Matching Magnetic Trends and Patterns Across the Tintina Fault, Alaska and Canada—Evidence for Offset of About 490 Kilometers

By Richard W. Saltus

Chapter C of

Recent U.S. Geological Survey Studies in the Tintina Gold Province, Alaska, United States, and Yukon, Canada—Results of a 5-Year Project

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Contents

Figures

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Abstract

Magnetic anomaly patterns on opposite sides of the mapped Tintina fault in eastern Alaska and western Canada show an apparent offset of about 490 kilometers (km), probably of Eocene age. This estimate is compared with previous geologically based estimates of 400 to 430 km and paleomagnetically based estimates of more than 1,100 km. The apparent geophysical alignments have geologic implications that deserve further study.

Introduction

The Tintina fault zone in eastern Alaska and western Canada (fig. C1) is a major tectonic boundary between cratonic North America and pericratonic rocks of the Yukon-Tanana and related terranes (Roddick, 1967; Gabrielse, 1985; Gabrielse and others, 2006). Numerous estimates have been made of the amount and timing of offset on this fault system (for example, Dover, 1994; Plafker and Berg, 1994; Gabrielse and others, 2006). Several of the latest estimates, based on matching of geologic elements across the fault, indicate probable offset of at least 400 kilometers (km), primarily during the Eocene (Dover, 1994; Gabrielse and others, 2006), although published displacement estimates based on paleomagnetic data have ranged as high as 1,100 to 2,400 km (Beck and others, 1981; Irving and others, 1985; Umhoefer and others, 1989).

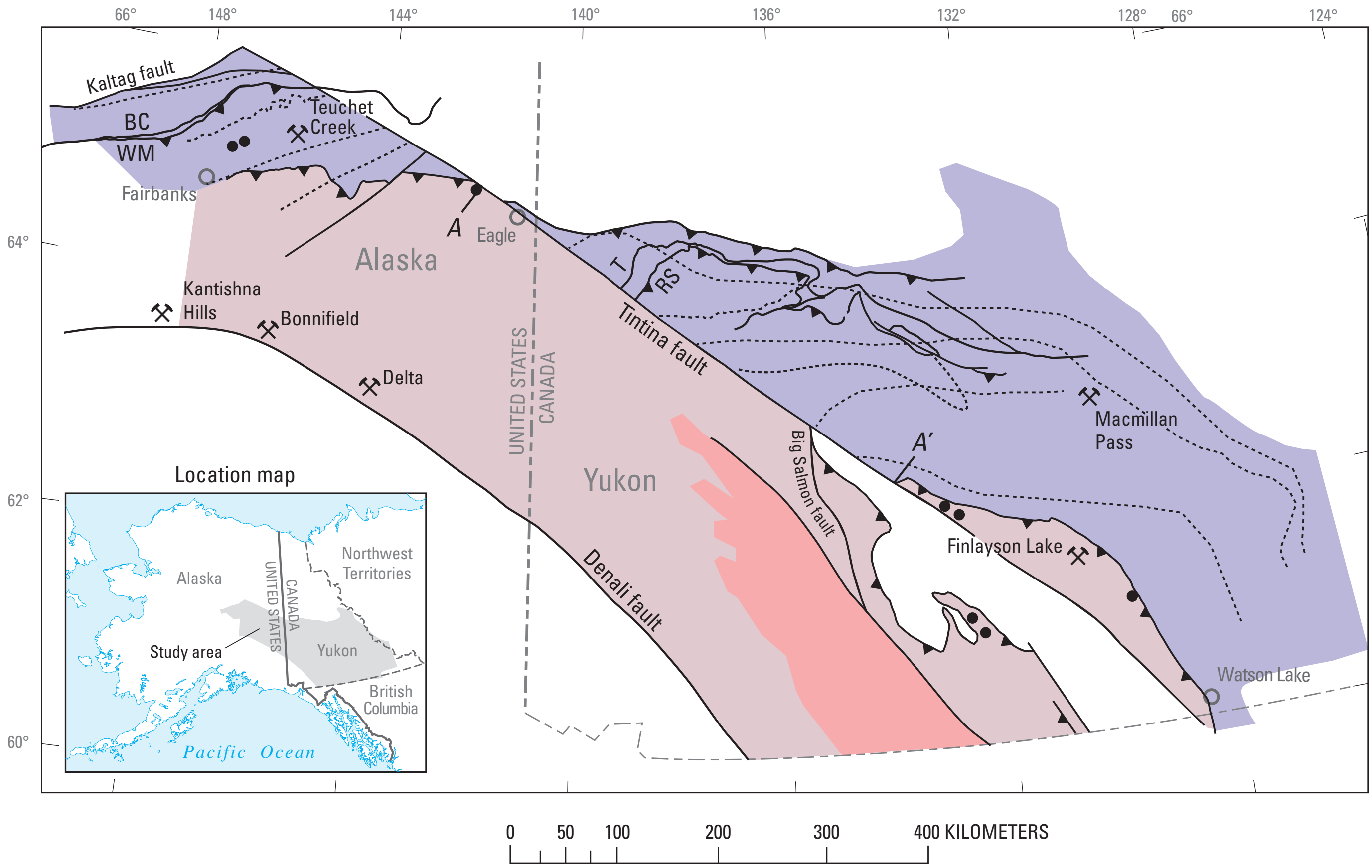
Regional geophysical data, such as magnetic and gravity field maps, display patterns and trends that are representative of the composition of the crust (for example, Blakely, 1995). The amount of offset on crustal faults can be investigated by "cutting and sliding" the geophysical maps to evaluate pattern and trend alignment under various slip scenarios. In particular, the compiled aeromagnetic data portrayed on the Magnetic Anomaly Map of North America (North American Magnetic Anomaly Group, 2002) provide an excellent base map for this endeavor.

