# Death Valley bright spot: A midcrustal magma body in the southern Great Basin, California?

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## ABSTRACT

**A previously unrecognized midcrustal magma body may have been detected by COCORP deep seismic reflection profiles in the Death Valley region of the southern Great Basin. High-amplitude, relatively broad-band reflections at 6 s (15 km) are attributed to partially molten material within a subhorizontal intrusion. This "bright spot" extends laterally at least 15 km beneath central Death Valley. A moderately dipping normal fault can be traced from the inferred magma chamber upward to a 690 000-yr-old basaltic cinder cone. The fault zone is inferred to have been a magma conduit during the formation of the cinder cone. Vertical variations in crustal reflection character suggest that the Death Valley magma body may have been emplaced along a zone of decoupling that separates a faulted brittle upper crust from a more ductile and/or intruded lower crust. The Death Valley bright spot is similar to reflections recorded by COCORP in 1977 in the Rio Grande rift, where both geophysical and geodetic evidence support the inference of a tabular magma chamber at 20-km depth.**

## INTRODUCTION

During the winter of 1982–1983, COCORP (Consortium for Continental Reflection Profiling) recorded five deep seismic reflection profiles, totaling more than 250 km in length, in the Death Valley area of the southern Great Basin (Fig. 1). Major tectonic features of this area of late Cenozoic normal and strike-slip faults include the left-lateral Garlock fault, the right-lateral southern Death Valley and Furnace Creek fault zones, and several range-bounding faults. Central Death Valley has been interpreted as a pull-apart basin formed by oblique extension between the en echelon southern Death Valley and northern Death Valley–Furnace Creek strike-slip fault zones (Burchfiel and Stewart, 1966; Wright et al., 1974; Stewart, 1983).

The most striking feature of these seismic profiles is a "bright spot," or locally very strong reflection at about 6-s two-way traveltime (15-km depth) beneath central Death Valley (DVBS, Fig. 2). This event is of much higher amplitude than other deep reflections in the area. The Death Valley bright spot (DVBS) strongly resembles the prominent series of reflections (SBS, Fig. 2) that occur at midcrustal levels on COCORP profiles within the Rio Grande rift near Socorro, New Mexico. Geodetic and geophysical data strongly suggest that the Socorro bright spot (SBS) corresponds to a tabular magma body at 20-km depth (Sanford et al., 1973; Brown et al., 1979). On the basis of the similarity between the Death Valley and the Rio Grande bright spots, the extensional geologic setting, and the evidence for young volcanism, the Death Valley amplitude anomaly is likewise inferred to represent partially molten material at midcrustal depth.

The Socorro geothermal area has been recognized for many years (for a review see Chapin et al., 1978), and the existence, depth, and gross lateral extent of the main magma body have been the focus of numerous geophysical studies (e.g., Sanford et al., 1977). In

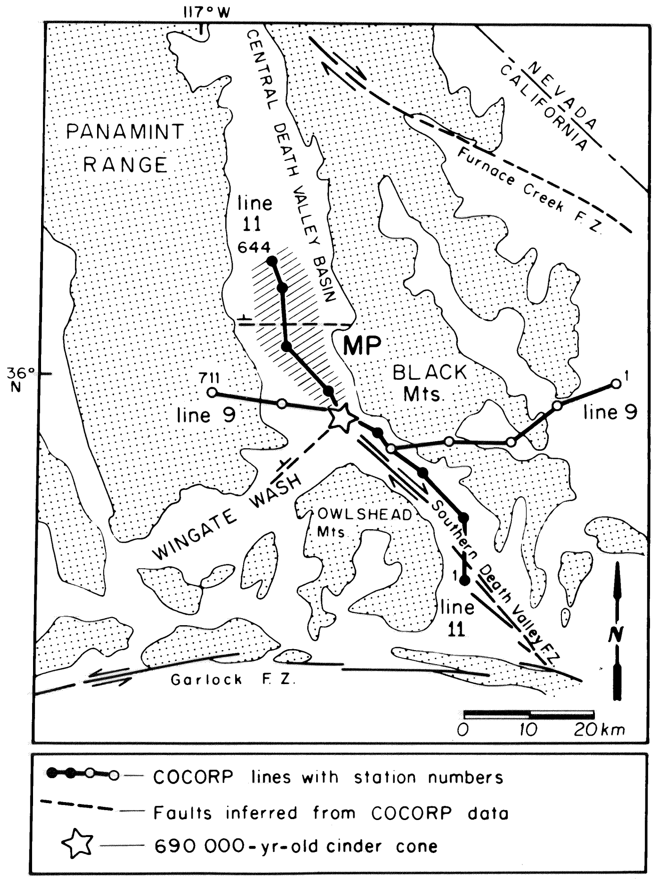

**Figure 1. Location of COCORP Death Valley lines 9 and 11; geology sketched from Wright (1974); stipple indicates ranges; white indicates young basins; diagonal lines indicate approximate extent of Death Valley bright spot; MP is Mormon Point turtleback.**

