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INSIDE

A New Magnetic View of Alaska

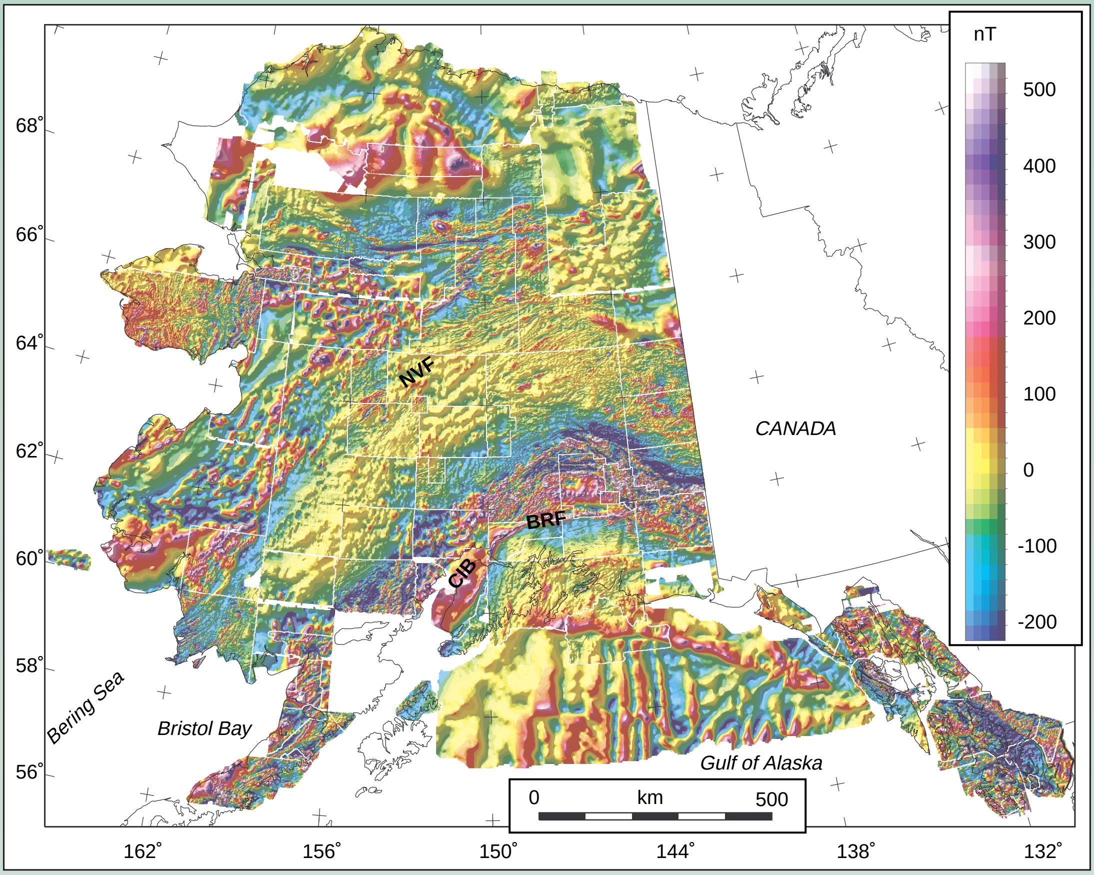

Figure 1. Composite aeromagnetic map of Alaska that depicts total field magnetic data values (International Geomagnetic Reference Field has been removed) from a compilation of 85 separate surveys and two grids. Thin data gaps mark the boundaries between data sets. CIB—Cook Inlet Basin, NVF—Nowitna volcanic field, BRF—Border Ranges fault. Data set can be downloaded from the Web at: ftp://greenwood.cr.usgs.gov/ pubs/open-file-reports/ofr-97-0520/data. A 1:2,500,000 plot file of this data set is available at: ftp://greenwood.cr.usgs.gov/pubs/open-file-reports/ofr-97-0520/plots.

