

## A PRELIMINARY ANALYSIS OF POTENTIAL FIELD DATA IN THE SOUTHERN CHUKCHI SEA

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### ABSTRACT

Marine gravity and aeromagnetic data in the southern Chukchi Sea provide evidence of magmatic activity prior to the Late Devonian and again in Tertiary time. We propose that an extinct north-trending magmatic arc within the pre-Late Devonian basement complex separates an unnamed terrane beneath the Chukchi platform from one beneath the Hanna trough. North-directed motion along the Herald thrust in the Latest Cretaceous to earliest Tertiary placed Paleozoic and Mesozoic crust over the southern extent of the eroded arc. South of the Herald thrust, in the northern Hope basin, potential field anomalies suggest that igneous intrusions accompanied northwest-directed, Tertiary transtensional deformation.

### INTRODUCTION

A reconnaissance map of the magnetic field in the Chukchi Sea (Cramer et al., 1986) shows a prominent anomaly up to 400 Nt in amplitude, which extends northward 200 km from an area west of Cape Lisburne. It was originally outlined in gross form by Grantz et al. (1982). A free-air gravity map derived from 1978 Seasat altimetry data (Haxby, 1987) shows only low amplitude anomalies in the Chukchi Sea and northern Hope basin. The contrast in anomaly character between the magnetic and gravity anomalies, and the possible evidence for a regional magmatic body not imaged by the seismic-reflection data, prompted the present study.

The database consists of multichannel seismic-reflection, marine gravity, and aeromagnetic data. Typical line spacing is approximately 10 km, a data density significantly improved over the 30- to 40-km line spacing of previously cited maps.

The southern Chukchi Sea, as defined for this report, lies between 68°15' and 71°00' N. latitude and between 158°00' and 169°00' W. longitude. Fig. 1a (following page) is a structure map of the top of acoustic basement, derived from seismic-reflection data. Basement rocks north of the Herald thrust are pre-Late Devonian and are thought to be argillite based on extrapolation from onshore wells in the National Petroleum Reserve in Alaska (NPRA) (Carter and Laufeld, 1975). The depocenter east of 165° W. longitude in the Chukchi basin commonly is referred to as the Hanna trough. At the Herald thrust, Paleozoic and Mesozoic rocks equivalent to Chukchi basin strata are faulted up to the seafloor to form the Herald arch (Grantz et al., 1982). These rocks form the basement complex in northern Hope basin.

Arctic slope sedimentary sequences recognized in the Hanna trough include the Lower Ellesmerian (Late Devonian to Permian), Upper Ellesmerian (Permian to Cretaceous), Lower Brookian (Cretaceous), and Upper Brookian (Tertiary and Quaternary). Regionally mapped unconformities include a Lower Cretaceous unconformity (LCU), a Jurassic unconformity (JU), a Permian unconformity (PU), and an Ellesmerian unconformity (EU). At the west end of the Hanna trough, a faulted, north-

trending basement ridge separates the basin from the more shallow Chukchi platform (Figs. 1a and 2a). Although Ellesmerian rocks are absent over parts of the Chukchi platform within the study area, Lower Ellesmerian or older sediments may be preserved within the graben separating this basement ridge from the Chukchi platform.

The Hope basin is separated from the Hanna trough and Chukchi platform by the Herald arch. Movement along the Herald thrust is thought to have occurred in the Late Cretaceous to early Tertiary (Holmes, 1975; Thurston and Theiss, 1987), predating the Eocene to Miocene transtensional faulting in the Hope basin (Tolson, 1987). Sedimentary rocks in the Hope basin are thought to be Eocene and younger (Tolson, 1987).