Death Valley, however, recent volcanism and normal faulting are apparent, but there have been no reports of the existence of a magma chamber at depth prior to this COCORP survey.

## DEATH VALLEY BRIGHT SPOT

The Death Valley amplitude anomaly lies along a subhorizontal zone of reflections at about 6 s (15 km depth). These reflections can be traced at about the same depth across most of the survey lines (Fig. 1) without apparent fault offset (Serpa et al., in prep.). The three-dimensional structure of the upper crust is constrained by intersecting COCORP lines and by surface mapping. Detailed processing and structural analysis of lines 9 and 11 indicate that at least two types of faults accommodate upper crustal extension (Serpa et al., in prep.). Sedimentary and volcanic rocks appear to be collapsing above the crystalline basement along listric normal faults that are restricted to the upper 3–4 km, essentially as described from field observations by Wright and Troxel (1973). Widely spaced, moderately dipping zones of reflections, interpreted as normal faults (such as C and D in Fig. 2), are traceable in the upper crust but do not appear to continue below the subhorizontal reflection zone at 6 s (15 km). Therefore, the subhorizontal zone of reflections may represent a midcrustal zone of decoupling, perhaps separating a brittle upper crust from a more ductile lower crust.

The DVBS stands out on both correlated, single-source field records (Fig. 3) and common midpoint (CMP) stacked data along half of line 11 (Fig. 2) and parts of line 9. On the northern part of line 11, the average amplitude of the DVBS is about 10 dB above the surrounding recorded amplitudes between VP 340 and VP 640 (Fig. 2). Over a lateral distance of 30 km, the DVBS exhibits an abnormally high amplitude when compared with other deep seismic reflection data. On unstacked traces, the DVBS appears as a complex, multicyclic event (Fig. 3).

Unusually strong reflections can be generated in several ways; these include (1) focusing of the seismic energy by structural curvature or velocity lenses, (2) constructive interference (tuning), or (3) a juxtaposition of materials with a large acoustic impedance contrast (O'Doherty and Anstey, 1971). There is no evidence of reflector curvature or any velocity anomalies that might give rise to the DVBS. Constructive interference, or tuning, within a thin-layered sequence is difficult to rule out. However, such tuning should be frequency dependent, causing differential amplification of different spectral components. The spectral content of the DVBS is relatively broad band (Fig. 4), which argues against a simple tuning mechanism. It is also questionable whether strong tuning conditions could be maintained over a distance of 30 km in such a complex region. Though some of the lateral variability in the high-amplitude reflections may be due to interference effects, it seems unlikely that tuning is dominant. Therefore, the most likely cause of the DVBS is a strong impedance contrast at depth.

