letters. DH, Desert Hound Peak EP, Epaulet Peak J, Jubilee Peak; PR, Panamint Range; RH, Rhodes Hill; b, basalt of Funeral Formation; c, Calico phase of chaos; vs, Virgin Spring phase of chaos as distributed along both sides of Desert Hound Peak.

Figure 5. Sketch of the terrane of the Amargosa chaos as viewed northward and westward from the vicinity of Jubilee Pass (point b, Fig. 2). Exposed in succession from the northern skyline toward the viewer are (1) the Precambrian crystalline complex, underlying the highest part of the landscape; (2) the Virgin Spring phase of the chaos forming a continuous belt along the intermediate slopes; and (3) the Jubilee phase of the chaos discontinuously exposed in low hills and ridges surrounded by alluvium. DH, Desert Hound Peak PR, Point of Rocks; cg, conglomerate of Funeral Formation; db, diabase of Crystal Spring Formation; f, fault contact between the Precambrian crystalline complex and the overlying Virgin Spring phase of the chaos; j, Jubilee phase of the chaos; jn, Johnnie Formation; n, Noonday Dolomite; s, Stirling Quartzite.

Figure 6. Sketch of a part of the Black Mountains, looking northward from lower Jubilee Wash (Point c, Fig. 2). The rock units underlying the prominent slopes are mostly of Precambrian age and were included by Noble (1941) in his Virgin Spring phase of the Amargosa chaos. They form, in general, an east-tilted fault block, broken by many normal faults of relatively small displacement and which cause repetitions of the sedimentary units; bs, Beck Spring Dolomite; ia, il, and iqd, arkose, limestone, and quartz-dolomite sandstone members of the Ibex Formation; jt and jg, transitional and quartzite members of the Johnnie Formation; ks, kt, and kc, siltstone, limestone, and conglomerate members of Kingston Peak Formation; Ts, Tertiary sedimentary rock.

in the Tertiary section, and our mapping has reinforced this view.

Monohthologic breccia of quartz monzonite underlies most of the east and middle hills and displays a cavernous type of weathering. The west hill is underlain mostly by breccia derived from the Crystal Spring Formation, including the diabase (green), carbonate member (red), and arkose of the lower units (gray). The evenly bedded conglomerate and sandstone exposed at Point of Rocks are representative of the other sedimentary rocks associated with the bodies of breccia.

Pahrump Group and latest Precambrian formations exposed on north wall of lower Jubilee Wash. As the traverse continues still farther westward and down Jubilee Wash, the Virgin Spring chaos north of the highway assumes a progressively less chaotic appearance. Viewed from a point about 1.5 mi (2.4 km) west of Point of Rocks (point d, Fig. 2), the north wall of the wash provides a cross section through the upper part of the Beck Spring Dolomite, the Kingston Peak Formation, and the basin facies of the Noonday Dolomite (Ibex Formation). Although faulted, these formations retain most of their original thickness and dip moderately eastward (Fig. 6).

Perhaps the simplest to identify is the unit of dark lavender strata in the middle part of the face. This is the arkose member of the Ibex Formation. It consists of arkosic sandstone and siltstone and composes the lowest part of the formation (Williams and others, 1976). It is underlain by small, discontinuous lenses of yellowish gray dolomite. These lenses are remnants of the southward-thinning lower dolomite member of the Noonday Dolomite (platform facies). Successively above the arkose member are well-bedded yellow limestone and limestone conglomerate, then massive dolomite-quartz sandstone.

The low hill at the western end of the face is underlain by the gray-appearing Beck Spring Dolomite. The generally orange to reddish orange strata between the Beck Spring and the lenses of Noonday Dolomite are units of the Kingston Peak Formation. A thin layer of thinly-bedded, black limestone separates the fine-grained lower siltstone member of the Kingston Peak from the conglomeratic middle member (diamictite). The upper member consists of a relatively evenly bedded unit of mixed conglomerate, sandstone, siltstone, and sedimentary breccia. At the Jubilee Wash locality, the part of the Kingston Peak that overlies the limestone member consists mostly of diamictite and includes only a thin occurrence of the upper member. All of the bodies of conglomerate contain abundant debris from the Beck Spring Dolomite and Crystal Spring Formation. We cite this as evidence that the Beck Spring and Crystal Spring once extended well to the north of their most northerly exposures in the Confidence Hills Quadrangle.

