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Aeromagnetic signatures of intrabasinal faults, Albuquerque basin, New Mexico: Implications for layer thickness and magnetization

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Summary

Aeromagnetic profiles over intrabasinal faults reveal a range of signatures, from symmetric curves with one inflection point to asymmetric curves with multiple inflection points. The most common symmetric signature matches the expected response of a layer offset at a fault. The most common asymmetric signature has an apparent low over the fault zone, which can easily mislead interpreters to infer a loss of magnetization at the fault zone. However, geophysical analysis and consideration of geologic and magnetic-property observations imply the curves are produced instead by a thin magnetic layer in the upthrown block offset from a thick magnetic layer in the downthrown block. The thicker, downthrown layer may have resulted from sedimentation related to growth faulting, and perhaps indicates a larger volume of coarse-grained material on the downthrown side of the fault.

All aeromagnetic expressions of intrabasinal faults examined for the Albuquerque basin can be explained by the juxtaposition of lithologic layers having different magnetic properties. Ground measurements of magnetic susceptibility and total-field magnetic data corroborate this finding. In particular, we examined a silica-cemented fault in search of secondary processes that might affect magnetization at the fault zone. However, magnetic variations at this fault relate to the difference in hanging-wall and footwall units rather than to differences in cementation. This result differs from the findings of previous studies of sedimentary basins.

Introduction

High-resolution aeromagnetic data were recently acquired over most of the Albuquerque and southern Española basins in central New Mexico (see URL address http://rmmcweb.cr.usgs.gov/public/mrgb/airborne.html). Nominal line spacings and heights above ground were 100-150 m. The data were acquired to delineate faults that bound different hydrostratigraphic units as part of a multi-disciplinary project to develop an improved hydrologic model of the Albuquerque basin area. The aeromagnetic data show expressions of faults, igneous rocks, Precambrian crystalline rocks, anthropogenic structures, and lithologic variations within the basin sediments (Grauch, 1999). Fault expression is recognized by the consistent correspondence of linear anomalies to surface evidence of faulting. Because the surface evidence is sparse in much of the basin, the aeromagnetic data have become a primary tool for mapping shallowly buried faults and extending mapped faults within the basin.

The linear anomalies associated with intrabasinal faults were examined in detail to determine the common expressions of faulting in the Albuquerque basin and what these expressions imply about fault geometry. In particular, the examination was designed to address whether the anomalies are produced by an offset of magnetic lithologies within the sediments or by secondary geochemical processes that have either destroyed or introduced magnetic minerals along the fault zone. As part of the examination, we inspected the survey data for common anomaly shapes in profile form, developed profile models for data examples that typified these shapes, and constructed idealized forward models for each type of signature.

To further address the question of secondary magnetization, we collected magnetic-susceptibility and total-field magnetic measurements over an exposed fault where secondary fluid flow is evidenced by strong silica cementation of the fault zone. A previous study from northern Alberta (Peirce and others, 1998) had found that anomalies associated with intrasedimentary faults were produced by secondary magnetization of fault planes. This conclusion was based on magnetic modeling, depth analysis, and comparison to seismic-reflection data. Other workers have observed the same phenomenon elsewhere (Pawlowski, 1999). We expected to find evidence of secondary magnetization in the Albuquerque basin as well, but found none.

Types of Aeromagnetic Signatures

The linear anomalies associated with faults can generally be described as fault-offset anomalies; that is, an anomaly due to magnetic layers that are vertically offset. Amplitudes of these anomalies from a merged version of the survey data continued to 100-m height above ground commonly range from 10-15 nT in the northern part of the survey area, from 5-10 nT in central part, and from 10-20 nT in the southern part, with some amplitudes as high as 40 nT near the basin margins.

Typical fault-related anomalies in profile show variations that range from the type of symmetric curve expected over a contact to curves with two asymmetric peaks and two or more inflection points. The range in types of signature is illustrated by their corresponding idealized forward models (fig. 1). One of the less common signatures in the observed data corresponds to the traditional fault-contact curve. This symmetric curve can be modeled by the truncated-layer model (fig. 1a) as a single magnetic layer juxtaposed against nonmagnetic material. In the figure the magnetic material is shown on the downthrown side of the fault with an acute angle describing the top edge of the truncated face. This signature also includes curves over a magnetic layer that is on the upthrown side of the fault, with an obtuse angle describing the top edge. The curves of the horizontal-gradient magnitude (HGM) of the reduced-to-pole (RTP) magnetic data and pseudogravity have large peaks over the single inflection point, as expected (Cordell and Grauch, 1984).

