

Basement Control of Selected Oil and Gas Fields in Kansas as Determined by Detailed Residual Aeromagnetic Data^{1,2}

S. Parker Gay, Jr.³

ABSTRACT

Basement control of Kansas oil and gas fields is shown to be very real and probably quite common. However, it is not possible to prove basement control with subsurface mapping, as few wells penetrate basement, nor with seismic, as the basement reflector is not always mappable. Residual aeromagnetics is the principal technique used in mapping basement, and it generally is employed only to outline the "basement fault block pattern," that is, the boundaries of the basement fault blocks. Trapping and reservoir-forming mechanisms, such as the presence or absence of basement hills and the amount and direction of throw on basement faults, must be determined independently from subsurface mapping or seismic studies. Nevertheless, magnetic basement mapping is a valuable exploration tool because it provides continuous large block coverage at low cost over both producing and non-producing areas and furnishes many valuable exploration leads. These can be augmented with seismic or subsurface techniques for citing wells. A number of Kansas oil and gas fields are shown that have magnetic signatures typical of the different mechanisms of basement control.

INTRODUCTION

This contribution to the Kansas Geophysical Atlas is not intended to illustrate the geophysical parameters of a single Kansas oil or gas pool; rather it is a discussion of a different approach to geological and geophysical thinking - basement control. Basement control can explain the presence of numerous oil and gas pools already discovered in Kansas, which, in turn, should prompt the discovery of additional pools using basement concepts. Some would say that the understanding of basement control of structure in the sedimentary section is not new, and in actuality, it does have a long, and seminal, history in Kansas. Nevertheless, this history has been largely forgotten and the early concepts have been so effectively superseded by strain theory that basement control concepts are not widely used.

I will here discuss briefly some of the early history. Taylor (1917), writing of oil field structures along the Nemaha Ridge in eastern Kansas, noted that "... the granite so far encountered has been found invariably under surface folds." His observations were noted by Moore (1920), state geologist of Kansas, 1916-1954, who proposed, that;

The structure of the sedimentary rocks, then, appears to be controlled almost wholly by the nature of the hard granite which underlies the surface, and instead of folding by lateral pressure, it appears that the structures are the result of vertical settling or condensation of the sediments from compression by weight of overlying rocks.

Moore deserves credit, along with Mehl and Blackwelder, all in 1920, for the nearly simultaneous recognition of compaction over basement topography as a cause of structure in the overlying sedimentary section. Acceptance of compaction theory was mixed in the decades of the 1920s, 30s, and 40s, but in 1949, the textbook, Principles of Petroleum Geology, by Professor Cecil G. Lalicker of the University of Kansas, was published with a full 20 pages devoted to the compaction phenomenon as a cause of structure and its value for petroleum exploration. This remained the most authoritative and extensive discussion of compaction for 40 years until a paper in the AAPG Bulletin in 1989 documented 30 basement hill cross-sections from well data and demonstrated that all 30 basement hills resulted in compaction structures ("graviclines") in the overlying sedimentary section (Gay, 1989). Nine of these hills are located in Kansas and had been documented earlier by Walters (1946, 1953).

¹Or: "There's more to geology than you learned in college!"

²Published 1995 in "Geophysical Atlas of Selected Oil & Gas Fields in Kansas," Kansas Geological Survey Bulletin 237, pp 10-16.

³Applied Geophysics, Inc., 675 South 400 East, Salt Lake City, Utah 84111, (801)328-8541

In spite of the rather auspicious Kansas-related beginnings of compaction theory and its later verification and thorough documentation, present-day Kansas explorationists do not use the concept effectively, undoubtedly for the same reason stated by Blackwelder over seventy years ago: Structures are explained by "lateral compression", i.e. strain theory, because "... it is a predisposition inherited from our college courses" (Blackwelder, 1920).

If we do wish to use basement concepts, where do we go for advice? The above references, especially Lalicker, will suffice for a start, and I will here attempt to outline in a brief form the principal concepts.

CONCEPTS OF BASEMENT CONTROL

The 100% correlation of 30 basement hills with overlying compaction structures in the Midcontinent (Gay, 1989) verified the concepts of the noted geologists of the 1920's, i.e. that compaction of the relatively soft sedimentary section over an irregular topography carved on the surface of the uncompactible crystalline basement results in a mimicking of the basement surface by the overlying sedimentary rocks. Structural highs appear over basement highs and structural lows over basement lows, although the amount of closure is much diminished, and structural development may cease at a prominent unconformity surface such as that developed at the top of the Mississippian section. Thus, it is not just isolated basement hills, or monadnocks, that affect the structure of the sedimentary section, it is the entire paleotopography of the basement.

In Figure 1 appears a map of structural high and low axes taken from a subsurface map with good well control in Pratt and Barber Counties, Kansas (Williams, 1968). In Figure 2 are shown the axes of residual aeromagnetic highs and lows of the same area. These magnetic highs and lows reflect the lithology of the basement rocks because of differences in the magnetite content of the igneous and metamorphic rocks comprising basement. These rock type changes and the generally sheared boundaries between them control the basement topography. Note the great similarity of the patterns in the two figures. Quantitative analysis resulted in a 74% correlation factor between the structural and basement alignments on the two maps. This demonstrates the pervasive basement topographic control of the structural axes, both highs and lows, in the lower parts of the sedimentary section in Kansas (and certainly elsewhere, as well).

The above concept opens up the exploration possibilities considerably. Now we must not only think of structural closure appearing over basement highs, we must also consider the possibility of fluvial deposits (Morrow channels, for example) occurring in structural-topographic lows on top of the Mississippian unconformity, or other unconformity surfaces in Kansas.

The second type of basement control, in addition to basement topographic control, is structural control, that is, faulting in the sedimentary section following old, reactivated basement faults. This is an old concept and adheres to the adage that "once a fault, always a fault." However, faults in the basement are not the type of sharp breaks we see in the sedimentary section. They are generally broad shear zones having widths of a half mile to a mile or more. These are the block boundaries of the "basement fault block pattern." Distances between basement shear zones vary considerably but are generally bracketed in the 2 to 5 mile (3-8 km) range. They occur in sets of parallel to sub-parallel fractures having different strike directions. They are of distinct ages and hence there are frequent terminations and truncations, and they are mappable with detailed residual aeromagnetics because of the rock type changes and magnetic susceptibility changes across them. These shear zones also generally erode low because they are intensely fractured, and this causes them to be visible on Landsat images of exposed basement, such as the Canadian Shield or other shield areas of the world.

For emphasis, I summarize the above concepts in Table 1.

TABLE 1

THE TWO BASIC TYPES OF BASEMENT CONTROL ON THE OVERLYING SEDIMENTARY SECTION

1. BASEMENT TOPOGRAPHIC CONTROL. Structure is created in the overlying sedimentary section because of gravitational compaction of the sediments over the irregular basement topography. This results in many stratigraphic phenomena as well. (See for example Gay, 1989).
 2. REACTIVATED BASEMENT FAULTS OR SHEAR ZONES. Regional stresses reactivate some of the basement weakness zones, thus localizing structure, as well as causing stratigraphic effects in the overlying sedimentary section.
-

Accepting the above concepts of basement control, we can now proceed to the next step -the actual use of these concepts in exploration for oil and gas. First of all, in what ways does basement control affect hydrocarbon trapping and reservoir development? An initial attempt at tabulating some of the ways this can occur is given in Tables 2 and 3. Nineteen different geological mechanisms are shown. However, this must be considered an abbreviated list. Familiarity with hundreds, or thousands, of oil fields would be necessary for constructing a complete list, if such is possible. For example, in preparation for this paper a new type of reservoir not previously considered was found: oolite shoal development on a sea floor high over a reactivated basement fault (Collier Flats Field, Comanche County, as described by Slamal, 1985. See Figure 13).

TABLE 3

**TYPES OF TRAPS AND RESERVOIRS
RESULTING FROM BASEMENT FAULT
CONTROL**

Direct

1. Fault traps
2. Fractured reservoirs
3. Fractured and dolomitized limestones

Indirect

4. Folds over basement faults
5. Reefs and algal mounds along basement faults
6. Sand bars, oolite shoals, and carbonate grainstone development along basement faults
7. Fluvial systems located over basement faults (Low topography due to jointing)
8. Fluvial systems following fault scarps
9. Fluvial systems over down-dropped basement faults
10. Pinchouts over raised basement blocks
11. Reverse dip over basement faults.

TABLE 2

**TYPES OF TRAPS AND RESERVOIRS
RESULTING
FROM BASEMENT TOPOGRAPHIC CONTROL**

Direct

1. Positive structural closure over basement hills
2. Fluvial systems in low topography over basement lows
3. "Reverse dip" due to basement lows
4. Fracturing on flanks of basement hills
5. Pinchouts on flanks of basement hills

Indirect

6. Reefs and algal mounds on crests of graviclinalines
7. Clean sands, oolites, and carbonate grainstones on crests of graviclinalines
8. Pinchouts on flanks of graviclinalines.

CONCEPTS OF BASEMENT GEOLOGY

In order to utilize the above described concepts of basement control on the structure and stratigraphy of the sedimentary section, it is helpful to understand a certain amount of basement, or Precambrian, geology. As a start, one could examine Landsat or SLAR images of outcropping basement areas worldwide ("shields") to get a feel for what the basement must look like underneath Kansas. However, it is not necessary to understand the details of Precambrian metamorphic and igneous petrology to grasp and apply basement concepts to exploration. Table 4 is a summary of sufficient information on basement geology to guide an exploration program.

