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AEROMAGNETIC MAP OF NORTHEASTERN ILLINOIS AND ITS GEOLOGIC INTERPRETATION

By

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GEOPHYSICAL INVESTIGATIONS
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INTRODUCTION

During 1960 the U.S. Geological Survey made an aeromagnetic survey of some 12,500 square miles of northeastern Illinois. Much of the bedrock geology of this area is known only through well data and this type of information is scanty for the basal sedimentary units and the crystalline basement. As the size and shape of most aeromagnetic anomalies are controlled by basement lithology and depth of burial, studies of the anomalies provide valuable supplements to the data from deep borings.

Very little additional magnetic information is available for northeastern Illinois. McClure (1931) studied the vertical magnetic intensity throughout much of Illinois, concentrating on regions of known structure. Jensen (1949) published an aeromagnetic profile along the 40th parallel, about 40 miles south of the area of the present survey. McGinnis and Heigold (1961) presented vertical intensity maps for the entire state, based on 118 stations occupied by U.S. Coast and Geodetic Survey parties during 1955.

One hundred thirty east-west flight lines spaced at about one mile intervals were flown across the area; topographic maps and county road maps were used for guidance. These flight lines were joined by north-south tie lines to permit compensation for diurnal and instrumental drift. The survey was flown at an altitude of 500 feet above ground level. The magnetic measurements were made with a modified AN/ASQ-3A airborne magnetometer.

GEOLOGIC SUMMARY

STRATIGRAPHY

The most complete stratigraphic section within the area is located along the southern margin, where sandstone, shale, and carbonaceous sedimentary rocks of Precambrian to Pennsylvanian age reach a thickness of at least 6,000 feet. To the north, along the Wisconsin border, the upper Paleozoic units are absent, and the Cambrian and Ordovician sandstones and dolomites are considerably thinner (Suter and others, 1959, p. 31). Workman and Bell (1948, p. 2048) recorded a pronounced northeastward thickening of the Fond du Lac (?) Sandstone of Winchell (1899) and the Mount Simon Sandstone, which represent the basal units of the sedimentary section in Illinois. This thickening apparently reflects the influence of a structural high in the Ozark area. However, Workman and Bell (1948) also cited evidence for a similar thickening away from the Wisconsin upland in the area adjacent to the northern border of Illinois. Additional evidence for northward thinning of the sedimentary section is provided by the Ivan A. Steels No. 1 basement test well in eastern Winnebago County, which penetrated less than 2,700 feet of Ordovician and older sandstone and dolomite before bottoming in granite at a depth of 1,786 feet below sea level.

The crystalline basement underlying this sedimentary sequence is not exposed within the boundaries of the surveyed area, and the limited well data do not justify a detailed discussion of basement lithology. Precambrian crystalline rocks described in adjacent areas include plutonic igneous rocks, mainly granitic in composition, as well as a variety of metamorphosed sedimentary rocks.

STRUCTURE

The major structural elements of northeastern Illinois, in particular the Illinois basin, La Salle anticline, and Kankakee arch, all probably developed during the Paleozoic as a result of prolonged minor warping and subsidence, accompanied by intermittent deposition. The structure of the area has been discussed in regional syntheses by King (1951), Lockett (1947), and by Bell and others (1956). Many of the structural features discussed by these authors and summarized below have been subjected to a critical reappraisal and modification by Green (1957). The interpretive geophysical techniques used in this study lack the sensitivity necessary to distinguish between similar sedimentary structures; consequently, the older terminology rather than Green's is adhered to here, with no implication as to its validity. The approximate locations of most of the structures discussed below are indicated on figure 1.

Most of the Illinois basin is located south of the surveyed area; the marked southward slope indicated by the basement contour map represents the northern margin of the basin. In gross outline the Illinois basin is an elongate, asymmetrical structural depression, transected by several small folds and faults, that reaches a depth of more than 11,000 feet below sea level in southeastern Illinois (Workman and Bell, 1948, p. 2060). The basin is separated into unequal parts by the La Salle anticline (Cady, 1920). This anticline is a sharp, highly asymmetrical fold which has been described by Willman and Payne (1942, p. 183) as "... a broad step-fold or monocline having a maximum westward dip of 2,000 feet per mile and an easward dip of less than 25 to 50 feet per mile on the higher formations."

