VAEDGE

VIRGINIA 1990 EDGE EXPERIMENT

Submitted by
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PASSCAL Data Report 93-006

IRIS DATA MANAGEMENT SYSTEM

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The EDGE seismic experiment shot on the M/V GECO Searcher in September 1990 recorded seismic reflection profiles to 16 sec. in a 560 km grid off the coast of Virginia. Shots of a 10,000 cu. inch, 2,000 psi airgun array were recorded on 12 ocean bottom seismometers across the continental margin, while 15 PASSCAL recorders formed a 110 km profile across the Coastal plain. The experiment was conducted to analyze the deep crustal structure in this area in relation to the Salisbury magnetic anomaly, the East Coast magnetic anomaly, and magnetic anomalies along the hinge line of the Baltimore Canyon Trough.

The University of Wyoming's part in this was to conduct land based recording of the offshore shooting with the IRIS instruments. We were most interested in recording line A, the southern most E-W line, as can be seen by the number of instruments (12) that we had recording that set of shooting. These 12 instruments were deployed along a line that was about 160 km in length and approximately in line with line A.

The geophones used in this experiment are Mark Products L-22, 2Hz triaxial and were buried at least 2 feet in the soil. Some were cemented onto concrete foundations and stn 16 was cemented to a rock. Each tape represents the recording of a particular line during the shooting. The instruments that we deployed recorded only line A (line801) and part of line B (line 802). The enclosed tapes are SEGY format and have a record length of 60s.

Since this experiment was performed on distance increments, the instruments were deployed and then programmed to run continuously for 2-3 days. Hence to create the 60s records, I used a program called Truecut written by David Okaya to cut the data based on the time of the shots. The shooting occurred on approximately 20 second intervals, so a 60 second record is a bit of overkill. Yet, because of the large offsets and the desirability of recording shear wave arrivals, I decided to make longer records so that further processing could be done on the traces to obtain information after 20s.

All of the tapes are similar in organization. They have channel defined as either 1, 2, or 3, where 1 is the vertical- 2 is oriented to magnetic North, 3 is oriented to magnetic East. They have been sorted so the first trace corresponds to the nearest source offset. This means that the trace 1 is from shot 1484 on line A and shot 935 on line B. Notice that there was overlap in the shot stations so there are more traces than shots. I have kept those traces and they have a different sequence number for a given channel. These repeated shots can also be seen in the ffids. In the majority of the data the ffids are sequential. Where they are not is a repeated section. There were 85 shot points repeated on line A, and 96 shot points on line B.

I have included a tar tape of all of the log and err files that were generated by the ref2segy program along with a copy of this report and the geometry file for each line. Also, I placed the diagnostic files that were generated by the truecut program.

After initial plotting of the vertical component, I found that two of the stations (stn 3 and stn 9) showed no coherent events at all. Two other stations (stn 7 and stn6) seemed to be very noisy but there was some energy that made it through. I have tried many different plotting parameters and filters, but I could not seem to improve these four stations. I found with this data that plotting of the data is best when each trace is balanced to the peak amplitude of the that trace. Also, more events can be seen when a bandpass frequency filter is applied that ranges from 8hz to 23hz. It was very difficult to observe signal in the whole bandwidth of the data, which is 0-25hz. The Nyquist frequency of this data is 25hz based on the sampling rate that was chosen at the time of deployment. This sampling rate was chosen because of the memory limitations of the recording instruments, and the length of recording 2-3 days, and the expected signal frequencies of interest (5-15hz). The logic used to set the instruments was to use 1/2 the capacity of the unit and use a low sampling rate, so that they could record for 3 days continuously.

Anyway, it is possible to see events on the data even though one has to squint. I believe there is usable data there but it will take some work to get it out.

Note: The geometry file contains x,y utm coordinates for both the receivers and shots for line a and line b. You will notice that in the shot locations for line b the shot numbers range from 6935-9977. The actual shot numbers from the boat were 935-3977. I had to change these numbers to have the geometry applied correctly in the Disco processing system. The shot numbers in the geometry of line a are the same as those generated by the boat.

The geometry file is a DISCO file. Its format is as follows:

Stations

LOCN 1 LXY 418123. 4059100.6.09

The above is the line describing station 1. The easting or x coordinate is 418123., the northing or y coordinate is 4059100., and the elevation is 6.09.

Shot points

SHOT 1484 1 440133.14072575.1 1

The above is the line describing shot point 1484. The easting or x component is 440133.1 and the northing or y coordinate is 4072575.. The first column and last two columns with 1 in them should be ignored.