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ABSTRACT

A new, publicly available aeromagnetic data compilation spanning Alaska enables analysis of the regional crustal character of this tectonically diverse and poorly understood part of the North American Cordillera. The merged data were upward-continued by 10 km (mathematically smoothed without assumptions about sources) to enhance crustal-scale magnetic features and facilitate tectonic analysis. This analysis reveals a basic threefold magnetic character: (1) a southern region with arcuate magnetic domains closely tied to tectonostratigraphic elements, (2) a magnetically neutral interior region punctuated locally by intermediate and deep magnetic highs representing a complex history, and (3) a magnetically subdued northern region that includes a large deep magnetic high. Our tectonic view of the data supports interpretations that Paleozoic extension and continental rift basins played a significant role in the tectonic development of northern and interior Alaska. Accretion of oceanic and continental margin terranes could be restricted to the southern region. The new magnetic view of Alaska can be compared and contrasted with other Pacific margin regions where convergent margin and accretionary tectonic processes are important.

INTRODUCTION

Alaska, an important part of the North American Cordillera, is a type example for the nature and significance of accretionary tectonics along a convergent continental margin (e.g., Coney and Jones, 1985; Plafker and Berg, 1994). The prevailing tectonic interpretation is that this vast part of North America has had a long history of accretion of diverse tectonostratigraphic terranes. These terranes are thought to represent a wide variety of oceanic, arc, and continental margin assemblages. They form an amalgamated, commonly 30-km-thick crust throughout

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interior and southern Alaska. The diversity of tectonostratigraphic elements suggests a complicated crustal basement that is covered by Mesozoic and Cenozoic sedimentary basins over much of Alaska. A new regional magnetic compilation (Fig. 1) provides an independent means for examining the character of this crust, even where younger sedimentary cover is extensive (Fig. 2). This paper presents this new magnetic compilation, explains how these data were compiled and processed to emphasize crustal-scale magnetic character, and illustrates how these data can be used to constrain regional geologic and tectonic interpretations.

Previous workers have examined regional aeromagnetic data based on older analog and digital compilations for parts of Alaska. The focus of these studies has been primarily on interpretation of shallow crustal features. For example, Griscom and Case (1983) discussed magnetic anomalies south of the Denali fault system; Cady (1989, 1991) and Saltus et al. (1997) interpreted magnetic and gravity data in northern and central Alaska. In contrast to these studies, we take a more regional and deeper view of the magnetic data.

Aeromagnetic surveys are generally flown over small regions and must be stitched together to create data sets large enough for deep characterization of the crust. In this study, a robust digital filtering scheme was applied to merged aeromagnetic data to separate the magnetic features caused by shallow (thin) crustal sources from those caused by deep (thick) sources. The term "deep" does not require that tops of these sources be deeply buried, but rather that the overall depth extent (thickness) of the sources is significant on a crustal scale.

MAKING A MAGNETIC QUILT

The merging of the aeromagnetic data sets was the first step. The new magnetic compilation (Saltus and Simmons, 1997) combines 85 aeromagnetic surveys and two previously compiled grids. The surveys were flown between 1945 and 1990 and vary in flight-line spacing and elevation. Data collected before about 1972 were digitized from maps or flight-line plots; newer data were mostly processed from digital flight-line information. The data total to about 1 million-line-km

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and would cost at least $6 million to reacquire.

Two digital data grids were produced with a 1-km grid spacing: A composite grid (Fig. 1) with all surveys at their original resolution and a merged grid with all surveys mathematically continued to a common flight height of 300 m above ground. Data processing was performed by Northwest Geophysical Associates, Inc. and incorporates a previous compilation for interior Alaska (Meyer and Saltus, 1995) processed by Paterson, Grant, and Watson, Ltd.

