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Walter A. Anderson, State Geologist

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Title: *Processing and Preliminary Interpretation of Bottle Lake Seismic Reflection Data*

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Special Geological Studies in the Department of Energy's Proposed Candidate High-level Nuclear Waste Sites in Maine

Introduction

In January, 1986, the federal Department of Energy released its Draft Area Recommendation Report which identified two granitic plutons in Maine, the Sebago batholith and the Bottle Lake Complex, as candidate sites for a high-level nuclear waste repository. The Maine State Legislature followed this action in early 1987 with a special appropriation to the Maine Geological Survey for the purpose of conducting studies intent on gathering additional, high quality, detailed geologic information with which to further assess the Department of Energy's designation of these areas. This report is one of a series of reports detailing the results of those studies.

In order to best utilize the funds provided by the Legislature, the Maine Geological Survey designed a research program which concentrated the majority of effort in the Bottle Lake Complex which, to that date, was the poorer studied of the two areas. The funds provided the Maine Geological Survey with the opportunity to contract services from some very well respected geologists and geophysicists working in Maine and elsewhere in the country. Our research program was divided into four parts: (1) Lineament studies of both the Bottle Lake Complex and Sebago batholith; (2) Bedrock mapping in the Bottle Lake Complex; (3) a gravity study of the Bottle Lake Complex; and (4) a seismic reflection analysis of the Bottle Lake Complex. Each of these studies is described more completely in the following sections.

Lineament Study (Open-File Report 90-25a)

The lineament study was conducted by Bradford Caswell of Caswell, Eichler, and Hill, Inc., a geological consulting firm with an extensive record of similar work in Maine. For both the Bottle Lake Complex and Sebago batholith, Maine Geological Survey file aerial photographs at a scale of 1:40,000 were interpreted for lineaments. Individual interpreted aerial photographs were submitted to the Survey where the final compilation from photograph to map was done through use of the Survey's geographic information system. This compilation eliminates the duplication of individual lineaments discussed in this report, which the compilation postdates. The lineament maps at a scale of 1:100,000 are presented as plates at the back of the Caswell, Eichler, and Hill report.

Bedrock Mapping (Open-File Report 90-25b)

Bedrock mapping was conducted in the Bottle Lake Complex during the summer and fall of 1988 by John T. Hopeck, a doctoral candidate at Queens College, New York with considerable experience mapping the complex geology of eastern Maine. The goal of this investigation was detailed mapping of joints and shear zones within the pluton. By combining detailed analysis of shear zones with understanding of the geology of surrounding rock units, a more thorough understanding of the timing of faulting in the Bottle Lake Complex was realized.

Gravity Study (Open-File Report 90-25c)

One of two geophysical studies in the Bottle Lake Complex, a gravity study was conducted by William E. Doll, Colby College, and student Stephen Potts during the summer and fall of 1988. Aimed at augmenting the sparse gravity data base for the region and defining the subsurface geometry and homogeneity of the complex, this work consisted of taking accurate gravity measurements at nearly 200 sites. Various analytical techniques were used to generate contoured gravity anomaly maps and models of the complex's geometry at depth. When combined with the seismic data described in the next section, these data constrained the bottom of the complex within the 3.5 to 4.5 km depth range and showed that the contacts with country rocks dip inward toward the center of the complex.

Seismic Reflection Study (Open-File Report 90-25d)

During October and November 1988, a total of 27 miles of seismic reflection data were collected in the Bottle Lake Complex by Western Geophysical Company, Houston, Texas, under contract with the Maine Geological Survey, using four Vibroseis trucks and a full compliment of recording and processing equipment. The digital records from this study were processed and analyzed by John Costain, Virginia Polytechnic Institute, over the following year and a half. The seismic sections resulting from this investigation, shown as plates in Costain's report, show the base of the Bottle Lake Complex at 1.5 to 2 seconds two-way travel time which corresponds with the depths defined in the gravity study. Perhaps the most prominent feature of the seismic sections is the steeply dipping Norumbega fault zone which is seen to offset the base of the crust at 30-32 km depth. Additional interpretation suggests that the Bottle Lake Complex is heterogeneous and has a series of faults below it.

Acknowledgements

The Maine Geological Survey thanks, in particular, the land owners in the area of the Bottle Lake Complex for their permission to conduct these investigations on private land. These include Georgia-Pacific Corporation, International Paper Company, and the Penobscot Nation. The residents of the town of Lee were most understanding when traffic was disrupted by seismic data acquisition.

Maine Geological Survey
Open-File 90-25d

Processing and Preliminary Interpretation of Bottle Lake Seismic Reflection Data

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PURPOSE OF STUDY

The objective of this study was to examine the shallow and deep crust beneath the Bottle Lake Complex using reflection seismology. The intent was to provide three-dimensional control to assist in determining shallow pluton geometry, and to complement other studies that place the crust in a regional tectonic setting. Preliminary geological and geophysical results related to the seismic data were reported by Doll et al. (1989).

The two lines are shown superimposed on the geologic map of Ayuso (1984) in Figure 1, and on the tectonic lithofacies map of Williams (1978) in Figure 2. The lines are shown on magnetic and gravity maps in Figure 3 and Figure 4, respectively.

DATA ACQUISITION PARAMETERS

The Bottle Lake seismic lines were recorded in late October 1987 by Western Geophysical seismic crew 717 with a 120-channel digital field system and four vibrators. A symmetric split-spread field configuration was used, with 165 feet (~50 m) receiver group spacings and appropriate source moveups to yield nominal 30 fold data. Line 1 initially was recorded with near and far offsets of 330 feet and 10,065 feet (~3 km), respectively, but after Station 488, in order to increase the signal-to-noise ratio at the near traces, the offsets were increased to 495 feet (~151 m) and 10,230 feet (~3.1 km). Offsets were further increased for acquisition of Line 2 to 660 feet (~173 m) and 10,395 feet (~3.17 km). A linear 14-56 Hz two-octave upsweep of 24 sec length was used throughout to give 8 sec of full correlation time. Vertical stacking of individual sweeps was done in the field.

With the exception of the differing spread configurations, all other recording parameters remained the same throughout the data acquisition, and are summarized in Table 1.

TABLE 1. RECORDING PARAMETERS

Rec. Instruments:	TI DFS V 120-channels
Source :	4 LRS 311 vibrators
Sweep :	14-56 Hz 24 sec
Group Interval :	165 feet
Spread:	10065-330-X-330-10065feet
	10230-495-X-495-10230 feet*
	10395-660-X-660-10395 feet**
Geophone Array :	24 geophones/415 feet inline
Source Array:	4X6/330 feet inline
Sample Rate:	4 ms
Record Length:	32 sec
Rec. Filters:	Low 12 Hz High 64 Hz
	Notch in
Rec. Format:	SEG-B
Gain Mode:	Instantaneous Floating Point

* Line 1 increased offset past STA 488
** Geometry for Line 2

DATA PROCESSING PARAMETERS

Processing of the Bottle Lake seismic lines was done at Virginia Tech in the Regional Geophysics Laboratory on a VAX 11/780 with an FPS 120-B array processor using DISCO (Cogniseis Inc.) software. The processing sequence included crooked line geometry, predictive inverse filtering (deconvolution), iterative velocity/residual statics, and finite-difference migration. The crooked-line geometry used for processing is shown in Figure 5. Non-standard processing steps included extended Vibroseis correlation and automatic line drawings. The processing sequence appears in Table 2.

Following demultiplexing, the record length was padded with zeroes to 41 sec and extended vibroseis correlation was carried out to produce 17 sec data. This additional 9 sec of data was necessary to study lower crustal reflections and required no extra field effort. Although the frequency bandwidth of the data

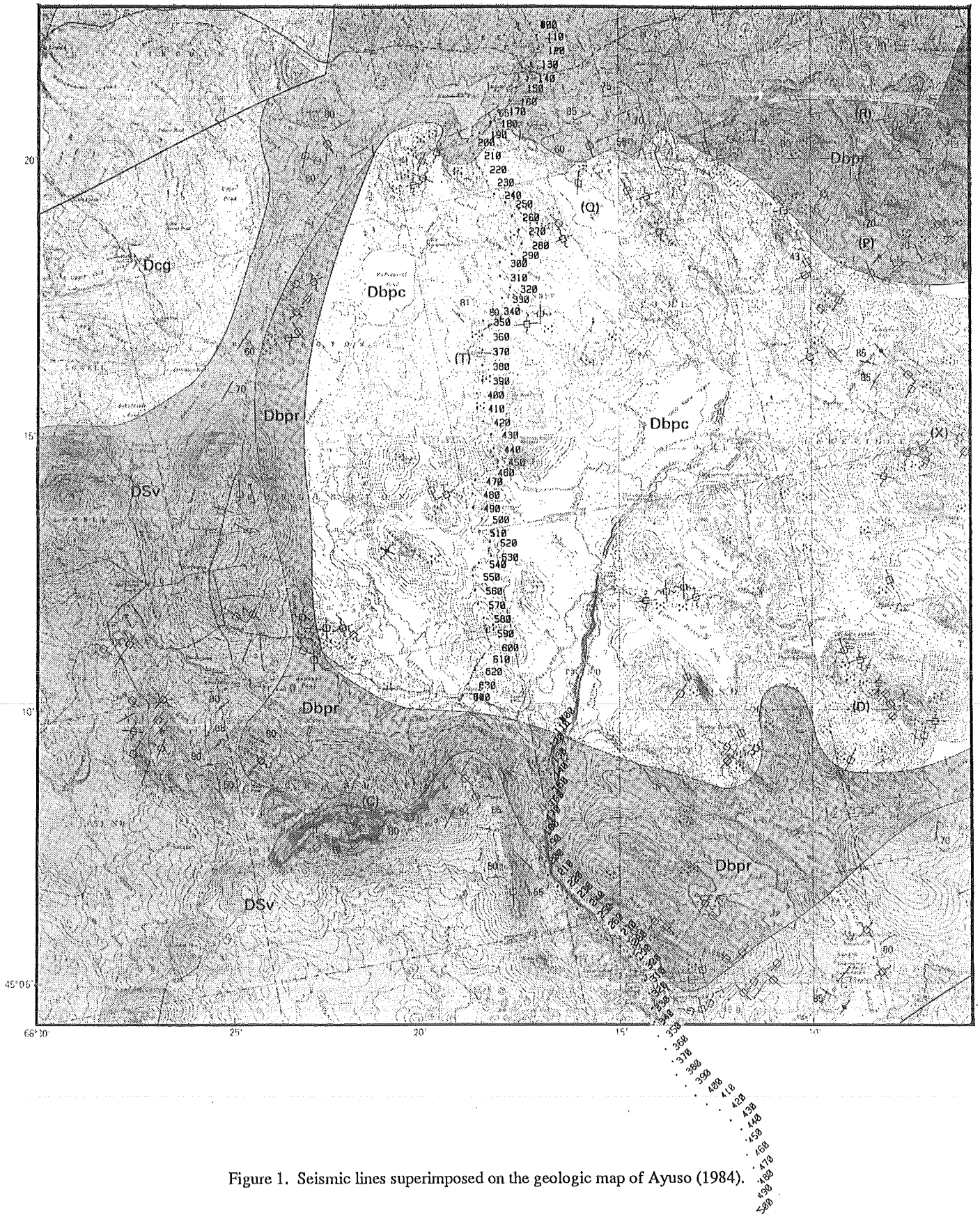

Figure 1. Seismic lines superimposed on the geologic map of Ayuso (1984).

