# High-resolution aeromagnetic data, a new tool for mapping intrabasinal faults: Example from the Albuquerque basin, New Mexico

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## ABSTRACT

**High-resolution aeromagnetic surveys flown over the Albuquerque basin, New Mexico, demonstrate that aeromagnetic methods can successfully map concealed and poorly exposed faults in sediment-filled basins. This is the first known use of aeromagnetic data as an aid to surficial mapping and hydrogeologic studies in a basin. Aeromagnetic maps show detailed fault patterns within the basin fill that revise the structural view of the basin. Concealed faults are more numerous and more closely spaced than expected. The Hubbell Springs fault is the central splay of three generally north-striking fault splays that can be traced for nearly 50 km. The splays converge on the north and may represent the southern extension of the Tijeras fault, contradicting the proposed southwest extension of the Tijeras fault across the basin. In profile view, the linear aeromagnetic anomalies associated with faults show a variety of signatures. One signature has potential for mapping fault-controlled sedimentation in the subsurface because it identifies increases in magnetic, likely coarse-grained, material in the hanging walls of faults.**


**Keywords:** aeromagnetic survey, faults, basins, mapping, surficial geology, hydrogeology.

## INTRODUCTION

Aeromagnetic methods have traditionally been used to map igneous and metamorphic rocks and related structures due to the generally high magnetizations of these rock types. In contrast, magnetizations of poorly consolidated sediments have been considered too low for most aeromagnetic applications. The results from high-resolution aeromagnetic surveys for the Albuquerque basin (Grauch, 1999) and related studies of the magnetic properties of the basin-fill sediments (Hudson et al., 1999) disprove this traditional view.

The aeromagnetic surveys for the Albuquerque basin were conducted to help understand subsurface hydrogeology. The basin sediments, collectively known as the Santa Fe Group, constitute the aquifer system from which residents of the basin obtain nearly all their water resources. The Santa Fe Group was deposited in the Albuquerque basin during the Tertiary to Quaternary development of the Rio Grande rift (Fig. 1), inset. The strata vary in thickness from 1000 to more than 4000 m and range from mudstone to conglomerate (Kelley, 1977; May and Russell, 1994).

Faults that offset strata of the Santa Fe Group are key to understanding the overall aquifer system and tectonic evolution of the basin. Surface mapping of these faults is typically difficult due to widespread cover and poor consolidation of strata cut by faults. Due to these difficulties, this first known use of high-resolution aeromagnetic data to map faults in basin fill has proved especially useful. In this report I present two example areas to show the association of aeromagnetic anomalies with mapped faults, discuss how the aeromagnetic data revise previous conceptions of fault patterns in these areas, and illustrate some typical signatures in profile form that help characterize the faults in the subsurface.

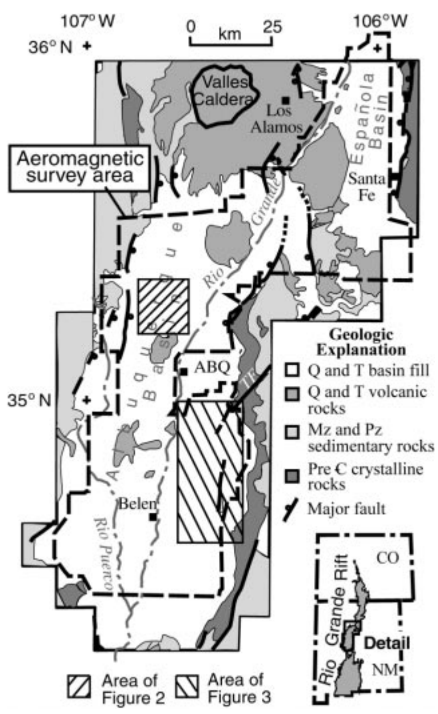


**Figure 1. Regional geology of Albuquerque basin generalized from Kelley (1977), outline of aeromagnetic survey areas, and locations of study areas of Figures 2 and 3. ABQ is Albuquerque, TF is Tijeras fault (just southwest of Albuquerque). Q, T, Mz, Pz, and pre-Є refer to Quaternary, Tertiary, Mesozoic, Paleozoic, and Precambrian, respectively. Inset map shows location of area with respect to Rio Grande rift.**