The data values are total field amplitude (in nanoteslas, nT) of Earth's magnetic field, with the long-wavelength core field (the International Geomagnetic Reference Field) removed. The variation in values reflects variations in the amount and type of magnetic minerals—chiefly magnetite (Fe_3O_4) and its solid solutions with ulvospinel (Fe_2TiO_4)—in the crust (Blakely and Connard, 1989; Reynolds et al., 1990; Blakely, 1995). To eliminate long-wavelength errors resulting from the data merging process, we replaced the longest wavelengths (>600 km) with comparable wavelengths of a satellite-derived Earth's magnetic field model to spherical harmonic order 65 (Arkani-Hamed and Dyment, 1996).

The aeromagnetic data grids as well as plot files and other information about the compilations are available via the World Wide Web (http://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-97-0520/alaskamag.html).

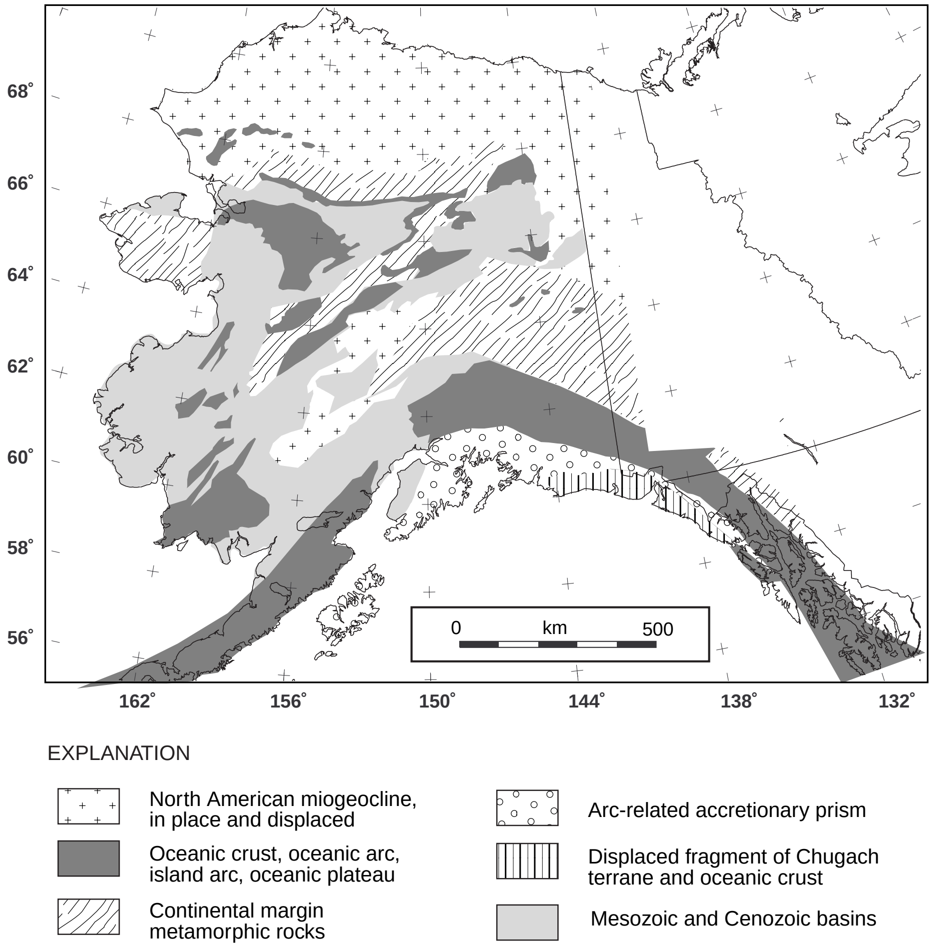

Figure 2. Tectonic affinity of selected terranes in Alaska (generalized from Plafker and Berg, 1994, Fig. 1). The diversity and mixing of genetic origins implies crustal heterogeneity, particularly in interior Alaska. Much of interior and southwestern Alaska is covered by Mesozoic and Cenozoic basins.