Regional magnetic anomalies reflect the amount and distribution of magnetic minerals, most notably magnetite, in regions of the crust and upper mantle at temperatures below about 580°C. Magnetic anomaly wavelengths are generally related to the depth to magnetic sources and show a geometric amplification of shallow-source amplitudes over those of deeper sources (Blakely, 1995; Sleep and Fujita, 1997). Thus, magnetic anomaly sources can arise from geologic features of varying depths within the crust and varying ages. Also, the magnetic properties of different sides of the fault may be modified by chemical and (or) thermal alteration before, during, or after fault slippage. Thus, the matching of magnetic anomaly patterns is somewhat subjective but can contribute to the larger body of evidence regarding the likely amount of displacement across a fault.

Methods

Regional geophysical data, specifically residual maps of the Earth's magnetic field, provide a complex proxy overview of crustal composition and structure as reflected in the occurrence of magnetic minerals, especially magnetite. Crustal magnetic field data are collected primarily from airborne platforms, usually by helicopter or fixed-wing aircraft. For the purpose of geological interpretation, the measured data are adjusted by the removal of a theoretical regional surface, the International Geomagnetic Reference Field (IGRF), which is created from ground-based observatory and satellite data (International Association of Geomagnetism and Aeronomy, 1992; Blakely, 1995). The IGRF is a model of the deep-seated and slowly varying geodynamic sources of the Earth's overall magnetic field. Once the IGRF is removed, residual magnetic field maps (frequently called "total field" maps) reflect anomalies (perturbations) in the regional field caused by magnetic material within the crust and upper mantle. The primary magnetic mineral, magnetite, has a Curie temperature

[1]U.S. Geological Survey.



EXPLANATION

Late Cretaceous plutons

Yukon-Tanana terrane

Paleozoic and Late Proterozoic off-shelf sedimentary rocks

Selected geologic lineaments—Strain zones and boundaries between groups of plutonic rocks

Major fault

Thrust fault—Sawteeth on upper plate. BC, Brush Creek; RS, Robert Service; T, Tombstone; WM, White Mountains

