ANNALI DI GEOFISICA, VOL. 42, N. 2, April 1999

Aeromagnetic map compilation: procedures for merging and an example from Washington

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Abstract
Rocks in Antarctica and offshore have widely diverse magnetic properties. Consequently, aeromagnetic data collected there can improve knowledge of the geologic, tectonic and geothermal characteristics of the region. Aeromagnetic data can map concealed structures such as faults, folds and dikes, ascertain basin thickness and locate buried volcanic, as well as some intrusive and metamorphic rocks. Gridded, composite data sets allow a view of continental-scale trends that individual data sets do not provide and link widely-separated areas of outcrop and disparate geologic studies. Individual magnetic surveys must be processed so that they match adjacent surveys prior to merging. A consistent representation of the Earth's magnetic field (International Geomagnetic Reference Field (IGRF)) must be removed from each data set. All data sets need to be analytically continued to the same flight elevation with their datums shifted to match adjacent data. I advocate minimal processing to best represent the individual surveys in the merged compilation. An example of a compilation of aeromagnetic surveys from Washington illustrates the utility of aeromagnetic maps for providing synoptic views of regional tectonic features.

Key words *aeromagnetic data – Antarctica*

1. Procedures for merging magnetic surveys into a digital regional compilation

1) Prepare individual digital data sets by removing diurnal effects and removing and/or correcting bad data. It may be necessary to adjust individual flight lines within a survey area if there were navigation problems, shifts due to improper compensation of the aircraft, or the diurnal was not adequately removed. This is either done by using crossovers at tie-lines to adjust the level or comparing the observed data to a reference surface (like a smoothed version of the original data if tie lines are unavailable). Analog contour maps or profiles must be digitized. There are different philosophies on the appropriate method of digitizing. At the USGS, points are digitized where contours cross flight lines and at inflection points of contours. Others digitize the original contours.

2) Choose a map projection appropriate for the final regional compilation and apply it to all data sets so that anomalies are not distorted. Grid all data sets at the appropriate spacing for the survey specifications (typically .2 to .33 of the original line spacing).

3) Remove the International Geomagnetic Reference Field (IGRF) from the point or gridded data using the same flight altitude as the observed data. The USGS uses the definitive IGRF (DGRF). DGRF model years currently include 1945, 1950, 1960, 1965, 1970, 1975, 1980, 1985, 1990 together with the 1995 revision of the IGRF. Fields in intervening years are

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calculated by linear interpolation of the coefficients from the surrounding models. Fields after 1995 are extrapolated using the IGRF 1995 secular variation coefficients. All surveys should be reduced using the same model. For data corrected with a reference field different from the accepted model, the old reference field should be added and the appropriate DGRF removed. One of the biggest sources of shifts between adjacent surveys is the difference in the reference model removed.

4) Continue all data sets to a selected flight level. Aeromagnetic surveys can be flown two ways: level (constant elevation) or draped (flown a constant clearance above terrain). To prepare these grids for merging, one must mathematically generate the magnetic field as it would be at the selected flight altitude, either level or draped. Some grids need to be continued up or down by a constant amount; other grids will need to be converted from one surface to another (drape-to-level or level-to-drape). The USGS typically continues surveys to an elevation of 300 m above the terrain surface. Regional topographic data are available for much of Antarctica and can be used to create a flight elevation grid. For the Antarctic compilation it might be easiest to pick a clearance above the surface (whether it be rock, ice or water), because of the lack of bedrock elevation and bathymetric data. Upward continuing data sets to the level of the highest survey is not a good option because low-altitude data are degraded. If any of the computer operations involve downward continuation, the data should be filtered during or after continuation. Aliasing may occur during downward continuation a distance greater than one grid interval, resulting in rings of anomalies. Regridding to a coarser grid interval may help, but causes a loss of resolution.

5) Regrid all continued data sets to a consistent grid interval and compatible origin increments. The choice of grid interval will depend on the desired resolution of the final map and capabilities of computer programs to handle large grids.

6) Create a reference grid (optional). It is useful to have a grid to which the individual surveys can be referenced to minimize level shifts between data sets and to have a common magnetic datum. Satellite data, continued to the selected flight elevation, might provide a suitable datum.

7) Determine a constant difference across survey boundaries and add or subtract this datum from one of the grids. In a perfect world, the leveled grids should differ along boundaries by a constant value. This is usually not the case. It is possible to remove surfaces from data sets to force them to match along boundaries but is recommended only if the user understands the source of the surface (rarely the case).

8) Merge grids. Blend adjacent grids by splining along the boundary. Add new grids to each blended grid until the final product is achieved. Where possible, merge the lowest resolution data first so that the highest resolution data is given priority.

9) Make the map of the merged data sets. It may also be useful to merge the original data together with a datum removed and the survey boundaries marked.