Deep seismic reflection data of EDGE U.S. mid-Atlantic continental-margin experiment: Implications for Appalachian sutures and Mesozoic rifting and magmatic underplating

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ABSTRACT

The EDGE seismic experiment across the Virginia continental margin delineated a Paleozoic suture, buried Appalachian terranes, and Mesozoic rifting and magmatic events. The seismic grid revealed that the Mesozoic Norfolk rift basin exists only in the northern one-third of the previously mapped area. The north-striking listric border fault of the Norfolk basin half-graben parallels seismic laminations in the basement. The Jurassic volcanic wedge pinches out just landward of the Baltimore Canyon trough hinge zone and downlaps on the hummocky oceanic basement under the continental rise. Under the continental slope, the volcanic wedge reaches depths >9 s (20 km). Two distinct intracrustal reflections at 4.0–5.0 s and at 7.0 s TWTT (two-way traveltime) dip southeastward at low angles (−15°). The Moho reflection is disrupted where it is intersected by the 7.0 s reflection. Northwest of this point the Moho dips landward; seaward it is horizontal. Seaward of this point, the lower-crustal boundary laminations exist in a narrow interval (10.5–11.0 s) and are of strong amplitude. These changes in the Moho and lower crust represent the seaward edge of the Grenville-age North American crust and the landward edge of Jurassic magmatic underplating. A northwest-dipping reflection observed for the first time on the U.S. Atlantic margin may be the top of the Jurassic magmatic-underplating layer; the northwest-dipping reflection truncates the southeast-dipping 7.0 s TWTT reflection. Landward projection of the 7.0 s reflection yields a north-south trace on the postrift unconformity under the center of lower Chesapeake Bay. This trace is near a basement fault between low-grade metamorphic rocks (Carolina slate–Avalonia) on the east and high-grade rocks (Goochland terrane) on the west. This fault boundary and the southeast-dipping 7.0 s reflection probably represent the Taconic suture.

INTRODUCTION

The U.S. Mid-Atlantic continental margin was the site for the third project of EDGE, a program for seismic-reflection studies of the submerged continental lithosphere (Fig. 1). The typical passive continental margin of eastern North America contains the roots of the Appalachian orogen, which play a role in the formation of the modern margin. Consequently, the seismic data image major Appalachian suture zones as well as rift and drift structures.

The EDGE transect includes a 560 km grid of seismic-reflection profiles MA 801–MA 804 (Fig. 1). The grid is complemented by existing U.S. Geological Survey (USGS) line 28. The shots were recorded on ten ocean-bottom receivers (Holbrook et al., 1992) and 11 portable land seismic stations.

TECTONIC FRAMEWORK

In this area, the Salisbury gravity and magnetic anomaly (Fig. 1) has been interpreted as resulting from mafic metavolcanic rocks (L. Glover III et al., unpublished). The Salisbury anomaly has been modeled as a southeast-dipping through-to-mantle Taconic suture (Pratt et al., 1988), although it has also been interpreted as a northwest-dipping Alleghanian suture (Lefort, 1990). Sheridan et al. (1991) found that the Salisbury anomaly in New Jersey is above a shallow (<8 km) body of mafic and ultramafic (ophiolitic) rocks of a detached, imbricate-thrusted, synformal wedge of a transported Taconic suture. Differences aside, most researchers agree that the Salisbury anomaly is related to a significant Paleozoic suture.

The Triassic-Jurassic rift stage is manifested in the Norfolk basin (Fig. 1). The USGS mapped the Norfolk basin as a half-graben with a northeast-striking listric border fault dipping to the southeast (Klitgord et al., 1988). Apparently, the U.S. Atlantic continental margin is a volcanic end-member type of passive margin (Mutter, 1985). Seaward-dipping reflections beneath the postrift unconformity characterize the continent-ocean boundary. This wedge of dipping reflections is thought to consist of Jurassic volcanic rocks, similar to volcanic wedges documented for other passive margins (Mutter, 1985; White et al., 1987).

In the early drift stage, a carbonate bank margin formed in the Late Jurassic to earliest Cretaceous (Schlee et al., 1988). The platform edge is well developed in the EDGE study area. Slower subsidence in the later drift stage accompanied Cretaceous and Cenozoic siliciclastic sediment burial of the carbonate platform and creation of the onlapping coastal plain (Fig. 1) (Olsson et al., 1988).

The East Coast magnetic anomaly (Fig. 1) (Taylor et al., 1968) has been interpreted variously as an edge effect of the continent-ocean boundary (Hutchinson et al., 1983), as an intrusive dike structure (Emery et al., 1970), as magnetic bodies in continental crust (Alsop and Talwani, 1984), as ophiolitic crust of the Alleghanian suture (McBride and Nelson, 1988; Hall, 1990), and most recently as a wedge of Jurassic volcanic rocks (Austin et al., 1990).

Between the East Coast magnetic anomaly and the hinge zone of the Baltimore Canyon trough (Fig. 1), 7.4 km/s crust was found by the large-aperture seismic experiment (Diebold et al., 1988). High-velocity crust is found elsewhere on the U.S. margin (Trehu et al., 1989; Austin et al., 1990) and on other passive margins (White et al., 1987; Keen et al., 1987). Recent theories favor magmatic underplating during breakup for the emplacement of this high-velocity crust (White et al., 1987).

