CRUSTAL STRUCTURE IN THE ADIRONDACKS

S. Klemperer, L. Brown, J. Oliver, C. Ando and S. Kaufman
Department of Geological Sciences, Cornell University

INTRODUCTION

The Adirondack dome of northeastern New York State is located near the eastern edge of the North American craton. As the southeastern extension of the Grenville Province, it constitutes the largest well-exposed Proterozoic crystalline terrain in the United States. COCORP has recorded a series of lines across the dome and the onlapping Paleozoic cover sequence (Brown et al, 1982; see location map Figure 1). In this article, line drawings are presented for lines 1, 7 and 10 (Figure 2) and data from line 7 is reproduced (Figure 3). Despite the extreme degree of deformation and metamorphism of the surface rocks, reflections from throughout the crust were recorded. The most striking result of this survey is a set of layered, gently northwest-dipping reflectors observed to span a depth range of about 17 to 25 km (10.5 to 15.5 mi) beneath the Marcy anorthosite massif. Such an observation is thusfar unique, but the geological interpretation of these data are still ambiguous.

GEOLOGICAL BACKGROUND

The rocks of the Adirondack mountains comprise a multiply-folded stratigraphic sequence of high-grade metasedimentary and metavolcanic rocks which are intruded by syntectonic bodies of metanorthosite and metagabbro (Isachsen and Fisher, 1970). Recent studies (McLelland and Isachsen, 1980) suggest that at least four phases of folding have occurred, and that the complex surface outcrop pattern is produced by the interference of large nappe structures with wavelengths of many kilometers. The Highlands region, which includes most of the Adirondack dome (Figure 1), consists principally of granulite facies rocks which were buried to a depth of 20 to 25 km (12.4 to 15.5 mi) during peak metamorphism (Bohlen, Essene, and Hoffman, 1980), The Highlands are bounded on the northwest by the Carthage-Colton mylonite zone, beyond which are the Lowlands, dominated by metasedimentary rocks equilibrated at somewhat lower pressures (equivalent to 16 to 21 km, or 10 to 13 mi, depth) (Brown, Essene, and Kelly, 1978).

The regional exposure of rocks metamorphosed to such high pressures raises the question, how were they brought to the surface? Since the Adirondack crust is now of normal thickness, was it formerly much thicker? If so, was this greater thickness caused by continental collision and subduction, or by some kind of igneous underplating? Several models have been proposed (Baer, 1981; Dewey and Burke, 1973; Seyfert, 1980; Wynne-Edwards, 1976) which represent the Grenville orogeny variously as the product of large-scale continental obduction, crustal thickening by basement reactivation to absorb continental convergence, or drift of a continent over a hot zone or chain of hot spots. A possibly related question concerns the current domical structure of the Adirondack basement. The present surface topography is apparently post-Devonian (Crough, 1981) but the age of uplift is uncertain. Isachsen (1975) has argued from geodetic data that the Adirondack dome is still rising, but this theory has been questioned (Brown and Reilinger, 1980).

DESCRIPTION OF DATA

Figure 2 contains line drawings abstracted from the unmigrated profiles along lines 10, 7 and 1, displayed as an overview of the regional transect. The full COCORP northeastern traverse includes two more lines in New York (Figure 1, lines 8 and 11) and a series of lines in Vermont and New Hampshire (Brown et al, 1982) all of which are to be published elsewhere. Since seismic sections reproduce poorly at small scale, line drawings are used here in an attempt to represent the main features of the full seismic traverse. The line drawings, however, do not necessarily reflect the wide range in amplitudes observed on the seismic sections. Reflection character varies substantially both vertically and laterally. For example, numerous reflections are visible throughout the crust on lines 7 and 1, whereas relatively little energy returns from the lower crust at the northern end of line 10. It is often unclear whether such variations are wholly due to geologic differences at depth, or whether they represent varying recording conditions at the surface.

Line 10 crosses the surface trace of the Carthage-Colton line at about vibration point (VP) 400, on both sides of which lie complex, multiply-folded rocks. These surface features lack a clear-cut seismic expression. Whether this is due to the inherent loss of signal redundancy at shallow depths, or the lack of sufficient reflectivity (Jones and Nur, 1982, found little evidence that mylonite zones are good reflectors), or whether structural dips are too steep to be properly imaged, is not known. In general, line 10 exhibits complex reflection patterns in the upper crust with apparent dips to both the northwest and southeast. The deeper parts of the section contain fewer reflections. On line 7 the situation is reversed, with sparse reflections and blank zones in the upper crust contrasting with prominent layered reflectors at depth. Because line 7 shows the strongest and most continuous reflections, these data have been chosen for reproduction (Figure 3) and are discussed here in more detail. On line 1 the reflections in about the top 1.5 secs are thought to be from Phanerozoic sediments. Below this is believed to be crust deformed in the Grenville orogeny. The main trends in the upper crust dip to the west, but below about 6 secs the several groups of reflectors dip quite sharply to the east, in a manner distinct from either the upper crust in this region or the lower crust on line 7. Although lines 7 and 1 are offset by 50 km (31 mi) (Figure 1) their juxtaposition in plate 1 suggests the possibility that certain reflections may be correlated from one line to the other. However, the deep layered sequence on line 7 seems to be restricted both to a particular depth range and to a particular area, although the limited seismic coverage precludes a complete mapping of its extent.