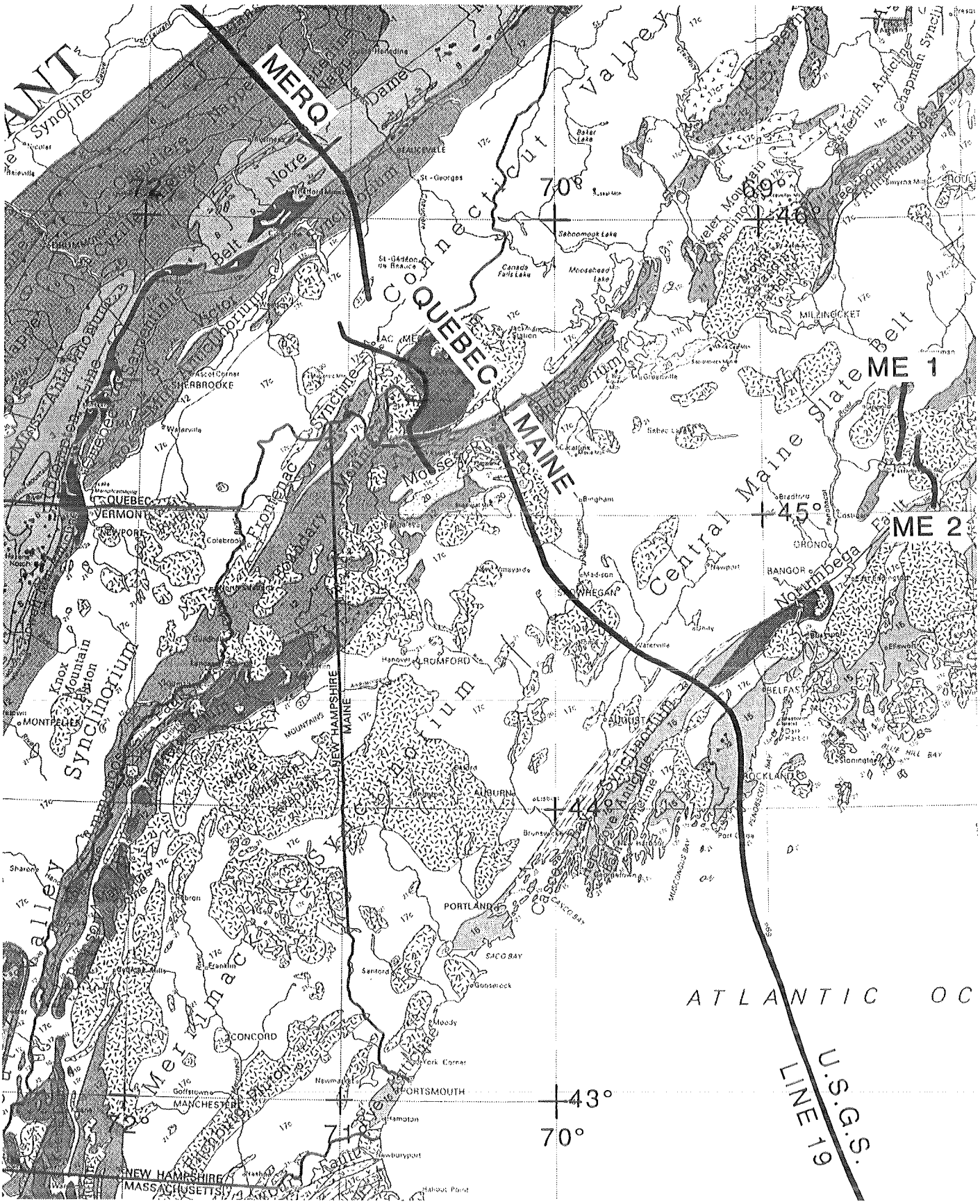

Figure 2. Seismic lines superimposed on the regional geologic map of Williams (1978).

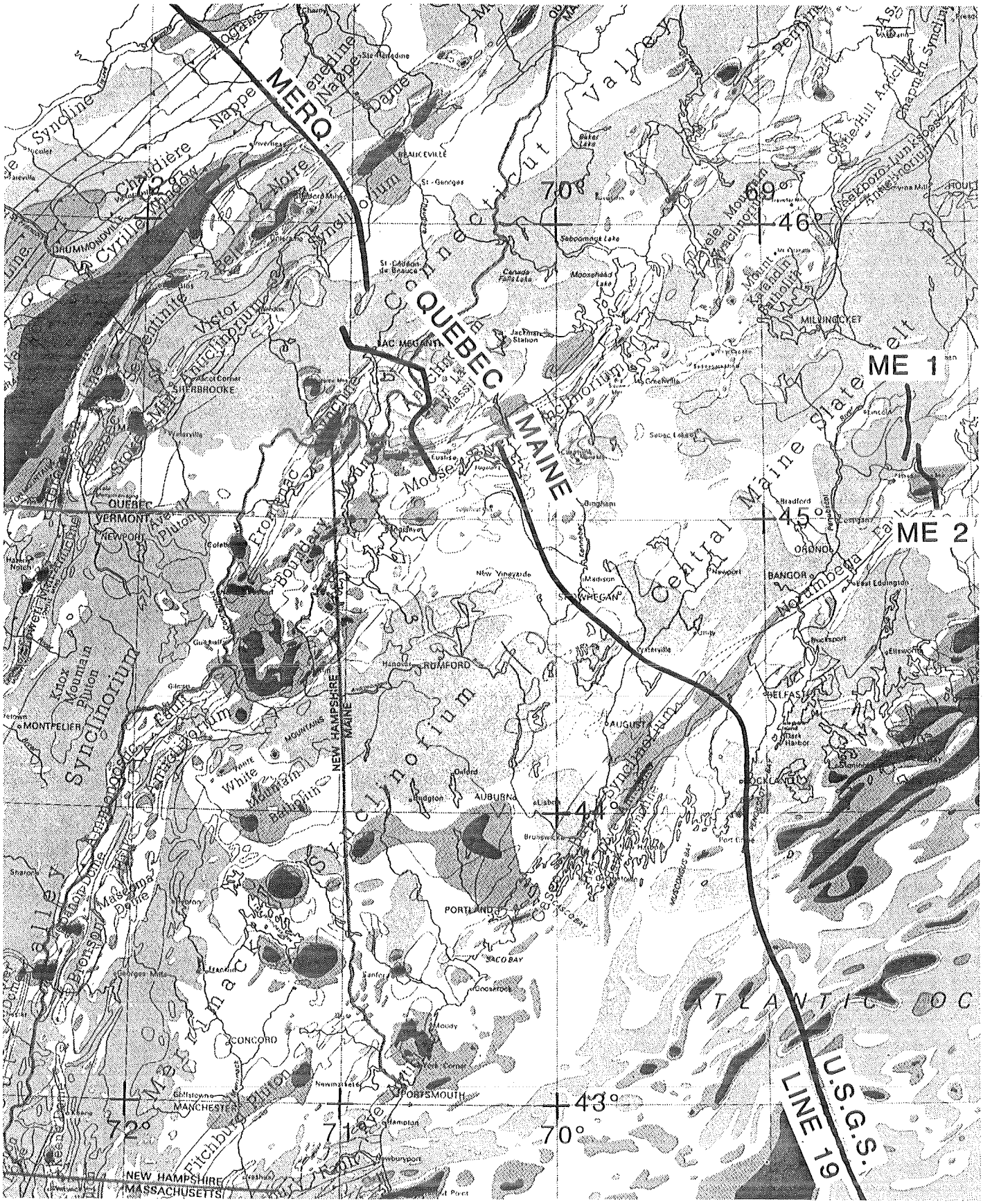

Figure 3. Seismic lines located on magnetic map: Magnetic map from Zietz et al. (1980).

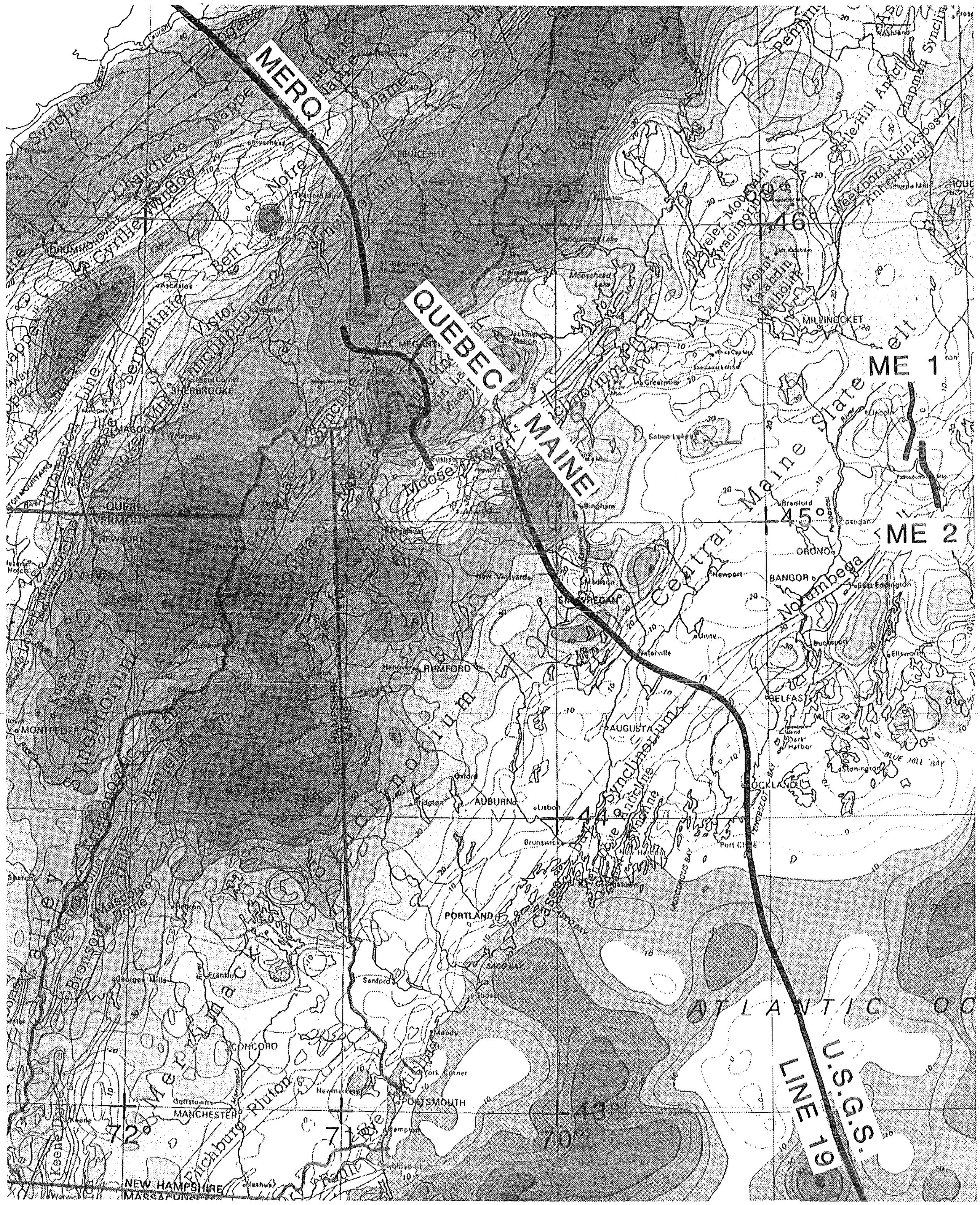

Figure 4. Seismic lines located on gravity map: Gravity map from Haworth et al. (1980).

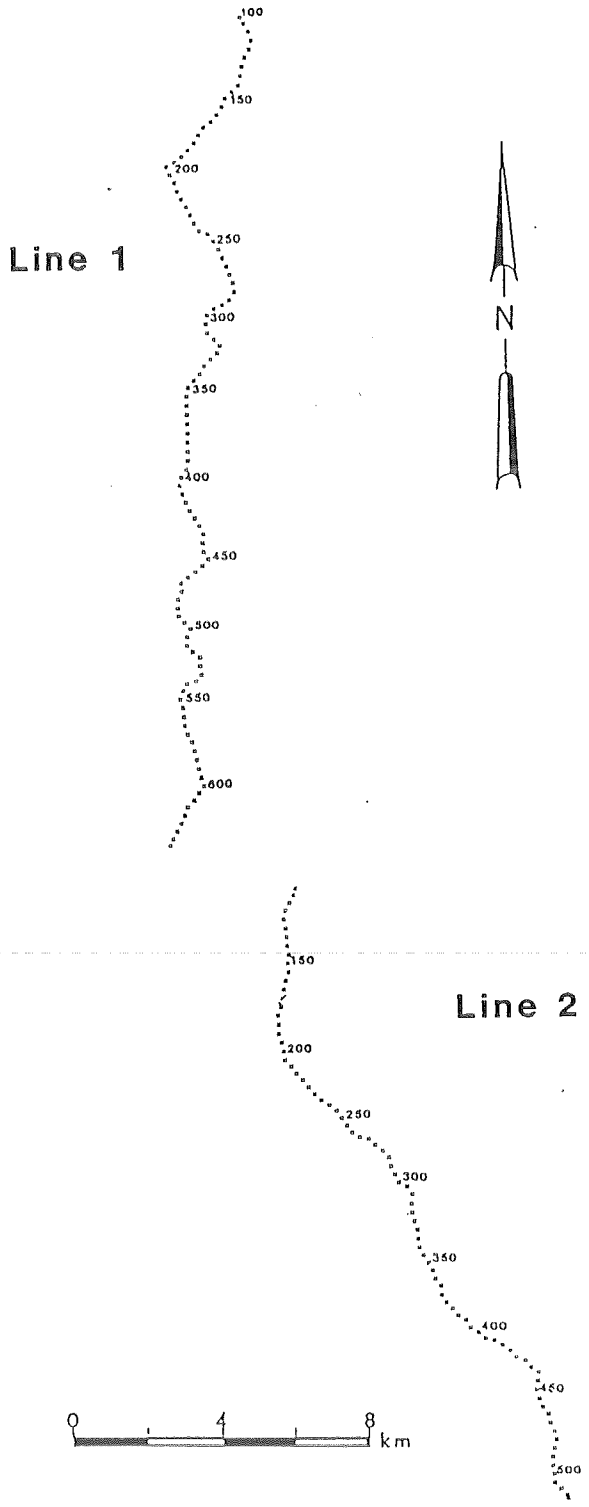

Figure 5. Crooked-line geometry used to process Lines 1 and 2.