ACQUISITION AND PROCESSING OF EDGE LINES

EDGE lines MA 801–MA 804 (Fig. 1) were shot in September 1990 by the M/V *GECO Searcher* using a 36-gun, 60-m-wide,

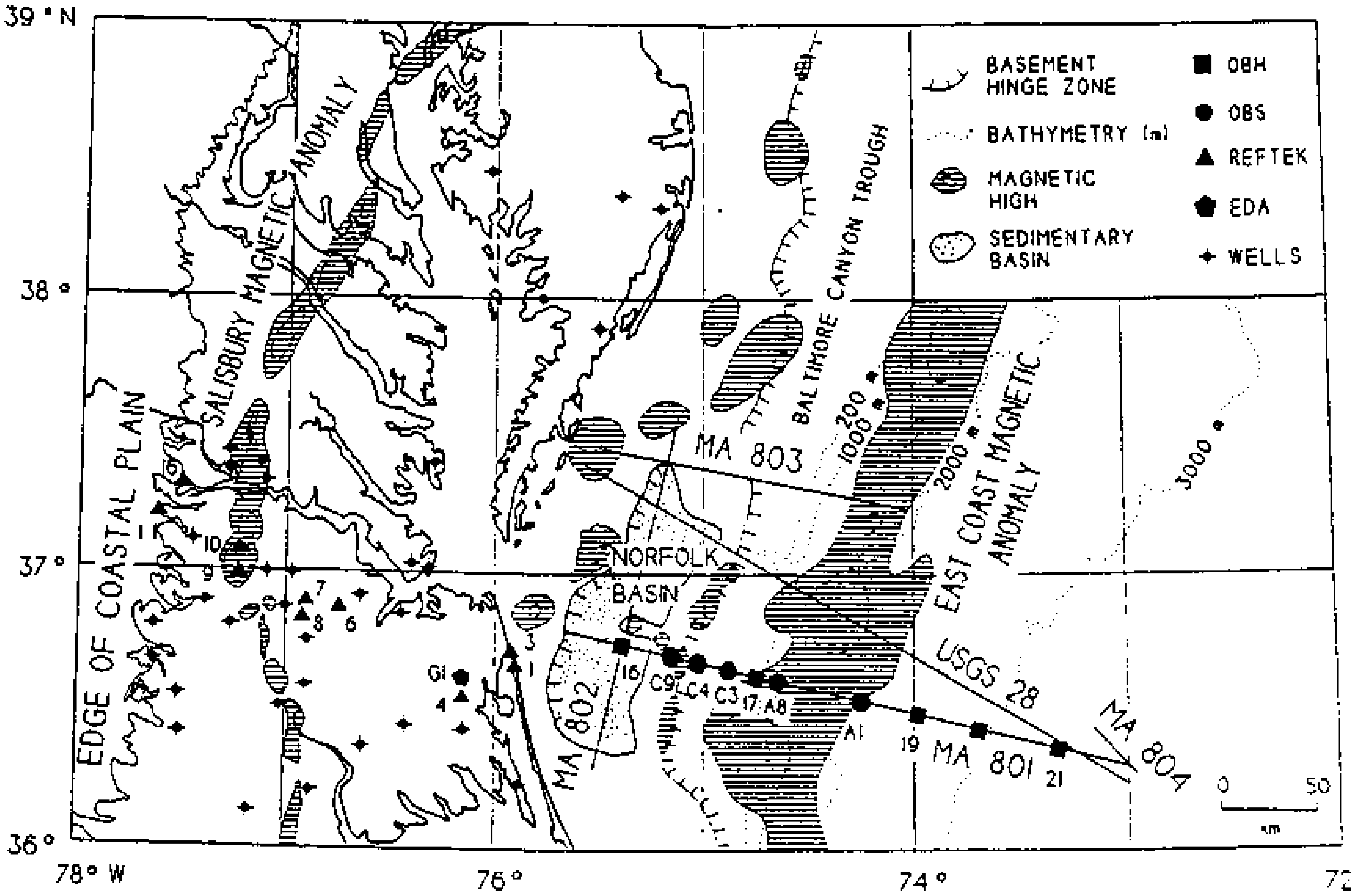

Figure 1. Map showing locations of EDGE vertical-incidence seismic reflection lines MA 801, 802, 803, and 804; ocean-bottom seismometers (OBS), hydrophones (OBH), and portable land seismic recorders (REFTEK, EDA); certain key coastal-plain wells; and key tectonic features and magnetic anomalies, such as Salisbury and East Coast magmatic anomalies, Baltimore Canyon trough, and Norfolk basin (after Klitgord et al., 1988).

symmetrical airgun array, with 10 800 in.^{3} of 2000 lb./in.^{2} air. Each shot was recorded for 16 s at a 2 ms sample interval by using a 6-km-long, 240-channel streamer with 25 m groups; shot spacing was 50 m yielding 12.5 m common depth points (CDPs) and 60-fold coverage. During acquisition, the Gulf Stream with a velocity of 4 kn was encountered on the southeast end of line MA 801 and on MA 804. The streamer rose into wave noise, leaving only the near 40 traces useful. Accordingly, the seaward ends of MA 801 and line MA 804 were not processed routinely and are not discussed here. All processing was done at the Houston Advanced Research Center and included decimation to 8 ms, CDP gathering, deconvolution, f-k filtering to suppress coherent noise and multiples, low-velocity multiple suppression (Z mult), muting, constant-velocity stacking analysis at 1 km spacing, normal-moveout corrections, dip-moveout stacking, summing adjacent 12.5 CDPs, finite-difference wave-equation migration, time-variable filter, and automatic gain control.

RESULTS OF VERTICAL INCIDENCE PROFILES

Reflections from deep-crustal horizons and from the Moho were recorded over most of profiles MA 801, 802, and 803 (Figs. 2, 3[1]). The base of the drift-stage sediments, the postrift unconformity (PRU in Fig. 2), is found at 1.0–2.0 s under the continental shelf. The unconformity can be traced across the continental slope to 8.0 s TWTT under the continental rise on lines MA 801 and 803. Above the unconformity under the continental slope, the Late Jurassic carbonate shelf edge (J) is well defined by a distinctly concave-upward escarpment reflection and diffractions (Figs. 2, 3). Beneath the unconformity on lines MA 802 and 803, the Norfolk basin (NB in Fig. 2) is identified by a listric border fault (BF in Fig. 2) and tilted synrift sedimentary reflections.

