A tale of two sutures: COCORP's deep seismic surveys of the Grenville province in the eastern U.S. midcontinent

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ABSTRACT

A pair of oppositely dipping, crustal-scale shear zones imaged within Grenville basement beneath the Paleozoic cover of Ohio can be correlated, via geopotential lineaments, with similarly oriented geologic and seismically imaged structures hundreds of kilometres to the northeast and southwest, suggesting a relatively simple structural framework for the eastern midcontinent region. An east-dipping zone extending from Lake Huron through western Ohio, and possibly farther southwest, marks the western edge of the Grenville province. Perhaps of greater consequence to an understanding of Grenville tectonics is the discovery of a west-dipping zone underlying the Appalachian basin from northern Alabama to New York within the Grenville province. Correlation of this feature with the seismogenic Clarendon-Linden fault in western New York and a boundary between terranes containing magmatic-arc rocks exposed in Canada suggests that it could mark the site of an intra-Grenville province suture zone. Implications of this interpretation are that the Precambrian foundation of the eastern U.S. midcontinent comprises a relatively simple assemblage of laterally extensive terranes or belts of coeval terranes accreted by familiar plate tectonic processes, and that deep seismic profiling is an effective tool for mapping the three-dimensional distribution of these terranes.

INTRODUCTION

Though the Grenville province has been accepted as representing the root of a mountain belt that flanked eastern North America ca. 1 Ga, the deep level of erosion in Canada and complete burial in the U.S. midcontinent have long thwarted recognition of regionally extensive, unequivocal traces of a plate tectonic origin. Discrete terranes containing the severely deformed and metamorphosed remains of a magmatic arc and thrust belt have been identified locally in Canada (Holm et al., 1986; Davidson, 1986), but the overall structural framework of the Grenville province—the lateral extent of its constituent terranes and the locations of collisional sutures separating them from the older craton and from each other—has remained unclear.

COCORP (Consortium for Continental Reflection Profiling) imaging of a pair of oppositely dipping, crustal-scale reflection zones within the Grenville basement of the eastern U.S. midcontinent (Figs. 1, 2, and 3[1]) contributes to the construction of such a framework. Beneath west-central Ohio, COCORP line OH-1 images the Grenville front tectonic zone as a 50-km-wide, east-dipping reflection sequence rising from mid-crustal depths to the base of Paleozoic cover. Rivaling the Grenville zone in scale, and perhaps in tectonic significance, is the west-dipping Coshocton zone beneath the Appalachian basin in eastern Ohio, within the heart of the Grenville province. Correlation of these dipping features, via prominent geopotential lineaments, with similar features imaged farther south and with collisional structures exposed in Canada supports the emerging view that the Grenville province is a collage of regionally extensive allochthonous terranes, accreted to North America during the Grenville and possible earlier orogenies.

[1]Figure 3 is a loose insert accompanying this issue.

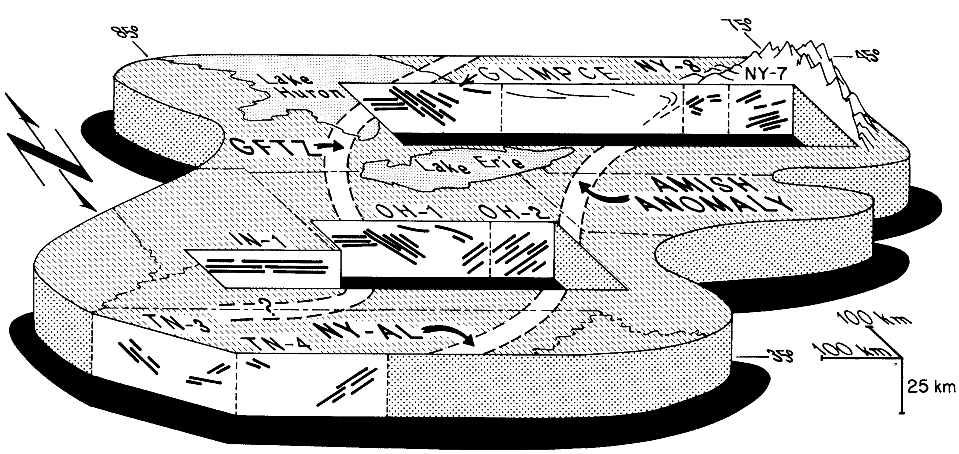

Figure 1. Schematic perspective view of eastern U.S. midcontinent. Principle features in COCORP and GLIMPCE seismic data are shown by bold lines on rear walls of imaginary excavations. Structures observed or inferred from field data are shown by lighter lines. GFTZ is Grenville front tectonic zone; NY-AL is New York- Alabama lineament.

