AEROMAGNETIC DEMONSTRATION SURVEY WITH BASEMENT INTERPRETATION AND DEEP STRUCTURE MAPPING

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FINAL REPORT

Prepared for

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by

David L. Copley
and
Oliver N. Mohar

Ardent Resources, Inc.
Sheridan Meadows Corporate Park
6245 Sheridan Drive, Suite 212
Williamsville, New York 14221

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NOTICE

ABSTRACT

An aeromagnetic survey was flown over a five-county area in Western New York state. The study, conducted by Ardent Resources, Inc. with assistance from NYSERDA had a multi-fold purpose. The primary objective was as an adjunct to an earlier 3D seismic demonstration project. That project sought to utilize 3D seismic to image near-basement anomalies for hydrocarbon potential. This complementary study was devised as a test of airborne magnetics to correctly identify known basement anomalies, and as an inexpensive reconnaissance technique to be used prior to running 2D or 3D seismic. Results obtained from the aeromagnetic survey generally correlated well with geologic mapping and/or known deep seated seismic anomalies. The conclusion is that aeromagnetics can be used as a reliable and cost effective deep exploration reconnaissance tool in western New York. With additional drilling experience aeromagnetics may ultimately become a primary exploration tool for deep hydrocarbons in New York State.

Table of Contents

Figures

Introduction

Exploration efforts in the Cambro-Ordovician section in the Appalachian basin are not a new occurrence. Over 8 trillion cubic feet (Tcf) of gas and 0.7 billion barrels of oil (BBO) have been produced from rocks of this age, particularly at the periphery of the basin where drilling depths are relatively shallow. Most of the drilling activity (and most of the production) occurred earlier this century but, within the past decade drilling for Cambro-Ordovician hydrocarbons has increased dramatically. Ohio has seen increases both in the numbers of wells drilled and overall hydrocarbon production, as has Ontario, Canada (although some of the increases here are associated with the adjacent Michigan Basin). To a lesser extent, Kentucky and Pennsylvania have also experienced increased drilling activity with some success, while New York state has only recently shown a modest increase in drilling activity with only limited success.

The targets range from the Rose Run Sandstone and Trempealeau limestone in Ohio, to the Trenton limestone and Mt. Simon sandstone in Ontario, the Beekmantown limestones in Pennsylvania, to the Theresa Sandstone and Trenton Limestone in New York. Even the Rome Trough sandstones in Kentucky have shown renewed interest. The trapping mechanisms are equally diverse and include pinchouts across a subcrop fairway, erosional remnants on an unconformity, secondary dolomitization of limestones, and faulting. The diversity of target and trap is quite apparent but, less diverse are the techniques that tie these drilling objectives together.

2D seismic is still the principal geophysical tool for hydrocarbon exploration in the Appalachian basin, used alone or in concert with subsurface well control. Other techniques, such as 3D seismic, geochemistry and a host of remote sensing techniques (satellite and radar imagery, gravimetrics, and airborne magnetics, etc.) which are routinely and successfully used in other basins have only rarely been used here. There are a number of reasons for this, the most prevalent is the overall perception of marginal hydrocarbon economics in the Appalachian basin. The fact that the basin has produced enormous amounts of oil and gas in the past is not a compelling argument for sustained exploration efforts and future production trends. Current production statistics seem to bear this out, because most hydrocarbon producing states in the basin show an overall decline in hydrocarbon production over time.

The key to exploration success in this basin, however, is not to attempt to reverse the trend but to become increasingly more efficient and effective in finding the reserves that remain. To do this, the most cost effective exploration tools available must be used-but which tools to use and in what measure? 2D seismic has been a mainstay in this basin for more than 30 years, and with advances in acquisition and processing, it continues to be our most powerful (i.e. successful) exploration method. Its cost effectiveness however is still debated.

Current Exploration Tools in the Appalachian Basin

Most exploration drilling in this basin is driven by 2D seismic, and that implies that sufficient reserves are being found to offset the exploratory expense and to sustain the specific exploration effort. The outcome of any exploration effort, however, usually occurs after the fact (after the major dollars have been expended), and only then do we gain a perspective on total expenditures versus net hydrocarbon revenue. Exploration for hydrocarbons is part science and part "leap of faith", and many exploration efforts do not ultimately find enough hydrocarbons to warrant the expenditures in the first instance. If too many seismic lines are run for the number of drillable anomalies found, or not enough hydrocarbons are generated from those anomalies, then the exploration effort is deemed a failure. In the Rose Run play in Ohio, it is common practice to lease as much acreage as possible in the "fairway" and then run seismic lines across the entire leasehold position in the hope that drillable prospects will be found, and that the successful wells will pay for the dry holes and exploration costs while still generating a profit. At times this approach works, but more often, particularly were fewer anomalies are identified per line mile of seismic run, it is ultimately not cost effective and fails on merit. What is necessary is an inexpensive reconnaissance tool able to identify prospective areas on a regional basis as a precursor to the application of 2D or 3D seismic.

The New York State Energy Research and Development Authority (NYSERDA), in conjunction with industry participants, undertook the first 3D seismic survey in New York State (project 4207-ERTER-ER-96). That project used existing 2D seismic data to identify a deep seated Cambro-Ordovician anomaly, which was then imaged with 3D technology. The results of that study are the subject of a separate report. However, it was clear from that study that for 3D seismic (and 2D as well) to be an effective deep exploration tool in New York, an inexpensive reconnaissance technique is necessary, ahead of running seismic, to give a regional picture of, and priority to, the most prospective areas. Airborne magnetics was viewed as a likely candidate for this reconnaissance because:

- Large areas can be covered at low cost, and
- Magnetic anomalies are generally associated with basement lithology, and the Cambro-Ordovician anomalies seen on seismic lines in western New York are all basement involved structural events.