Distinct seismic laminations and reflections at 4.0–5.0 s in the basement (A in Fig. 2) show antiformal horsehead structures interpreted as a pre-Mesozoic thrust sequence (Figs. 2, 3). At ~7.0 s on the strike line, MA 802 (Fig. 2), there is an apparently horizontal reflection event. This reflection (TS in Fig. 2) marks the top of a reflective crust that might be mistaken for the laminated lower crust typical of the Appalachians (McBride and Nelson, 1988; Pratt et al., 1988; Sheridan et al., 1991). However, on lines MA 801 and 803, the 7.0 s reflection dips consistently southeast at a low angle (~15°). Moreover, on all three lines there appears to be a detachment associated with this 7.0 s reflection. The antiformal structures in the reflections above are disharmonic to and sole out or are truncated at the 7.0 s event (Figs. 2, 3). These features and the southeast dip of the 7.0 s reflection indicate that this reflection marks the base of a major pre-Mesozoic thrust sequence related to Appalachian collisional tectonics.

The Moho reflection (M in Fig. 2) landward of the Baltimore Canyon trough hing zone is a gently northwest dipping event : 11.0–12.0 s (Figs. 2, 3), very similar to th Moho under the exposed and buried Pie(mont province of the Appalachians (M(Bride and Nelson, 1988; Pratt et al., 198: Sheridan et al., 1991). Seaward of the troug hinge zone for a distance of 25 km, the Moh reflection and the lower crust change late ally on line MA 801 (Figs. 2, 3). The Moh reflection is taken as the base of high-ampl tude lower-crustal boundary laminatior that exist in a narrow interval (10.5–11.0 s The Moho is near horizontal on line MA 8(seaward of the Baltimore Canyon troug hinge zone but dips gently northwestwa landward of the hinge zone. This change o(curs just where the southeast-dipping 7.0 reflection intersects the Moho (Figs. 2, : On line MA 803, the lower crust is mo: acoustically transparent seaward of tl hinge zone than landward, and there an apparent northwest-dipping reflectic (marked MU on Fig. 2) that intersects tl Moho just beneath the hinge zone. Tl Moho is slightly deeper landward of this i: tersection and slightly shallower seawar The Moho reflection is not imaged well u der the continental slope and upper rise (lines MA 801 and 803 (Figs. 2, 3); howeve it reappears as reflections at 10.0 and 11.0 on the seaward end of line MA 801.

Under the continental slope and upp rise, the crust below the postrift unconforr ity is dominated by the seaward-dipping r flections of the interpreted Jurassic volcan wedge (JVW, Figs. 2, 3). The dipping refle

[1]Loose insert: Figure 3 is on a separate sheet accompanying this issue.