### OBSERVATIONS

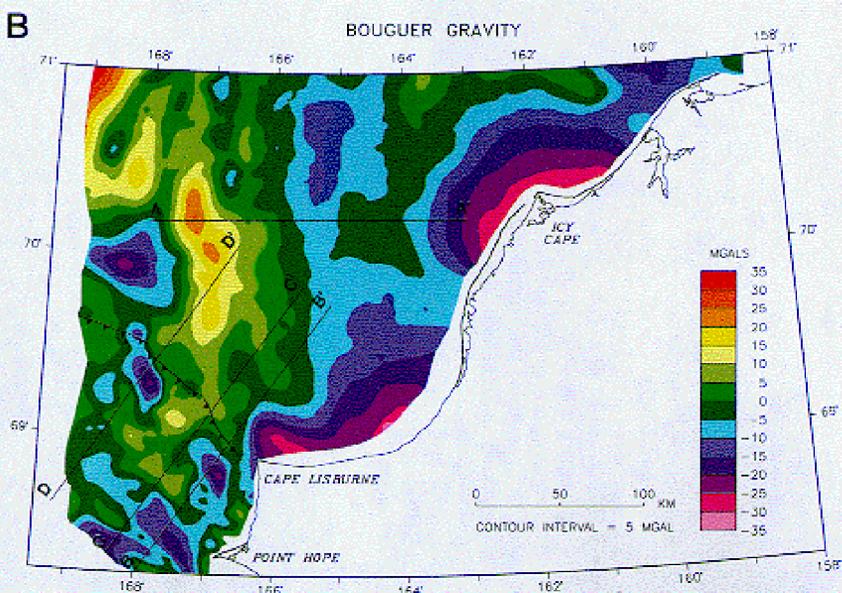
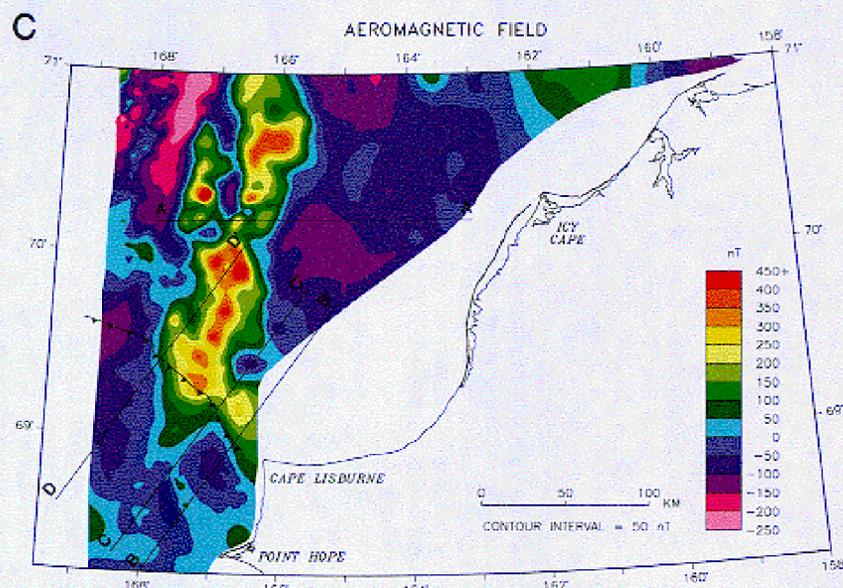
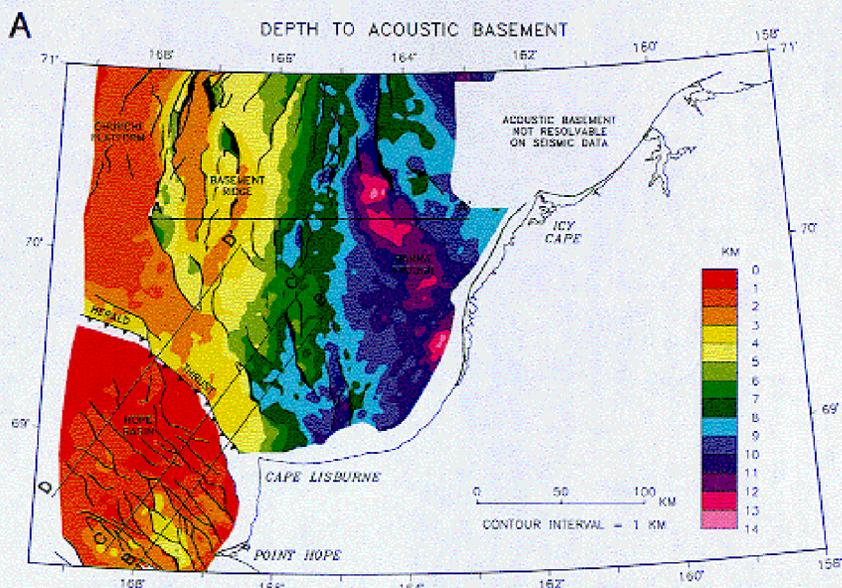
The magnetic and Bouguer gravity fields north of the Herald thrust exhibit prominent, generally north-trending positive anomalies between 166° and 168° W. longitude (Figs. 1b and 1c). The highs coincide with, and extend south of, the basement ridge east of the Chukchi platform (Fig. 1a). The distinctive shapes of the magnetic and gravity highs suggest that their origins are somewhat different. For example, the magnetic-anomaly high extends 60 km south of the Herald thrust. The gravity anomaly south of the thrust also appears to be an extension of the north-trending anomaly, but the anomaly pattern is disrupted. Prominent gravity highs also occur north of profile A-A' at 169° W. longitude.