The term Kankakee arch has been applied to the broad shelf separating the Illinois and Michigan basins. Green (1957) pointed out that past attempts to fix the location of an axis for this feature have contributed to a moderate amount of confusion; consequently, no attempts to define such an axis will be made in this report. Where used, the term Kankakee arch refers simply to the structurally high portion of the area situated north of the Sandwich fault zone.

Three smaller structural features, the Sandwich fault, Ashton arch, and Hersher anticline, also seem to be reflected in the geophysical maps discussed in this report.

The Sandwich fault zone has been traced for a distance of at least 68 miles across the map area, trending approximately N. 60° W., and has a maximum throw of more than 900 feet (Willman and Templeton, 1951, p. 123).

The Ashton arch (Willman and Templeton, 1951, p. 121-122) consists of a broad, domal uplift, elongated roughly N. 50° W. It merges at its western end with the La Salle anticline. The northeastern flank of the Ashton arch is truncated throughout its length by the Sandwich fault zone.

The Hersher anticline is separated from the southeastern end of the Ashton arch by a shallow syncline. As shown on the structure-contour map of Willman and Templeton (1951, p. 122), the Hersher anticline is a highly asymmetrical, arcuate fold of moderate structural relief. Like the La Salle anticline, its steeper slope lies to the west.

A fourth minor structure (not shown) of an unusual nature is located in central Cook County, where a nearly rectangular area of some 25 square miles is underlain by complexly faulted sedimentary rocks ranging in age from Ordovician to Mississippian. Elsewhere in the vicinity relatively undisturbed Silurian dolomite lies immediately beneath the glacial drift. This small mass of severely faulted rocks has been described as cryptovolcanic structure, the Des Plaines disturbance. It has recently been studied in detail by Emrich and Bergstrom (1962) who interpreted it, with some reservations, as the product of meteor impact.

GEOPHYSICS

AEROMAGNETIC MAP

In the absence of strong magnetic contrasts within the sedimentary column, aeromagnetic relief is almost wholly a function of three factors, lithology, topography, and depth of burial, all pertaining to the crystalline basement. Of these factors, diverse basement lithology is thought to be the most significant. Basement topographic relief also may be the source of magnetic anomalies. However, anomalies with amplitudes of more than 500 gammas, such as are common in northeastern Illinois, would require improbably high magnetization contrasts and structural displacements if attributed solely to topographic relief of a magnetically uniform basement. (See, for instance, Nettleton, 1940, p. 220-222). Such anomalies most probably indicate lithologic contrasts within the basement. However, these contrasts may be accompanied in places by structural or erosional topographic relief at the basement horizon, thereby modifying the associated magnetic anomalies. Finally, depth to basement exerts a controlling influence on the curvature of magnetic gradients (Vacquier and others, 1951, p. 5).

Despite these considerations, some general correlations between aeromagnetic features and sedimentary structure in northeastern Illinois are apparent. The southern third of the aeromagnetic map displays a distinct north-northwesterly grain roughly parallel to the trend of the major structural elements in the area. To the north the lack of recognizable magnetic grain may reflect the relative structural stability of the Kankakee arch. Between these two areas is a belt of high-amplitude positive anomalies trending S. 60° E. across the map from a point on its western margin near lat. 42° N., long. 89°15′ W. This belt probably is related to the Sandwich fault zone, and may indicate mafic intrusions localized along a zone of structural weakness. Extended to the southeast beyond the mapped limits of the fault, this magnetic lineation passes into a moderately steep, linear gradient near the Indiana state line, suggesting a continuation of the fault in that direction.