TABLE 2. PROCESSING SEQUENCE

Demultiplex	
Record pad	
Vibroseis correlation with recorded sweep	
Trace edits/datum statics	
CDP crooked line sort	
Predictive inverse filtering	
Bandpass filter	
--> Velocity analysis	
Residual statics	
NMO correction	
Mute/Scaling	
CDP stack	
Bandpass filter/Scaling ---------->	Migration (after resampling to 8 ms)
Display	Bandpass filter/Scaling
Automatic line drawing	Display
	Automatic line drawing

progressively decreases past the full correlation time of 8 sec, the frequency bandwidth at 17 sec was 14-40 Hz, and at Moho times (11 sec) was 14-50 Hz.

In the Bottle Lake area the presence of glacial drift overlying crystalline rock created a seismic wave guide that required the use of inverse filtering to remove unwanted reverberations. The reverberation problem was acute in Line 2, obscuring most of the shallow data, but was effectively reduced with standard prediction inverse filtering (predictive deconvolution). This technique, applied to the CDP gathers, measurably improved the quality of both seismic lines.

Velocity determination was by constant velocity stacks in conjunction with iterative surface-consistent residual statics to update the stacking velocities/statics. For Line 1, four sets of velocity analyses were obtained at thirteen locations along the profile, and six sets of residual statics were applied to the data. Along Line 2, three sets of velocities at twelve locations were determined, and six sets of residual statics were applied.

Although the data were acquired and processed individually along two separate profiles, the lines were located with respect to each other (see Fig. 5) such that they could be successfully displayed as one continuous section. Prior to migration the data were resampled to 8 msec, the two lines were composited as a single line and migrated to 13 sec using a DISCO finite difference migration scheme.

The final processing step was to apply an automatic line drawing (ALD) algorithm (Çoruh et al., 1987). The unmigrated ALD is shown in Figure 6. The migrated and interpreted ALD is shown in Figure 7.

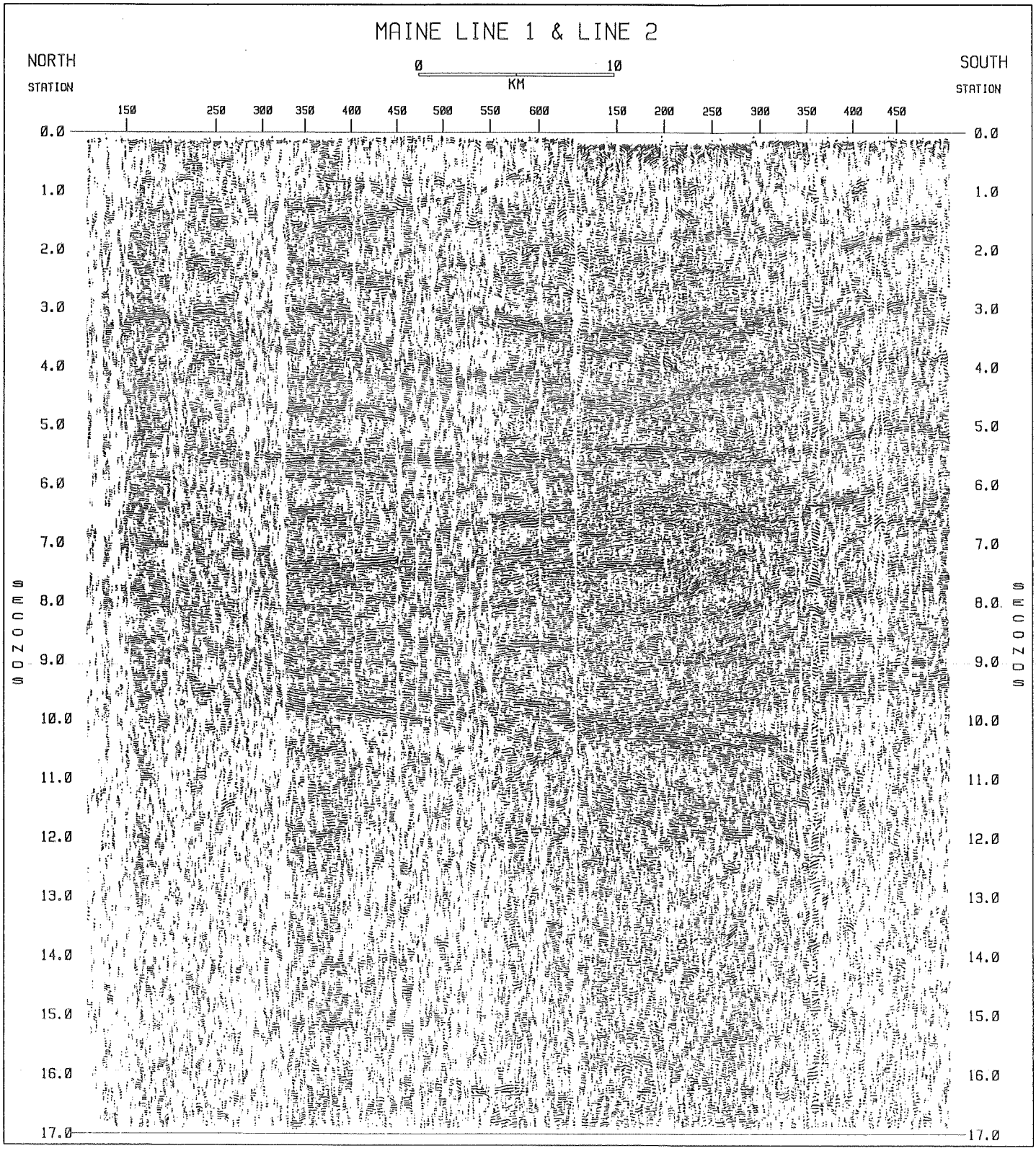

Figure 6. Automatic line drawing of unmigrated Lines 1 and 2: This figure is the same as Plate III. Full-scale copies of the unmigrated and migrated seismic data are included with this report.

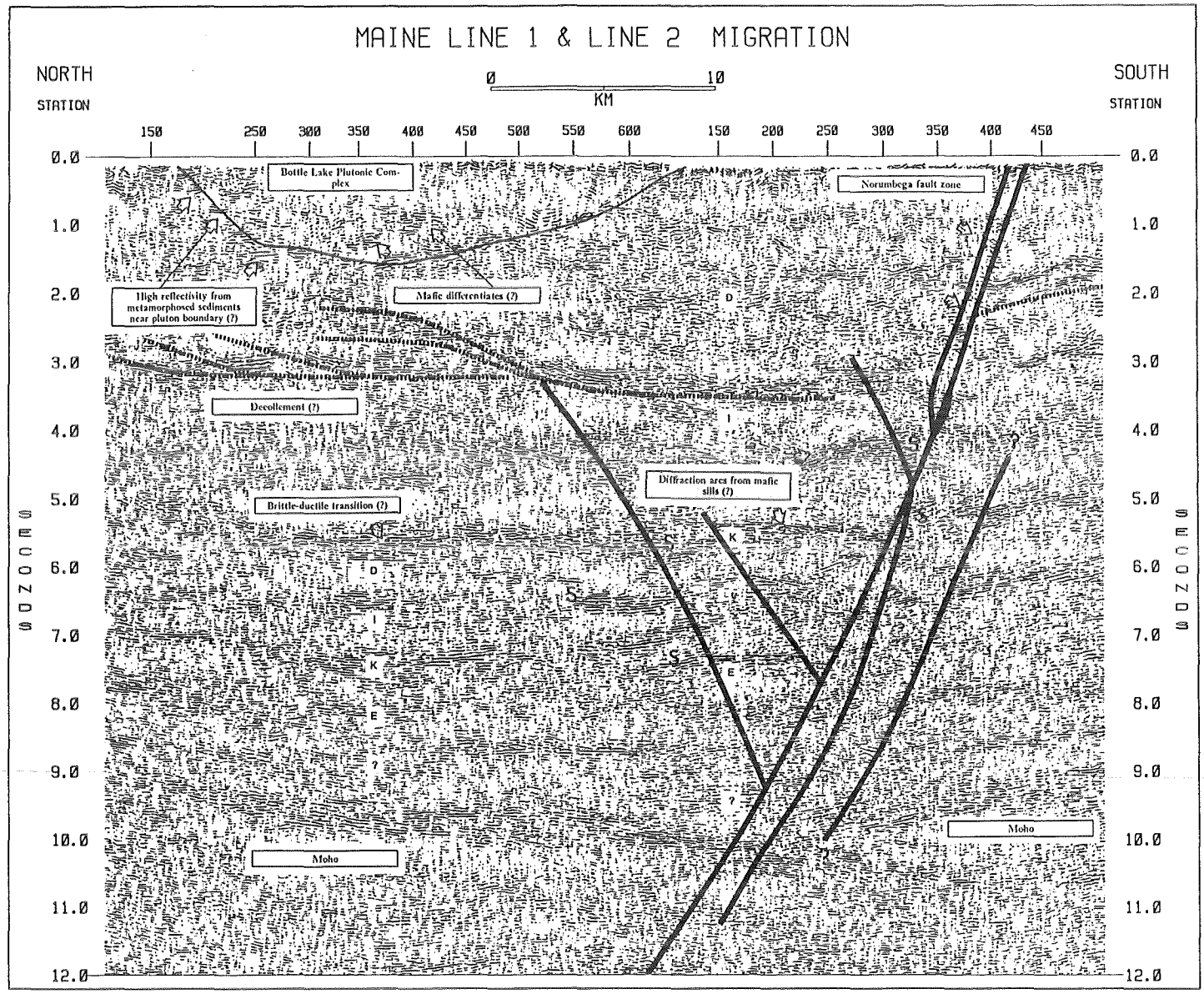

Figure 7. Automatic line drawing of migrated and interpreted Lines 1 and 2: This is the same as Plate IV. Full-scale copies of the unmigrated and migrated seismic data are included with this report. The Norumbega fault zone is interpreted as the southeastern branch of a negative flower structure. Other surface manifestations of the flower structure may be the fault segments mapped at the surface and parallel to the Norumbega fault zone. Most of the "seismic crocodiles" (see Fig. 6 or Plate III) have disappeared after migration, suggesting that they may have been portions of diffraction arcs. The exception occurs under Station 500 on Line 1 (CDP 1000) at 3 sec. Discontinuous, bright reflection segments may be associated with different metamorphic mineral assemblages near the contact of the Bottle Lake Complex. Indicated is a décollement and associated duplex structures that may continue across the Norumbega fault zone. "S" are interpreted to be diabase (Mesozoic) sills from feeder dikes injected along the Norumbega fault zone. The three vertical white "no-record" strips beneath Station 350 on Line 1 (CDP 700), Station 590 on Line 1 (CDP 1180) and Stations 48-63 on Line 2 (CDPs 1370-1400) may be the seismic signatures of Mesozoic feeder dikes. These areas are not associated with low fold.

Full-scale copies of the unmigrated (Plate I) and migrated (Plate II) wiggly line-variable area seismic sections are included with this report. Full-scale copies of the automatic line drawings are shown unmigrated in Plate III and migrated in Plate IV. Note that for the migrated sections (Plates II and IV) station locations have been renumbered so that the two lines could be migrated as one. Ground locations on Plates II and IV must be referenced to Plates I and III.

TECTONIC FRAMEWORK

The seismic lines were located over the Bottle Lake Complex (Fig. 1), and extended south to the Norumbega fault zone. The Norumbega fault zone consists of several high-angle, northeast-trending faults in a zone at least 13 km wide (Wones, 1978; Ludman, 1986a, 1986b). Ludman (1981) discussed the significance of transcurrent faulting in eastern Maine in the broad zone of cataclasis that extends for at least 45 km across strike between Calais and Topsfield (Fig. 2).

The zone has been considered by others to be a major tectonic element because it separates two geochemically distinct granitoid source regions (Andrew et al., 1983), and because it can be traced from south-central Maine to the Canadian border (Fig. 2). It has been postulated to mark the location of the post-Acadian suture between Avalonia and North America, that is, the western edge of the Avalonian "continent". Ludman (1986b) questioned the Norumbega fault zone as the site of such a proposed megasuture, and suggested instead that it is the locus of relatively unimportant later strike-slip faulting. Neuman (1984) concluded that a single faunal province extended from northern Maine to the coast during the Ordovician. Most of the accretionary history of Maine thus ended before the Silurian; the faults now mapped in the Silurian-Devonian strata were formed by later reactivation of major pre-Silurian boundaries (Ludman, 1986b). Ludman pointed out that if the Norumbega fault zone is a megasuture between distinct crustal blocks, then the suturing must have occurred before deposition of the Silurian-Devonian strata in which the zone occurs, because there is little offset of these strata in eastern Maine; the Norumbega fault zone lies entirely within a Silurian-Devonian stratigraphic package. Ludman concluded that the boundaries between lithotectonic belts in eastern Maine formed no later than Early Devonian, and that Eastern Maine has acted as a single tectonic entity since then. The Norumbega fault zone is not the site of a major post-Acadian fault boundary between the North American craton and a second continental plate. Ludman (1986b) concluded that the likely source of the geochemical discontinuity must lie beneath the cover rocks in the pre-Silurian "basement".