The data reproduced from line 7 (Figure 3, unmigrated and migrated versions) show a well-defined band of gently west-dipping and subhorizontal reflection segments which form a wedge in the lower crust. The wedge tapers westward from between 5.3 and 7.7 secs (about 17 to 25 km, or 10.5 to 15.5 mi, depth) at the east end of the line to between 7 and 8 secs beneath VP 300. Immediately beneath this layered sequence are many fewer reflections. Below about 8.3 secs better defined reflections again appear, particularly under the east half of the section. They die out at even deeper levels until below about 10 secs, where reflectors are very sparse and of small amplitude. The line-ups at 8.5 to 10 secs include some with measurable apparent dips (5° and rarely 10°), predominantly west-directed, but with a significant number dipping to the east. Below 10 secs, dips are no more than 1 or 2°.

Data from cross-line 11 (not displayed here) confirm that the deep layered sequence is not due to side-swipe. The true dip of the upper surface is about 20° in the direction N30°W. The apparent dips seen on line 7 within the deep layered reflectors range from about 10° at the top to sub-horizontal at the base. Locally, dips may be greater than 20° to the west, but of the very few east-directed line-ups present, none have a dip exceeding 8° (migrated) and none of these are laterally persistent. Migration also moves the reflections several kilometers to the east, away from the center of the Marcy anorthosite. Individual wavelets may be followed virtually unchanged for up to 4 km (2.5 mi), and have possible lateral correlatives extending 10 km (6.2 mi).

DISCUSSION AND INTERPRETATION

Since the most intriguing reflections in these COCORP surveys lie at too great a depth to be drilled and have not been traced to the surface by existing seismic profiles, additional constraints must be sought from other geophysical evidence. Gravity and aeromagnetic anomalies in the Adirondacks (Simmons and Diment, 1973; Zietz and Gilbert, 1981) are strongly correlated with surface geology and probably have little bearing on lower crustal structure. Heat flow in the Adirondacks is typical of shield areas (Birch, Roy, and Decker, 1968), thus any deep anomalies must be very young. Regional refraction studies indicate the crustal thickness beneath the Adirondacks to be about 34 km (21 mi) (Katz, 1955). Several teleseismic experiments have also been reported (Fletcher, Sbar, and Sykes, 1978; Jordan and Frazer, 1975; Taylor and Toksoz, 1979) but the information they contain is very different from and on a much broader scale than that obtained by the seismic reflection technique. Controlled and natural source electromagnetic induction studies by Connerney, Nekut, and Kuckes, (1980) in the Adirondacks have been interpreted as evidence for a crustal layer of very high conductivity lying below 20 km (12.4 mi) depth, approximately the depth of the pronounced deep seismic layering. Water in the lower crust was their preferred explanation.

There are a variety of possible explanations for the layered character of the deep crust of the eastern Adirondacks. Perhaps it results from lithologic variations stacked by tectonic interleaving or recumbent isoclinal folding. Another possibility is that the layering is due to primary igneous laminations. In mapped layered intrusions, thicknesses of the order of 3 to 5 km (1.9 to 3.1 mi) are common, while the Bushveld complex may in places be 8 km (5 mi) thick (Carmichael, Turner, and Verhoogen, 1974). Thus the seismic thickness of the Adirondack layered sequence, about 8 km (5 mi), is not excessive. The conductivity anomaly referred to above could perhaps be explained by magnetite-ilmenite segregations (such as are found in economic quantities in the March massif) in a layered igneous complex, or by sulfide concentrations. It is possible that such a layered body might represent the mafic or ultramafic differentiates of the parent magma from which the now overlying anorthosite rose. Alternatively, this hypothesized body might be an intrusion too young to have affected the surface heat flow patterns. Only a small interconnected fraction of partial melt is required to considerably increase electrical conductivity in rocks, and elsewhere magma bodies have been inferred from magneto-telluric soundings (Jiracek, Arder, and Holcombe, 1979). A major mantle thermal anomaly associated with this hypothetical recent igneous intrusion might also account for doming of the Adirondack mountains.

Another possibility is that the seismic layering is relict sedimentary stratification. It has been demonstrated that sediments can be taken to substantial depths by overthrusting of large crustal sheets during continental collision (Cook et al, 1979). The fine structure of the layered reflections described earlier could represent original lithologic variation modified by tectonic imbrication and metamorphism during underthrusting. In fact, these reflections mimic geometries usually associated with depositional sequences, that is, onlap, toplap, progradation and wedge- or bank-like external form. The high electrical conductivity in the lower crust might therefore be due to hydrous metamorphic assemblages, graphitic schists and/or magnetite deposits in the metasedimentary pile. Such overthrusting would probably have been associated with the Proterozoic Grenville orogeny.