## AEROMAGNETIC DATA

High-resolution aeromagnetic data were acquired during 1996–1998 over most of the Albuquerque and southern Española basins in central New Mexico (Fig. 1; U.S. Geological Survey and SIAL, Ltd., 1997; U.S. Geological Survey and Sander Geophysics, Ltd., 1998; U.S. Geological Survey et al., 1999). High-resolution aeromagnetic surveys are flown closer to the ground and with narrower line spacing than conventional aeromagnetic surveys, which allows enhanced detection of weakly magnetic sources and better resolution of details in map view. Nominal line spacings and heights above ground were 100–150 m, a narrower line spacing than commonly used in modern hydrocarbon and mineral exploration. For ease of examination, the data from each survey were digitally continued onto a surface 100 m above ground then merged together. The examples shown in Figures 2 and 3 are extracted from this merged data set that has a grid interval of 50 m.

Although intrabasinal faults are the focus of this paper, the data also show expression of basement features, shallowly buried igneous rocks, and many anthropogenic structures (Grauch, 1999). Images of the aeromagnetic data can be accessed at the URL address http://rmmcweb.cr.usgs.gov/public/mrgb/airborne.html.

## FAULT EXPRESSION ON AEROMAGNETIC MAPS

To illustrate typical fault expression in the aeromagnetic data, images for two study areas were extracted from the larger aeromagnetic data set: one in an area northwest of Albuquerque near the town of Rio Rancho (Fig. 2), the other from an area south of Albuquerque, including the major basin-bounding Hubbell Springs fault system (Fig. 3). Semilinear, generally northerly striking features on the images are primarily due to faults that offset strata of the Santa Fe Group. The anomalies commonly range in amplitude from 2 to 50 nT, with typical amplitudes of 10–15 nT. The correspon-

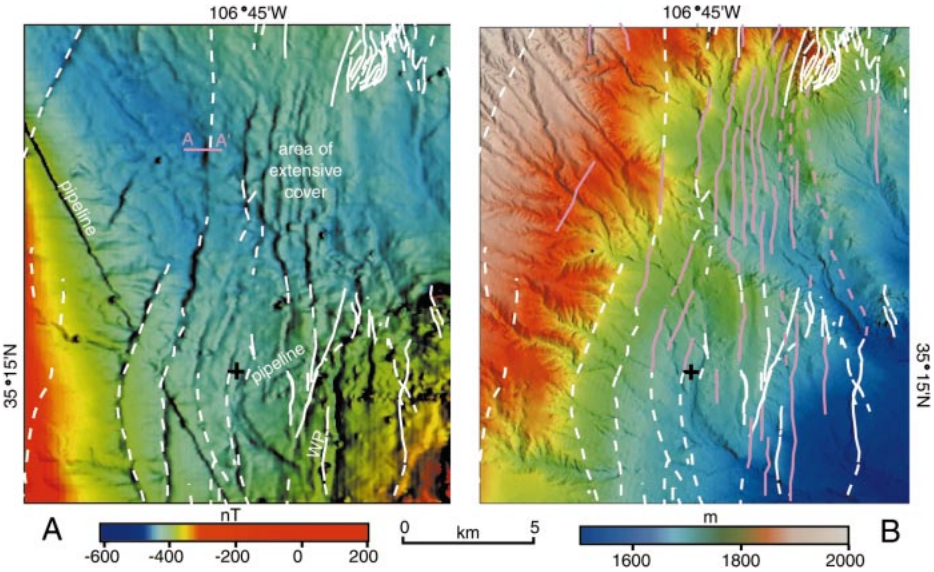


**Figure 2. Aeromagnetic and topographic images from Rio Rancho study area (Fig. 1). Area is mapped as Santa Fe Group and younger surficial deposits (Kelley, 1977). Mapped faults (Cather et al., 1997; Personius et al., 1999, 2000) are shown as solid or dashed white lines where they are mapped or inferred from surface evidence, respectively. WP is West Paradise fault. A: Color shaded-relief aeromagnetic image, illuminated from east. Dimpled anomalies are produced by manmade structures. Profile A-A′ is modeled in Figure 5A. B: Color shaded-relief topographic image from 30 m digital elevation model (U.S. Geological Survey, US GeoData). Pink lines are concealed faults inferred from aeromagnetic data for comparison to topography. Maximum local relief in arroyos is typically 20–40 m.**