Unless the rocks exposed at the surface on both sides of the Norumbega fault zone are allochthonous, such differences in protoliths suggest that the seismic signatures from crustal rocks on each block might be quite different. If the Norumbega fault zone marks the subsurface location of a megasuture, it would have to be identified in the infra-structure of the orogen on the basis of reflection seismic data, because rocks on opposite sides of the Norumbega fault zone fit into a simple sedimentologic model; there is no evidence for either structural or metamorphic discordance in the rocks exposed at the surface. As noted below, the seismic data are not demonstrably different on each side of the Norumbega fault zone. One possible way to accommodate differences between supra- and infra-structure is by large-scale horizontal transport as a result of horizontal compression or transpression.

INTERPRETATION OF THE SEISMIC DATA

Much of the interpretation that follows is speculative because

1. The seismic line is relatively short (43 km),
2. Much (most?) of the seismic events that we see in data from the deep crust in other orogens we still do not understand, and
3. The structural connections between supra- and infra-crustal structure in most orogens is not understood (for this and many other reasons we need more crustal seismic data. How deep can we project the surface geology?)

Geometry of the Bottle Lake Plutonic Complex

The most reflective part of the pluton geometry appears to be the bottom of the pluton (Fig. 7) where the dips are not very great. Perhaps this is because the signal-to-noise ratio is better where the contacts are less steep. A more likely possibility suggested by Allan Ludman, however, is that lateral changes in reflectivity occur in metamorphosed sediments because of the quite different mineral assemblages that can form in lateral facies changes in sedimentary rocks where the carbonate content, for example, increases or decreases. Although the rocks are essentially all at the same metamorphic grade, the reflectivity of the mineral assemblages depends upon the metamorphic mineralogy adjacent to the pluton.

According to Figure 7 and an assumption of 6 km/sec for the pluton velocity, the maximum thickness of the plutonic complex in the vicinity of the seismic line is about 5 km near Station 370 on Line 1. The seismic data provide control for off-line determinations of pluton thickness using gravity data.

The relatively horizontal reflections (see Fig. 7) that appear above the base of the pluton we interpret to be from mafic differentiates from within the pluton complex. We also interpret vertical no-record strips near Stations 360 (Line 1) and 160 (Line 2) on Figure 7 to be from Mesozoic mafic dikes. The presence of mafic differentiates, Mesozoic intrusive dikes and sills, and the nearby Norumbega fault zone suggest that the rocks within and proximal to the Bottle Lake Complex are sufficiently inhomogeneous and fractured that this complex is not a good candidate site for waste storage.

The relative reflectivity of the northward-dipping base(?) of the Bottle Lake Complex and the Lexington batholith (reproduced here as Figure 8 from Stewart et al., 1986) appear to be similar.

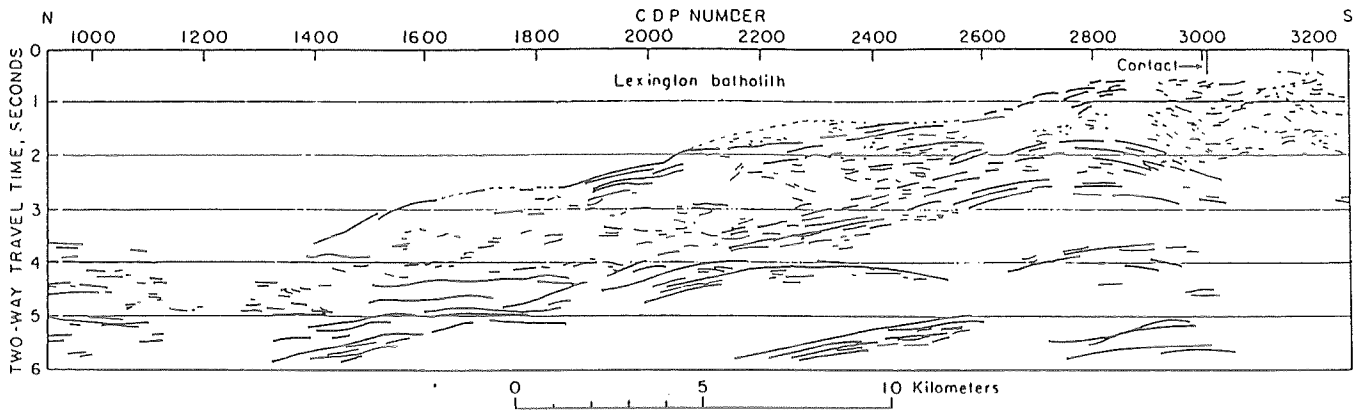

Figure 8. Line drawing of a portion of the Quebec-Maine line: A portion of Profile 3A. From Stewart et al. (1986).

Norumbega Fault Zone

One of the most prominent seismic signatures on the unmigrated data (Fig. 6 and Plate III) is a steeply-dipping zone (Fig. 7) interpreted as the Norumbega fault zone. On Plate IV (migrated data), reflection segments (labeled "S"on Fig. 7) terminate at this zone. The fault zone appears to cut the entire crust and projects to the surface at the approximate location of the northwestern edge of the mapped Norumbega fault zone. On Plate IV, the zone can be drawn in adjacent to short, high-amplitude reflection segments, from the intersection of the bow-tie (not perfectly migrated) to 9 sec at Station 118 (Line 2, CDP 1510), to 5.5 sec at Station 212 (Line 2, CDP 1700) to 3.5 sec at Station 268 (Line 2, CDP 1810) to about 2 sec at Station 275 (Line 2, CDP 1825). If one squints down the record section from the Moho end, it is possible to see a linear "fault shadow" that is en echelon in places, and dips steeply northward. This disrupted zone has survived all variations in data processing steps, and always emerges as steeply-dipping to the north. The geometry resembles that shown by Boone and Boudette (1989, Fig. 4) where the Norumbega fault zone is the boundary between the Gander Terrane and the Avalonian Terrane. The present depth to the Moho shown on their Figure 4 is exactly what we estimate from the Bottle Lake seismic data.

The steep attitude of the Norumbega fault zone as imaged on the Bottle Lake Complex lines is consistent with the interpretation of Ludman (1986b). That is, the simple through-going discontinuous zone on Figure 7 is not the seismic signature generally associated with the remarkable reflections from mylonites formed by the compressional or transpressional collision of continents, at least within our experience in the southeastern United States. Crustal reflectivity and reflection geometry appear to be similar on either side of the Norumbega fault zone, contrary to what might be expected if the Norumbega fault zone were a megasuture that separates blocks that acted as geochemically distinct granitoid source regions.

Grenville crust in the southeastern United States is commonly described as acoustically transparent, except where stretched by thinning or compressed during the formation of mylonites (Çoruh et al., 1987, 1988). The I-64 line in central Virginia is a striking example of this, where crustal reflectivity is restricted to stretched crust bounded on the surface by exposed Mesozoic basins (Çoruh et al., 1988). This is also the site of extensive Paleozoic development of mylonites during compression and transpression. The reflectivity of the crust beneath the Bottle Lake Complex is at least as high as that of Grenvillian crust beneath central Virginia.

The seismic geometry beneath the Bottle Lake Complex would allow a scenario of major pre-Silurian accretion followed by later (Alleghenian?) crustal thickening by overthrusting of thin (~8-12 km) crystalline sheets followed by erosion and relatively minor Mesozoic reactivation of the Paleozoic megasuture. The discordance in dip of reflection segments across the Norumbega fault zone appears to be the only difference in internal structure between the two blocks on each side of the Norumbega fault zone. Crustal reflectivity on each side of the Norumbega is about the same.

Flower Structures(?). If the Norumbega fault zone is the locus of major strike-slip displacement, then "flower structures" might be expected to develop near the Norumbega fault zone. The geometry of fault zones that make up such structures can be just about anything (Lemiszki and Brown, 1988). These might become zones of weakness that could become extensional cracks for later (Mesozoic?) injection of diabase. We have sketched in one possible flower structure, but at the present time, this interpretation is not entirely convincing. The fault segments parallel to the Norumbega fault zone as shown by Ayuso (1984) to the northwest (see Fig. 1) could be considered as part of the surface expression of the flower structure. The slightly deeper reflection segments beneath Station 38 on Line 2 (CDP 1350) at 3 sec, and Station 575 on Line 1 (CDP 1150) at 4-4.5 sec, and the overall character of the disrupted zones suggest that the

Norumbega fault zone might be the more prominent southeastern limb of a negative flower structure.

Mohorovicic Discontinuity

As far as reflection continuity is concerned, the base of the crust is the most conspicuous feature on Plate IV. Depth to the Moho is different on either side of the Norumbega fault zone. Using a velocity of 6.4 km/sec, the depth to Moho is 30.4 km (9.4 sec) southeast of the Norumbega, and about 32 km (10 sec) west of the Norumbega fault zone. We interpret the arcuate reflection geometry at the Moho to be a "bowtie" associated with offset at the Moho.

Diabase Sills(?)

One interpretation of the short, bright reflection segments (S) could be that they originate from diabase sills fed from feeder dikes emplaced along the Norumbega fault zone during Mesozoic crustal extension. This interpretation is admittedly biased by other seismic data that we have seen from the Newark basin (Costain and Çoruh, 1989) and the I-64 line in central Virginia (Çoruh et al., 1988), where magnetic and gravity data support the interpretation of seismic images of feeder dikes and sill emplacement; however, Unger et al. (1987) interpreted migrated line drawings of portions of the Quebec-Maine line and interpreted some prominent reflection segments to be from steeply-dipping Mesozoic dikes that are located near where a marked gravity gradient occurs along the profile. These locations are coincident with "steps" on the Moho and are in excellent agreement with those determined from closely spaced refraction data (Leutgert, 1985). Unger et al. (1987) noted that a change of 30 mgal in the regional gravity field (Stewart et al., 1986, Fig. 2b) can be accounted for by the crustal thinning observed on the reflection profiles.

The velocity of diabase is about 7.2 rbl km/sec and the density is in the range of 3 rbl gm/cm sup 3; both are therefore consistent with a large reflection coefficient and the bright reflection segments. Furthermore, diabase dikes of presumed Mesozoic age are known to crop out near the area. As noted by Unger et al. (1987), the prominent central Maine gravity gradient (Kane and Bromery, 1968) may result from a Mesozoic structure, because of the occurrence of a Jurassic dike along it for hundreds of kilometers to the northeast (Burke et al., 1973). Some events labeled "S" appear to be stronger than, and cut across, horizontal events of lesser amplitude. These could be from a sill that is not perpendicular to the plane of the record section; the event must therefore originate from out of the plane of the section. The reflections of largest amplitude may therefore be attributed primarily to impedance contrasts caused by diabase. The average velocity of the crust appears to be higher than that reported for crust affected by the Grenville orogeny further south. This is also consistent with emplacement of higher-velocity mafic material into the crust. If the bright reflection segments (S) originate from diabase sills, then their abundance and high reflectivity would probably mask any differences in crustal reflection signatures that might otherwise be detected on either side of the Norumbega fault zone. If they are from diabase sills, they might be expected to terminate at the Norumbega fault zone (which they do, more or less), and they might not be expected to be as laterally continuous as, for example, a décollement (the events marked "S" are not very continuous laterally).

Seismic Lamellae and Seismic Crocodiles as Kinematic Indicators

Meissner (1967) used the term "seismic lamellae" to describe densely packed (and presumably planar) reflections from the lower crust down to the Moho:

> "a multifold, dense, individually hardly distinguishable, set of reflections, mostly subhorizontal, occasionally dip- ping, curving and overlapping, so far mainly observed in the lower crust of tectonically young areas, mostly ending abruptly at Moho level."

Magmatic sills have been suggested as the origin of such reflections (Meissner, 1967; Klemperer et al., 1986; Allmendinger et al., 1987). Meissner (1989) later suggested that such "crystallization seams of intruded magmas" might not be the only explanation, and that a widespread creep process in the low-viscosity lower crust is of major importance, possibly together with a magmatic or metamorphic differentiation. Meissner (1989) noted that young crust (Cenozoic) was characterized by an average P-wave velocity of 6 - 6.2 rbl 'km/sec' whereas the velocity of old crust (≥ Proterozoic) was 6.2 - 6.5 rbl 'km/sec'.