At present all interpretations are at best speculative. Additional profiling within the United States and, in particular, the Grenville Province of Canada may provide data to allow a more unique interpretation.

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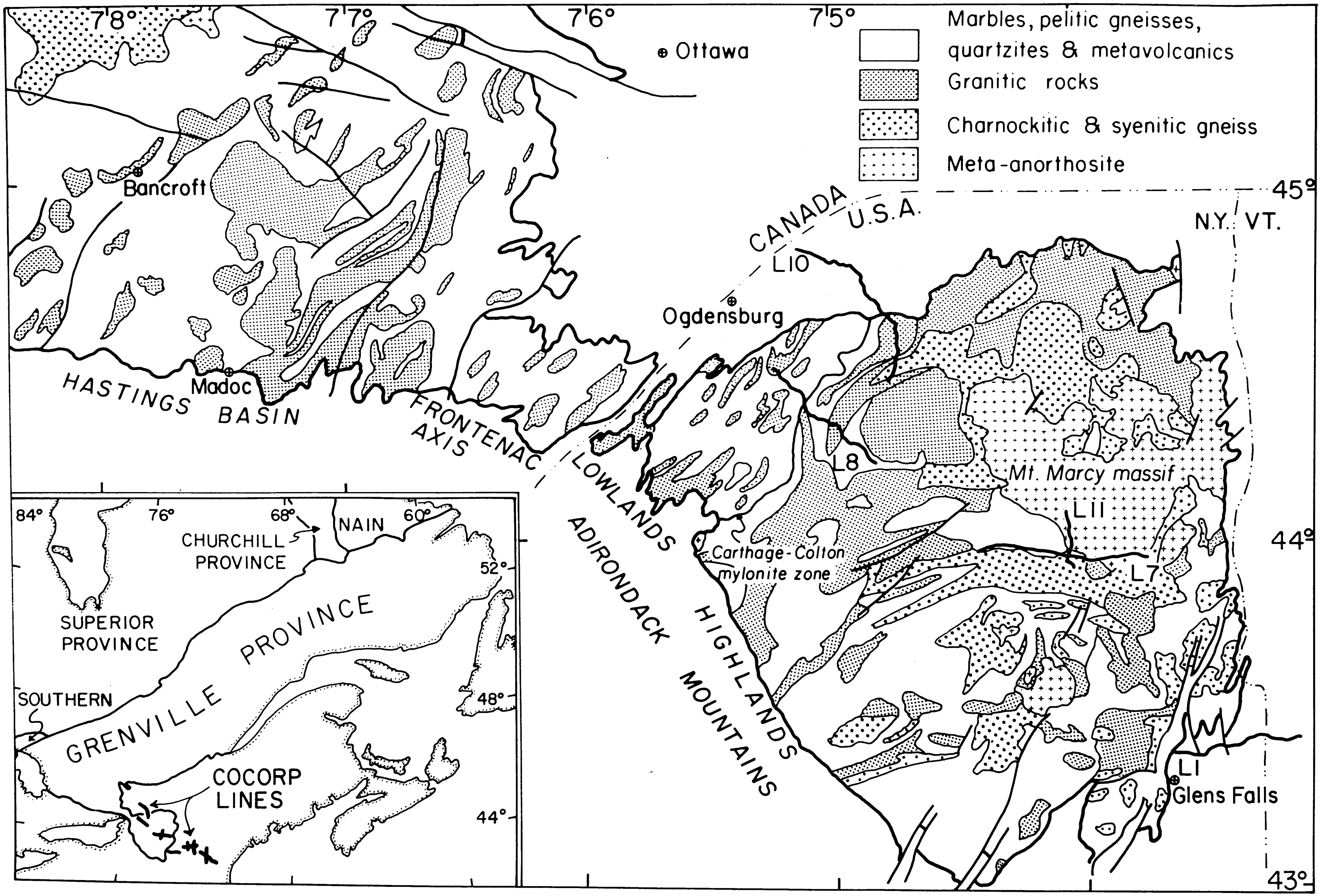


Figure 1: Location of the COCORP surveys in the Adirondack Mountains of the Grenville Province.