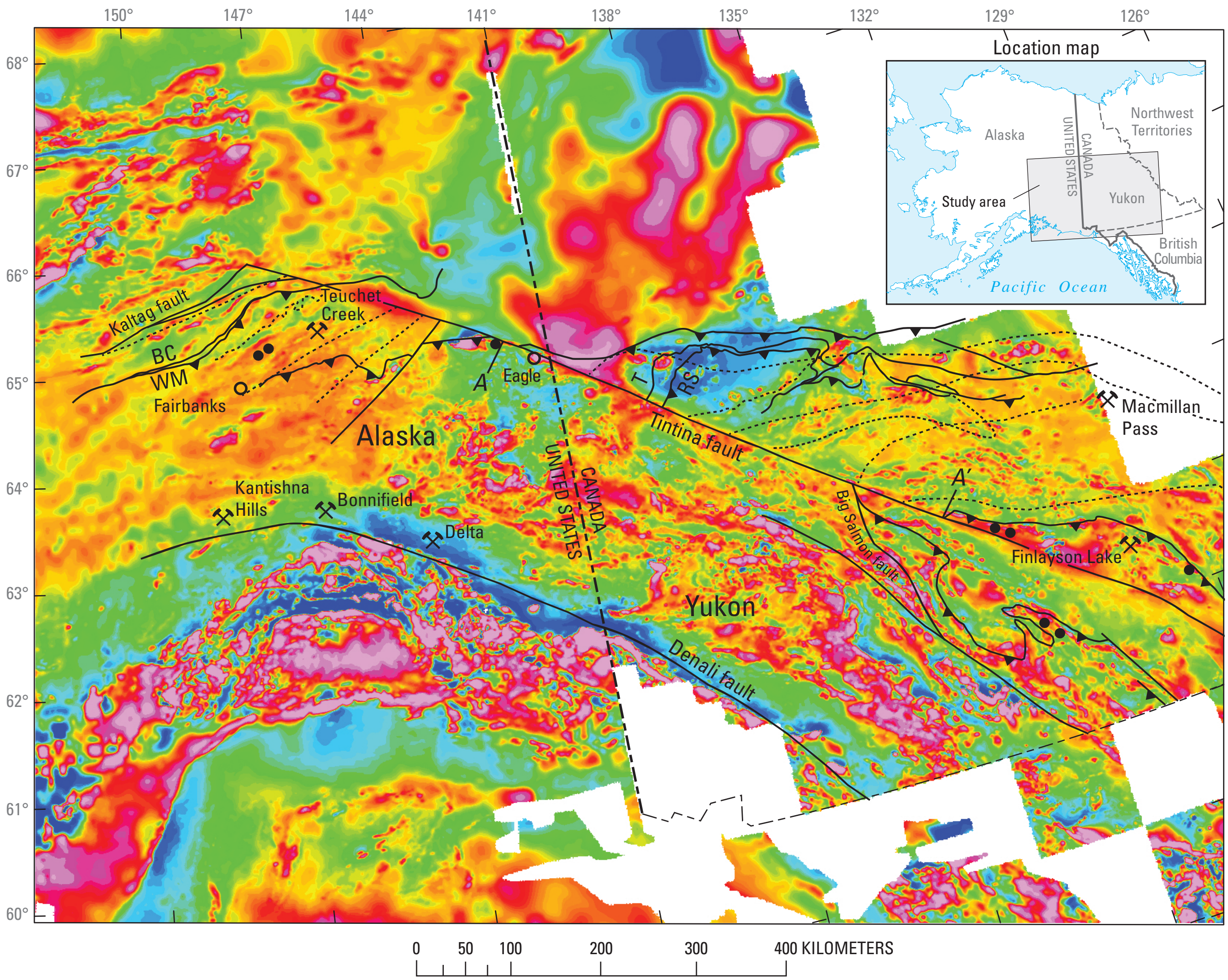
Mining district in Devonian to Mississippian rock

Blueschist or eclogite occurrence

Figure C1. Regional geology with faults and features (adapted from Gabrielse and others (2006) and Dusel-Bacon and others (2006)). Markers *A* and *A′* are measurement points for proposed fault restoration.

of about 580°C, so magnetic sources have a thermal limit with depth that typically falls somewhere near the crust-mantle boundary, which is typically about 35 to 40 km deep.