GRENVILLE FRONT TECTONIC ZONE

Rocks exposed in the western Grenville province in Canada have moderate to high metamorphic grade and southeast-dipping structural fabric acquired during the Grenville orogeny, ca. 1.3–1.0 Ga (van Breemen and Davidson, 1988), and short wavelength magnetic character (Fig. 2). Rocks west of the Grenville province—referred to here as "cratonic"—were not strongly metamorphosed or deformed during the orogeny. The western edge of the Grenville province—the 10–100-km-wide Grenville front tectonic zone—includes reworked cratonic rock, and is delineated by a pronounced negative gravity anomaly (Thomas, 1985). Where the Grenville zone projects beneath Georgian Bay, the GLIMPCE (Great Lakes International Multidisciplinary Program on Crustal Evolution) seismic survey images a spectacular east-dipping reflection zone (Figs. 1 and 2; Green et al., 1988).

The southward continuation of the Grenville front tectonic zone into western Ohio was previously estimated from the western limit of gneiss and marble recovered in drillholes and the coincident western edge of a region of short-wavelength, high-amplitude magnetic anomalies (Fig. 2; Denison et al., 1984; Lidiak et al., 1985; Lucius and von Frese, 1988). At this boundary, COCORP line OH-1 (Fig. 3) images an east-dipping zone approximately 50 km wide, penetrating to 25 km depth and having a 25°–30° dip and multicyclic reflection character similar to that seen in the GLIMPCE data. (For details and location map, see Pratt et al., 1989.)

Few basement samples are available to constrain the edge of the Grenville province south of Ohio (Denison et al., 1984). It may lie along a northeast-trending magnetic discontinuity in central Kentucky (Fig. 2; Lidiak et al., 1985). However, where this discontinuity projects into northernmost Alabama, COCORP line TN-4 reveals a reflective zone that dips west, opposite to the Grenville front tectonic zone in Ohio (Figs. 1 and 2). This could mean that the Grenville zone switches vergence between Ohio and Alabama, but several lines of evidence suggest that significant Grenville deformation penetrated farther west than previously suspected, and that the TN-4 west-dipping zone is something other than the Grenville front tectonic zone. First, the high-frequency magnetic pattern that characterizes the Grenville province in eastern Ohio and Kentucky continues into western Tennessee and Arkansas (Fig. 2). A northeast-trending component is also recognized in filtered gravity data (Lidiak et al., 1985). Second, high-grade metamorphic rocks drilled in northeast Arkansas yield K-Ar whole-rock ages of 0.8–1.0 Ga (Howe, 1985). Third, COCORP lines TN-3 in western Tennessee (Fig. 1; M. Giguere, unpublished data) and AR-6 in Arkansas (K. Nelson and J. Zhang, unpublished) image reflectors that dip east, like those within the Grenville province to the north.

COSHOCTON ZONE

If the Grenville province extends into western Tennessee or Arkansas, what is the west-dipping zone imaged in northernmost Alabama on line TN-4 (Fig. 1)? This zone projects updip toward one of the most prominent magnetic anomalies in eastern North America (lower arrow in Fig. 2), extending from northern Alabama through eastern Tennessee to central West Virginia. King and Zietz (1978) extrapolated this feature along a fainter trend in central Pennsylvania and eastern New York, naming it the New York–Alabama lineament. We note, however, that a more conspicuous anomaly—referred to here as the Amish anomaly (upper arrow in Fig. 2)—that has frequency and amplitude like those of the Alabama to West Virginia segment extends northward along the Ohio–West Virginia border into western Pennsylvania. West of this point, COCORP line OH-2 images a west-dipping zone—here named the Coshocton zone—similar to that seen on line TN-4 (Figs. 1 and 3). This zone is at least 100 km wide and penetrates to 30 km depth. The combined Alabama-Amish anomaly is thus spatially associated with major west-dipping features imaged seismically in eastern Ohio and northern Alabama (Figs. 1 and 2). Although proof must await extension of the seismic lines across the magnetic anomaly, we speculate that these features represent a single crustal-scale shear zone of considerable lateral extent within the Grenville province; i.e., the anomaly marks the east edge of a crustal block with west-dipping tectonic fabric. Such major magnetic lineaments have long been suspected to mark terrane boundaries (King and Zietz, 1978), and the associated west-dipping Coshocton zone resembles reflection patterns from shear fabrics developed in suture zones within Phanerozoic mountain belts (e.g., Nelson et al., 1985).