The great complexity of basement structure results from active tectonism over the very long time span of the Precambrian Era, 4 billion years. This is approximately 7 times longer than the time from the beginning of Cambrian to the present. Not only this, but tectonism seems to increase as one goes back in earth time, i.e. plate tectonics is apparently slowing down, in spite of the fact that we are

awed by the assemblage and breakup of Gondwana and Laurentia in the last 500 million years. A preliminary analysis of magnetic basement mapping in north central Oklahoma - south central Kansas revealed approximately 8 major tectonic events that affected the Precambrian crust of the region (Gay, 1986). The great majority of these events, six and perhaps more, took place prior to 1.4 billion years ago. An emerging concept among students of Precambrian geology is that all the continents contain pieces of all the other continents due to the hectic pace of plate tectonics in the early stages of earth's history.

Some probable early Precambrian plate boundaries are visible in the residual magnetic data of the Midcontinent region. Figure 3a is a banded contour version of residual magnetic data in south central Kansas covering approximately 3 degrees of longitude and 1 of latitude. This figure is a regional map of the same magnetic data that is shown in the individual oil field examples, Figures 4 through 13. It is made up of alternating bands of black, gray, and white between magnetic contour lines, rather than using the contour lines themselves. This type of presentation could also be called "variable density magnetics" and is extremely useful for seeing regional trends, or "sutures," in magnetic data.

Tectonic boundary A-A' in Figure 3a, herein named the Argonia Suture, separates all - northeast trending basement blocks on the east from all-north trending basement blocks on the west. The area of northeast trending blocks has previously been named the Sumner Terrane and the area of north trending blocks the Sedgwick Terrane (Figure 3b) for the counties that fall within them (Gay, 1986). Sixty miles (80 km) to the west lies tectonic boundary B-B', the Pratt Suture, which separates all-northwest trending basement blocks of the Pratt Terrane on the west from the NE, NW, and NS trends of the Barber Terrane on the east. The parallelism of A-A' and B-B' suggest a related origin, and one is reminded of the accreted terranes still active along the west coast of North America from California through Alaska. The ages of the Precambrian tectonic boundaries in Figure 3 must be considerably in excess of an age date of 1386 Ma obtained within the Wichita intrusive complex shown on the east side of Figure 3, as the intrusive complex seems to be younger than A-A'. Even older are tectonic boundaries C-C' (Pretty Prairie Suture) and D-D' (Joy Suture) which are truncated by A-A' and B-B' respectively. Certainly all the basement terranes, tectonic boundaries and individual block boundaries were in place by Cambrian time and would have appeared much as they appear today in Figure 3.

The long strike length and great amount of inferred displacement of the tectonic boundaries in Figure 3 indicates that they are zones of greater than average weakness, and as such, should be easily reactivated by later stress systems. This appears to be the case for the Pratt Suture, which is almost exactly coincidental with the Pratt anticline or "Yellowstone-Peace Creek Tectonic Zone" (Berendsen and Blair, 1986, and Slamal, personal communication, 1992). This is one of many zones in Kansas that are parallel to the Nemaha Ridge and are of latest Mississippian - early Pennsylvanian age. Perhaps such Mississippian - Pennsylvanian disruption also exists along the Argonia Suture (A-A'), but we have not examined subsurface data to investigate that possibility.

MAPPING BASEMENT GEOLOGY WITH AEROMAGNETICS

As outlined in Table 4, basement tectonism juxtaposed rocks of differing magnetic susceptibilities across shear zones long before Cambrian time. It is this fact which allows us to map the shear zones with residual aeromagnetics. The shear zones thus fall on the magnetic gradients between the residual magnetic highs and lows. They are the principal zones of weakness in the basement that were reactivated by later (Paleozoic) tectonic events. Extensive comparison of reliable subsurface and seismic maps over large areas of the Midcontinent and the Rockies at Applied Geophysics, Inc., have shown that fully 65 to 70% of the faults cutting the sedimentary section in these areas lie on magnetically mapped basement shear zones. Possibly the percentage of correlation would be higher if the mapped fault traces were more exact, but there are also cases where reliably defined faults cut through the interiors of basement blocks rather than following block boundaries. There are no absolutes in geology, but certainly a map of the basement fault block pattern is a good starting point for understanding the structure of an area.

TABLE 4

**THE BASEMENT FAULT BLOCK PATTERN:
BASIC CONCEPTS**

1. Blocks of complexly faulted and folded metamorphic and igneous rocks are bounded by wide linear shear zones of crushed and broken mylonitized rock.
2. The individual blocks are composed of different rock types, or rocks of different metamorphic grade, and hence of different magnetic susceptibility. This makes it possible to map the block boundaries with residual high-resolution aeromagnetics.
3. Block boundaries generally fall into parallel sets, and several overlapping sets may exist in an area, resulting in a polygonal pattern for the individual blocks (H. Cloos, 1948).
4. Distances between parallel block boundaries generally vary between 3 and 8 kilometers (2-5 miles) in all areas studied to date.
5. Later tectonic events reactivate the various fracture sets preferentially, according to their strike directions. Those most suited to relieving the imposed stress are the ones reactivated. ("The New Basement Tectonics", 1972).
6. Erosion of the Precambrian surface generally results in topographic highs within the blocks and topographic lows following the block boundaries.

Likewise, a map of the basement fault block pattern is an aid in locating basement topographic features. Basement shear zones, i.e. the edges of basement blocks, generally erode topographically low. That is why they are so evident on Landsat images of outcropping basement. This means that basement topographic highs generally fall within the block interiors, but where? Is the whole basement block a topographic high, is one edge higher, or are there several topographic highs within a single block? It is generally not possible to answer these questions with magnetics. In fact, some basement hills correspond to magnetic lows (see Figure 5). This would be the case where a basement hill is carved on a block that is less magnetic than surrounding blocks. Quartzite is one rock

type that falls in the weakly magnetic category, and basement hills of quartzite are not uncommon in Kansas (Walters, 1953; J. Brewer, personal communication, 1983).

This brings up the problem of the ambiguity of magnetic data for mapping the vertical dimension, for example, attempting to determine whether a basement block is high or low or has a hill on it, or which side of a basement fault is up or down. Since the magnetic pattern is caused by the lithology of the basement rocks, neither of these problems is generally solvable with magnetics, especially in areas of low basement relief and limited fault throw, as in Kansas. In the highly-regarded GSA Memoir 47, the first book ever written on aeromagnetic interpretation, it is stated: "Most magnetic anomalies arise from the lithology and not from the topography of the basement rock" (Vacquier, et al., 1951, p. 8). In the third edition of Introduction to Geophysical Prospecting a similar statement is made: "The magnetic relief observed over sedimentary basin areas is almost always controlled by the lithology of the basement rather than by its topography" (Dobrin, 1976, p. 534). On the other hand, the determination of the edges of magnetic anomalies, i.e. the boundaries of the basement blocks, or the horizontal dimensions, x and y, is not ambiguous.

It is recommended that the vertical dimension, z, be determined from subsurface or seismic data, which is precisely what these techniques measure. Thus, to obtain the best picture of the geology of an area in all three dimensions, x, y, and z, one should integrate magnetic basement mapping with seismic and subsurface data. And in reality, magnetics, like subsurface studies, must come before seismic, in order to determine where to most economically acquire seismic data and how much to obtain.

How does gravity surveying fit into this picture and when should it be employed? The writer feels that, in most cases, gravity should be used like seismic as a follow-up tool run at a tight station spacing of 200 to 500 ft. along specific profile lines, each a few miles long. This could indicate whether a basement hill is present, in many cases, or which side of a fault is up. However, gravity is almost never used in this fashion. It is generally run on grids of 1 mile spacing, sometimes with tighter spacing along roads, to give a regional picture. Here, it competes with aeromagnetics, which does a better and more detailed job of mapping the basement fault pattern. Aeromagnetic readings are spaced from tens of feet apart up to about 200

ft., maximum, along line, and this high density of data essentially defines the magnetic profile completely. The profile lines can be flown at any line spacing desired, but are generally flown at a separation equal to one third to one half the depth to basement.

Many, or most, basement block boundaries are not readily defined by gravity, as there is little contrast in the densities of the juxtaposed blocks. Overall, densities of basement rocks vary from about only 2.5 gms/cc to a high of 3.2 gms/cc (in rare cases) - a 28% change. However, magnetic susceptibilities of basement rocks routinely vary from 50 microcgs to about 5000 microcgs. This is a 100 times change, or in percent: 10,000%.

SELECTED EXAMPLES OF BASEMENT CONTROL ON OIL AND GAS FIELDS IN KANSAS

In the following pages are shown selected examples of known oil and gas fields in Kansas that are controlled, or apparently controlled, by basement features. All these examples are relatively clear-cut and straightforward. That is, the magnetic pattern conforms closely to an oil or gas field or some basement structure which apparently controls the subsurface structure or stratigraphy of the field. One could argue that the veracity of the presented cases is not proven and that the correlations may be fortuitous, but on the other hand, one could never prove basement control anywhere at any time unless there are many wells to basement on a given trap or structure. Such a situation is not achievable in actual practice due to the limited number of wells to basement, and we must work with available data and the known principles of geology and geophysics to arrive at answers that satisfy the data in a logical manner. For the topographic aspects, it is important to remember the scattered cases throughout the Midwest where there were sufficient wells to basement to define individual basement hills and to realize that compaction anticlines ("graviclinalines") were present in 30 out of 30 cases (Gay, 1989). For the structural aspects, we must keep in mind that about 65% of the well-documented faults in the sedimentary section that occur within the boundaries of aeromagnetic surveys coincide with residual magnetic gradients, that is, on magnetically-mapped basement shear zones.

1. Moore SW Field, Pratt County, Figure 4. This example shows a structural high that coincides with a residual aeromagnetic high. For this reason it is considered a probable compaction structure ("gravicline")

over a basement hill. Similar examples could be presented for Newbury Field in Wabaunsee County, Coleman and Lake Creek Fields in Montgomery County, Wellington Field in Sumner County, and a number of others. Many additional fields correlate with residual aeromagnetic highs, but there is no published information that they are structural fields.