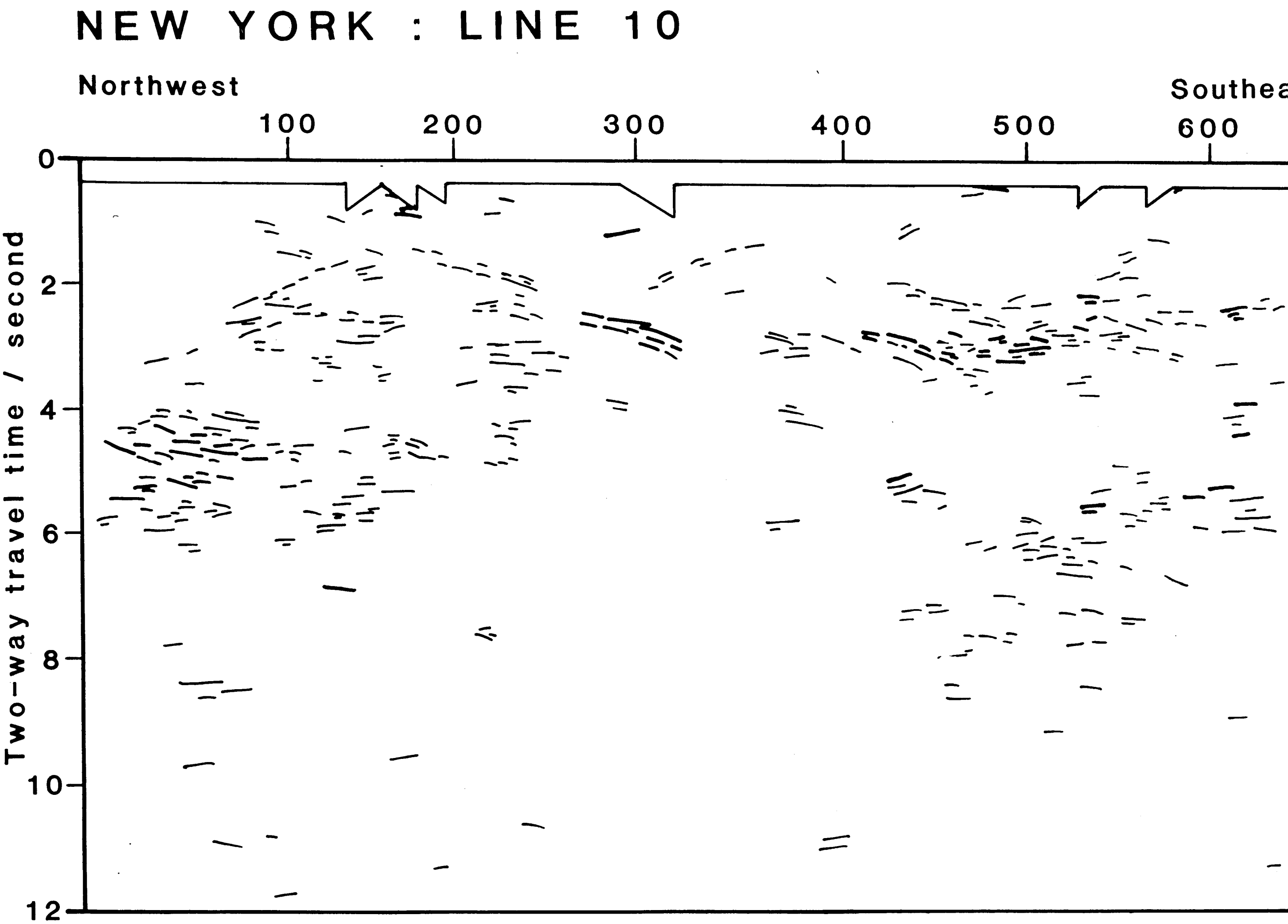
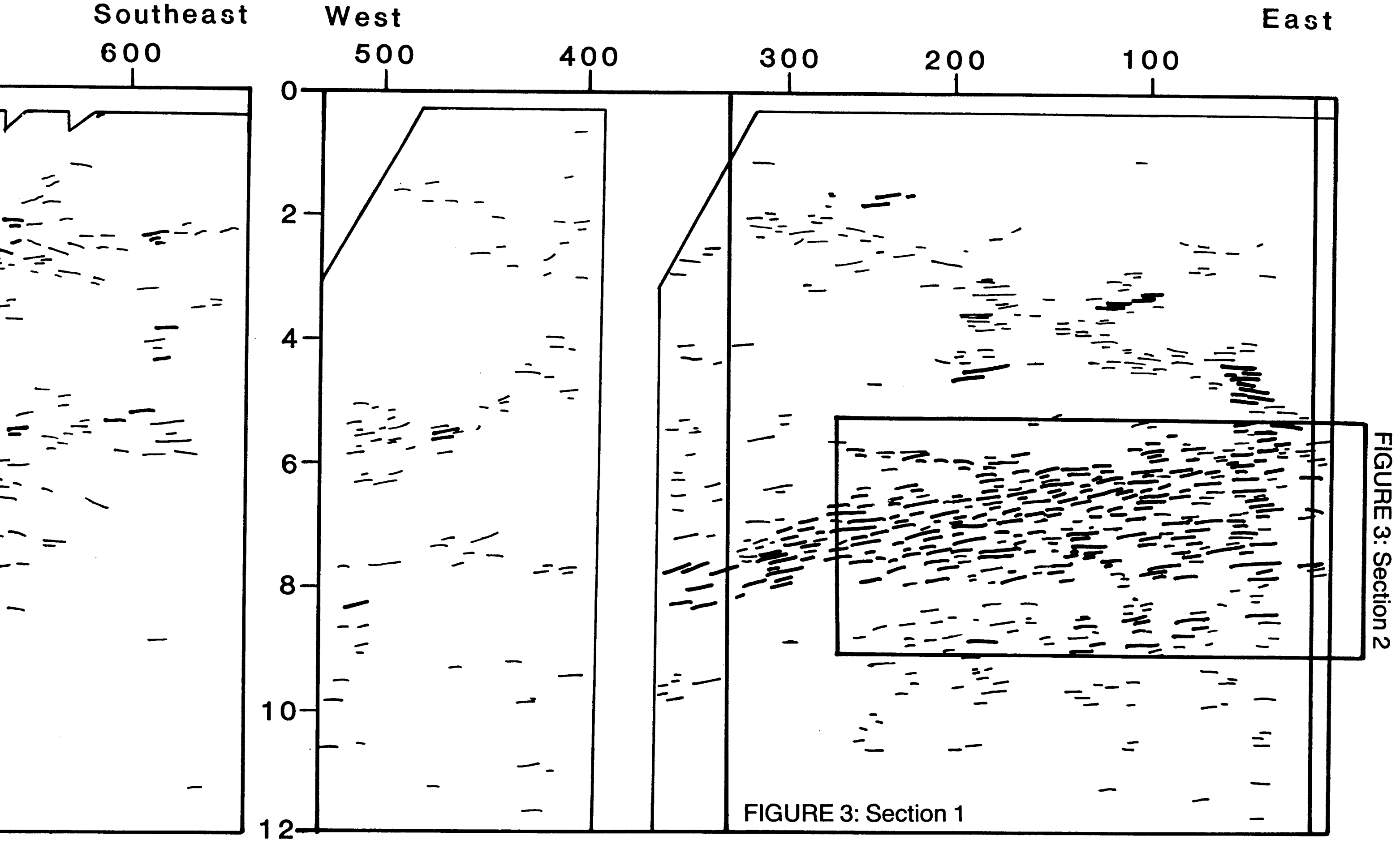
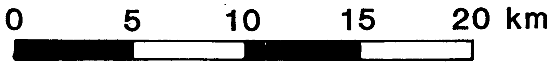

