

COCORP Arizona transect: Strong crustal reflections and offset Moho beneath the transition zone

E. C. Hauser, J. Gephart, T. Latham

INSTOC (Institute for the Study of the Continents), Snee Hall, Cornell University, Ithaca, New York 14853

J. Oliver, S. Kaufman, L. Brown

INSTOC and Department of Geological Sciences, Snee Hall, Cornell University, Ithaca, New York 14853

I. Lucchitta

U.S. Geological Survey, 2255 North Gemini, Flagstaff, Arizona 86001

ABSTRACT

The Consortium for Continental Reflection Profiling (COCORP) transect across the southwest margin of the Colorado Plateau in Arizona reveals prominent subhorizontal zones of reflections, here termed the Bagdad reflection sequence (BRS), which dominate the upper and middle crust in the transition zone (TZ) between the Colorado Plateau and the Basin and Range province. A Cenozoic origin for the BRS is considered most likely; it may represent fragmented or sheared zones related to detachment faulting or a series of intrusions, possibly emplaced along preexisting zones of weakness. Moho reflections observed beneath the TZ and the Basin and Range province contrast with the nonreflective Moho beneath the Colorado Plateau, suggesting that extension and its associated igneous processes probably played a key role in the development of reflectors at the Moho. The Moho and a prominent midcrustal reflector are offset by about 3 km in a normal sense in at least one place; this is the best example of offset Moho yet found by COCORP and contrasts sharply with COCORP observations of a smooth Moho elsewhere. This offset is probably a late tectonic expression of crustal extension and thinning across the TZ.

INTRODUCTION

During 1986, COCORP collected 550 km of deep seismic reflection data to explore the crustal structure along a transect in Arizona (Fig. 1). The transect extends from the Colorado Plateau and across the broad transition zone into the Basin and Range province, a region especially important in the ongoing debate over the nature of continental extension. Oligocene to late Miocene extensional tectonism resulted in the formation and exposure of the metamorphic core complexes, detachment faults, and their imbricately normal-faulted upper-plate rocks in the southern Basin and Range province to the southwest; but widely spaced, fault-bounded basins characterize the broad transition from the southern Basin and Range province to the unextended Colorado Plateau (see Frost and Martin, 1982; Fig. 1). These structures and relations have spawned various models of extension (Wernicke, 1981; Lucchitta and Suneson, 1981; Hamilton, 1982). Significant differences exist among the models largely because subsurface information has been lacking.

The deep reflection data of this transect are of unusually high quality. Prominent reflectors can be traced across the TZ in the upper and middle crust, and Moho reflections are observed along the transect beneath the southern Basin and Range province and the western part of the TZ. The data also reveal the first clearly offset Moho in COCORP data.

BAGDAD REFLECTION SEQUENCE

The prominent zones of subhorizontal reflections that can be traced in the upper and middle crust across the TZ are here termed the Bagdad reflection sequence (BRS; Figs. 2 and 3) after the town through which line 3 passes (Figs. 1 and 3). They dominate the upper crust in the TZ to a depth of about 15–18 km (5–6-s two-way traveltime). They are generally continuous and subparallel but locally lenticular (A in Fig. 3), and they appear generally synformal as indicated by the opposing dips on lines 1 and 3 (Fig. 3). The synformal character of the BRS appears almost to ramp or drape over the lower crustal offset (discussed further below). Zones of reflections similar to the BRS and probably correlative are observed nearby (Fig. 1) on 6-s industry data (Galvan and Frost, 1985).