Simple comparison of seismic amplitude ver-

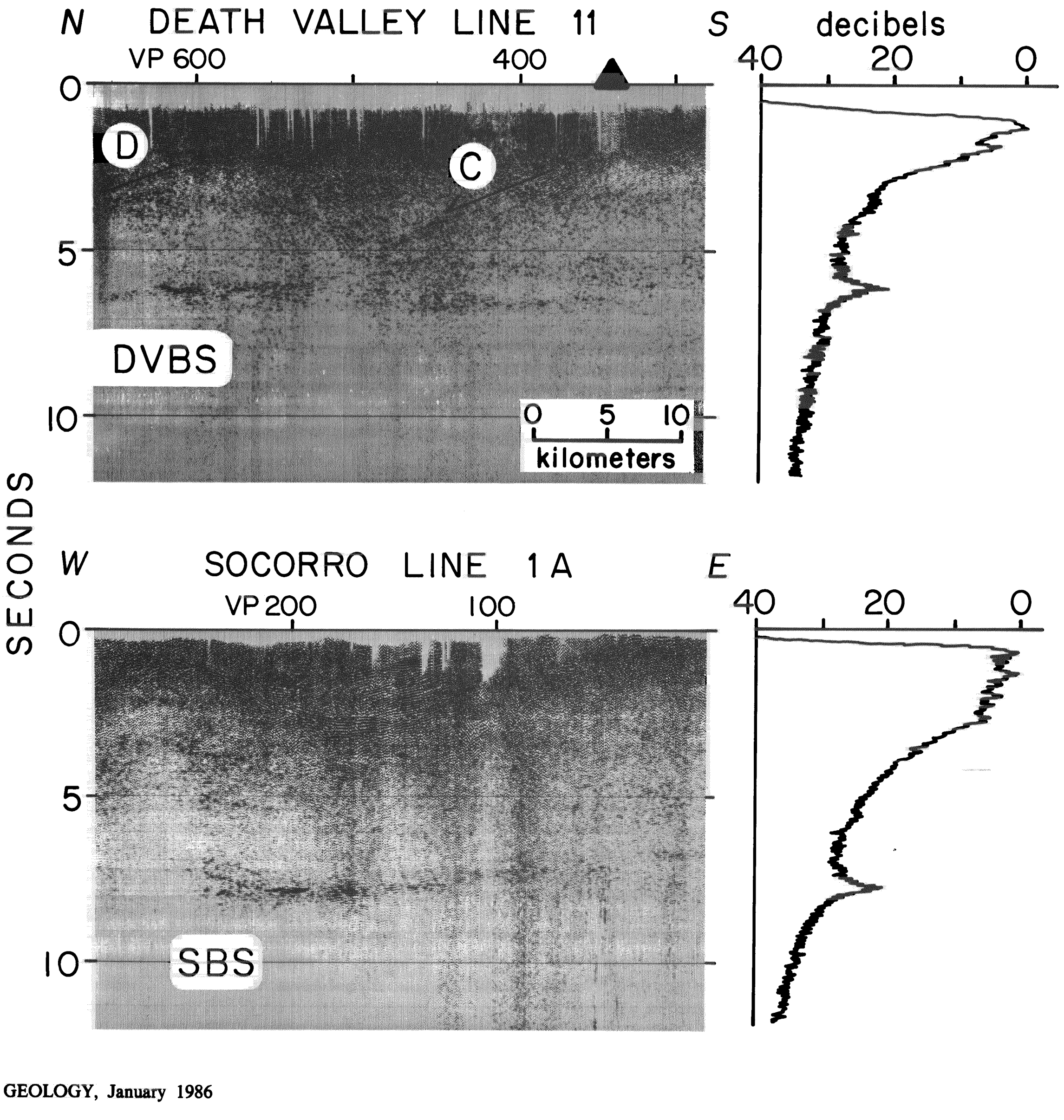

Figure 2. True amplitude display of Death Valley line 11 (top), compared with Socorro line 1A (bottom); plotted to right are average amplitude decay curves along these profiles, illustrating strength of "bright spots" labeled DVBS and SBS on seismic sections; black triangle marks surface location of 690 000-yr-old basaltic cinder cone discussed in text; no vertical exaggeration at velocity of 4 km/s.

sus traveltime curves, such as shown in Figure 2, indicates comparable reflectivity for the DVBS and the SBS. Alternatively, the reflection coefficient corresponding to the DVBS can be directly estimated from unstacked data, using the reflection off the top of the basement as a reference. If the DVBS corresponds to a single highly reflective layer, as suggested by the lack of variation of the relative amplitude of the DVBS with frequency, a reflectivity between 20% and 45% is found. Reflection coefficients from a single interface of rocks thought to exist in the crust do not exceed 10%, and are most likely well below 8% (Smithson et al., 1977). However, fluids can easily provide the large reflection contrast that could explain the unusually high reflection amplitudes (Ewing et al., 1957, p. 74–121). On the basis of strong amplitudes, the similarity between the Death Valley and the Rio Grande rift bright spots, and the evidence for young volcanism in Death Valley (690 000 yr; R. Drake, 1985, oral commun.; Wright and Troxel, 1984), the DVBS is reasonably suggested to represent partially molten material at midcrustal depth.

## MAGMA PLUMBING

Equally remarkable on line 11 is a moderately north-dipping band of reflections and/or diffractions that extends from the south end of the DVBS to the surface (event C, Fig. 2). This band is interpreted as a normal fault zone, the Wingate Wash fault zone of Serpa et al. (in prep.) at the southern end of the central Death Valley basin (Fig. 1). Geometrically, it connects the inferred magma body with a 690 000-yr-old basaltic cinder cone (Figs. 1, 2) at the surface (R. Drake, 1985, oral commun.). This suggests that the DVBS may have been a magma source for this recent volcanic eruption, the moderately dipping (25°–30°) Wingate Wash fault zone acting as a feeder (Fig. 2). This interpretation is supported by the observation that in the southern Death Valley region some of the exposed basaltic dikes have been intruded along normal faults of late Cenozoic age (Wright and Troxel, 1984).