NEW YORK : LINE 10

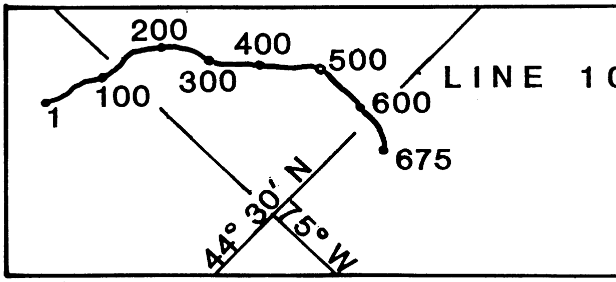
FIGURE 2

NEW YORK : LINE 7



Horizontal & vertical scale for line drawings





NEW YORK : LINE 1

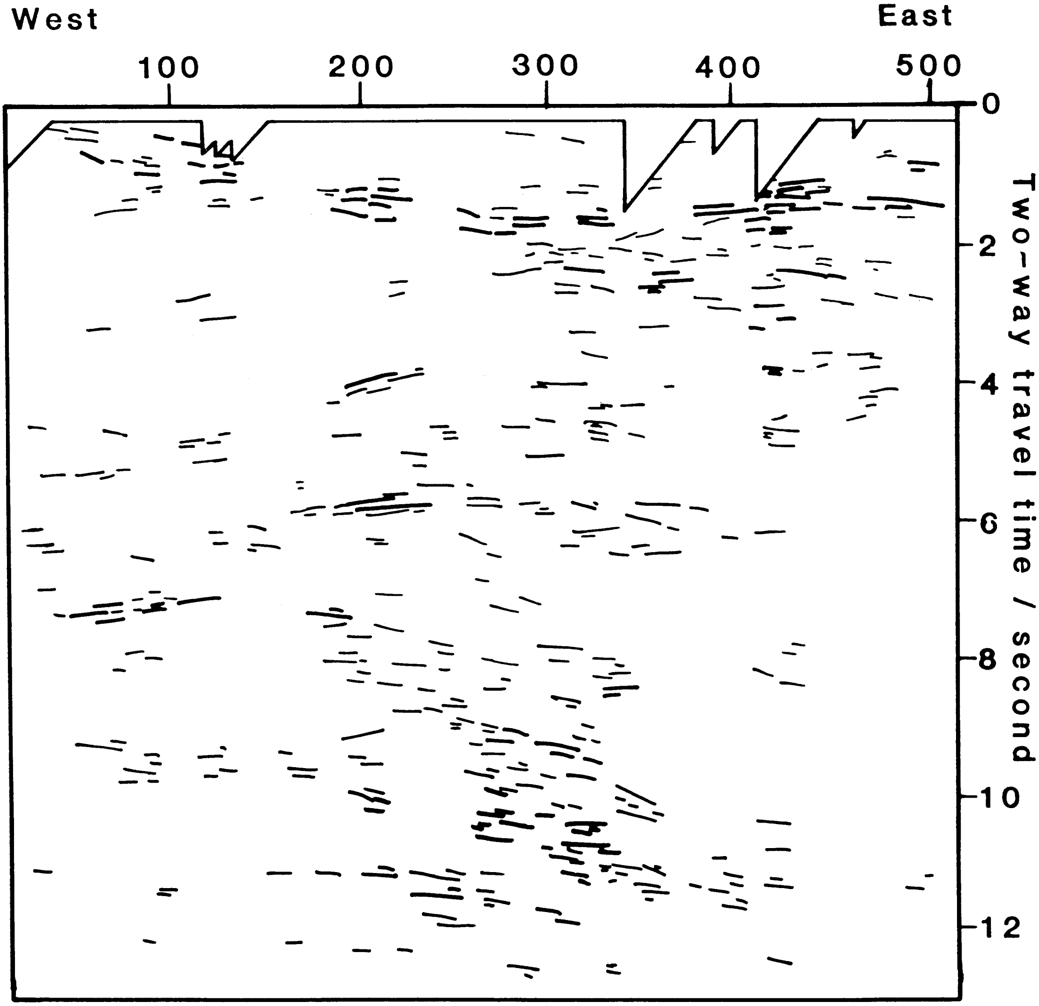
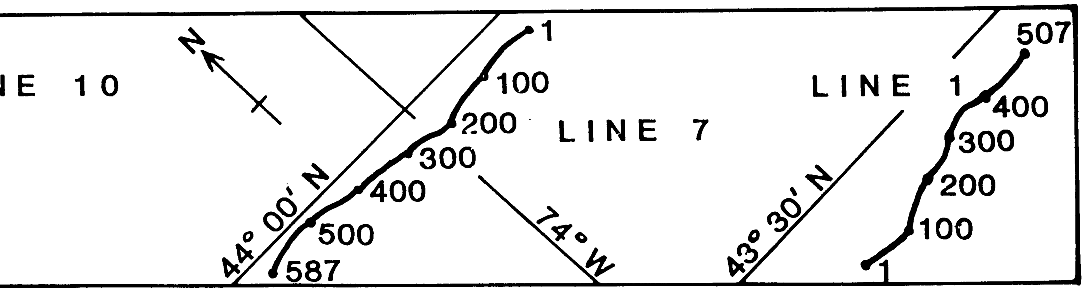