BASEMENT CONTOUR MAP

The technique of depth-determination from magnetic data, (Vacquier and others, 1951), provides a direct approach to the question of the relation of basement topography to the structure and thickness of the overlying sedimentary strata. Sources of error inherent in this method arise from the assumption that the rock mass responsible for a given anomaly can be approximated by a bottomless, vertical, rectangular prism with a horizontal upper surface, uniformly magnetized in the direction of the earth's field. Vacquier and others (1951, p. 7-8) have shown that no serious error is introduced by reasonable departures from this assumption, and experience indicates that accurate results can be obtained when care is taken in selecting anomalies for analysis (Henderson and Zietz, 1958, p. 27-28; Vacquier and others, 1951, p. 10).

In the present study, excellent correspondence was obtained between a computed depth in southern De Kalb county (−2900 feet) and the depth of basement encountered in a well 3 miles to the southeast (−2788 feet). In general, however, nothing approaching this degree of reliability should be attributed to the depth computations for the Chicago area. Errors in excess of 10 percent may be commonplace, and may be as much as 35 percent for deeper determinations. Thus, although the basement contour map, figure 1, may depict the general configuration of basement underlying northeastern Illinois, it should not be regarded as a reliable guide to the details of buried basement topography.

The basement contour map shows several noteworthy features. A steeply plunging basement ridge apparently underlies the La Salle anticline throughout the area. Control for the ridge is sparse, but the general similarity in trend of the two features is unmistakable. Evidence supporting a western flank for the basement ridge is provided by wells located several miles west of the limits of the map, in central Lee County.

An ill-defined basement high branches off the main ridge near the northwestern end of the Sandwich fault. It appears to follow the trend of the fault for at least 40 miles to the southeast, at which point it becomes unrecognizable owing to a complete absence of control. Throughout this distance the axial trace of the ridge approximately coincides with that of the Ashton arch and Sandwich fault zone.

Separating these two ridges is a marked depression, or trough. The relatively steep southerly plunge of this feature seems to record the northeastern margin of the Illinois Basin.

No correlatives of the Sandwich fault zone and Hersher anticline are obvious in figure 1. Mean displacement on the Sandwich fault zone is about equal to the general range of uncertainty in depth calculations, and the sense of displacement on the fault is such as to complement the northeastern flank of the Ashton arch. Consequently, the fault cannot be distinguished by this method. On the other hand, the existence of a basement equivalent of the Hersher anticline should be readily detectable, but in this area there are no anomalies suitable for depth determination. Such anomalies as are present, however, suggest the presence of basement at a relatively shallow depth. On the basis of aeromagnetic evidence, Henderson and Zietz (1958, p. 28) defined a basement high in northwestern Indiana which appears to extend into the southeastern corner of the present map area. Thus, there is reason to suspect that the Hersher anticline also is underlain by a basement topographic high, although as yet very little is known of its shape or geographic extent.

The area of the Kankakee arch is characterized by shallow basement with gentle slopes. The average dip is to the southeast, at 40 feet per mile. Superimposed on this sloping surface are a basement ridge and adjacent trough, both of which plunge to the southeast. The easterly and northeasterly dips in Lake and Cook Counties possibly record the southwestern edge of the Michigan basin.

MAGNETIC UNITS AND BOUGUER GRAVITY

In an area underlain by a thick blanket of nearly horizontal, lithologically continuous sedimentary rocks, lateral density contrasts of sufficient magnitude to affect gravity measurements must in general originate in topographic or compositional irregularities in the crystalline basement. Thus, in northeastern Illinois,