Meissner (1989) also described certain seismic reflectivity patterns (after migration) in Phanerozoic continental crust that he called "crocodiles". The "crocodile" seismic signature is that of clearly diverging and rather plane, strong reflections in migrated seismic sections. It corresponds to the "wedge tectonics" or "interwedging" of Price (1981, 1986), and is interpreted to be the image of crustal indentation and detachment processes where stiff, rather rigid layers, intermingle in a sandwich-like sense with weaker layers (Meissner, 1989, p. 18). The "crocodile" signature is associated by Meissner (1989) with compressional tectonics, although he suggested that the divergent reflections are not necessarily syntectonic in origin. The conclusions of Price (1981, 1986) and Meissner (1989) seem to support the idea that seismic crocodiles can be created by a single major compressional event. The colder the crust remains during and after the compressional event, the better the crocodiles will survive (Meissner, 1989). Meissner (1989) circled several "crocodiles" in his Figure 6 which included the spectacular seismic image of the Grenville Front (reproduced here as Fig. 9)

Crocodiles (C) and lamellae (L) are both evident on the Bottle Lake lines before and after migration (Plates III and IV). At the present time, such terminology is useful if only to ensure

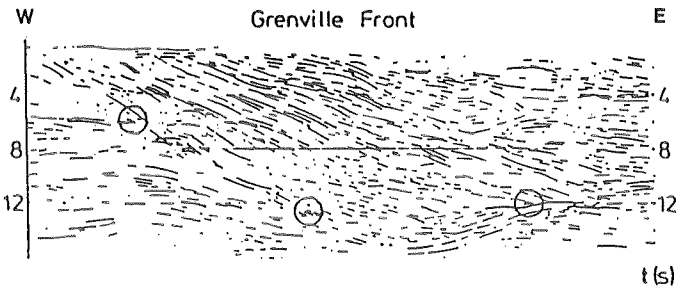

Figure 9. Figure 6 from Meissner (1989): Circled diverging seismic reflectors have been termed "crocodiles" by Meissner (1989). If such diverging reflections can be considered to be kinematic indicators, then by inference the direction of transport was from east to west for the crocodiles in the Grenville Tectonic Front.

that when we discuss seismic sections, we are all looking at the same features, whatever their origin. It should be kept in mind that, undoubtedly, much of what we image is not coming from the vertical plane of the seismic section.

Meissner's crocodiles are a common seismic signature where compression of the lithosphere by continental collision has taken place. Crocodiles occur in, for example, the ADCOH data (Çoruh et al., 1987) where similar geometry was referred to as "duplex tuning wedges" (Costain et al., 1986a). An example from the ADCOH data is shown in Figure 10. In this part of northwestern South Carolina, the Blue Ridge crystalline metamorphic allochthon is known to have been thrust over early Paleozoic shelf strata. The "duplex tuning wedges" are interpreted by us to have been formed in the shelf strata by the simple and well-known process of duplex formation. The shear planes form more or less at an angle of less than 45° with respect to the principal (horizontal) compressive stress. In this case, the kinematic indicators for the direction of transport for such a duplex structure exposed at the surface are mappable lithologic units that define the strain geometry and infer the principal stress directions and direction of transport. Are Meissner's crocodiles analogous kinematic indicators for crustal seismic data? According to Meissner (1989), crocodiles seem to represent hard "splinters", possibly created by strain-hardening in concentrated shear zones. Can such *discontinuous* shear zones be recognized and mapped on the surface? The wavelengths of the seismic data shown on Plate IV range from about 500 meters to 1,000 meters. That is, the data sense reflection geometries that are *at least* hundreds of meters in size, as opposed to at least tens of meters. If the crocodiles are real and originate from strain anisotropy, then we should be able to recognize, map and examine such features at the surface. Furthermore, we might expect a size distribution of such geometries that might have the same fractal dimension; i.e., from thin section to hand specimen to aeromagnetic data to seismic data.

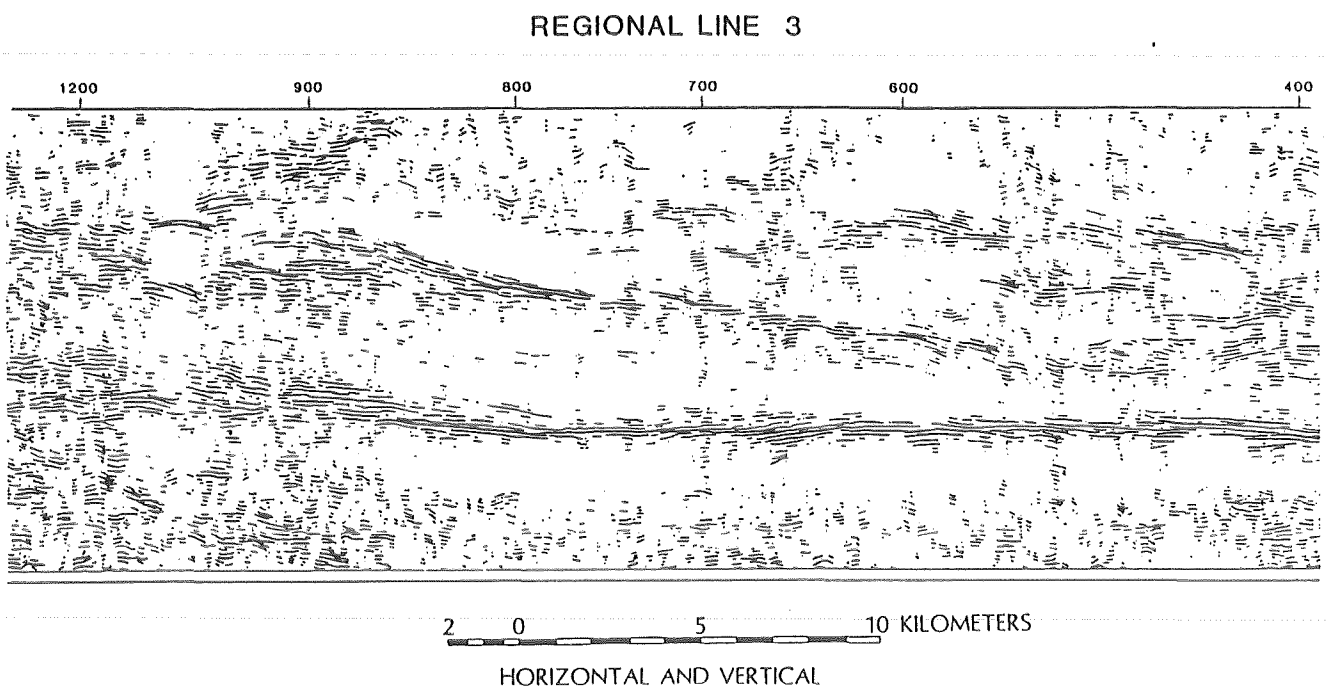

Figure 10. An example of wedge tectonics from Appalachian ultradeep core hole (ADCOH) data: This is a "seismic crocodile" formed in early Paleozoic shelf strata beneath the Blue Ridge metamorphic allochthon in north-western South Carolina. From Costain et al. (1989b).

Brittle-Ductile Transition

The top of the lower crust at about 5.5 sec appears to be the next most continuous event. In other parts of the world this crustal level marks the top of a highly reflective lower crust, as it does in eastern Maine at a depth of 17-18 km, and it might coincide with the present-day brittle-ductile transition (~250-300°C). As such, it may not be a candidate for a regional décollement; however, in terranes that have not been deeply buried since the last major compressional event, the depth to the past brittle-ductile transition should be approximately coincident with the present. In the southeastern United States, mélanges have been tectonically transported to present locations that are considerably to the west of the collisional sites where the mélanges were formed. Brittle-ductile transitions are the best candidates for peeling off (relatively) thin crustal slices and for facilitating tectonic transport of thin slices. One should therefore not rule out the possibility that seismic events in the 4-6 sec range might be the signatures of regional, relatively horizontal, décollements.

Décollements

A more or less continuous reflection package can be seen at about 3 sec (~9.6 km, "décollement"), on Fig. 7), and this is a good candidate for a regional décollement. We select this as the most probable seismic signature of a possible regional décollement. The crocodile beneath Station 500 on Line 1 (CDP 1000) at about 3 sec (Fig. 7 and Plate IV) suggests a westward direction of tectonic transport. If the crocodile is a duplex, then the roof of the duplex (a shallower décollement) is at about 2 sec (~6.4 km).

A décollement at a depth of 7-10 km would then appear to be a ubiquitous structural element of the continental crust in both the northeastern and southeastern United States (Costain and Glover, 1980; Costain et al., 1986b; Costain and Decker, 1987; Costain et al., 1989a) with implications for (Alleghenian?) horizontal transport of and tectonic control (truncation?) of pluton geometry such as the Bottle Lake Complex.

Implications From Heat Flow Data. Such a décollement near 7-10 km might explain the remarkable linear relationship between heat flow and heat generation discovered in the northeastern United States by Birch, Roy, and Decker (1968) and further developed by Roy et al. (1968, 1972). To many geophysicists, this remains one of the most remarkable and unexplained geophysical discoveries in the last 20 years, and we therefore elaborate on the implications of the empirical relationship for the Appalachian orogen.

In an important study, Birch et al. (1968) showed that variations in heat flow in New England and the Adirondacks are caused primarily by differences in upper crustal concentrations of the radioactive, heat-producing isotopes of uranium, thorium, and potassium. They found that surface heat flow, q, and heat production, A, are related by

$$q = q^* + DA$$

The parameter D has the dimensions of depth, and has been interpreted in several ways as characterizing the vertical distribution of heat sources within the sampled rocks. For the northeastern United States (Sass and others, 1981),

$$q = 33 + 7.5\,A$$

In the last two decades much attention has been focused on this remarkable relationship. The linear relationship for northeastern United States, and observed relationships for other continental areas, led to the definition of continental heat-flow provinces (Roy et al., 1968), and the definition of q^* as the "reduced heat flow" or the flux from the lower crust and upper mantle (Roy et al., 1972). The empirical relationship has now been observed on several continents (Sass et al., 1981).

Many of the heat-flow values reported in the eastern U. S. have been determined in syn- and post-metamorphic unmetamorphosed granitoids. Initial differences in concentrations of U and Th at the time of granite emplacement depend upon the composition of the granitic source rock, but heat flow is also affected by the metamorphic redistribution and depletion of U and Th. In both the northeastern and southeastern U.S., the highest heat-flow values are associated with unmetamorphosed granitoids.

Heat-flow and heat-generation values from drill holes in the Piedmont of the southeastern United States (Costain et al., 1986b) also define a regression line:

$$q = 29.8 + 7.8\,A$$

Values from syn- and post-metamorphic granitoids fall on the high heat production end of the line. Three values from a metamorphosed granitoid appear to be concordant with the lower end of the line as does a felsic metapyroclastic rock (slate belt volcanic rocks).

Models that will give a linear relation between q and A include:

1. The concentration of heat-producing elements is constant from the surface to a depth D. The numerical value of D is equal to the thickness of crust containing the heat-producing elements.

2. The concentration of heat-producing elements decreases exponentially downward from the surface according to $A(z) = A_0 \exp(-z/D)$, where A_0 and $A(z)$ are the concentration of heat-producing elements at the surface and depth z, respectively. D is here a logarithmic decrement, not a thickness parameter.

Both of the above models yield the same temperature (Lachenbruch, 1968) to within a few degrees to a depth of about 3 km; below this depth the exponential model predicts somewhat higher temperatures because of the continuing heat production with depth in this model. In either model, it is the vertical

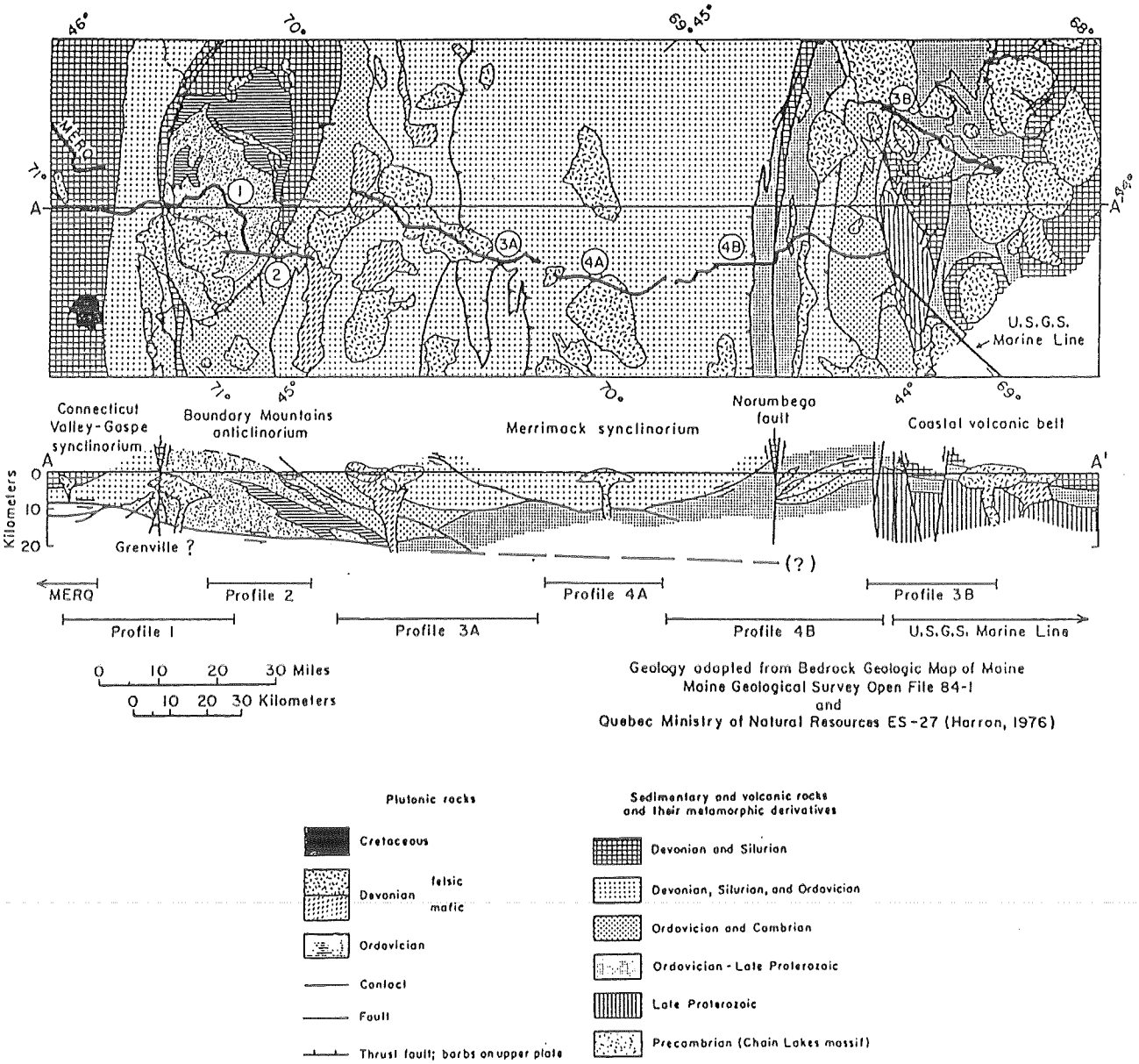

Figure 11. Figure 2a from Stewart et al. (1986): Top of Grenville(?) has been projected southeastward beneath the Kearsage-central Maine (Merrimack) synclinorium to intersect the Norumbega fault zone at about 28 km.

distribution of heat-producing elements that is important, not the lateral changes.

