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5. Data Report: Marine Geophysical Data on the Newfoundland Nonvolcanic Rifted Margin around SCREECH Transect 2[1]

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ABSTRACT

Marine geophysical data collected from the eastern Grand Banks across the Newfoundland Basin during the summer of 2000 comprise a grid of seismic, magnetic, gravity, and multibeam bathymetric data around Sites 1276 and 1277. Multichannel seismic reflection profiles image the sedimentary and crustal structure of the Newfoundland nonvolcanic rifted margin. This report presents prestack time-migrated seismic reflection profiles together with the coincident magnetic and gravity data collected during the site survey.

INTRODUCTION

In July–August 2000, >3000 km of multichannel seismic (MCS) reflection, magnetic, gravity, and multibeam bathymetric data and 1000 km of wide-angle reflection/refraction data were acquired along three transects across the eastern Grand Banks and Newfoundland Basin during the Studies of Continental Rifting and Extension on the Eastern Canadian Shelf (SCREECH) survey (Fig. F1). This was a two-ship program, with MCS, magnetic, gravity, and multibeam bathymetric data acquired by the *Maurice Ewing* (Cruise 00-07) and wide-angle reflection/refraction data acquired by ocean-bottom seismometers/hydrophones (OBS/

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Hs) deployed and retrieved by the *Oceanus* (Cruise 359-2). The northern two transects were collected conjugate to seismic and drilling transects on the Iberia margin (Ocean Drilling Program [ODP] Legs 103, 149, and 173) based on the reconstruction of Srivastava et al. (2000). SCREECH transect 1 is conjugate to the ODP Leg 103 transect, and SCREECH transect 2 is conjugate to the ODP Leg 149/173 transect. Taken together, the geophysical data sets collected on the Newfoundland and Iberia margins constitute the most complete information available for conjugate margins of a nonvolcanic rift.

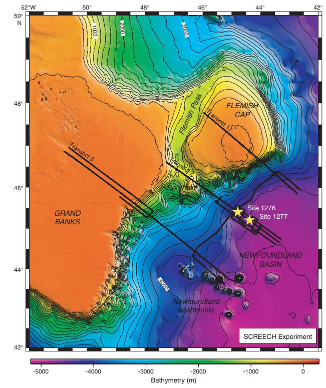
The purpose of the SCREECH program was to (1) distinguish between competing hypotheses for the origin of "transitional" crust lying between unambiguous oceanic crust and continental crust on the Newfoundland margin, (2) compare the crustal structure of the Newfoundland margin to the conjugate Iberia margin in order to learn more about the processes that extend and ultimately rupture continental crust, and (3) obtain site survey data that could be used to select and justify ODP drill sites in the Newfoundland Basin. In a larger context, the SCREECH program was germane to investigating broader issues related to continental rifting, such as the relative importance of pure and simple shear during margin formation (Lister et al., 1986; McKenzie, 1978; Wernicke, 1985) and the transition from late-stage rifting to early seafloor spreading (Cochran and Martinez, 1988; Hopper et al., 2004; Taylor et al., 1995).

Nonvolcanic rifted margins are produced by rifting that is not accompanied by significant magmatism, which is in contrast to the voluminous magmatism that commonly covers and masks extensional structures on volcanic margins (e.g., Louden and Chian, 1999). Thus, nonvolcanic margins are excellent places to image the structures associated with rifting and initial seafloor spreading. The lack of magmatism on nonvolcanic margins is often attributed to very slow and cold rifting, where conductive heat loss may suppress melt generation (Bown and White, 1995), although alternative theories call for rapid strain localization and continental rupture (Harry and Bowling, 1999) or depressed subcontinental geotherms (Reston and Phipps Morgan, 2004).

Seismic and drilling investigations of nonvolcanic margins, particularly the Iberia margin, have identified zones of serpentinized peridotite between thinned continental crust and "normal" oceanic crust (Beard and Hopkinson, 2000; Boillot et al., 1992; Dean et al., 2000; Pickup et al., 1996; Whitmarsh et al., 2001). Geochemical studies of samples recovered during ODP Legs 149 and 173 suggest that this altered mantle is subcontinental in origin (Abe, 2001; Hébert et al., 2001). Exhumed, serpentinized mantle has been emplaced over a width of as much as 100 km on some sections of the Iberia margin (Dean et al., 2000; Pickup et al., 1996). Additionally, bright, subhorizontal reflections have been observed in seismic sections from the Galicia Bank and the southern Iberia Abyssal Plain margin, and they are interpreted to be mechanical structures (detachment surfaces) related to final thinning of continental crust, unroofing of subcontinental mantle, or both (Chian et al., 1999; de Charpal et al., 1978; Krawczyk and Reston, 1995; Manatschal et al., 2001; Reston et al., 1996, 2001).

The identification of exhumed subcontinental mantle on the Iberia margin immediately raises the question of the origin and characteristics of crust on the conjugate Newfoundland margin. Previous geophysical studies recognized a zone of crust of disputed affinity between oceanic crust and continental crust on the Newfoundland margin (Keen et al., 1989; Reid, 1994; Srivastava et al., 2000; Tucholke et al., 1989). Here,

F1. Bathymetric map of the Newfoundland margin, p. 9.



this is termed "transitional crust." The presence of low-amplitude magnetic anomalies, the unusual reflection characteristics of basement in MCS sections, and a previous lack of extensive wide-angle reflection/refraction data allowed three possible explanations for the origin of this transitional crust: (1) slow-spreading oceanic crust (Srivastava et al., 2000; Sullivan and Keen, 1978), (2) thinned, possibly intruded continental crust (Tucholke et al., 1989; Tucholke and Ludwig, 1982), and (3) exhumed, serpentinized mantle (Reid, 1994). A significant part of the motivation for collecting seismic reflection and refraction data during the SCREECH survey and for drilling during ODP Leg 210 was to investigate the origin of the transitional crust on the Newfoundland margin and thus to better constrain the evolution of the Newfoundland–Iberia rift. Site 1276 was located within the zone of transitional crust, and Site 1277 was drilled seaward of transitional crust near magnetic Anomaly M1 on crust that is interpreted to be oceanic.

In this contribution, we present prestack time-migrated seismic reflection sections, together with the coincident magnetic and gravity data, to place Leg 210 drilling results into a regional context. SCREECH line 2MCS is conjugate to the ODP Leg 149/173 drilling transect across the Iberia Abyssal Plain on the Iberia margin (Srivastava et al., 2000). Interpretations of prestack depth migrations of the SCREECH transect 2 survey will appear in a forthcoming paper.

GEOPHYSICAL DATA

During the SCREECH experiment, coincident MCS reflection, wide-angle seismic reflection/refraction, magnetic, gravity, and multibeam bathymetric data were collected along three primary transects across the Newfoundland margin. Each transect reached from unambiguous continental crust seaward past a magnetic anomaly identified by Srivastava et al. (2000) as M3, and thus onto presumed oceanic crust (Fig. **F1**). MCS data were also collected on lines parallel and perpendicular to all transects, particularly around line 2MCS.

MCS data were acquired using the 480-channel, 6-km streamer of the *Maurice Ewing*. The MCS data have a sampling interval of 4 ms, a shot-spacing of 50 m, a fold of 60, a recording length of ~16 s, and a common midpoint (CMP) spacing of 6.25 m. The tuned 8540-in^3 air gun array of the *Maurice Ewing* provided the seismic source. A CMP navigation map for SCREECH transect 2 MCS lines can be found in the **"Supplementary Material"** contents list.

Wide-angle data along transects 1, 2, and 3 were recorded on 29 OBS/Hs from Dalhousie University, the Geological Survey of Canada, and Woods Hole Oceanographic Institution, and they were deployed and recovered from the *Oceanus*. Twenty-seven of these instruments were deployed along SCREECH transect 2; the locations of instruments on the seaward portion of SCREECH transect 2 are shown on the CMP track map (see the **"Supplementary Material"** contents list). The wide-angle data have a shot spacing of 200 m and a sampling interval of ~10 ms.

Magnetic data were acquired throughout the SCREECH survey using a towed Geometrics G-886 marine magnetometer. Gravity data were also collected along each line using a BELL BGM-3 gravimeter with gyro-stabilizing platform.

Data acquired along SCREECH line 2MCS and the attending gridlines, hereafter called the SCREECH transect 2 survey, are the subject of this chapter (Figs. F1, F2). Line 2MCS begins at the edge of the eastern Grand Banks and then passes southeast over Flemish Pass, Beothuk Knoll, and transitional crust in the Newfoundland Basin. It ends ~60 km seaward of magnetic Anomaly M0, which is widely recognized as one of the oldest unambiguous seafloor-spreading anomalies in the basin (Tucholke et al., 1989). Line 2MCS crosses both Sites 1276 and 1277.

DATA PROCESSING AND DESCRIPTION

Seismic Reflection Data

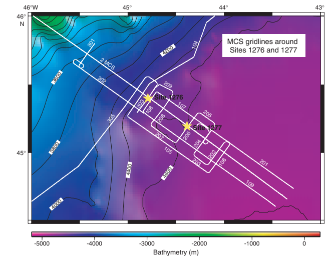
Figure F3 shows a prestack time migration of the seaward portion of line 2MCS, and Figure F4 shows the rest of the lines in the SCREECH transect 2 survey. Prior to migration and stacking, processing consisted only of muting bad traces and applying a minimum-phase bandpass filter that limited the frequency content to 10–100 Hz. For all lines except lines 104 and 305, smoothed interval-velocity sections were generated from stacking velocities picked on semblance plots and were used to apply Kirchhoff migrations to prestack data. Kirchhoff migration of CMP gathers yielded migrated gathers, which were then stacked to produce the final prestack time-migrated section. Lines 104 and 305 have a different processing flow. Line 104 is a poststack, water-velocity, frequency-wavenumber migration, and line 305 is an unmigrated stack.

Time migrations of the SCREECH transect 2 survey reveal several first-order seismic characteristics of the crust. Three distinct crustal zones are readily identified (Fig. F3). Unambiguous continental crust extends seaward to at least CMP ~220000 on line 2MCS. At this location, a continental block capped by what may be faulted prerift sediments is observed both on line 2MCS and on line 301, which crosses line 2MCS at this location (Figs. F3, F4Q). Seaward of CMP 220000, apparently featureless basement, capped by a sequence of very bright reflections including the U reflection, continues seaward for ~70 km. This interval constitutes the transitional crust in this part of the Newfoundland Basin. It is unclear where the top of basement lies in most of this crustal domain. However, toward the seaward end of this zone, some basement topography gradually becomes apparent and then gives way to higher-amplitude relief at CMP ~230000 (near magnetic Anomaly M3). High basement relief (>1 km) continues seaward to the end of the SCREECH transect 2 survey.

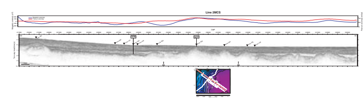
Basement in the 70-km-wide transitional zone from CMP 220000 to 230000 appears nearly featureless in MCS sections (Figs. F3, F4A, F4E, F4P, F4R, F4S, F4T, F4U). The top of basement usually cannot be identified, and intracrustal reflections are not observed in most of this domain. A few hints of the seismic character of this crust can be observed on lines 209 and 303 (Fig. F4P, F4S), where some basement topography can be identified. The apparent lack of reflectivity of the transitional crust might indicate that it is homogeneous, that its impedance is little different from the overlying deep lithologic section, or that there is low signal penetration through the U reflection and other bright reflections in the lowermost lithologic section.

Basement topography seaward of magnetic Anomaly M3 on line 2MCS forms a series of margin-parallel ridges; a contoured plot of basement topography (in two-way traveltime) is shown in Figure F5. The ridge topography is most apparent where lines 204a, 204b, and 206 (Fig. F4J, F4K, F4M) cross line 2MCS (Fig. F3) and along lines 107 and

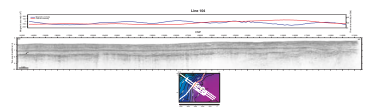
F2. Bathymetric map of the seaward part of SCREECH transect 2, p. 10.



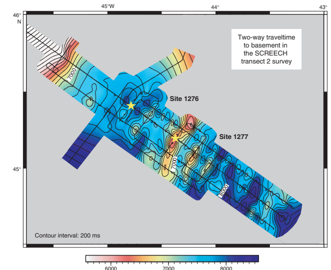
F3. Prestack time migration of SCREECH line 2MCS, p. 11.



F4. Other MCS lines, p. 12.



F5. Gridded picks of prestack time migrations, p. 33.

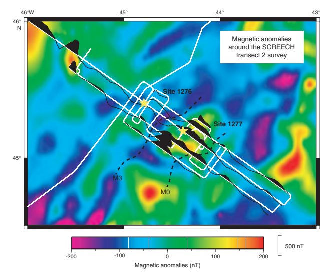


109 (Fig. F4D, F4F); in this area, three distinct high-amplitude ridges are observed. One of these ridges rises above the seafloor, as is seen on line 205 (Fig. F4L). The reflective character of the ridges is consistent between lines; the uppermost basement is highly reflective, whereas the deeper crust appears relatively transparent.

Magnetic Data

Magnetic anomalies were calculated by subtracting the International Geomagnetic Reference Field (2000–2005) for epoch 2000.0 from the total magnetic intensity measured on the ship (Mandea et al., 2000). Total magnetic intensity readings were taken from a towed Geometrics G-886 marine magnetometer at 12-s intervals. All values where the magnetometer stopped working (and the measured total magnetic intensity equaled zero) were removed, and the remaining data were smoothed using a boxcar filter with a length of 1 km. Figure F6 shows ship-track magnetic data collected on margin-normal lines plotted on top of an image of gridded magnetic data compiled by Verhoef et al. (1996). The shipboard magnetic data are also plotted in blue above each of the seismic sections in Figures F3 and F4. Missing data in the figures indicate long periods of time when the magnetometer was not working.

F6. Magnetic anomalies from the gridded data, p. 34.

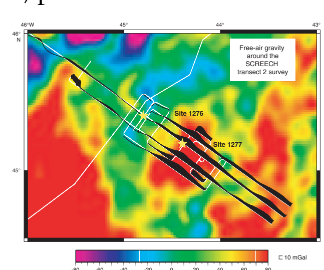


Magnetic anomalies in the transitional crust along line 2MCS display comparatively low amplitudes, as observed in previous magnetic profiles collected in this region (e.g., Srivastava et al., 2000; Verhoef et al., 1996). Average magnetic-anomaly amplitudes are typically <100–150 nT. The "J-anomaly," which is located at the seaward edge of the transitional crust, has been identified on both the Newfoundland and Iberia margins and was formed between Anomalies M0 and M2 (Rabinowitz et al., 1978; Russell and Whitmarsh, 2003; Tucholke and Ludwig, 1982). Although this is a high-amplitude anomaly in the southern Newfoundland Basin, its amplitude in the area of the SCREECH transect 2 survey is similar to anomaly amplitudes in the transitional crust. The locations of magnetic Anomalies M3 and M0 that were previously identified by Srivastava et al. (2000) are labeled on Figures F3 and F4 by arrows that indicate the center of an idealized block of constant polarity. These anomalies are also labeled as dashed lines on Figure F6.