FIGURE 3: Section 2

km

LOCATION MAP : LINES 1, 7 & 10



NEW YORK: LINE 7 SECTION 2: MIGRATED

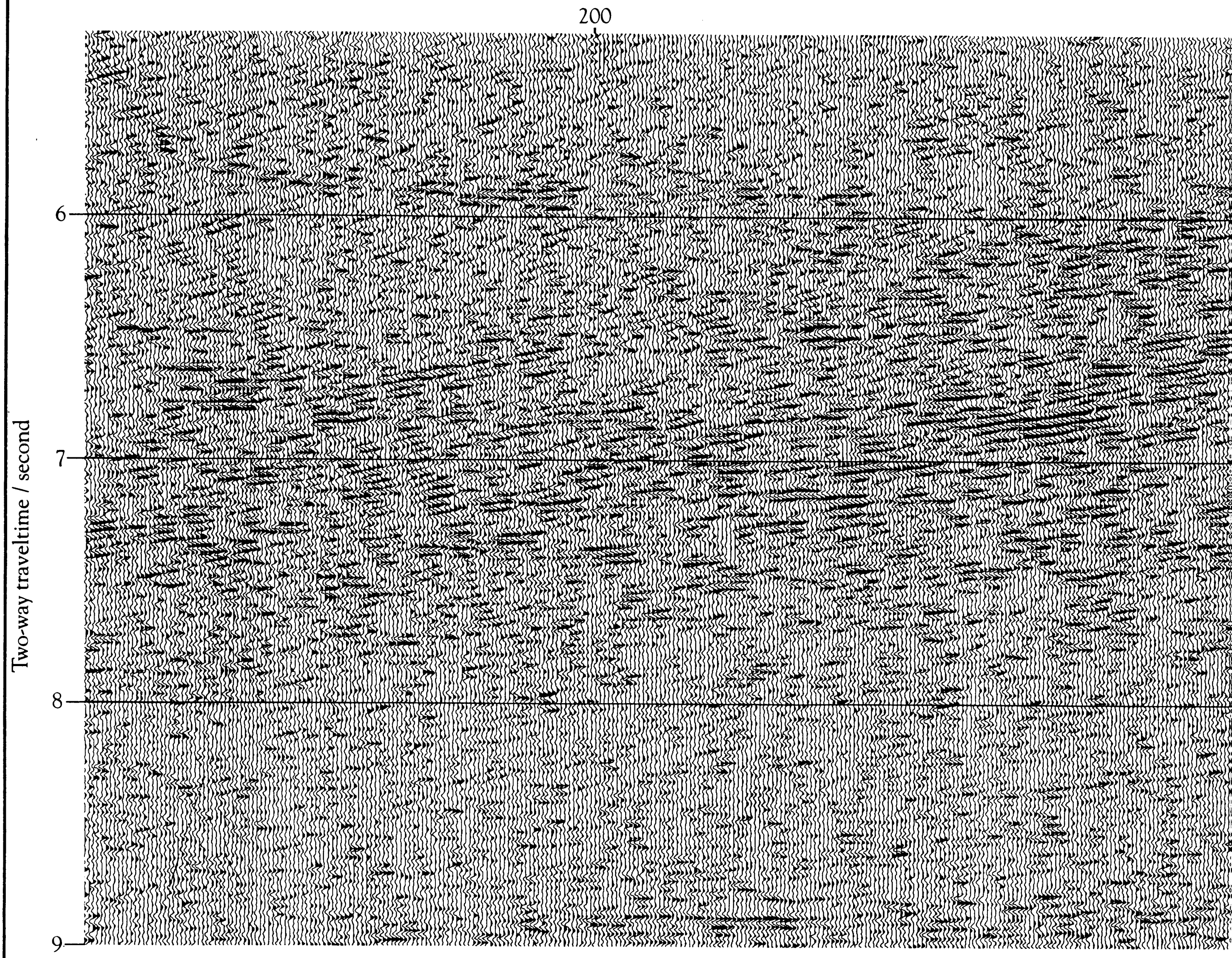
