GL00838

INTERPRETATION OF
N.U.R.E. AEROMAGNETIC DATA
DURANGO AND MONTROSE, COLORADO
AMS QUADRANGLES

by

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ILLUSTRATIONS

INTRODUCTION

Geo-Logic, Inc. of St. Helena, California has identified a large area of promising hydrocarbon potential in the Durango-Montrose region of southwestern Colorado, shown in Figure 1. The area is geologically complex due to Tertiary volcanic activity and rifting and as a result is relatively unexplored for deep hydrocarbon potential. Target concepts and an exploration strategy for the area were developed by Geo-Logic and Dr. Roger Kolvoord (DESI) who contacted the Earth Science Laboratory regarding the status of aeromagnetic survey data for this region.

The Earth Science Laboratory, University of Utah Research Institute (ESL/UURI) personnel called attention to aeromagnetic data acquired simultaneously with radiometric data during the National Uranium Resource Evaluation (NURE) program. The NURE aeromagnetic data were available to the public in the form of raw (unedited and non-leveled) data values on digital magnetic tapes. The data could be corrected and compiled into map form by a few geophysical survey contractors at a cost of $3000 to $4000 per AMS quadrangle and a realistic time schedule of 3 or more months. ESL was aware of a Department of Energy (DOE) program which had just begun, to compile the NURE magnetic data for the entire United States. Conversations with Bendix Field Engineering Corporation (Grand Junction Office) indicated that a priority could be established for compilation of the Durango and Montrose 1:250,000 quadrangle data and that the compiled magnetic data could be available to Geo-Logic at a minimal cost.

Geo-Logic, Inc. entered into an agreement with the ESL/UURI dated November 30, 1982 whereby ESL/UURI would interface with Bendix to expedite compilation of the data and would carry out a quantitative geologically