View of the Black Mountains escarpment from Ashford Mill site; Pahrump Group and Noonday Dolomite. The Pahrump Group and the overlying Noonday Dolomite, where exposed on the Black Mountains escarpment, are much less faulted and more completely exposed than they are in the chaos of lower Bradbury Wash. When viewed from Ashford Mill site (point e, Fig. 2) in the afternoon sun or on a cloudy day, the escarpment clearly shows the differences in color that permit identification of the various Precambrian units. The yellowish gray unit, supporting the highest point, is the Noonday Dolomite. The change from the platform to the basin facies (Ibex Formation) occurs abruptly near lower Jubilee Wash. The gray unit, beneath the Noonday and traceable diagonally up the escarpment, south to north, is the Beck Spring Dolomite. The Kingston Peak Formation is missing along all but the southernmost part of the escarpment, as it wedges out a short distance north of Jubilee Wash. Detectable even from this distance, however, is an interlayering of gray dolomite typical of the Beck Spring, and orange strata like those of the siltstone member of the Kingston Peak.

Successively exposed beneath the Beck Spring along the rest of the escarpment are the various members of the Crystal Spring Formation. Especially obvious are the dark green diabase sills at various positions within the formation. The upper sedimentary units are varicolored; the dolomite, which here forms the carbonate member, is orange, and the lower arkosic units are various shades of gray and lavender.

SITE 28. TURTLEBACK SURFACES

B. W. Troxel

LOCATION AND ACCESS

Turtleback surfaces are exposed along the west front of the Black Mountains between about 15 and 35 mi (24 and 56 km) south from Furnace Creek Ranch, Death Valley, California. They lie within a few miles of the paved road that extends southward from Furnace Creek Inn to Shoshone, California. Access to the northernmost turtleback, the Badwater turtleback, is obtained by driving to the parking area at the east end of a gravel road identified by a sign that denotes "Natural Bridge Canyon." The northwestern tip of the turtleback is cut by Natural Bridge Canyon. The southwest wall of the Badwater turtleback is well exposed and easily accessible by hiking from the parking area.

The next turtleback to the south is the Copper Canyon turtleback. Access to it is gained by parking near the mountain front at the south edge of the Copper Canyon fan and hiking north along the mountain front to the point where the crystalline rocks beneath the turtleback surface plunge northwestward beneath the faulted Tertiary sedimentary rocks. A moderately steep, but short, climb affords excellent detailed exposures of the turtleback fault.

The Mormon Point turtleback, a few miles farther southwest from the Copper Canyon turtleback, plunges northwestward beneath Quaternary gravel. Details of the bedrock beneath the turtleback surface can be observed at many points along the west flank of the mountain front south from Mormon Point.

SIGNIFICANCE

The turtleback surfaces were recognized and named by Curry (1938). Since then they have been the subject of considerable debate as to their origin and significance. Five significantly different origins have been proposed for the surfaces. Parts of the surfaces are moderately easily accessible; these features invite intense field discussions. The features are important in that they have been involved at least in Tertiary Basin and Range extension and perhaps in Mesozoic compression.

SITE INFORMATION

Background information. Curry's pioneer work (1938) led him to attribute the origin of the three turtleback surfaces to compressional folding of a regional thrust fault (Curry, 1954). Noble (1941) and Hunt and Mabey (1966) likewise related them to thrust faulting. Drewes (1959) proposed that differential erosion produced an "undulating topographic surface upon which the Cenozoic rocks were deposited and from which they later slid, propelled by gravity" (Wright and others, 1974). Sears (1953) related the arching to the intrusion of shallow plutons. Hill and Troxel (1966) stated that the turtleback surfaces were formed during regional compression and that the Tertiary cover rocks essentially moved as the basement rocks folded. Wright and others (1974) and Otton (1974) stated that the turtleback surfaces "were colossal fault mullion resulting from severe crustal extensions which were localized along undulating and northwest-plunging zones of weakness that were in existence prior to this deformation." Stewart (1983) considered the turtleback surfaces to be gigantic mullions related to the detachment and transport of the overlying rocks 50 mi (80 km) northwestward.