The BRS is traced in the upper crust beneath the TZ (Figs. 1 and 2) from beneath the Hualapai Mountains near the surface exposure of the gently east-dipping Buckskin-Rawhide detachment fault to beneath Chino Valley near the margin of the Colorado Plateau. Several Tertiary detachment fault zones are exposed in the Buckskin Mountains (Davis et al., 1980) and the Mohave Mountains (Howard et al., 1982); however, no detachment faults are exposed within the TZ where the exposed Proterozoic basement consists of northeast-trending lithologic belts with steeply dipping, northeast-trending foliation and lithologic layering (Karl-

strom and Conway, 1986; Condie, 1982). The observed subhorizontal pattern and distribution of the BRS beneath the TZ suggest that these reflections image structures related to Tertiary detachment faulting. These reflectors may resemble in nature and origin the zone of mylonitization, brecciation, and mineral alteration that commonly is developed along the detachment faults of the region (e.g., Coney, 1980; Reynolds and Rehrig, 1980). Limited Tertiary extension is indicated by the widely spaced half grabens across the TZ, but the anomalous width of the TZ in Arizona, as compared to this transition in Utah, may result from the development of such a subhorizontal detachment system at depth, indicated by the BRS.

The BRS reflections have anomalously high amplitudes and are prominent on individual source-point gathers without gain scaling. Among the possible explanations for such high-amplitude reflections (the focus of continuing study) are altered or fluid-filled fragmented zones of anomalously negative seismic impedance (low velocity and density). Fluids and fluid pressure have an increasingly appreciated role in the development and evolution of low-angle detachments, as well as in mineralization along detachment faults by ascending metamorphic fluids (Bartley and Glazner, 1985; Spencer and Welty, 1986; Kerrich and Rehrig, 1987; Reynolds and Lister, 1987). Alternatively, these prominent reflections may indicate layers of anomalously positive seismic impedance (high velocity and density)—e.g., mafic intrusions in a more granitic basement. The prominent reflectors of the BRS are observed on lines 1, 3, and 5, around the south margin of the Tertiary volcanic center in the Aquarius and Mohon mountains (Figs. 1 and 2), a spatial correlation which may suggest that the BRS, in part, represents mafic intrusions (middle to late Miocene). The subhorizontal pattern of such intrusions may have been influenced by zones of weakness beneath the TZ, inherited from Tertiary detachment faulting.

Late Proterozoic diabase dikes and sills that postdate the complex deformation of the Proterozoic basement are locally important in southern Arizona (Shride, 1967) and are locally