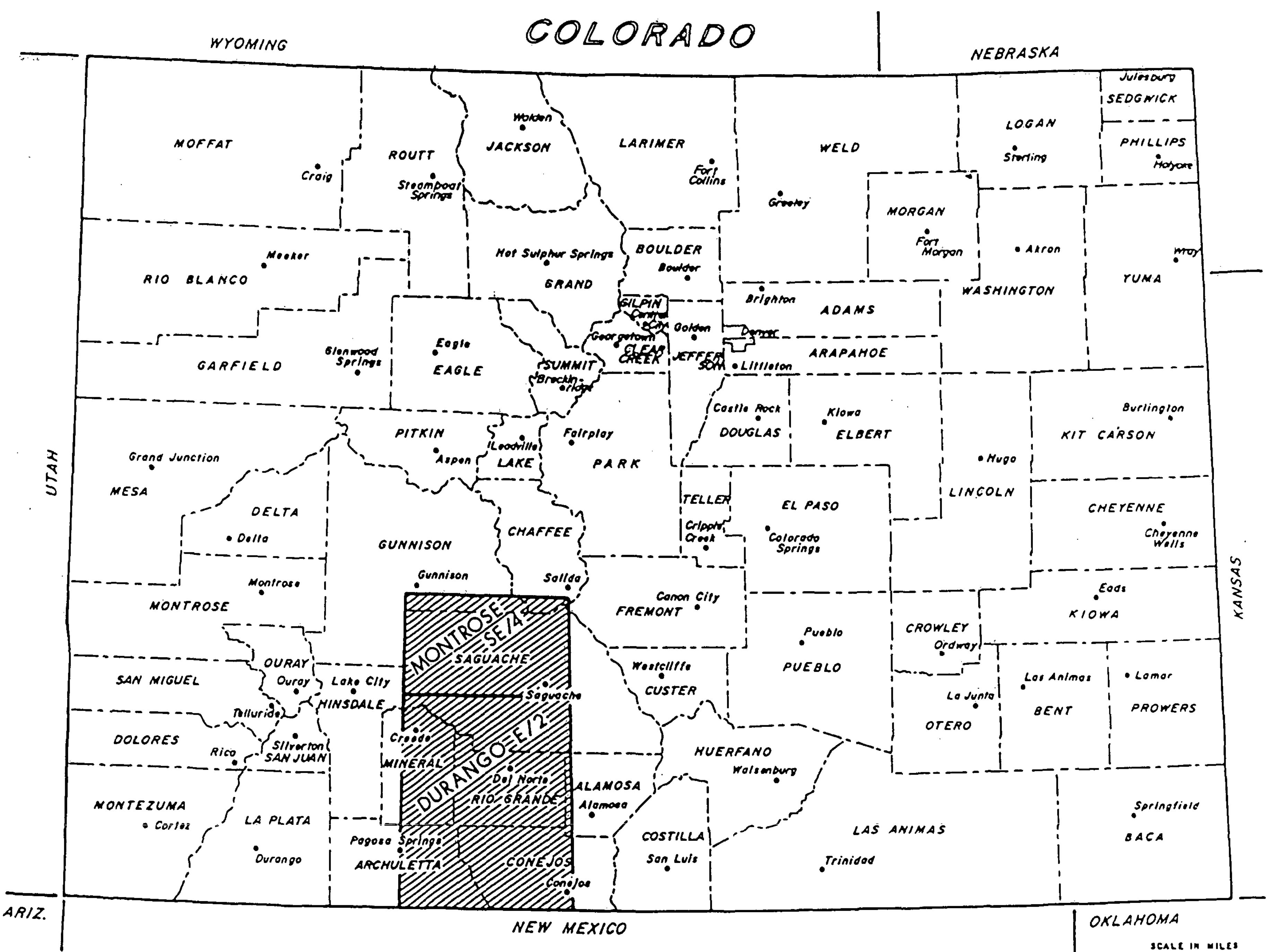

Figure 1. Aeromagnetic Study Area, Montrose and Durango NTMS Quadrangles.

oriented interpretation of the data. Shifting priorities by DOE and compilation difficulties resulted in a substantial delay in acquiring the completed contour maps. This report is submitted as documentation of the evaluation and interpretation of the subject data.

MAGNETIC DATA

Data Characteristics

The accuracy of an aeromagnetic survey and its subsequent interpretation are limited by the data density, accuracy and compilation procedures. The Durango quadrangle was flown with east-west flight lines spaced two miles apart and north south tie lines spaced approximately twelve miles apart. Two areas occur where two adjacent flight lines were not recorded (lines 1100 and 1120, and lines 1380 and 1400) thus leaving two six mile wide gaps for the full length of the quadrangle. In addition several other lines have data gaps of several miles each.

The Montrose quadrangle was flown in a less detailed fashion with east-west flight lines spaced six miles apart in the southwestern quarter of the quadrangle, and three miles apart in the southeastern quarter of the quadrangle, and four miles apart for the northern half of the quadrangle. North-south tie lines were again spaced twelve miles apart.

Both surveys were flown at a mean terrain clearance of approximately 400 feet to meet the requirements of the radiometric survey. The relatively low flight elevation is not appropriate for areas with magnetic rocks at or near the surface. The magnetic anomalies associated with deep magnetic sources such as Precambrian basement are obscured and distorted by high frequency anomalies of these surface magnetic sources. A more reasonable terrain clearance for magnetic surveys of this area would be 750 or 1000 feet. The wide spacing between flight lines generally results in a poor representation of the true magnetic field for both high frequency anomalies and low frequency anomalies arising from larger and deeper sources. This phenomena which results from improper spatial sampling is referred to as 'aliasing' and is present in all degrees in the data for the Montrose and Durango quadrangles.

Data Compilation Procedures

The compilation procedures for the NURE aeromagnetic maps are not straightforward and deserve some discussion so that limitations in the compiled magnetic maps may be properly understood. The following summary results from the detailed report of Tinnel and Hinze (1981) and numerous discussions with Bendix personnel currently engaged in the NURE aeromagnetic data processing.

The Department of Energy (DOE) has recognized that the NURE aeromagnetic data comprise a valuable national resource which should be made available to the public as compiled aeromagnetic contour maps. Data processing procedures had to be simplified and standardized in order to complete the compilation of over 600 NTMS (National Topographic Map Service) 1:250,000 scale quadrangles on a reasonable schedule and within existing budget constraints. Reduction of the total number of data samples in every quadrangle was instrumental to meeting these program goals. The effects of data reduction and data density had to be documented as a series of three maps of profile data which could supplement the contoured magnetic map.

