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COCORP DEEP SEISMIC REFLECTION PROFILING IN THE NORTHERN SIERRA NEVADA, CALIFORNIA

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Abstract. A COCORP seismic reflection profile across the northern Sierra Nevada in California shows several east-dipping zones of discontinuous reflections. Correlation with surface geology suggests that these zones probably originate from faults of the Foothills fault system. In particular, the Melones fault, which coincides with the "Mother Lode" of the central and southern Sierra foothills, appears to be marked by prominent reflections in the midcrust. Migration of the COCORP data suggests that these faults are approximately planar, have moderately steep east dips (35°-47°), and penetrate at least to midcrustal depths (>20 km). At present it is unclear whether these faults are primary Nevadan thrusts, "late" Nevadan backthrusts (retrocharriage), or younger Cretaceous or Cenozoic faults, also known to occur in the region. Other more problematic features imaged on the profile include a prominent west-dipping zone of reflections in the midcrust beneath the Eastern belt, and subhorizontal reflections at 22- to 26-km depth beneath the Tahoe graben. The former might represent a west-dipping thrust analogous to the Taylorsville thrust cropping out to the north of the survey route. The latter might represent the base of the Sierra Nevada batholith, the westward extension of any one of several thrust systems cropping out in Nevada, a low-angle extensional detachment, or Moho.

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INTRODUCTION

During the summer of 1982 the Consortium for Continental Reflection Profiling (COCORP) completed a deep seismic-reflection profile across the northern Sierra Nevada in California (line 7). This profile represents the first sizable set of deep seismic-reflection data collected within the complexly deformed and variably metamorphosed accreted terranes that comprise much of the interior portions of the Cordillera. The region traversed by the COCORP profile lies north of the main mass of the Sierra Nevada batholith and is underlain by several distinct, generally north-trending, tectonostratigraphic terranes (Figure 1). These include [Speed and Moores, 1980]: the Eastern belt, composed of deformed lower- to middle-Paleozoic eugeoclinal metasedimentary and metavolcanic rocks that are generally steeply dipping at the surface and overlain unconformably by Devonian to Jurassic volcanic rocks [Schweickert, 1981; Harwood, 1983]; the Central belt, composed of complexly deformed upper Paleozoic-lower Mesozoic eugeoclinal sedimentary and volcanic rocks and structurally inter-

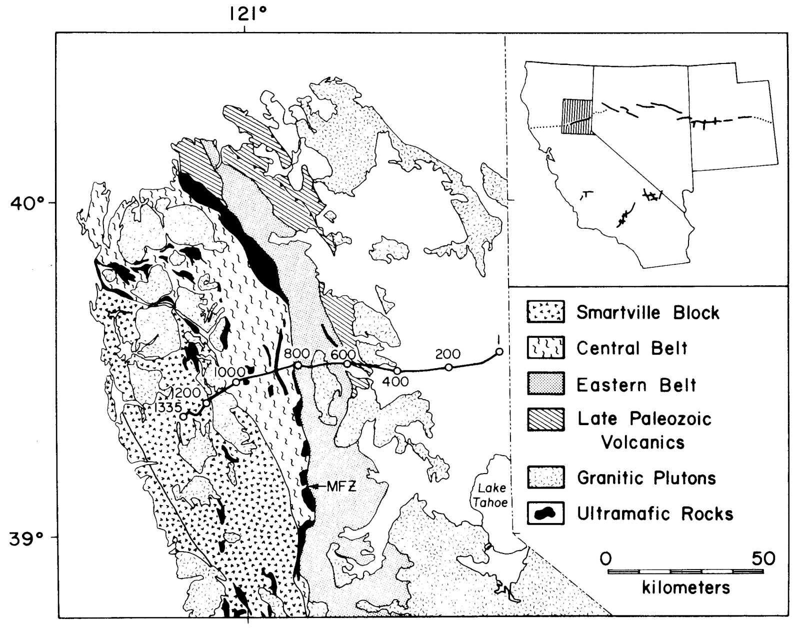

Fig. 1. Generalized geologic map of the northern Sierra showing location of COCORP profile and its relation to major geologic terranes in the region. MFZ - Melones fault zone. Inset map shows location of COCORP profiles in the western U.S.

leaved ophiolite fragments [Schweickert and Cowan, 1975; Hietanen, 1973, 1981; Moores and Day, 1984; Day et al., 1985]; and the Smartville block, composed of weakly metamorphosed Jurassic volcanic and volcaniclastic strata overlying an inferred ophiolite complex [Menzies et al., 1975; Xenophontos and Bond, 1978; Day et al., 1985]. As with much of the Cordillera, the assembly of these several terranes is generally thought to have resulted from complex plate interactions that occurred along the western margin of North America, beginning perhaps as early as Devonian time and continuing through the Mesozoic [e.g., Coney et al., 1980]. There is, however, considerable debate concerning the paleogeographic origin of the individual terranes and the plate boundary configurations that led to their subsequent amalgamation (contrast Schweickert and Cowan [1975] and Schweickert [1981] with Saleeby [1981], Burchfiel and Davis [1981] and Moores and Day [1984]).