2. Willowdale Field, Kingman County, Figure 5. This example shows a structural high that coincides with a residual aeromagnetic low. Note the near-straight line gradients on west, south and east on both sets of contours, indicating the existence of a probable underlying basement hill carved in a weakly magnetic basement rock, such as quartzite. Subsequent conversations in Wichita revealed that some exploration groups had previously noted the same phenomenon and used this concept as an exploration tool in Kansas (J. Brewer, personal conversation, 1983). Other similar correlations of structural highs with residual aeromagnetic lows have been noted for Bloom Field in Barber County, Rosedale Field in Kingman County, and Wiltex Field in Harper County.

3. Alameda Field, Kingman County, Figure 6. This is an interesting example, and could have been included with those in the first example as it falls on a localized magnetic high. However, it is possible to interpret more of the basement geology here, as the field falls precisely within a circular area of lower magnetic susceptibility than the area surrounding it. This is especially evident on the 3D stereo pair of the magnetic map. It is thus proposed that the area is underlain by a 4-to-5 mile diameter Precambrian igneous intrusion onto which a basement hill was eroded. A down-to-the-NW fault cuts all formations older than Pennsylvanian and coincides precisely with 3 to 5-gamma residual magnetic gradient. This is typical of the fault correlations obtained with basement mapping where reliable geological data exists.

4. Coats Field, Pratt County, Figure 7. This example was included to illustrate a remarkable fault correlation, but there is reason to suspect that Coats Field is a compaction structure over a basement hill. What else would cause a structure in south central Kansas less than one mile wide having over 450 feet of total vertical displacement on the Arbuckle? (Localized basement "uplift", piston fashion, is not a viable tectonic mechanism.) Realizing that such a basement topographic high probably does exist on the edge of a 3 x 3 mile wide basement block as mapped by the magnetic high (Figure

7), one might speculate that there is a basement rock type here which erodes to a "knobby" terrain (granite, perhaps?). The four "corners" of this block - NW, NE, SE, and SW - corresponding to the magnetic high thus become interesting places to use subsurface or seismic data to look for other structural highs. What is remarkable in Figure 7 is that the short NNE trending fault within Coats Field and the long seismically mapped fault underlying the Pratt anticline correlate precisely with residual magnetic gradients, i.e. the locations where one draws basement shear zones.

5. Stateline Trend, Wallace and Greeley Counties, Kansas, and Cheyenne and Kiowa Counties, Colorado, Figure 8. If high basement topography causes structural highs in the overlying sedimentary section, then low basement topography must result in overlying structural lows. It is possible then, through the process of erosion, that Mississippian structural lows in western Kansas - eastern Colorado became Pennsylvanian topographic lows. They would thus be favorable sites for the deposition of Morrow channel sands.

One user of residual aeromagnetic data in southeast Colorado in 1985 found an 85% correlation of Morrow channels with residual aeromagnetic lows. This suggests that there is a rock type in the basement of southeast Colorado that is magnetically weak and erodes topographically low. The Morrow channels there seem to follow magnetic lows and avoid magnetic highs. The subsequently discovered additions of Mt. Pearl and Siaana Fields to the Sorrento Trend in Colorado and the later discovery of the Stateline Trend along the Kansas-Colorado line substantiated this observation. In Figure 8, the Stateline Trend is seen to bend sharply around a strong northeast striking residual magnetic high and generally follows the magnetic gradients (i.e., the shear zones, which we expect to erode low) or the magnetic lows themselves. Thus, residual magnetics may be of some value in the search for new channels in the Morrow play, but again, only if integrated, or followed up, with other geological and geophysical information.

6. Gillian and O.S.A. Fields, Sedgwick County, Figure 9. Gillian Field has been described as a fault trap on a structurally high horst block (Shawver, 1965a). O.S.A. Field is an updip pinchout of the uppermost Simpson sandstone on this same block (Shawver, 1965b). The west bounding fault was precisely defined by a 1983 interpretation of a residual aeromagnetic survey covering this area. A series of similar parallel faults, two of which

are shown in Figure 9, have been equally well defined by the aeromagnetic data and present additional exploration opportunities. The logical follow-up would be detailed subsurface studies followed by seismic profiling over selected "look-alikes."

7. Ponca City Field, Kay County, Oklahoma, Figure 10. Many truly prolific oil fields have been found along the Nemaha structural system in eastern Kansas and north central Oklahoma. The Ponca City Field in Oklahoma is included in this paper (it is only 20 miles south of the Kansas line) as a remarkable example of such a field. Figure 10 shows the location of the field relative to a strong residual magnetic gradient, corresponding to a basement shear zone. Eastward directed reverse fault movement of the shear zone as shown in the sketch at the bottom would explain the asymmetry of the fold. Such fields are common along the Nemaha Ridge, the Beaumont anticline, and other parallel trends in both Kansas and Oklahoma.

8. Davis Ranch Field, Wabaunsee County, Figure 11. This field is located 160 miles northeast of the Ponca City, Oklahoma, field on the "Alma Trend" lying 10 miles east of, and parallel to, the Nemaha Ridge. It is a structural look-alike to the Ponca City Field and is likewise a large producer. It falls along a magnetically-mapped basement shear zone, although not precisely on it to the south. Auburn and John Creek Fields to the south and Mill Creek Field to the north are similar fields located over basement faults.

9. Cunningham Field, Pratt and Kingman Counties, Figure 12. This structural field is similar to both the Ponca City Field and those of the Alma Trend just mentioned. However, it lies some 75 miles west of the Nemaha Ridge along an apparent splay of the Yellowstone-Peace Creek Tectonic Zone, which is parallel to the Nemaha Ridge and apparently resulted from the same late-Mississippian compression. Note the excellent correlation of Cunningham Field with the underlying magnetically mapped basement shear zone. Other Kansas fields that seem to fall in the same category are Weathered in Cowley County, N. Yellowstone in Comanche County, and Bartholemew in Sedgwick County.

10. Collier Flats Field, Comanche County, Figure 13. It is fitting to end this suite of field correlations with a stratigraphic example, as many times it is stated that structure mapping of the basement is not relevant to

certain exploration plays as they are "purely stratigraphic". Some examples of such stratigraphic plays we have had experience with are the Shannon-Sussex-Ferguson offshore sandbars in the Powder River Basin, which lie along basement faults; the Muddy fluvial system of the Powder River Basin, which also follows basement faults; and the Desert Creek algal mounds of the Paradox Basin, which likewise fall along basement faults. In Comanche County, Kansas, the Collier Flats Field is described by Slamal (1985) as an oolite shoal that developed on a "structurally high element." It coincides almost precisely with a magnetically-mapped basement shear zone, and Slamal states that this could have been vertically reactivated to produce a sea floor high that localized the oolite development of Missourian age in the Swope Limestone of the Kansas City Group (personal communication, 1992).

CONCLUSIONS

The discussion and the oil and gas field examples in this paper demonstrate two main points:

- 1) Basement control of oil and gas field traps and structures is highly prevalent, if not pervasive, in Kansas, and
- 2) Residual magnetic maps provide leads for exploring for these basement controlled traps and structures.

The first point, that basement control exists, is academic if we can't somehow map basement in order to take advantage of basement control. That is why point number two is important. There is a means of mapping basement to some degree, even if that means, residual aeromagnetics, is imperfect. Basement hills cannot be located with certainty with magnetics, nor can it be determined which of the multitude of basement shear zones mapped has been offset by faulting, and in what direction. Nevertheless, residual aeromagnetics can be used as a starting point, and then followed up in favorable areas with other exploration tools.

In the writer's opinion, the quickest and surest way to use the concept of basement control as an exploration technique is to search for nearby analogs ("look-alikes") to known basement controlled fields. If Collier Flats Field, for example, resulted from Pennsylvanian oolite deposition on a fault scarp over a basement fault, is it possible that similar features exist either 1) along strike, or 2) on adjacent basement faults? Basement tectonic concepts indicate that there are probably parallel faults 2 or 3 miles away on either side, and in this short distance

the sedimentary processes may not have changed much. If Willowdale Field is a gravicline over a basement hill carved in a quartzite block characterized by a residual magnetic low, are there other similar magnetic lows nearby? If Davis Ranch Field is an asymmetrical fold over a reverse fault in the basement, surely the stresses were not local and there must be other such structures along strike (which there are), or parallel to it a few miles away (unknown).

When Applied Geophysics, Inc., first came to Wichita a decade ago to promote basement mapping with aeromagnetics, several prominent geologists told us: "We're beyond that stage in Kansas". Actually, it appears the reverse is true. Many Kansas geologists (along with geologists in other parts of the United States) haven't yet reached "that stage", that is, the stage of understanding that extensive basement control is present in the sedimentary section and that there are ways and means of taking advantage of it. Those geologists who do will certainly discover additional important oil and gas reserves.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the continuing encouragement to prepare this paper given by William A. Miller; the helpful discussions over the years with many Kansas geoscientists, but especially R. Walters, A. James, T. Ray, and D. McGuire; and the valuable review and discussions by R. Slamal and D. Baars. He is also greatly indebted to the staff at Applied Geophysics, Inc., for their useful assistance and innovative ideas in preparation of this paper: B. Opfermann, B. Hawley, P. Haslam, R. Andrus, B. Wallin, D. Pap and F. Benjamin.