Noble (1941) related his "Amargosa thrust" to the "turtleback fault" of Curry (1954) but later doubted the existence of the Amargosa thrust (Noble and Wright, 1954). The turtleback folds and metamorphism of mantling carbonate rocks are now considered to be analogous to core complexes in that they are domal, consist of a core of gneiss that dips away from the domes, have a mantle of metamorphosed rocks, and are covered by deformed but unmetamorphosed rocks separated from the mantled core by mylonitized rocks beneath the detachment surface. The three turtlebacks are overlain by Cenozoic sedimentary rocks cut by abundant listric normal faults that flatten and merge with the detachment faults atop the turtlebacks. Similar fault patterns are characteristic of the Virgin Spring area farther south (see Wright and Troxel, this guidebook).

Physical features of the Death Valley turtlebacks. The three turtlebacks as identified by Curry (1938) are, from north to south, the Badwater, Copper Canyon, and Mormon Point turtlebacks. The antiformal and topographic axes of the turtleback surfaces trend northwest, and the crests plunge northwest.

Slickensides on the southwest flanks of the turtleback surfaces and on many of the frontal faults on the west side of the Black Mountains trend northwest and plunge 10° to 15° to the northwest (unpublished data). Each of the turtleback surfaces is underlain by a mantle composed of discontinuous carbonate rocks, which are internally highly deformed. The rocks beneath the detachment surface are usually mylonitized and commonly

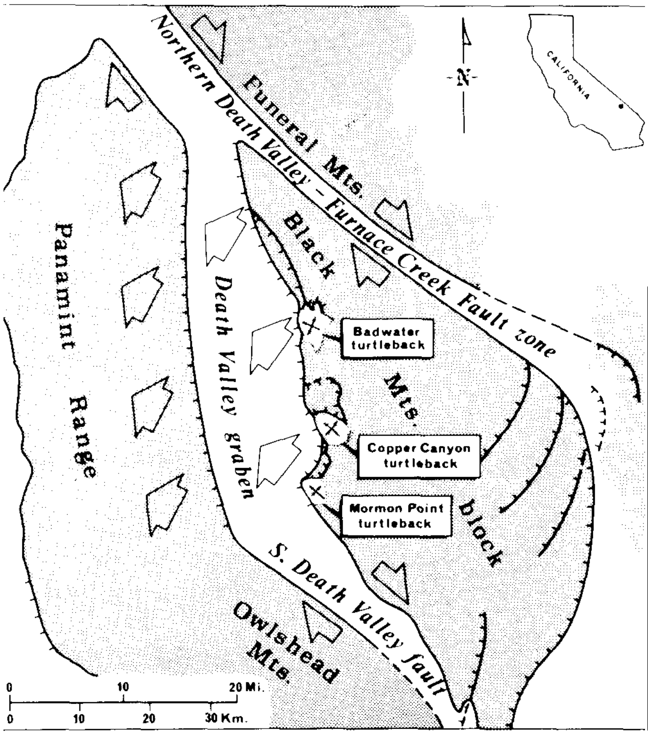


Figure 7. Generalized structural map of Death Valley region, showing position of three turtleback surfaces of Black Mountains. Hachured lines mark positions of major normal faults; full arrows show inferred direction of crustal extension; half arrows show relative displacement on strike-slip fault zones. Figure from Wright and others (1974).

enriched in iron. The mantle of carbonate rocks is underlain by foliated gneissic rock of Precambrian age (Drewes, 1963) and intruded by Mesozoic (?) dioritic rocks (Otton, 1974). The southeastern extension of the Mormon Point turtleback (the Desert Hound anticline of Noble, 1941) is intruded by Miocene (?) quartz monzonite (Drewes, 1963; Wright and Troxel, 1984). Tertiary intrusive rocks crop out also southeast of the domal crests of the other turtleback surfaces.

The common northwest trend of the antiformal axes of the three turtleback surfaces and the continuation of the Mormon Point turtleback surface into the Desert Hound anticline of Noble (1941) are significant. Moreover, the trend of these features is remarkably coincident with the trend of the Northern and Southern Death Valley fault zones, the other anticlines in the Virgin Spring area (Noble, 1941; Wright and Troxel, 1984), and the trend of the domed surface formed beneath the Boundary Canyon and Keene Wonder faults in the Funeral Mountains (Troxel and Wright, unpublished data) situated farther north. Most of these trends are apparent on the Geologic Map of California (Jennings, 1977).