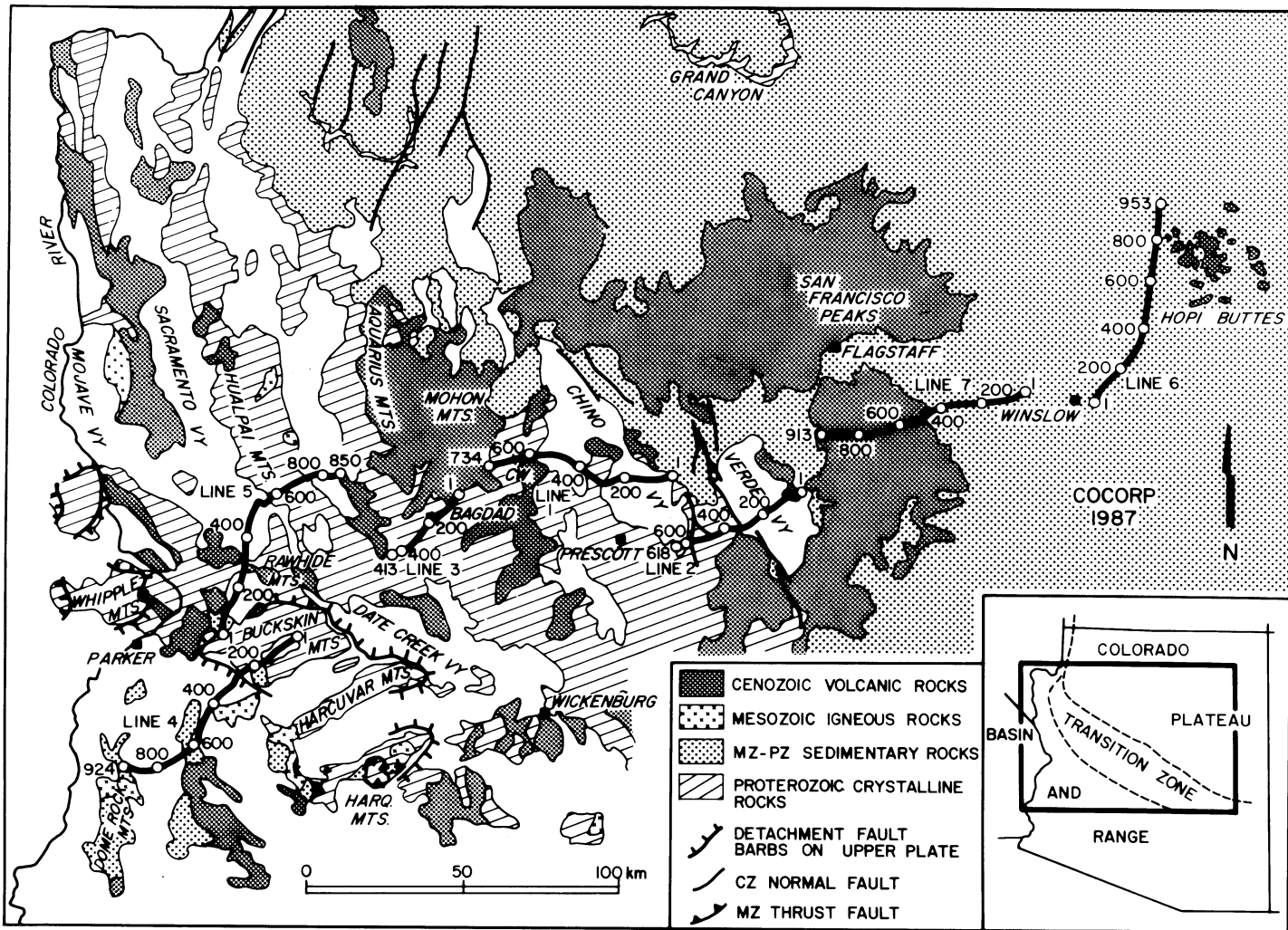


Figure 1. Generalized geologic map of west-central Arizona. Heavy, numbered lines are COCORP lines. Harq. Mts. = Harquahala Mountains. MZ-PZ = Mesozoic-Paleozoic. CZ = Cenozoic. Mylonitic rocks of Whipple-Buckskin-Harcuvar core complexes include Mesozoic rocks not differentiated here.