REFERENCES

- Berendsen, P., and K. Blair, 1986, Subsurface structural maps over the CNARS with discussion: Kansas Geol. Surv., Publication 56-8.
- Blackwelder, E., 1920, The origin of the central Kansas oil domes: AAPG Bulletin, Vol. 4, p. 89-94.
- Clark, S.K. and J.I. Daniels, 1929, Relation between structure and production in the Mervine, Ponca, Blackwell, and south Blackwell oil fields, Kay County, Oklahoma, in Structure of Typical American Oil Fields, Vol. 1, AAPG, Tulsa.
- Cloos, H., 1948, The ancient European basement blocks - preliminary note: Am. Geophy. Union Transactions, Vol. 29, No. 1, p. 99-103.
- Cruce, J.D., 1956, Willowdale Pool, in Kansas Oil and Gas Pools, Vol. 1, p. 95-97: Kansas Geol. Soc., Wichita.
- Curtis, G.R., 1956, Coats Field, in Kansas Oil and Gas Pools, Vol. 1, p. 19-24: Kansas Geol. Soc., Wichita.
- Dobrin, M.B., 1976, Introduction to geophysical prospecting, third edition: McGraw Hill, 630 p.
- Gay, S.P., 1985, Gravitational compaction, a neglected mechanism in structural and stratigraphic studies: new evidence from Midcontinent, U.S.A.: Applied Geophysics, Inc., Salt Lake City, 109 p.
- _____, 1986, Relative timing of tectonic events in newly recognized Precambrian terranes in south-central Kansas, U.S.A., as determined by residual aeromagnetic data: Basement Tectonics Proceedings, Vol. 6, p. 153-167.
- _____, 1989, Gravitational compaction, a neglected mechanism in structural and stratigraphic studies: new evidence from Midcontinent, U.S.A.: AAPG Bulletin, Vol. 73, p. 641-657.
- Hellman, T.D., 1985, Moore SW Field, in Kansas Oil and Gas Fields, Vol. 5, p. 175-181: Kansas Geol. Soc., Wichita.
- King, C.R., 1965, Alameda Field, in Kansas Oil and Gas Fields, Vol. 4, p. 1-17: Kansas Geol. Soc., Wichita.
- Lalicker, C.G., 1949, Principles of petroleum geology: New York, Appleton-Century-Crofts, 377 p.
- Mehl, M.G., 1920, The influence of the differential compression of sediments on the attitude of bedded rocks (abs.): Science, New Series, Vol. 51, p. 520.
- Moore, R.C., 1920, The relation of the buried granite in Kansas to oil production: AAPG Bulletin, Vol. 4, p. 255-261.
- Shawver, D.D., 1965a, Gillian Field, in Kansas Oil and Gas Fields, Vol. 4, p. 78-87: Kansas Geol. Soc., Wichita.
- _____, 1965b, O.S.A. Field, in Kansas Oil and Gas Fields, Vol. 4, p. 175-184: Kansas Geol. Soc., Wichita.
- Skelly Oil Co., Geol. Dept., 1956, Cunningham Field, in Kansas Oil and Gas Pools, Vol. 1, p. 25-28: Kansas Geol. Surv., Wichita.
- Slamal, R., 1985, Collier Flats Field, in Kansas Oil and Gas Fields, Vol. 5, p. 43-52: Kansas Geol. Soc., Wichita.
- Taylor, C.H., 1917, The granites of Kansas: Bulletin of the Southwestern Assoc. of Petrol. Geol., Vol. 1, p. 111-126.
- Vacquier, V., N.C. Steenland, R.G. Henderson, and I. Zietz, 1951, Interpretation of aeromagnetic maps: Geol. Soc. of America, Memoir 47.
- Walters, R.F., 1946, Buried pre-Cambrian hills in northeastern Barton county, central Kansas: AAPG Bulletin, Vol. 30, p. 660-710.
- _____, 1953, Oil production from fractured pre-Cambrian basement rocks in central Kansas: AAPG Bulletin, Vol. 37, p. 300-313.
- Williams, C.D., 1968, Pre-Permian geology of the Pratt anticline area in south-central Kansas: M.S. thesis, Wichita State University.

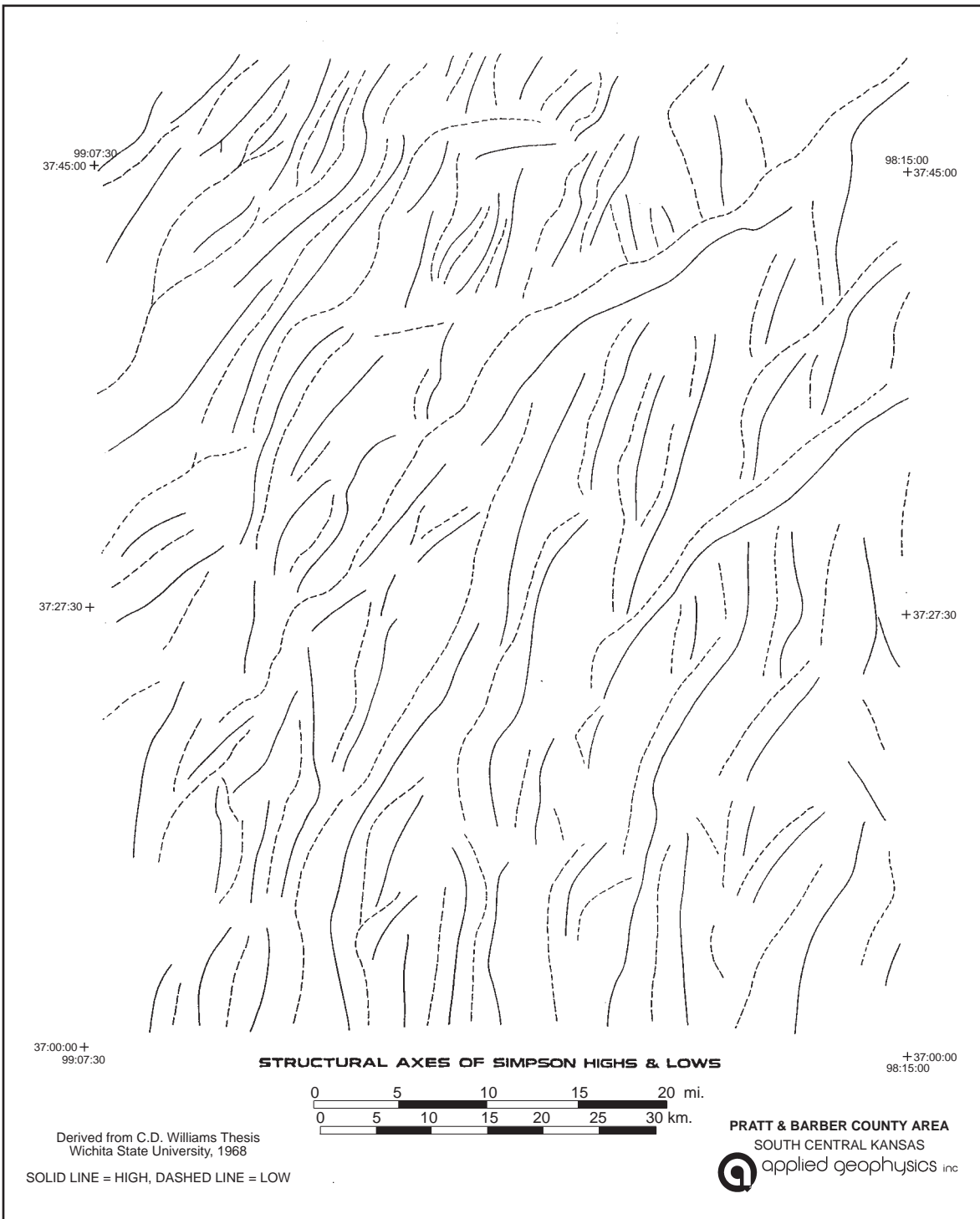


FIGURE 1. Axes of Simpson structural highs and lows, taken from Williams (1968).

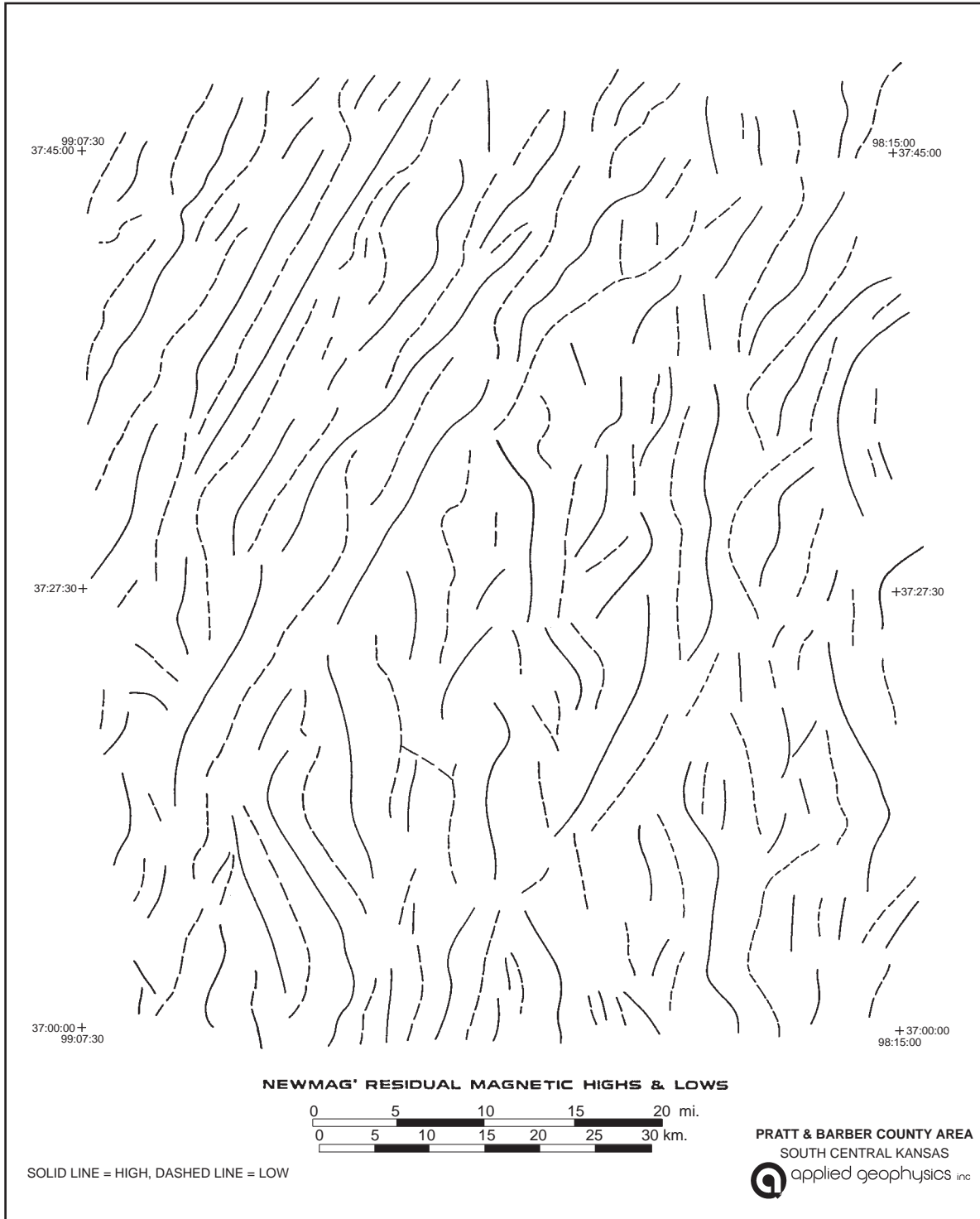


FIGURE 2. Axes of residual magnetic highs and lows of area of Figure 1, taken from proprietary aeromagnetic basement mapping by Applied Geophysics, Inc., 1982-83.