Gravity Data

Prior to calculating gravity anomalies, Eötvös corrections were applied to raw gravity readings to correct for ship course and speed. The free-air anomaly was calculated by subtracting the theoretical gravity from the corrected measured gravity. Theoretical gravity was derived by the 1980 Gravity Formula (Moritz, 1988). All measurements where the gravimeter stopped working or was not level (and the reading equaled zero) were removed, and the remaining data were smoothed using a boxcar filter with a length of 1 km. The free-air gravity data are plotted in red above each seismic section in Figures F3 and F4. Figure F7 shows ship-track free-air gravity data along margin-normal lines plotted on top of gridded Geosat free-air gravity data (e.g., Douglas and Cheney, 1990). Missing data indicate long periods of time when the gravimeter was not working.

F7. Gridded Geosat free-air gravity data, p. 35.

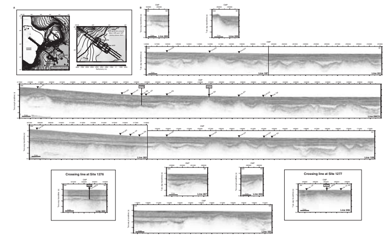


The seaward portion of the SCREECH transect 2 survey lies in a region of consistently positive free-air anomalies. In the SCREECH survey, as in prior studies (Verhoef et al., 1987), little variation in free-air anomaly values is observed.

SUMMARY

MCS reflection data collected around Sites 1276 and 1277 (Fig. F8) delineate three distinct crustal zones. The first of these, in the western portion of the SCREECH transect 2 survey, is extended continental crust; at its seaward edge is a probable continental block topped by faulted, possibly prerift sediments. Seaward of the continental crust, a 70-km-wide zone of nearly featureless basement, capped by the U reflection, is observed. Site 1276 was drilled over this zone of transitional crust. Toward the seaward end of this zone of transitional crust, basement topographic relief gradually increases and gives way to a zone of high-relief basement at the seaward end of the SCREECH transect 2 survey. This crust contains the oldest recognized magnetic anomalies (M3, M1, and M0) generated by seafloor spreading. Basement in this domain forms a series of margin-parallel ridges that are highly reflective in the upper 0.5 s of the crust in seismic reflection records. Site 1277 was drilled on one of these basement ridges near Anomaly M1. In future studies, interpretations of the SCREECH geophysical data will be used in conjunction with Leg 210 drilling results to constrain the evolution of rifting and early seafloor spreading in the Newfoundland–Iberia rift.

F8. SCREECH line 2MCS and parallel track lines with location maps, p. 36.



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Whitmarsh, R.B., Manatschal, G., and Minshull, T.A., 2001. Evolution of magma-poor continental margins from rifting to seafloor spreading. *Nature,* 413:150–154.

Figure F1. Bathymetric map of the Newfoundland margin extracted from the *GEBCO Digital Atlas* published by the British Oceanographic Data Centre on behalf of Intergovernmental Oceanographic Commission and the International Hydrographic Organization (British Oceanographic Data Centre, 2003). Contour interval = 200 m. Black lines = tracks of the SCREECH survey, yellow stars = locations of Sites 1276 and 1277. Coincident MCS, wide-angle seismic reflection/refraction, magnetic, gravity, and multibeam bathymetric data were acquired on transects 1, 2, and 3. MCS, magnetic, gravity, and multibeam bathymetric data were acquired on other lines.

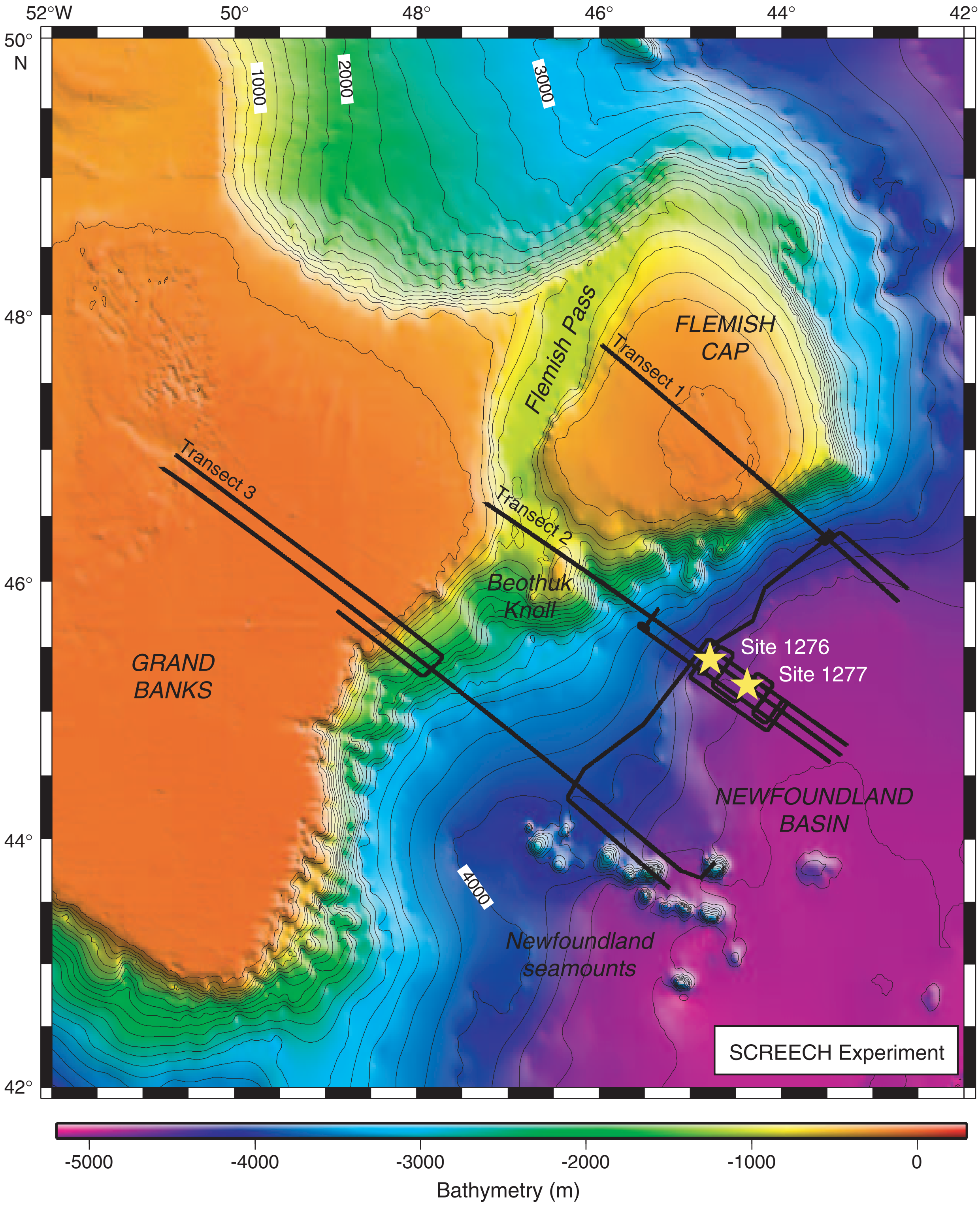

Figure F2. Bathymetric map of the area around the seaward part of SCREECH transect 2 from the *GEBCO Digital Atlas* (British Oceanographic Data Centre, 2003). Contour interval = 200 m. MCS lines are indicated with white lines and labeled by line number, and they are shown in Figures **F3,** p. 11, and **F4,** p. 12. Yellow stars = locations of Sites 1276 and 1277.

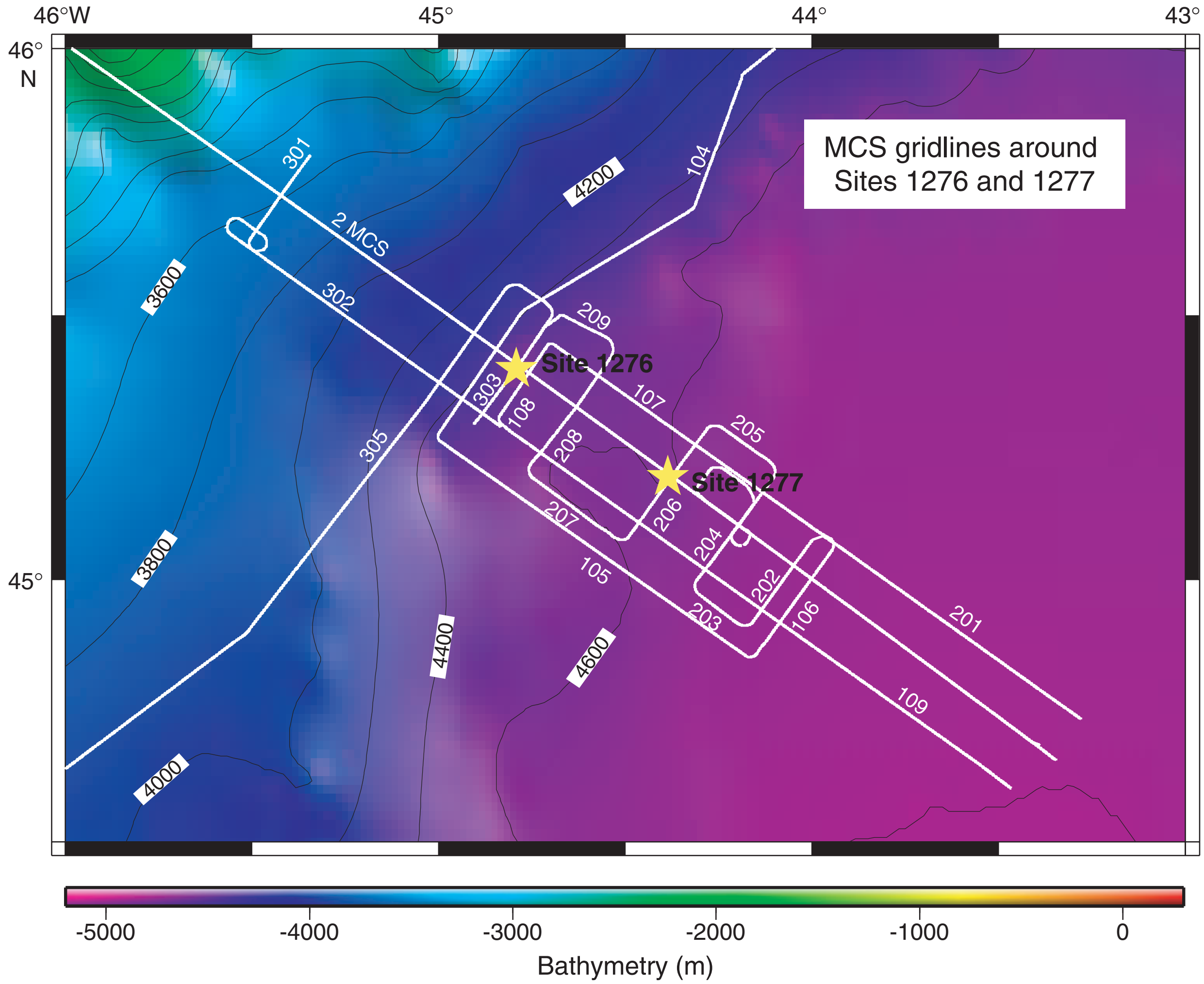

Figure F3. Prestack time migration of SCREECH line 2MCS. See Figure F2, p. 10, and the map at the bottom for the location. A CMP navigation map for SCREECH transect 2 MCS lines can be found in the "Supplementary Material" contents list. Inverted solid triangles with labels = crossings with other MCS profiles. Solid arrows = locations of Anomalies M0 and M3 as identified by Srivastava et al. (2000). CMP = common midpoint. (This figure is available in an oversized format.)

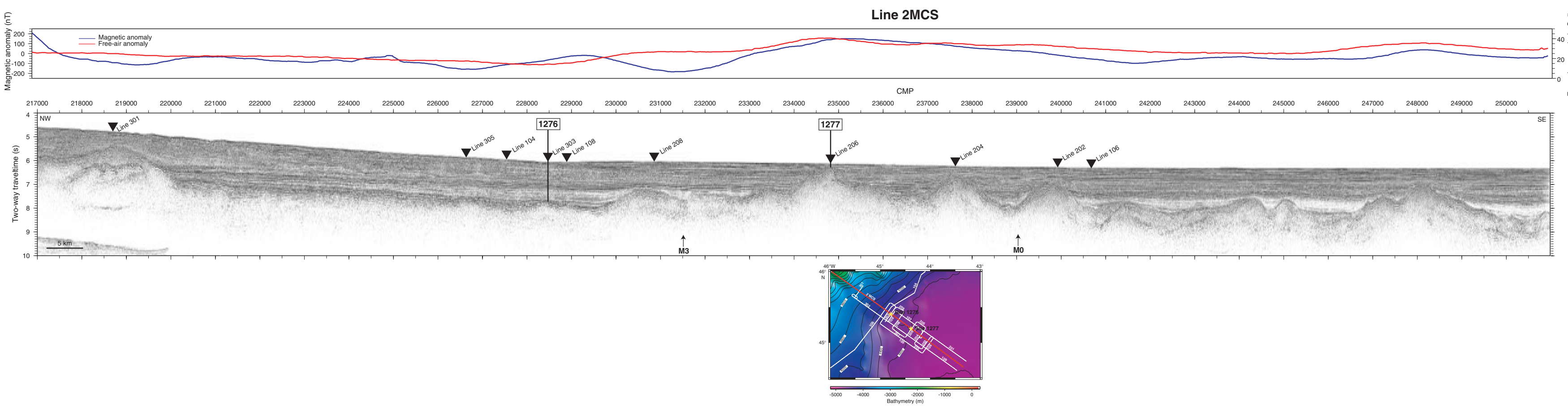

Figure F4. Other MCS lines within the SCREECH transect 2 survey. All sections except lines 104 and 305 are prestack time migrations. Line 104 is a water-velocity frequency-wavenumber migration, and line 305 is an unmigrated stack. See Figure **F2,** p. 10, and the map at the bottom of each figure for the location, indicated by a thick red line. A CMP navigation map for SCREECH transect 2 MCS lines can be found in the **"Supplementary Material"** contents list. Inverted solid triangles with labels = crossings with other MCS profiles. Solid arrows = locations of Anomalies M0, M1, and M3 as identified by Srivastava et al. (2000), yellow stars = locations of Sites 1276 and 1277. CMP = common midpoint. **A.** Line 104. (This figure is available in an **oversized format.**) (Continued on next 20 pages.)