2. The utility of a merged compilation for delineating regional tectonic features: an example from Washington State

A merged aeromagnetic map of Washington (Finn and Stanley, 1997; Finn *et al.*, 1996, 1998) was compiled from 40 separate aeromagnetic surveys of varied quality (fig. 1). When merged together on a common observation surface, these separate surveys provide the first relatively high-resolution, synoptic view of anomalies associated with regional tectonic features. The aeromagnetic compilation has been used to delineate crustal blocks, plutons, volcanic rocks and fault and dike trends, as well as to connect tectonic features (Finn and Stanley, 1997). The delineation of faults in Washington is important for unraveling the tectonic history of the region and for assessment of seismic hazards. Some accreted terrane boundaries are also seismically active. Many of these old boundaries have been reactivated repeatedly and present seismic hazards. Linear features observed on the aeromagnetic map that cross-cut anomalies associated with these old boundaries may define a serious seismic hazard (Finn and Stanley, 1997). Dike

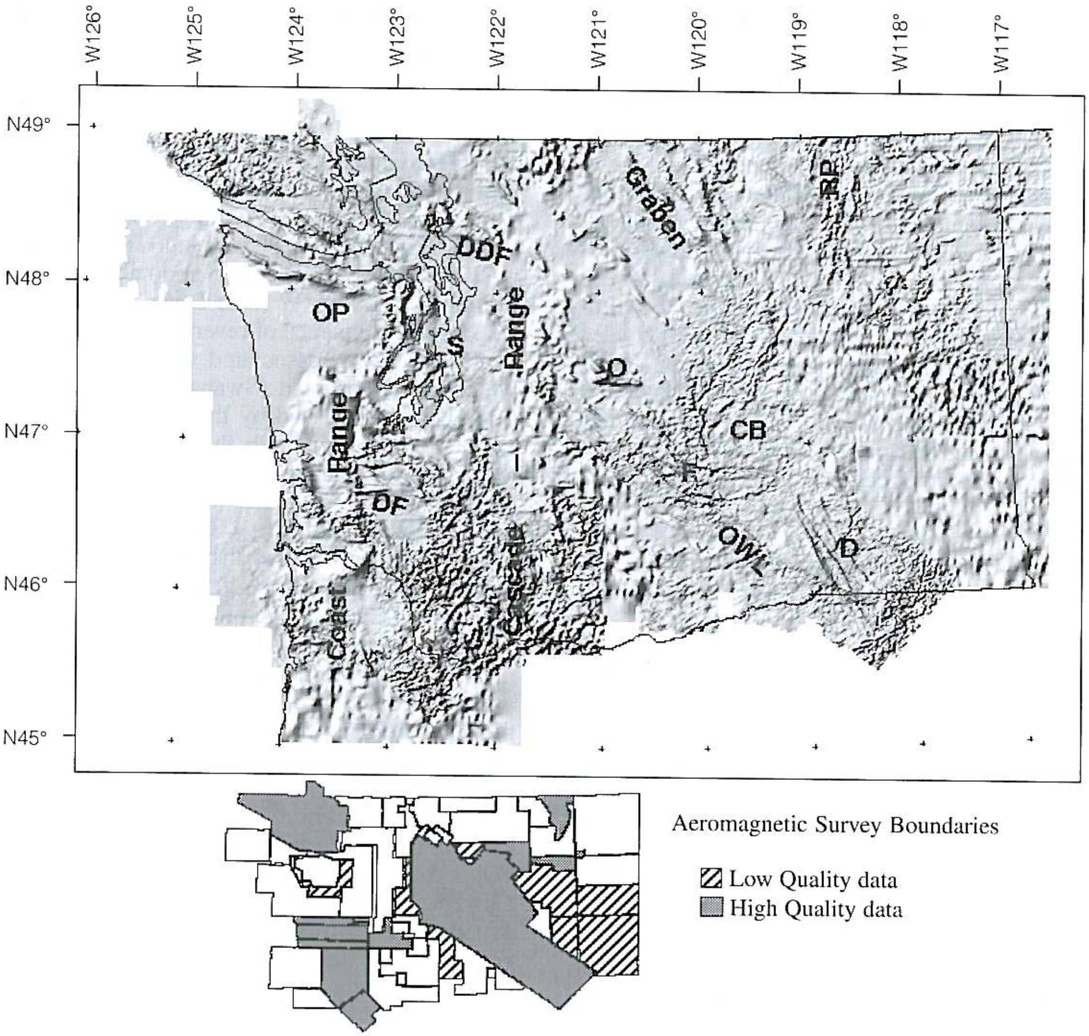

Fig. 1. *Top*: gray-shaded relief map of the merged aeromagnetic data for Washington. Letters refer to anomalies discussed in the text. O = ophiolite; DDF = Darrington-Devil's Mountain Fault; S = Seattle; DF = Doty Fault; I = Intrusions; F = Folds; CB = Columbia Basin; OWL = Olympic-Wallowa Lineament; and D = Dikes. *Bottom*: index map showing flightline spacing of original surveys.

trends can help to unravel the stress-field during their emplacement. In Antarctica, we would expect to see anomalies of regional extent similar to those observed in Washington, probably at a lower resolution due to the greater distance to the source and generally wider line-spacing of the surveys. The following section describes the relation of selected regional aeromagnetic anomalies and tectonic features which extend past the boundaries of individual survey boundaries (Finn and Stanley, 1997). These are examples of the kind of anomalies that might be expected in a compilation of aeromagnetic data from Antarctica.