Central to this debate is the question of the geometry and age of the faults comprising the Foothills fault system [Clark, 1960]. These generally north-trending faults occur within individual geologic terranes in the Sierra and also delineate their boundaries. Thus they are primary structural features of the region. These faults are also of considerable economic interest in that the famous lode gold deposits of the Sierra are preferentially developed within or adjacent to them ["Mother Lode" sensu loto; Clark, 1970]. Most of these faults are Nevadan-age (late Jurassic), ductile, high-strain zones that were reactivated as brittle structures during both Cretaceous and Cenozoic times [Schweickert et al., 1984]. Several, however, are also known to have a pre-Nevadan history (e.g., basal thrust of the Feather River Peridotite, Calaveras/Shoo Fly Thrust [Speed and Moores, 1980; Schweickert, 1981]). Although these faults are prominent features of the Sierra, their subsurface attitude and mode of origin have remained controversial. The Nevadan structures have variously been regarded as a system of transcurrent faults [Clark, 1960; Saleeby, 1981, 1982], a system of west-vergent thrusts [Bateman and Clark, 1974], and most recently, as a system of east-vergent thrusts that were subsequently backthrust ("retrocharriaged") toward the west [Moores and Day, 1984; Day et al., 1985].

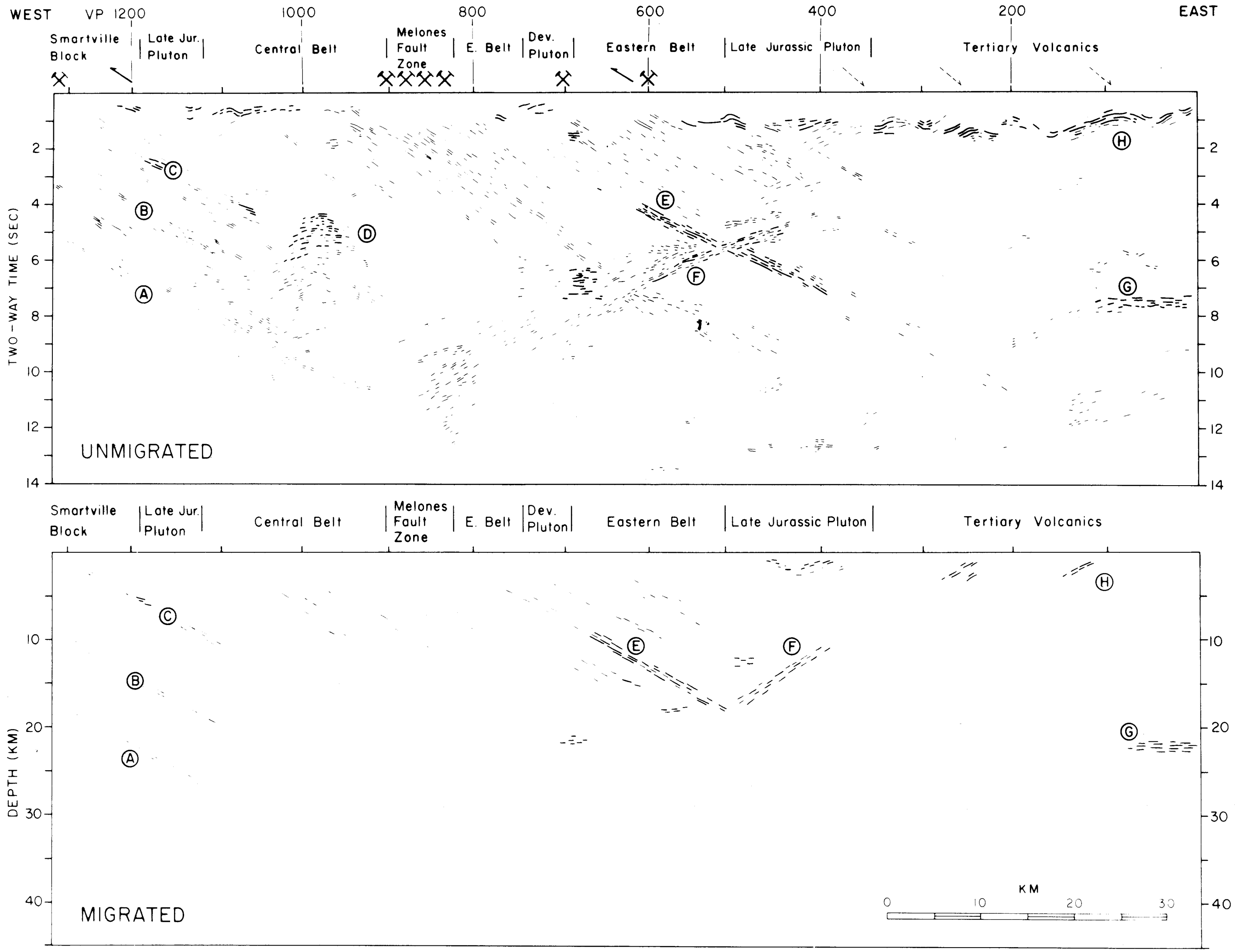

Fig. 2. (top) Line drawing of the upper 14 s of the COCORP Sierra profile (unmigrated). The figure is approximately 1:1 assuming an average crustal velocity of 6 km/s. The line weights illustrate schematically the relative prominence of reflections as seen on the seismic section. (Bottom) Line drawing of COCORP Sierra profile after migration and depth conversion. Figure is 1:1 (see text for discussion).