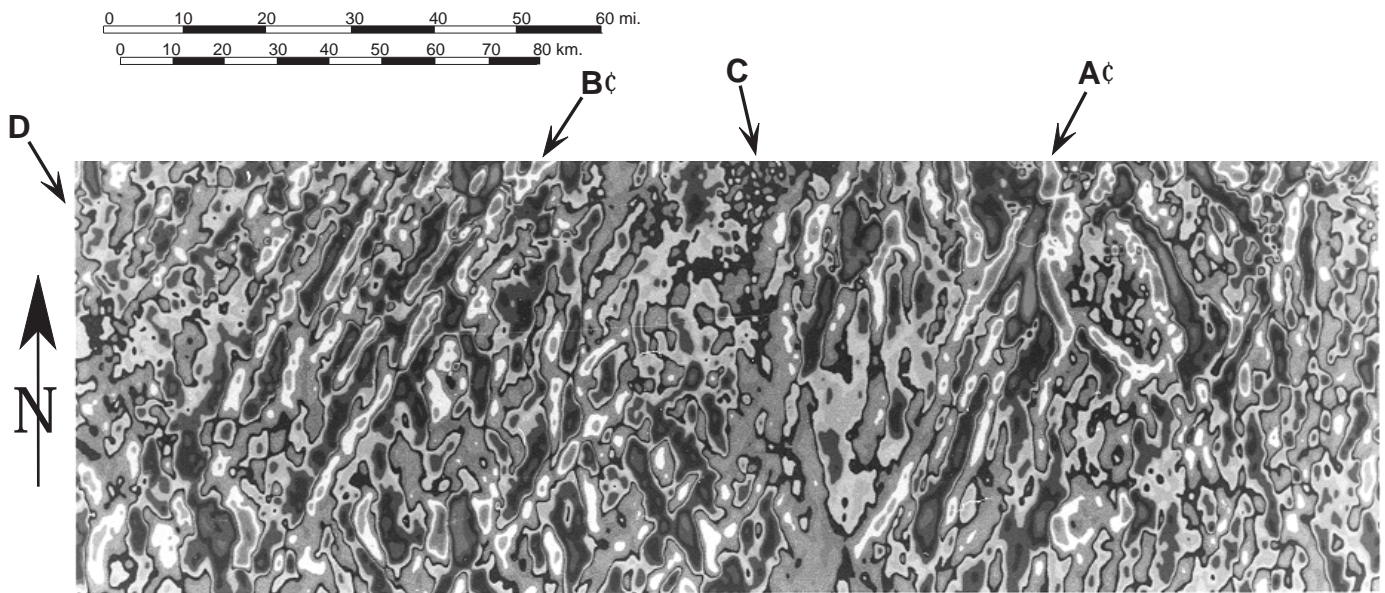


FIG. 3a

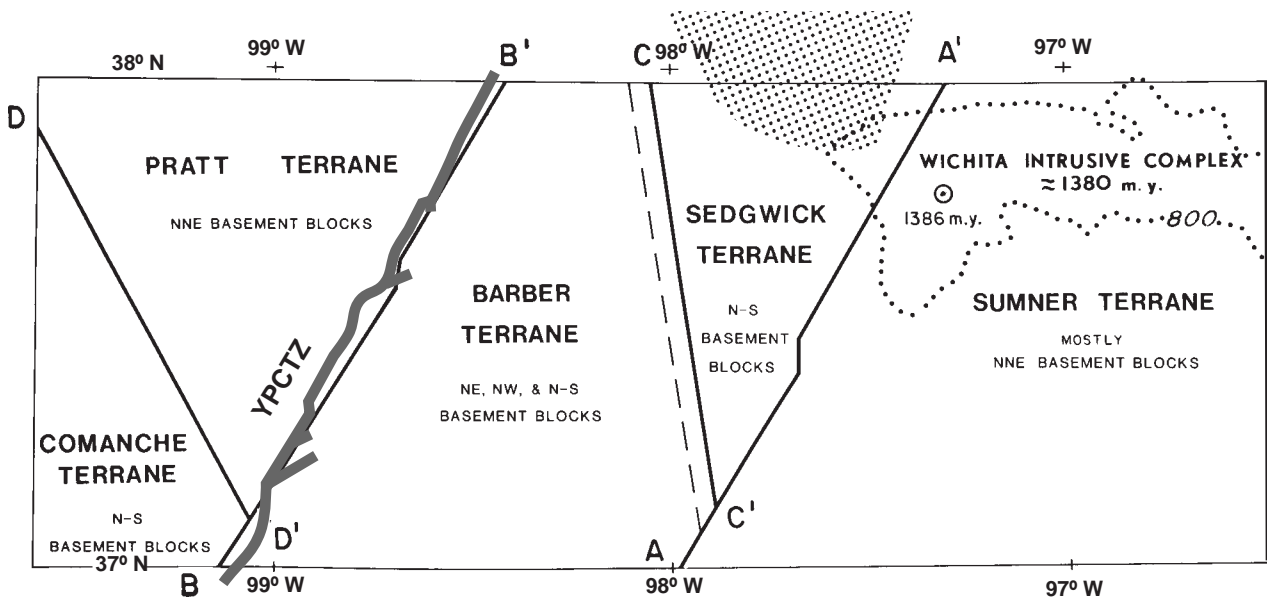


FIG. 3b

FIGURE 3a (top). Banded contours of residual magnetic map of part of south-central Kansas. Note the four obvious basement sutures (tectonic boundaries), as indicated by the arrows.

FIGURE 3b (bottom). Names are given for the various Precambrian terranes that are separated by the indicated sutures (from Gay, 1986, reproduced by permission of the Basement Tectonics Association). In the present paper, the sutures themselves are given names: A-A': Argonia suture, B-B': Pratt Suture, C-C': Pretty Prairie Suture, D-D': Joy Suture. Note the close correlation of the "Yellowstone - Peace Creek Tectonic Zone" (YPCTZ) with the Pratt Suture. It would be surprising if the Argonia Suture has not been similarly reactivated.

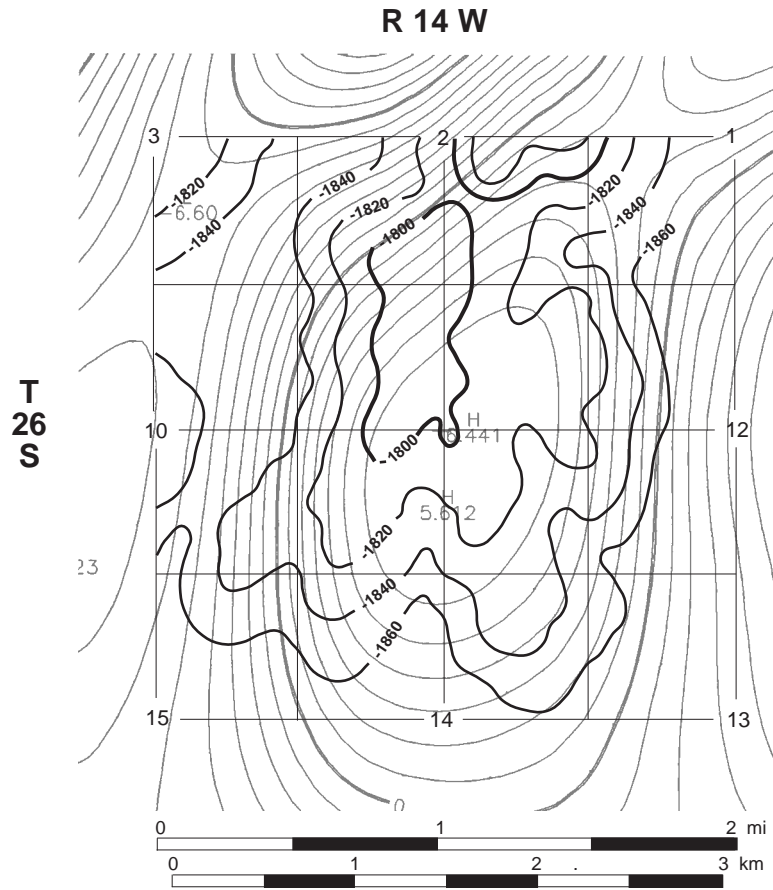


FIGURE 4. Moore SW Field, Pratt County, a probable gravicline, as evidenced by the close correspondence of the Lansing structure contours (black) with the residual aeromagnetic high (gray). Structure is from Hellman, 1985.