A shaded-relief version of the aeromagnetic compilation, illuminated from the northwest, (fig. 1) shows positive magnetic anomalies (light grays) produced by normally magnetized rocks and negative anomalies (dark grays) related to rocks less magnetic than adjacent rocks or to reversely magnetized volcanic rocks. Unavoidable problems with the compilation appear as: 1) largely north-south or east-west linear features representing boundaries between surveys of varying resolution, 2) striping in the northeast corner of the map due to problems between flight line levels or navigation problems, and 3) areas of poor data quality (*e.g.*, in the southeast corner of the map). Nevertheless, linear trends and aeromagnetic patterns that outline a variety of geologic provinces can still be distinguished.

2.1. *Relation of aeromagnetic anomalies to regional geologic features*

Basement in the Coast Range of Western Washington consists of Eocene marine basaltic and mafic intrusive rocks formed in a near-margin rift setting that were accreted to the continent in the Eocene (Wells *et al.*, 1984; Babcock *et al.*, 1992). Positive aeromagnetic anomalies in the Coast Range (fig. 1) reflect exposed and buried normally magnetized Eocene basalts (Finn, 1990; Finn and Stanley, 1997). Gravity and magnetic data (Finn *et al.*, 1984; Finn, 1990) indicate that the Coast Range rocks form discrete, commonly fault-bounded blocks. Wells *et al.* (1984) suggested that the mafic blocks are bounded by northwest- and west-striking, thrust faults that formed in response to a north-directed component of oblique subduction. The aeromagnetic data show some of these thrust faults as linear trends. One of these trends is associated with the Doty Fault (DF, fig. 1). The westerly trending Seattle fault (south of S, fig. 1) is visible as a linear sharp gradient truncating a magnetic high on the south.

Magmatic products from the Cascade Range (fig. 1) have intruded and covered the older basement east of the Coast Range since the late Eocene. Positive magnetic anomalies are associated with exposed and inferred buried plutons (I, along 121°30′W north of 47°N, fig. 1) and volcanic rocks (high frequency anomalies south of 47°) in the Cascade Range.

The geology of Southeastern Washington is dominated by the Columbia Basin (CB, fig. 1), which is covered by basalts erupted between 17 and 6 Ma and filled with Tertiary continental sediments (see Reidel *et al.*, 1989). High-resolution aeromagnetic data (Washington Public Power Supply system, proprietary data) show a set of positive and negative linear anomalies with a trend of about N25°W (near D, fig. 1) that correspond to a sequence of reversed and normally magnetized dikes associated with fisures from which basalts erupted (Swanson *et al.*, 1979). The anomalies caused by the dikes in the Columbia Basin align with the north-northwest-trending anomalies at the top of fig. 1, between 120°15′ and 121°W, that are associated with graben-related faulting (*e.g.*, Graben, fig. 1). This alignment suggests that the dikes could have formed along pre-existing faults in the pre-Tertiary basement. An ophiolite, part of the pre-Tertiary basement, produces a large amplitude magnetic high (O, fig. 1), a typical signature.

Subsequent to dike formation, folds and thrusts developed under north-south compression (Reidel *et al.*, 1989). The folds cause a fanning set of curving positive and negative anomalies that trend from N60°W to east-west (near F, fig. 1) (Swanson *et al.*, 1979). The fold belt is cut by the Olympic-Wallowa geomorphic Lineament (OWL) (Raisz, 1945), which is associated with a diffuse zone of anticlines in the central part of the basin. The OWL is similar to other lineaments mapped in the western part of the Basin and Range province to the southeast that have been interpreted as right-lateral megashears that accommodate extension and other North America plate interior effects of oblique subduction between the Pacific and North American plates (Reidel *et al.*, 1989). The aeromagnetic data show that part of the OWL (fig. 1) cuts the dikes in the southeast and transects the central part of the curving set of folds (F, fig. 1). In the aeromagnetic data, the OWL (fig. 1) continues from the Columbia Basin (through the area marked F, fig. 1) until it intersects the eastern end of the Seattle fault (south of S, fig. 1). There is no expression of the OWL in the aeromagnetic data northwest of this intersection.

3. Conclusions

Aeromagnetic data for Washington State provide a complex but coherent image of geologic features that contributes to understanding of the geology and tectonic history. Regional aeromagnetic anomalies reflecting crustal structure and composition can be identified more clearly in the compiled data than in individual surveys. A similar synoptic view of the Antarctic continent may be possible after merging disparate surveys into a single compilation.

Acknowledgements

We thank Bob Kucks and Ron Sweeney for thoughtful comments on the manuscript. This work was funded by National Science Foundation Grant OPP-9319877 and the U.S. Geological Survey Mineral Resource Program.

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