The COCORP profile crosses several of these faults, perhaps the most prominent being the Melones fault, which, in the region traversed by the survey, separates the Eastern and Central belts.

The COCORP profile also crosses several isolated granitoid plutonic bodies. These include the upper Devonian Bowman Lake batholith [409 m.y. U/Pb age, Girty et al., 1984], an upper Jurassic granodiorite body abutting the east flank of the Smartville Block (150 m.y. hornblende K/Ar age), and a second upper Jurassic granodiorite body cropping out just east of the outcrop area of the Eastern belt (154 m.y. hornblende K/Ar age) [Evernden and Kistler, 1970]. (The K/Ar ages were recalculated using revised decay constants of Steiger and Jager [1978]). Field mapping indicates that both late Jurassic age plutons cut Nevadan structure in the surrounding country rock [Schweickert et al., 1984].

COCORP DATA

In general there are fewer reflections visible on the COCORP Sierra profile than occur on most other COCORP profiles. This may be due in part to data acquisition problems (e.g., excessive traffic noise, sinuous line geometry, difficult static corrections), and in part to the difficulty of imaging complex and/or steeply dipping geologic structure. However, despite the general sparcity of reflections, there are several features visible on the profile that we believe have implications for crustal structure in the Sierra.

Figure 2 (top) is a line drawing of the upper 14 s of the unmigrated Sierra profile. This is a nominal 48-fold Vibroseis (trademark Conoco Inc.), unmigrated, CDP-stacked section, with a correlated record length of 16 seconds. Owing to lack of access in the mountainous terrain of the Sierra, it was not possible to provide crossline control for the survey. Hence there is some inherent ambiguity in the attitude of features imaged on the profile. However, the survey runs approximately perpendicular to regional strike, and therefore, with some specific exceptions, features visible on the profile are assumed to lie within the plane of the section. Figure 2 (bottom) is a line drawing of the same profile after migration and depth conversion. Interval velocities input to the migration and depth conversion routines were calculated from Prodehl's [1979] refraction-velocity structure of the northern Sierra. Owing to a lack of horizontal reflectors, the detailed velocity information necessary for a rigorous migration could not be derived directly from the COCORP reflection data. In general, refraction lines along and across the Sierra indicate that velocities of 6 km/s or more are reached within the upper several kilometers of the crust, and that velocities greater than 7 km/s are not reached until depths of roughly 40 km or more [Prodehl, 1979]. Hence velocities ranging from 6 to 7 km/s should bracket the actual crustal velocities for all but the upper 1 or 2 s of data illustrated in Figure 2. Minimum and maximum "true" dip estimates, given in the following section, were determined from constant velocity migrations at these two respective velocities.

East-Dipping Reflections

Perhaps the most notable features visible on the seismic section are several east-dipping zones of discontinuous reflections, traceable to two-way times in excess of 7 s (>20 km depth) (A,B,C,E, Figure 2). On the unmigrated section these zones appear to be approximately planar and have apparent dips ranging from 26° to 32°. The line weights on the drawing illustrate schematically the relative amplitudes of these events as they appear on the stacked section. The dipping events marked E on Figure 2, occurring beneath VPs 400 to 600, are the most prominent events visible on the Sierra profile (Figure 3, top). The dipping events marked A at the west end of the profile are also clearly visible, though considerably less dramatic than those just mentioned. The other east-dipping horizons (B,C) are quite subtle features of the stacked section that do not stand out dramatically above the ambient noise level. Reference to individual VP files, however, indicates that these reflections can be discerned in the raw data, in some cases more clearly than on the stacked section (Figure 4). The data on the western third of the profile were recorded under relatively noisy conditions. This, along with the difficult statics problem, is the probable cause of the poor coherence of these reflections on the stacked section.