A more common signature is the curve associated with the offset-layer model (fig. 1b), which consists of one magnetic layer that has been displaced along the fault. In the observed data, the curve is usually not as symmetric as depicted in the forward model due to variations in the thickness or magnetization of the basin-fill units. Analogous to the truncated-layer model, the RTP and pseudogravity HGM curves both have one large peak over the main inflection point.

Another common signature in the observed data exhibits asymmetry, with two peaks of different amplitude, an intervening low, and multiple inflection points (fig. 1c). This signature is explained by the thin-thick layers model, which consists of a thin magnetic layer on the upthrown side and a thick magnetic layer on the downthrown side of the fault. The HGM curves for the RTP data show two prominent peaks, each with different bandwidth. A wider bandwidth indicates a deeper source (Roest and Pilkington, 1993). The thick layer on the downthrown block of this model is required (1) to explain the large discrepancy in amplitude between the anomalies associated with the two offset layers, (2) to account for the difference in bandwidth of the RTP HGM curves, and (3) to maintain reasonable values of susceptibility for the basin fill sediments (Hudson and others, 1999). An increase in magnetization along with an increase in thickness is also plausible. In this case, the increase in magnetization may also indicate an increase in grain size because of the positive correlation between magnetization and grain size found in a corehole west of Albuquerque (Hudson and others, 1999). Again, diversity in the shapes of the curves in the observed data arises from variations in the thickness or magnetization of the offset layers. The thin-thick model and its variations can be explained geologically as a consequence of growth faulting.

Another observed, but uncommon, fault signature corresponds to the disparate-layers model (fig. 1d). This model consists of two layers of equal thickness but disparate magnetizations that are offset vertically from each other. This signature appears as a linear magnetic low in map view, and could easily be interpreted as a loss of magnetization at the fault zone. However, the difference in bandwidth between the two prominent peaks in the HGM curves of both pseudogravity and the RTP, which is consistent with analysis of the observed data, indicates two layers at different depths. Moreover, no unusual lack of magnetization at the fault zone is required to explain the signature. The apparent low is produced by interference between the anomalies of the two thin layers comprising the model.

Fault-zone Measurements

To supplement the analysis of the aeromagnetic data, we collected magnetic-susceptibility and total-field magnetic measurements in ground traverses across several exposed faults to test for variations at the fault zones in particular. A loss of magnetization within the fault zone at first seemed plausible because many faults exposed near the margins of the basin are cemented, showing evidence of past fluid flow along the fault (Mozley and Goodwin, 1995). However, in all cases we found that significant variations in magnetic susceptibility are related to differences in material across the fault rather than to the fault zone itself. This observation held even with measurements across an exposed cemented fault-zone, where the magnetization of the cement did not significantly vary from the magnetization of the host material.

Conclusions

All aeromagnetic expressions of intrabasinal faults examined for the Albuquerque basin study can be explained by the juxtaposition of magnetic lithologies. This result contradicts our initial expectation of finding evidence of either enhanced or reduced magnetization along the fault zones, similar to observations of other workers. Although alteration of magnetic properties along some fault zones cannot be ruled out, we found no aeromagnetic expression that requires that explanation. Even an apparent low over the fault zone can be explained by offset magnetic layers.

The common occurrence of the signature associated with the thin-thick layers model implies that the aeromagnetic data can indicate thick concentrations of magnetic material on the downthrown sides of faults. Thus, the thin-thick layers signature has importance for understanding subsurface structural development within the basin. Moreover, if higher magnetization also indicates coarser-grained material, the signature could also predict areas of higher hydraulic permeability next to faults.

The multiple inflection points associated with the thin-thick and disparate-layers models are reflected in multiple peaks of the HGM curves of both RTP and pseudogravity data. As a consquence, the common practice of using HGM maps to locate faults becomes problematic unless these signatures are taken into account.