Other models have been proposed, with each radioelement having its own depth scale, i.e., value of D (Jaupart et al., 1981). Potassium gives a depth scale for the primary differentiation of the crust. Thorium gives the depth scale of magmatic or fluid circulation. Uranium reflects the late effects of alteration due to meteoric water. The physical significance of D remains unresolved.

A notable distinction made by Lachenbruch (1968) between Models 1 and 2 is that Model 2 will survive differential erosion of many km between heat flow sites and still yield a linear relationship but Model 1 will not. Model 1 implies a geochemically or structurally uninterrupted (no décollements), constant concentration of heat-producing isotopes down to a depth D. Model 2 would have to imply an uninterrupted, exponentially decreasing concentration of U and Th, uninterrupted to a depth of about 2D or possibly 3D (because $e^{-2/D} = e^{-3D/D} = e^{-3} = 0.05$). In the southeastern United States where $D \sim 8$ km, an uninterrupted exponential distribution of U and Th to a depth of about 15 km appears to be inconsistent with interpretations of COCORP seismic data beneath the Elberton Granite in Georgia (Cook et al., 1981; Cook et al., 1980; Iverson and Smithson, 1982).

Model 1 is appropriate for the southeastern United States if an essentially constant distribution of heat-producing elements

within the post- and synmetamorphic granitoids exposed in the Piedmont extends uninterrupted to a depth, *D*, where it is tectonically truncated by a major décollement. The value of *D* would be numerically equal to the slope of the observed linear relation. The seismic and heat flow data available to date appear to support the interpretation of tectonic termination of heat-producing isotopes in the upper crust (Costain et al., 1986b). Cook (1984) suggested that the change in the regional gravity field and the surface transition from the Inner Piedmont to the Charlotte belt are spatially unrelated, and that the central Piedmont suture (Taconic suture) has been transported from the east. The heat flow data are thus consistent with his conclusions that post-Ordovician westward transport of the upper crust seems to provide a viable explanation of the magnetic, gravity, and seismic data. One concludes that, if major décollements truncate heat-producing crust, then heat flow data can contribute to our understanding of the architecture of an orogenic belt.

Lux et al. (1986) suggested that low-P/high-T metamorphic terranes in the New England Appalachians could have been formed by rapid overthrusting of a slab (12 km thick), and that all low-P/high-T terranes may not result from anomalously high mantle heat flow brought about by rifting, as implied by Wickham and Oxburgh (1985). Support for this model of allochthony in eastern Maine on the basis of the limited seismic data now available might be premature.

Newfoundland. In Newfoundland, the Dunnage terrane may be entirely allochthonous and "superposed structurally" (Boone and Boudette, 1989), in its western part, upon Laurentian crust and, in its southeastern part, upon the basement of the Gander terrane (see references in Boone and Boudette, 1989, p. 32). The interpretation that the Dunnage and Gander terranes east of the termination of the Grenville crust may be allochthonous is based primarily on surface geology (Keen et al., 1986; Colman-Sadd and Swinden, 1984). As noted by Keen et al. (1986), the published seismic data are not good, and do not contribute to this model of allochthony one way or the other. The "Upper limit of seismic data" in Figure 3 of Keen et al. (1986) may simply be a data processing artifact, or the no-record crustal interval above 10 km might again be a consequence of a regional décollement near a depth of 10 km.

Quebec-Maine Line. Green et al. (1986), Stewart et al. (1986), Spencer et al. (1989), and Boone and Boudette (1989) interpreted a prominent regional reflection on data acquired along the Quebec-Maine reflection seismic line as the top of Grenvillian crust, and concluded that

1. The top of Grenvillian crust dips uniformly eastward and is at a depth of about 12 km (4 sec) beneath the southwestern part of the Connecticut Valley-Gaspé synclinorium on line QM1 (see Fig. 11; also Fig. 2 of Green et al., 1986),

2. The Chain Lakes Massif in the Boundary Mountains Terrane was thrust westward over Grenvillian crust, and

3. Grenvillian crust extends southeastward to about 30 km southeast of the Chain Lakes Massif (Fig. 2) where the top of Grenvillian crust is at a depth of about 24 km (8 sec) (Boone and Boudette, 1989, p. 18). This is "considerably to the southeast" of the western-Maine-to-northern New Brunswick ophiolite line of Zen (1983; Hurricane Mountain Belt of Boone and Boudette, 1989).

The delineation of the eastern edge of the North American craton during early Paleozoic time remains a key problem throughout the Appalachian orogen (for example, Zen, 1983). In Newfoundland, Williams et al. (1989) placed the eastern edge of the Grenville lower crustal block as roughly coincident with the surface trace of the Red Indian Line, and predicted a suture in the vicinity of Red Indian Lake. The eastern edge of the lower Grenville block in Newfoundland if projected southwestward along strike would be considerably southeast of the Norumbega fault zone.

If chemically distinct adjacent terranes have been tectonically juxtaposed by a décollement(s) of shallow dip, then the surface chemistry may not be indicative of the nature of the crust (down to the Moho) beneath either terrane. It is therefore essential to know whether the near-surface geometry of bounding faults that separate different terranes is steep or shallow before weighing surface chemistry too heavily in the interpretation.

Reflection seismic data in the southeastern United States have now documented a remarkable on-strike continuity of crystalline thrust sheets of uniform thickness with horizontal or near-horizontal décollements. Even linear structural ramps where décollements ramp up to shallower crustal levels in crystalline rocks or shelf strata have on-strike continuity of hundreds of km (Costain et al., 1989a). Whether this structural style is present to the same extent in the northern Appalachians has yet to be documented by reflection seismology data.

Although not interpreted as such, the line drawing of Stewart et al. (1986) suggests a discontinuity (décollement?) at about 4 sec on their unmigrated data. Their line drawing is reproduced in Figure 8. Even though geologic arguments might disallow an allochthonous Kearsage-central Maine (formerly called Merrimack) synclinorium, the arcuate geometry and the discordance in dip of some of the reflections beneath the Lexington batholith as shown on their profile 3a might accommodate a décollement at 3-4 sec along the entire line beneath the western part of the Kearsage-central Maine synclinorium. On the other hand, it should be noted that the top of a highly reflective lower crust at 4-6 sec (such as in Figure 8) is a commonly observed and unexplained phenomena on many continents. Sometimes it seems to coincide with the brittle-ductile transition (Çoruh et al., 1987).

If the Kearsage-central Maine synclinorium is allochthonous, then this model would provide structural control for the truncation of overlying heat-producing crust (the granitic intrusions, mostly identified as "21" on the map of Williams, 1978, and identified as "Granite intrusions, mainly mid-Paleozoic but ranging in age from Precambrian to Mesozoic"). As noted by Zen (1983), "we need to have some firm information on the nature of the crust underlying the en tire Kearsage-central Maine synclinorium". Zen (1983) suggested that perhaps accreted terranes typically have low-angle contacts except where they are

bounded by transcurrent faults. The "granite intrusions" include the peralkaline White Mountain magma series of New Hampshire where some of the highest heat flow values used to define the linear relation between heat flow and heat generation were obtained (Birch et al., 1968, Figure 33-1).

Possible Correlation of Bottle Lake Complex Crust with Crystalline Crust in Central Virginia

At this point, a speculative correlation might be made between the Bottle Lake Complex lines and the I-64 seismic data (Çoruh et al., 1987) from Virginia. On the Bottle Lake Complex data, a décollement(?) at about 3 sec limits projections from the surface to deeper parts of the crust (except for the Norumbega fault zone). There is a reflection package at about 5-6 sec that marks the top of a reflective lower crust, and reflections from the Moho arrive at 9.5-10.5 sec. Çoruh et al. (1988) suggested that the highly reflective crust in central Virginia was caused by compression and stretching of the crust. The reflective crust in Maine might also indicate there a similar megadisturbed zone. The highly reflective crust on the Bottle Lake Complex data between the 3-sec décollement and the Moho suggests that this part of the crust has undergone compression and stretching. If so, then because of similar seismic signatures on both sides of the Norumbega fault zone, one may suggest, by analogy with central Virginia, that the main zone of stretched (by compression and extension) crust (the southeastern edge of the early Paleozoic North American continent) lies even further to the southeast.

SUMMARY

One of the most prominent seismic signatures on the lines over the Bottle Lake Complex is the steeply northwest-dipping Norumbega fault zone along which reflection segments appear to terminate. The fault zone cuts the entire crust and projects to the surface at the approximate location of the northwestern edge of the mapped Norumbega fault zone.

"Crocodiles" and seismic lamellae are both evident on the Bottle Lake lines before and after migration. The "crocodile" seismic signature is that of clearly diverging and rather plane, strong reflections in migrated seismic sections, corresponding to the "wedge tectonics" or "interwedging" or "duplex tuning wedge" of others. The signature is interpreted to be the image of crustal indentation and detachment processes where stiff, rather rigid layers, intermingle in a sandwich-like sense with weaker layers. The "crocodile" signature is associated with compressional tectonics. The most likely candidate for a regional décollement on the Bottle Lake Complex lines is the reflection at about 3 sec (~9.6 km). If seismic crocodile images are interpreted as kinematic indicators, the sense of transport on this décollement(?) is from east to west.

The top of the lower crust at about 5.5 sec (~17-18 km) appears to be the top of a highly reflective crustal interval, as it is in other parts of the world. It might coincide with the present-day brittle-ductile transition.

As far as reflection continuity is concerned, the base of the crust (Moho) at a depth of about 32 km is the most continuous feature on the seismic data. It is conspicuous and unambiguous over most of each of the Bottle Lake lines.