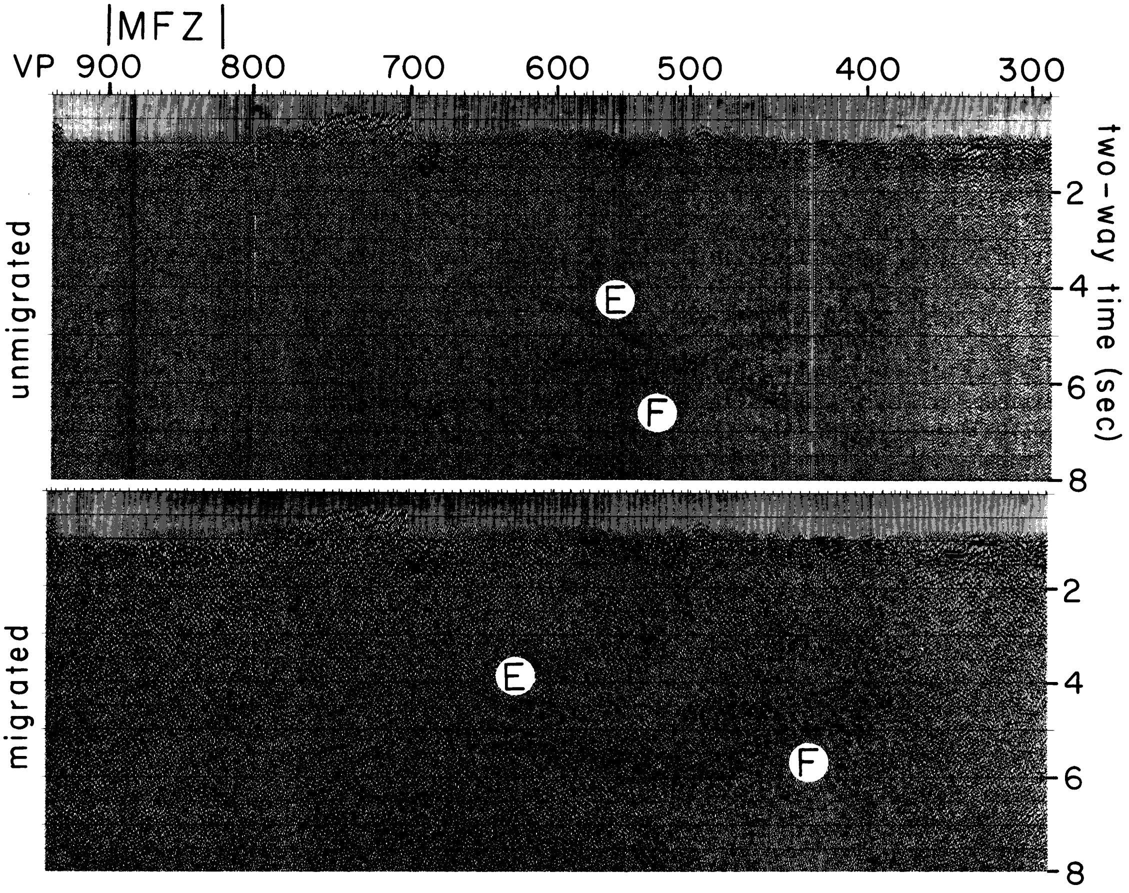

Fig. 3. Center portion of the COCORP Sierra profile showing prominent crossing reflections before and after migration. The east-dipping reflections (E) are suggested to represent the downdip extension of the Melones fault. The west-dipping reflections (F) are of problematic origin. (top) Unmigrated CDP-stacked section; (bottom) same section after migration.

Unfortunately, the east-dipping reflection zones cannot be traced clearly through the upper 2 to 3 s of the seismic section to surface outcrop. Hence their interpretation is equivocal. Two possibilities suggested by the regional geology are (1) they originate from faults, or (2) they originate from within, or perhaps mark the boundaries of, inclined, sheet-like, intrusive bodies such as have been recognized in outcrop in the southern Sierra (J. Saleeby, personal communication, 1974). Simple projection of the east-dipping zones to the surface suggests that the fault interpretation is probably correct. In particular the prominent zone marked E on Figure 2 projects to the surface at the position where the Melones fault intersects the seismic line (between VPs 820-900). At this locality the Melones fault consists of several fault strands marked by sheared serpentinite in a zone approximately 6 km wide. Similarly, the reflections marked A, though they extend off the west end of the profile, project to approximately the position of a broad NNW-trending "shear zone" mapped within the Smartville block [Burnett and Jennings, 1962; Alt et al., 1977; Day et al., 1985]. The east-dipping zones marked B and C are somewhat problematic in that they do not project to mapped faults of which we are aware. However, their similar attitude coupled with the generally faulted nature of the region suggests that they probably also represent faults.

As noted, the COCORP profile runs approximately perpendicular to the strike of the Foothills fault system. Allowing that the east-dipping zones of reflections do

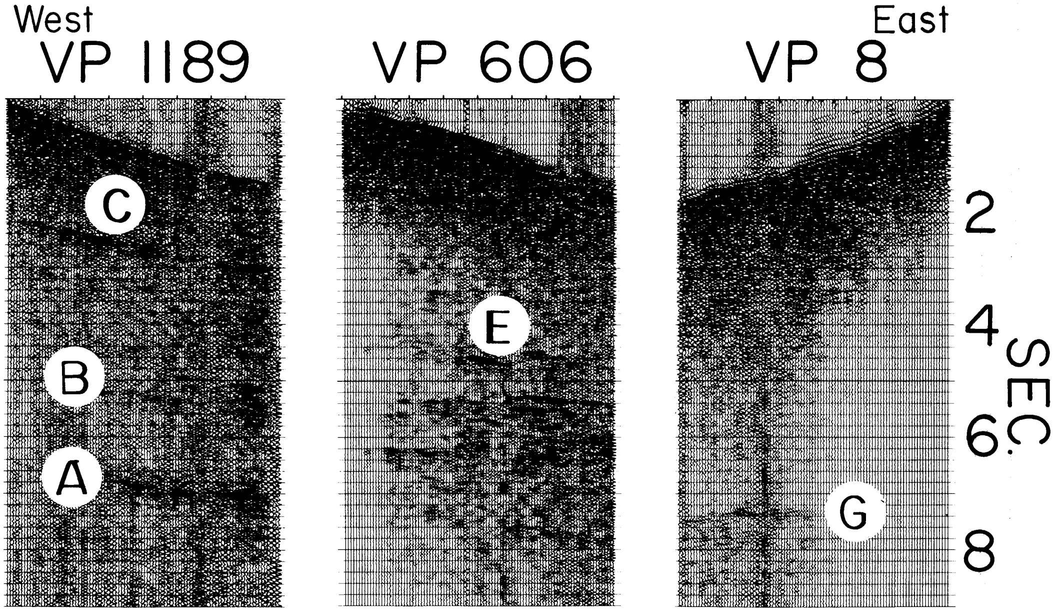

Fig. 4. Individual VP files, section scaled, no automatic gain control. Letters correspond to features shown in Figure 2 and discussed in the text.