The compilation process may be summarized as a series of basic steps.

1. Conversion of survey contractor digital tapes to a standard format.
2. Data verification tests, error and noise editing procedures, line

leveling, diurnal removal, IGRF removal and base level adjustments.

3. Plot contractor supplied magnetic anomaly profile map.

4. Apply a low pass, moving median filter with window width of 0.6 to 1.0 km to contractor supplied magnetic profiles to eliminate instrumental and cultural noise. Use a more severe, recursive filter to attenuate anomalies due to very short wavelength geologic and topographic effects. This high frequency filter is set at 12 db per octave for specified wavelengths of 1 to 6 km, as seems appropriate.

5. Plot the low-pass (high-cut) filtered profiles on a magnetic anomaly profile map.

6. Complete line leveling, diurnal removal, IGRF removal, and other base level adjustments.

7. Apply a critical point selection (CPS) process to each filtered profile to determine the minimum number of data values needed to represent the filtered observed data within a statistically acceptable limit. This process typically results in the retention of 1,500 to 3,000 samples from filtered data sets containing 40,000 to 75,000 data points (Tinnel and Hinze, 1981).

8. Plot the final CPS profiles on a magnetic anomaly profile map.

9. Select profiles to be eliminated from map compilation procedure, if necessary, to fulfill maximum number of data points criteria for map compilation and contouring.

10. The critical data points selected from CPS profiles are input to a data file which is the data base for the contoured map. Machine contouring is performed by General Purpose Contouring Program, GPCP-II. GPCP-II interpolates a neighborhood of data point values for portions of the map, applies smoothing controls and contours the data. Several variations in cell size and smoothing operators may be tried and the best result selected for the final map.

11. Plot the residual intensity magnetic anomaly contour map.

Evaluation of Profile Plots and Contour Maps

Four data maps were obtained for each of the Montrose and Durango quadrangles:

1. Residual Intensity Magnetic Anomaly Profile Map - Contractor supplied data (CSD); Plates IA, IB, this report.

2. Residual Intensity Magnetic Anomaly Profile Map - Filtered (Blackman 91 point or 51 point window function); Plates IIA, IIB, this report.

3. Residual Intensity Magnetic Anomaly Profile Map - Critical Data Points

(not included in this report).

4. Residual Intensity Magnetic Anomaly Contour Map; Plates IIIA, IIIB, this report.

The profile plots are presented at a horizontal scale of 1:250,000 as is the contour map. The flight path locations are indicated. The magnetic profiles are plotted at a scale of 400 gammas per inch (hence very compressed vertical scale). Final maps are contoured at an interval of 20 gammas.

The contractor supplied (CSD) profiles, Plates IA, IB, are extremely noisy even at the compressed vertical scale. They include many large amplitude spikes, data errors and numerous valid anomaly responses that cut across many adjacent profiles. They are useful only in evaluating the validity of the filtered data, and occasionally, geologic caused anomalies in areas of thick sedimentary rocks (i.e. southwestern Durango quadrangle).

The Blackman filtered data (BFD) profiles, Plates IIA, IIB, are substantially easier to work with since much high frequency noise has been removed. The effect of varying terrain clearance over magnetic surface rocks is substantially reduced. Anomalies with a wavelength of two miles or more are essentially unchanged. Unfortunately very large amplitude noise spikes were not totally removed from the CSD profiles and these occur as numerous, somewhat smoothed, anomalies in the filtered data set. A more careful job of editing out the spikes would have resulted in much improved filtered profiles (BFD) and a better final map. Nonetheless the filtered profiles provide the better data set for correlation with geologic and topographic maps, and for most depth estimates. The Blackman filter has of course smoothed the gradients of anomalies of interest, thus stretching out the steep linear gradients which are the primary indicator of magnetic source position and depth. This is bothersome but of much less concern than the large distance between flight lines.

The Critical Data Point profiles simulate the filtered data profiles with a greatly reduced (i.e. 1:20) number of data samples connected by straight lines. The critical values are generally taken at maxima, minima, inflection points and other statistically selected intervals. These profiles simulate the main anomalies of the filtered data to a remarkable degree, but do loose the details of anomaly gradients necessary for good depth and body position estimates.