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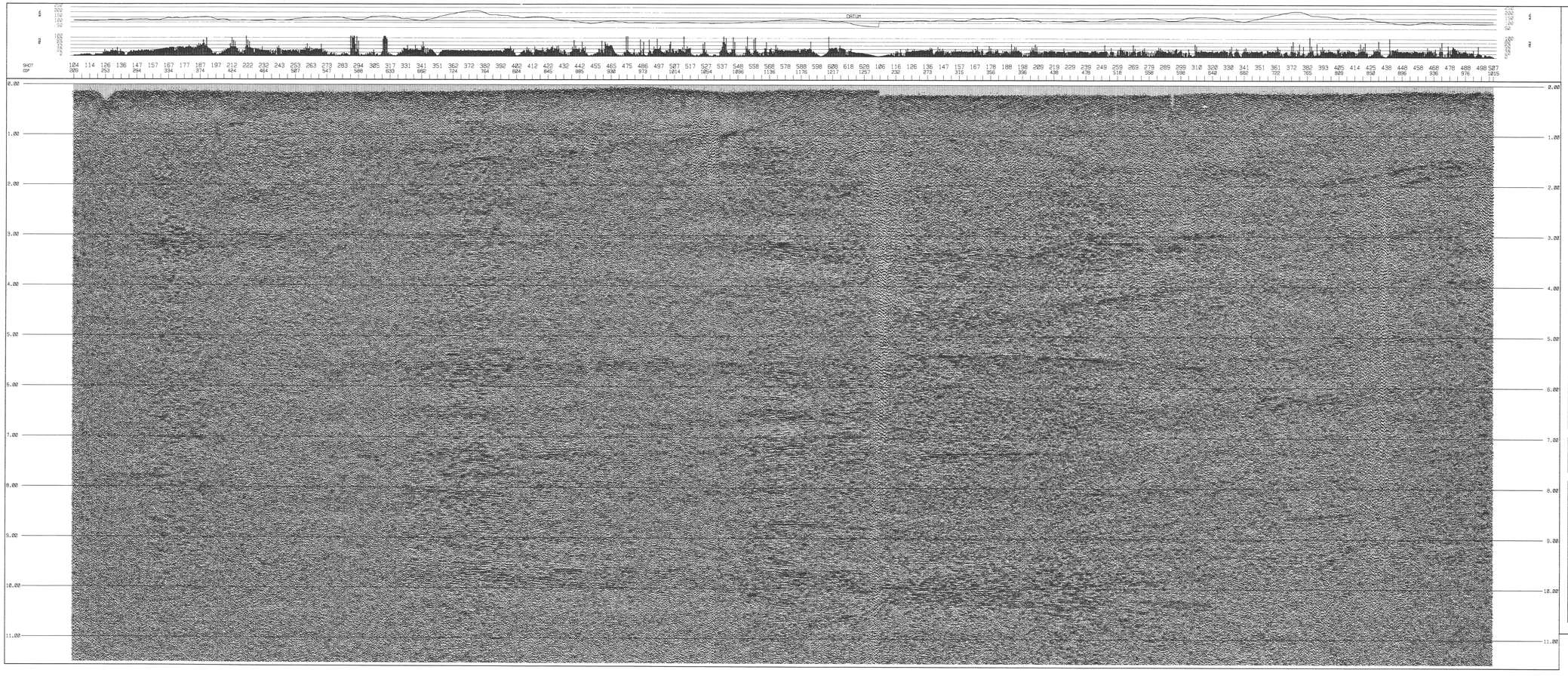
COGNISEIS UAX START
USERNAME: WJDIST SITE: VPI&SU DATE: 14-AUG-1989 04:00
RUNS SOFTWARE BY CEDAR/DIS DEVELOPMENT INC.
RUN DESCRIPTION GATHERING F.3 AVP.3
RUN NO. 200
RECORD TYPE : DATA
LINE : LINE1
TRACE : ALL
TRACE FILE : DATA:PLATE1DS.DAT
GP TYPE : CDP
GP TYPE : CDP
POLARITY NORMAL - POSITIVE FILL (FROM 0 @ 4. MS SAMPLE RATE)
DISPLAY 0.0-11.0 SECS (0-2750 SAMPLES) INCLUDING ZERO SAMPLES
DISPLAY 0.0-11.0 SECS (0-2750 SAMPLES) INCLUDING ZERO SAMPLES



BOTTLE LAKE, MAINE

LINES 1 & 2

FINAL STACK WITH AUTOSTATICS

DATUM 120 METERS

2:1 DISPLAY ASSUMING V=6400 M/S

SOUTH

RECORDING PARAMETERS

DATE RECORDED :	OCT. 1987	SOURCE ARRAY :	4X6 SWPS/100.6 M
CONTRACTOR :	WESTERN GP 717	SHOT INTERVAL :	100.6 METERS
GROUP INTERVAL:	50.3 METERS	FAR OFFSET :	3160.4 METERS
NEAR OFFSET :	201.2 METERS	SAMPLE RATE :	4 MSEC
INSTRUMENTS :	DFS V	RECORD LENGTH :	8 SEC
CHANNELS :	120	RECORD FILTS :	12HZ LO 64HZ HI N
ENERGY SOURCE :	4 VIB LRS-311	SWEEP FREQ. :	14-56 HZ
SWEEP LENGTH :	32 SEC	RECEIVER ARRAY:	24 PH/120.5 M

SPREAD CONFIGURATION:

```
TR 1                TR 60          TR 61                TR 120
<-------------------+  *  +-------------------------------->
3168 M              201 M  VP   201 M                 3168 M
```

PROCESSING SEQUENCE

DEMULTIPLEXING
RECORD PRO - TO 41 SEC
XCOR
TRACE EDITS/DATUM STATICS
COMMON MIDPOINT SORT/CROOKED GEOMETRY
DECONVOLUTION - GAPPED
20 MS GAP 200 MS OPERATOR
AUTOCOR. GATE 100-2400 MS
FILTER 10-14-56-62 HZ
VELOCITY ANALYSIS - CONSTANT VEL. STKS.
RESIDUAL STATICS - SURFACE CONSISTENT
ITERATIVE W/ VEL. ANALYSIS
NMO/MUTE/1000 MS AGC
COMMON MIDPOINT STACK - 30 FOLD NOM.
FILTER 10-14-56-62 HZ 0-11.5 SEC
AGC - 1000 MS
ARCHIVE TAPE V1805 FILE: PLATE1.DSK

DISPLAY PARAMETERS

TRACES PER INCH: 42.67 DATE PROCESSED: MAR 1989
INCHES PER SEC: 1.5 POLARITY: NORMAL

MAINE GEOLOGICAL SURVEY

AND

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

REGIONAL GEOPHYSICS LABORATORY

PROCESSED BY: VPI&SU/WJD

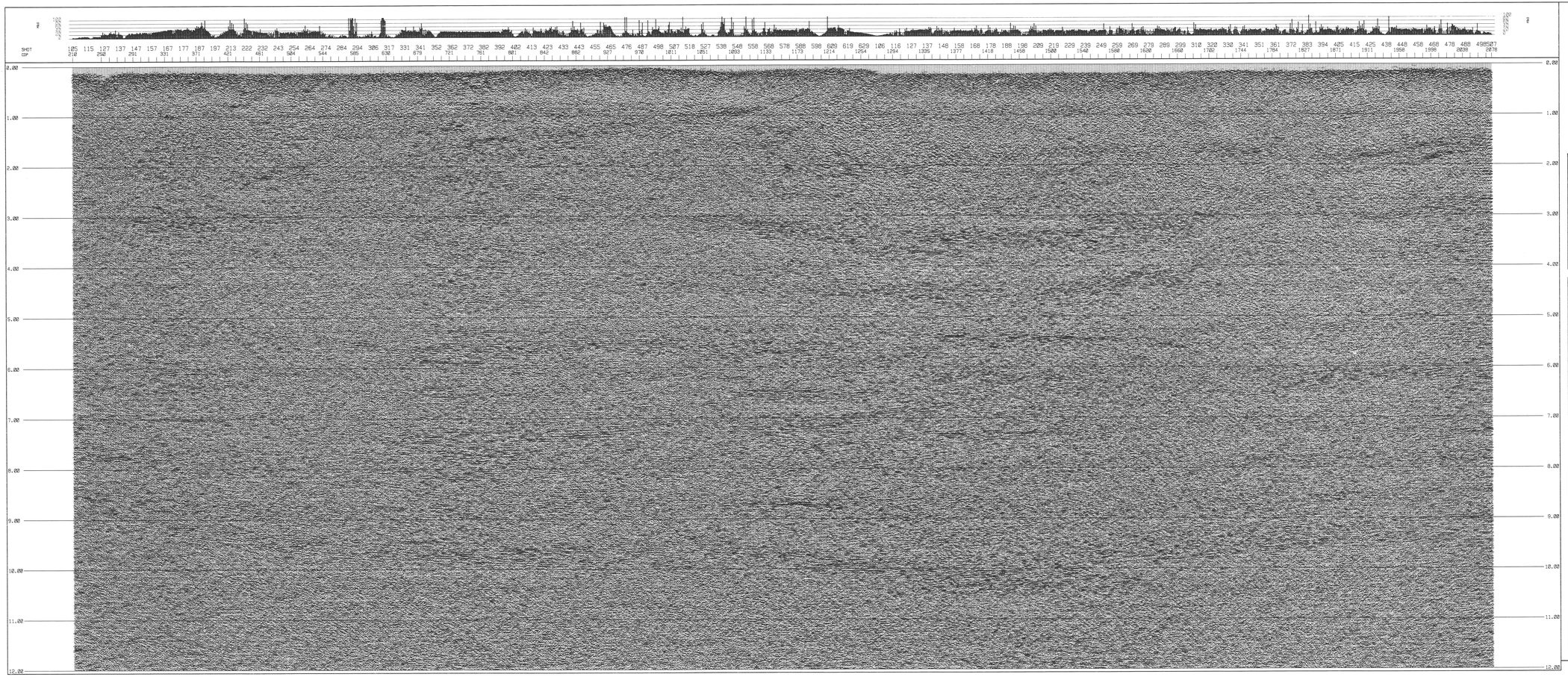
C O G N I S E I S
A DIVISION OF
ALDI SOFTWARE BY GERMANISIS DEVELOPMENT INC.

VRX START
SITE: VPI&SU

DATE: 14-AUG-1989 03:43

DISCO MONITOR VERSION 7.3 /07.3
PROJECT : 0000
PROFILE : MAINE
CLIENT : VPI&SU
TITLE : SEISLIS 1 & 2 FOR MIGRATE DISP
INPUT FILE : SEISLIS/TRAIN.DJB.JONK3FPLOTH24H.SHT:31
SHOT : 105
CDP : 210
OPTIONS : /LIST/MONCHECK/MODGUP/MONMEDIA/QUEN

PROJECT: MAINE
DISPLAY: POSITIVE /FILL / 1989 PS Mod. 8: MS SAMPLE RATE
DATA: 8 MS SAMPLE RATE, 1024 SAMPLES, 2020 SAMPLES
SCL: X - 8.1242/Y-0.89 X-1.00 Y-1.00 Mode: 1



BOTTLE LAKE, MAINE

LINES 1 & 2

MIGRATED STACK

DATUM 120 METERS

2:1 DISPLAY ASSUMING V=6400 M/S

SOUTH

RECORDING PARAMETERS

DATE RECORDED :	OCT. 1987	SOURCE ARRAY :	4X8 SWPS /100.6 M
CONTRACTOR :	WESTERN GP 717	SHOT INTERVAL :	100.6 METERS
GROUP INTERVAL:	50.3 METERS	FAR OFFSET :	3168.4 METERS
NEAR OFFSET :	201.2 METERS	SAMPLE RATE :	4 MSEC
INSTRUMENTS :	DFS V	RECORD LENGTH :	8 SEC
CHANNELS :	120	RECORD FILTS :	10HZ LO 64HZ HI N
ENERGY SOURCE :	4 VIB LRS-311	SWEEP FREQ. :	14-56 HZ
SWEEP LENGTH :	32 SEC	RECEIVER ARRAY:	24 PH/100.5 M

SPREAD CONFIGURATION:

TR 1	TR 60		TR 61	TR 120
←----------	----------→	*	←----------	----------→
3168 M	201 M	VP	201 M	3168 M

PROCESSING SEQUENCE

DEMULTIPLEXING
RECORD PAD - TO 41 SEC
XCOR
TRACE EDITS/DATUM STATICS
COMMON MIDPOINT SORT/CROOKED GEOMETRY
DECONVOLUTION - GAPPED
20 MS GAP 200 MS OPERATOR
AUTOCOR. GATE 100-2400 MS
FILTER 10-14-56-62 HZ
VELOCITY ANALYSIS - CONSTANT VEL. STKS.
RESIDUAL STATICS - SURFACE CONSISTENT
ITERATIVE W/ VEL. ANALYSIS
NMO/MUTE/1000 MS AGC
COMMON MIDPOINT STACK - 30 FOLD NOM.
FILTER 10-14-56-62 HZ
AGC - 1000 MS
RESAMPLE TO 8 MS
WAVE EQUATION MIGRATION
FINITE DIFFERENCE MIG. TO 13 SEC
FILTER 10-14-56-62 HZ
AGC - 1000 MS
ARCHIVE TAPE V1805 FILE: PLATE2.DSK