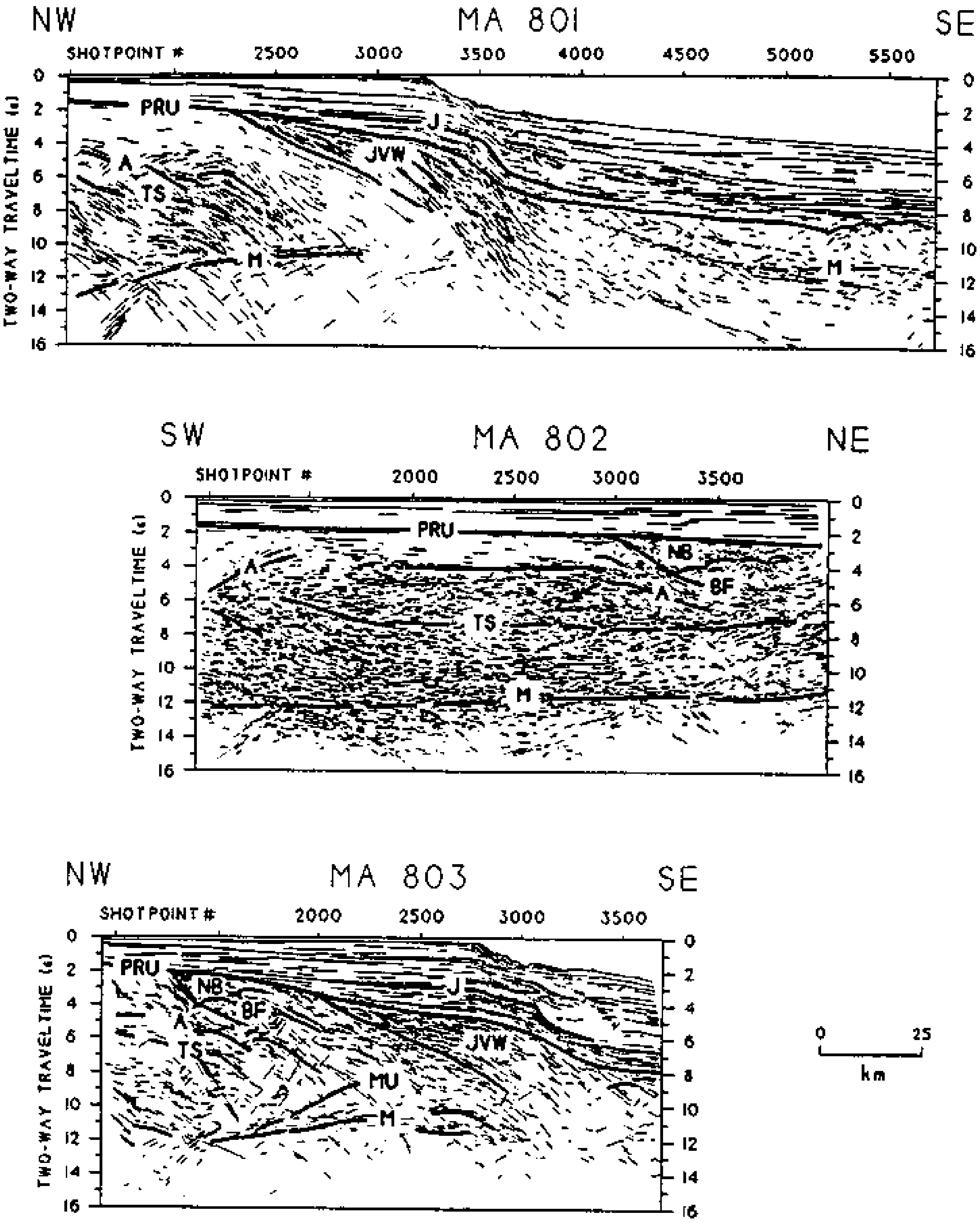

Figure 2. Line drawings of vertical-incidence, seismic reflection profiles MA 801, 802, and 803 from unmigrated 60-fold stacked data. J, PRU, JVW, NB, BF, A, TS, MU, and M are key reflections identified in text.

tions reach to depths >9.0 s (~20 km). Seaward under the continental slope and rise, the dipping reflections appear to be truncated by, or in toplap relation to, the postrift unconformity. The dipping reflections continue under the rise and appear to downlap on the oceanic basement until they pinch out against the oceanic basement J3 escarpment (Klitgord et al., 1988) where the basement shallows to 9.0 s.

INTERPRETATIONS

Jurassic Volcanic Wedge

Others have interpreted the seaward-dipping reflections of the U.S. Atlantic margin below the postrift unconformity as a Jurassic volcanic wedge (Benson and Doyle, 1988; Austin et al., 1990). The divergence, continuity, amplitude, and position of these reflections near the continent-ocean boundary are analogous to other volcanic wedges documented elsewhere (Mutter, 1985; White et al., 1987). The landward pinch-out on lines MA 801 and MA 803, and on USGS line 28, is consistently just west of the hinge zone in the Baltimore Canyon trough postrift unconformity (Fig. 4). This juxtaposition is also found to the north in the trough on USGS line 25 (Klitgord et al., 1988) and to the south in the Carolina trough (Klitgord et al., 1988; Austin et al., 1990). The seaward pinch-out of the wedge on line MA 801 (Figs. 2, 3) and USGS line 28 shows a consistent relation to the East Coast magnetic anomaly. Recent magnetic models applying a Jurassic remanence with basaltic magnetizations to the wedge imply that the wedge contributes significantly to the anomaly (Fig. 4) (Austin et al., 1990; M. Talwani et al., unpublished).

The seismic and magnetic characteristics of the seaward-dipping wedge indicate that it consists of interlayered basalts and volcaniclastic rocks (Fig. 5). These volcanic deposits formed along the entire U.S. margin at the time of breakup in the Middle Jurassic. Considerable volcanism, such as occurred in the Norwegian Sea, apparently also occurred all along the U.S. margin. The truncated Jurassic volcanic wedge may have stood above sea level as volcanic islands during the time of breakup. The great 10–15 km thickness and cross-sectional width of the volcanic deposits along the length of the U.S. Atlantic margin (Fig. 5) represent a volume that rivals the volumes of other great basaltic accumulations, such as the Deccan Traps.

Magmatic Underplating

Magmatic underplating of passive continental margins during breakup has been suggested by others for Atlantic margins elsewhere (Weigel et al., 1982; Mutter, 1985; White et al., 1987; Keen et al., 1987) and for the U.S. Atlantic margin in particular (Diebold et al., 1988; Trehu et al., 1989; Austin et al., 1990). In the underplating hypothesis, the thick, high-velocity (7.4–7.5 km/s) crust under the deep Baltimore Canyon trough just west of the East Coast magnetic anomaly (Fig. 5) consists of mafic and ultramafic magma intrusions and cumulates formed at breakup. These mafic and ultramafic magmas ponded in the lower crust, perhaps because of density differentiation, and the magmas were the source of the basaltic extrusions in the overlying volcanic wedge (Fig. 5) (White et al., 1987).