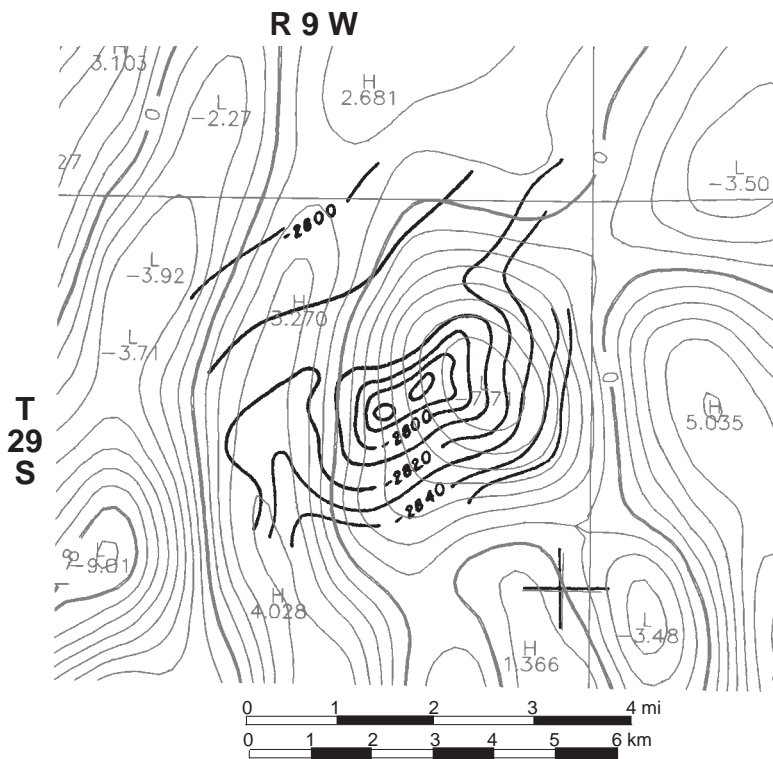


FIGURE 5. Willowdale Field, Kingman County, a probable gravicline, as evidenced by the close correspondence of the Viola structure contours (black) with the residual aeromagnetic low (gray). Structure is from Cruce, 1956.

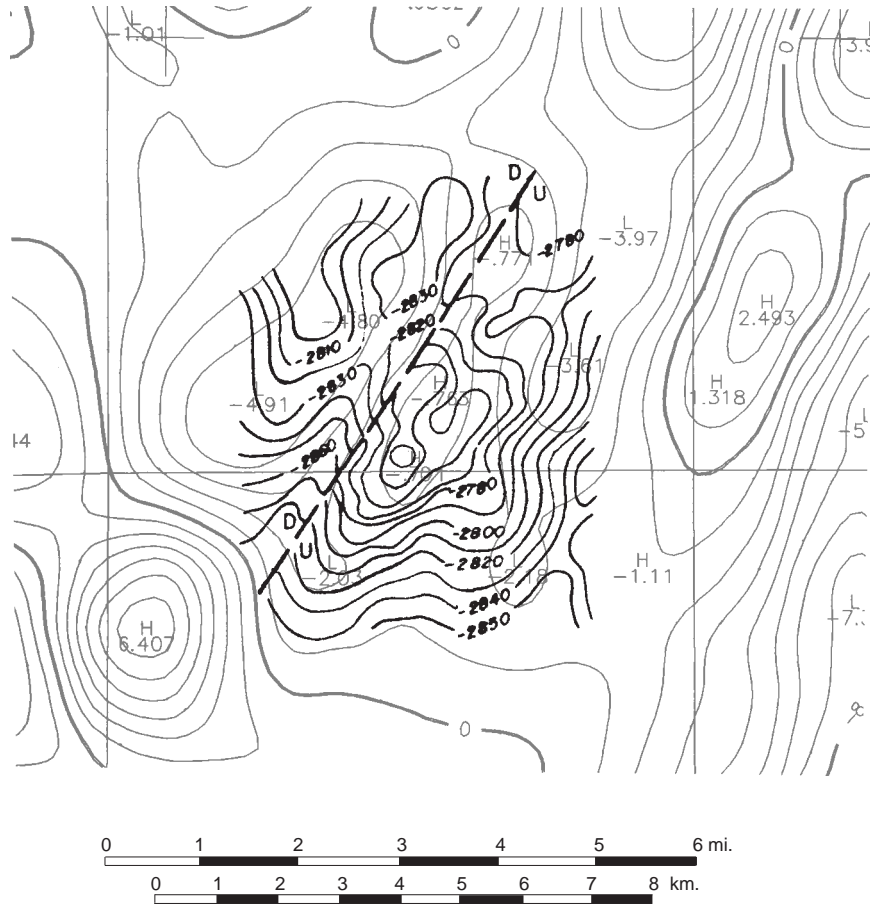


FIGURE 6. Alameda Field, Kingman County, a probable gravicline, as evidenced by the close correspondence of the Viola structure contours (black) with the residual aeromagnetic high (gray). Structure is from King, 1965.

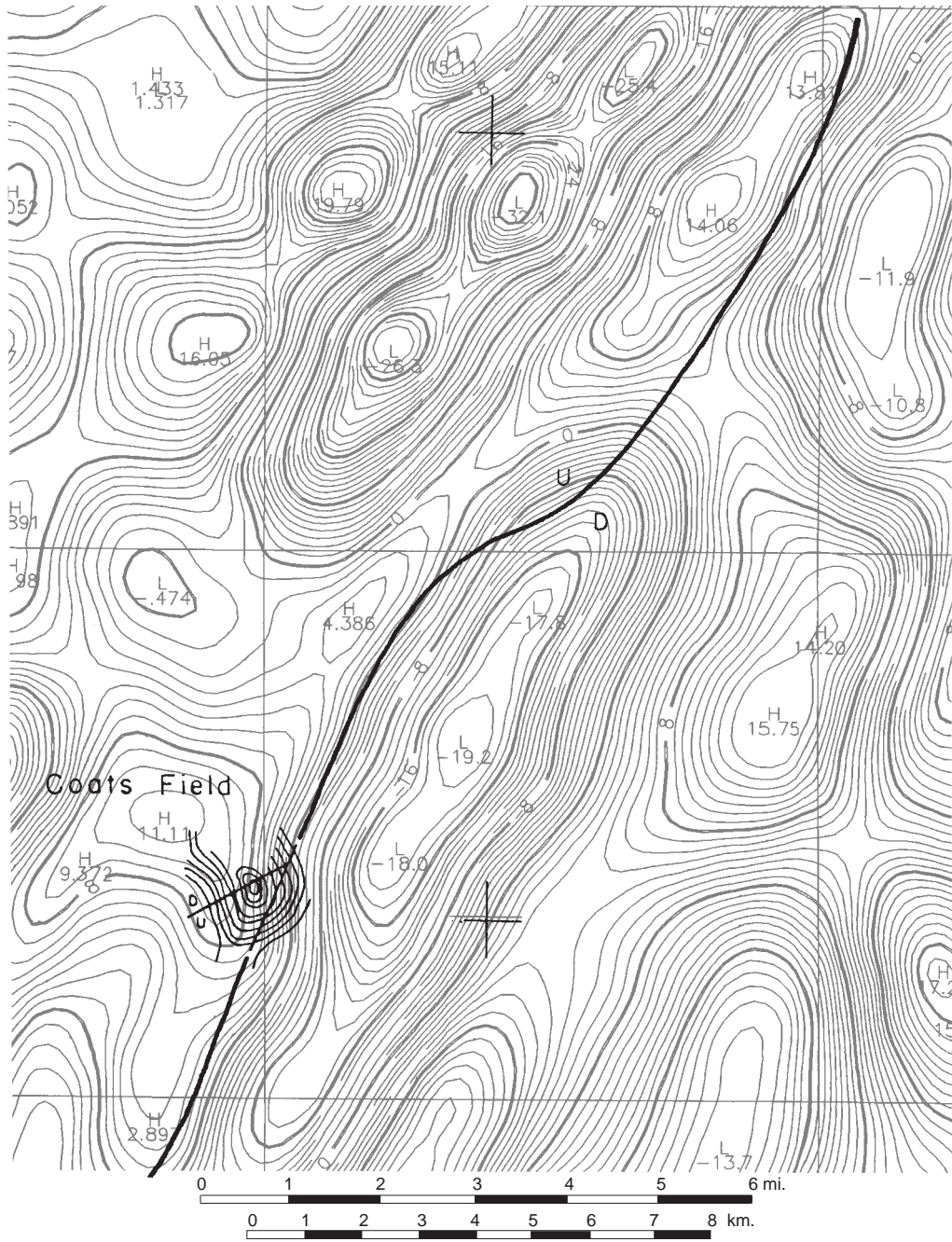


FIGURE 7. Coats Field, Pratt County, a possible gravicline. Other possible graviclins would be the "corners" (noses) of the same magnetic high where Coats field is located. Structure (black) is on top of Arbuckle at a 50 ft. contour interval and is from Curtis, 1956. Note the correlation of the long NE fault, the deep manifestation of the shallow Pratt anticline, along the "Yellowstone - Peace Creek Tectonic Zone" with the residual magnetic gradients (gray).