Two 25-mgal gravity lows, one northeast of Cape Lisburne and the other near Icy Cape, have no correlation to mapped acoustic basement structures. Aeromagnetic data over the gravity lows are unavailable. The intervening local gravity high, which trends northwest near the coast and northward at 164° W. longitude, corresponds to the acoustic basement structural low of the Hanna trough. There is no associated magnetic anomaly where this gravity high extends into the area of aeromagnetic coverage.

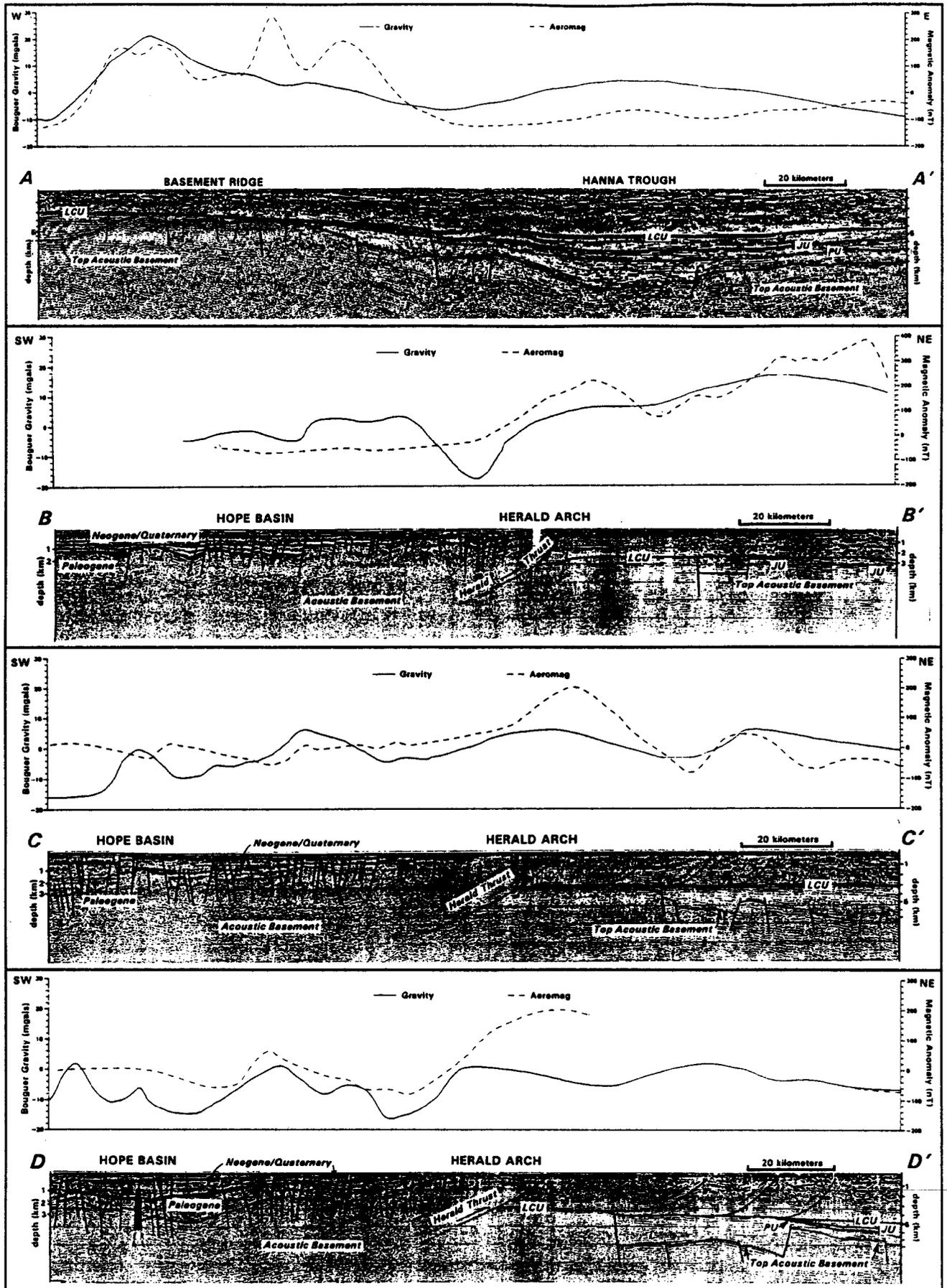
Bouguer anomalies in the study area generally are subparallel to basement structure, although amplitudes correlate poorly to variations in basement depth in areas such as the Chukchi platform and the Hope basin. Anomaly patterns in the Hanna trough, the Chukchi platform, and the Hope basin are visually distinct. Anomalies over the Hanna trough have the longest