Accordingly, a proposal was made to NYSERDA and industry participants to run a tight grid aeromagnetic survey over eastern Erie and western Wyoming counties in New York. The survey was to be centered on the 3D seismic study area and adjacent areas (where regional subsurface geology had already been done) to determine the applicability and cost effectiveness of this technique as an exploration tool for identifying Cambro-Ordovician anomalies.

Acquisition of Aeromagnetic Data

Pearson, deRidder and Johnson, Inc. (PRJ) of Lakewood Colorado was contracted on January 09, 1996 to conduct an aeromagnetic survey over an area which incorporated not only the 3D seismic survey area but a much larger contiguous area covering the towns of Concord and Sardinia in Erie County, and Arcade, Java and Wethersfield in Wyoming County.

To obtain high resolution aeromagnetic data, a tight grid array of flight lines was laid out on 1/4 mile east/west spacing and 1/2 mile north/south spacing. A total of 1552 line miles of data were run covering an area of over 170,000 acres. Figure 1 (see appendix for figures) shows a regional view of western New York and the location of the aeromagnetic survey, and figure 2 shows a localized view of the location of the survey area, its relation to the prior 3D seismic survey, and the flight lines (as run). Keystone Aerial Surveys, Inc./Airmag Surveys, Inc. from Philadelphia Pennsylvania was sub-contracted to fly the survey and acquire the raw data. Acquisition began on February 16, 1996 and was completed in 23 days.

Total cost for acquisition and subsequent processing of the magnetic data was $37,000.00.

Processing the Aeromagnetic Data

PRJ was responsible for processing of the raw magnetic data which involved the utilization of a proprietary analysis software package, Starmag™.

The Starmag™ analyst inputs predefined models of the predicted magnetic signature of deep seated anomalies, and Starmag™ employs algorithms based on a neural network design to analyze the data. Through an iterative process, Starmag™ searches for subtle aeromagnetic features similar in character to the predefined models, and displays these as a spatial interpretation of basement structure. By supposition, the largest localized basement structural anomalies have the greatest likelihood of affecting the overlying sedimentary cover, particularly in the deeper Cambro-Ordovician section.

Analysis of the Aeromagnetic Data

Preliminary Data Interpretations

PRJ submitted a series of interpretative maps to highlight the progression of processing steps required to derive the final basement structure map, which was of primary interest in this study. These maps are briefly discussed below.

- Total Magnetic Intensity (TMI): This map shows the general magnetic susceptibility of basement rocks and the inherent variation. Areas of strong positive anomalies likely indicate a higher concentration of magnetically susceptible minerals (principally magnetite). Similarly, areas with broad magnetic lows are likely areas of low magnetic concentration, and therefore lower susceptibility. The whole principle of airborne magnetics works because basement rocks generally have a quantifiable magnetic response, whereas the overlying stratigraphic section is mostly non-magnetic, and their overall contribution to the TMI is therefore minimal. An aeromagnetic survey measures *variations in basement susceptibility*. Interpretation is how the variations in this susceptibility affect the overlying sedimentary section.

- Reduction to Pole (RTP): The RTP filtering process removes the effect of the earths magnetic field by way of a gross shift of the observed magnetic readings. The procedure is nothing more than a correction factor applied across the study area to remove the non-vertical magnetic component (the earths magnetic field) and leave only the vertical component (causative body) in its correct spatial position. Additionally, this process helps better define boundaries between different basement lithologies with different magnetic susceptibilities. Figure 3 shows total magnetic intensity reduced to pole across the study area. Magnetic response is measured in gammas, and the contour interval is 20 gammas. The range of values is from a low of -550 gammas to a high of 400 gammas.

- Horizontal Gradient (HG): With an RTP correction, a magnetic body is spatially associated with its attendant magnetic response. As the magnetic response across this body changes, the maximum change or gradient of the magnetic slope occurs at or near the body edge. The horizontal gradient map depicts these changes in slope, and in presentation, the net result is that horizontal gradient maxima and minima appear as ridges and valleys, respectively. Therefore, a horizontal gradient map is useful in defining contacts between basement lithologies, and these contacts may represent individual basement blocks, faults or fault boundaries, and other linear features.

- Vertical Gradient/Vertical Derivative (VG): The VG aids in defining the edges of shallower magnetic bodies. The vertical derivative gives a measure of the difference of magnetic values at different elevations. Since source bodies of limited depth possess a higher rate of vertical change of their magnetic field than deep crustal sources, the vertical derivative will be greater over the localized feature than over the deeper crustal features. The VG emphasizes the higher frequency components and makes residual anomalies stand out against the background field.

- Second Vertical Derivative (SVD): A SVD of the RTP/TMI was done to enhance anomalies of possible structural origin. Since high amplitude anomalies are associated with shallower sourced bodies, structural detail is more sharply focused, and magnetic lineament directions are better delineated. The second vertical derivative map is one of the more important and useful maps in aeromagnetic interpretation because of its ability to show shallower structural anomalies. Figure 4 is a second vertical derivative map of the study area. Units are gammas and the contour interval is 0.5 gammas.