The geology of the Death Valley turtlebacks is shown on various geologic maps. These include Curry (1954), Drewes (1959, 1963) Otton (1974), the Death Valley 1:250,000-scale map (Streitz and Stinson, 1974) and the Geologic Map of California (Jennings, 1977). Noble (1941) published a map of the Virgin Spring area of chaos, and Noble and Wright (1954) published a general structural map of Death Valley.

Some important differences exist between the turtlebacks of Curry (1938, 1954), the anticlines in the Virgin Spring area (Noble, 1941; Noble and Wright, 1954; Wright and Troxel, 1984), and the domal detachment surface exposed in the Funeral Mountains (Troxel and Wright, unpublished data). The common trend of these features and of the major strike-slip faults is obvious. Its meaning is less so. The subtle to obvious differences in the rocks and their fabric is also important and incompletely understood at this time. The following field traverse is suggested to stir interest and acquaint you with features of Curry's (1938, 1954) original observations.

FIELD EXCURSION

A traverse from south to north in the floor of Death Valley is suggested. A review of the discussion of the Amargosa chaos by Wright and Troxel (1984, and this volume) is recommended before progressing northward from the Virgin Spring area into central Death Valley, where the Death Valley turtlebacks are exposed.

Proceed on California 178 and 127 for 1 mi (1.6 km) north from Shoshone, California. Shoshone is about 60 mi (97 km) north of Baker, California, which is situated on I-l 5 that connects Las Vegas, Nevada, and Los Angeles, California. Proceed west on California 178, into the floor of Death Valley (about 30 mi; 48 km), then north along the paved road that follows the east side of Death Valley to the intersection of California 190 at Furnace Creek Inn.

When you obtain the position of Mormon Point (the northwestern promontory of the Mormon Point turtleback (Fig. 7) you are at the point where lateral motion on the southern Death Valley fault zone gives way to transtension in a pull-apart region that lies between the Southern Death Valley fault zone and the Northern Death Valley-Furnace Creek fault zone. The Death Valley turtlebacks lie within this transtension zone (Fig. 7). This part of Death Valley has been identified as a pull-apart basin (Burchfiel and Stewart, 1966; Wright and others, 1974). The direction of motion is implied to trend parallel with the orientation of the crests of the Death Valley turtlebacks (Curry, 1938, 1954) as shown on Figure 7. The topographic low of central Death Valley occupies a half-graben that lies between the Panamint Mountains to the west and the Black Mountains to the east. For the most part, the Black Mountains are devoid of Precambrian and Paleozoic rocks that are exposed on nearly all sides of the Black Mountains (e.g., see Jennings, 1977). The lack of the Precambrian and late Paleozoic strata in most of the Black Mountains block (Fig. 7), and other phenomena, led Stewart (1983) to postulate a 50-mi transport (80 km) of the Panamint Mountains northwestward from a position above the Black Mountains block along a fault plane (or planes) related to the turtleback surfaces.