represent several of these faults, then two-dimensional migration should be adequate for estimating their true dips. The reflections correlated with the Melones fault (E) represent the most gently east-dipping feature visible on the profile (apparent dip 26°). Using 6.0 and 7.0 km/s respectively as lower and upper bounds for migration gives a "true" dip for the Melones fault of between 32° and 39°. Taking 6.4 km/s as a reasonable approximation for the average crustal velocity yields an actual dip of about 35°. The "shear zone" reflections (A) are slightly steeper (apparent dip 32°). The same analysis indicates that this structure has a true dip of somewhere between 44° and 54°. Again using 6.4 km/s as a reasonable average crustal velocity yields a true dip for this structure of about 47°. The other east-dipping features (B and C) have apparent dips intermediate between those of A and D, and therefore their migrated dips are intermediate between those of A and D, also.

Problematic Reflections

Along with the east-dipping reflections just described, there are a number of other features visible on the Sierra profile of more problematic origin. Most prominent of these is a sequence of west-dipping reflections visible beneath VPs 450 to 550 (apparent dip 21°, F on Figure 2). On the unmigrated section these reflections cross the prominent east-dipping reflection marked E at about 5.5-s two-way travel time beneath VP 500. Migration using velocities of 6.4 km/s or greater rotates both E and F in opposite senses, far enough so that the prominent west-dipping reflections (F) appear to lie entirely to the east of the east-dipping reflections (E) that have been interpreted here as a fault (Figure 3). However, which set of reflections actually cuts the other is unclear from the seismic data. The origin of the west-dipping reflections is also unclear since they cannot be traced directly to features visible in outcrop. One possible explanation is that they originate from a west-dipping Nevadan thrust fault. West-dipping thrusts do crop out approximately 50 km along strike to the north of the survey route [Taylorsville and Grizzly Mtn. thrusts; Speed and Moores, 1980; Moores and Day, 1984]. Alternatively, these reflections might originate from the boundary of a plutonic body, or conceivably may have resulted from sideswipe of some structure out of the plane of the section. Without crosslines we are presently unable to resolve the latter possibility.

Another feature that is prominent on

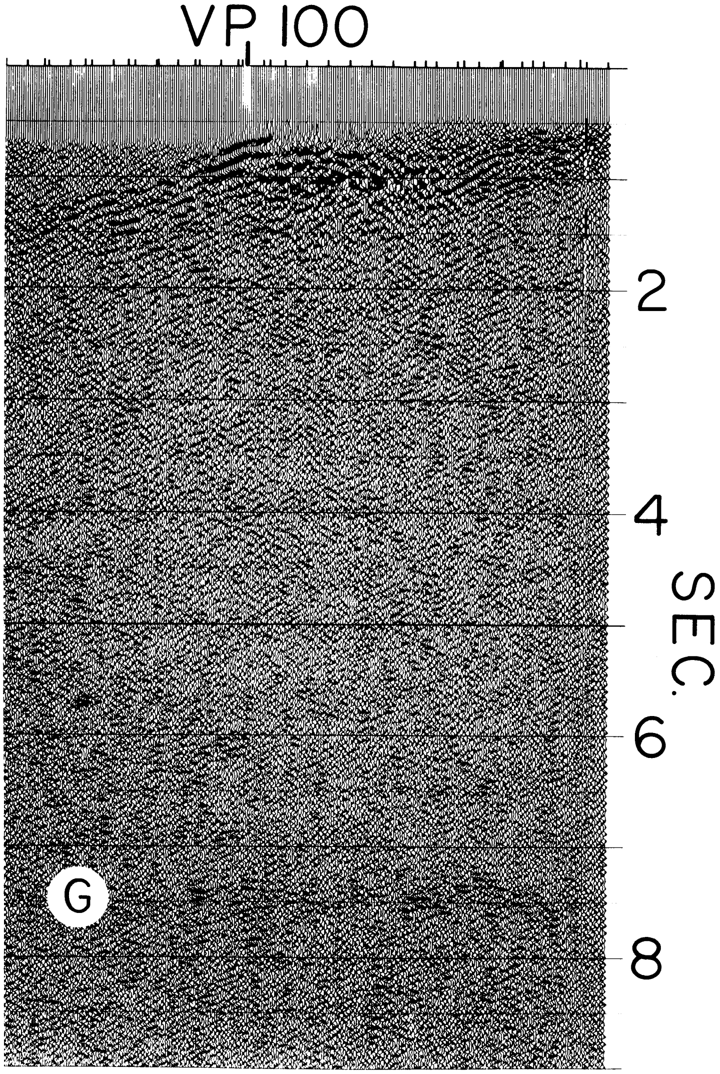

Fig. 5. Eastern portion of the COCORP Sierra profile showing prominent subhorizontal reflections at 7.4-s two-way travel time (unmigrated CDP, stacked section).