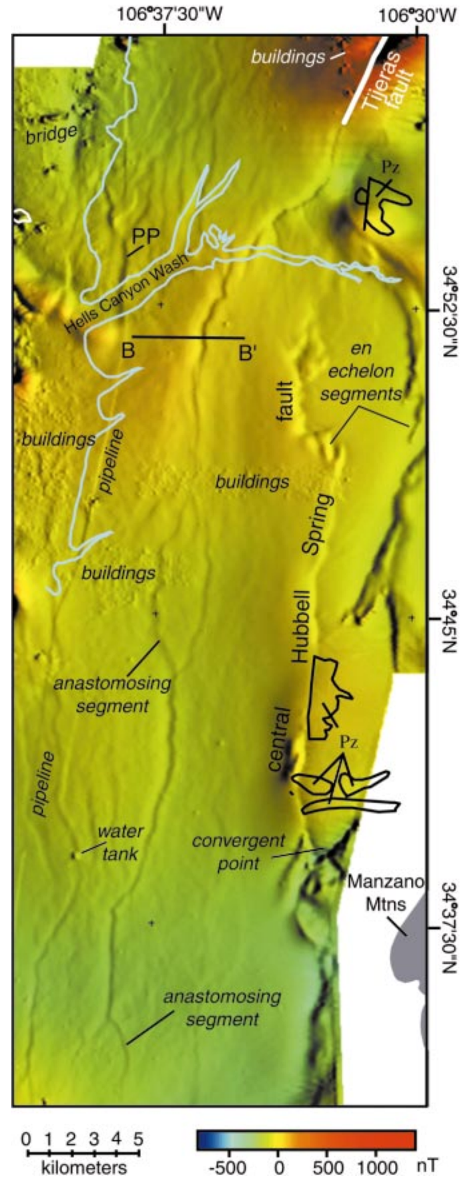


**Figure 3. Color shaded-relief aeromagnetic image of Hubbell Springs fault area, illuminated from east. Area is mapped as Santa Fe Group and younger surficial deposits (Love et al., 1996; Kelley, 1977) except for isolated exposures of Paleozoic sedimentary rocks (Pz; from Green and Jones, 1997). Compare difference in expression of north-striking faults versus Hells Canyon Wash (light blue outline), which has ~15–50 m of relief in this area. Dimpled anomalies are produced by manmade structures. PP is Palace-Pipeline fault. Profile B-B′ is modeled in Figure 5B.**

dence between surface evidence of faulting and aeromagnetic anomalies is illustrated in the Rio Rancho study area (Fig. 2A). The aeromagnetic anomalies serve both to extrapolate and extend the locations of the mapped faults and locate totally concealed faults (pink lines in Fig. 2B). For geologists, the linear anomalies have become important aids for connecting and extending isolated exposures of faults, confirming questionable surface evidence of faults, inferring buried faults, and pinpointing areas to look for fault evidence on the ground (e.g., Cather et al., 1997; Personius et al., 1999). The mapped faults that do not have corresponding linear anomalies juxtapose materials of similar magnetic properties, have too little offset, or both (Grauch, 1999).

In contrast to the expression of faults, aeromagnetic anomalies associated with topographic features unrelated to faults commonly correlate with topography, and are lower in amplitude and more limited in extent. For example, in the Hubbell Springs study area (Fig. 3) the subtle to absent aeromagnetic expression of the 50-m-deep Hells Canyon Wash contrasts with the prominent linear anomalies associated with fault scarps that cross or terminate at the canyon and are only about 5–10 m high (Love et al., 1996). Linear anomalies that correspond to fault-related topographic scarps may be produced in part by the topography and in part by a difference in magnetization across the fault.