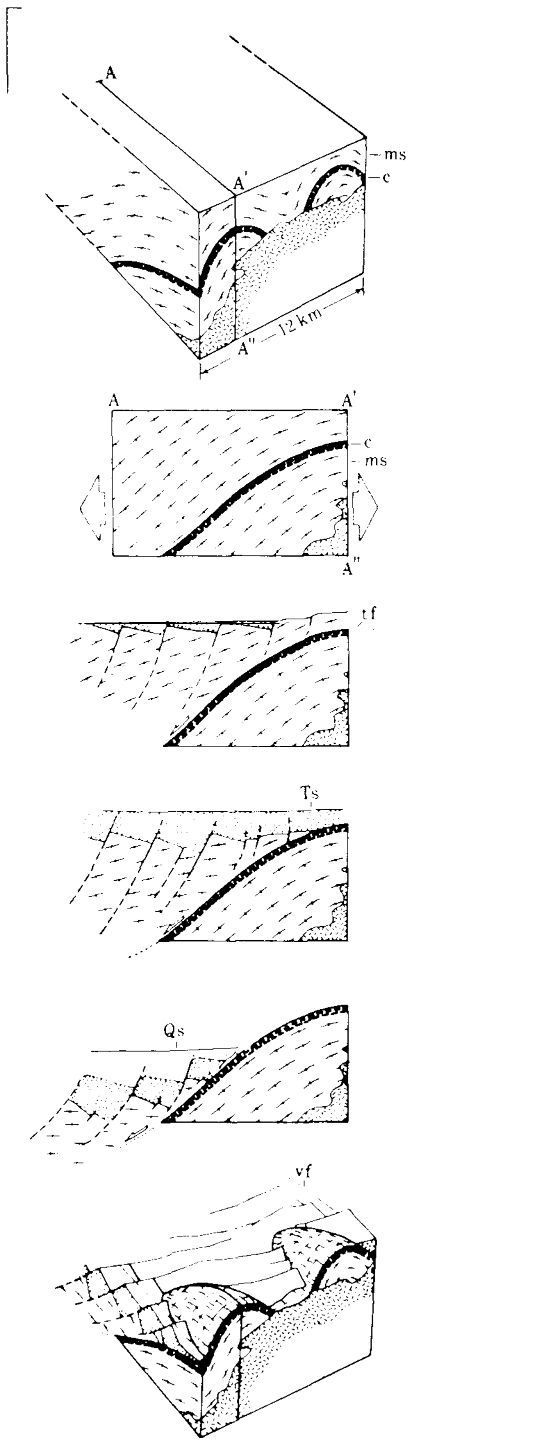


Figure 8. Idealized block diagrams and cross sections, illustrating pull-apart concept of turtleback formation; based on observations of Copper Canyon and Mormon Point turtlebacks, Death Valley. c, Carbonate layers; ms, mixed metasedimentary rock; Qs, Quaternary sediments; tf, turtleback fault; Ts, Tertiary sedimentary rock vf, valley floor. Figure from Wright and others (1974).

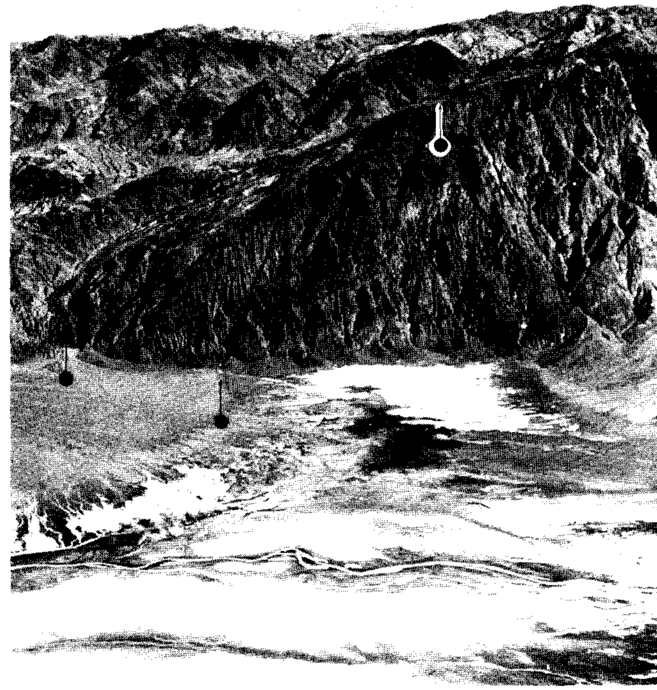


Figure 9. Copper Canyon turtleback from west. Left arrow denotes place to observe turtleback surface, transported overriding rocks, and fractured bedrock. Central arrow denotes suggested place to park. Third arrow marks crest of turtleback. Copper Canyon fan in lower left foreground. Photo by L. A. Wright.

Figure 8, idealized block diagrams and cross sections, demonstrates the pull-apart concept of Wright and others (1974). Each of the three turtlebacks is discussed below.