The inferred fault zone appears as a relatively high-amplitude event on the stacked seismic section (C, Fig. 2) and on field records. This observation suggests that the fault zone may contain material distinctively different from the country rocks, although deep crustal fault zones alone have been found quite reflective, possibly due to fine layering and seismic anisotropy (Jones and Nur, 1984). If dikes were emplaced along the fault zone at the time of the last volcanic event (i.e., 690 000 yr ago), they should be solidified now (Carslaw and Jaeger, 1959, p. 282–296). Such dikes may provide the impedance contrast observed. Hydrothermal alteration products developed along the fault zone may also explain its relatively high reflectivity.

## COMPARISON WITH SOCORRO BRIGHT SPOT

The interpretation of the DVBS is strongly influenced by previous COCORP results from the Rio Grande rift in the southern Albuquerque-Belen basin, New Mexico (Brown et al., 1980). Prominent seismic bright spots at midcrustal depths dominate COCORP profiles from Socorro and from Death Valley (Fig. 2). True amplitude displays of Death Valley line 11 and Socorro line 1A (Fig. 2) are characterized by reflections from inferred extensional structures in the uppermost crust underlain by a somewhat less reflective zone and by a midcrustal (about 18 km deep) subhorizontal zone of unusually strong reflections. Some events are evident in the lower crust on gain balanced (AGC) sections, and reflections attributed to the crust-mantle transition can be seen on both profiles (Brown et al., 1980; Serpa et al., in prep.).

Socorro line 1A is an east-west transect across the southern Albuquerque basin, roughly perpendicular to regional structural trends. Though Death Valley line 11 is parallel to the average trend of the basin, like Socorro line 1A it extends across the strike of major normal faults (Figs. 1C, 1D; 2) that are inferred to control upper crustal extension (Serpa et al., in prep.).

The Socorro bright spot (SBS) is a prominent band of reflections occurring beneath VPs 40–220 at two-way traveltimes of 7 to 8 s (about 20 km). The apparent relief on the SBS appears to be a velocity pulldown effect due to the varying thickness of the overlying graben fill. To the east, the reflections end in diffractions on line 1 (Brown et al., 1980). To the west, beneath VP 220, the SBS splits and reflections become disrupted and diffuse. Although virtually continuous, the reflections change in amplitude, phase, and frequency content across the profile. The amplitude decay curve shown in Figure 2 illustrates the strength