WORKING WITH REGIONAL MAGNETIC DATA

The short-wavelength features that are visible in Figure 1, but not in Figure 3, are the part of the magnetic field most commonly used in local-scale geologic analysis. For example, contrasts in the short-wavelength data help define depth of sedimentary basins, distribution of certain igneous rocks, and locations of faults or other geologic boundaries. Examples at the scale of Figure 1 include the Cook Inlet basin, the Nowitna volcanic field, and the Border Ranges fault. Many of these magnetic features, which can be very important for understanding surface and near-surface geologic relationships,

Magnetic View *continued on p. 4*

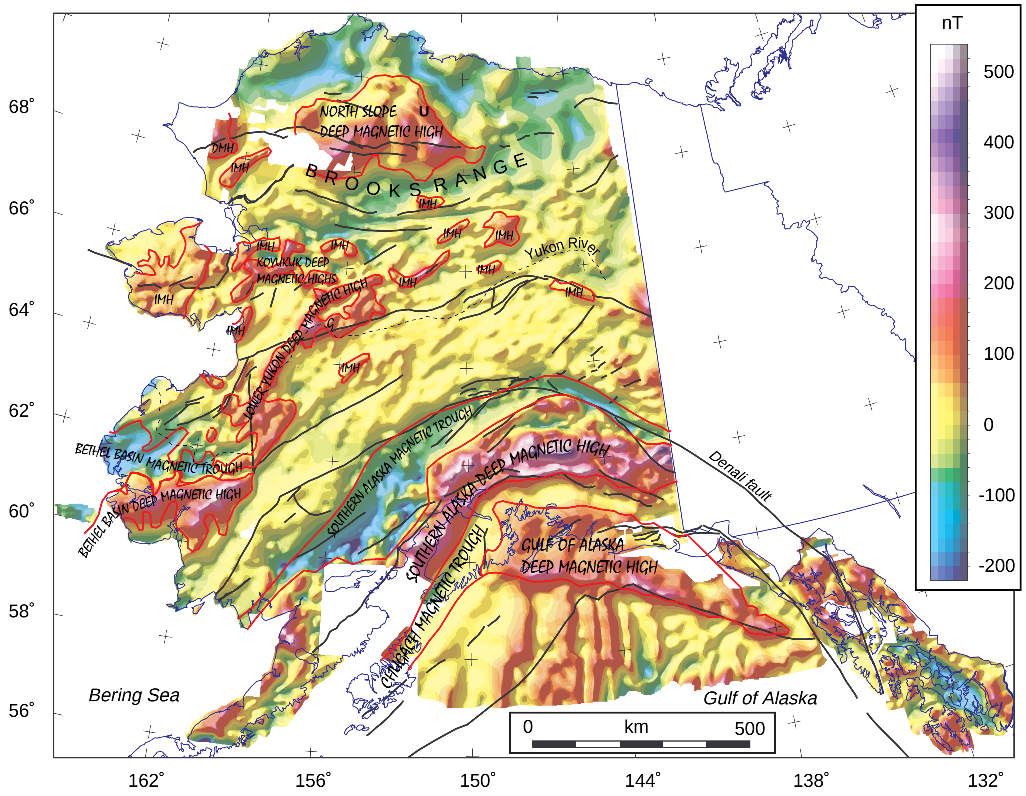

Figure 3. Deep magnetic feature map that depicts a 10 km upward continuation of merged aeromagnetic data. Upward continuation is a mathematically stable way to smooth the data set without making assumptions about magnetic sources (Blakely, 1995). Black lines mark major faults of Alaska. Red lines show boundaries between the magnetic domains discussed in the text (Table 1). U—Umiat.

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are not crustal-scale components of the region (e.g., Cretaceous and Tertiary plutons).