Aeromagnetic Fault Signatures

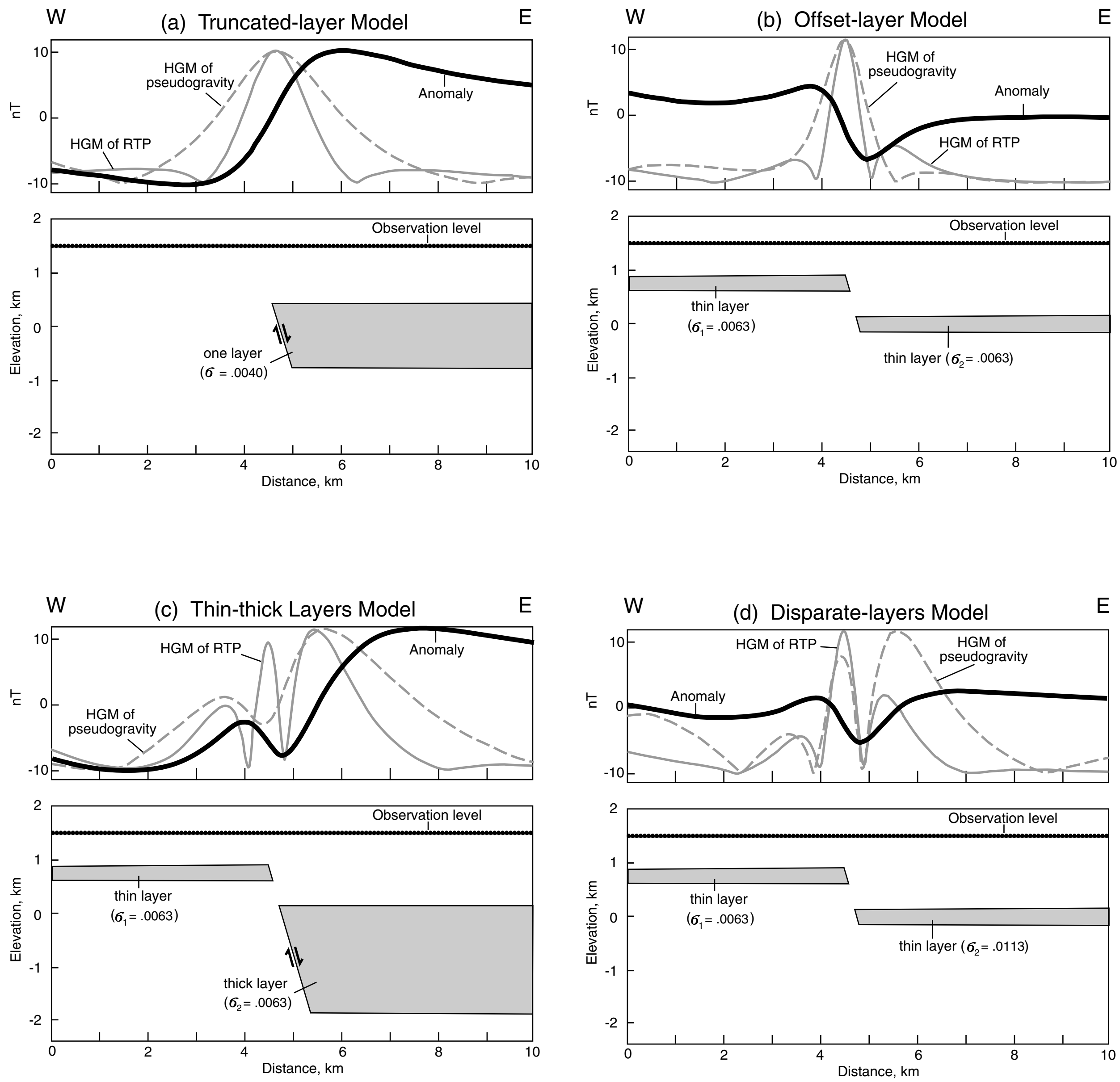

Figure 1. Forward calculations of models illustrating the aeromagnetic signatures of intrabasinal faults typically observed in high-resolution aeromagnetic data from the Albuquerque basin. Curves computed for each model are the magnetic anomaly (bold black line), the horizontal-gradient magnitudes (HGM) of the reduced-to-pole (RTP) magnetic data (solid gray line) and pseudogravity (dashed gray line). (a) The truncated-layer model is similar to a fault-contact model. (b) The offset-layer model has one layer that has been displaced along the fault. (c) The thin-thick layers model has a downthrown layer that is much thicker (or thicker *and* more magnetic) than the upthrown layer, and (d) the disparate-layers model has two offset layers that have equal thickness but differing magnetizations. The signatures for the offset-layer and thin-thick layers models are the most commonly observed. The two-dimensional Talwani models were developed in the program PDEPTH (Phillips, 1997). Magnetic susceptibilities are in SI units. Earth's field, inclination, and declination used in all models were 51715 nT, 63°, and 11°, respectively.

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