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Interpretation of magnetic maps of the northern Gulf of Alaska, with emphasis on the source of the Slope anomaly

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ABSTRACT

East of the Aleutian trench, a linear magnetic high extends for 500 km along the continental slope of Alaska. The high also extends 220 km to the west of the trench and is here interpreted to be subducted beneath the Alaska continental shelf. Based upon new magnetic data near the trench, recontoured older data to the southeast, plus dredged samples and magnetic model studies, we interpret the anomaly to be caused by the thickened south edge of a relatively flat slab of highly magnetic, Eocene, formerly oceanic crust. Depth calculations on the anomaly show that this subducting continental margin floored by Eocene crust is down-warped to the west at the Aleutian subduction fault by a local monocline having vertical offset of about 4 km and probably striking about N30°E.

INTERPRETATION

East of the Aleutian Trench the continental slope of Alaska is associated with a linear magnetic high (Naugler and Wageman, 1973; Taylor and O'Neill, 1978; Schwab and others, 1980), 100-500 nanotesla (nT) in amplitude and extending 500 km southeast along the continental margin (fig. 1). This high is termed the Slope anomaly (Schwab and others, 1980) and it separates the north-trending oceanic magnetic stripes of the Pacific plate on the south from the relatively subdued magnetic pattern of the continental shelf. The source rocks of the Slope anomaly and some of the oceanic magnetic stripes have also been subducted to the northwest at the Aleutian subduction zone (Schwab and others, 1980; Bruns, 1985) so that the Slope anomaly continues westward across the continental shelf for 220 km to the Alaska mainland west of Montague Island. Total length of the anomaly is about 700 km.

In order to better understand the Slope anomaly, an aeromagnetic map (figure 2) of the Middleton Island area, Alaska, was flown as part of the Trans Alaskan Crustal Transect (TACT) program for the U.S. Geological Survey by a private contractor in November, 1987 (U.S. Geological Survey, 1988). The survey covers an area of approximately 23,400 km^2 (9000 mi^2). Flight lines were north-south and spaced 1.6 km (1 mi) apart with an altitude of 153 m (500 ft) above sea level. Location over water was obtained primarily by satellite navigation with Loran C as a back-up. The previously published map has a scale of 1:250,000 and is contoured at intervals of 10 and 50 nT. The aeromagnetic data of this map are presented here on a page-sized illustration (fig. 2) with a contour interval of 50 nT because only the long-wavelength features associated with the Slope anomaly are discussed below.

The Slope anomaly east of long. 141°W. (figure 1) was described by Taylor and O'Neill (1978) and displays a somewhat irregular pattern. The magnetic chart (U.S. Naval Oceanographic Office, 1970) indicates severe chevroning of contours along northeast-trending flight paths crossing the Slope anomaly. The Slope anomaly here is situated between the two Loran stations used for navigation so that accurate location was not possible along individual flight lines. Accordingly, we have recontoured the data after arbitrarily repositioning the values along 7 flight lines for distances up to 10 km (while maintaining the same value spacings) in order to force the southwest side of the Slope anomaly to be linear. Figure 3 shows the Slope anomaly of Schwab and others (1980) as modified by substituting this recontoured Navy survey plus a simplified version of figure 2. Compare figures 1 and 3 to see the changes.

The cause of the Slope anomaly is not entirely clear, but available data place major constraints on the source. Models of the anomaly both by Bruns (1985) and us (fig. 4, 5, and 6), although differing in significant details, agree that the feature predominantly represents the thickened south edge of a rather flat slab of highly magnetic rocks. The magnetization is probably induced rather than remanent because (1) the Slope anomaly extends over 100 km farther west of the Aleutian fault than do the marine magnetic stripes (which are caused by remanent magnetization) and (2) the anomaly does not lose amplitude upon entering the subduction zone the way the stripes do. These two observations suggest that low-temperature metamorphism rapidly destroyed the remanent magnetization of the ocean floor basalts but, as one would expect, did not affect the induced magnetization of the Slope anomaly rocks until they reached much higher temperatures at greater depths farther west. Considerable geologic information is available from dredge hauls along the slope between 138°W. and long. 143°W. (Plafker, 1987). Although at least 1.3 km of flat-lying Eocene basalt is identified west of long. 138°30'W., the average magnetization of the basalt (16 samples described in Plafker and others, 1980) is only 1.2 A/m or approximately 25 percent of that required for the model studies. The bulk magnetization is even smaller if interbedded sediments or tuffs are present, so we conclude that the basalts are not a major cause of the anomaly. Also, we were unable to make the model of figure 4 (cross-section A-A') match the observed data if the top of uniformly magnetized basalt was used for the top of the magnetic mass. East of long 138°30'W., the basalt is absent and the submarine outcrops consist of weakly metamorphosed sedimentary rocks believed to be Cretaceous flysch (Plafker, 1987, p. 245), a rock that is not magnetic. Accordingly, the magnetic rocks must here underlie the two areas of flysch outcrops, which are both antiforms and clearly associated with magnetic highs (fig. 3). Along the slope west of long 138°30'W., the source of the Slope anomaly is probably highly magnetic, Eocene, former oceanic crust (sheeted dikes, mafic plutons, and serpentinized ultramafic rocks) lying beneath the Eocene basalt, and this source in turn implies that the Cretaceous flysch was emplaced tectonically over this oceanic crust (perhaps during subduction) in order to explain the association of anomalies also with flysch. Other more complex explanations are clearly possible.