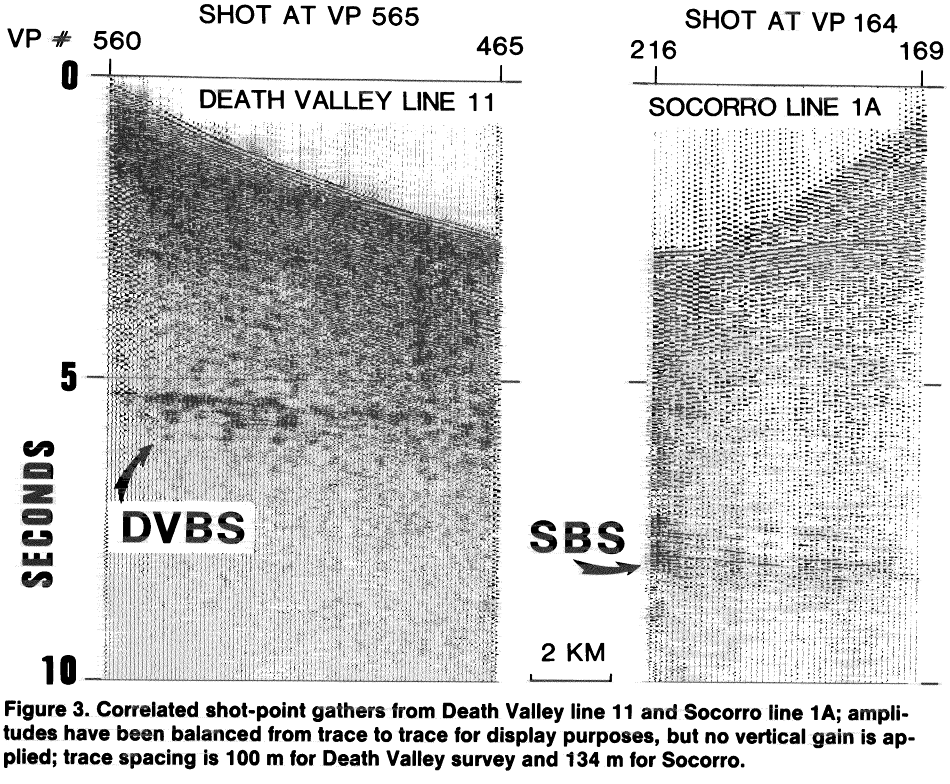

**Figure 3. Correlated shot-point gathers from Death Valley line 11 and Socorro line 1A; amplitudes have been balanced from trace to trace for display purposes, but no vertical gain is applied; trace spacing is 100 m for Death Valley survey and 134 m for Socorro.**

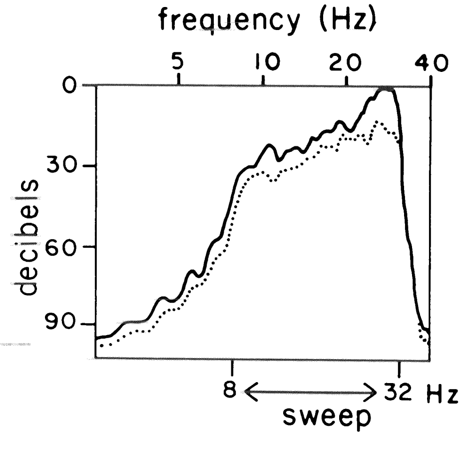

**Figure 4. Average amplitude spectrum, calculated from Death Valley unstacked traces shown in Figure 3; near traces (500–1800 m nominal offset) were not included because they are dominated by low-frequency source-generated noise; time window used is 1 s long, centered on DVBS for solid curve, and immediately above DVBS for dotted curve.**

of the SBS. Analysis of the data by several spectral ratio methods indicates a reflectivity possibly as high as 30% or 40% (Brocher, 1981). Brocher's study of the amplitude and frequency content of the COCORP reflections is consistent with their being caused by partially molten rocks at 20-km depth, perhaps a zone of interlayered magma pods.

Interpretation of the SBS as a magma layer (or layers) is consistent with several lines of evidence. The depth of the SBS (19–20 km) coincides with that of an unusually strong shear-wave reflector previously detected in microearthquake studies in the Socorro area (Sanford and Long, 1965; Sanford et al., 1973). Magma inflation in the Socorro area is supported by earthquake swarms (Sanford et al., 1977) and historic crustal deformation (Reilinger and Oliver, 1976; Reilinger et al., 1980; Larsen et al., 1986). These data together with the tectonic setting have led to the interpretation that a thin magma body underlies at least 1700 km$^2$ of the southern Albuquerque basin (Rinehart et al., 1979; Sanford and Einarsson, 1982).

The seismicity, both historic and instrumental, in the Albuquerque basin does not have a counterpart in Death Valley. Though this discrepancy could be due partly to differences in population and instrument deployment, it may also be that the Death Valley body is currently inactive with reference to earthquake generation. Geodetic measurements to assess possible crustal motion are not available for Death Valley.

## SUMMARY

1. Unusually strong reflections from mid-crustal depth are evident on new COCORP profiles from the Death Valley region of the southern Great Basin, a region of active extension and recent (690 000-yr) volcanism. This amplitude anomaly, the Death Valley bright spot, is remarkably similar to reflections from a tabular magma body observed on earlier COCORP surveys from the Rio Grande rift near Socorro. Thus, the Death Valley bright spot suggests that a previously undetected magma body may underlie central Death Valley.

2. The Death Valley bright spot may lie along an inferred zone of regional decoupling. The COCORP data in this area are compatible with models of crustal extension where brittle upper crust is underlain by lower and middle crust characterized by laminar flow and intrusion (e.g., Wright and Troxel, 1973; Eaton, 1982).

3. A dipping reflector can be traced between this inferred magma body and a 690 000-yr-old basaltic cinder cone. Thus, the Death Valley profiles may image, perhaps for the first time, crustal-scale plumbing associated with a deep magma chamber.

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*Reviewer's comment*

Interesting and provocative. May spark some deep crustal research in the Death Valley region. The magma hypothesis is less clear-cut than the authors indicate.

James McClain

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