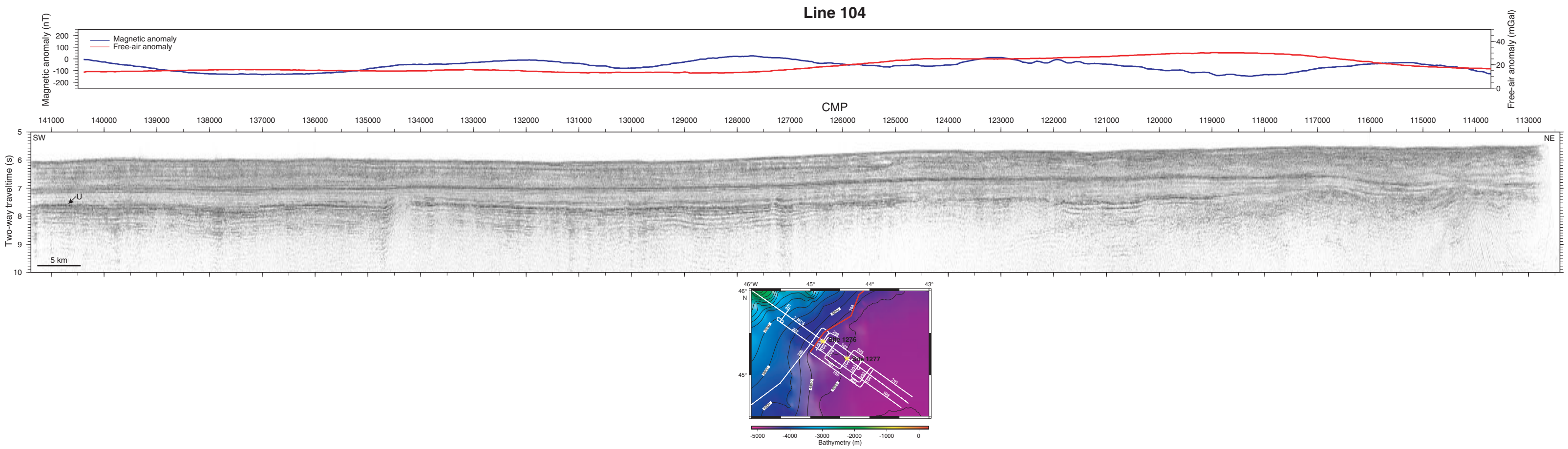

Figure F4 (continued). B. Line 105. (This figure is available in an oversized format.)

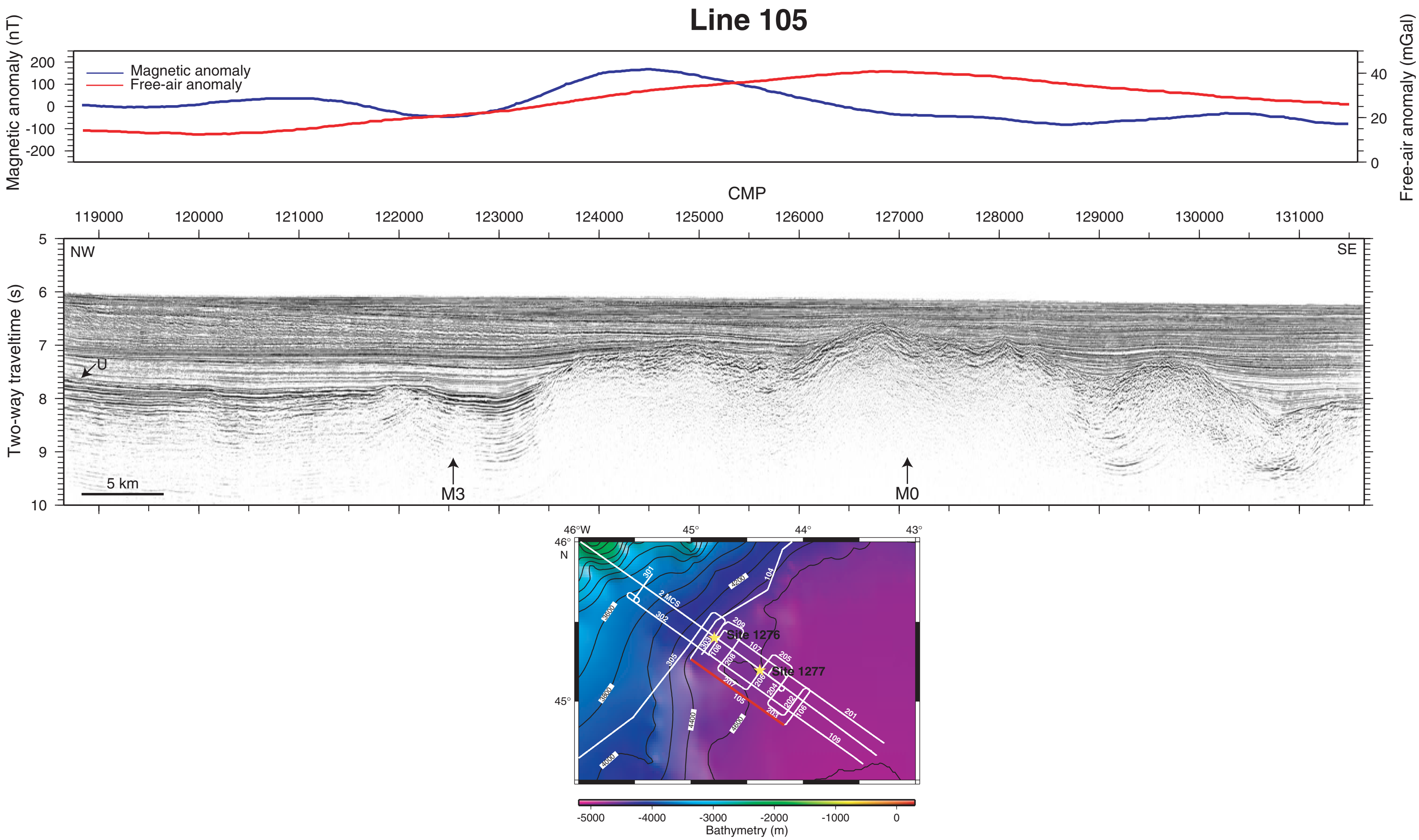

Figure F4 (continued). C. Line 106.

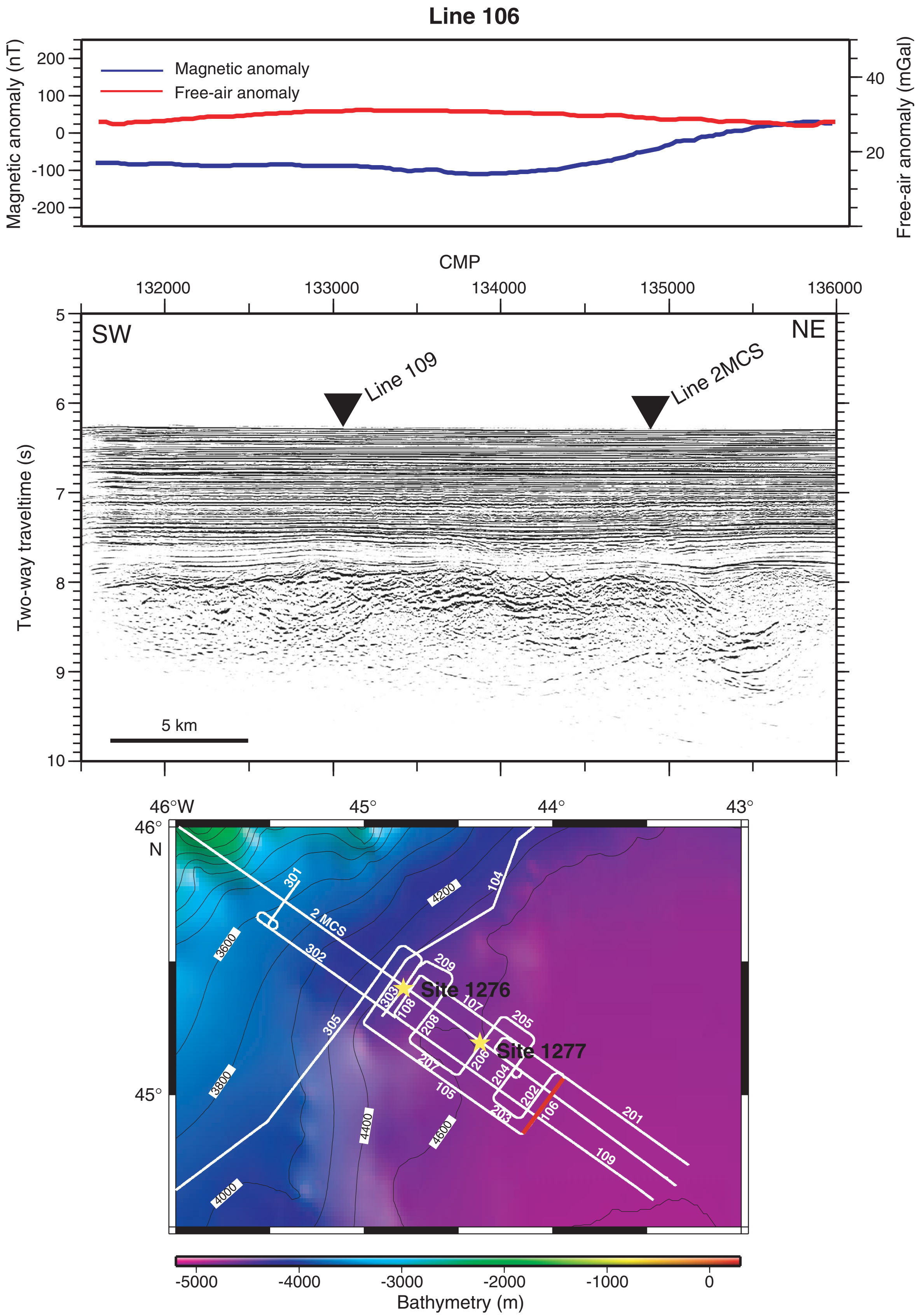

Figure F4 (continued). D. Line 107. (This figure is available in an oversized format.)

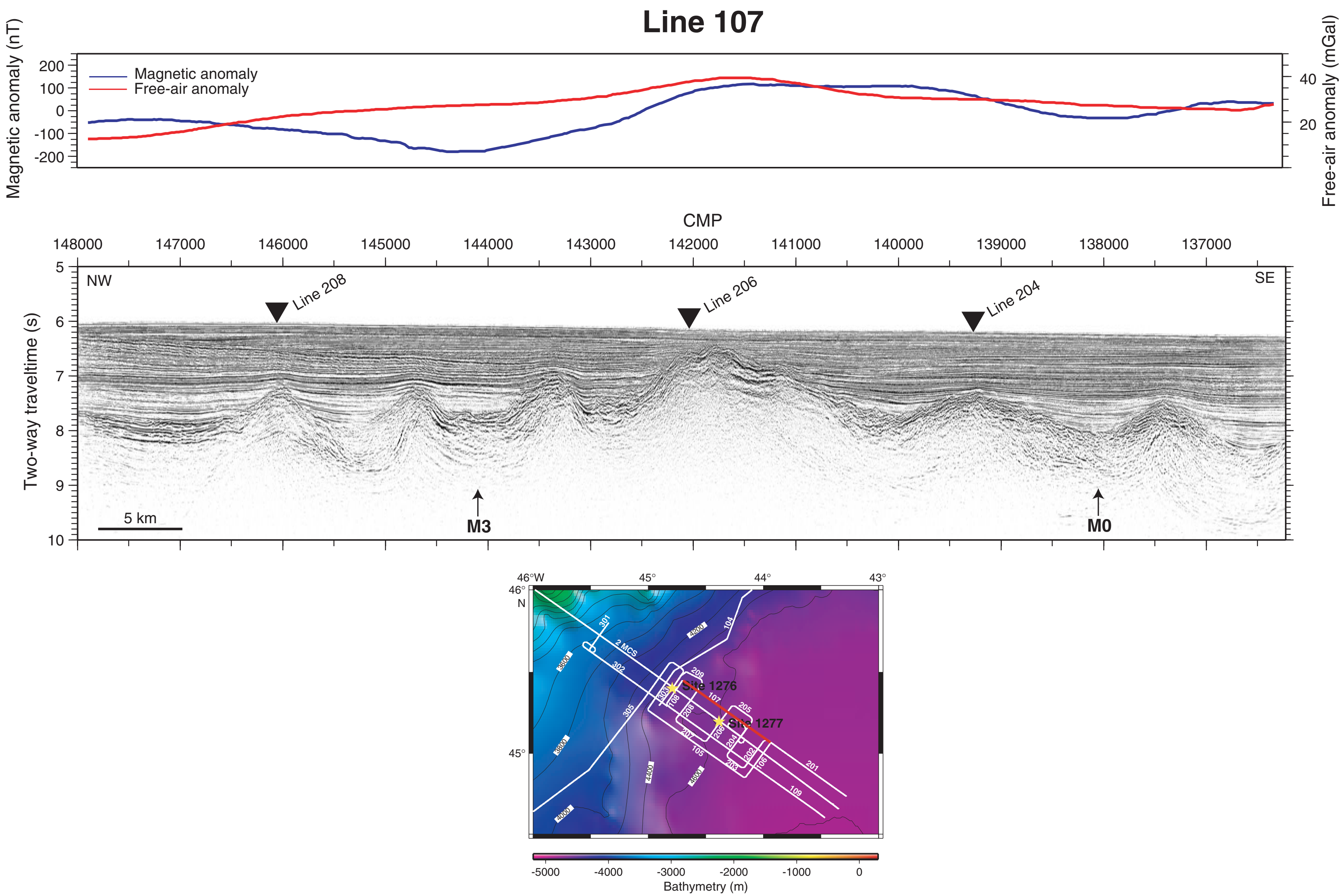

Figure F4 (continued). E. Line 108.