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**Fig. 2. (second following page) Multichannel seismic-reflection profiles with marine Bouguer gravity and aeromagnetic anomalies. Bouguer gravity anomalies are reduced by a 3rd-order polynomial fit to the regional data. Profile locations are shown on maps in Fig. 1. Unconformity names are defined in the text. In D-D', the solid black body near the southwest end of the profile is believed to be an igneous intrusion.**



**Fig. 1.** All maps are at Universal Transverse Mercator projection. The location of the Herald thrust fault is shown where it truncates the LCU, which in turn forms the top of acoustic basement just north of the thrust. (A) Depth to acoustic basement contoured at 1 km interval. (B) Bouguer gravity anomaly contoured at a 5 mgal interval. (C) Aeromagnetic field contoured at a 50 nT interval.



wavelengths, and those over the Hope basin have the shortest. Magnetic anomalies in these three areas also are distinctive, but they do not correlate well with trends in basement structure nor with changes in basement depth.

The total range in the magnetic anomalies in the study area, -200 to 500 Nt, is an order of magnitude greater than the range of gravity anomalies. This suggests that while the area is nearly in isostatic equilibrium, there are significant lateral variations in crustal composition.

## MODELLING RESULTS

### *Profile A-A'*

A-A' is an east-west profile across the Chukchi platform and the Hanna trough (Fig.2a; see Fig.1 for location). The Bouguer gravity anomalies plotted above the seismic-reflection lines in Fig.2 are reduced by a 3rd-order polynomial fit to all the data in the study area. The previously described gravity and magnetic highs over the basement ridge east of the Chukchi platform and the gravity high over the axis of the Hanna trough are clearly discernible.

The general shape of the magnetic anomaly over A-A' can be explained by a single body whose upper surface corresponds to the top of acoustic basement and whose lower surface is set to the estimated 20-km depth to the Curie isotherm (Fig.3). The depth to the isotherm is derived by extrapolation of temperature-depth profiles from Chukchi basin exploratory wells (Craig, pers. commun., 1993). The causative body in this simple model has a susceptibility of 0.02 (SI). Details of the anomaly over the basement ridge have not been modelled. However, correlation of the mapped anomalies in Fig.1c with the peaks in A-A' shows that these peaks have significant north-south continuity.

As noted earlier, the mapped north-trending magnetic high is associated with a Bouguer gravity high, although the two differ in detail (cf. Figs.1b and 1c). A preliminary density model of the crust beneath A-A' (Fig.4) is dissimilar to the susceptibility model (Fig.3). Rock densities are based on samples from exploratory wells in NPRA (Barnes et al., 1990) and the Chukchi Sea. All recognized regional unconformities are shown in the model, but only two densities are used for sedimentary rocks. Both the pre-Upper Devonian argillite acoustic basement and the Lisburne carbonate are assigned a density of 2.70 Mg/m<sup>3</sup>. This density also is used for the standard

crust. All remaining sedimentary rocks above the EU are assigned a density of 2.62 Mg/m<sup>3</sup>. The Bouguer gravity high associated with the north-trending magnetic high over the eastern half of A-A' is well modelled by the density contrast across the acoustic basement unconformity (EU) and a simple intrabasement body with a density of 2.76 Mg/m<sup>3</sup>. This body is only one-third the width of the susceptibility causative body.