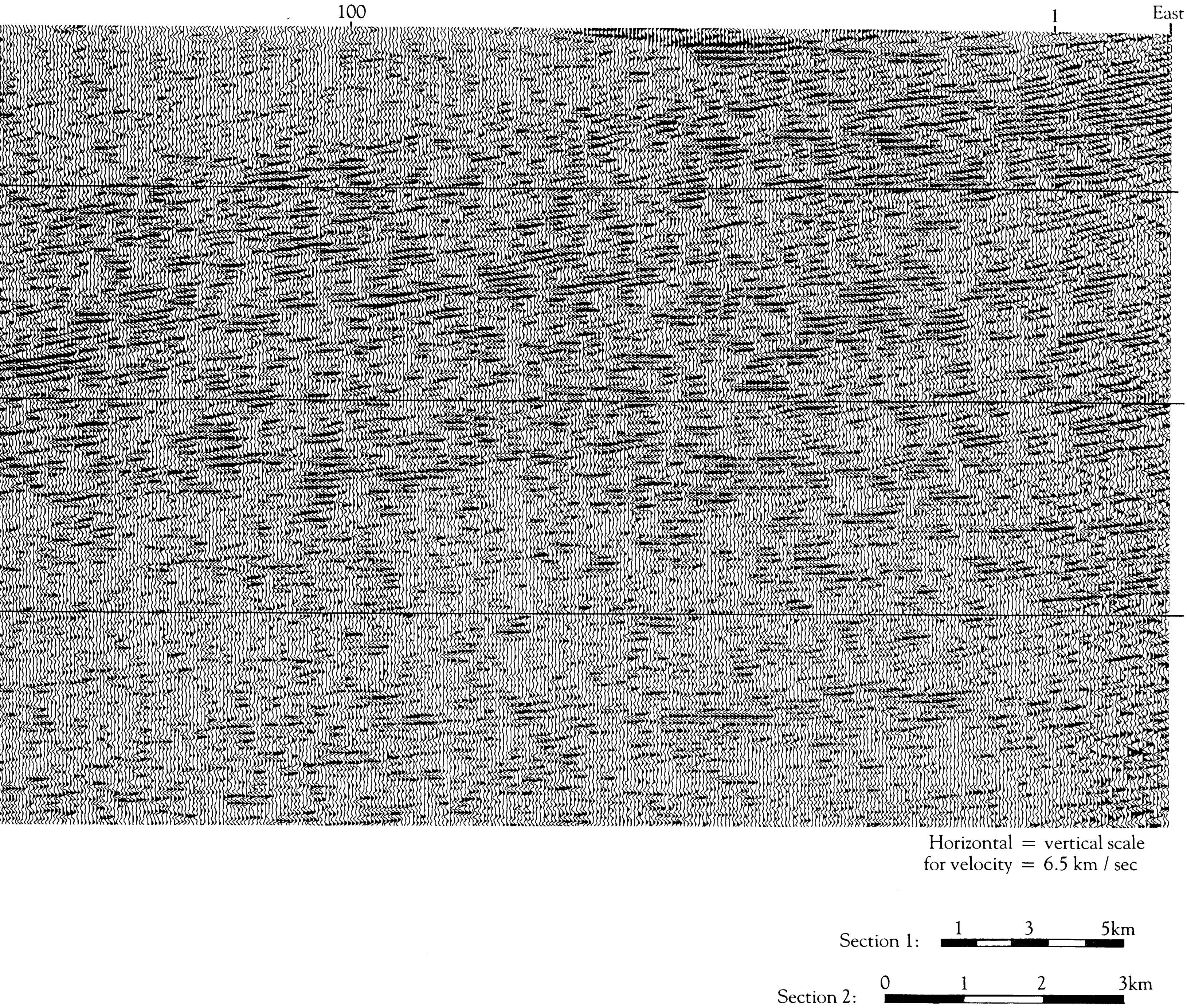
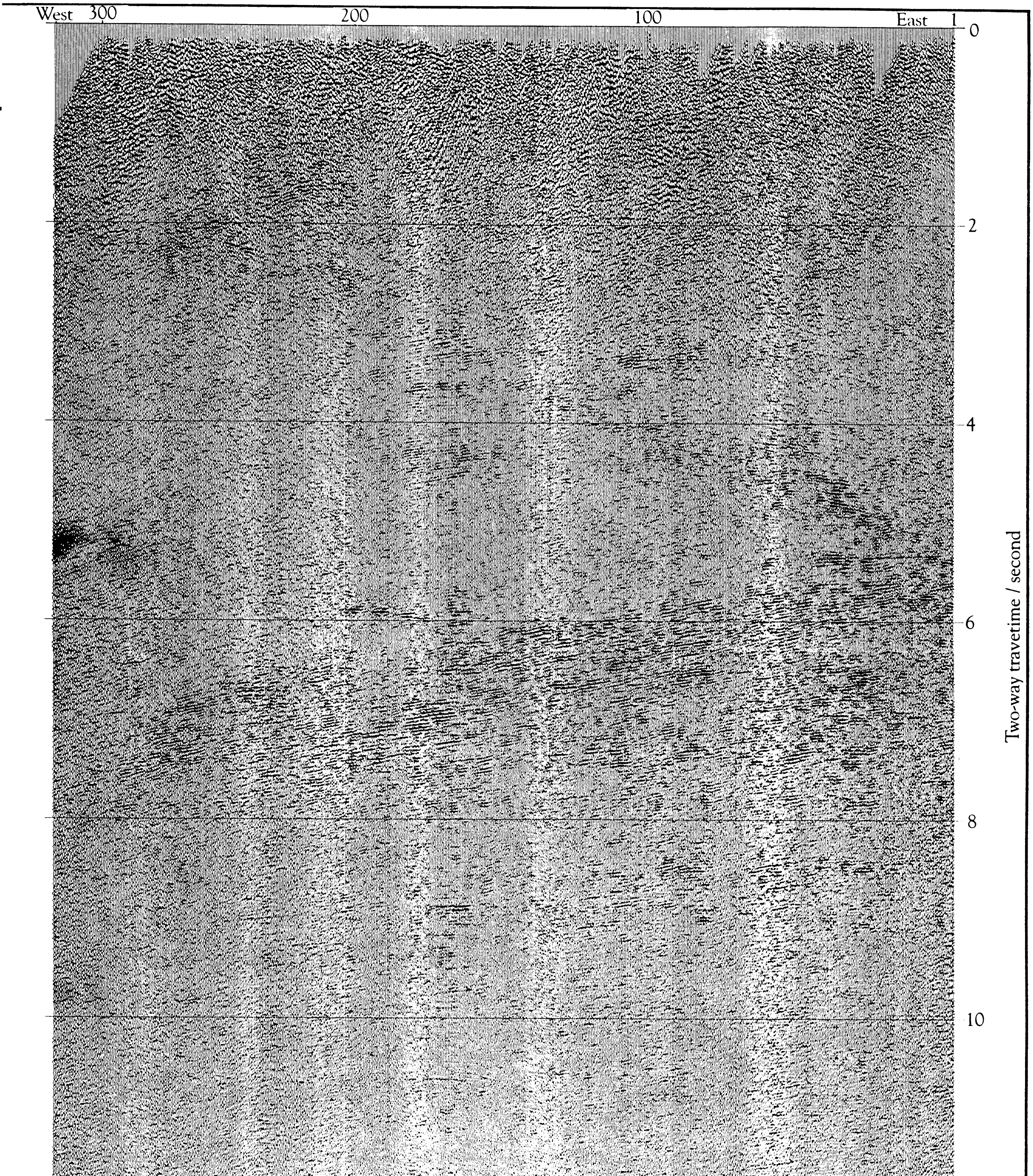


FIGURE 3



SECTION 1: UNMIGRAT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