The Transition fault (fig. 1 and 3) is considered to be either an active oblique subduction fault (von Huene and others, 1979; Plafker, 1987) or an inactive transform fault (Bruns, 1985). Earlier magnetic models across the fault (Bruns, 1985, fig. 25 and 26) were consistent with the latter hypothesis but produced inconsistencies in the location of the fault. The present models (fig. 4, 5, and 6) assume a flat-lying magnetic slab, 3-5 km in thickness, and are designed both to support the oblique subduction idea and also to produce fault locations consistent with seismic reflection data. Because of the ambiguity of potential field interpretation, the models support but do not prove the subduction hypothesis for the Transition fault. As shown on figure 4, the highly magnetic slab lies about 1.5-2.0 km below the top of the moderately magnetic Eocene basalt which, though not modeled here, must contribute to the higher part of the anomaly as shown by short wavelength irregularities in the observed data. It is possible that the moderately magnetic Eocene basalt sampled in the dredge hauls grades downwards into the highly magnetic slab inferred to be the source of the Slope anomaly. On figure 6, the two major discrepancies between observed and computed curves are caused by shallow magnetic sources in the overlying plate.

In order to gain a better understanding of the changes in depth to the top of the magnetic slab, depth calculations were performed on individual north-south magnetic profiles of the Slope anomaly using the methods of Vacquier and others (1951) and Peters (1949). The calculated depths are compiled on figure 7 and represent averages of results from 2-7 adjacent profiles. It appears that the relative accuracy between the depths may be ±5%, but the three eastern depths (7.1, 7.7, and 8.7) are certainly about 2 km too deep because the assumptions of the method are not met, namely that the magnetic object should have a flat top and steeply-dipping sides. The three western depths, judging from the different form of the anomaly curves, may be more nearly correct, so perhaps the thin tapering lip of the south edge is here losing its magnetic minerals by alteration, thus creating a more steeply-dipping south flank for the magnetic slab. If so, then the west part of the Transition fault lies about 10 km south of the location shown on figure 7. The depth results are also displayed in cross-section I-I' (fig. 7 and 8) which shows a significant local downwarp of the Yakutat terrane (fig. 8) where it is subducted beneath the Prince William terrane at the Kayak zone. The downwarp or monocline probably strikes N30°E parallel to the Kayak zone. The section also shows that three mutually moving plates are superposed at the Prince William terrane north of the Transition fault because the Pacific plate in turn underlies the Yakutat terrane. A similar interpretation of the plate relationships was deduced by Plafker (1987, fig. 3) from regional geologic and geophysical data. Note that space considerations and the lack of significant amounts of off-scraped sediments nearby require that each of these plates have at least 2 km of sediments on top, thus implying at least two zones of velocity reversals for seismic interpretation. Plafker has pointed out to us (oral communication, 1990) that preliminary interpretation of a northeast-trending seismic refraction line on Montague Island (fig. 1 and 3) indicates a low-velocity zone at depths of about 12-16 km (John Tabor and Gary S. Fuis, written communication, 1987). This result compares favorably with the sedimentary deposits inferred at depths of 12.5-14.5 km on the west end of figure 8.

Other major features interpreted from the magnetic maps (fig. 1, 3, and 7) are briefly listed below:

1. The "attenuated zone" of Schwab and others (1980) is an area of subdued magnetic anomalies south of the exposed Transition fault (fig. 1) and east of long. 143°W. Using flight lines from U.S. Naval Oceanographic Office (1970) that were relocated as described above, the marine magnetic stripes appear to be present and striking north-south as expected thus supporting the idea of attenuation. The zone of subdued anomalies approximately correlates (fig. 1) with the 2.0 and 2.5 km isopachs (Bruns, 1985, fig. 16A) of sediments overlying the oceanic basalt, suggesting that mild thermal effects due to burial may have partly destroyed the remanent magnetization.

2. A newly-recognized transform fault in the Pacific plate is interpreted to trend east-west beneath Middleton Island based on terminations of magnetic stripes (fig. 1 and 7). This fault lies parallel to another transform fault located 150 km to the south (fig. 1) and is almost completely subducted. Its parallel association with the Slope anomaly and Transition fault may be a coincidence though major ocean-floor relief at the transform could be a factor in its location, if the Transition fault is presently locked.
3. Three northwest-trending regional magnetic highs (fig. 3) with associated lows on their northeast sides are observed on the continental shelf northeast of the Slope anomaly. These highs are interpreted to be caused by northwest-trending antiformal uplifts of the same deep magnetic slab that produces the Slope anomaly.