Based only on susceptibility data compiled by Carmichael (1982), we would speculate that the magnetic high is caused by an extinct pre-Late Devonian mafic magmatic arc. However, arc rock

densities of 2.70 to 2.76 Mg/m<sup>3</sup> preclude significant quantities of gabbro or basalt in the remains of the arc. Oliver (1977) reported magnetic susceptibilities of 0.01 to 0.05 (SI) and densities of 2.67 Mg/m<sup>3</sup> for granitoids and other intermediate plutonic rocks of the Sierra Nevada of California. The similarities of these susceptibilities and densities to those of the models presented here suggests that the proposed magmatic arc is intermediate in composition and related to a pre-Late Devonian subduction zone.

The gravity high over the axis of the Hanna trough is unexpected. It could be caused by Lisburne carbonates, if they are restricted to the axial portion of the trough. This requires a lateral facies change in the Lisburne that is not observed elsewhere in the Arctic. It also requires a 0.13-Mg/m<sup>3</sup> density contrast between the acoustic basement and the Lisburne carbonates, which is inconsistent with observed densities if the basement is Franklinian argillite as is generally believed. The model would be viable only if the basement density were lower than that of the typical argillite from NPRA, or if the Lisburne carbonates were mineralized and had an unusually high density.

The axial Bouguer gravity high can be equally well modelled by a high-density (3.1 Mg/m<sup>3</sup>) body near the base of the crust. The modelled density suggests a basic intrusive such as gabbro or a composite of mantle peridotite and crustal rock (Johnson and Olhoeft, 1982). The implied crustal thinning likely would have taken place during the Carboniferous crustal extension, when the basement horst-and-graben structure developed (Thurston and Theiss, 1987; Haimila et al., 1990).

### *Profile D-D'*

D-D' (Fig.2d) is a northeast striking line that crosses the northern Hope basin, the Herald thrust and, beneath a detached foldbelt, the southern Hanna trough. Basement structural highs in the Hope basin along D-D' are associated with gravity highs, but the relative magnitudes of the two do not vary systematically; the most prominent basement ridges do not have the largest gravity anomalies. The correlation of magnetic anomalies with basement structures in the Hope basin is poorer than that of gravity anomalies. Near the Herald thrust there are broad anomalies in both the gravity and magnetic fields whose shapes do not suggest a simple relationship to the thrust. North of the thrust, the potential fields do not correlate simply with each other or with basement relief (Fig.1).

Gravity modelling of D-D' (Fig.5) demonstrates that very little of the observed gravity field in the Hope basin is explained by the basement geometry. Three bodies of relatively high density within the basement complex are required in addition to a low-density body just behind the thrust. The high-density bodies are associated with the basement highs, which are the loci of the major wrench faults. At 20 km, a piercement structure rises into the Neogene section at a fault plane that offsets basement by over 1 km. These observations suggest that the bodies are igneous rocks intruded in association with late-stage wrench faulting. The significance of the low-density body behind the Herald thrust is uncertain. North of the thrust, the basement geometry and the relatively high-density Lisburne

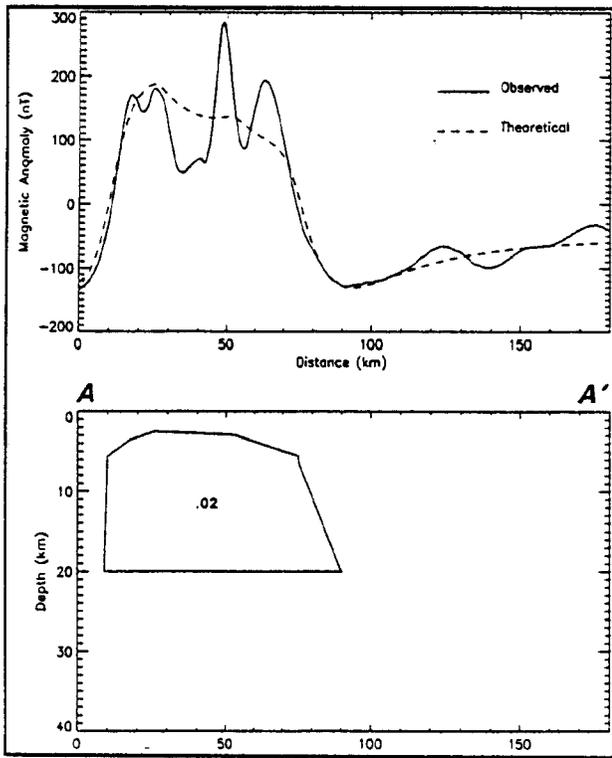


Fig.3. Aeromagnetic model for profile A-A'. Annotated susceptibility is in SI units.