Mormon Point turtleback. The Mormon Point turtleback, mapped most recently and in most detail by Otton (1974), is easily accessible from the paved road in Death Valley that follows closely the west flank of the turtleback. Many small west-flowing stream channels afford access into the flank of the ridge. In some of the channels, one can observe the turtleback fault preserved beneath Quaternary grave1 that has been deposited upon the fault surface and subsequently moved essentially down the dip of the fault surface. Normal faults that dip more steeply to the west cut the Quaternary gravel and merge with the renovated turtleback fault (see Troxel, 1986). Beneath the turtleback fault, the bedrock, most commonly Precambrian carbonate rocks (Otton, 1974), is intensely brecciated. The degree of brecciation diminishes downward away from the fault surface. The Quaternary gravel has been rotated downward to the east during slip on the main fault plane and subsidiary fault planes that merge downward into it. This pattern is typical of listric faults that merge downward into major extensional fault planes in many parts of the Death Valley region. A particularly good exposure of the

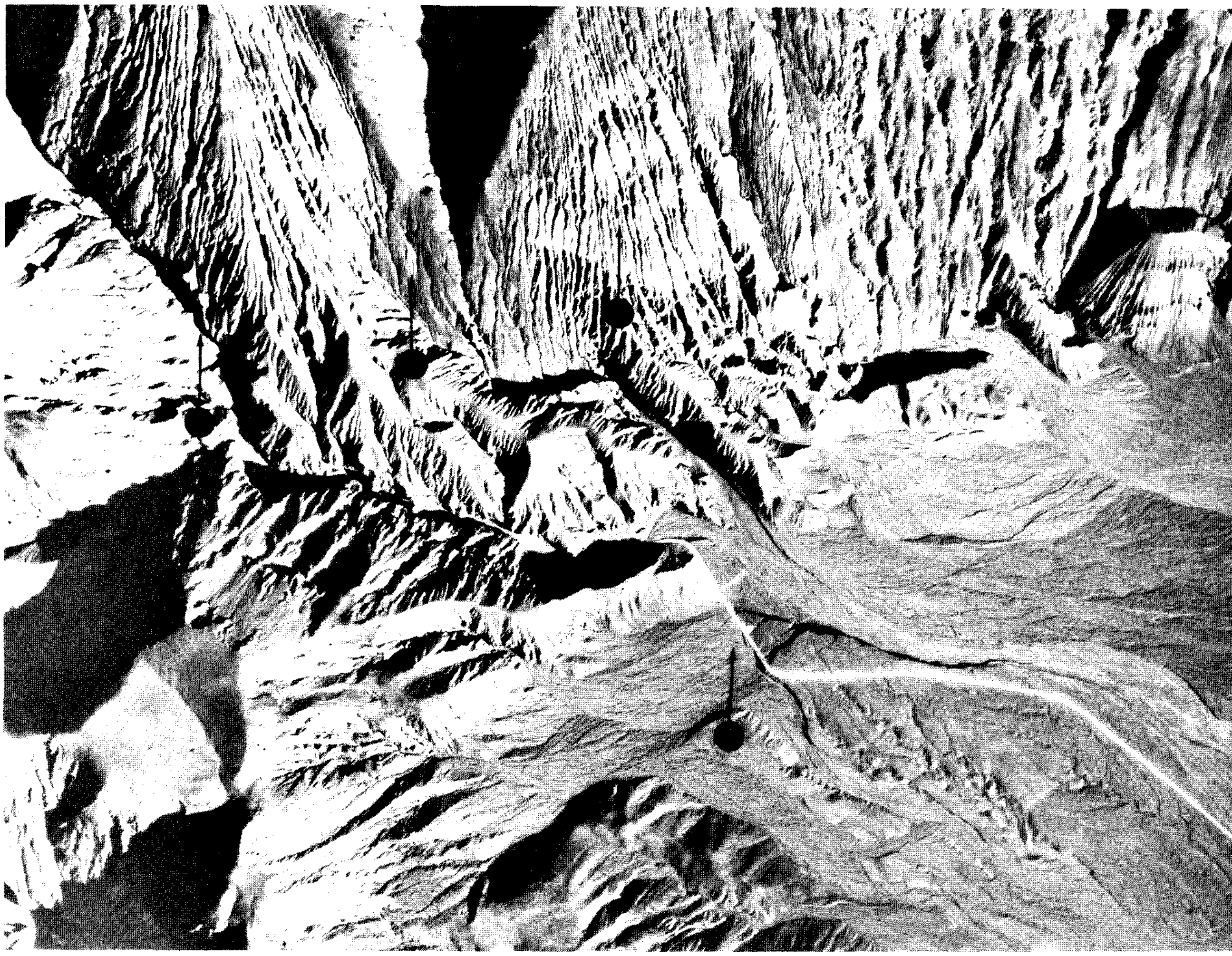


Figure 10. Badwater turtleback. White line on fan surface is Natural Bridge Canyon road to parking area (lower arrow). Arrows denote approximate location of natural bridge (left), exhumed turtleback surface (center), and a triangular-shaped erosional remnant of Tertiary rocks transported over turtleback fault (right). North is to the left. Photo scale 1:12,000. Low sun-angle photograph; courtesy of D. B. Slemmons.