The high-amplitude, lower-crustal boundary laminations just above the Moho on line MA 801 (Figs. 2, 3, and 5) are evidence of this ponding. Holbrook et al. (1991) suggested that ultramafic sills would pond just above the Moho in rifted crust and that these sills would have a greater impedance contrast than mylonitized shear zones. Furthermore, we interpret the northwest-dipping reflection (MU, Fig. 2) on line MA 803 as the upper boundary of the underplated magma that truncated the southeast-dipping Appalachian structures. Both the northwest-dipping reflections (MU, Fig. 2) on line MA 803 and the abrupt landward limit of the high-amplitude lower-crustal boundary laminations on line MA 801 (Figs. 2, 3, and 5) indicate that the magmatic underplating did not extend landward of the Baltimore Canyon trough hinge zone. Support for the hypothesis of spatial restriction of the underplated crust comes from a preliminary analysis of the ocean-bottom seismometer data, which show average lower-crustal velocities landward of the hinge to be 6.85

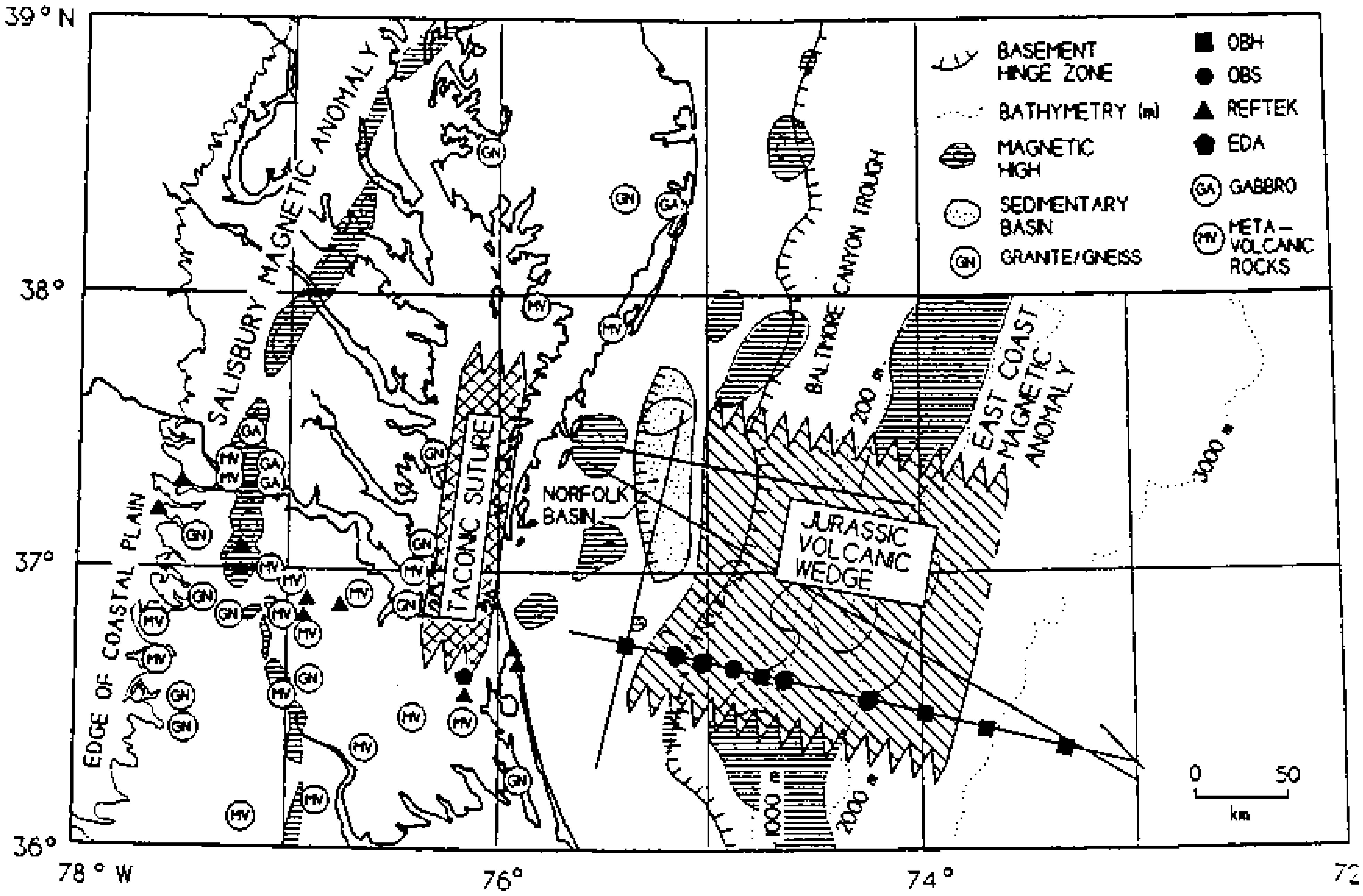

Figure 4. Location map showing new mapped location and north-striking border fault of Norfolk basin. Diagonal-line pattern indicates landward and seaward pinch-out position of Jurassic volcanic wedge systematically related to East Coast magnetic anomaly and Baltimore Canyon trough hinge zone; cross-hatched pattern represents projected trace of interpreted Taconic suture detachment fault on post-rift unconformity under central part of southern Chesapeake Bay.