Starmag™ Basement Interpretation

The primary goal of the aeromagnetic survey was to image structural complications in the basement with the assumption that the largest localized structural features may have affected the overlying sedimentary column. This relationship, in turn, would have implications for the trapping of hydrocarbons. The Starmag™ program attempts to do this by searching the data for a predefined magnetic anomaly or a range of anomalies. Obviously this pre-definition should have a real world counterpart, preferably complete with demonstrated hydrocarbon production. In the study area, a 3D seismic survey was used to image the deep anomalies on which the Matusik No.1 and Stahl No.1 were drilled (API # 31-121-22520 and 31-121-22655, respectively). Additional 2D seismic data were incorporated both within the 3D survey area and adjacent to it. The net result was a template for the morphology (size and shape) of a deep seated feature but had no indication as to its lithology and magnetic signature because basement rocks had not been penetrated in the area. Assumptions had to be made for the magnetic signature of this otherwise known feature, and it was these assumptions which were utilized by Starmag™ in its search for similar anomalies. Figure 5 is the Starmag™ interpretation of the study area. Contour units are in feet and the contour interval is 20 feet, although units for this type of interpretation are actually dimensionless.. The presentation implies that residual basement features found by Starmag™ can be quite high, but in fact, because no basement lithologies are known, the size of these basement features is only in a relative sense (anomaly A is higher than anomaly B, etc.).

Unified Interpretation

In the previous 3D seismic demonstration study, nearly 500 well logs (primarily shallow Medina penetrations) were used to prepare a regional interpretation of subsurface geology in an area covering southeastern Erie and southwestern Wyoming Counties. The 3D study are was roughly centered within this larger area. The geological interpretation could not directly focus on the deeper Cambro-Ordovician section because only 22 of the 500 study wells penetrated the Ordovician Trenton or deeper horizons. The emphasis was rather on what the data from the shallow section could indirectly tell us about possible structural complication at depth. To this end, structure contour maps at the top of the Devonian Onondaga limestone, contour interval 20 feet (Figure 6) and the Silurian "Packer Shell" (Irondequoit-Reynales limestone), contour interval 20 feet (Figure 7) were prepared, as was an isopach of the interval between the Onondaga and Packer Shell, contour interval 5 feet (Figure 8). Finally, a structure map on the top of the Trenton limestone was done, contour interval 20 feet (Figure 9), but could only be used for regional strike and dip because of the limited number of Trenton penetrations.

In the area of the 3D survey, the aeromagnetic data clearly shows a magnetic high both on the total magnetic intensity map and the subsequent interpretations, most notably in the Starmag™ interpretation. Moreover, the residual feature predicted by Starmag™ is consistent with the general strike as determined from 2D seismic and subsurface well control. The subsurface well control also shows both a nosing on the Packer Shell and thinning of ispoach between the Onondaga and Packer Shell, both very consistent with the aeromagnetic interpretation.

In other areas, where subsurface well control indicates possible structural anomalies, the aeromagnetic interpretation shows a parallel anomaly. So invariable is this apparent correlation between the aeromagnetic interpretation, seismic control, and subsurface mapping, that about the only features not definitively recognized in comparative evaluation are predicted magnetic anomalies for which there is no corresponding local subsurface control or seismic data. This correlation implies that aeromagnetics may have identified heretofore unknown deep anomalies.

Given the close correlation between the different data sets, the question becomes not: Can deep anomalies be recognized using airborne magnetics? but rather, Which of the magnetic anomalies are the most prospective? As previously mentioned, only a handful of deep well tests have been drilled in the study area, and these penetrations, more often than not, correspond with aeromagnetic anomalies. This correspondence in itself shows a consistency, since most of these deep tests were based on anomalies interpreted from 2D seismic, and a correlation might be expected. The problem is that many of these wells were not economically successful, and that clearly means that deep seated structural complications (as indicated by aeromagnetics and/or seismic and subsurface well control) do not necessarily translate into economically viable prospects.

Moving forward, the key to success may be to differentiate the *types* of prospects, and prioritize those most likely to contain economic volumes of hydrocarbons. It may even be possible to someday use aeromagnetics as a site-specific exploration tool rather than as a reconnaissance tool as it was used in this study. For that to happen however, considerably more knowledge about our Cambro-Ordovician targets will be required.

Conclusions

The aeromagnetic study supported conclusions arrived at from the previous 3D seismic project in that basement complications may have a structural and/or stratigraphic effect on the overlying sedimentary section. More importantly, the aeromagnetic interpretation of residual basement features exhibits a strong correlation with sub-surface geological mapping (both structure and isopach mapping) and previously defined deep seismic features.

Based on these encouraging results, aeromagnetics appear to be a viable and cost effective exploration method with direct application to Cambro-Ordovician targets in western New York, especially when used in conjunction with subsurface well control and 2D and/or 3D seismic.

One aspect of aeromagnetic interpretation still to be addressed is the differentiation and prioritization of magnetic anomalies. While many aeromagnetic anomalies appear to be real, not all are prospective. The necessary factor is a consistently recognizable aeromagnetic signature that coincides with a prospective and economically proven Cambro-Ordovician anomaly. To achieve this, more work is necessary both in interpretation and in the drilling of anomalies.

Summary

Aeromagnetics appears to be an inexpensive, yet reliable technique for deep hydrocarbon exploration in western New York on a regional basis. The $37,000 price tag for flying the aeromagnetic survey and processing the data equates to a cost of approximately $0.22/acre to cover the entire 170,000 acre study area. The results give a geologically reasonable, regional view of basement geology, which in turn may narrow the search for potential deep prospects. Even if more expensive techniques, such as 2D and/or 3D seismic are necessary as confirmation tools, the potential savings in the reduction of the number of seismic lines necessary to define a drillable prospect are significant.