The contoured maps, Plates IIIA, IIIB, reflect the problems which result from deleting entire profiles, omitting half the tie lines, letting numerous bad data values slip through the filtering, and the overall data decimation process. The contouring routine gives rise to nicely smoothed contours but includes several totally erroneous anomalies. In areas of smooth magnetic field variations (deep magnetic basement, few volcanic or intrusive rocks) and no data busts, the magnetic contour map gives a good representation of the true magnetic field, and even depth information is reasonably well preserved. In more complex areas typical of our interest, the data must be interpreted with considerable caution.

INTERPRETATION PROCEDURES

Interpretation of most magnetic surveys typically involves a small amount of map compilation verification, then acceptance of the map and its interpretation as supplemented by limited study of the profiles. Numerical models which closely simulate the observed contour map quantify and give confidence in such a typical interpretation.

The nature and compilation procedures of the NURE data reported here have necessitated a greatly modified interpretation procedure which must be explained. It has been necessary to make detailed comparisons between the CSD and the BFD profiles to identify bad data and fictious anomalies and to assess the attenuation of the filter on legitimate anomalies and on terrain clearance effects. The contoured map had to be studied with respect to flight lines actually used in the compilation so the unreliable portions of the map could be identified. It was determined that the combination of limited flight line profiles and the critical data selection process, coupled with the interpolation of the contour program, resulted in contour maps which are unreliable in several parts of the Montrose and Durango quadrangles.

To improve the reliability of the contour map magnetic highs and lows on all filtered flight line profiles were transferred to the contour map. The character of the profiles was studied in detail and used to establish the continuity of anomalies through line-to-line correlation techniques. These high-low anomaly patterns were superimposed on the magnetic contour map and later correlated with known geologic and topographic features. The response of various topographic features was also correlated directly with the filtered flight line profiles.

The limitations of the contour map and filtered profiles make detailed numerical modeling of the magnetic sources inappropriate, since magnetic contour patterns are not reliable to this level. The magnetic source and geologic structure locations were determined through reference to standard models and through correlation with NTMS scale geologic maps, of Steven et al (1974) and Tweto et al (1976).

The depth to the top of magnetic sources is of particular interest to

Geo-Logic. Substantial depths (4000-10000 feet) would suggest a magnetic Precambrian rock and would indicate a better probability of encountering a Paleozoic-Cretaceous sedimentary section beneath Tertiary volcanic cover. Shallow depth estimates may indicate an intrusive or volcanic origin to the magnetic source, or alternatively magnetization changes within a shallow Precambrian bedrock. Neither of these possibilities are favorable to petroleum exploration.

Depth estimates have been made using a qualitative rule-of-thumb technique according to the expression

$$d \simeq K \cdot \Delta S - t.c.$$

where ΔS is the horizontal extent of the steepest linear slope of the magnetic anomaly as determined from the profile plot. K is a constant which can vary from 0.5 to 1.5, and t.c. is the terrain clearance. A value of 1.0 has been assigned to K in this study, based on numerical model results for Precambrian basement type sources at depths of 2,000 - 10,000 feet below the aircraft. The data scale and quality do not justify additional sophistication.

Over 60 depth estimates were made by determining the extent of the steepest linear gradient on the filtered (BFD) profiles, modifying this distance (if required) by comparison with the unfiltered (CSD) profiles, subtracting the mean terrain clearance, and rounding off to the nearest 100 feet. Due to the aerial extent of the magnetic anomalies, the depth estimate is somewhat of a "mean" depth for a 1-2 square mile area along the flight line. The depth estimates are thought to be accurate within ± 20% where the anomalies are not obscured by volcanic and topographic noise, such as the San Luis Valley. In areas of complex volcanic-intrusive geology the accuracy may be more like ± 40%. The great majority of anomalies are too erratic, noisy or complex for quantitative interpretation on the unfiltered (CSD) profiles, and too greatly modified by smoothing on the filtered (BFD) profiles. Magnetic depth estimates are presented on Plate V.