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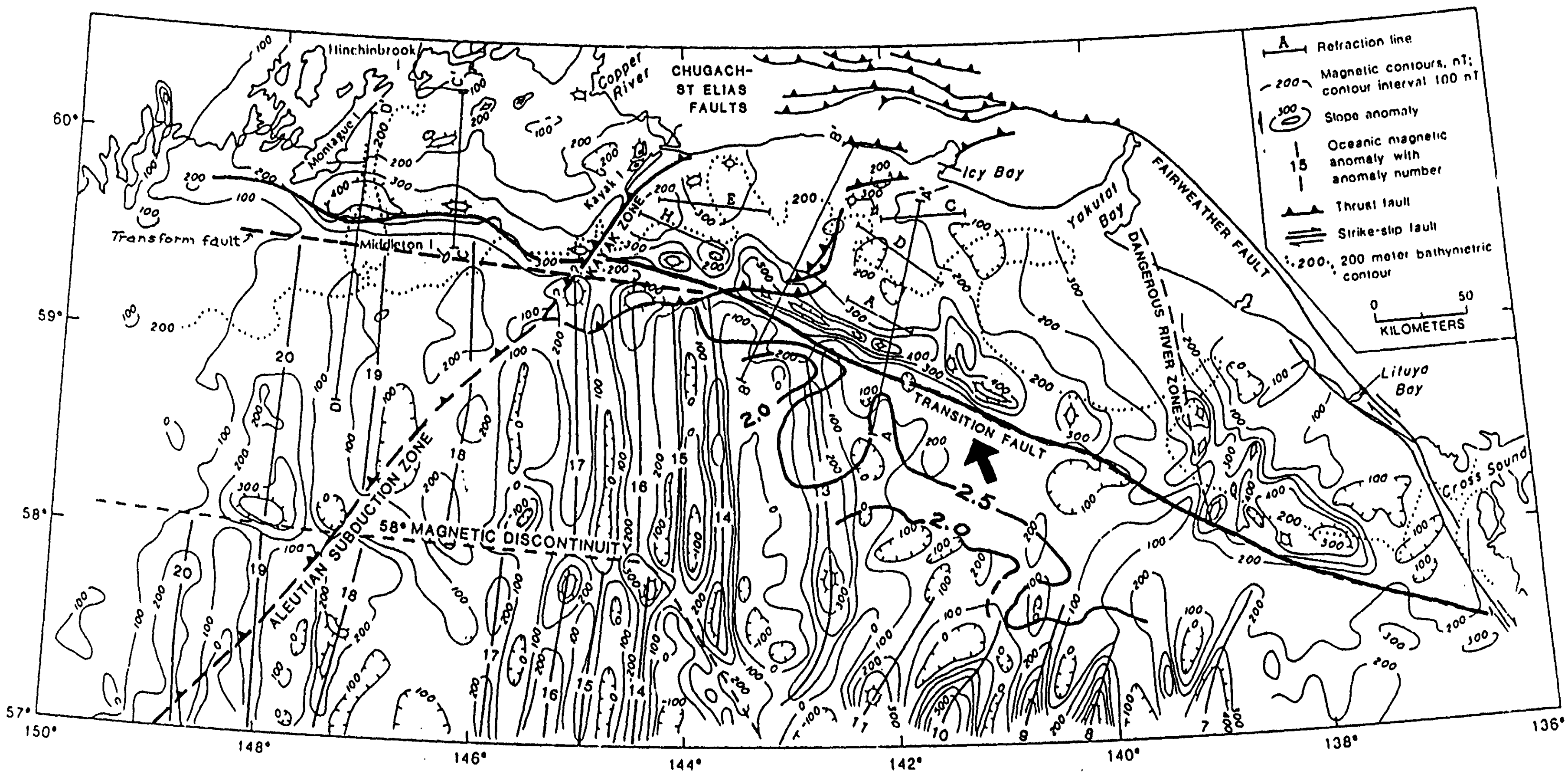

Figure 1. Magnetic map of the northern Gulf of Alaska with major tectonic features superposed; from Schwab and others (1980) and Bruns (1985). Additions include: a transform fault at Middleton Island and isopachs in km (from Bruns, 1985, fig. 16A) of sediments overlying oceanic basalt south of the Transition fault. Large arrow shows direction of Pacific plate relative motion of 6.3 cm/yr (Engebretson, 1982). The Slope anomaly crest lies 5-20 km north of the Transition fault.