If one or more sutures lie within the Coshocton zone, they must bound Grenville terranes that had separate precollision histories. Unfortunately, basement samples in the midcontinent are too sparse to permit accurate terrane mapping; however, the Amish anomaly can be traced northeastward toward the exposed Grenville province in Canada along a course that coincides with a variety of geologic and geophysical features which together constitute evidence for a collisional suture (Fig. 2). In western New York the Amish anomaly coincides with the northeast-trending Clarendon-Linden Bouguer gravity anomaly and a zone of moderate seismic activity attributed to reactivation of a major fault in the Grenville basement (Hutchinson et al., 1979). All these features are flanked by more subtle magnetic anomalies, which Forsyth et al. (1988) correlated with the boundaries of the central metasedimentary belt—a Grenville terrane that consists largely of rocks deposited ca. 1.3 Ga, just prior to the Grenville orogeny (Figs. 2 and 4; Davidson, 1986). The Clarendon-Linden Bouguer gravity anomaly and the northward projection of the

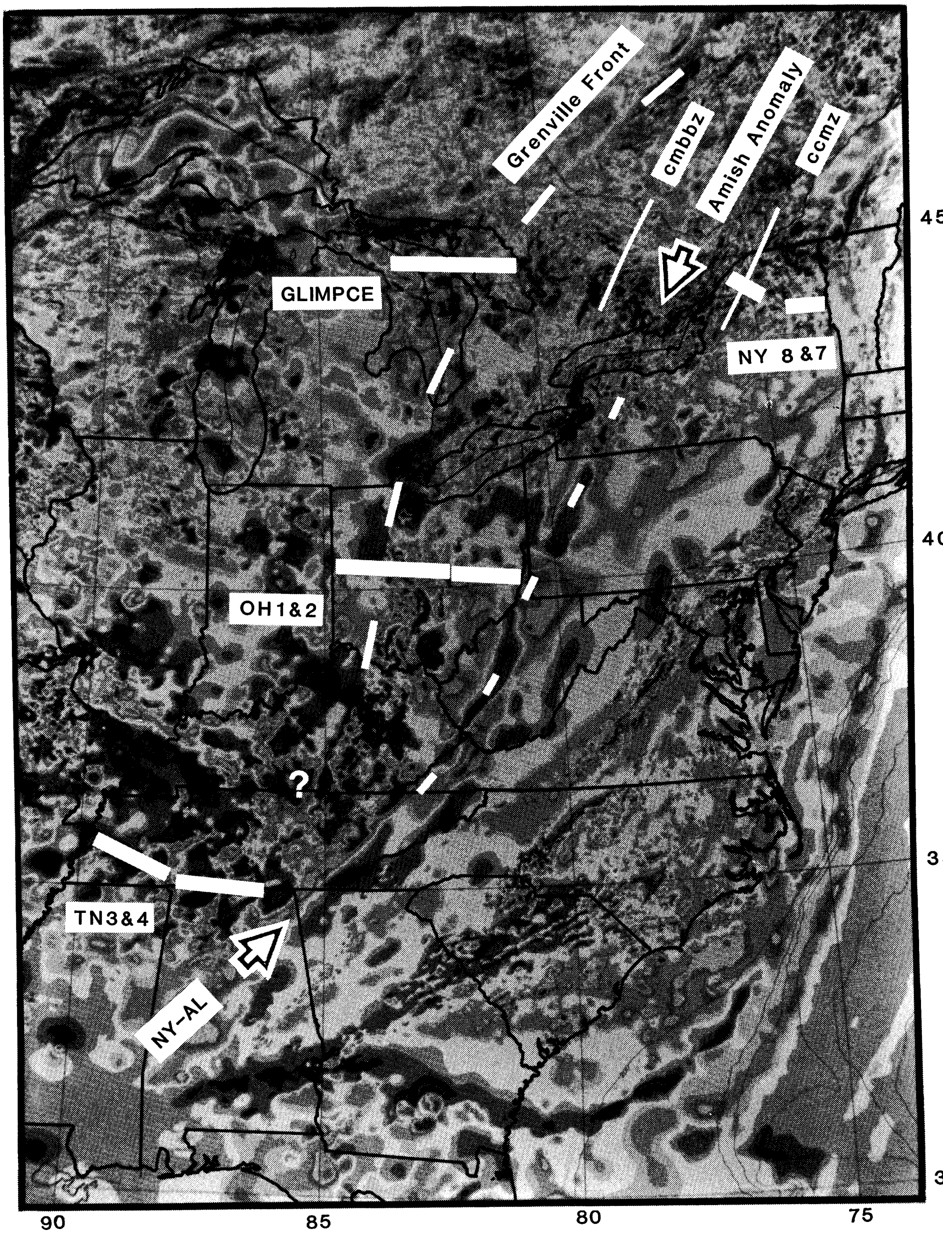

Figure 2. Magnetic anomaly map of eastern midcontinent (black and white photograph from color original by Committee for the Magnetic Anomaly Map of North America [1987]). Wide white lines—location of seismic profiles; thin white lines—approximate boundaries of central metasedimentary belt; cmbbz—central metasedimentary belt boundary zone; ccmz—Carthage-Colton mylonite zone; long white dashes—Grenville front; short white dashes (between arrows)—Alabama-Amish anomaly; NY-AL—New York-Alabama lineament.