In plan view the linear anomalies reveal previously unrecognized faults and fault patterns. Mapped and concealed faults from the Rio Rancho study area (Fig. 2A) are closely spaced and converge to even closer spacing in the northern part of the area. The area of tightest spacing between faults is in the area of extensive cover, which is near the west side of a buried horst (Russell and Snelson, 1994). A prominent linear anomaly is located <500 m east of the well-exposed West Paradise fault (WP, Fig. 2A; Personius et al., 1999), where there is no surface evidence of faulting. The high amplitude and broad character of this anomaly indicate that the concealed fault has significant throw, perhaps even greater than that of the West Paradise fault.

In the Hubbell Springs study area, linear anomalies indicate a laterally extensive, splayed fault system with en echelon and anastomosing fault segments (Fig. 3). The patterns show three splays of the Hubbell Springs fault (Figs. 3 and 4; Maldonado et al., 1999). Originally only the central splay was recognized as the 34-km-long Hubbell Springs fault (Fig. 4A), a major basin-bounding fault on the eastern side of the Albuquerque basin (Kelley, 1982). The splays converge on the north into the Tijeras fault, which is part of a major, long-lived, slip system exposed in the neighboring mountains (Kelley, 1977; Lisenbee et al., 1979). The west splay, which was mapped earlier along the northern 8 km of its extent by Machette (1982), extends a total of 45 km on the aeromagnetic map. The east splay, which is difficult to detect at the surface, apparently converges with the central splay just north of 34°37′30″N (convergent point, Fig. 3). The combined splay continues south (HS, Fig. 4B) and out of the study area another 15 km to the southern edge of aeromagnetic data coverage (U.S. Geological Survey et al., 1999), indicating that this portion of the Hubbell Springs fault has a north-south rather than northeast-southwest orientation, as previously inferred by Kelley (1977; Fig. 4A).