The work done also strengthens the conclusion that basement structures have an effect on the overlying sedimentary section, as is implied from subsurface mapping of shallower horizons, and the close correlation with the aeromagnetic interpretations.

Appendix

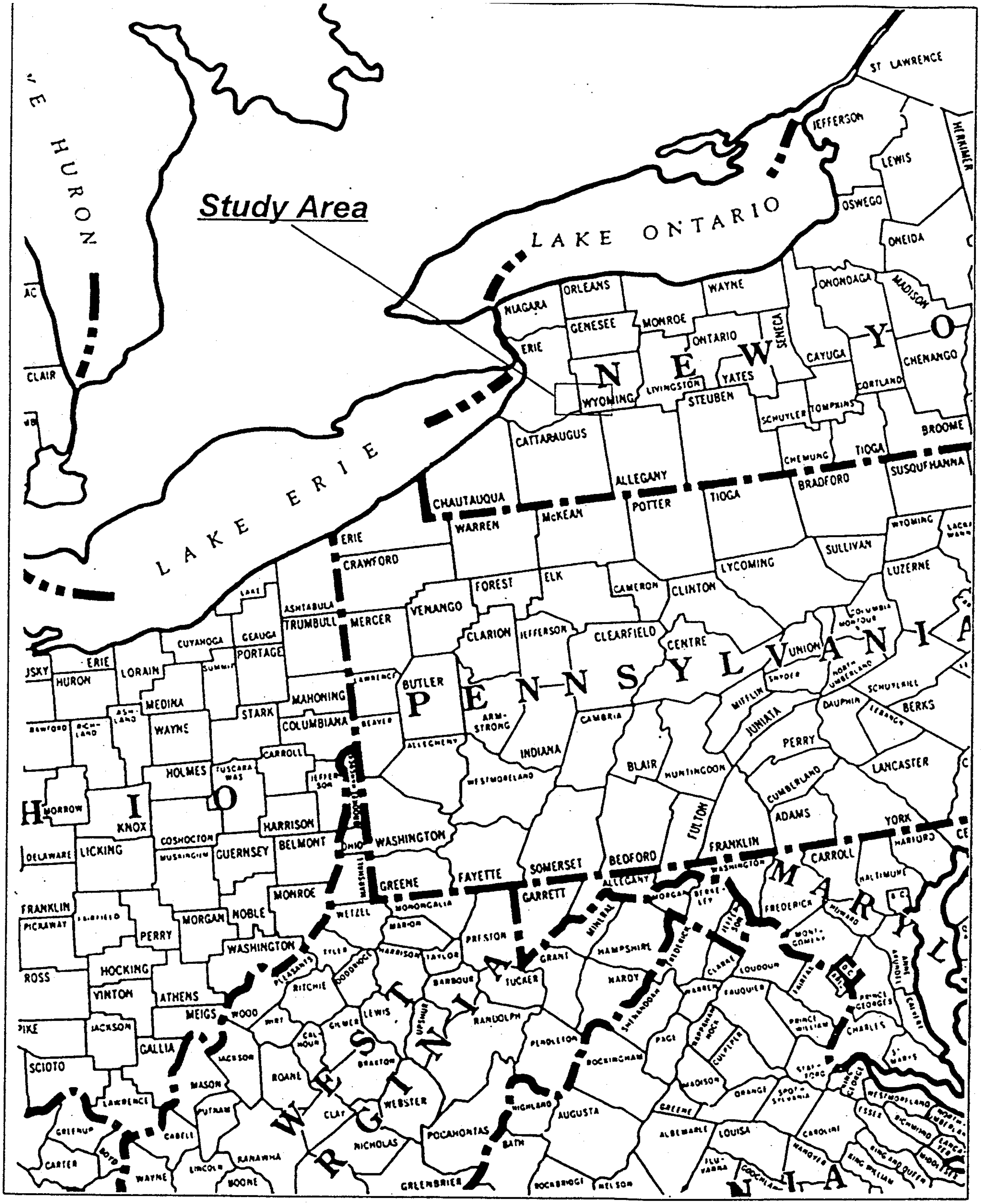

Figure 1 Regional map of western New York showing location of the aeromagnetic survey.