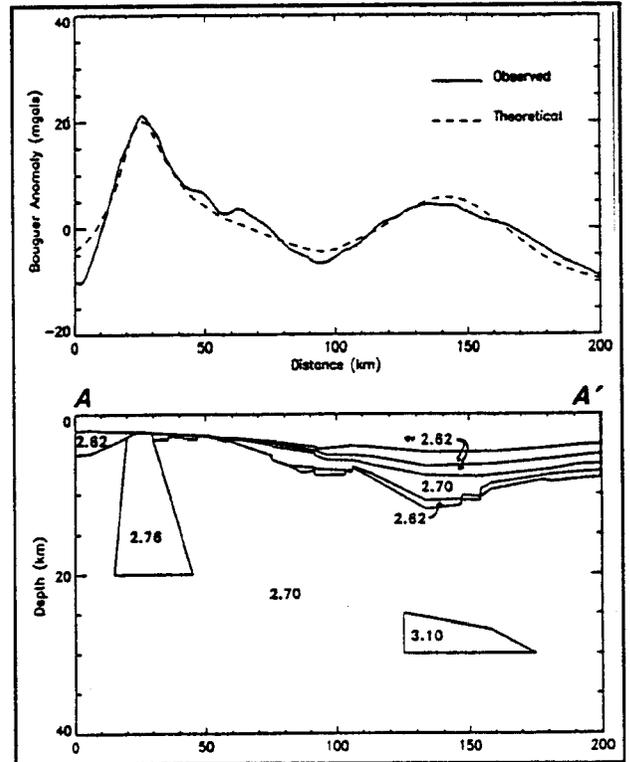


Fig.4. Bouguer gravity model for profile A-A'. Gravity is reduced by a 3rd-order polynomial fit to the regional data. Annotated density is in  $Mg/m^3$  units. Unconformity names are defined in the text.

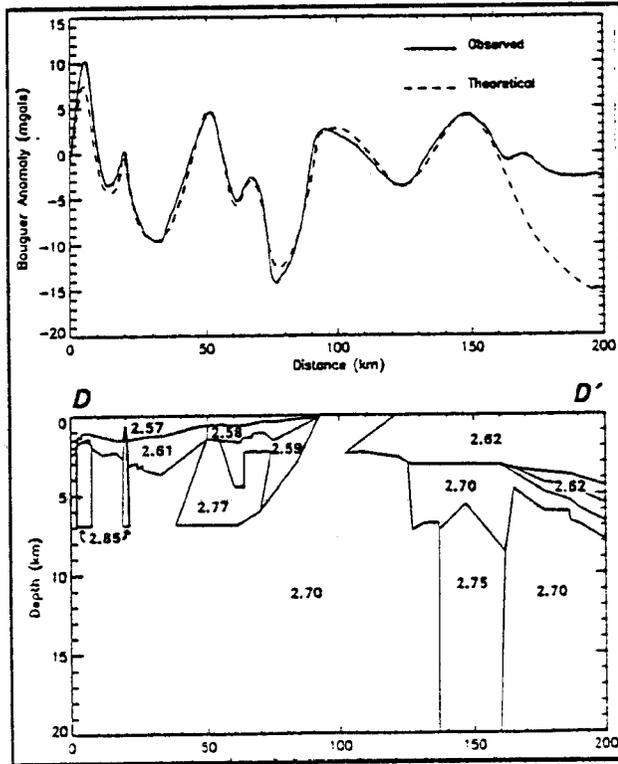


Fig.5. Bouguer gravity model for profile D-D'. Gravity is reduced by a 3rd-order polynomial fit to the regional data. Annotated density is in  $Mg/m^3$  units.