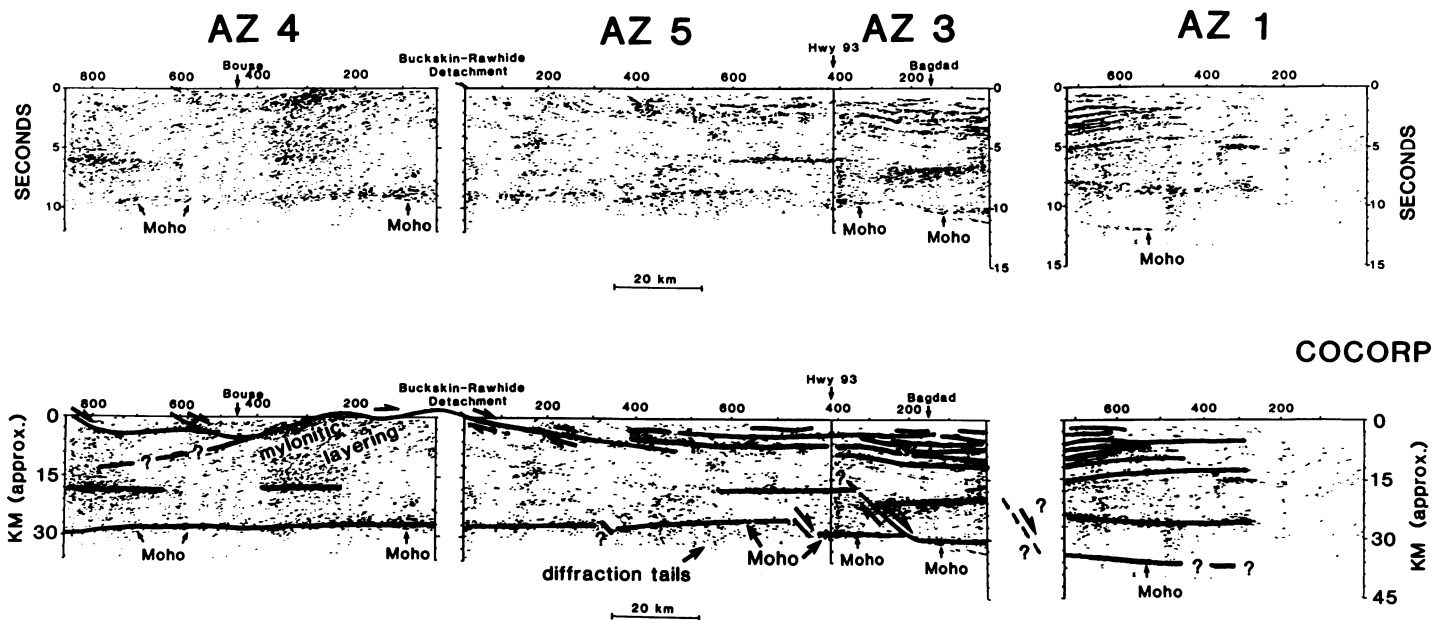


Figure 2. Annotated and unannotated line drawing of COCORP Arizona transect abstracted from stacked sections. Scale is 1:1 at 5 km/s.

exposed along the transect in the Hualapai and Mohave mountains (Nakata, 1982; Stensrud and More, 1980; Howard et al., 1982). Such diabasic intrusions commonly occur as thick, subhorizontal sheets and might be an important candidate for some of these prominent subhorizontal reflectors. The BRS, though, is apparently restricted to the present TZ and is not observed to continue in the Colorado Plateau crust to the east. The Late Proterozoic dikes might be expected to have a distribution independent of the TZ, which is a Tertiary-age feature. Unless the lateral distribution of the dikes and the TZ is a coincidence, the BRS probably does not largely represent Late Proterozoic dikes.

Thrust faults involving Phanerozoic platformal strata and Proterozoic basement have been described southwest of the TZ (e.g., Reynolds and Spencer, 1985). The BRS comprises a sequence of reflectors as thick as 15–18 km (5–6-s two-way traveltime) and seems unlikely to represent a sequence of thrust faults or imbricated Phanerozoic strata and basement emplaced in the upper and middle crust at the margin of the present Colorado Plateau.

Moho Reflections and Moho Offset

A subhorizontal zone of reflections at Moho depths can be traced on the profile beneath the Basin and Range and western TZ (Figs. 1 and 2). The Moho reflections are generally at a two-way traveltime of 9–10 s (27–30 km) in the Basin and Range province but reach 12 s (~36 km) where last observed, dipping gently east-

ward beneath the central TZ (M4 in Fig. 3). A remarkable 1-s (more than 3 km) steplike offset of both the Moho and a midcrustal reflector occurs on line 3 (Fig. 3) and is the first clear offset of Moho on COCORP data. The positions of termination of these midcrustal and Moho reflections suggest offset in a normal sense along a moderately east-dipping zone, presumably a ductile shear zone in the lower crust. A zone of reflections (M3 in Fig. 3) at 11 s near the east end of line 3 has a gentle northeast apparent dip and is the subject of continuing migration and modeling studies to test whether it could represent a dipping segment of the Moho at the offset or perhaps a fault-plane reflection from within the upper mantle. Similar but less clear Moho offsets may occur elsewhere beneath the TZ along this transect (Fig. 2). For example, Moho reflections occur at 10–10.5 s (~30–32 km) on the northeast end of line 3 (M2 in Fig. 3) and at 12 s (~36 km) beneath the south end of line 1 (M4 in Fig. 3); near the east end of line 5 (Fig. 2), Moho reflections may step down from 8.5 s (~26 km) near VP 700 to 9–10 s (~27–30 km) at the northeast end of that line.