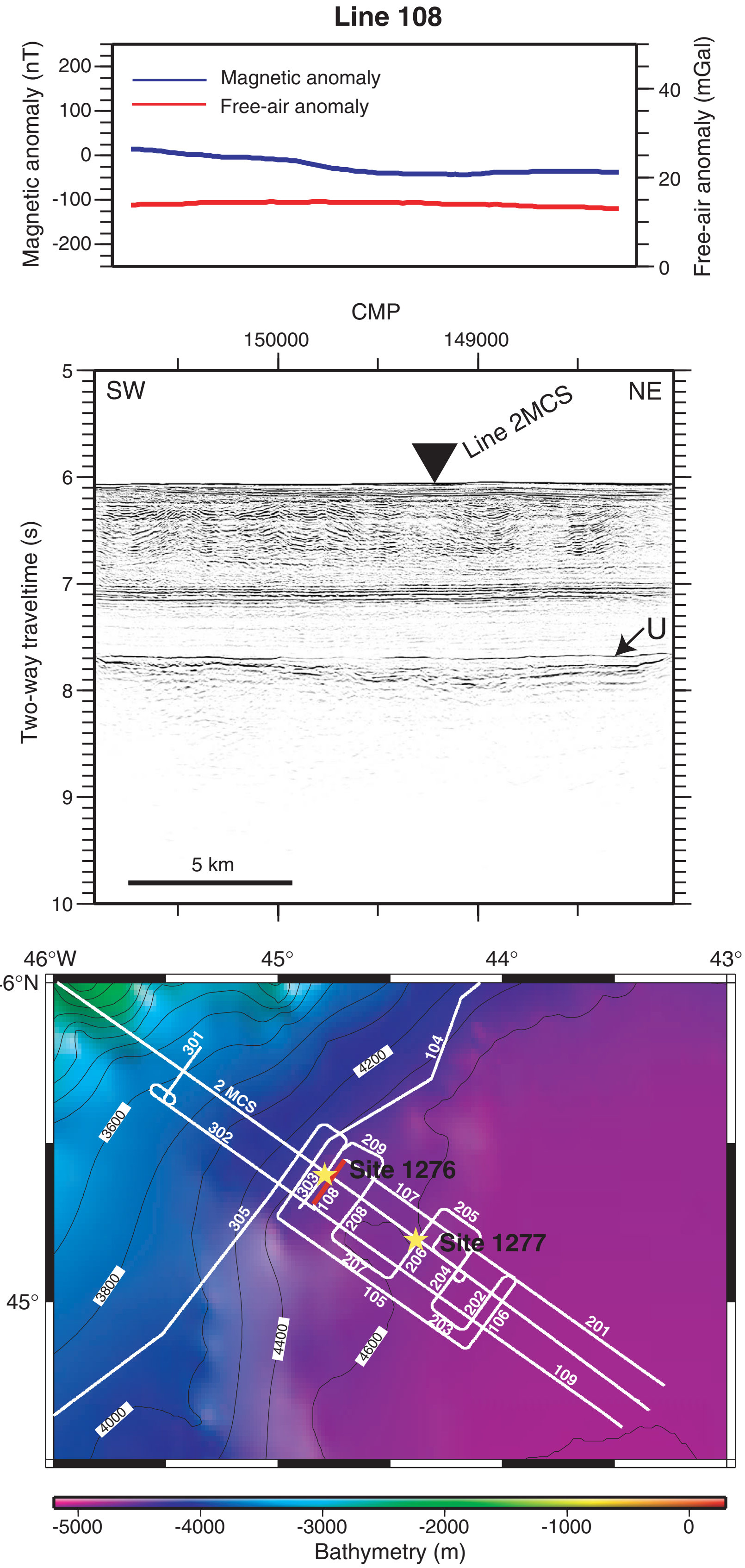

Figure F4 (continued). F. Line 109. (This figure is available in an **oversized format.**)

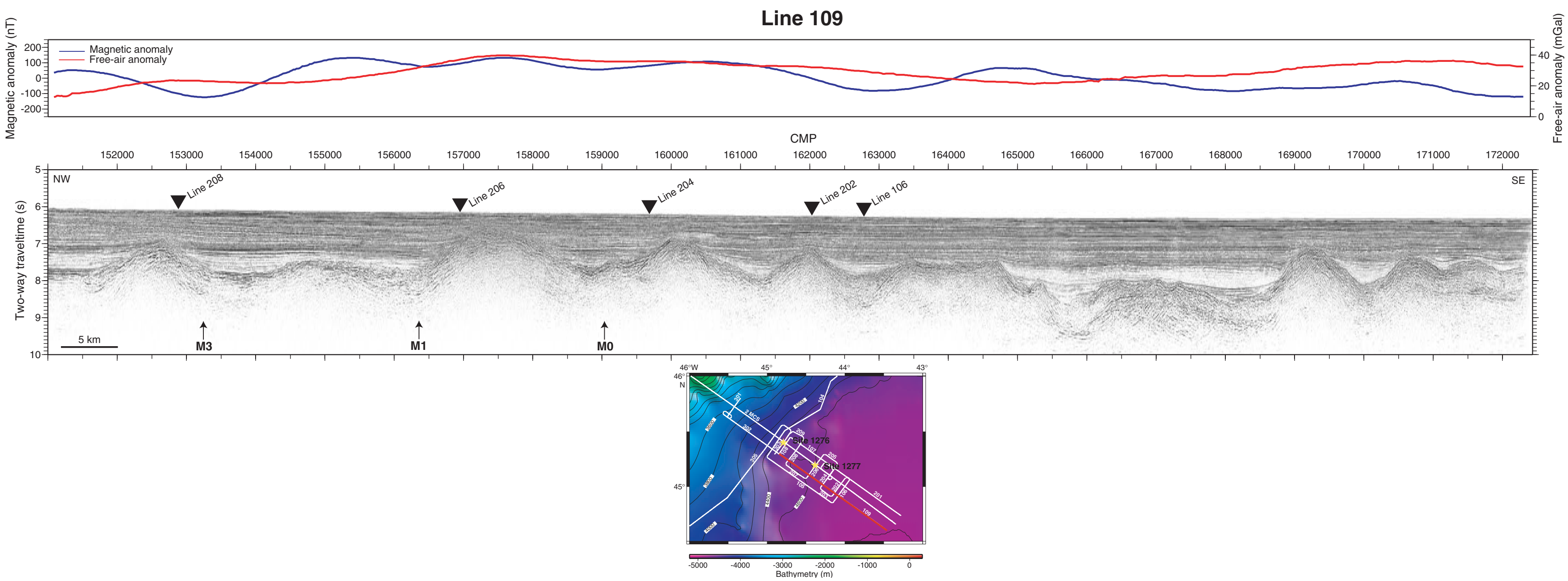

Figure F4 (continued). G. Line 201. (This figure is available in an oversized format.)

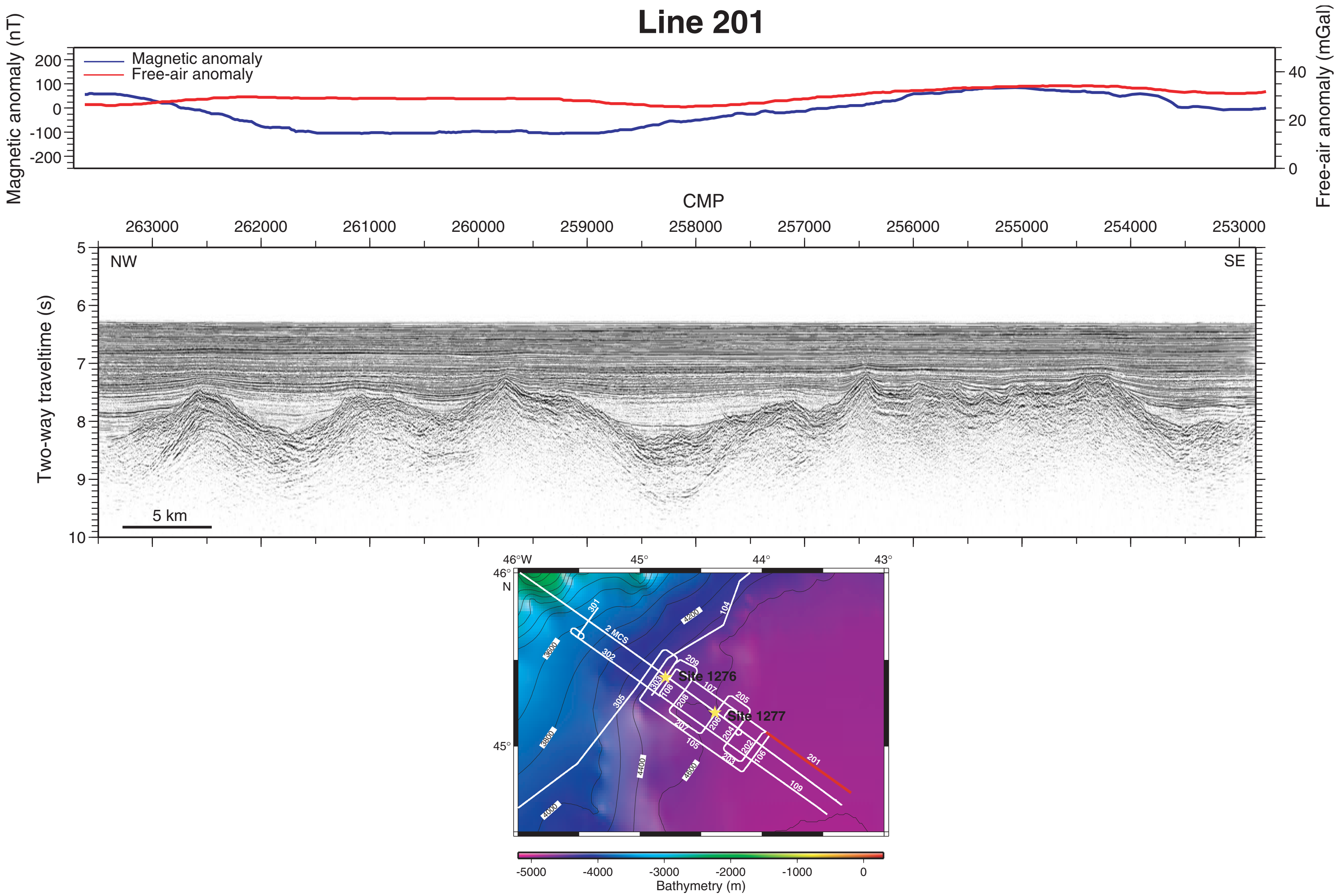

Figure F4 (continued). H. Line 202.

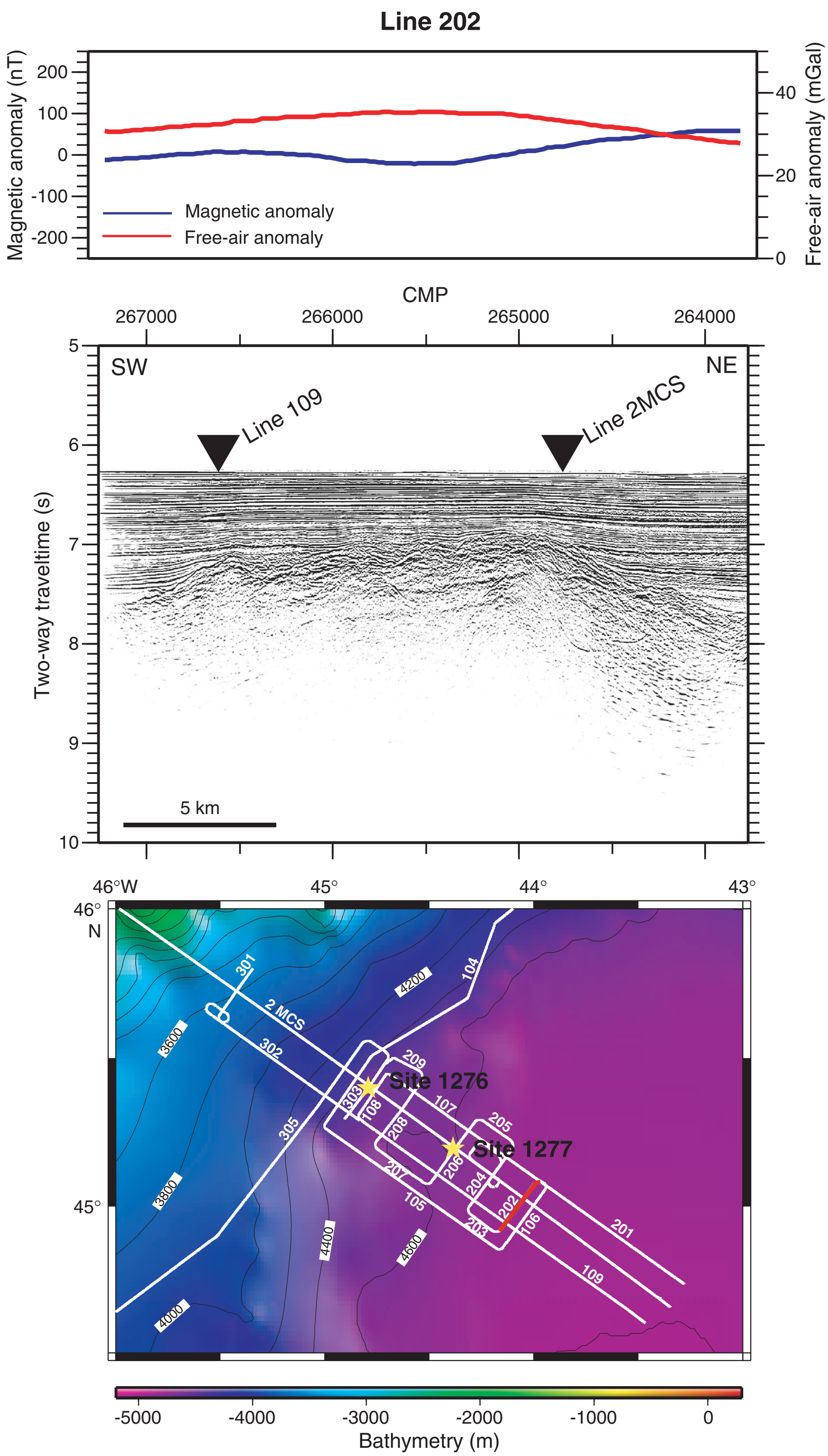

Figure F4 (continued). I. Line 203.

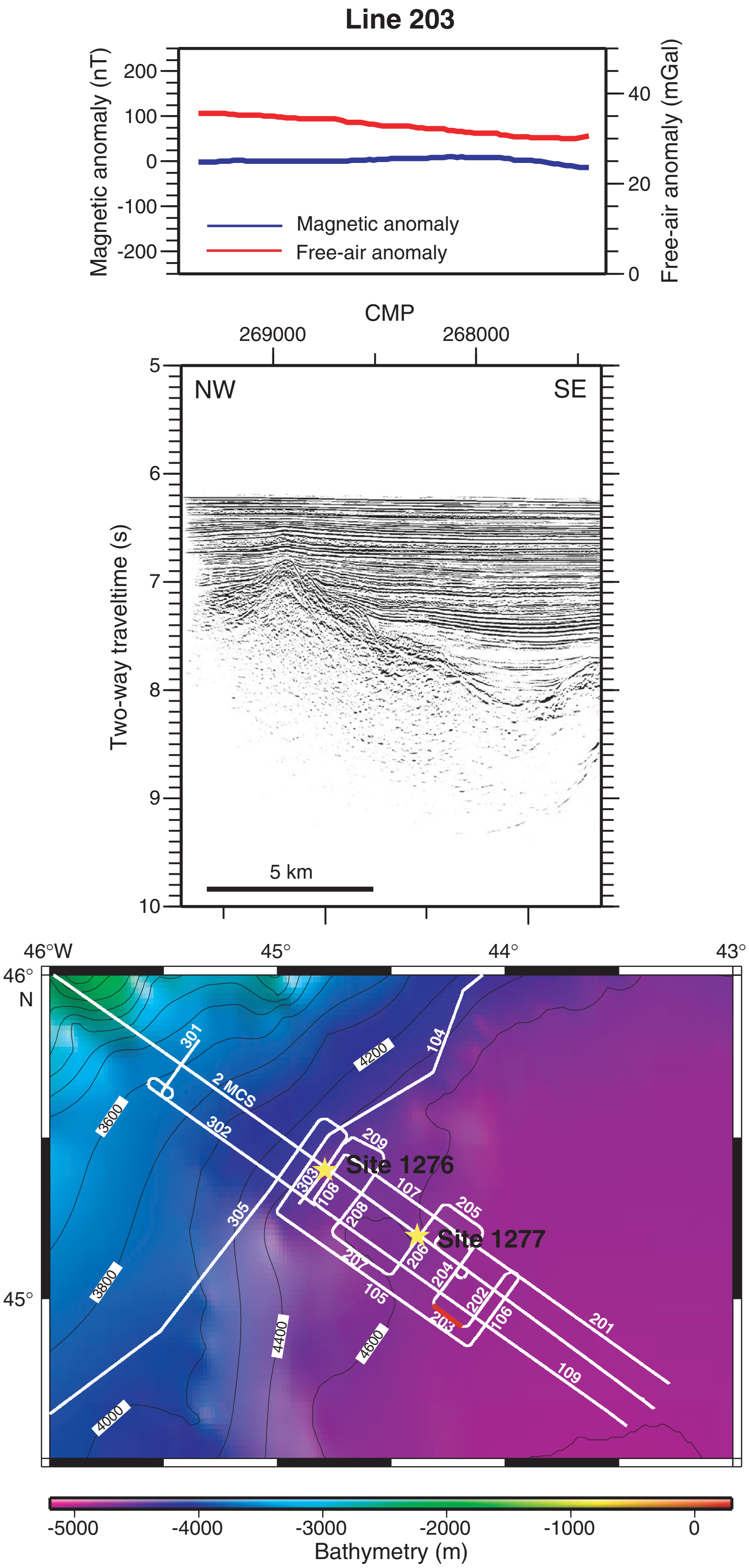

Figure F4 (continued). J. Line 204a.