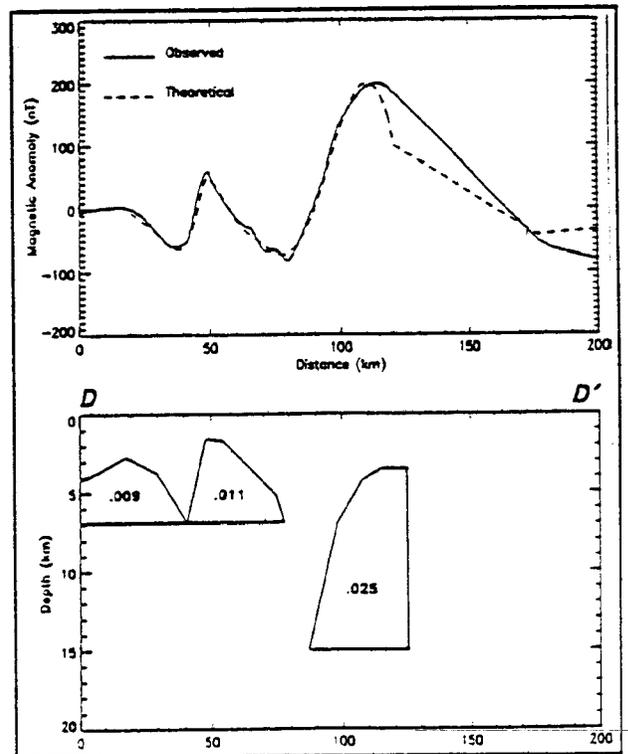


Fig.6. Aeromagnetic model for profile D-D'. Annotated susceptibility is in SI units.

sediments in the structural low may explain the gravity data.

The magnetic field south of the thrust can be modelled by two bodies having a positive susceptibility contrast with the surrounding basement rocks (Fig.6). Their susceptibilities are one-third to one-half that of the basement ridge east of the Chukchi platform, possibly indicating that they have a more felsic composition. Alternatively, the relatively low susceptibilities may result from a significant component of country rock within the boundary of the causative body. North of the thrust, the positive magnetic anomaly is modelled by a body within basement similar to the body east of the Chukchi platform (see Fig.3). The aeromagnetic field map shows that this anomaly is offset from the north-trending anomaly (Fig.1c), so its relation to the proposed arc is uncertain.

#### *Profile C-C'*

Because models of the gravity and magnetic anomalies in C-C' have not been completed, basement composition is inferred from the anomaly pattern and comparisons to D-D' (Fig.5). As at D-D', the amplitudes of the gravity highs do not correlate with the basement relief in the Hope basin (Fig.2c), suggesting that these basement highs also are sites of intrusive igneous activity. The minor magnetic anomalies at some of the basement highs also may indicate igneous intrusions. A gravity low just south of the thrust is diminished relative to that in D-D'. The low-density section within the acoustic basement complex observed in D-D' may not extend continuously along the thrust. North of the Herald thrust, C-C' crosses two magnetic highs. Both may be related to the proposed magmatic arc, although the northernmost magnetic and gravity highs may be due to a separate magmatic event.

#### *Profile B-B'*

Gravity highs in the northwestern Hope basin along B-B' (Fig.2b) are not as peaked as those at C-C' and D-D', and the magnetic field essentially is flat. Igneous activity here may have been insignificant. A low-density intrabasement body behind the thrust is suggested by the prominent gravity low. North of the Herald thrust, B-B' crosses the north-trending basement ridge. The potential field anomalies are consistent with those from A-A'.

### CONCLUSIONS

Aeromagnetic and marine gravity data suggest the presence of a north-trending, pre-Late Devonian subduction-related magmatic arc at the eastern edge of the Chukchi platform. Model densities of arc rocks suggest that this is the site of a collision between lithosphere beneath the Chukchi platform and that below the Hanna trough. The proposed arc extends at least 60 km south of the present-day site of the Herald thrust. This arc may have served as a back-stop over which the Herald thrust rode during the Late Cretaceous to early Tertiary.

In the Hope basin, igneous intrusions correlate to local gravity anomalies. At least some of these intrusions are associated with Neogene transtensional faulting. Relatively low-amplitude magnetic anomalies in the Hope basin suggest that these intrusives are more felsic than those of the

proposed extinct arc north of the Herald thrust.

### ACKNOWLEDGMENTS

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