The analysis and interpretation of magnetic anomalies typically involve some form of inversion to deduce the individual magnetic sources from their composite representation in the total field. In a strictly mathematical sense, this is a non-unique problem, which means that some assumptions must be made to constrain the solution. For the purpose of fault reconstruction by pattern matching, it is not required that the magnetic anomalies be inverted or interpreted. However, if the conclusions from geophysical pattern matching are to be evaluated geologically, it is useful to explore the possible geological associations of the geophysical features.



EXPLANATION

Magnetic intensity (in nannoteslas)

-280 -160 -110 -75 -50 -30 -5 10 25 40 65 95 130 210 415

Selected geologic lineament

Major fault

Thrust fault—Sawteeth on upper plate. BC, Brush Creek; RS, Robert Service; T, Tombstone; WM, White Mountains

Mining district in Devonian to Mississippian rock

Blueschist or eclogite occurrence

Figure C2. A subset of the Magnetic Anomaly Map of North America (North American Magnetic Anomaly Group, 2002) with selected geology elements (see fig. C1). Markers *A* and *A′* are reference points for proposed fault restoration.

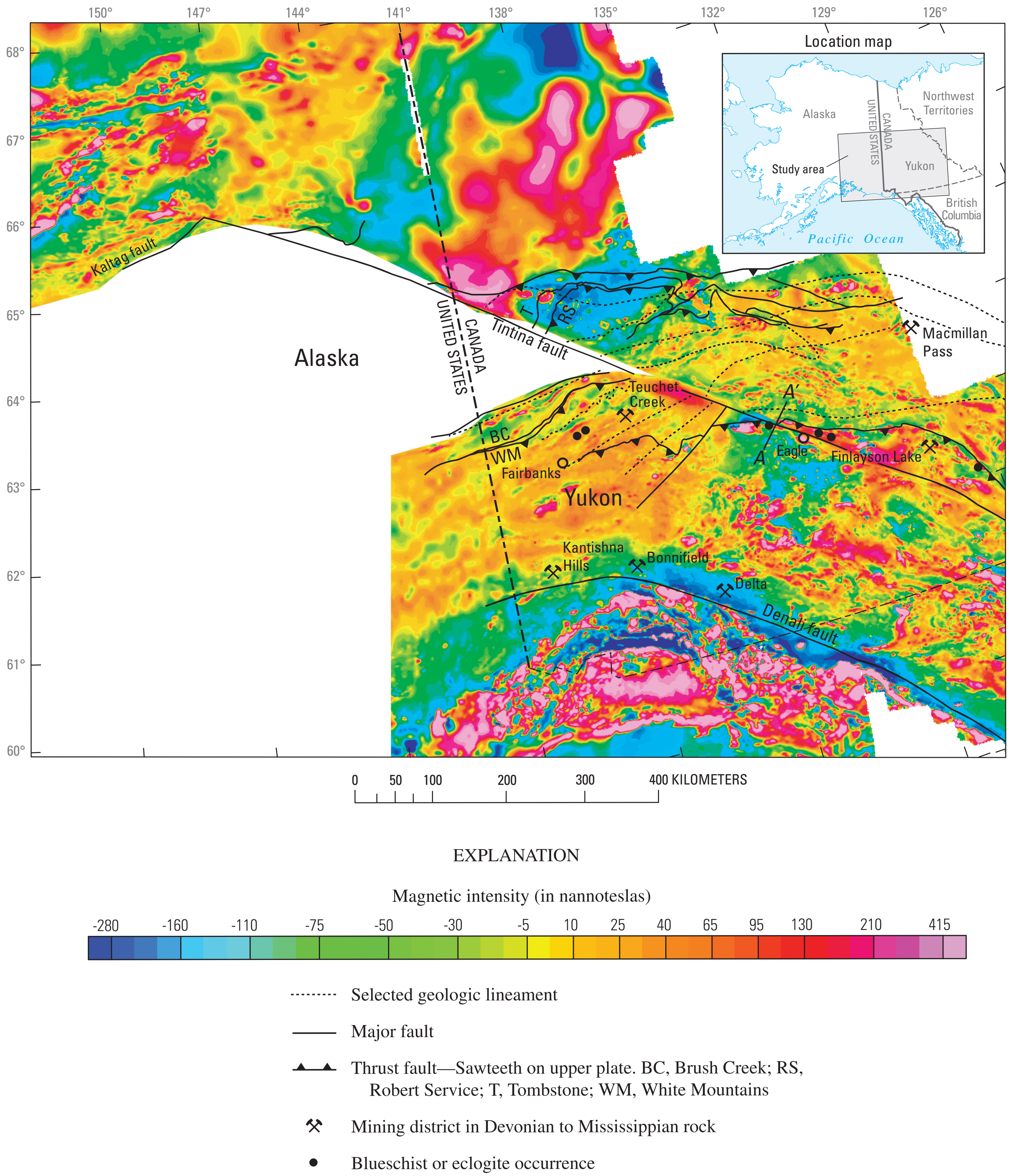


Figure C3. Proposed palinspastic restoration based on matching of magnetic anomalies across the Tintina fault. This figure is made by cutting and shifting figure C2. A shift of about 490 km from west to east aligns markers *A* and *A′* as shown.

This study involves a very simple visual approach to magnetic anomaly interpretation for this study. I selected a subset of the recently compiled Magnetic Anomaly Map of North America (North American Magnetic Anomaly Group, 2002). The Magnetic Anomaly Map of North America was created by carefully merging hundreds of individual aeromagnetic surveys into a single grid with uniform effective survey height. This compilation minimizes any artifacts related to individual magnetic survey boundaries and allows one to concentrate on geologically significant anomalies and patterns.

A visual image (fig. C2) of the selected grid subset was created using a histogram-stretched color scale adapted to the data ranges and statistics for the region. This coloring enhances subtle magnetic anomaly amplitude variations in the central part of the anomaly range. This is appropriate for identifying geologically significant variations that would otherwise be difficult to see if a linear color scale were used.