The general variation of crustal thickness shown by the Moho reflections on the COCORP data generally agrees with that indicated by the very limited refraction data of southwestern Arizona (Warren, 1969; Sinno et al., 1981). The Moho offsets on the COCORP data, however, indicate that the crustal thickness changes in part in a steplike manner. Moho steps in this region are not generally recognized from the re-

fraction experiments, although a Moho offset of similar magnitude (4 km) has been suggested near the margin of the Mogollon Plateau in central and eastern Arizona from analysis of delays of Pn arrivals (Gish et al., 1981; Warren, 1969).

The Proterozoic basement of the Colorado Plateau, beneath the flat-lying Phanerozoic platform cover, is characterized by both dipping and subhorizontal discontinuous reflections and diffractions and a Moho inferred from the termination of crustal reflections at depth. This contrast with well-developed Moho reflections observed in the region of thinned and extended crust to the southwest supports the contention that processes of extension and related magmatism play an important role in the evolution of a reflection Moho (Klemperer et al., 1986; Potter et al., 1986; Allmendinger et al., 1987). The Moho beneath the Buckskin-Rawhide core complex is remarkably flat at about 9–9.5 s (~27–29 km), despite the uplift and arched exposure of the overlying core complex (Fig. 2). This suggests that the flat reflection Moho in its present form is a young feature (Tertiary) perhaps evolving through dynamic processes at the base of the crust such as ductile deformation, partial melting, and magmatism. The offset of this reflection Moho, as described above, also probably developed during Tertiary extension but probably represents a younger and perhaps waning phase of Cenozoic extension and crustal thinning.

The present data cannot clearly reveal whether the BRS is offset like the midcrustal and Moho reflections (Fig. 3) because the zone of