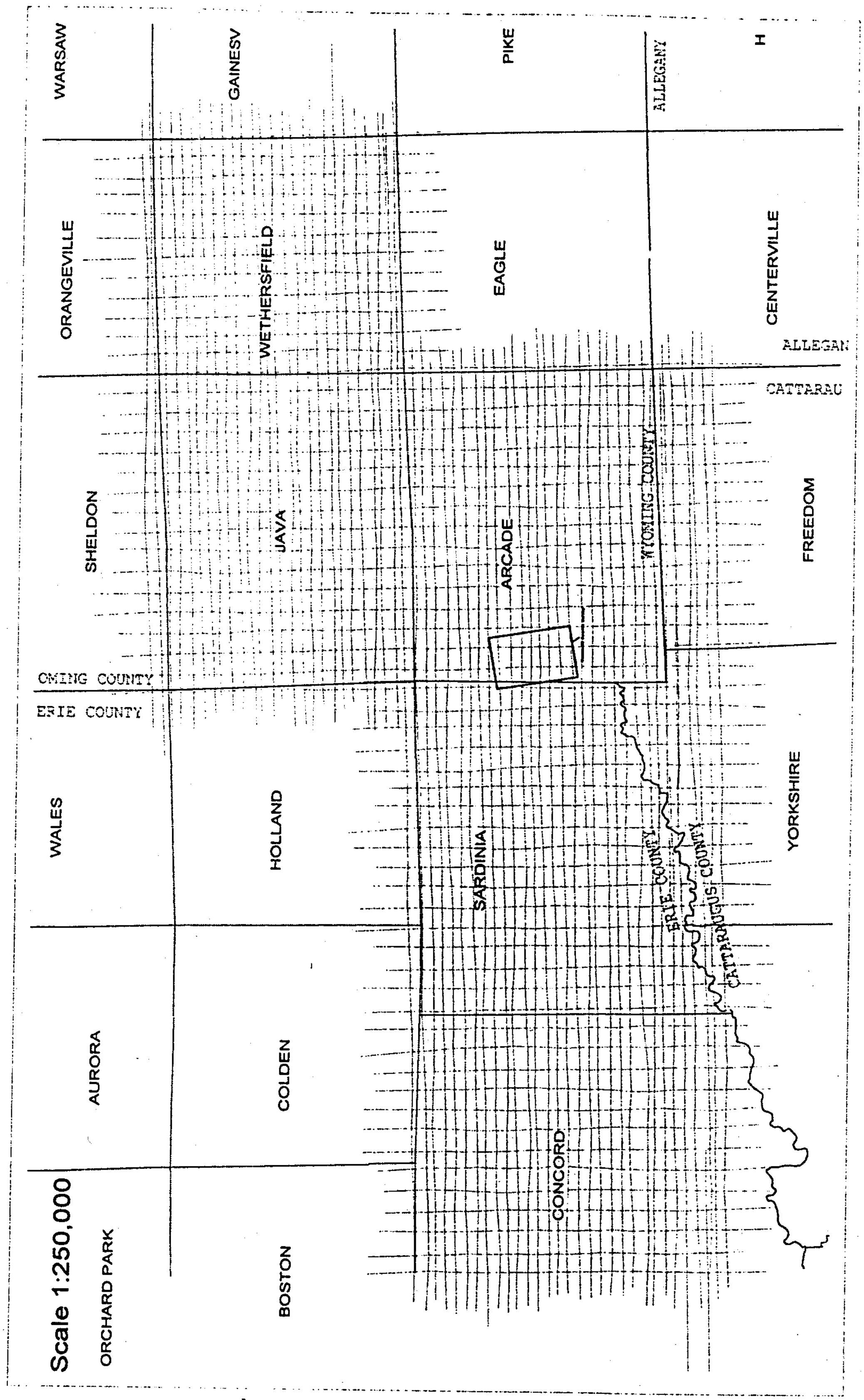

Figure 2 Map showing area covered by the aeromagnetic survey and the flight lines flown in relation to the 3D seismic survey.