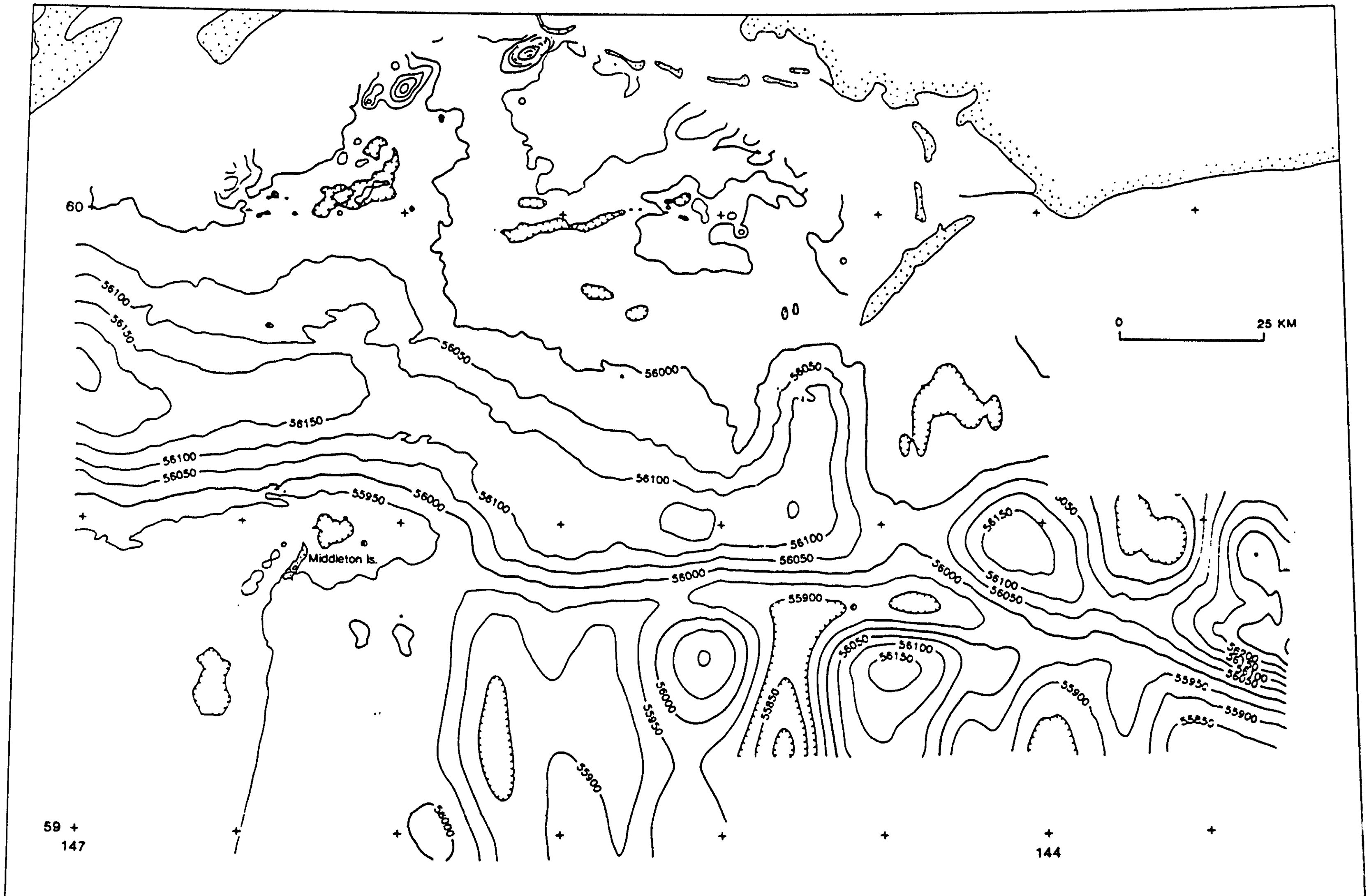

Figure 2. Magnetic map of the Middleton Island area, Alaska.