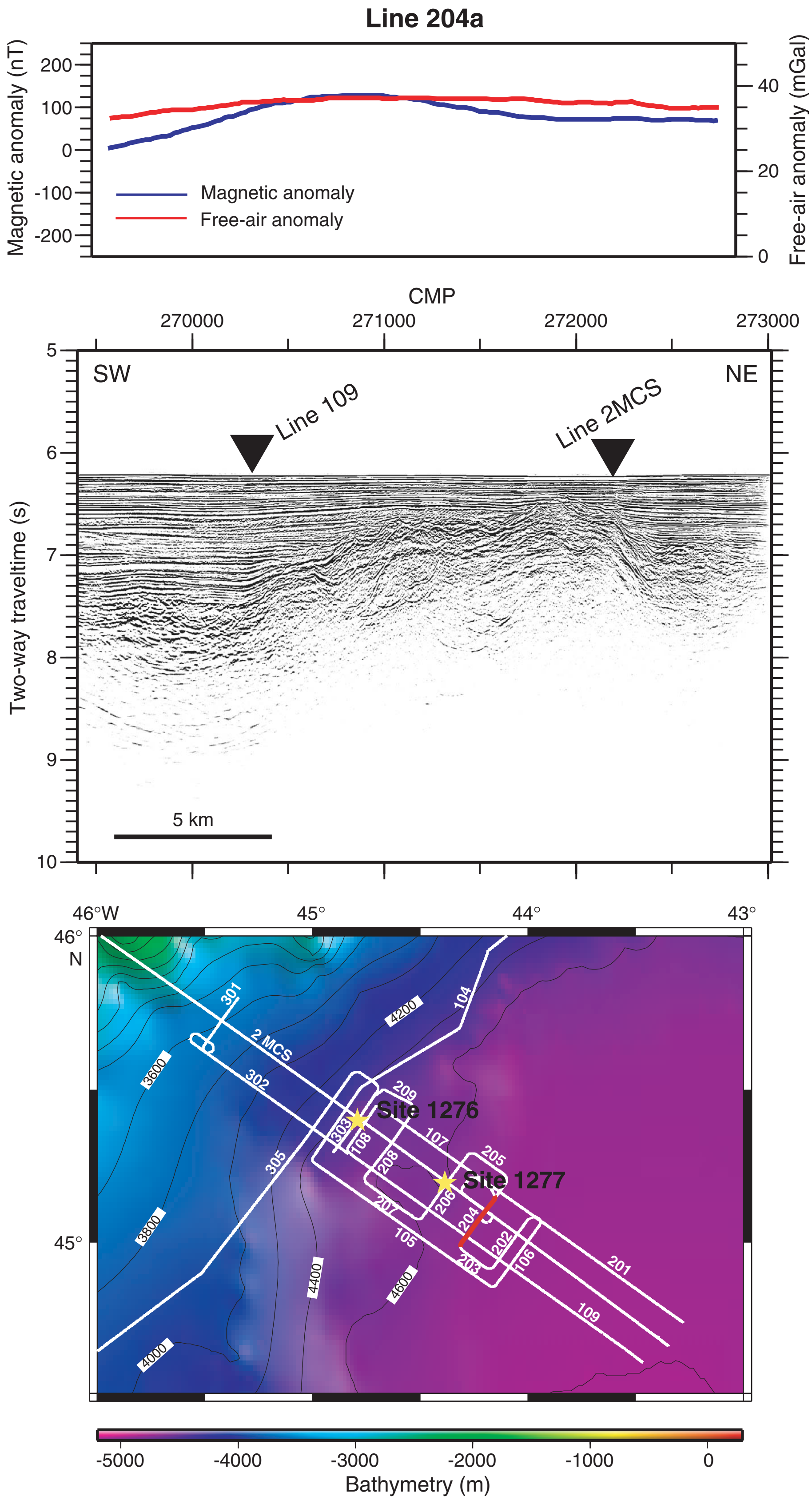

Figure F4 (continued). K. Line 204b.

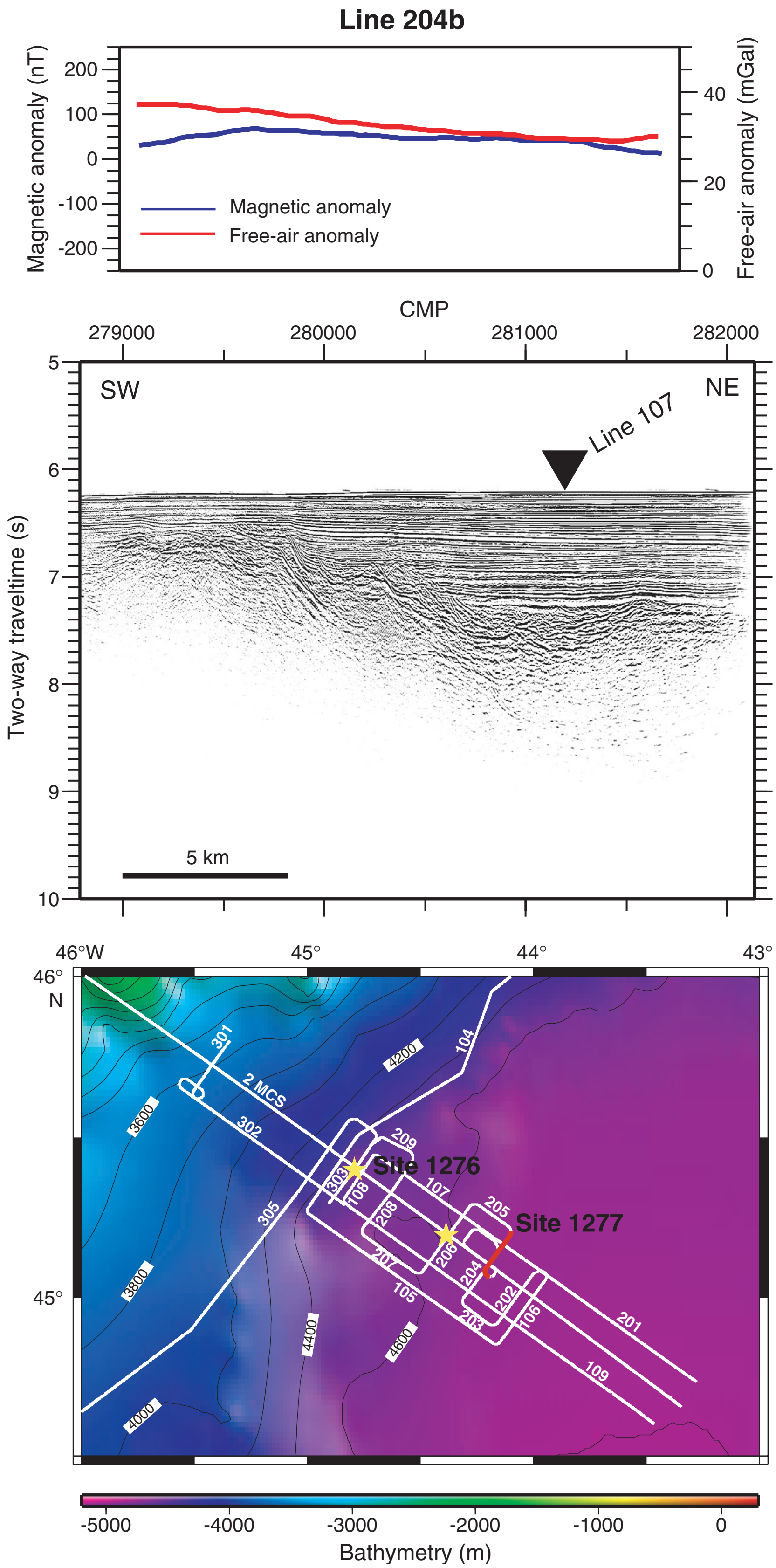

Figure F4 (continued). **L.** Line 205.

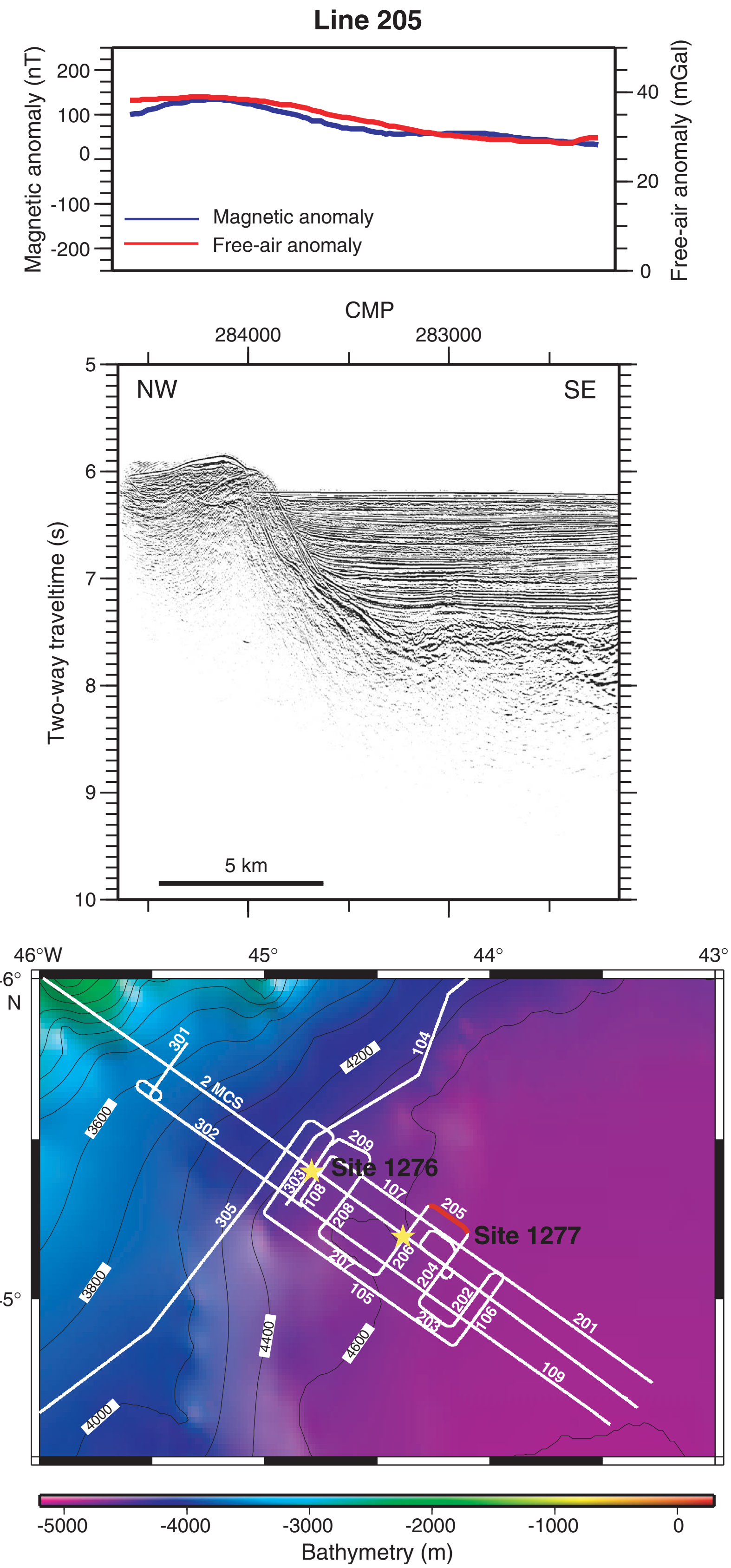

Figure F4 (continued). M. Line 206.

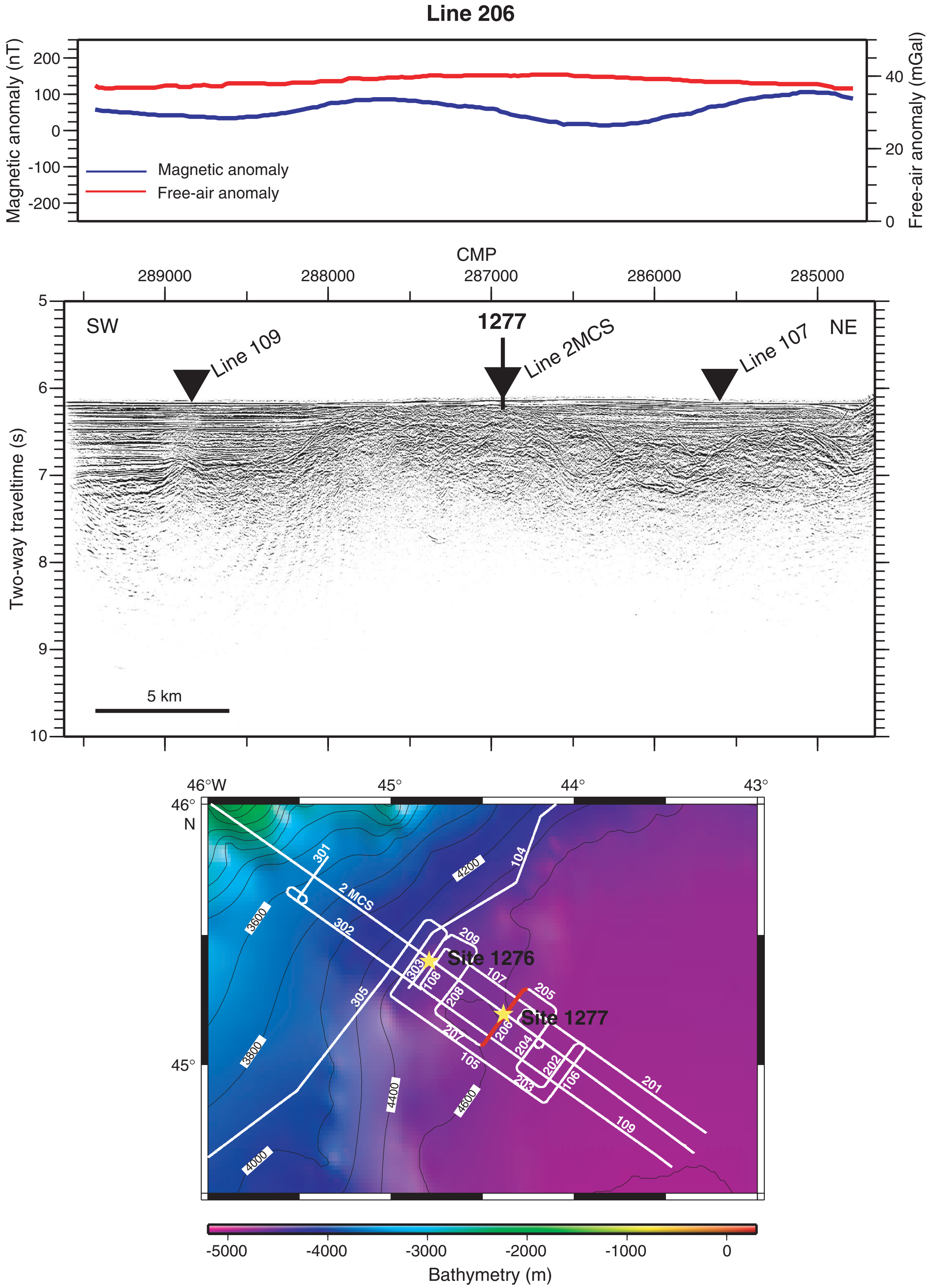

Figure F4 (continued). N. Line 207.