Although the mathematics of upward continuation has long been known, we feel it is underutilized in regional magnetic interpretation. We use this simple and robust filter (e.g., Blakely, 1995) to separate the magnetic expression of shallow and deep crustal magnetic features. Generally, a magnetic feature caused by a deep (thick) distribution of magnetic minerals will have a broader (longer wavelength) shape than those caused by a shallow (thin) distribution. We found that upward continuation to 10 km (Fig. 3) and 40 km proved most useful for delineation of domains in Alaska, but results may vary by tectonic setting and overall crustal thickness. A 10 km upward continuation severely damps wavelengths smaller than 25 km. A shallow magnetic domain map, particularly useful for detailed geologic and geophysical analysis, can be produced by subtracting the upward continued data grid from the merged aeromagnetic data grid.

Just as every magnet has a positive and negative pole, all magnetic source bodies are dipolar; they cause magnetic features that consist of both positive and negative parts. For most regional-scale magnetic sources, the shallower positive pole causes a focused high, whereas the deeper negative pole causes an associated broad low. We have mostly delineated the positive parts of features; exceptions include the very large magnetic troughs in southern Alaska.

Crustal-scale features in aeromagnetic data compilations may contain significant errors as a result of data adjustments made during the merging process. We address this problem by adjusting the longest wavelengths in our compilations to agree with a satellite magnetic model of Earth's field (Arkani-Hamed and Dyment, 1996). However, as there is a gap in resolution between the size of the typical aeromagnetic survey and the satellite models, it is important to check regional magnetic features for correlation with survey boundaries.

To interpret crustal affinity from large-scale magnetic features, we assume that bulk crustal-scale magnetization is primarily dependent on the total content of iron in the crust. Thus, we expect a typical bulk increase in magnetization from sialic to mafic crust. This is a first-order simplification of the complex field of rock magnetism (for more detail see Reynolds et al., 1990). Of concern is the possibility that patterns of magnetization, particularly in interior Alaska, are related to metamorphic alteration of the composite terranes. Metamorphism can either produce or destroy magnetic minerals, but usually diminishes magnetization of igneous rocks (Reynolds et al., 1990). The presence of crustal-scale magnetic highs in interior Alaska shows that wholesale destruction of magnetization has not occurred there, but metamorphism may still have had an important effect.

CRUSTAL-SCALE MAGNETIC DOMAINS OF ALASKA

There are many crustal-scale magnetic domains in Alaska (Fig. 3, Table 1). Some have magnetic highs that do not persist to depth if the data are upward continued to 40 km (intermediate highs in Table 1, labeled IMH in Figure 3). Some have strong spatial correlation with tectonostratigraphic terranes; others don't (Table 1).

At the broadest scale, Alaska may be subdivided into three magnetic regions: (1) a southern region that spans much of the area south of the Denali fault system and is composed of a series of arcuate magnetic domains (both highs and lows) with strong tectonostratigraphic ties (Table 1) that parallel the continental margin; (2) an interior region extending from Canada west to the Bering Sea, that contains a few local magnetic highs with mixed tectonostratigraphic ties interspersed in a broad expanse of neutral magnetic character; and (3) a northern region that includes the Brooks Range and North Slope and is dominated by a subdued magnetic character but is also host to a large magnetic high. Within these broad divisions, both long- and short-wavelength magnetic domains reflect features of tectonic and geologic significance. In a general way, the southern region mainly reflects continental margin and oceanic