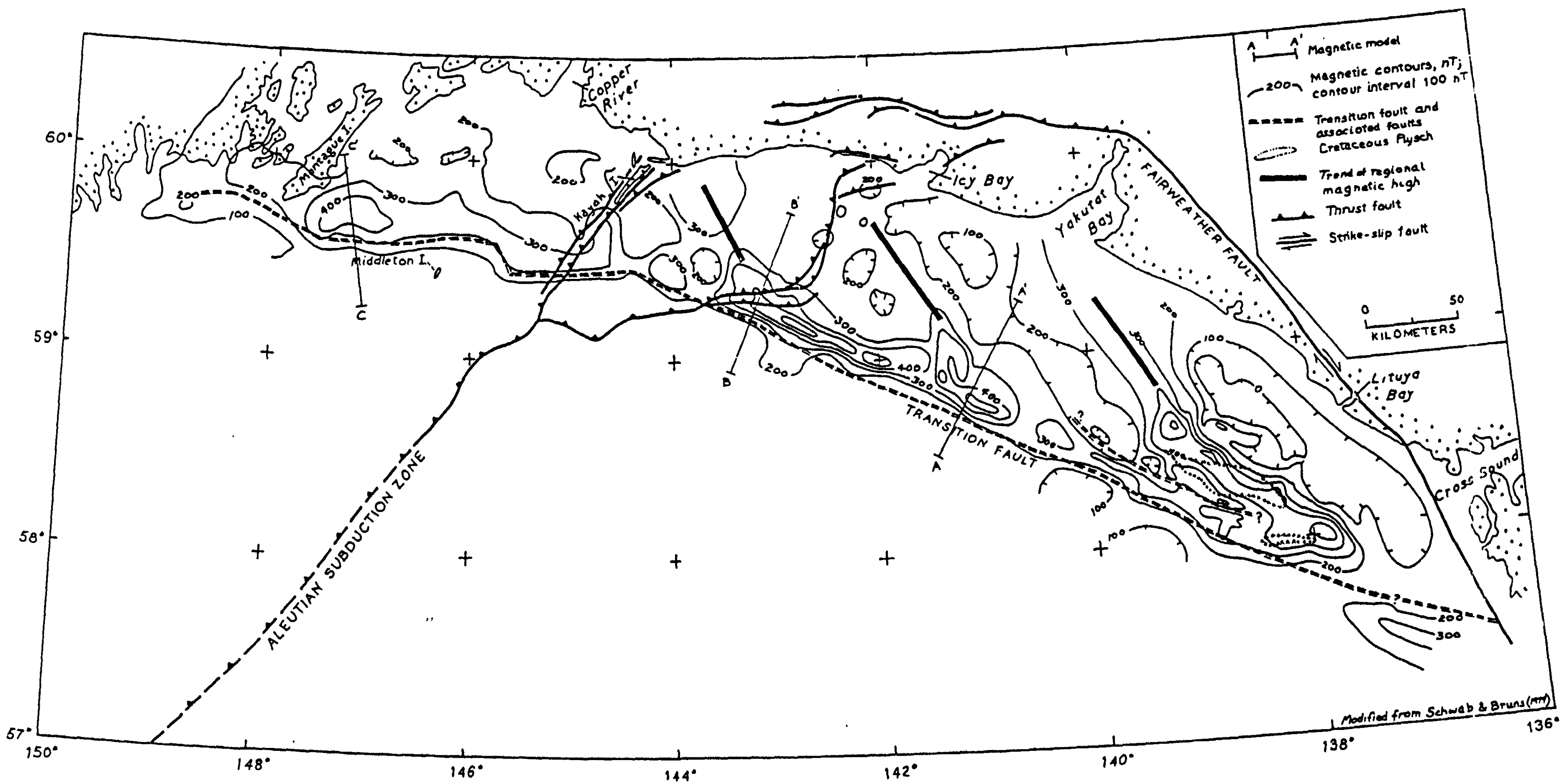

Figure 3. Magnetic map of the Slope anomaly with major tectonic features superposed and showing location of cross-sections; based upon Schwab and others (1980) and Bruns (1985) but with the Middleton Island area revised to accord with figure 2 and the area east of long. 141°W recontoured from U.S. Naval Oceanographic Office (1970) as explained in the text.

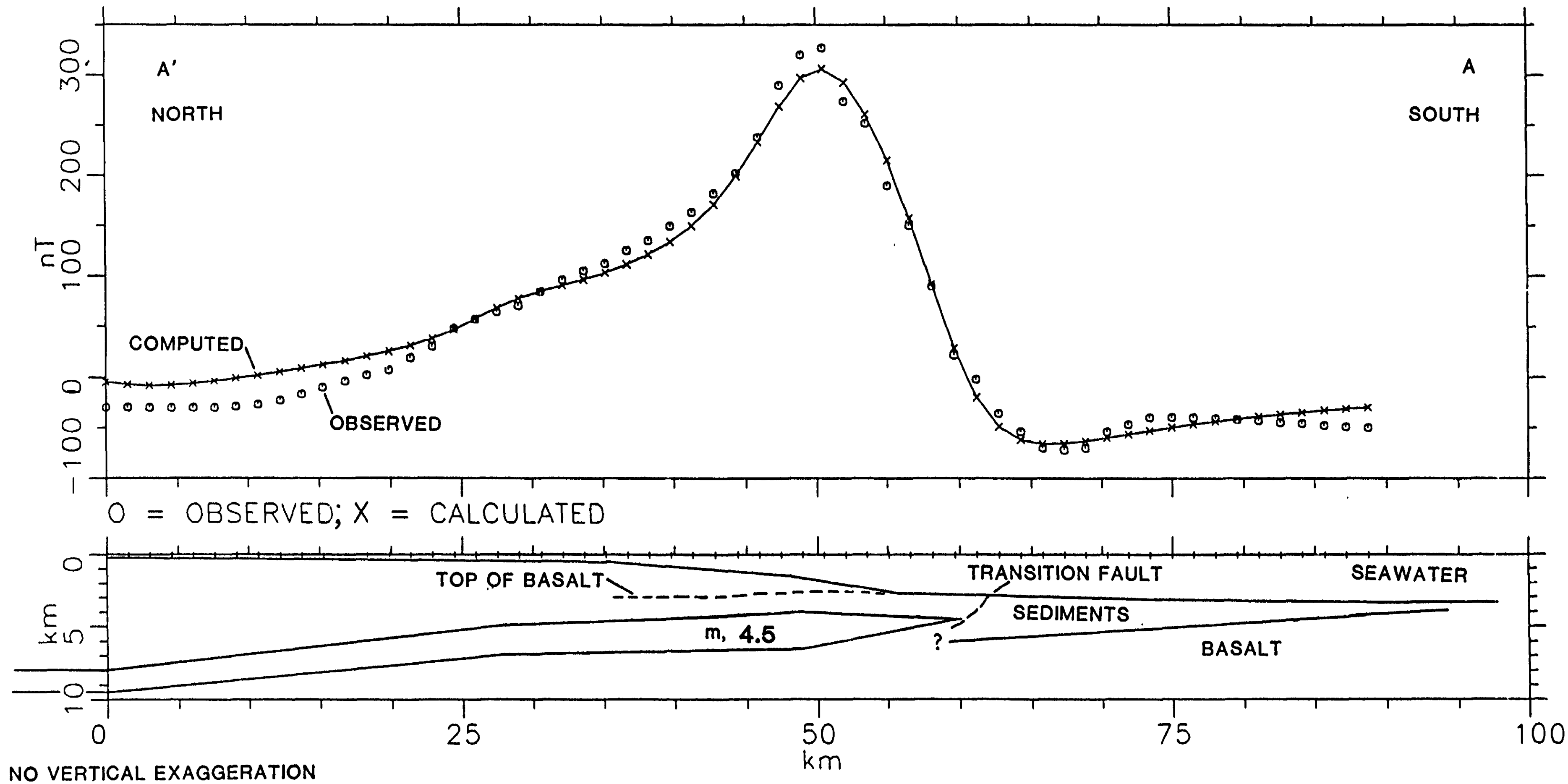

Figure 4. Magnetic model for cross-section A-A'. Top of basalt is located from seismic reflection line 403. Magnetization (m) in si units (A/m).