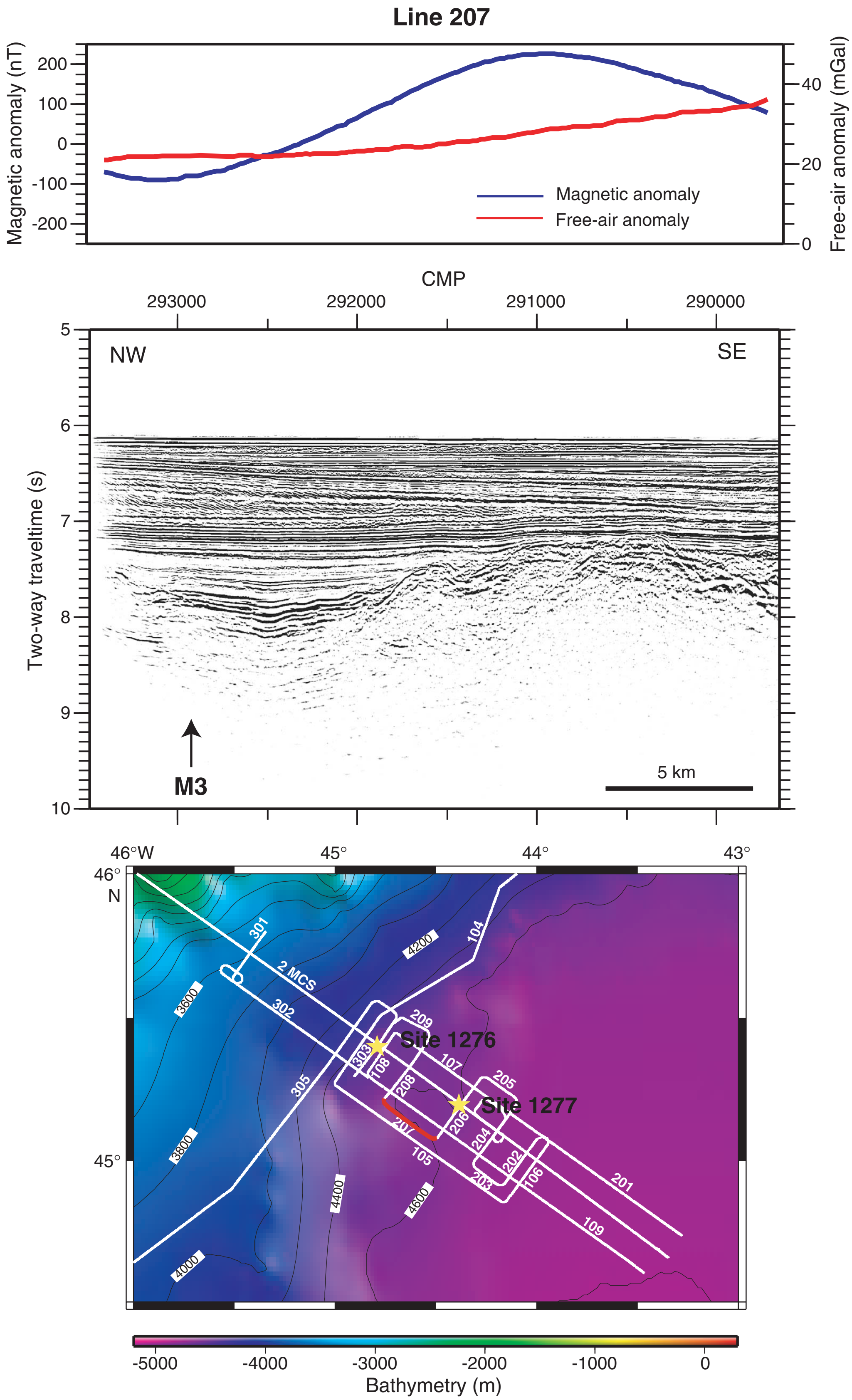

Figure F4 (continued). O. Line 208.

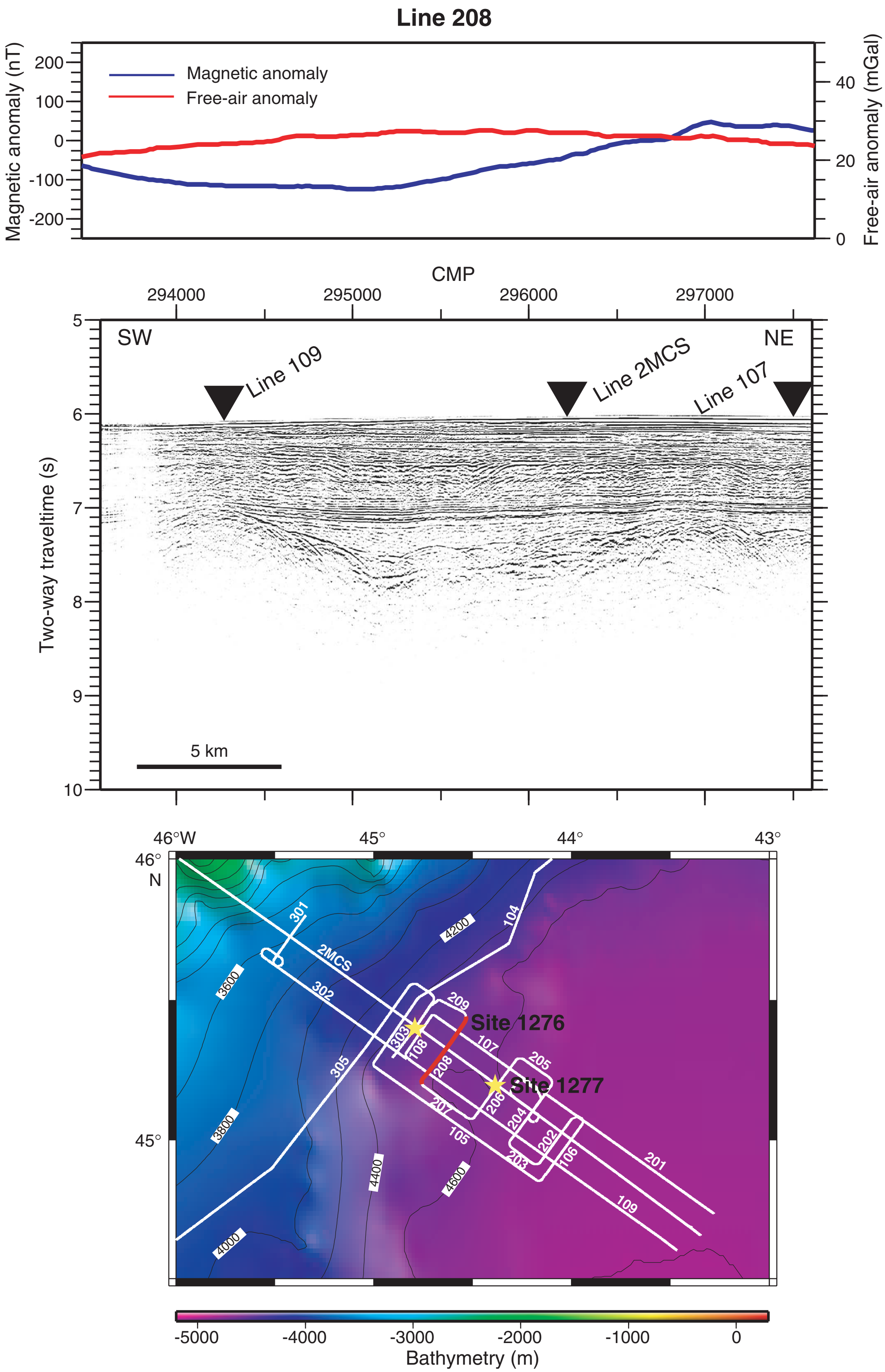

Figure F4 (continued). P. Line 209.

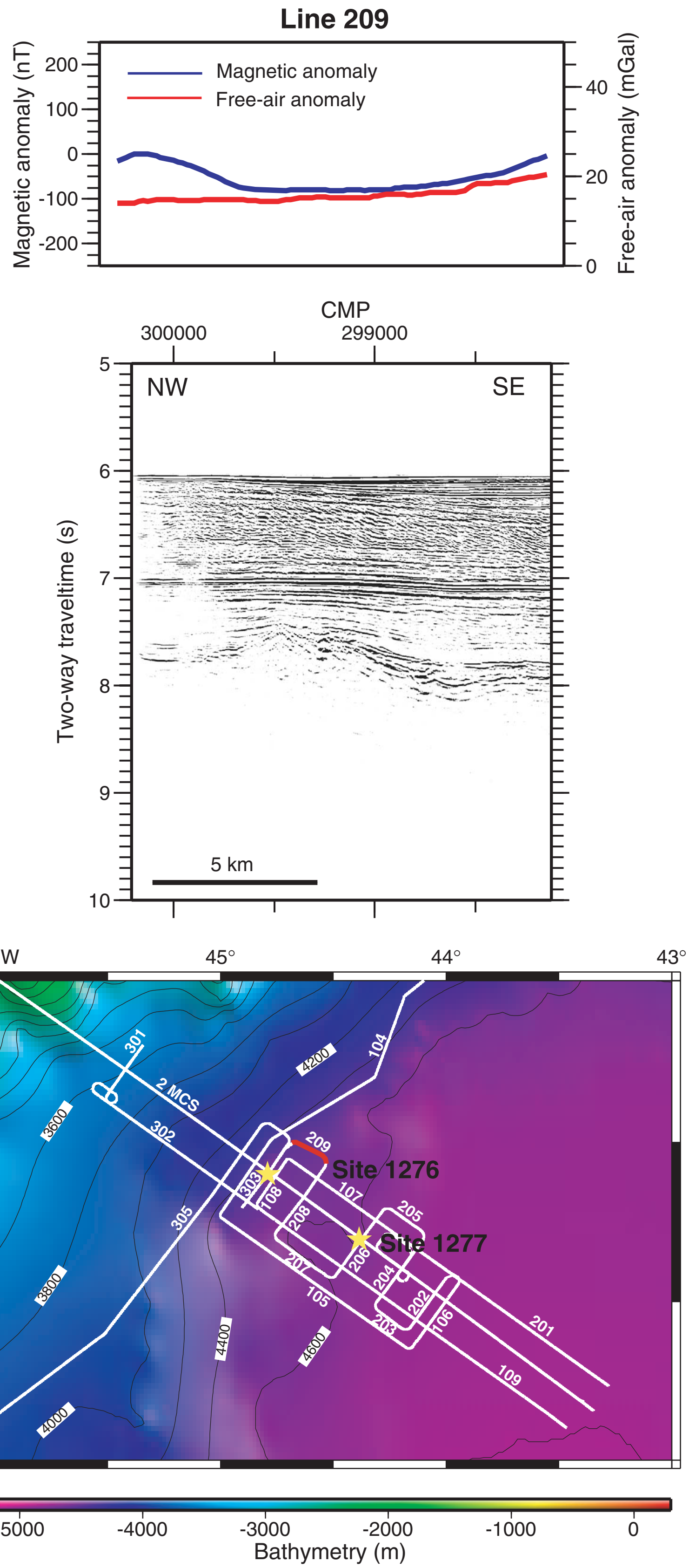

Figure F4 (continued). Q. Line 301.

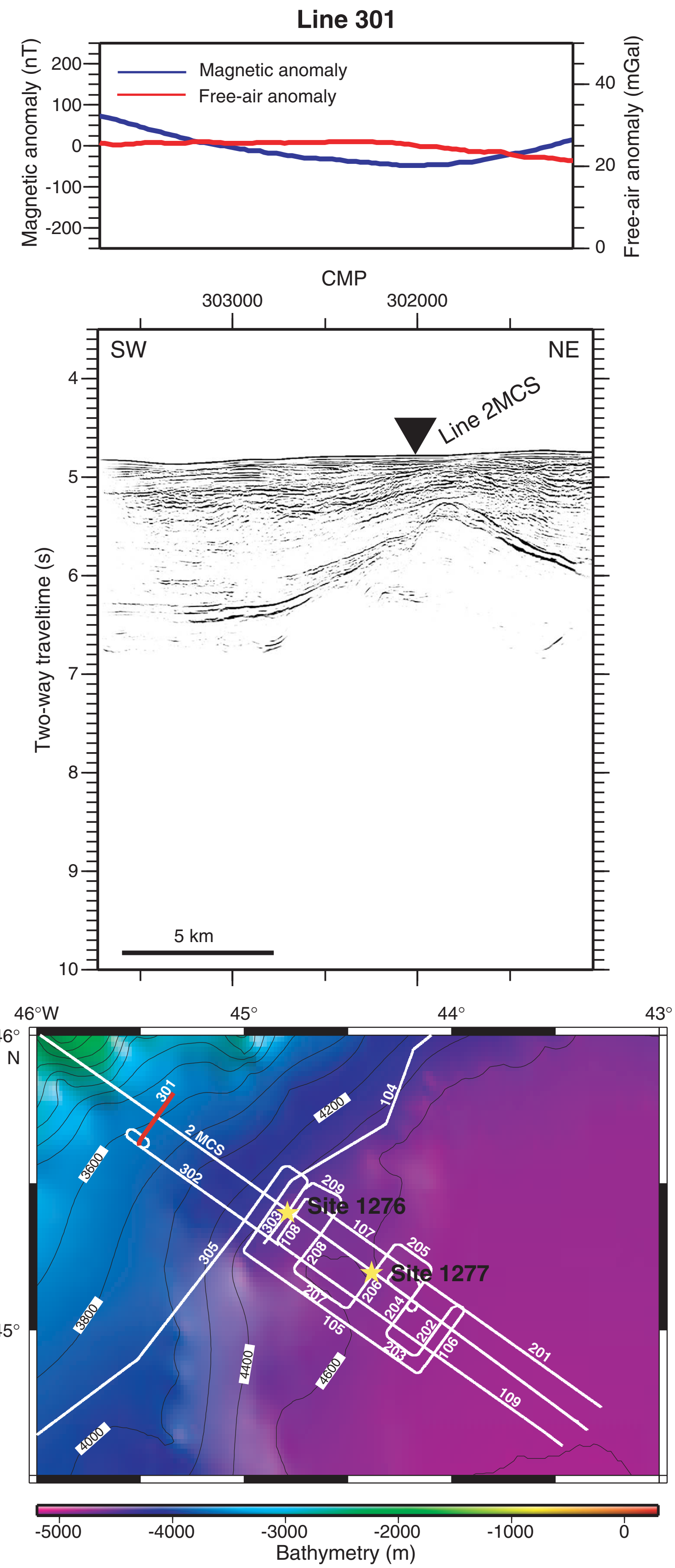

Figure F4 (continued). R. Line 302. (This figure is available in an **oversized format.**)