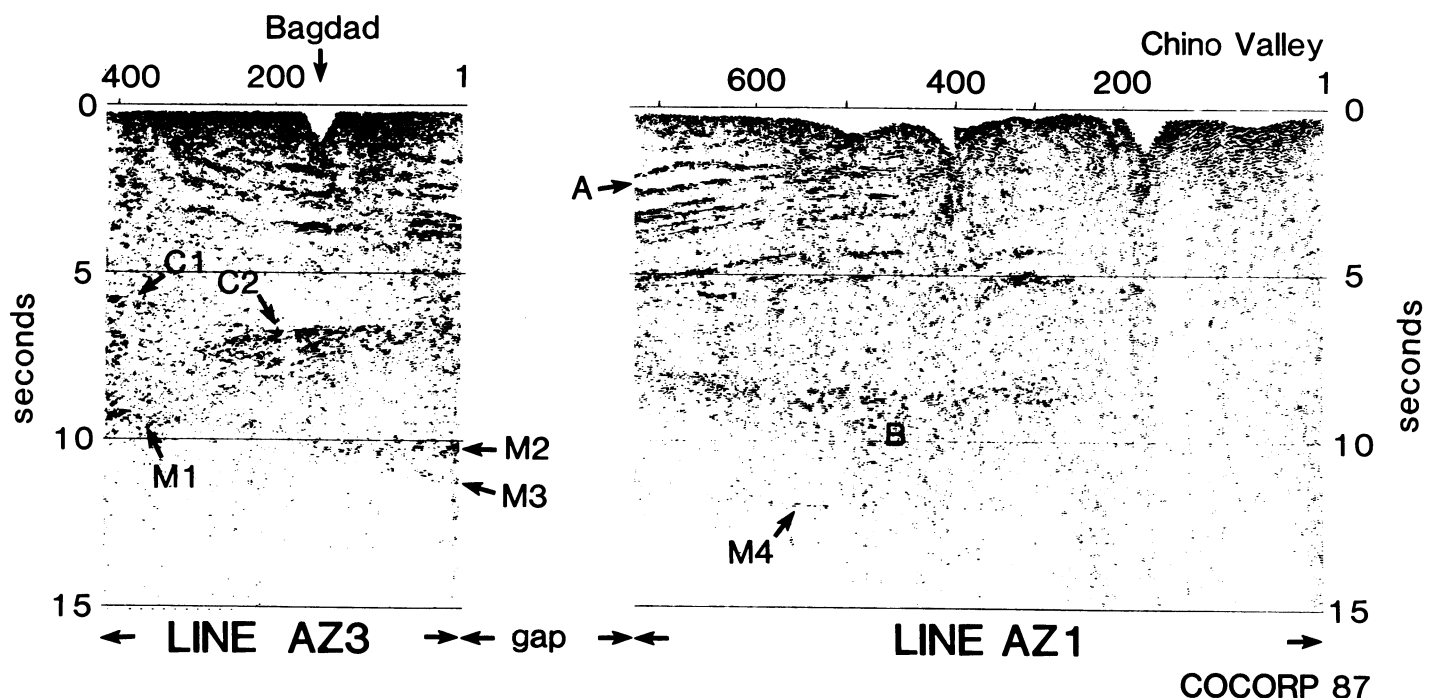


Figure 3. Stacked sections of COCORP Arizona lines 1 and 3 in central transition zone. Display is 1:1 at velocity of 6 km/s. Coherency filtered after stack for photographic enhancement.

offset projects to the surface west of the end of line 3, and line 5, which shows the continuation of the BRS, is farther to the north (Fig. 1). However, Tertiary faults of significant displacement are generally absent at the surface southwest of line 3 except at the margin of the Buckskin-Rawhide core complex north and northwest of Date Creek Valley (Fig. 1; Otton, 1982). This suggests that the 3-km offset observed on line 3 is probably accommodated by faulting at the margin of the core complex.

Core Complex Reflections

Gently west-dipping, discontinuous reflections characterize the upper and middle crust of the core complex (Fig. 2) and probably represent the distributively deformed, mylonitic rocks exposed in the lower plate (Davis et al., 1980). The character of these dipping reflections resembles the character of subhorizontal reflections of the lower crust along this transect in the Basin and Range province and the western TZ (Fig. 2). This may suggest that the discontinuous and pervasive, but subhorizontal, reflection pattern observed in the middle and lower crust here and elsewhere in deep-reflection data sets in extended regions represents, in part, a deformational and metamorphic fabric like that uplifted and exposed in these core complexes. Such a suggestion further implies that the now subhorizontal middle- and lower-crustal reflection fabric and Moho beneath the core complex may be younger and may largely postdate development of the fabric uplifted and exposed in the core complex.

East-dipping detachments, such as the Plo-mosa detachment, west of the core complex do not appear to crosscut or disrupt the west-dipping reflection character beneath the core complex; this suggests that they may merge with the Buckskin-Rawhide detachment at depth (Fig. 2). A continuation of the Buckskin-Rawhide detachment westward to depth (Fig. 2) is not ruled out by the data.

SUMMARY

The COCORP deep-reflection transect in Arizona traces an extensive set of subhorizontal reflectors that are likely related to Cenozoic detachment faulting across the TZ between the Colorado Plateau and the southern Basin and Range province. A flat reflection Moho along the southwest part of the transect suggests that the Moho in its present form is a young and probably dynamic feature. Local offset of the Moho reflectors is the first clear example of offset Moho on COCORP data and probably represents the youngest phase of extension and crustal thinning beneath the TZ.

The tectonic interpretation of the transect and the detailed nature of the bright reflections are the subjects of continuing study (Hauser et al., in prep.).

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ACKNOWLEDGMENTS

Supported by National Science Foundation Grants EAR 84-18157 and EAR 86-09992. The Arizona transect was proposed to COCORP by I. Lucchitta and J. Sass. J. Spencer provided summary geologic maps along part of the southwest end of the transect. P. Blacet of Cyprus-Bagdad helped locate a route across the rough terrain southwest of Bagdad. A. Barnes and J. Lundy assisted in processing the data. Institute for the Study of the Continents Contribution no. 80.

Manuscript received April 10, 1987
 Revised manuscript received August 10, 1987
 Manuscript accepted August 28, 1987