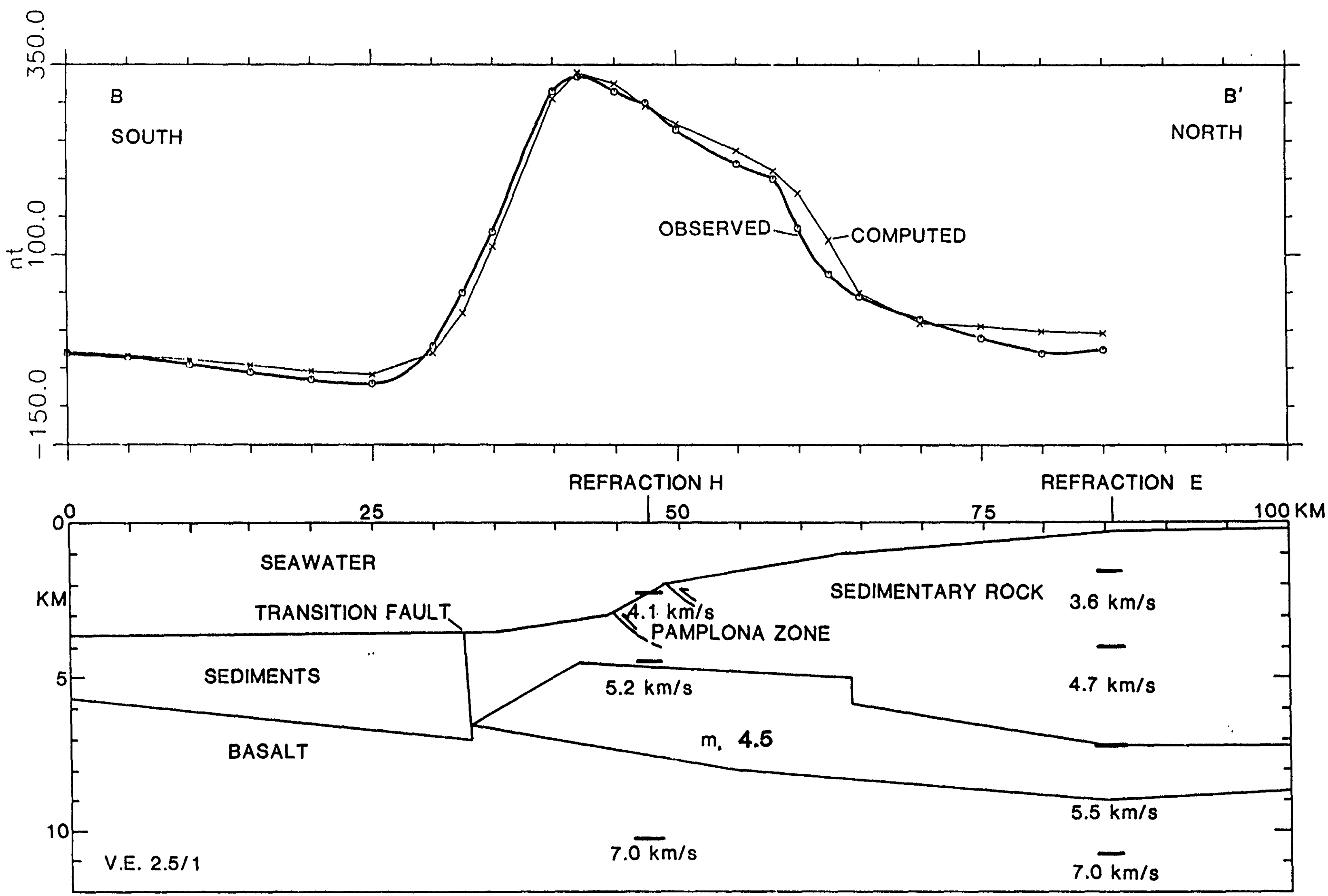

Figure 5. Magnetic model for cross-section B-B'. Magnetization (m) in si units (A/m). Refraction lines H and E (Bayer and others, 1978) are projected into the section from the northwest.