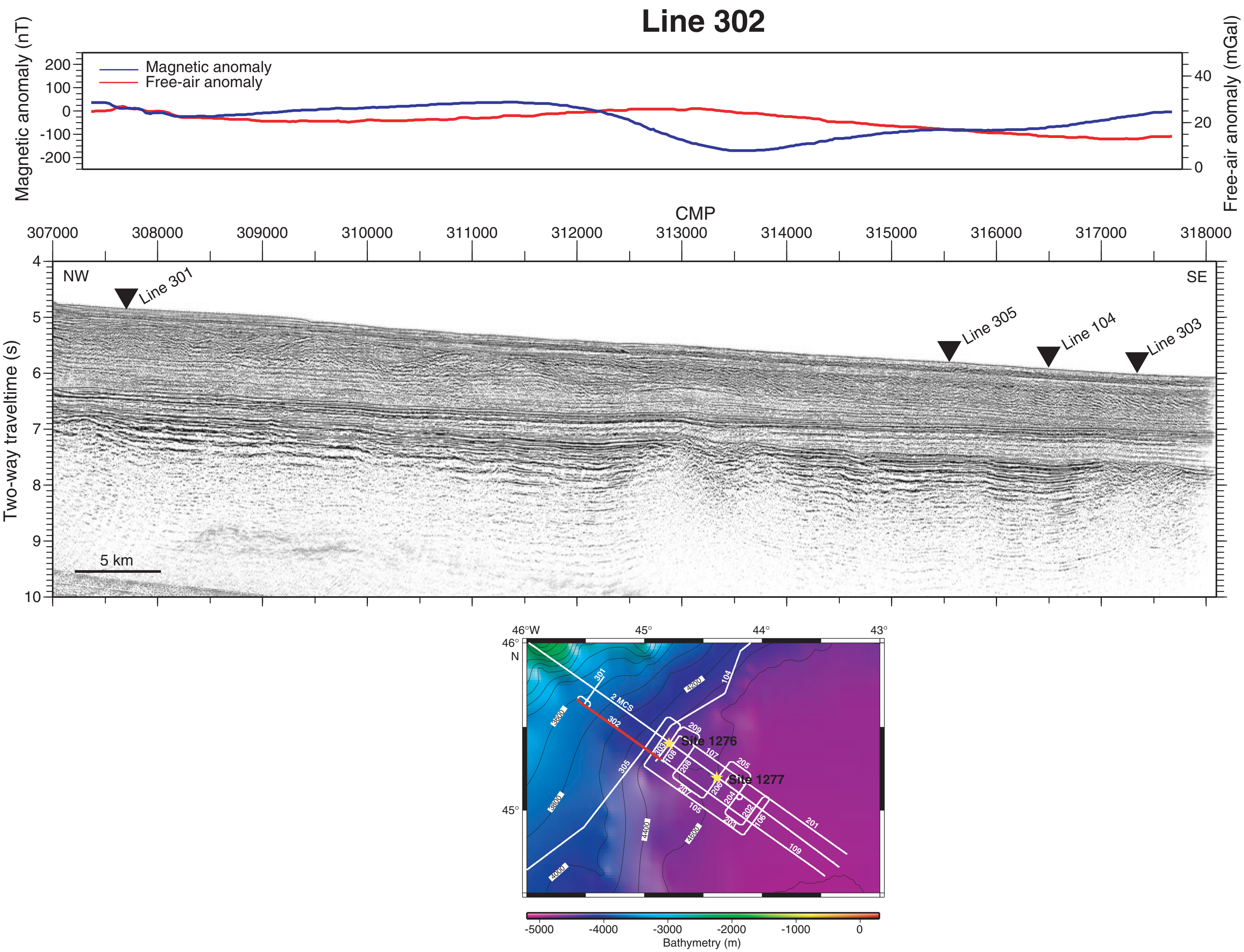

Figure F4 (continued). S. Line 303.

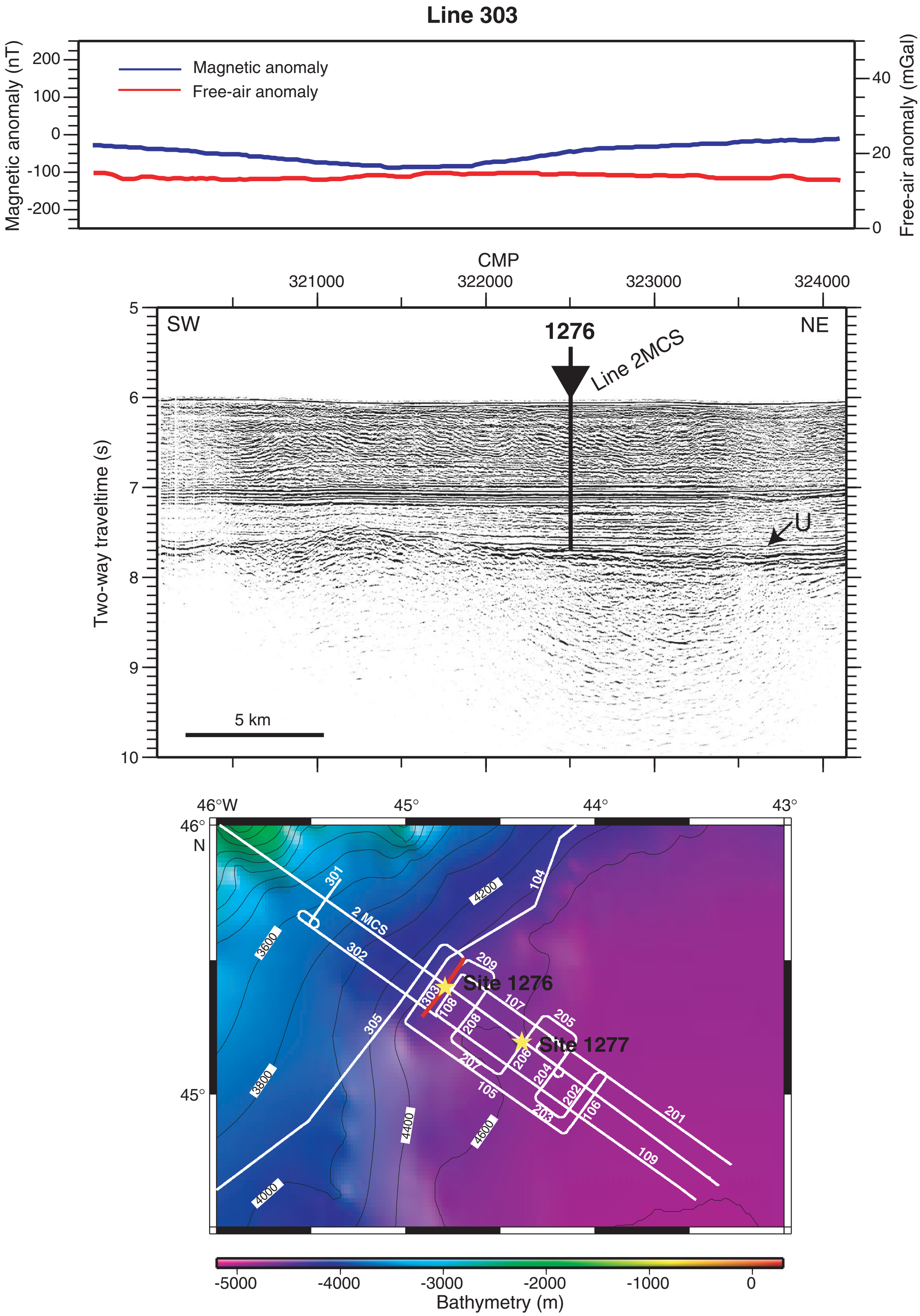

Figure F4 (continued). T. Line 304.

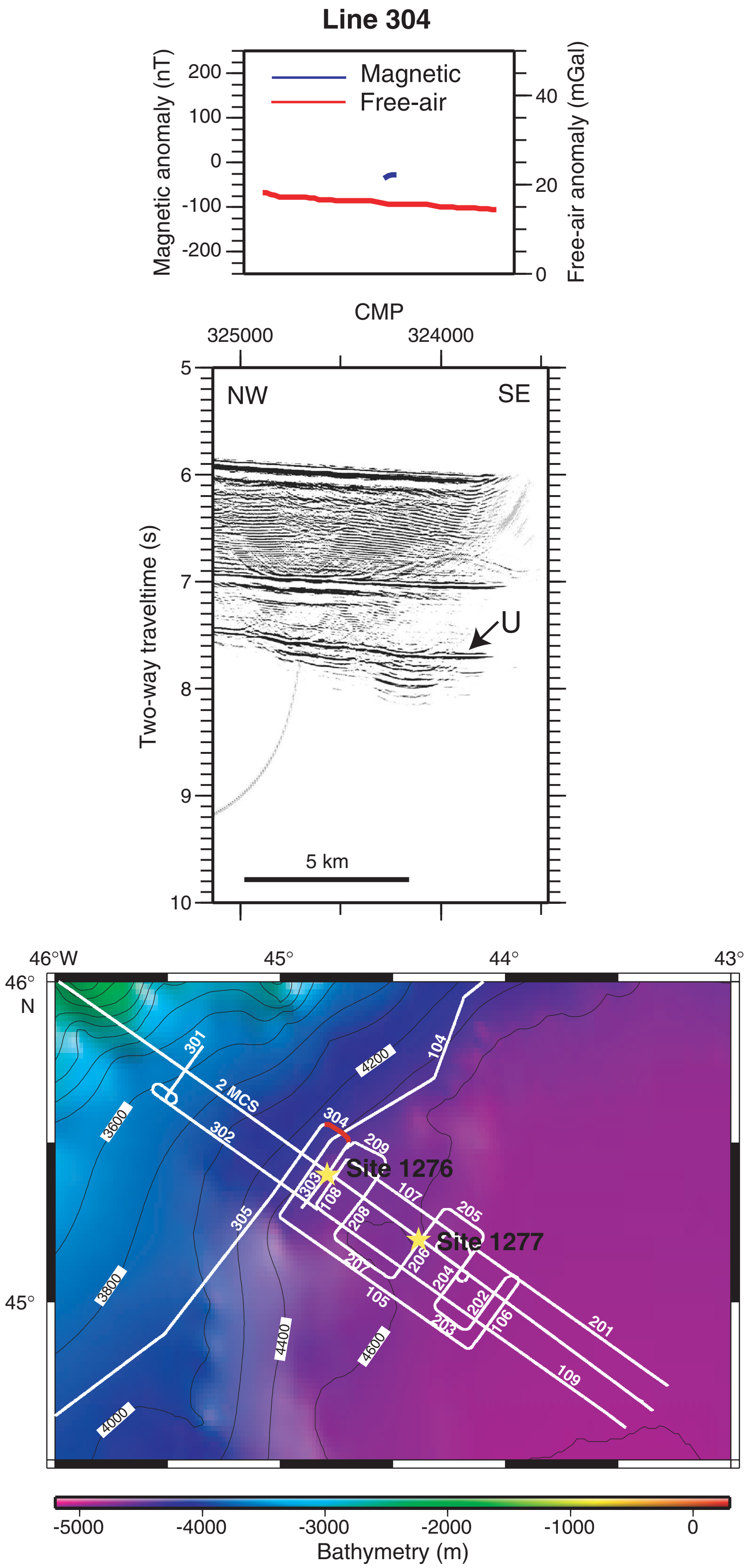

Figure F4 (continued). **U.** Line 305.

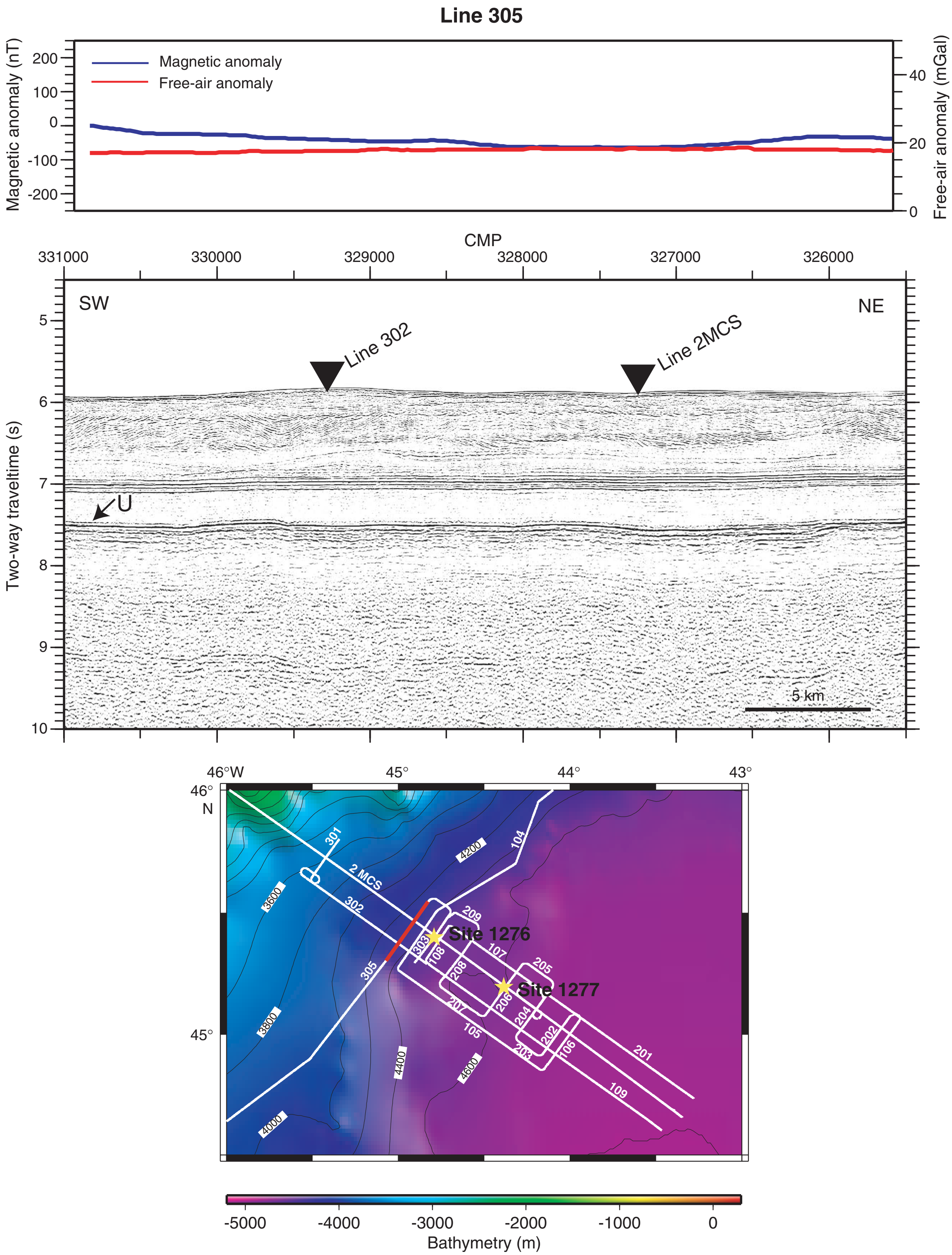

Figure F5. Contoured two-way traveltime (TWT) to basement from gridded picks of prestack time migrations shown in Figures F3, p. 11, and F4, p. 12. The map covers the same area as Figure F2, p. 10. Note the north-northeast/south-southwest–oriented margin-parallel ridges in the seaward portion of the SCREECH transect 2 survey. Yellow stars = locations of Sites 1276 and 1277. Contour interval = 200 ms.