The colored magnetic anomaly image was then cut along the regionally mapped trace of the Tintina fault (Gabrielse and others, 2006) and slid by variable amounts along the fault trace to examine pattern and trend correlations for different slip scenarios. This pattern matching was based only on the magnetic anomalies and was done independent of geology. Our preferred matching of magnetic anomalies across the fault (fig. C2) requires about 490 km of total shift along the Tintina fault.

Results and Importance

What are the geologic implications of this hypothetical fault slip restoration on the Tintina fault system? Figure C3 shows the geologic base map from figure C1 cut along the Tintina fault and subjected to a 490-km shift. This shift produces a number of interesting geological alignments. Here we point out several implications of the proposed reconstruction, from southeast to northwest. For the purpose of discussion, the restored alignment points *A* and *A′*, located about 50 km northwest of the restored position of the town of Eagle, are used as the zero position for specifying features along the restored Tintina fault.

Perhaps the broadest scale geologic alignment is the matching of the separate strands of the Inconnu thrust fault (IT as shown by Gabrielse and others, 2006) at both ends of the orphaned Yukon-Tanana block that lies northeast of the Tintina fault. The southeastern edge of this block, near Watson Lake (about 400 km southeast of *A-A′*), ends up near the three-way intersection of the Inconnu fault, the Big Salmon fault, and the Tintina fault. The northwestern edge of the orphan Yukon-Tanana block connects at position *A-A′* with the thrust fault (thought to represent a continuation of the Inconnu thrust fault; Gabrielse and others, 2006) that separates the Yukon-Tanana terrane from off-shelf Late Proterozoic and Paleozoic sedimentary rocks to the northwest.

Another interesting alignment produced by this proposed restoration is the coincidence of eclogite and blueschist occurrences (as shown by Dusel-Bacon and others, 2006) near the restored position of the town of Eagle with those across the Tintina fault in the northwestern edge of the orphan Yukon-Tanana block. The restoration then puts these occurrences along the trend with two occurrences to the west near Fairbanks.