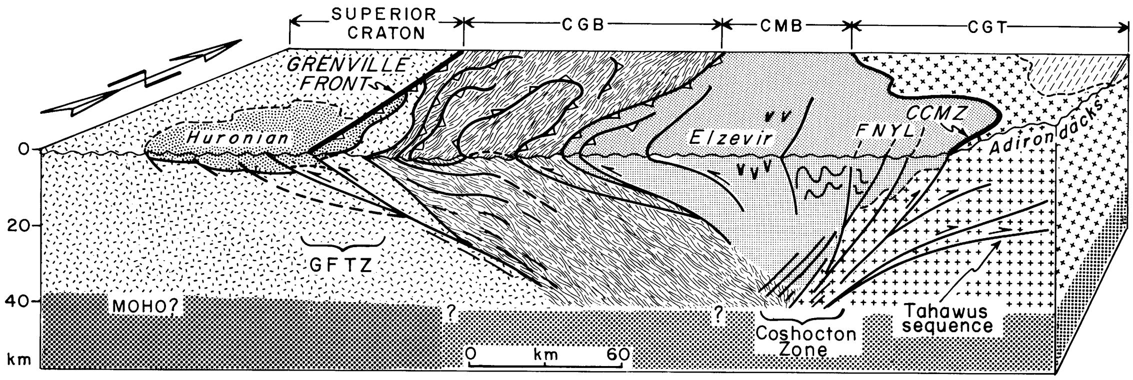

Figure 4. Schematic block diagram summarizing structural framework of Grenville province in eastern midcontinent. Though generally representing features observed in northern transect (see Figs. 1 and 2), key elements such as Coshocton zone and imbricated craton basement and cover are projected from along strike and generalized. Grenville terranes: CGB—central gneiss belt; CMB—central metasedimentary belt (two main subterranes are Elzevir and FNYL [Frontenac-New York lowlands]); CGT—central granulite terrane. CCMZ—Carthage-Colton mylonite zone. V—arc volcanics. Note lateral variability of basement involvement along Grenville front tectonic zone (GFTZ). Sources for surface structures cited in text. Depth of Moho beneath craton and western Grenville province from Mereu et al. (1986).

Amish anomaly align with the boundary between the Elzevir and Frontenac–New York lowlands subterranes of the central metasedimentary belt (Fig. 4; Forsyth et al., 1988). The degree of metamorphism decreases from granulite grade at this boundary to greenschist grade within the Elzevir subterrane, where a suite of metavolcanic and metaplutonic rocks apparently marks the site of an Andean magmatic arc and possible back-arc basin (Holm et al., 1986). The Amish anomaly may thus arise from mafic material preserved in an underlying structure—perhaps the northward continuation of the Coshocton zone.