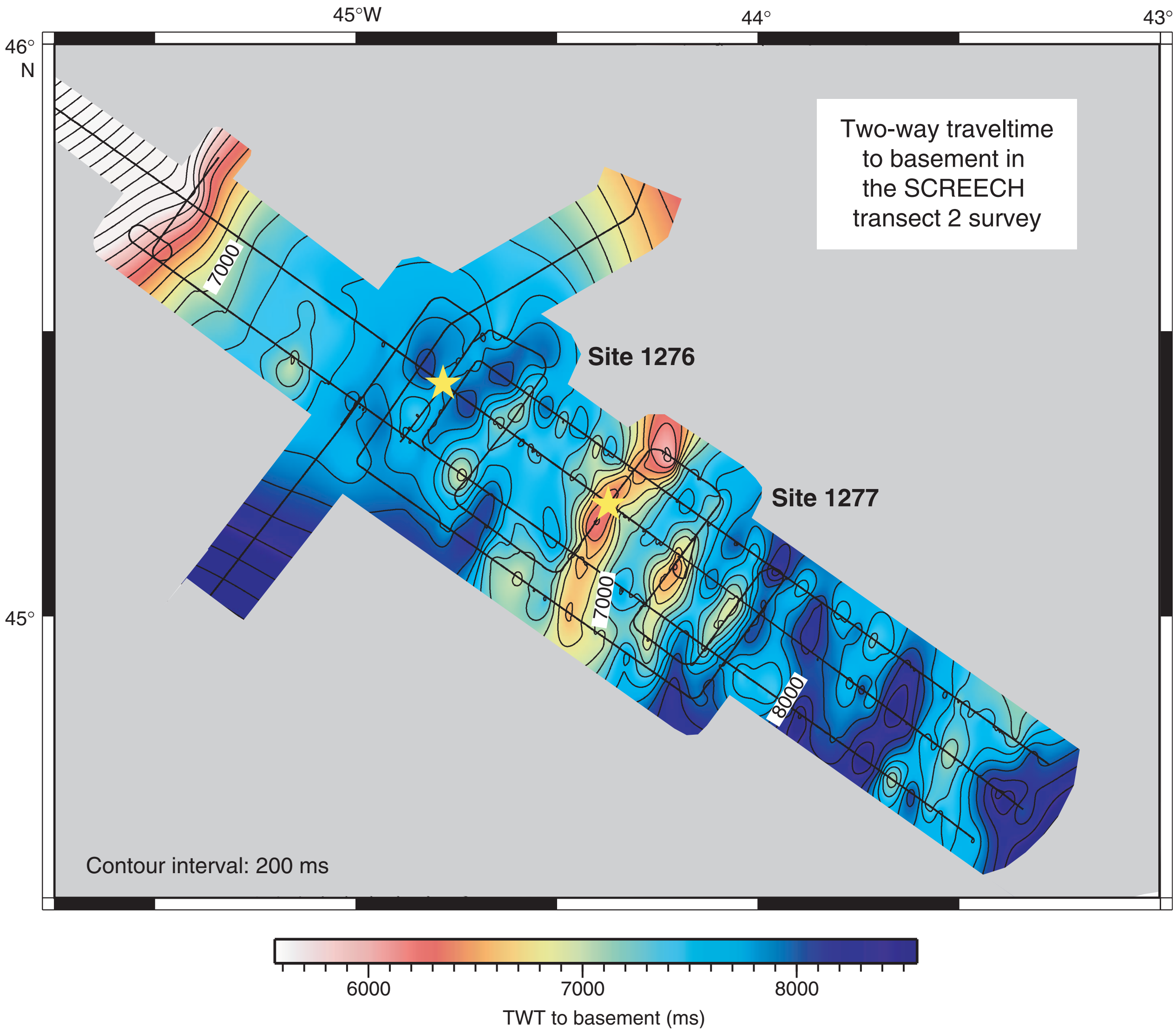

Figure F6. Color map of magnetic anomalies from the gridded data compiled by Verhoef et al. (1996). The map covers the same area as Figure F2, p. 10. The SCREECH survey lines in this area are indicated in white, with magnetic anomalies plotted along the margin-normal tracks. Positive anomalies are shown in black. Yellow stars = locations of Sites 1276 and 1277. Dashed lines = locations of Anomalies M0 and M3, as identified by Srivastava et al. (2000).

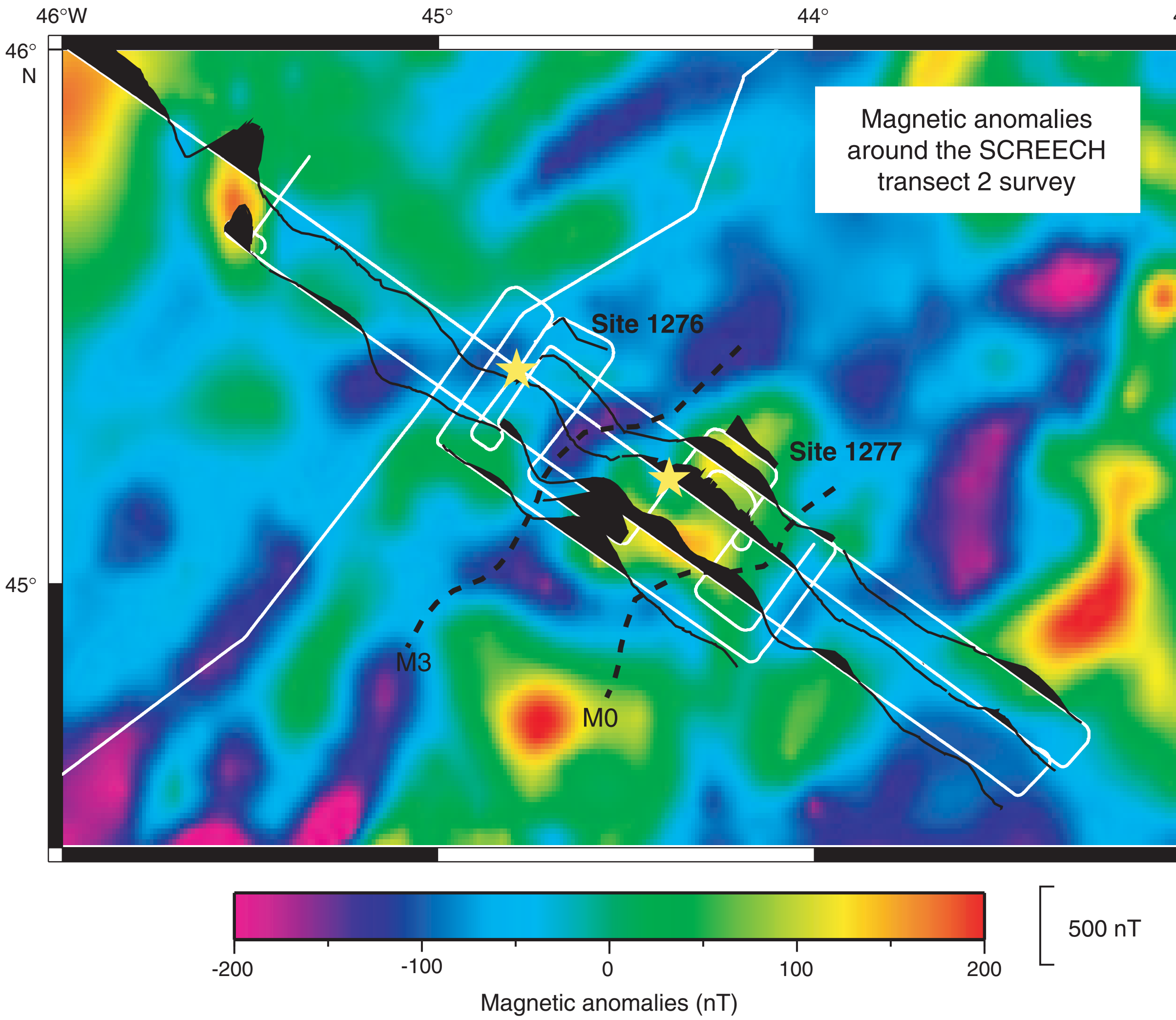

Figure F7. Color map of gridded Geosat free-air gravity data (Douglas and Cheney, 1990). The map covers the same area as Figure F2, p. 10. The SCREECH survey lines in this area are indicated in white, with gravity data plotted along the margin-normal tracks. Values above 20 mGal are shown in black. Yellow stars = locations of Sites 1276 and 1277.

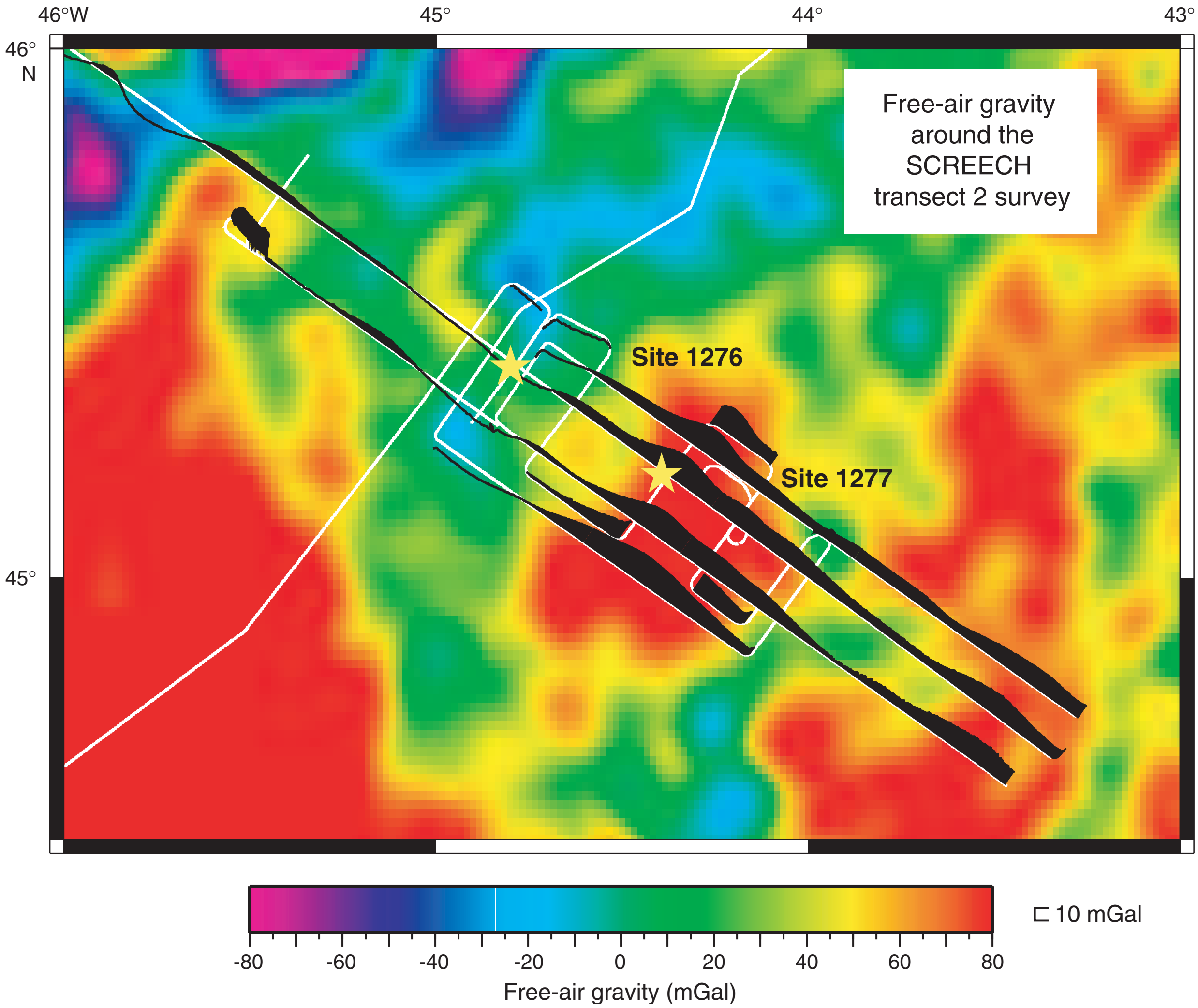

Figure F8. A. Studies of Continental Rifting and Extension on the Eastern Canadian Shelf (SCREECH) experiment location maps. Bathymetric maps showing the locations of multichannel seismic (MCS) reflection profiles acquired during SCREECH. White stars = locations of Sites 1276 and 1277. The map at the far left shows the entire SCREECH experiment, and the map at right shows a close-up of the SCREECH transect 2 MCS grid around Leg 210 drill sites. **B.** SCREECH line 2MCS and parallel MCS lines showing prestack time-migrated, multichannel seismic (MCS) dip-line reflection profiles from the seaward portion of the SCREECH transect 2 survey. Line 2MCS crosses both Sites 1276 and 1277. The profiles are arranged according to their location within the MCS grid, shown on the bathymetric maps at the left. Line number is indicated in the lower right-hand corner of each profile. Inverted solid triangles = intersections with margin-parallel MCS strike lines. Two of these strike profiles that cross line 2MCS at Sites 1276 and 1277 are shown at the lower left and lower right, respectively. All profiles are labeled by common midpoint (CMP) number, and a map with CMP navigation is available (see the **"Supplementary Material"** contents list). Additionally, a description of data processing and plots of prestack time migrations of all sections from this grid are available (see **"Data Processing and Description,"** p. 4, and Figs. **F3,** p. 11, and **F4,** p. 12). (This figure is available in an **oversized format.**)