Quaternary faults that join the rejuvenated turtleback fault is in a small canyon situated 1 mi (1.6 km) south from Mormon Point. It can also be found by parking 0.3 mi (0.5 km) north of highway mileage marker 36. The mouth of the canyon is crossed by west-facing fault scarps in very young stream gravel. The north wall of the mouth of the canyon contains gently east-tilted fine-grained sediments overlain and underlain by coarse gravel.

From many points on the paved road can be seen pale-colored marble intruded by dark green dioritic rock. The marble forms a coating or shell beneath the turtleback fault surface (Otton, 1974). It must be assumed that the southwest downdip continuation of the turtleback surface has been downdropped beneath the Death Valley floor along Quaternary (and older?) normal (oblique slip?) faults that abound along the range front.

Copper Canyon turtleback. Mormon Point affords an excellent view of the profile of the Copper Canyon turtleback crest and the overlying Tertiary sedimentary and volcanic rocks that have been transported northwestward over the turtleback surfaces. From Mormon Point the view to the northeast is almost at a right angle to the northwest plunge and trend of the crest of the turtleback surface.

Not visible from this viewpoint is the relatively thin skin of carbonate rock directly beneath the turtleback surface. This is mainly because the southwest flank of the turtleback surface has been cut by younger faults along the mountain front. Precambrian foliated gneissic rock and flow-banded or foliated Mesozoic dioritic rock form most of the rangefront in view beneath the turtleback surface (Fig. 9). A few small patches of carbonate rock are exposed at the crest of the turtleback, which is nearly coincident with the ridge crest visible from Mormon Point.

A few dikes of Tertiary intrusive rocks cross the turtleback mass at nearly right angles to the trend of the ridge crest. The dikes are oriented in a proper direction to be fractures that were tilled as the basement mass extended during northwest transport of the rocks above the turtleback fault surface. Proceed east, then north, along the road from Mormon Point to the point where the road begins to veer northwest from the mountain front. Park here if you wish to hike to the point where the turtleback fault is exposed beneath the transported Tertiary rocks.

In a distance of less than 1 mi (1.6 km) one can hike northward, parallel to the mountain front, to a small canyon that cuts across the northwestward-plunging nose of the Copper Canyon turtleback. At this point, it is advisable to climb the steep (and moderately difficult) surface on the north side of the narrow stream channel. After a few tens of yards, the topography becomes less steep and one is rewarded with excellent exposures of the multiple faults that separate the Tertiary rocks from the underlying Precambrian rocks. One would probably want to spend one to two hours at this locality noting the details of mylonitization, fault imbrication, iron enrichment, and brecciation associated with the Copper Canyon turtleback fault.

Badwater turtleback. The Badwater turtleback, some 12 to 15 mi (19 to 24 km) north of the Copper Canyon turtleback, is more easily accessible than the Copper Canyon turtleback, and, in addition, contains remnants of the Tertiary cover rocks preserved along the southwest flank of the turtleback surface (Fig. 10). After leaving the parking lot at Badwater and traveling north along the highway, the patches of Tertiary rocks can easily be distinguished at a distance from the underlying drab Precambrian bedrock by the distinct bright and pale colors of the Tertiary rocks. Proceed to the turnoff denoting Natural Bridge Canyon, then east to the end of the gravel road.

From the parking area at the end of the road it is recommended that you proceed east across the fan and deep channel that cuts it to observe the patches of Tertiary rocks preserved above the Badwater turtleback fault (Fig. 10). The footpath up Natural Bridge canyon permits you to see Quaternary gravel in the nearer canyon walls cut by many faults. Up-canyon, beyond the natural bridge, are exposures of Tertiary rocks in fault contact with the underlying Precambrian rocks, however, access is more difficult than to the remnants of Tertiary rocks preserved along the mountain front, where the exhumed surface of the turtleback is exposed and details of bedding in the Tertiary strata are preserved.

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