Davidson's (1986) and Hanmer's (1988) mapping in southern Ontario shows that the western central metasedimentary belt and central gneiss belt are characterized by west-vergent thrust sheets. High-frequency seismic data in eastern Ohio (Beardsley and Cable, 1983) image similar features. These observations, together with southwestward extrapolation of the central metasedimentary belt boundaries defined by Forsyth et al. (1988; Fig. 2), suggest that Ohio may be partly underlain by the central metasedimentary and/or gneiss belt. A band of east-dipping reflections on COCORP line OH-1 may mark a tectonic gneiss/metasedimentary belt boundary (Fig. 3, VP 2250–2500, 1–5 s).

Conversely, the mapping of Wiener et al. (1984) shows that structures in the eastern central metasedimentary belt become vertical to steeply northwest-dipping in the Carthage-Colton mylonite zone, believed by McLelland et al. (1988) to be a fundamental tectonic boundary, possibly a suture (Figs. 1, 2, and 4). COCORP line NY-8 (Fig. 1) shows some west-dipping events, but the general structure may be too steep to image. Farther east beneath the Adirondacks, COCORP line NY-7 records the thick, shallowly west-dipping Tahawus sequence (Figs. 1, 4, and 5)—interpreted as, among other things, a ductile shear zone within the central granulite terrane (Klemperer et al., 1984).

Although the various pieces in this great puzzle could be related in a more complex way than presented here, it is striking how an integrated picture of a collision zone 100 km wide emerges when the west-dipping Coshochton zone imaged in the COCORP midcontinent survey is tied via the Amish anomaly into this collage of compressional features in the exposed Grenville province.

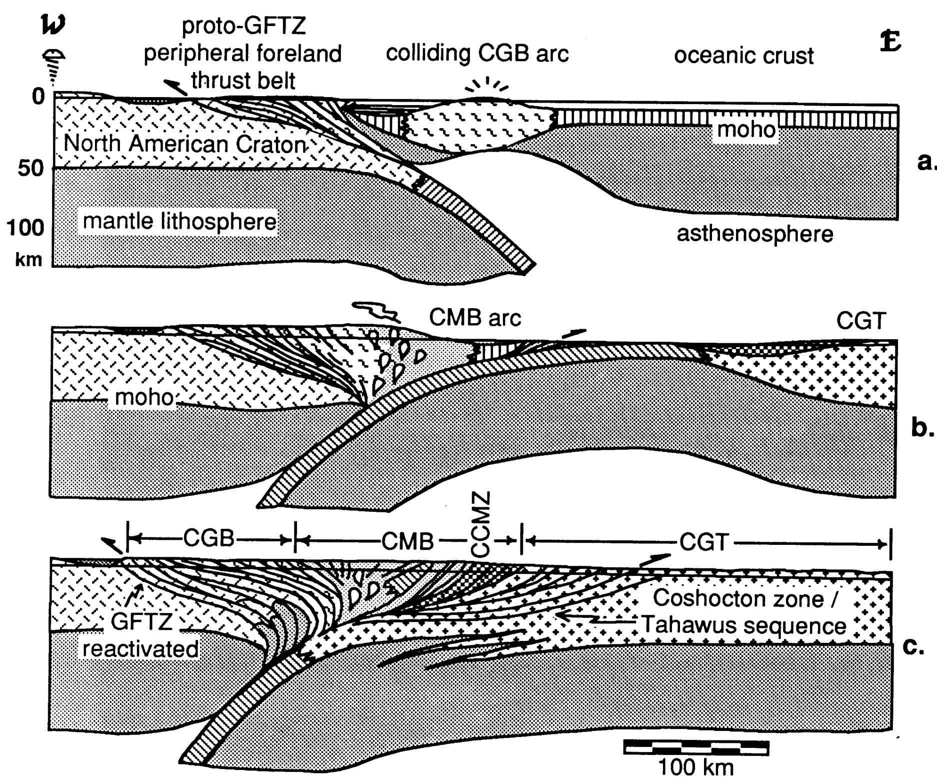

Figure 5. Simplified plate-tectonic history. a: Collision of central gneiss belt (CGB) island arc with North American craton along east-dipping proto-Grenville front tectonic zone (GFTZ); b: reversal of subduction polarity and construction of Andean arc in central metasedimentary belt (CMB); c: collision 1.3–1.0 Ga of eastern CMB and central granulite terrane (CGT) along west-dipping Coshocton zone and Carthage-Colton mylonite zone (CCMZ). Back-arc basin may have opened and closed between phases b and c.