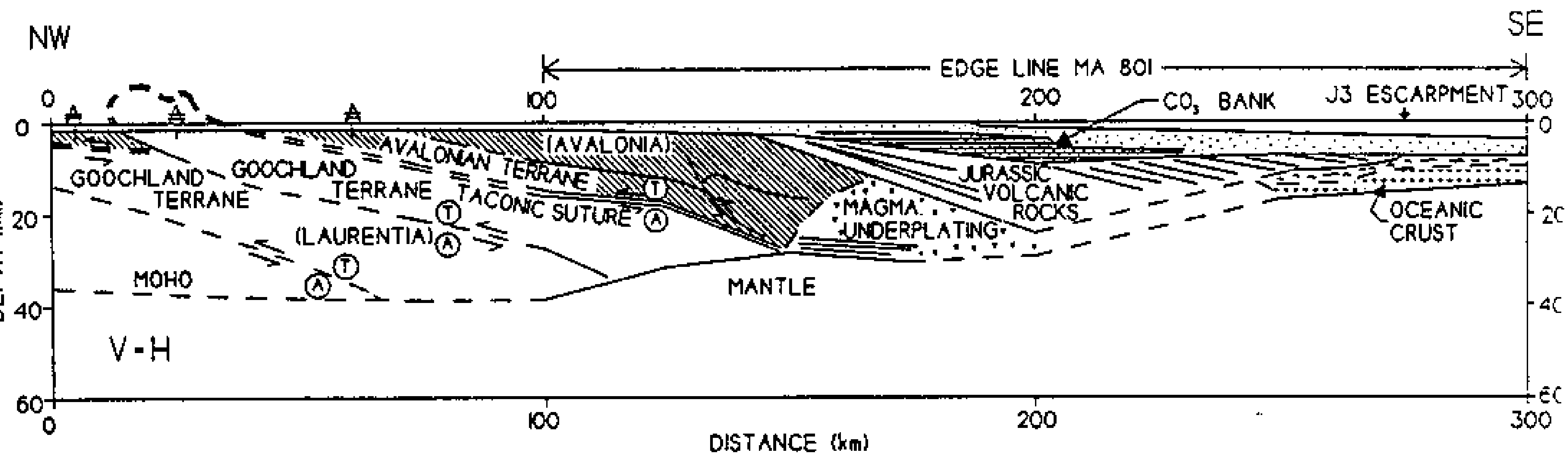

Figure 5. Interpreted geologic cross section across U.S. mid-Atlantic continental margin drawn without vertical exaggeration. Note that projection of Taconic suture between Avalonian (Carolinian) and Goochland terranes intersects base of coastal-plain sediment where well data indicate thrust-fault contact (L. Glover, III et al., unpublished). Jurassic magmatic-underplated crust apparently is localized where Taconic suture intersects Moho, which marks seaward edge of older Laurentian crust.

km/s; however, velocities are 7.4 km/s under the continental slope and rise (Fig. 3) (Holbrook et al., 1992). The Jurassic underplating has not significantly altered the North American crust landward of the Baltimore Canyon trough hinge zone.

Norfolk Basin

EDGE lines MA 802 and 803 and USGS line 28 show that the Norfolk basin occupies only the northern one-third of the basin previously mapped by the USGS (Klitgord et al., 1988) (Figs. 1, 4). Moreover, whereas previous mapping showed a northeast strike for the border fault of the basin, the EDGE lines restrict the strike to due north (Fig. 4).

The north strike is more compatible with concepts of back-slipping of Paleozoic thrust faults for the origin of the Mesozoic basin half-graben border faults (Ratcliffe et al., 1986). The Norfolk basin border fault (BF, Fig. 2) appears to be listric on the reflection profiles and appears to parallel basement reflections interpreted as pre-Mesozoic thrust sequences. If the Norfolk basin border fault strikes north, then the pre-Mesozoic thrusts probably also strike north. The general strike of major Paleozoic structures under the Virginia Coastal Plain, such as the Salisbury magnetic anomaly (Figs. 1, 4), is north. Thus, the northeast-striking East Coast magnetic anomaly and, therefore, the Jurassic magmatic underplating clearly are discordant to the north-striking Appalachian Paleozoic structures under the continental shelf, and the Jurassic underplating and volcanic deposits are herein interpreted as younger, crosscutting structures.

Taconic Suture

The reflections from pre-Mesozoic thrust sequences (Fig. 3; also A and TS in Fig. 2) are interpreted on lines MA 801, 802, and 803. With this grid they are mapped as having a gentle true dip of ~15° southeast under the continental shelf. The upper thrust sequence (A in Fig. 2; Fig. 3) is detached above the deeper thrust sequence at the reflection marked TS (Fig. 2). Landward projection of the TS reflection, which appears to be a major detachment fault surface, yields a north-striking trace at the postrift unconformity under the center of southern Chesapeake Bay (Figs. 4, 5). Uncertainty in crustal seismic velocities prevents a precise projection of this detachment fault's trace, so the projection is shown as a rectangular zone in Chesapeake Bay.

Coastal-plain wells (Figs. 1, 4) on the eastern shore of Chesapeake Bay recovered low-grade metavolcanic rocks correlated with the Carolina slate of the Avalonian (Carolinian) terrane (Fig. 5) (L. Glover, III et al., unpublished). Wells west of the metavolcanic rocks in Maryland recovered high-grade metamorphic granitic gneiss that is correlated with the Goochland terrane. The Goochland terrane is thought to be Grenville-age North American crust (Laurentia) (L. Glover, III et al., unpublished). Consequently, the gently dipping detachment surface under the mid-Atlantic continental shelf is interpreted as the boundary between North American Grenville-age crust (Laurentia) and the obducted alien volcanic-magmatic arc terrane of Avalonia (Carolinia) (Fig. 5). This probably is the Taconic suture.