Magnetic susceptibility estimates are often determined in a quantitative magnetic interpretation. An evaluation of magnetic response over outcropping Precambrian rocks indicated a wide range of susceptibility within the Precambrian itself, reducing the potential for identifying Precambrian sources on the basis of susceptibility contrast alone. The wide line spacing prevented accurate delineation of the magnetic source dimensions, and hence the accuracy of the susceptibility estimates. For these reasons susceptibility determinations were discontinued early in the interpretation and are not reported here.

INTERPRETATION

The magnetic interpretation resulting from this study is presented in Plates IV and V. Positive magnetic anomalies (highs) are shown as a distinct border shaded on the positive side. Magnetic lows are indicated by a toothed line. The high-low patterns shown here were determined from a careful study of all filtered profile plots, and the continuity of anomalies determined, where possible, from a line-by-line correlation of anomaly character. This high-low pattern map greatly improves, and often corrects, the total magnetic intensity map compiled by Bendix. These patterns when supplemented by the magnetic contour map, provide the basis for subsequent interpretation.

The positions of specific magnetic sources and probable major structures have been interpreted from the magnetic data and are shown on Plate IV. The accuracy of location and subsequent interpretation is limited by the flight line spacing, typically two miles, and by several major gaps in the data. The dominant north-south fault pattern is fairly well defined by the east-west flight line direction but the north-south extent of magnetic sources and the position of east-west structures are accurately located only on north-south flight lines, typically spaced twelve miles apart. The interpretation of probable faults, intrusives and other magnetic features is greatly aided by correlation between the AMS scale geologic maps and the various magnetic data (detailed profile plots, contour map, and high-low map).

Outcropping Precambrian granite is generally expressed as a magnetic high as noted throughout the Montrose quadrangle (Tweto et al, 1976). The Precambrian basement however is highly varied here, as we have noted elsewhere in the western United States. Correlation of the magnetic and geologic maps indicates metasediments, granites and other units may occur as magnetic lows in contrast to mafic (amphibolite?) units, which are large amplitude highs, and the dominate Precambrian expression as moderate amplitude highs. Thus the interpretation of magnetic highs as shallow Precambrian is subject to some ambiguity and error. Volcanic units and intrusives also are variably expressed in the magnetic data as noted when correlated with the geologic map of Steven et al (1974). The general rule used in this interpretation is that broad coherent magnetic lows occuring over Tertiary volcanics, sediments and alluvium, and not spatially restricted to a single mapped rock type, reflect greater depth to Precambrian basement, either as a result of faulting or basin environment.

The study area is geologically complex. An irregular configuration of sedimentary basins have been titled, uplifted and subjected to erosion.

Tertiary volcanic activity was accompanied by the development of several major calderas, intrusive activity, and followed by graben and horst development along the northern end of the Rio Grande rift. The north-south faulting is well expressed in the magnetic data and dominates the magnetic expression in the eastern third of the prospect area.

It would be desirable to map the sedimentary basins directly from the magnetic data. Several factors complicate this possibility, including: the graben and horst development along the Rio Grande rift; post basin faulting (east-west, northwest and northeast structures); intrusive and volcanic magnetic anomalies; and irregular flight line spacing. Thus a careful integration of geologic information, and some uses of the existing gravity data must supplement the magnetic interpretation advanced in Plate IV.

Plate V presents the depth estimates determined for the deeper magnetic sources within the study area. Each depth estimates is annotated with a best estimate as to the nature of the magnetic discontinuity, such as: within the Tertiary volcanics (Tv); base of the Tv; Tertiary intrusives (Ti); top of Precambrian (p€); and within the p€. These judgments are based on an integrated evaluation of the magnetic data and regional geology and are, of course, subject to some uncertainty. No acceptable depth estimates were obtained for several large areas. This could be due to: 1) the dominance of near surface noise, or 2) the absence of a broad, coherent anomaly arising from a source at depth. The latter situation may indicate thick basin fill (both volcanic and sedimentary), uniformly or weakly magnetized Precambrian basement, or both.

The major structural trends relating to Precambrian highs and sedimentary or volcanic basins, as interpreted from the magnetic and geologic data, are also indicated on Plate V. The location of outcropping Precambrian rocks is taken from Tweto et al. (1976), and Steven et al. (1974). Plate V summarizes the major results of this study.