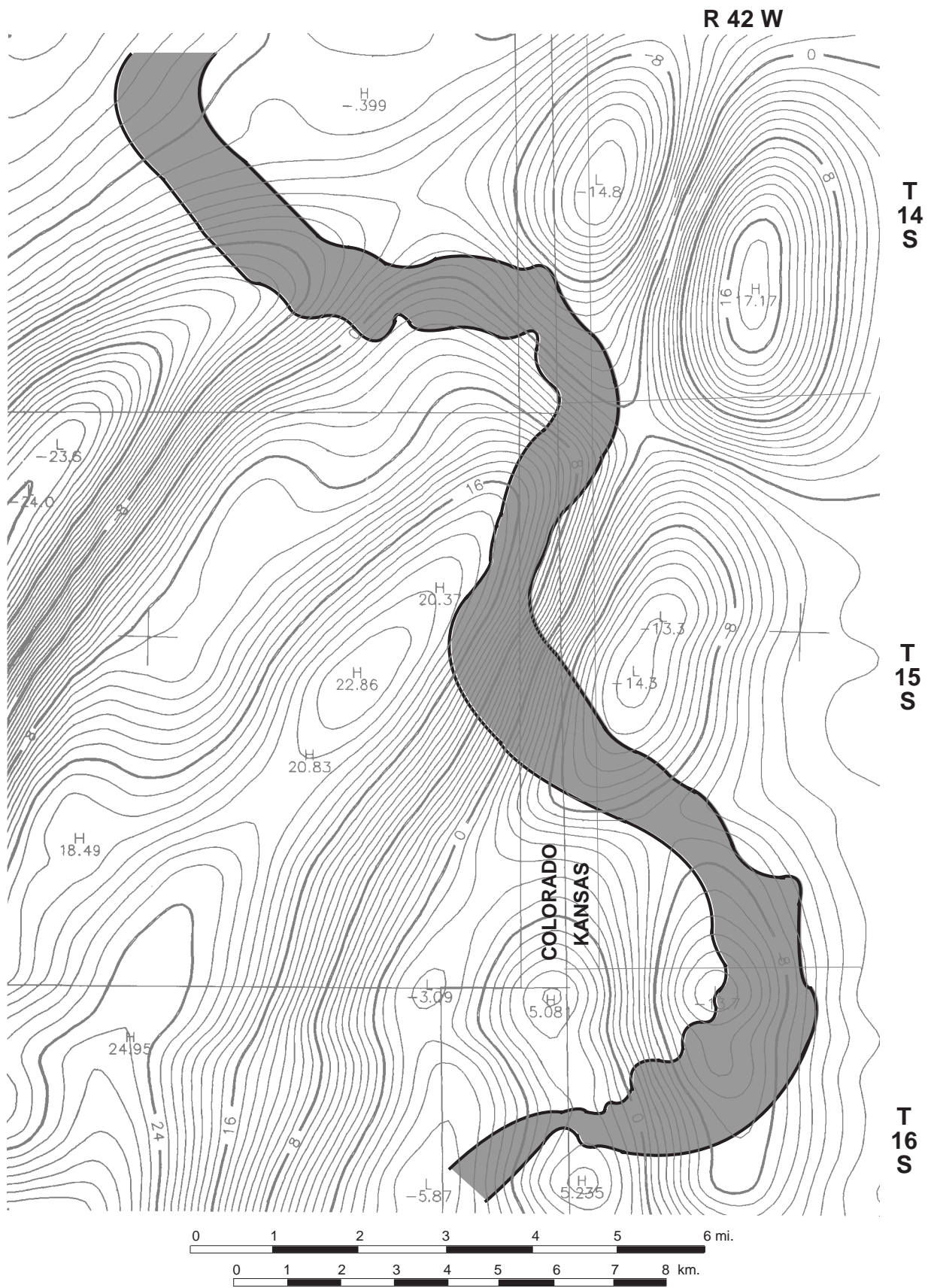


FIGURE 8. Stateline Trend, Wallace and Greeley Counties, Kansas, and Cheyenne and Kiowa Counties, Colorado, Superimposed on residual magnetic contours (gray). This prolific Pennsylvanian Morrow channel avoids residual magnetic highs and follows the magnetic lows and gradient areas, as do many similar channels in southeast Colorado.

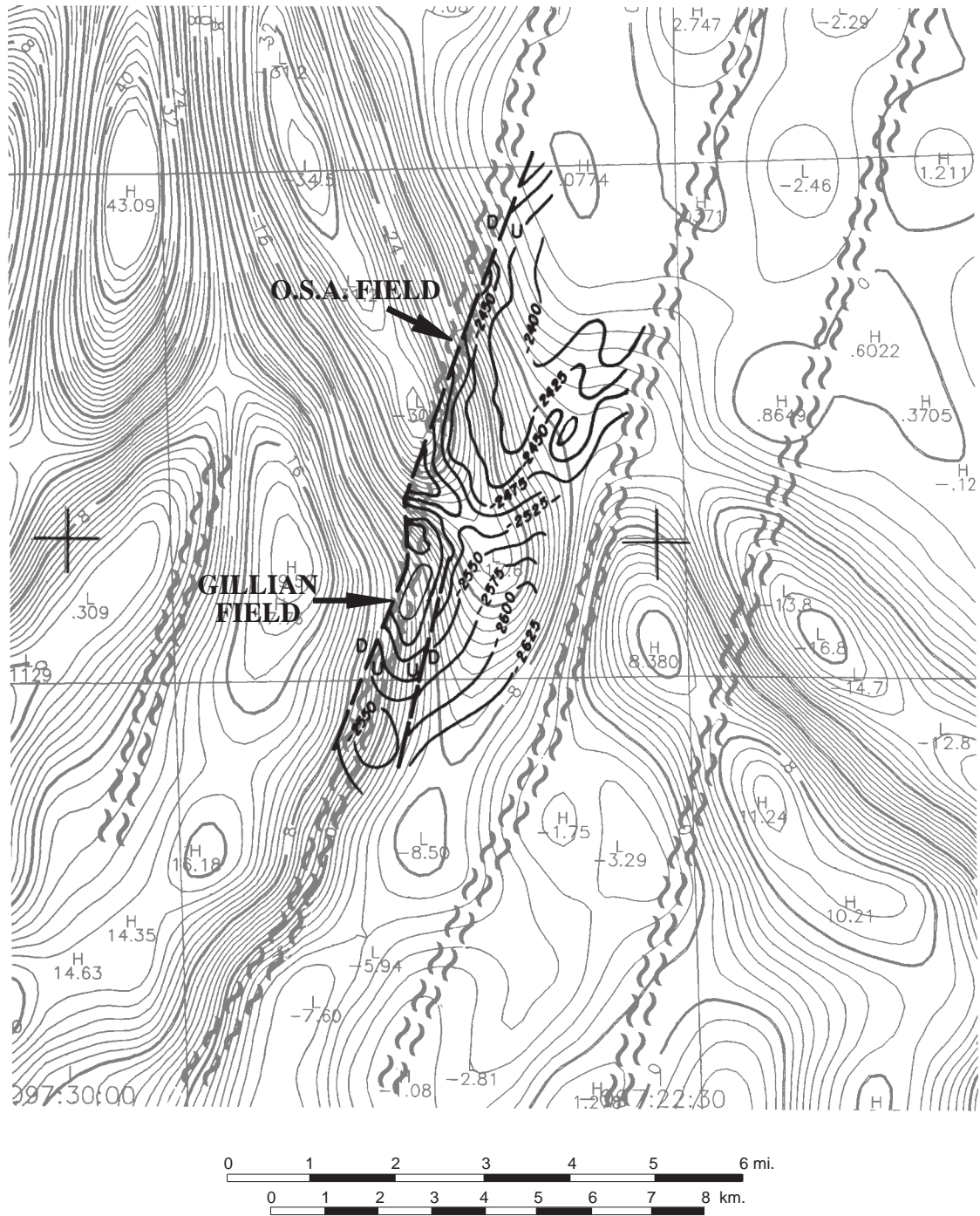
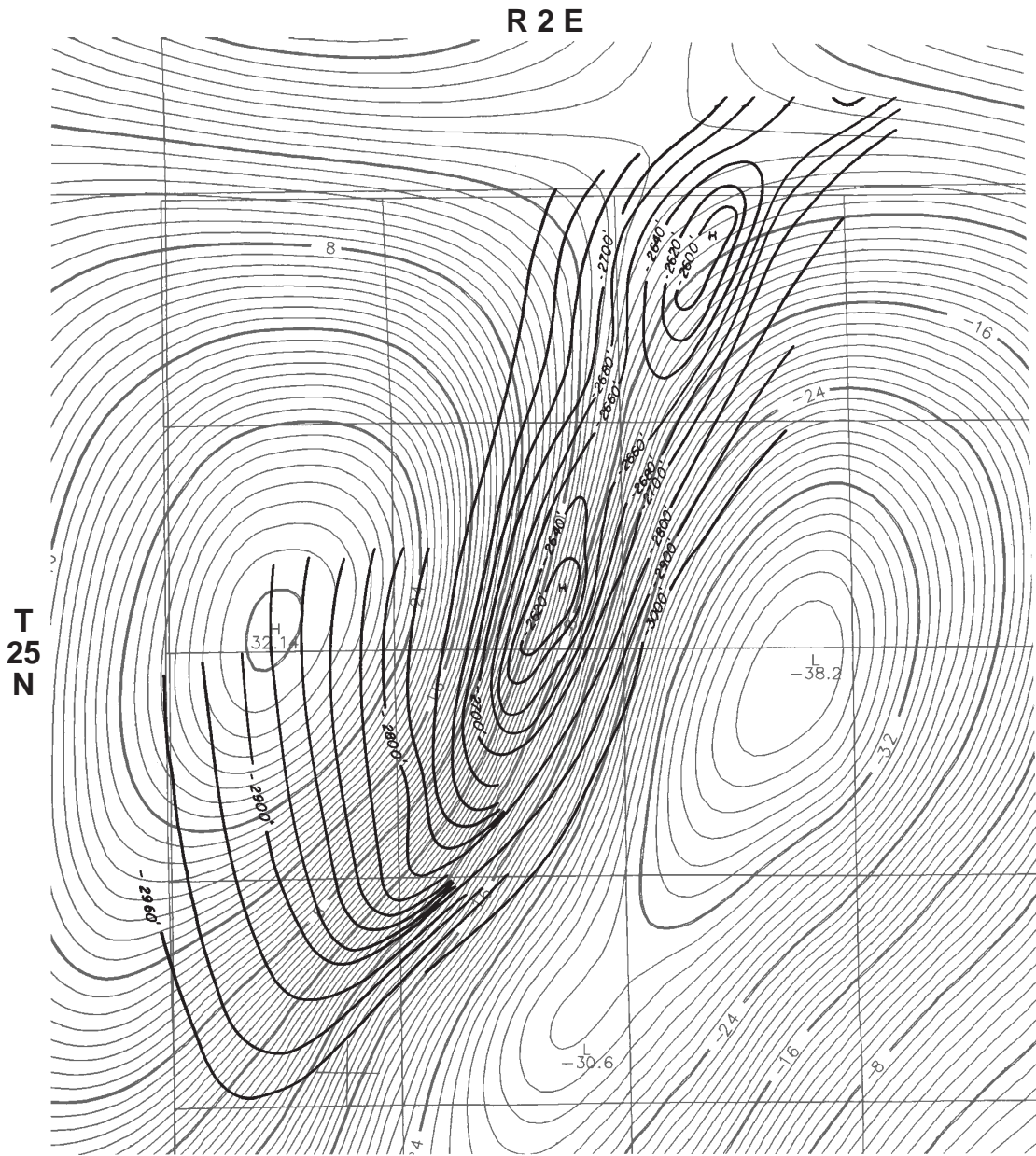


FIGURE 9. Gillian and O.S.A. Fields, Sedgwick County. The west fault on Gillian Field, which forms the trap, was exactly defined by a 1983 interpretation of the residual aeromagnetic map (gray contours). Structure contours (black) are on top of the Simpson Group, the producing horizon, and are from Shawver, 1965, a and b.