The Taconic suture dips southeast and intersects the Moho at the landward limit of Jurassic magmatic underplating. The Taconic suture, as a crustal boundary between Laurentia and Avalonia (Carolinia) (Fig. 5), apparently localized the emplacement of Jurassic magmas during breakup of the modern Atlantic.

CONCLUSIONS

The Taconic suture and the boundary between the Grenville-age North American crust (Laurentia) and the obducted Avalonian (Carolinian) volcanic-magmatic arc terrane are preserved under the U.S. Mid-Atlantic continental shelf. Rifting in the upper brittle crust, as evidenced by the north-striking Norfolk basin, appears to be passive back-slipping along older Paleozoic thrusts. This rifting style persists seaward to a point immediately adjacent to a younger, cross-cutting Jurassic volcanic wedge and magmatic underplated crust. The wedge and underplating under the deep Baltimore Canyon trough displaced any remnants of Paleozoic structures. However, in the U.S. Mid-Atlantic area, the Jurassic magmatic underplating is generally localized at the Moho by the boundary between the Avalonian (Carolinian) magmatic arc crust and the more ancient Laurentian crust and the Moho. Perhaps different rheologies, temperatures, and/or crustal anisotropies in these contrasting crusts favored the localization of breakup there.

ACKNOWLEDGMENTS

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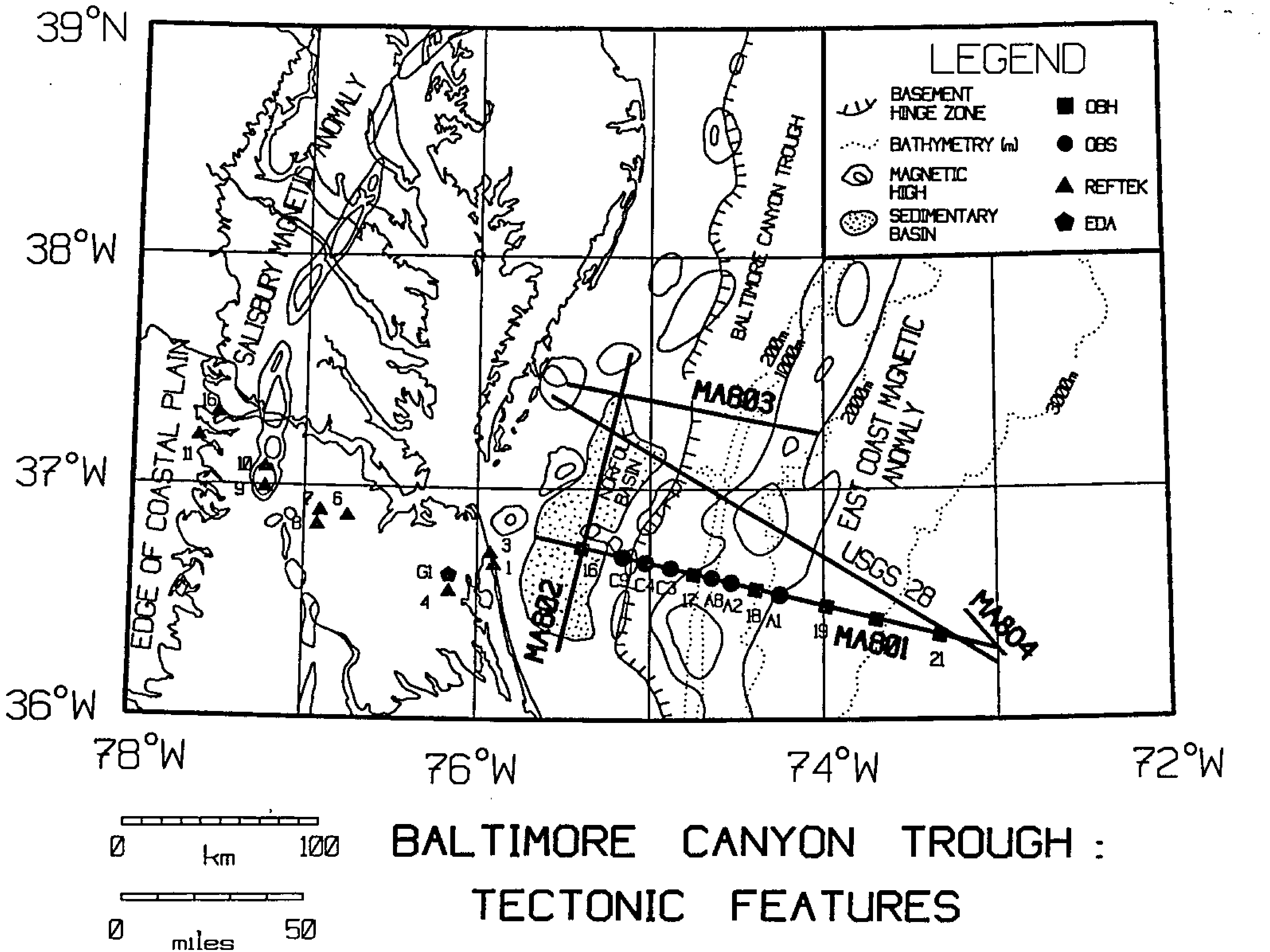

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