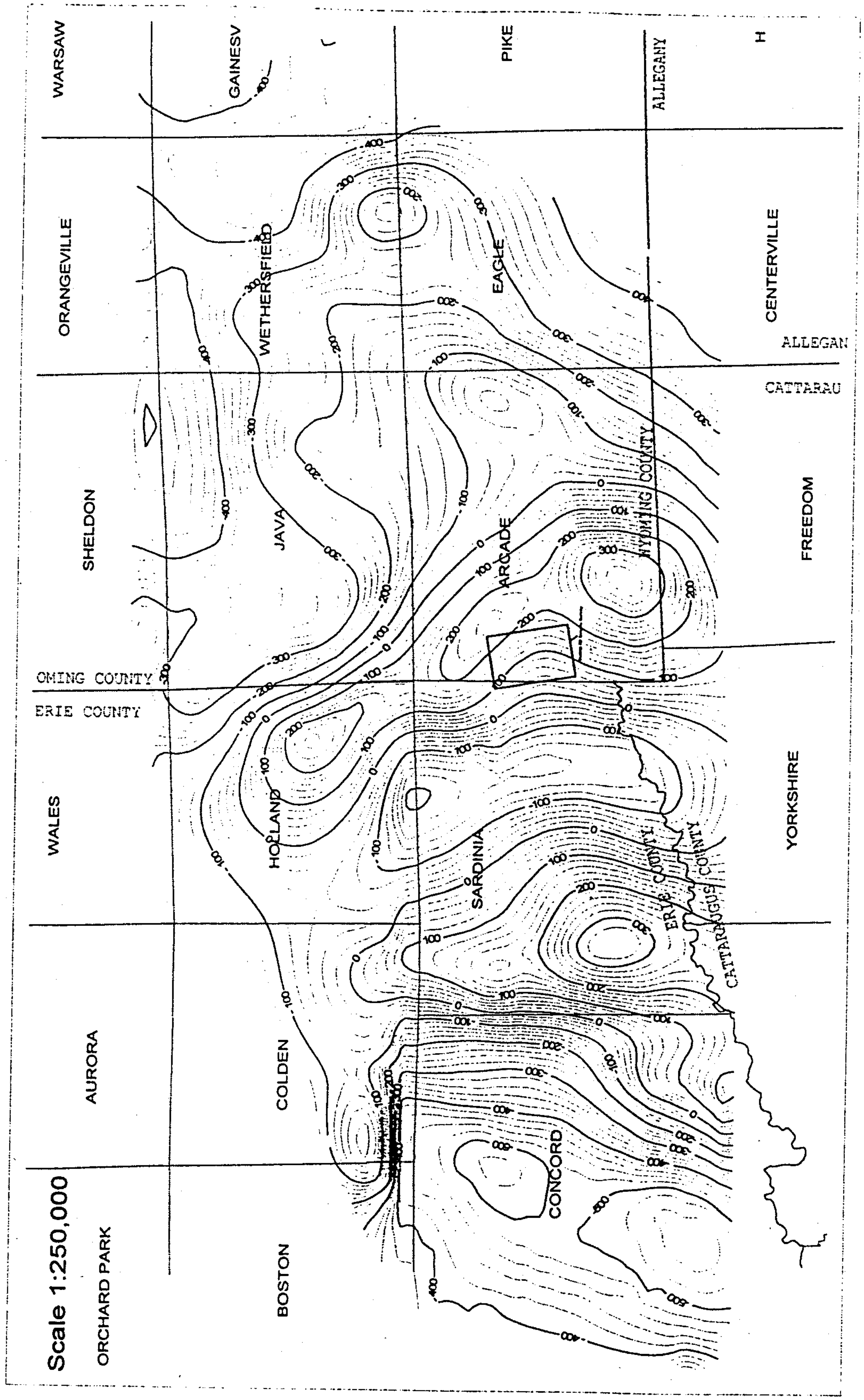

Figure 3 Total magnetic intensity reduced to pole.

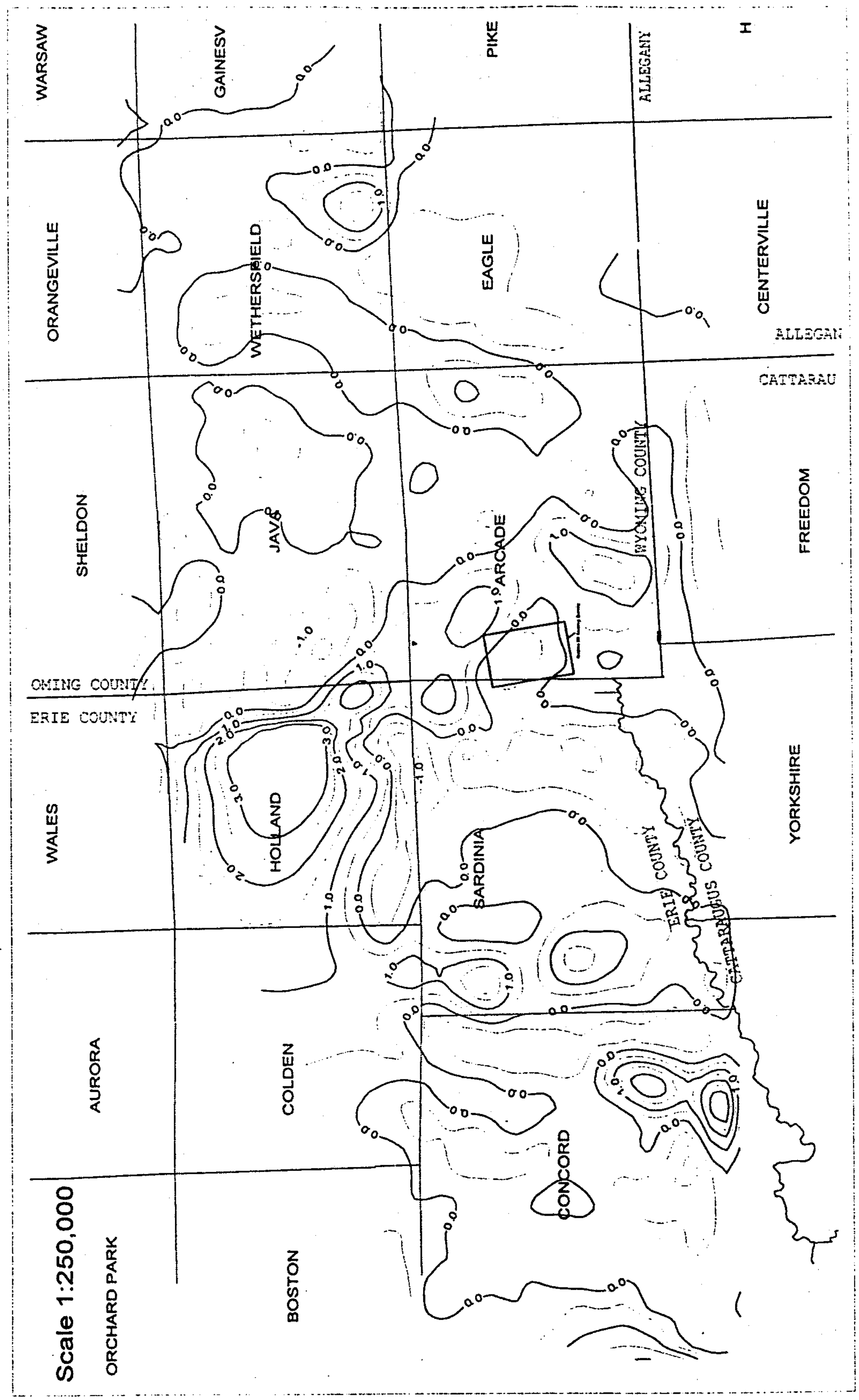

Figure 4 Second vertical derivative of reduced to pole total magnetic intensity.