DISPLAY PARAMETERS

TRACES PER INCH:	42.67	DATE PROCESSED:	JUNE 1989
INCHES PER SEC:	1.5	POLARITY:	NORMAL

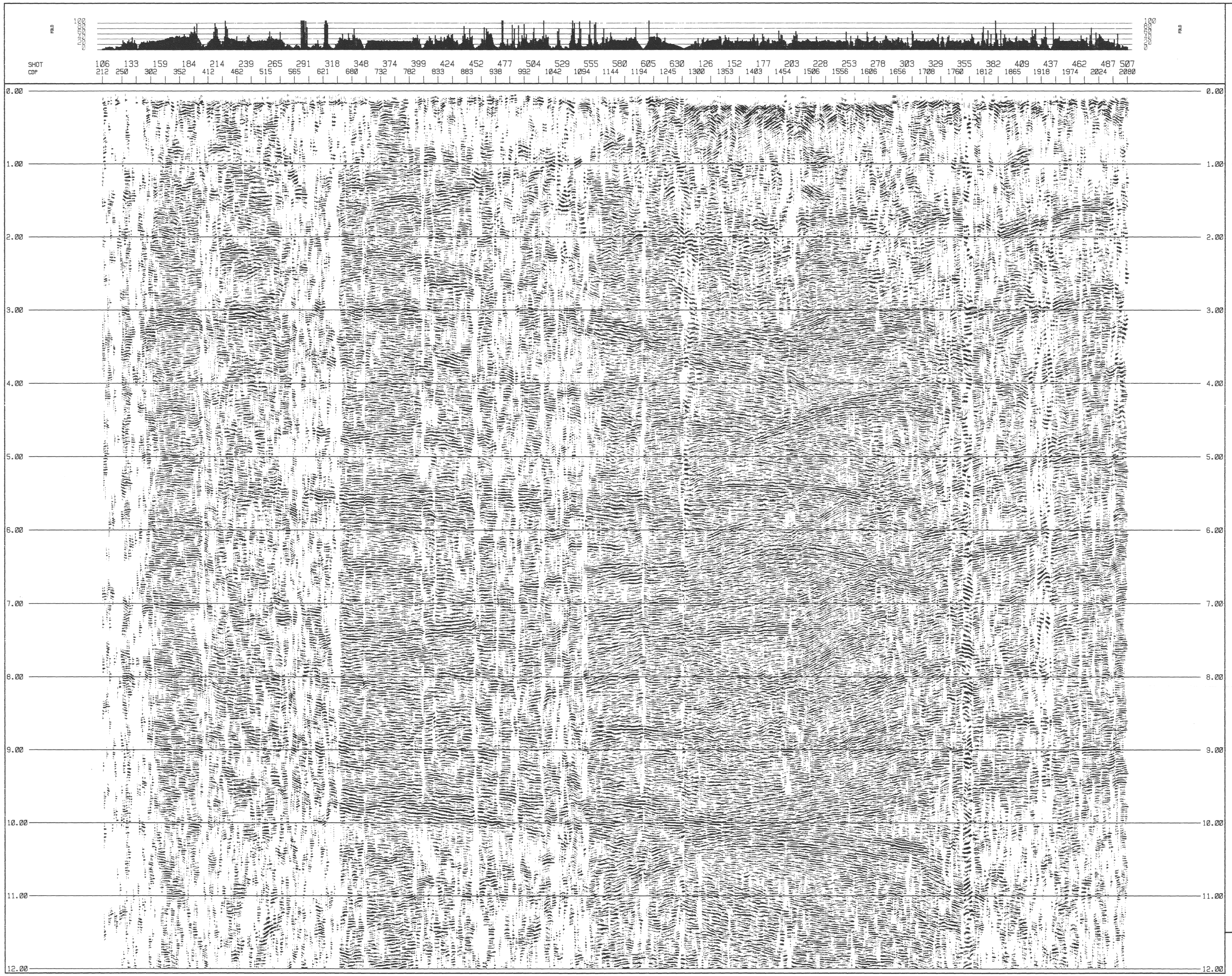
MAINE GEOLOGICAL SURVEY

AND

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

REGIONAL GEOPHYSICS LABORATORY

PROCESSED BY: VPI&SU/WJD



COGNISEIS VAX START
USERNAME: WJDTEST SITE: VPI&SU DATE: 14-AUG-1989 00:54
PLOT SOFTWARE BY COGNISEIS DEVELOPMENT INC.

DISCO MONITOR VERSION 7.3 /V7.3
DISCO JOB : 32693
PROJECT : MAINE
LINE : L5
USER : MRBILL
TITLE : LDRAW FROM SIGIC.DSK
INPUT FILE : /VOL1/TRAIN.OJD.JUNK/LDPIN2+SIDE.DAT:4
SITE : VPI&SU
DP TYPE : (FPS)
OPTIONS : /LIST/NOCHECK/NODUMP/NOMEMCHK/VARN

POLARITY NORMAL
FORMAT 16BITS INC 4 WORDS PER ENTIRE TRACE INCLUDING ZERO SAMPLES
RHS 0.31875E-01 GAIN 1.00

BOTTLE LAKE, MAINE

LINES 1 & 2

AUTOMATIC LINE DRAWING - STACK
DATUM 120 METERS
1:1 DISPLAY ASSUMING V=6400 M/S

SOUTH

RECORDING PARAMETERS

DATE RECORDED :	OCT. 1987	SOURCE ARRAY :	4X6 SWPS /100.6 M
CONTRACTOR :	WESTERN GP 717	SHOT INTERVAL :	100.6 METERS
GROUP INTERVAL:	50.3 METERS	FAR OFFSET :	3168.4 METERS
NEAR OFFSET :	201.2 METERS	SAMPLE RATE :	4 MSEC
INSTRUMENTS :	DFS V	RECORD LENGTH :	8 SEC
CHANNELS :	120	RECORD FILTS :	12HZ LO 64HZ HI N
ENERGY SOURCE :	4 VIB LRS-311	SWEEP FREQ. :	14-56 HZ
SWEEP LENGTH :	32 SEC	RECEIVER ARRAY:	24 PH/126.5 M

SPREAD CONFIGURATION:

TR 1	TR 60		TR 61	TR 120
3168 M	201 M	* VP	201 M	3168 M

PROCESSING SEQUENCE

DEMULTIPLEXING
RECORD PAD - TO 41 SEC
XCOR
TRACE EDITS/DATUM STATICS
COMMON MIDPOINT SORT/CROOKED GEOMETRY
DECONVOLUTION - GAPPED
20 MS GAP 200 MS OPERATOR
AUTOCOR. GATE 100-2400 MS
FILTER 10-14-56-62 HZ
VELOCITY ANALYSIS - CONSTANT VEL. STKS.
RESIDUAL STATICS - SURFACE CONSISTENT
ITERATIVE W/ VEL. ANALYSIS
NMO/MUTE/1000 MS AGC
COMMON MIDPOINT STACK - 30 FOLD NOM.
FILTER 10-14-56-62 HZ
AGC - 1000 MS
RESAMPLE TO 8 MS
AUTOMATIC LINE DRAWING
ARCHIVE TAPE V1805 FILE: PLATE3.DSK

DISPLAY PARAMETERS

TRACES PER INCH:	85.3	DATE PROCESSED:	JUNE 1989
INCHES PER SEC:	1.5	POLARITY:	NORMAL

MAINE GEOLOGICAL SURVEY

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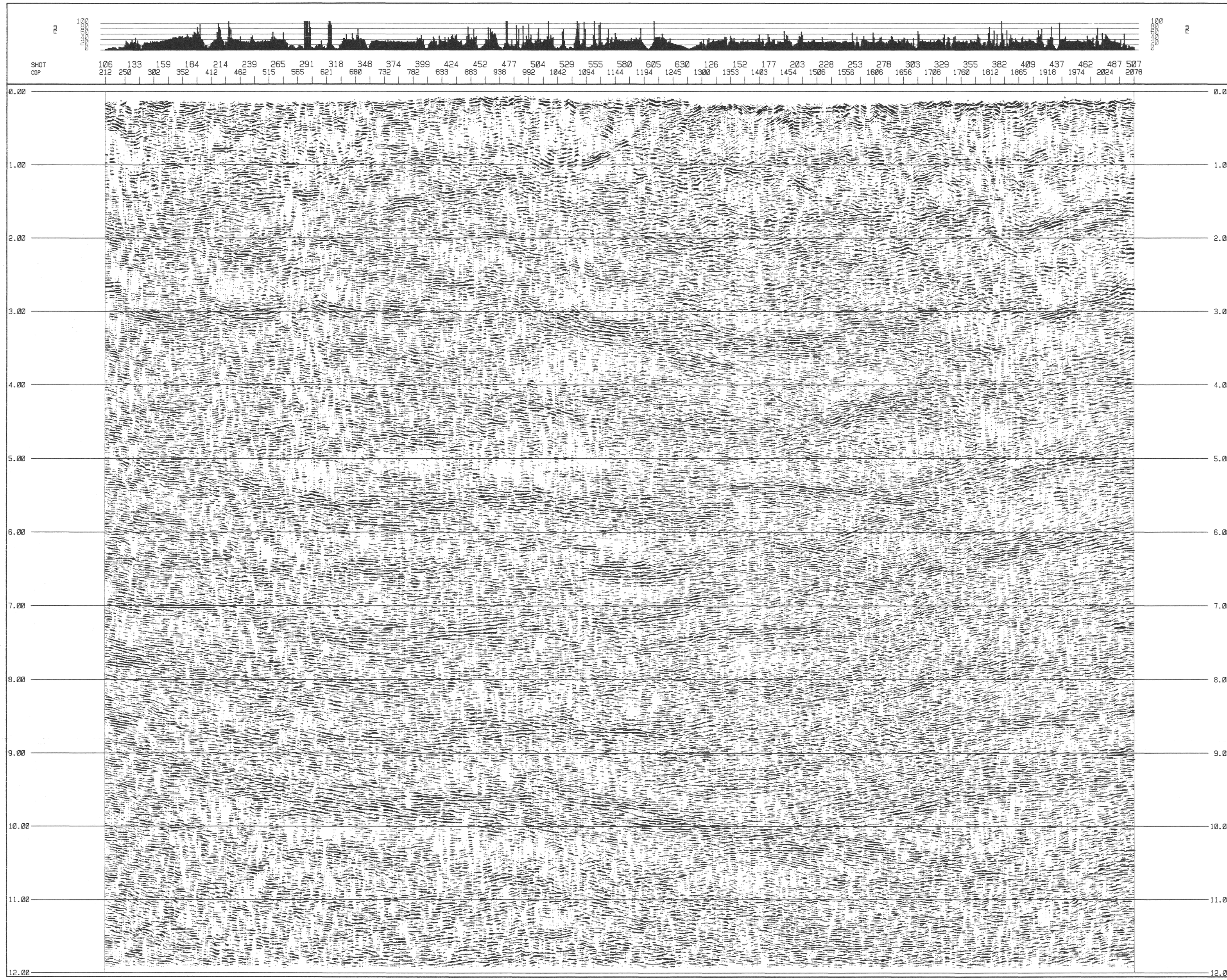
AND STATE UNIVERSITY

REGIONAL GEOPHYSICS LABORATORY

PROCESSED BY: VPI&SU/WJD



C O G N I S E I S
USERNAME: WJDTEST
PLOT SOFTWARE BY COGNISEIS DEVELOPMENT INC.

VAX
SITE: VPI&SU

START
DATE: 14-AUG-1989 01:25

DISCO MONITOR VERSION 7.3 /V7.3
PROJECT : MAINE
LINE : COMBO
VIEW : ALL
TITLE : DMSPLY MIGRATED COMBO
INPUT FILE : DRA1:[TRAIN.WJD.JUNK]LDPIN2+SIDE+M.DAT;4
SP TYPE : VP(SPS)
OPTIONS : /LIST/NOCHECK/NODUMP/NOMEMCHK/VARN

POLARITY NORMAL - POSITIVE FILL (12000 MS @ 8. MS SAMPLE RATE)
SECOND AVERAGE USING 4 WINDOWS OVER ENTIRE TRACE INCLUDING ZERO SAMPLES
RMS = 0.28/8/3E-01 GAIN = 1.00

BOTTLE LAKE, MAINE

LINES 1 & 2

AUTOMATIC LINE DRAWING - MIGRATION
DATUM 120 METERS
1:1 DISPLAY ASSUMING V=6400 M/S

SOUTH

RECORDING PARAMETERS

DATE RECORDED :	OCT. 1987	SOURCE ARRAY :	4X6 SWPS /100.6 M
CONTRACTOR :	WESTERN GP 717	SHOT INTERVAL :	100.6 METERS
GROUP INTERVAL:	50.3 METERS	FAR OFFSET :	3168.4 METERS
NEAR OFFSET :	201.2 METERS	SAMPLE RATE :	4 MSEC
INSTRUMENTS :	DFS V	RECORD LENGTH :	8 SEC
CHANNELS :	120	RECORD FILTS :	12HZ LO 64HZ HI N
ENERGY SOURCE :	4 VIB LRS-311	SWEEP FREQ. :	14-56 HZ
SWEEP LENGTH :	32 SEC	RECEIVER ARRAY:	24 PH/126.5 M

SPREAD CONFIGURATION:

TR 1	TR 60		TR 61	TR 120
3168 M	201 M	* VP	201 M	3168 M

PROCESSING SEQUENCE

DEMULTIPLEXING
RECORD PAD - TO 41 SEC
XCOR
TRACE EDITS/DATUM STATICS
COMMON MIDPOINT SORT/CROOKED GEOMETRY
DECONVOLUTION - GAPPED
  20 MS GAP 200 MS OPERATOR
  AUTOCOR. GATE 100-2400 MS
FILTER 10-14-56-62 HZ
VELOCITY ANALYSIS - CONSTANT VEL. STKS.
RESIDUAL STATICS - SURFACE CONSISTENT
  ITERATIVE W/ VEL. ANALYSIS
NMO/MUTE/1000 MS AGC
COMMON MIDPOINT STACK - 30 FOLD NOM.
FILTER 10-14-56-62 HZ
AGC - 1000 MS
RESAMPLE TO 8 MS
WAVE EQUATION MIGRATION
  FINITE DIFFERENCE MIG. TO 13 SEC
FILTER 10-14-56-62 HZ
AGC - 1000 MS
AUTOMATIC LINE DRAWING
ARCHIVE TAPE V1805 FILE: PLATE4.DSK

DISPLAY PARAMETERS

TRACES PER INCH:	85.3	DATE PROCESSED:	JUNE 1989
INCHES PER SEC:	1.5	POLARITY:	NORMAL

MAINE GEOLOGICAL SURVEY

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VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

REGIONAL GEOPHYSICS LABORATORY

PROCESSED BY: VPI&SU/WJD