MODEL FOR THE ORIGIN OF THE TWO OPPOSITELY DIPPING ZONES

We speculate that our geophysical observations and the large-scale elements of the surface geology can be accounted for in a three-phase tectonic model involving (1) accretion of the central gneiss belt along an east-dipping proto–Grenville front tectonic zone suture (Fig. 5a); (2) construction of an Andean arc east of the central gneiss belt in the Elzevir subterrane of the central metasedimentary belt (Fig. 5b); and

(3) accretion of the central granulite terrane and eastern central metasedimentary belt along the west-dipping Coshocton zone, reactivating the tectonic zone in a retroarc setting (Fig. 5c).

The proto–Grenville front tectonic zone may be interpreted as the root zone of a peripheral foreland thrust belt (Thomas, 1985): whereas the eastern central gneiss belt is of suspect origin (Rivers et al., 1989), the tectonic zone includes highly altered fragments of cratonic basement and sedimentary cover that may have been partly subducted beneath colliding central gneiss belt terranes before being torn from the passive margin edge and thrust westward. This interpretation requires a suture east of the reworked cratonic rock within the central gneiss belt, but its age and precise location remain problematic. Dickin and McNutt (1989) identified a Penokean (1.9–1.8 Ga) suture 60 km southeast of the Grenville front in southern Ontario; however, deformation of 1.7–1.3 Ga granite-rhyolite rocks (Fig. 3) requires a later age in the U.S. midcontinent. Rivers et al. (1989) identified a boundary of Grenville age or older between parautochthonous and allochthonous rocks in western Quebec and eastern Ontario. The east-dipping reflections on COCORP line OH-1 at VP 2250–2500 could mark such a suture instead of a central gneiss belt/central metasedimentary belt boundary.

Though the number and polarity of subsequent episodes east of the central gneiss belt is controversial, the building of an Andean arc in the medial central metasedimentary belt is compatible with a northwest-dipping episode, as is projection of the western part of the 100-km-wide Coshocton zone into this area. Where the eastern part of the Coshocton zone is projected into the exposed eastern central metasedimentary belt, the 1.3 Ga Gouveneur Marble and Major paragneiss are deformed along the northwest-dipping Carthage-Colton mylonite zone. The bulk of these metasedimentary rocks may represent a platform sequence deposited on the northwest margin of the central gneiss terrane, whereas parts of the Major paragneiss reported to have had a volcaniclastic graywacke origin (Engel and Engel, 1953) could represent an accretionary prism thrust southeastward onto the central gneiss terrane. The implication that the present dip of the Carthage-Colton mylonite zone reflects an episode of southeast transport is not easily reconciled with reports of kinematic indicators of top-to-the-northwest motion (Lumino and Mitra, 1988). A later extensional episode, possibly denoting postorogenic collapse (McLelland et al., 1988), may have masked surficial evidence of southeastward motion. Plutonism in the Adirondacks may be related to west-dipping subduction farther east, where the Grenville terranes of New England were eventually accreted. Grenvillian collisions along the Coshocton zone or farther east may have reactivated the region of the Grenville front tectonic zone.

CONCLUSIONS

These first steps in the deep seismic exploration of the Grenville province have shown it to be broken by inclined crustal-scale reflective zones similar to those observed in Phanerozoic mountain belts. The eastern U.S. midcontinent is underlain by an east-dipping zone that marks the western edge of the Grenville province and, farther east, by the west-dipping Coshocton zone, interpreted as an intra-Grenville province suture zone. We have correlated these dipping zones with nearby geopotential lineaments, and with similarly oriented features observed in field and seismic data hundreds of kilometres to the northeast and southwest. This general picture supports the view that the foundation of this vast region consists of an assemblage of laterally extensive teranes or belts of roughly coeval terranes, accreted by the same plate tectonic processes that produced the Phanerozoic orogens. Deep seismic profiling, interpreted in the context of geopotential and geologic data, provides an effective means to map the three-dimensional distribution of these terranes.