TABLE 1. CHARACTERISTICS OF SELECTED ALASKA MAGNETIC DOMAINS

Name	Size (km)	Description	Tectonostratigraphic Setting
Magnetic Domains With Strong Tectonostratigraphic Ties			
Pacific Ocean domain	>900 × >300	Distinctive north-south high and low stripes	Oceanic crust of Pacific Ocean basin
Gulf of Alaska high	700 × 200	Broad 100 nT magnetic high	Accreted oceanic crust and continental margin sediments of Prince William and Yakutat terranes
Chugach trough	>1000 × 100	Arcuate magnetic low	Accreted Upper Cretaceous flysch of Chugach Terrane
S. Alaska high	>1400 × 200	Arcuate zone of large-amplitude magnetic highs	Jurassic arc-related rocks and their basement, Wrangellia composite terrane
S. Alaska trough	>1200 × 100	Arcuate magnetic low	Collapsed Mesozoic flysch basin of Hagemeister subterrane (Decker et al., 1994), Kahiltna terrane (Nokleberg et al., 1994), and Gravina-Nutzotin belt (Berg et al., 1972)
Intermediate highs	<100 × <50	Isolated highs that do not persist when data are upward continued to 40 km	Mainly allochthonous mafic rocks of the Oceanic composite terrane
North Slope high	400 × 200	Broad magnetic high with superimposed north-south high bands; magnetic data gap prevents evaluation of the western continuity of this domain	Coincides with thick parts of the Ellesmerian section in the Umiat basin; Paleozoic continental rift?
Magnetic Domains Without Strong Tectonostratigraphic Ties			
Bethel Basin high	300 × 150	Broad 200 nT magnetic high	Area of extensive Quaternary cover rocks; oceanic or continental rift?
Bethel Basin trough	300 × 100	Broad >100 nT magnetic low	Area of extensive Quaternary cover rocks; sialic continental crust?
Lower Yukon high	500 × <100	Northeast- trending group of narrow magnetic highs	Most closely coincides with Cretaceous and Tertiary igneous rocks
Koyukuk highs	250 × 50	Irregularly circular group of magnetic highs	Does not closely coincide with surface geology; oceanic arc or continental rift?

Note: Terrane nomenclature follows Plafker and Berg (1994) unless otherwise indicated.

rocks, the interior region reflects crystalline sialic rocks, and the northern region reflects thick sedimentary rock sequences. The crustal-scale magnetic domains of these three large regions, and the relations of magnetic domains to defined tectonostratigraphic terranes within them, have implications for understanding convergent continental processes and the tectonic evolution of Alaska.

Southern Region

The southern region is magnetically distinct from other parts of Alaska. There, strong magnetic highs and lows are continuous high-amplitude features that extend for over 1000 km along strike and have strong tectonostratigraphic ties (Table 1). Examination of offshore magnetic data (Godson, 1994) indicates that the southern Alaska deep magnetic high and flanking troughs continue westward to the Bering Sea shelf edge (also see Worrall, 1991, Fig. 15C). Combining these extensions with the southeasterly extension seen in Figure 3 doubles the length of these features. The coupled character of the very long and arcuate southern Alaska deep magnetic high (arc-related) and the adjoining magnetic trough (deformed flysch belt) to the north suggests tectonic links between them.

The southern region magnetic domains are strongly tied to convergent margin tectonostratigraphic terranes that include arc systems, deformed flysch belts, and accreted oceanic rocks (Fig. 2, Table 1). The characteristic magnetic features are large, elongate, vertically and horizontally continuous, fault-bounded highs flanked by similarly extensive lows. As this region is a type example of convergent margin processes, this crustal magnetic character could be expected along similar margins elsewhere.

Northern Region

The overall magnetic character of the northern region reflects the thick, weakly magnetic sedimentary rocks of this important petroleum province. Also present is the North Slope deep magnetic high, the largest individual onshore domain of intense magnetic highs outside of the southern Alaska region.