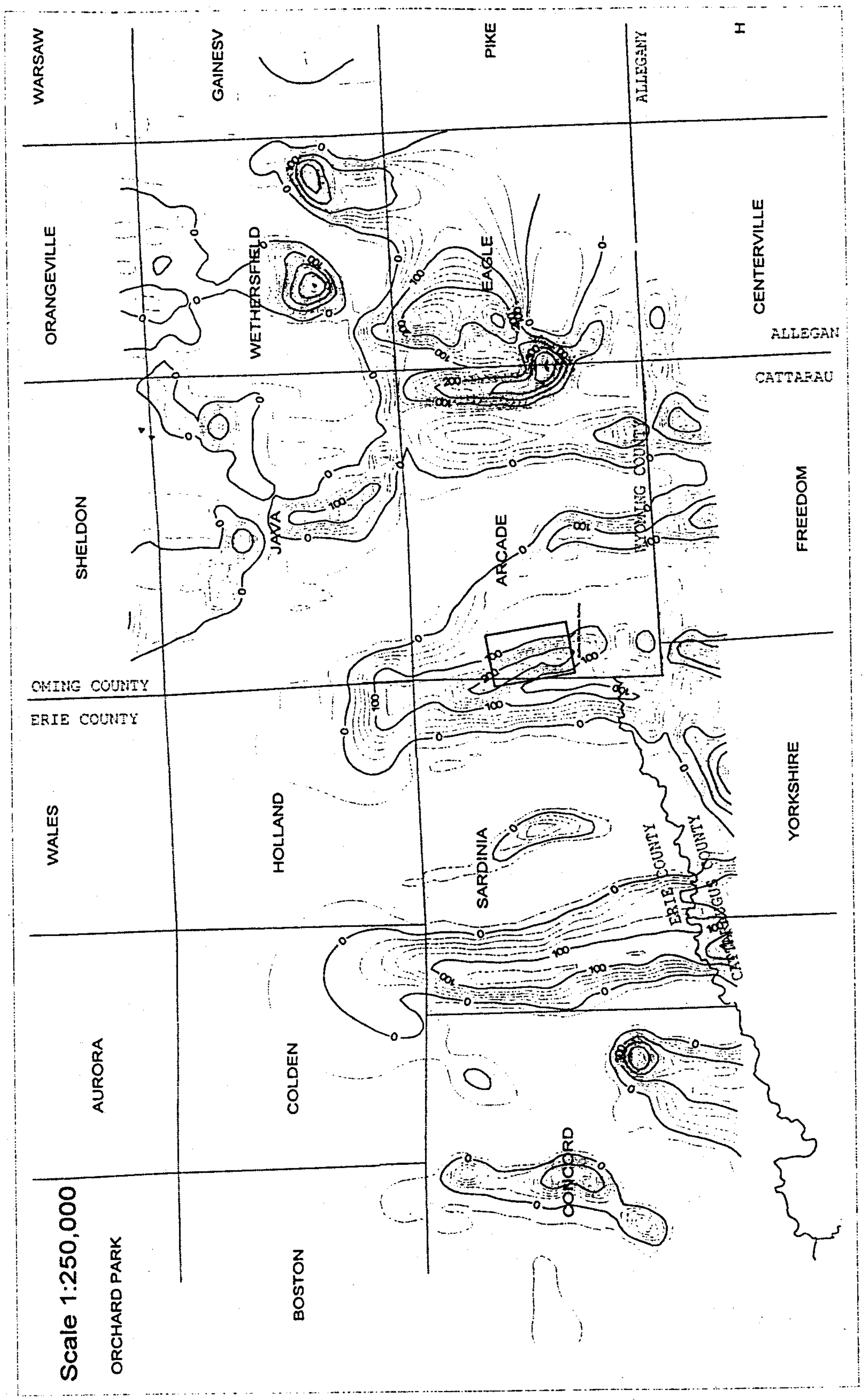

Figure 5 Starmag™ basement interpretation.