On the basis of seismic and borehole stud-

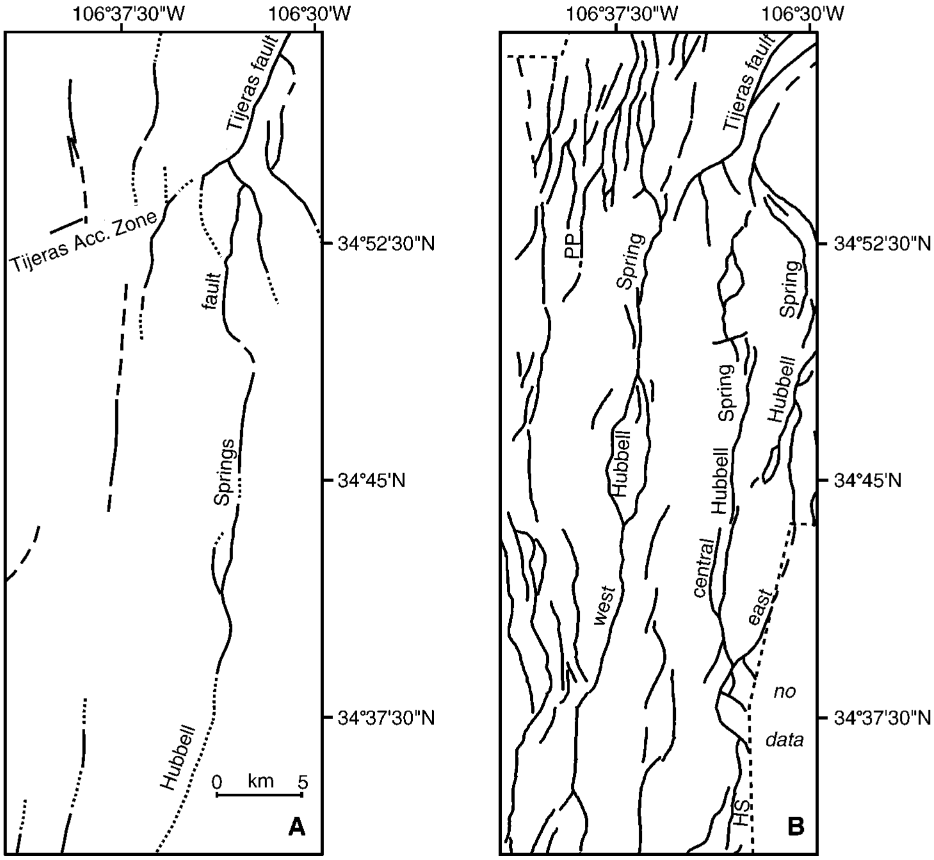


**Figure 4. Mapped versus aeromagnetically inferred fault patterns for area of Figure 3. A: Faults mapped without aid of aeromagnetic data from Machette (1982), with additional faults from Kelley (1977). Tijeras accommodation zone (gray dashed line) is from Russell and Snelson (1994). B: Faults inferred from aeromagnetic data showing division of Hubbell Springs (HS) fault into eastern, central, and western splays. PP is Palace-Pipeline fault.**

ies, Russell and Snelson (1994) proposed a major accommodation zone that extends from the Tijeras fault southwest and west across the entire basin, following Hells Canyon Wash on the west side of the Hubbell Springs study area (Fig. 3; Tijeras accommodation zone, Fig. 4A). From the aeromagnetic map, faults do not appear disrupted near the proposed accommodation zone (Fig. 4), which makes questionable its presence in this area. For example, the Palace-Pipeline fault (PP, Figs. 3 and 4B; Maldonado et al., 1999) can be traced in the aeromagnetic data from north to south across the zone until it cannot be distinguished from the expression of the pipeline. Gravity data suggest instead that a major structural zone trends northwesterly across the basin, north of the area of Figure 3 (Grauch et al., 1999; Maldonado et al., 1999).

## FAULT EXPRESSION IN AEROMAGNETIC PROFILES

Typical signatures of aeromagnetic profiles across individual linear anomalies range from symmetric curves of the type expected over offset layers to curves with two asymmetric peaks and two or more inflection points (Grauch et al., 2000). Profile A-A′ over an inferred fault (Figs. 2 and 5A) demonstrates a symmetric curve that can be modeled as a single magnetic layer juxtaposed against nonmagnetic material. In this case, geologic evidence (Cather et al., 1997) indicates that the magnetic material is on the downthrown side of the fault (Fig. 5A).

Profile B-B′ over the west splay of the Hubbell Springs fault demonstrates another common signature that exhibits asymmetry, with two peaks of different amplitude and an intervening low (Figs. 3 and 5B). This signature is unusual geophysically, because it has an apparent low over the fault zone that can mislead interpreters to attribute properties to the fault zone that are not characteristic of the basin (Grauch et al., 2000). Instead, a better explanation is a model with a general geometry of a thin magnetic layer on the upthrown side and a thick magnetic layer on the downthrown side, called the thin-thick model (Grauch et al., 2000). This profile also suggests that magnetic material thins dramatically away from the fault in both directions.

The magnetic material in the hanging wall, as indicated by the models, may represent strata of generally coarser grain size compared to the footwall. This inference is based on a positive correlation between magnetization and grain size (to coarse sand size) in a magnetic-property study of Santa Fe Group sediments in a core hole west of Albuquerque (Hudson et al., 1999). Thus, the model for profile B-B′ can be interpreted to represent coarse-grained sediment accumulation associated with growth faulting. The accumulation may have resulted from localization of stream and/or alluvial-fan deposits at the fault scarp that increased in lateral extent over time, deposition of these same types of deposits in a subsiding antithetic graben, episodic erosion of the uplifted footwall, or any combination of these processes. In any case, the potential to recognize accumulations of coarse-grained material adjacent to faults in the aeromagnetic