Several major Devonian to Mississippian mineral districts fall within the study area (fig. C1; Dusel-Bacon and others, 2006) and their relative locations are affected by the proposed restoration. The Kantishna Hills, Bonnifield, and Delta districts contain syngenetic volcanogenic massive sulfide deposits (see chapters B, E, I, and J in this volume). The proposed restoration brings these districts closer to the Finlayson Lake massive sulfide district in southeastern Yukon (fig. C3). The Teuchet Creek stratiform sedimentary exhalative (SEDEX) mineral district aligns along the geologic trend with the Macmillan Pass SEDEX district after restoration (fig. C3).

To the northwest of *A-A′*, several geologic trends are mapped on opposite sides of the Tintina fault. These include faults, strain zones, and Cretaceous plutonic belts (shown as dashed lines on figs. C1 and C3). The first set of matching features, as mentioned above, is the opposite strands of the Inconnu thrust fault that join up at *A-A′*. Proceeding to the northwest, two plutonic suite boundaries line up on opposite sides of the fault. Farther to the northwest, two strands of the strain zones line up approximately on opposite sides of the restored fault. Continuing northwest, the trends and zones on the Alaskan side appear to be increasingly compressed relative to the trends on the Canadian side. This is presumably the result of overall compression on the Alaskan side approaching the Kaltag fault and possibly of extension on the Canadian side. Up to 250 km of variation in relative offset due to compression and extension is suggested by the differential positions of the trends in the off-shelf sequence on opposite sides of the fault in this zone.

Discussion and Conclusions

The preliminary observations in this short paper are intended to stimulate continued comparative geologic study across the Tintina fault in Alaska and adjacent Canada. Correlations between magnetic anomalies and patterns can provide useful hypotheses about apparent fault slip but do not indicate timing of slip unless the individual anomalies and patterns are interpreted to associate them with geologic features with known ages. The significance of the geophysical alignments needs to be tested through geologic studies.

The most detailed analysis of the Eocene slip history of the Tintina fault to date is by Gabrielse and others (2006). They conclude that geologic evidence supports slip estimates between 400 and 430 km. This amount of slip lines up the Beaver Creek-White Mountains thrust system on the Alaskan side with the Tombstone-Robert Service thrust system on the Canadian side of the Tintina fault. Their conclusions also depend on alignment of the Tombstone and McQuestern plutons across the fault.

The preferred restoration of between 400 and 430 km of fault slip (Gabrielse and others, 2006) results in a 60+ km mismatch of the two crossings of the Inconnu thrust fault from the Alaskan side to the Canadian side of the fault. Gabrielse and others (2006) interpret this as indication of extension on the Canadian side, presumably related to extensive Late Cretaceous magmatism in the region. This extension would have preceded the later Eocene movement of the Tintina fault yet used the trace of the Tintina as a bounding "transform" between zones of differential extension.

An alternate hypothesis to explain the difference in spacing of geologic features across this portion of the fault is that compressional deformation took place on the Alaskan side relative to the Canadian side. The amount of shortening might logically be expected to increase to the northwest toward the bend in the Tintina fault near its intersection with the Kaltag fault. This interpretation seems consistent with the character of magnetic anomalies along this part of the fault, although that conclusion is somewhat subjective.

The apparent slip estimates based on alignment of magnetic anomalies fall far short of published displacement estimates from paleomagnetic studies (for example, 1,900±700 km by Marquis and Globerman, 1988; Johnston and others, 1996; Wynne and others, 1998). I agree with Gabrielse and others (2006) that the burden for resolving this discrepancy appears to fall on the side of the paleomagnetic studies.

In conclusion, comparison matching of magnetic features on both sides of the Tintina fault in east-central Alaska and northwestern Canada indicates a good match of several key anomalies and magnetic patterns if slip of about 490 km is restored on the fault. This hypothetical fault slip restoration makes pre-slip predictions of the relation of geologic elements on opposite sides of the fault. The apparent relative compression of various thrust belts on the Alaskan side relative to the Canadian side may be due to tectonic compression or lateral ramps on the Alaskan side, possibly related to the geometry of the southwest bend of the Tintina fault near its intersection with the Kaltag fault.