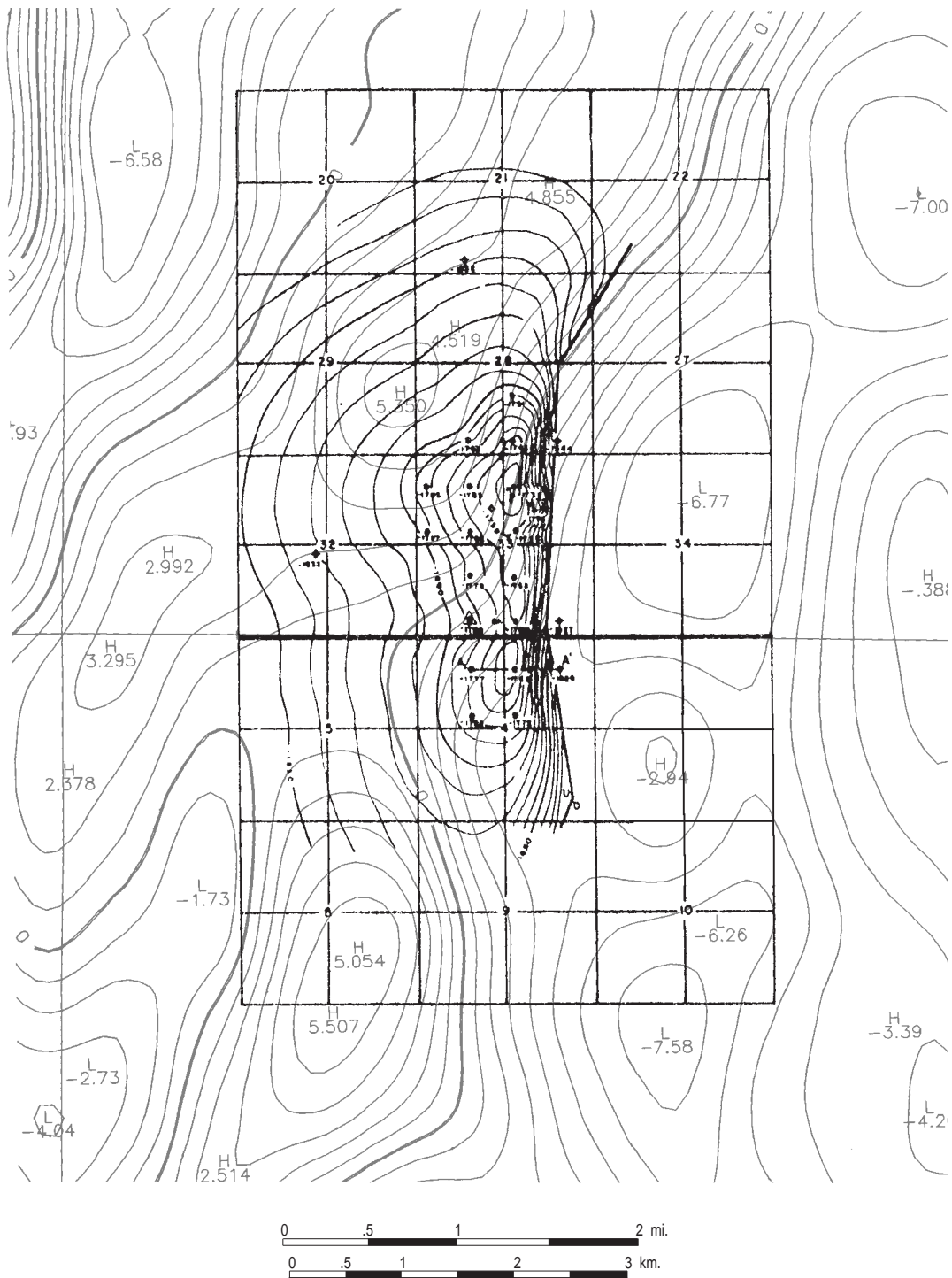


FIGURE 11. Davis Ranch Field, Wabaunsee County. A Kansas analog to Ponca City Field (Fig.10), 160 miles north of Ponca City in the Alma Trend along the same Nemaha-related fault system. Black contours are top of Viola formation; gray contours are residual magnetics. Structure is from Kansas Oil and Gas Fields, Vol. 3, 1960, p.53.



FIGURE 12. Cunningham Field, Pratt and Kingman Counties. Close correlation of the underlying basement shear zone with the asymmetric anticline indicates a probable reverse fault here, as in other similar fields in Kansas and Oklahoma. Black contours are on top of the Lansing formation; gray contours are residual magnetics. Structure is from Skelly Oil Company, Geology Dept., 1956.

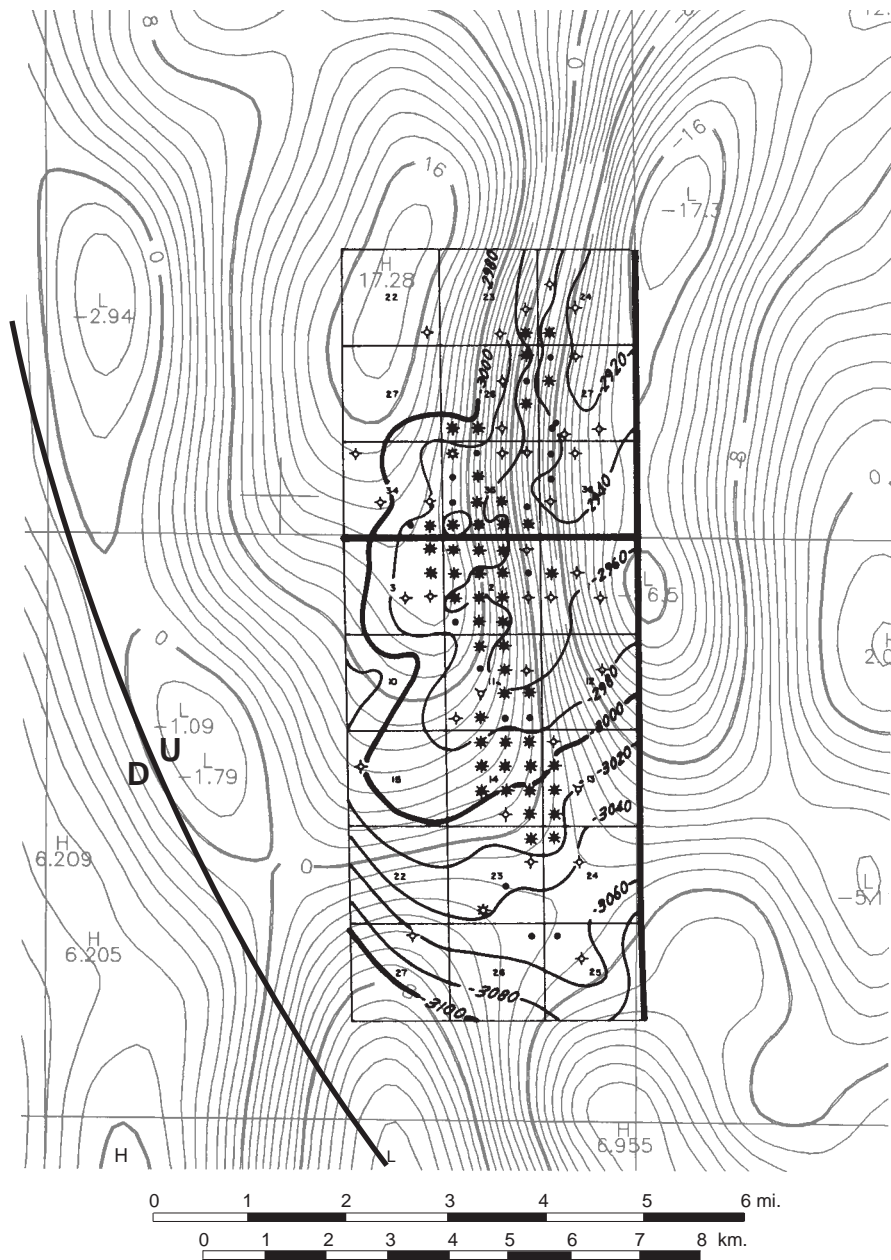


FIGURE 13. Collier Flats Field, Comanche County. Production in this field is from an oolite shoal that evidently developed on a fault scarp over an underlying basement fault defined by the gradient in the residual magnetic contours (gray). Structure contours (black) are on top of Pennsylvanian Swope limestone. Structure and wells are from Slamal, 1985.