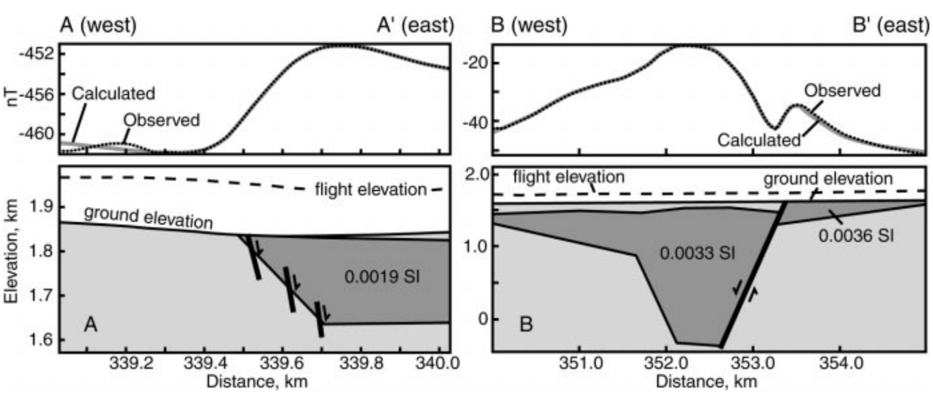


**Figure 5. Models of aeromagnetic profiles across selected faults illustrating two common aeromagnetic signatures. Layers modeled with nonzero magnetization are shown in medium gray along with associated magnetic susceptibilities (volume SI units). Magnetic layers may represent accumulations of medium- to coarse-grained sediments. A: Model of profile A-A′ across inferred fault (Fig. 2A), which shows one magnetic layer in footwall. Model indicates shallow dip to fault that may be more realistically represented by series of step-down faults. B: Model of profile B-B′ across west splay of Hubbell Springs fault (Fig. 3), which shows thin-thick model; i.e., thick magnetic layer in hanging wall compared to footwall. Model also requires that thick layer thins to west, suggesting accumulation of channel or colluvial deposits against fault scarp or antithetic graben structure.**

data is important because (1) the coarse-grained material may provide channels for groundwater flow, and (2) aeromagnetic methods have potential for mapping growth faults across the basin, a capability heretofore unrealized.

## SUMMARY AND CONCLUSIONS

High-resolution aeromagnetic surveys flown in the Albuquerque basin are useful for mapping intrabasinal faults, which are generally poorly exposed. Isolated fault exposures can be connected and traced with confidence using the aeromagnetic map, resulting in a view of fault patterns that show curvilinear patterns, splays, and en echelon and anastomosing segments. These patterns in turn have revised the interpretations of faulting in the basin. Concealed faults are more numerous and more closely spaced than expected. The Hubbell Springs fault appears as the central splay of three generally north-striking fault splays. Some splays can be traced for 50 km and revise the structural view of the southern part of the basin. The convergence of the splays with the Tijeras fault system on the north in the neighboring mountains suggests that the northeast-southwest–striking Tijeras fault likely turns south as it enters the basin to become part of the Hubbell Springs fault system. Thus, the previously proposed south-west-west extension of the Tijeras fault across the basin (Russell and Snelson, 1994) is not evidenced by aeromagnetic expressions of faults that offset basin fill.

In profile view, the linear anomalies associated with faults show a range of typical signatures. The positive correlation of grain size with magnetization (Hudson et al., 1999) suggests that the aeromagnetic signatures can be used to infer relative grain size across faults. An unanticipated, but common, signature is associated with a thin-thick model, characterized by a thin magnetic layer on the upthrown side of the fault and a thick magnetic layer on the downthrown side. In addition, a decrease in thickness of the downthrown layer away from the fault suggests that the signature arises from coarse-grained material that has concentrated at a growth fault. The concentration may represent sedimentation related to growth faulting and/or to erosion of the footwall. This aeromagnetic signature has important implications for recognizing increased hydraulic conductivity on the downthrown side of the fault and shows that aeromagnetic methods have potential for mapping lithologic variations across faults as well as determining their locations.


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