the seismic section, but not traceable to surface outcrop, is a band of horizontal reflections occurring beneath the east end of the profile at approximately 7.4-s two-way time (G on Figure 2, Figure 5). These reflections are clearly visible on individual VP files and can be traced continuously from the east end of the line westward to about VP 150, beyond which they appear to die out. At present it is not clear whether the disappearance of these reflections toward the west represents a real geologic change at depth or a data acquisition problem. Assuming that the reflections are from within the plane of the section, they represent an interface at 22- to 26-km depth. Refraction studies in northwest Nevada indicate that thin (i.e., 22-25 km thick) Basin and Range crust extends at least as far west as the California/Nevada border at the latitude of the COCORP survey [Priestley et al., 1982]. Thus the 7.4-s reflections at the east end of the COCORP profile might represent Moho. We are unsure of this interpretation, however, since COCORP data in northwest Nevada show "crustal-type" reflections continuing to somewhat greater depths than was anticipated from these same refraction results [e.g., 10 s;

Hauser et al., 1984]. At present, it is not clear how this discrepancy should be reconciled, or how it may bear on the interpretation of 7.4-s reflections in eastern California. If these reflections do represent Moho, then anomalously thin Basin and Range crust extends west of the California/ Nevada border beneath the Verdi range and Tahoe graben. More likely, the 7.4-s reflections represent some type of interface within the lower crust. Possibilities include the westward extension of the Paleozoic or Mesozoič thrust systems that crop out in central Nevada (Roberts Mtn., Golconda, or Fencemaker thrusts?), a low-angle extensional detachment, or the base of the Sierra Nevada batholith, which is inferred to extend northward beneath the Tahoe graben.

Another problematic feature visible on the seismic section is a convex upward "patch" of short but relatively prominent reflections and/or diffraction segments centered beneath VP 990 (D on Figure 2). The top of this feature lies at approximately 4.3-s two-way time (13-15 km). Migration appears to collapse this feature, suggesting that it represents a diffraction from a point source. The source of the diffraction, however, is unknown.

Finally, beneath the eastern portion of the line, prominent reflections are observed at relatively shallow crustal levels (approximately 0.5 to 1.5 s, H on Figure 2). These reflections almost certainly originate within, or mark the base of, Cenozoic volcanic strata filling the Tahoe graben. Surface mapping indicates that these volcanics are cut by a number of northwest trending normal faults [Burnett and Jennings, 1962]. The variable dip of the Cenozoic strata, evidenced on the seismic section, probably reflects rotation of several normal-fault-bounded blocks.

DISCUSSION

Faults in the Northern Sierra

As noted, it appears likely that the east-dipping reflection zones (A,B,C,E), and perhaps the west-dipping zone (F), originate from faults of the Foothills fault system. This interpretation leaves open the question of the age and mode of origin of faults or structures associated with the faults that are actually imaged on the seismic profile. One hypothesis is that the east-dipping reflections originate directly from Nevadan mylonite zones and/or sheared serpentinite bodies that are typically associated with these zones [Clark, 1960; Schweickert et al., 1984]. These ductile high-strain zones could mark either a primary system of west-vergent thrusts, as originally suggested by Bateman and Clark [1974], or alternatively, a system of "late" Nevadan backthrusts that overprint more fundamental east-vergent (originally west dipping) structure, as recently proposed by Moores and Day [1984]. In the latter case, zone F might mark one of the earlier east-vergent structures.

A second hypothesis is that the dipping reflections originate from structures, which, though associated with Nevadan faults, are actually of post-Nevadan age. One possibility suggested by the surface geology is that the east-dipping reflections originate from Cretaceous quartz veins and/or hydrothermal alteration zones associated with the Nevadan faults. The aerial distribution of these features is well known since they host the famous lode gold deposits of the region. These vein systems are preferentially developed within or adjacent to faults of the Foothills fault system. For example, the "Mother Lode" of the central and southern foothills consists of a 190-km-long sequence of gold-bearing quartz veins cropping out along the Melones fault zone [Clark, 1970]. Similarly, the quartz veins of the Allegheny mining district occur within the Melones fault zone in the region crossed by the COCORP profile. The thickness and outcrop extent of individual veins associated with fault zones in the Sierra is quite variable. However, many are up to several tens of meters thick and can be traced for kilometers along strike [Clark, 1970]. Although there is a clear spatial association of the Sierran quartz veins with Nevadan faults, the exact nature of the relationship between these two sets of structures remains enigmatic. In detail the veins typically cut across and dip less steeply than the Nevadan faults. Furthermore, the veins themselves commonly exhibit reverse offsets of up to several tens of meters [Knopf, 1929; Ferguson and Gannett, 1932; R. Schweickert, personal observation, 1974). These observations indicate that vein formation was associated with reverse faulting and that this movement postdated the initial (late