Gravity Data

A regional Bouguer gravity map of the prospect area was made available by Dr. Roger Kolvoord. The map scale is 1:250,000 and the contour interval is 5 milligals. These data provide a useful comparison with the magnetic data and show several regional gravity highs which are reasonably interpreted as Precambrian basement highs. Major gravity lows reflect greater thicknesses of low density Tertiary volcanics and Quaternary and Tertiary sediments and valley fill. These features may include the Platoro Cauldera, the postulated Mt. Hope Cauldera, and a graben which trends north-south, west of Antonio.

A detailed comparison of gravity and magnetic responses is sometimes confusing. The station density and locations are not indicated for the gravity data, and little is known about the accuracy of elevation control, gravity readings and reduction, and topographic corrections. The complex graben-horst distribution indicated by the aeromagnetic data is not well expressed in the gravity data, probably due to limited number of gravity stations. Until the details of the gravity data are better known, only gravity features of approximately a township size or larger should be accepted as fact.

Geologic Integration

The magnetic interpretation map presents the distribution of major magnetic sources and provides many depths to these sources. The detailed geologic interpretation of these sources will be limited by some ambiguity and uncertainty, and is best addressed by those more familiar with the geology of the area. We understand that Diversified Exploration Services Inc. is responsible for integrating other data sets with these results on behalf of Geo-Logic.

SUMMARY AND RECOMMENDATIONS

This magnetic interpretation has identified a complex north-south fault grain beneath Tertiary volcanic cover in the eastern portion of the Durango NTMS quadrangle. These structures seem to indicate a graben-horst development related to the Rio Grande rift. These structures cut across Cretaceous sedimentary basins but appear to be older than the younger volcanic units. Numerous intrusives cut the sedimentary and volcanic rocks, and these reduce the petroleum exploration potential of several local areas. Several areas are identified where sedimentary rocks may be present in grabens or intact portions of the Cretaceous sedimentary basin. Numerous depth estimates indicate Precambrian basement highs at depths of 2000 to 4000 feet throughout the survey area. Unfortunately most depth estimates are subject to considerable error and by some uncertainty as to the origin of the magnetization contrast, i.e. changes deep within the Tertiary volcanics, or changes in the Precambrian basement.

The indicated geologic complexity dictates that future petroleum exploration, especially drill siting, be addressed on a very site specific basis. Additional geophysical exploration would certainly be cost effective before drilling. Discussions with Dr. Roger Kolvoord, DESI, have attempted to evaluate the more appropriate techniques for this environment.

The present gravity data base is limited by irregular station distribution and an average station density of 1-2 points per township. New data acquisition may require helicopter support, detailed elevation control, and accurate topographic corrections, probably resulting in an average cost of $50-$80 per station. A density of one station per section would be desirable in areas of high interest defined by lease position and favorable geologic-magnetic interpretation. Thus the cost is fairly large but good gravity coverage would reduce much of the ambiguity in the magnetic interpretation.

Electrical prospecting methods sometimes appropriate on a regional scale may not be appropriate here due to the complex three-dimensional geometries indicated by geology and magnetics. Magnetotellurics would be quite costly and limited in lateral and depth resolution. Schlumberger electrical resistivity soundings would suffer greatly from lateral effects and dipole-dipole resistivity would be limited to depths of about 4000 feet, and complicated by the rough topography. Some higher frequency (0.5 - 2000 Hz) controlled source audiomagnetotelluric (CSAMT) surveys may offer the best option for electrical soundings and profiling.

In view of the large information content of the aeromagnetic data reviewed in this study, a more detailed aeromagnetic survey may be the most cost-effective means to proceed with drill siting. Such a survey could offer many improvements over the present data by using a reduced flight line spacing (one or one-half mile), with no major data gaps. The survey should be flown north-south at a mean terrain clearance of approximately 1000 feet to provide more attenuation of the volcanic "noise". Depth and susceptibility determinations could be greatly improved over the present interpretation effort. The approximate cost for a survey of six hundred (600) square miles flown at a one mile interval is estimated at $11,000 with an additional cost of approximately $5000 for a detailed interpretation. A survey such as this would substantially refine the areas favorable for hydrocarbon exploration.

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