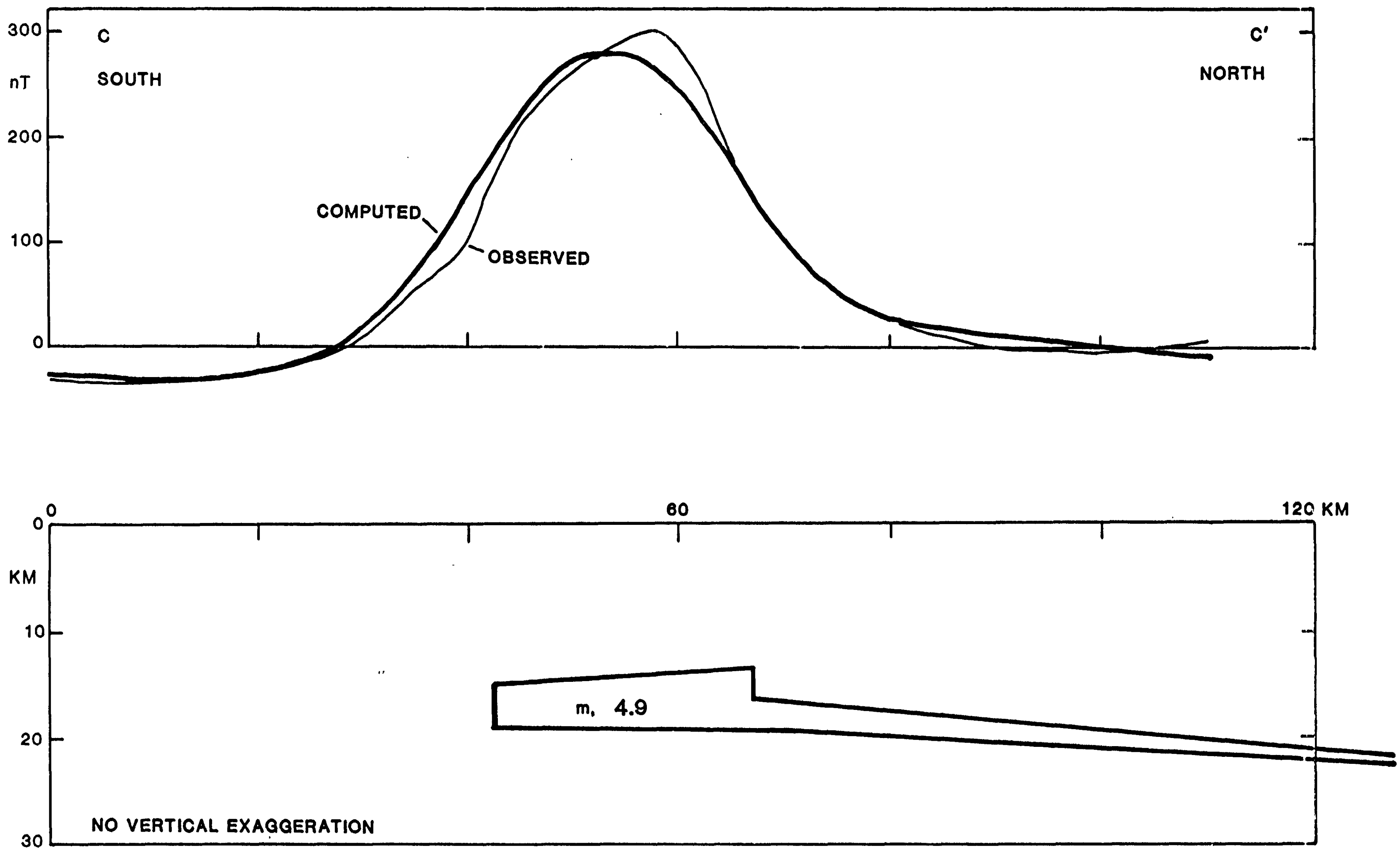

Figure 6. Magnetic model for cross-section C-C'. Magnetization (m) in si units (A/m).