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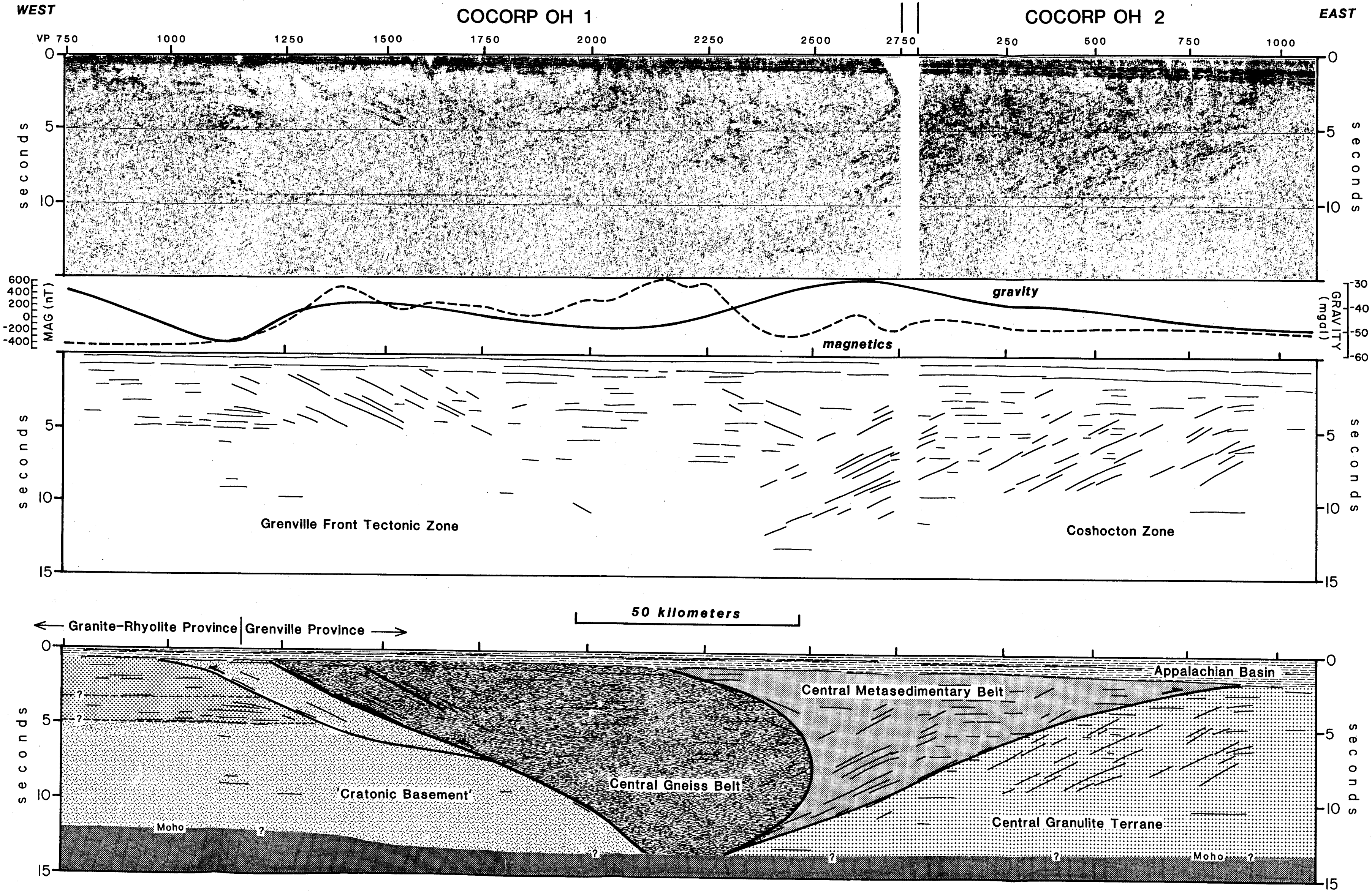

Figure 3. Time section, line drawing, and speculative interpretation of COCORP lines OH-1 and OH-2 (location in Figs. 1 and 2). Patterns as in Figures 4 and 5. Bouguer gravity and magnetic profiles from Lucius and von Frese (1988).

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Figure 3
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