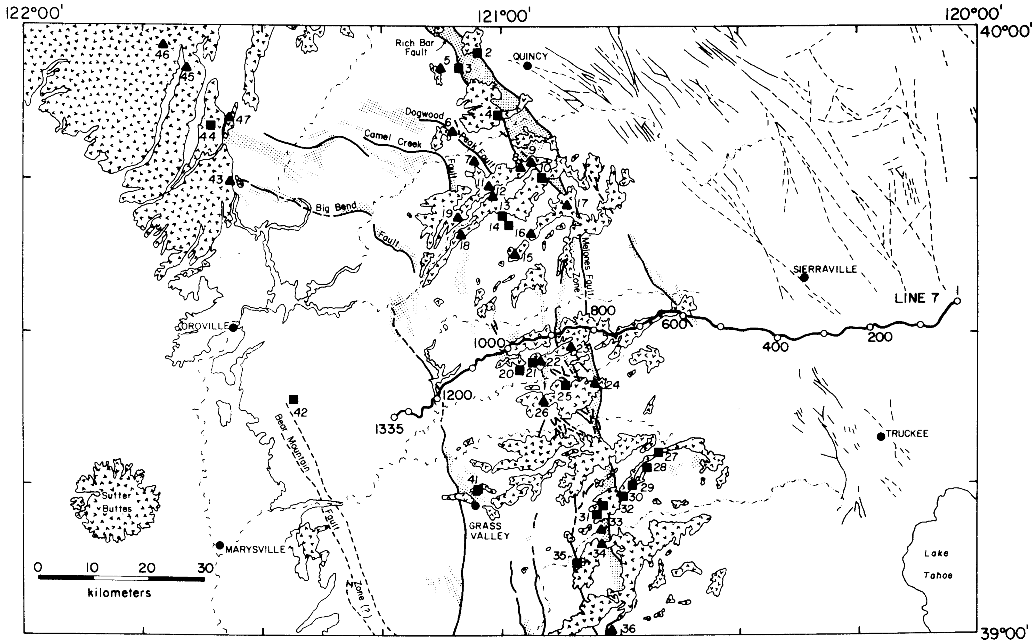

Fig. 6. Fault map of the region encompassed by the Chico 2° sheet. Heavy lines, mapped faults of the Foothills fault system; fine lines, faults cutting Tertiary volcanics in the Tahoe graben; v pattern, Tertiary volcanics west of the Tahoe graben; fine stipple, ultramafic rocks. Numbers refer to localities where Woodward-Clyde geologists have identified fault offsets in upper Cenozoic volcanics (triangles, identification based on geomorphic feature; squares, fault observed in outcrop) [Alt et al., 1977]. Geology after Burnett and Jennings [1962], Heitanen [1973], Clark [1976].

Jurassic) development of the Foothills fault system. Concordant K/Ar and Rb/Sr ages on Sierran gold-bearing quartz veins range from 140 to 110 m.y. [Bohlke, 1984] (i.e., 10-30 m.y. after Nevadan deformation). Apparently, reverse faulting took place in the northern Sierra during early Cretaceous time as well as during the late Jurassic. The veins are brittle and thus presumably shallow structures that formed within or across what were originally deeper-seated ductile high-strain zones. Unless the spatial association of the veins with the Nevadan faults is fortuitous, there must be some en echelon arrangement of the veins downward, within, or adjacent to the Nevadan fault zones.

It is also possible that the dipping reflection zones originate from Cenozoic normal faults. Alt et al. [1977] have identified some 46 localities in the northern Sierra where upper Cenozoic volcanics are cut by brittle faults (Figure 6). The majority of these are associated with Nevadan ductile faults identified in the underlying basement [Alt et al., 1977]. These young faults are generally high-angle features where observed at the surface and have identifiable dip-slip displacements ranging from less than one meter to greater than 180 meters. In almost all cases the sense of slip is down to the east.

These observations indicate quite clearly that during late Cenozoic time the northern Sierra has undergone east-west extension. Furthermore, it appears that this extension has been accommodated by dip-slip motion along what were originally Mesozoic thrusts of the Foothills fault system [Schwartz et al., 1978]. The very gentle westerly dip of the upper Cenozoic volcanics in the region, together with the relatively small offsets on the faults cutting those strata, suggest that the magnitude of crustal extension in the northern Sierra is quite small. However, based on the recent Oroville earthquake and microearthquakes monitored in the central Sierra foothills, it appears that this extension is ongoing [Wong and Savage, 1983]. These earthquakes occur within the region of the Foothills fault system and commonly have focal mechanisms indicating east-west extension. They are some of the deepest intraplate earthquakes recorded within the continental U.S. (12-40 km), and although they have not been associated with particular faults, the COCORP data suggest that faults mapped at the surface do extend at least to these depths.

Implications for Genesis of the Sierran Gold Deposits

The COCORP traverse passed through two of the most productive gold mining districts of California, as well as several smaller ones. The Sierra City, Allegheny, and other districts within 5 km of the traverse have yielded at least 90 tons of gold, and the eroded portions of the veins contributed to the even more productive Yuba River placer deposits. Detailed descriptions of these deposits have been made by Ferguson and Gannett [1932], Cooke [1947], Carlson and Clark [1956], Clark [1970], and Coveney [1981]. In common with other great lode gold deposits there has been a long-standing controversy concerning the sources of the gold and the ore-forming fluids, and the cause of the fluid flow that generated the gold deposits.