The sources for the North Slope deep magnetic high are buried by at least 10 km of sediments. This cover includes an Ellesmerian (Mississippian to Early Cretaceous) section that is over 4 km thick in the Umiat basin. The early Ellesmerian (Upper Devonian? and Mississippian) sediments include a nonmarine coal-bearing section up to 3 km thick (Eo-Ellismerian section of Grantz and May, 1988; Grantz et al., 1994) that was deposited in sags and half grabens (Kirschner and Rycerski, 1988). A similar early Ellesmerian section could be present in the Hanna trough, 150 km west of the North Slope in the Chukchi Sea (Grantz and May, 1988) where an analogous magnetic high occurs (Godson, 1994). Kelly and Brosge (1995) argued that Late Devonian depocenters, produced by wrench faulting or rifting are also important elements of the Brooks Range. As such, a Late Devonian to Early Mississippian extensional tectonic setting seems well established.

The deep magnetic sources in the Umiat basin area are likely to be basalt and related mafic intrusives. These mafic rocks could be either pre–Late Devonian in age or associated with the Late Devonian extension responsible for the development of the Umiat basin. If these persistent magnetic highs are related to the Umiat basin, extension could have significantly thinned the pre-Devonian crust or replaced it with mafic (oceanic) crust. The Umiat basin could be a largely undeformed example of a continental rift basin with extensive basaltic magmatism that formed in the Devonian and continued as a significant regional depocenter into the Jurassic.

Interior Region

The interior region is a broad expanse of neutral magnetic character containing local and irregular intermediate-depth and deep magnetic highs with generally poor tectonostratigraphic ties. A key to tectonic interpretation of these highs is whether the region has a broadly oceanic (like the southern region) or continental (like the

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northern region) crustal character. An oceanic crustal character is consistent with the view of Plafker and Berg (1994; Fig. 1) that this part of Alaska is composed of accreted assemblages from the ancestral Kobuk Sea (Plafker, 1990) or Angayucham Ocean (Moore et al., 1994). A continental character is consistent with a collapsed continental-rift interpretation (Gemuts et al., 1983; Dover, 1994).

The mostly neutral magnetic character of the interior region compares with the subdued magnetic background of the northern region, as would be expected for a sialic crust. Such a signature is consistent with the widespread occurrence of crystalline and supracrustal rocks in interior Alaska (e.g., the Central composite terrane, Ruby terrane, Kilbuck terrane, Idono Complex, and Yukon composite terrane; Plafker and Berg, 1994).

In a continental framework, the various magnetic highs of the interior region could reflect collapsed fragments of an ancient rift basin analogous to the Umiat basin on the North Slope. Such fragments would be long-standing crustal elements that provided loci for later episodes of extension (Miller and Hudson, 1991), or Cretaceous and Tertiary magmatism. In these cases, the magnetic sources in these domains would be composite features with long and complicated Phanerozoic histories complicating their present-day magnetic character. This interpretation is consistent with the view (Dover, 1994) that many of the Devonian to Jurassic mafic igneous rocks and related basinal sediments of interior Alaska are best interpreted as rift-related sequences with ties to substrate and peripheral geologic elements; perhaps they do not represent highly allochthonous, far-traveled oceanic elements.

CONCLUSIONS

Regional aeromagnetic compilations provide independent three-dimensional synthesis of regional crustal character and recently developed regional satellite magnetic models for the Earth can help to validate the longest wavelengths in these compilations. Modern digital compilations offer the opportunity to apply filters, such as upward continuation, for selective enhancement of features related to various depths and scales of geological investigation.

The new compilation of aeromagnetic data for Alaska presented here provides a view of the major crustal character across this large and complex part of the North American Cordillera. The focus of this paper has been on the long-wavelength data because of their important implications for interpreting the tectonic evolution of Alaska. The long-wavelength data have directed us toward the view that much of Alaska is underlain by sialic crust and that Paleozoic extension has played a significant role in the development of continental rift basins in Alaska. The best examples of convergent margin and ancestral Pacific Ocean rocks seem to be restricted to southern Alaska.

The value of these magnetic data and this compilation will be realized when many workers critically evaluate the data and incorporate them into their syntheses and interpretations. We invite everyone to take advantage of the data for their studies—we are confident that there is much to learn from them.

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