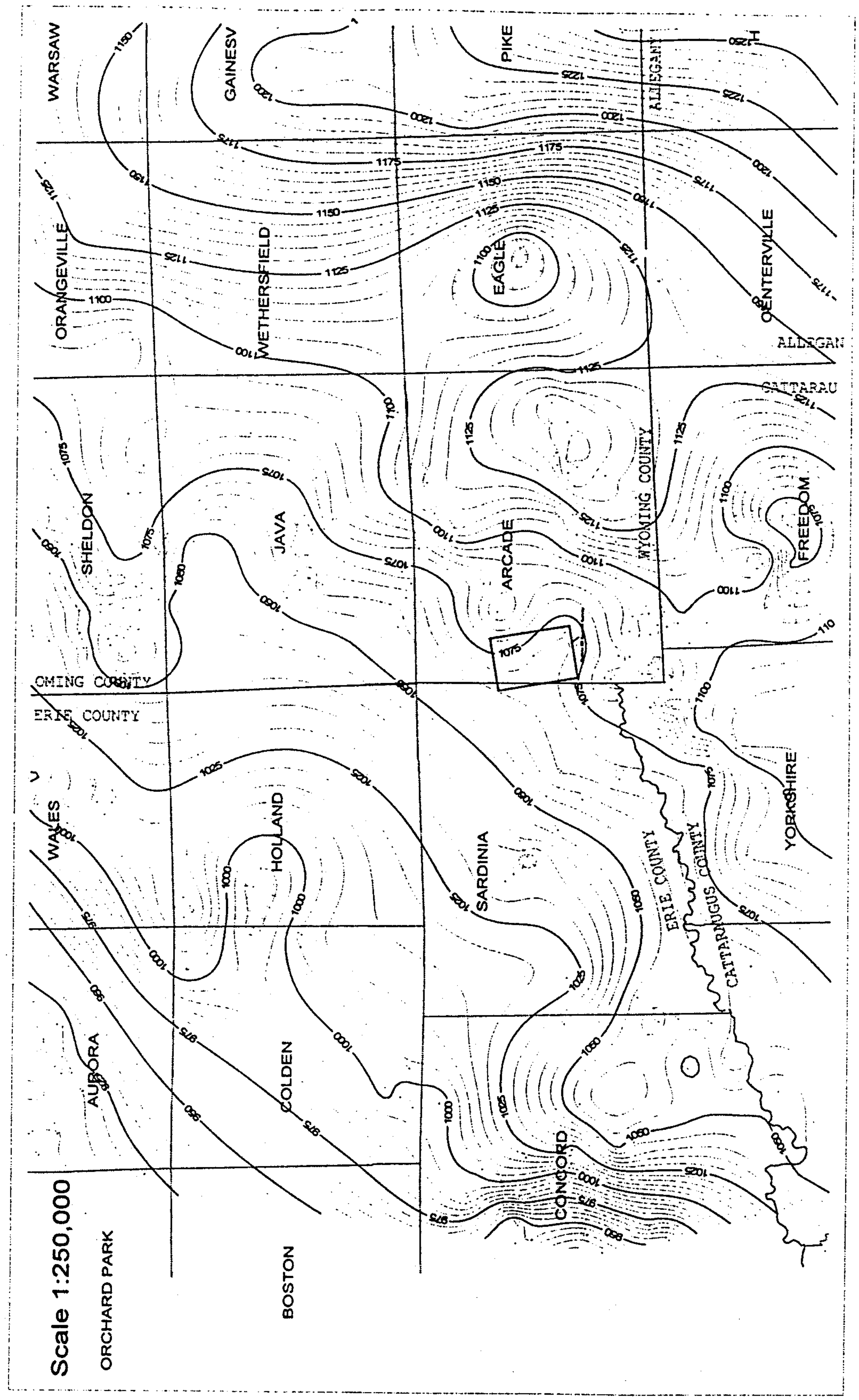

Figure 8 Isopach Onondaga to Packer Shell.

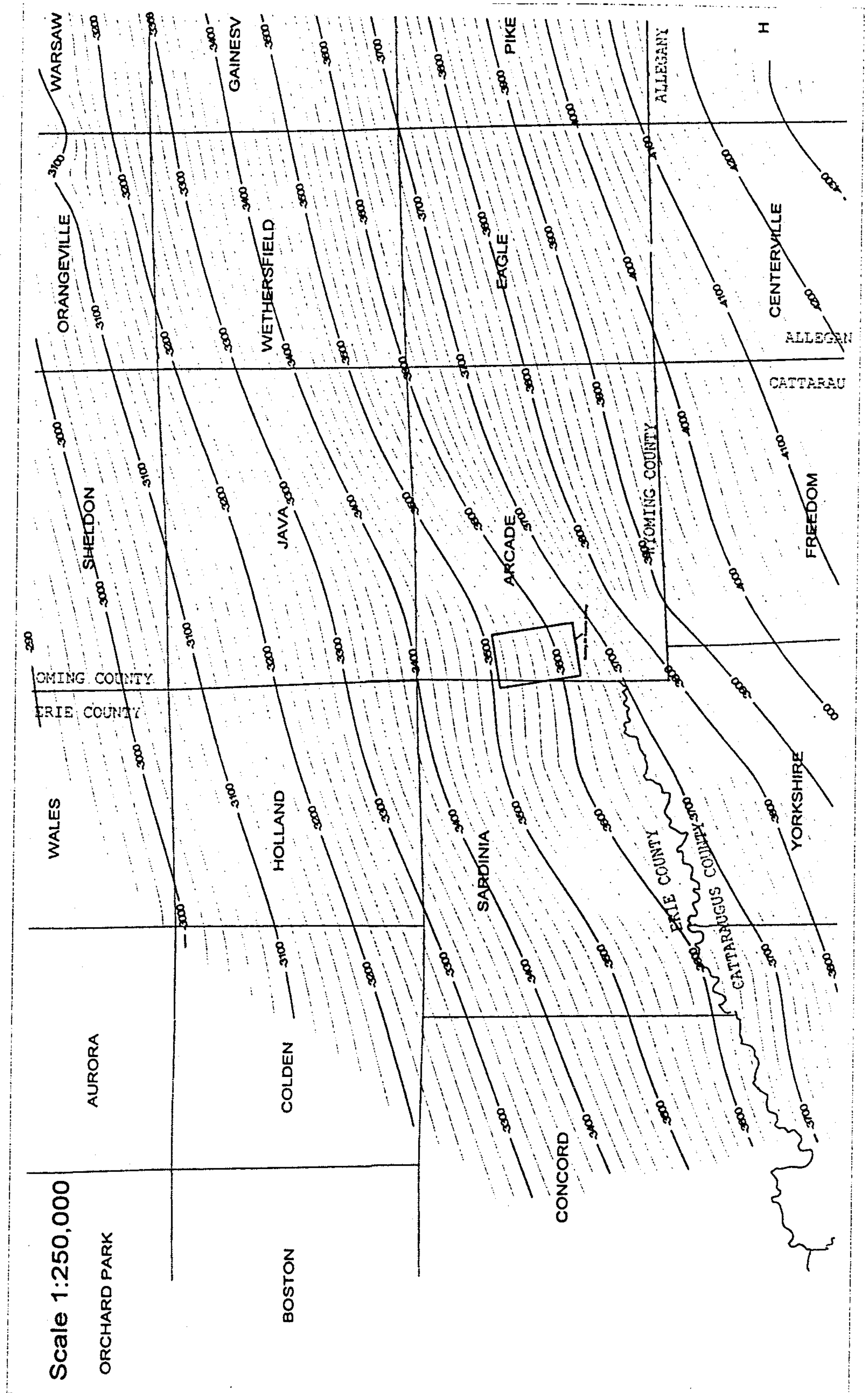

Figure 9 Structure top of Trenton.