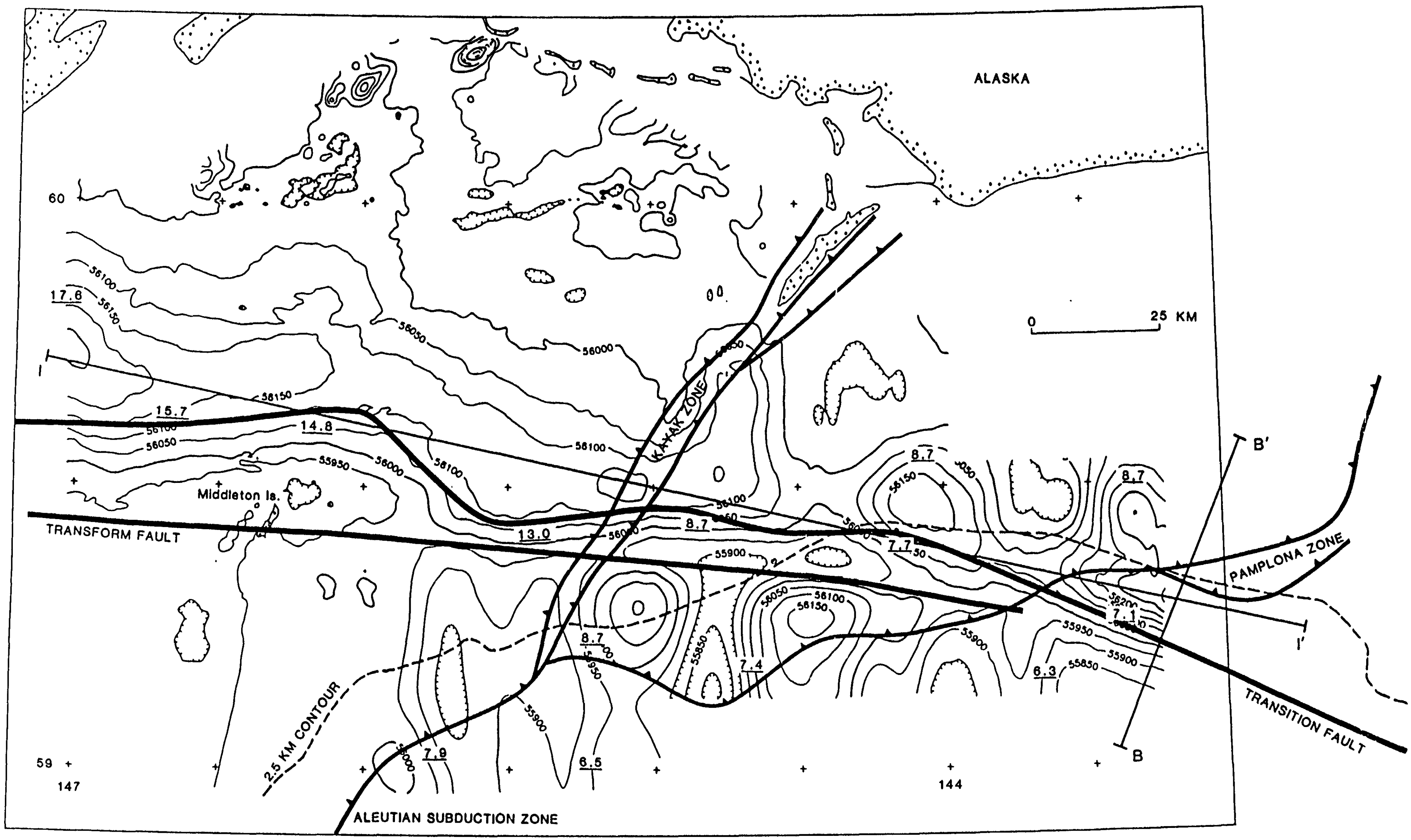

Figure 7. Magnetic map of the Middleton Island area, Alaska, with superposed tectonic features and interpreted faults (Transition fault and transform fault). Underlined numbers show calculated depths in km to magnetic source rocks. Locations of cross-sections B-B' and I-I' are shown.

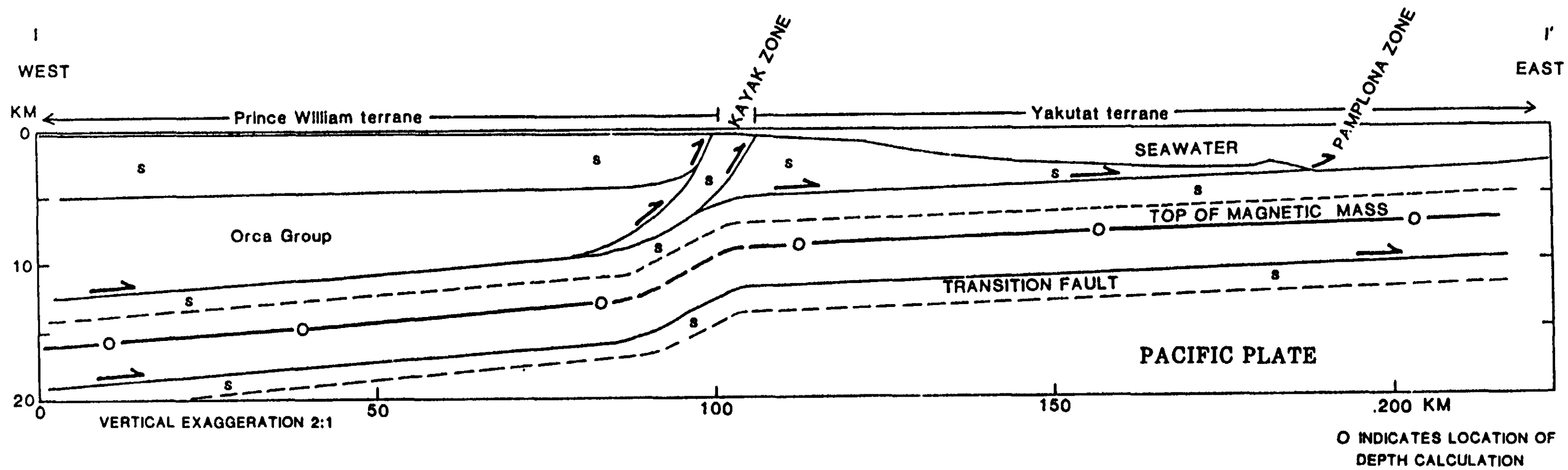

Figure 8. Simplified cross-section I-I' showing calculated depths to magnetic rocks along crest of magnetic high at Transition fault. Short dashed lines are inferred upper contacts of basaltic rocks; "s" indicates Cenozoic sedimentary deposits. Actual depths for east half may be about 2 km shallower (see text). Near surface sedimentary deposits west of the Pamplona zone actually display structural relief of several kilometers caused by folding and faulting.