Acknowledgments

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References Cited

Beck, M.E., Jr., Burmester, R.F., Engebretson, D.C., and Schoonover, R., 1981, Northward translation of Mesozoic batholiths, western North America; paleomagnetic evidence and tectonic significance: Geofisica Internacional, v. 20, no. 3, p. 143–162.

Blakely, R.J., 1995, Potential theory in gravity and magnetic applications: New York, Cambridge University Press, 441 p.

Dover, J.H., 1994, Geology of part of east-central Alaska, *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska, chapter G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, p. 153–204.

Dusel-Bacon, Cynthia, Hopkins, M.J., Mortensen, J.K., Dashevsky, S.S., Bressler, J.R., and Day, W.C., 2006, Paleozoic tectonic and metallogenic evolution of the pericratonic rocks of east-central Alaska and adjacent Yukon, *in* Colpron, Maurice, and Nelson, J.L., eds., Paleozoic evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera: Geological Association of Canada Special Paper 45, p. 25–74.

Gabrielse, Hubert, 1985, Major dextral transcurrent displacements along the northern Rocky Mountain Trench and related lineaments in north-central British Columbia: Geological Society of America Bulletin, v. 96, no. 1, p. 1–14.

Gabrielse, Hubert, Murphy, D.C., and Mortensen, J.K., 2006, Cretaceous and Cenozoic dextral orogen-parallel displacements, magmatism, and paleogeography, north-central Canadian Cordillera, *in* Haggart, J.W., Enkin, R.J., and Monger, J.W.H., eds., Paleogeography of the North American Cordillera; Evidence for and against large-scale displacements: Geological Association of Canada Special Paper 46, p. 255–276.

International Association of Geomagnetism and Aeronomy, 1992, Analysis of the main field and secular variation "International Geomagnetic Reference Field, 1991 revision": Geophysics, v. 57, no. 7, p. 956–959.

Irving, Edward, Woodsworth, G.J., and Wynne, P.J., 1985, Paleomagnetic evidence for northward motion of the Western Cordillera in latest Cretaceous to early Tertiary times: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 363.

Johnston, S.T., Wynne, P.J., Francis, Don, Hart, C.J.R., Enkin, R.J., and Engebretson, D.C., 1996, Yellowstone in Yukon; The Late Cretaceous Carmacks Group: Geology, v. 24, no. 11, p. 997–1000.

Marquis, Guy, and Globerman, B.R., 1988, Northward motion of the Whitehorse trough; Paleomagnetic evidence from the Upper Cretaceous Carmacks Group: Canadian Journal of Earth Sciences, v. 25, no. 12, p. 2005–2016.

North American Magnetic Anomaly Group, 2002, Digital data grids for the magnetic anomaly map of North America: U.S. Geological Survey Open-File Report 02–414, 1 sheet; scale 1:10,000,000. (Also available online at *http://pubs.usgs.gov/of/2002/ofr-02-414/*.)

Plafker, George, and Berg, H.C., 1994, Overview of the geology and tectonic evolution of Alaska, *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska, chapter G–1 *of* The geology of North America: Boulder, Colo., Geological Society of America, p. 989–1021.

Roddick, J.A., 1967, Tintina Trench: Journal of Geology, v. 75, no. 1, p. 23–32.

Sleep, N.H., and Fujita, Kazuya, 1997, Principles of geophysics: Malden, Mass., Blackwell Science, 586 p.

Umhoefer P.J., Dragovish, Joe, Cary, Jeff, and Engebretson, D.C., 1989, Refinements of the “Baja British Columbia” plate-tectonic model for northward translation along the margin of western North America: Geophysical Monograph, v. 50, p. 101–111.

Wynne, P.J., Enkin, R.J., Baker, Judith, Johnston, S.T., and Hart, C.J.R., 1998, The big flush; Paleomagnetic signature of a 70 Ma regional hydrothermal event in displaced rocks of the northern Canadian Cordillera: Canadian Journal of Earth Sciences, v. 35, no. 6, p. 657–671.