Many workers have considered that Sierran plutonism played a key role in the formation of the gold deposits, either providing the actual source of the gold and fluids, or indirectly, providing the heat that drove a hydrothermal circulation system that in turn leached these constituents from the surrounding country rock [e.g., Knopf, 1929; Cloos, 1935; Clark, 1970; Albers, 1981]. Field relations, however, have not provided clear support for this hypothesis. As noted, surface mapping indicates that the auriferous veins are associated with Nevadan faults rather than with any particular granitic intrusions or group of intrusions. Furthermore, the majority of the gold veins crop out 20-50 km west of the main mass of the Sierra Nevada batholith rather than being concentrically distributed within or around it.

It has also proved difficult to relate the veins directly to their surrounding wall rocks. Geochemical evidence indicates that the vein-forming fluids were of the CO_2-rich type that could have been generated by prograde metamorphism. However, the wall rocks surrounding the presently exposed veins had already been metamorphosed during the Nevadan orogeny at temperatures higher than those associated with the ore-deposition episode [Coveney, 1981]. Furthermore, the volume of hydrothermally altered rock immediately surrounding the veins is generally considered insufficient to have yielded the amount of gold deposited within the veins [Knopf, 1929; Ferguson and Gannett, 1932; Coveney, 1981]. These relations imply that both the gold and fluids were derived from much larger volumes of rock, presumably at depth.

Thus the Sierran gold veins are not obviously related to shallow plutonism and do not appear to have been derived from their surrounding (currently near-surface) wall rocks. They are, however, clearly associated with faults, which, based on the COCORP data, appear to be deeply penetrating, and their chemistry indicates that the vein-forming fluids could have been derived from prograde metamorphic reactions. These relationships, together, lend support for a "tectonic" model for Sierran gold-ore genesis. We suggest that metamorphism of underthrust eugeoclinal rocks at mid- to lower crustal depths liberated ore fluids that migrated upward along active thrust faults. These fluids precipitated the lode deposits in the upper crust and produced the hydrothermal alteration zones in the immediately surrounding country rock. The heating and compression necessary for the prograde metamorphic episode may have been due directly to thrusting (collision), or alternatively may have been related to deep-seated intrusion associated with the Sierra Nevada batholith. In either case this scenario implies that metamorphism in the northern Sierra continued, at least at depth, into the early Cretaceous, i.e., 10-30 m.y. after the age generally accepted for Nevadan metamorphism. This may not be unreasonable since the upper limit for Nevadan metamorphism is based primarily on K/Ar dates from postkinematic plutons [Schweickert et al., 1984], and as these dates represent cooling ages for rocks presently exposed at the surface, metamorphism in the deep crust may well have continued to significantly younger times.

The "tectonic" model suggested here for derivation of the Sierran gold deposits may be applicable to other gold provinces as well. The prominent Precambrian gold fields of Canada, Australia, and India have geochemical, mineralogical, and regional geologic similarities with the Sierran deposits. As with the Sierran example, they are also associated with prominent shear zones. Although ore-deposition models have been proposed for each of these regions [e.g., Kerrich et al., 1977; Fyfe et al., 1978; Boyle, 1979], in each case the source of the ore fluids has remained an enigmatic aspect of their genesis. A model based on metamorphic dewatering in the deep crust associated with active thrust faulting might be applicable to these gold provinces also.

SUMMARY

Although hampered to some extent by a relative paucity of good reflections, COCORP profiling in the northern Sierra has delineated a number of features in the crust of that region:

1. Several east-dipping zones of discontinuous reflections are probably associated with faults of the Foothills fault system. In particular, the Melones fault, which coincides with the "Mother Lode" of the central and southern Sierra foothills, appears to be marked by prominent east-dipping reflections in the midcrust. The impedance contrasts necessary to generate these reflections might be caused by mylonitization, sheared serpentinite bodies, or extensive quartz veins and hydrothermal alteration zones, all of which are observed along these faults where they crop out at the surface.
2. Migration of the COCORP data suggests that these faults are approximately planar and have moderately steep dips (35°-47°). Unlike the situation in typical foreland thrust belts, these faults do not appear to flatten within the upper crust. Rather, they appear to maintain relatively steep dips at least to midcrustal depths (20 km), and conceivably could penetrate the entire crust.
3. At present it is unclear whether these structures represent a system of primary, predominantly west-vergent, Nevadan thrusts, a system of "late" Nevadan backthrusts (retrocharriage), or younger Cretaceous or Cenozoic faults.
4. Several other reflection sequences also occur on the COCORP profile. These include prominent west-dipping reflections in the midcrust beneath the Eastern belt, and subhorizontal reflections at 22- to 26-km depth beneath the Tahoe graben. The former might represent a west-dipping thrust fault analogous to the Taylorsville thrust cropping out to the north. The latter might represent the base of the Sierra Nevada batholith, the westward extension of any one of several low-angle fault systems cropping out in Nevada, or Moho.
5. The association of gold-bearing quartz veins with faults of the Foothills fault system, and the deep penetration of these faults implied by the COCORP data, together, lend support for a "tectonic" model for Sierran gold-ore genesis. We suggest that prograde metamorphism of eugeoclinal material in the deep crust during early Cretaceous thrusting produced ore-depositing fluids that migrated upward along active thrust faults. In this scenario magmatic intrusion in the upper crust would not be critical to formation of the lode-gold deposits.

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