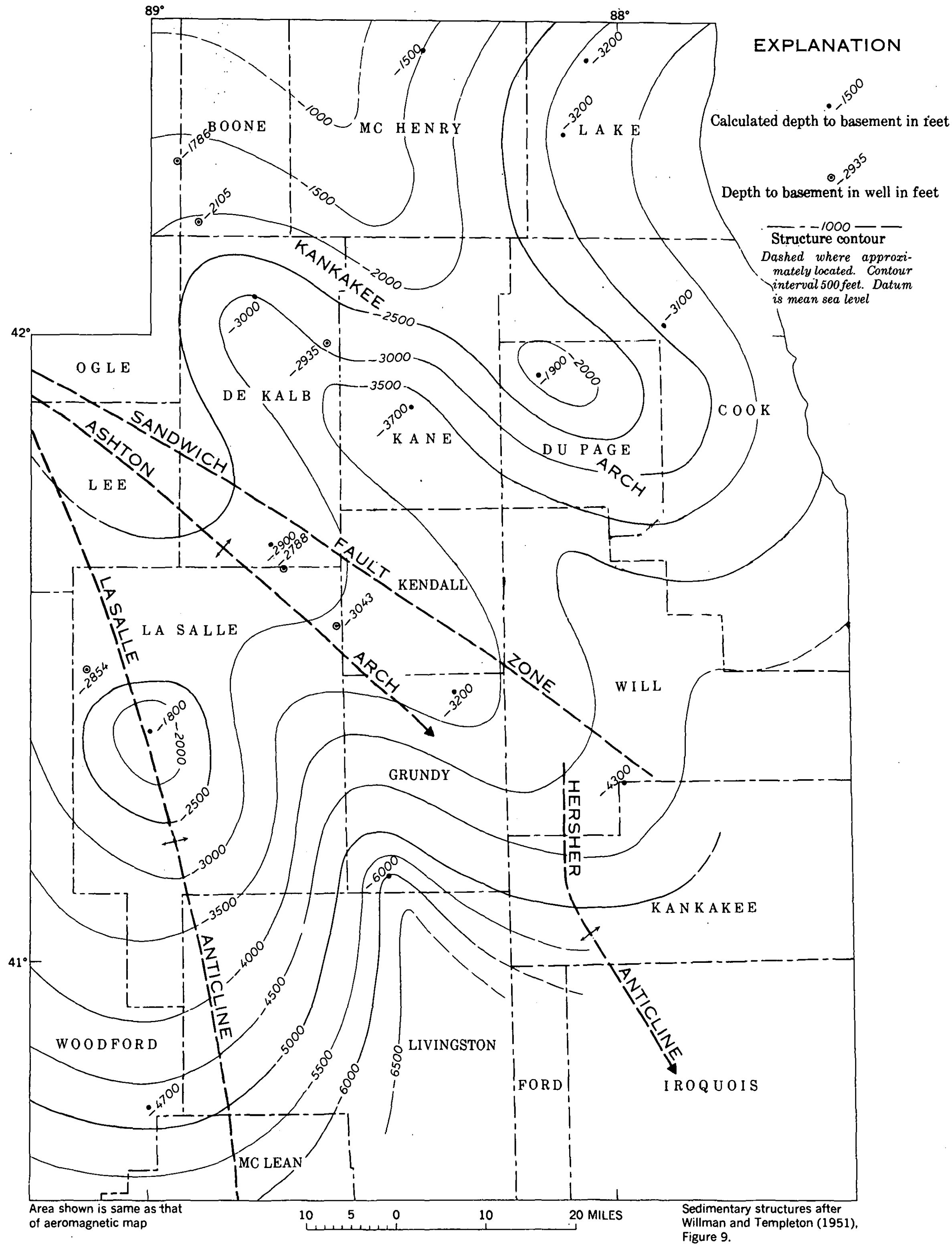

FIGURE 1. CONTOURS ON PRECAMBRIAN BASEMENT SURFACE OF NORTHEASTERN ILLINOIS

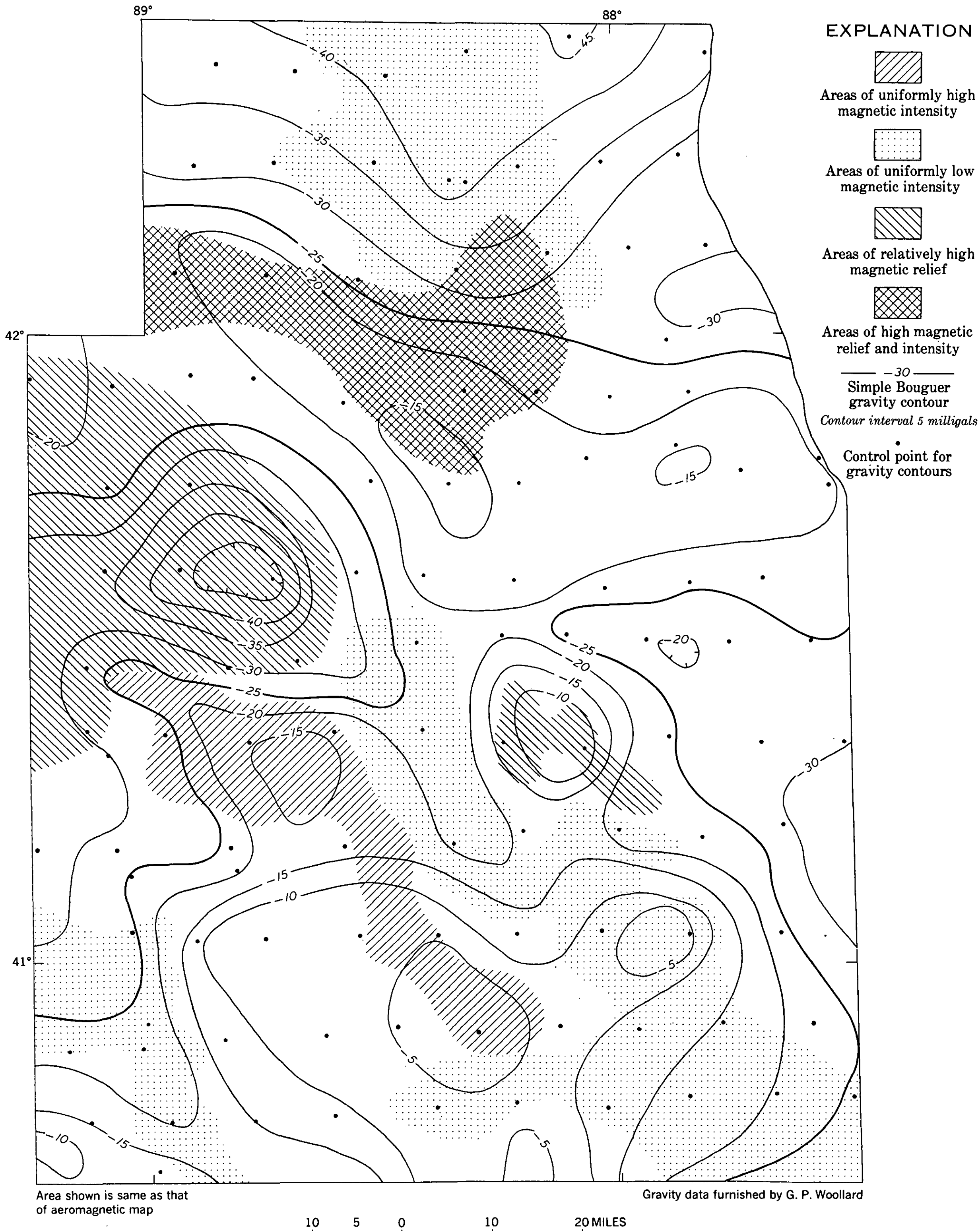

FIGURE 2. MAGNETIC UNITS AND SIMPLE BOUGUER GRAVITY MAP OF NORTHEASTERN ILLINOIS

the regional pattern of simple Bouguer gravity anomalies might reflect variation in thickness of sedimentary cover, compositional change in the basement, or both. Comparison of the gravity contours with the basement contour map suggests that in this area the effect of sedimentary thickness is minimal. For example, the marked increase in sedimentary thickness indicated by the basement topographic depression in La Salle, Grundy, and Livingston Counties appears to coincide with a gravity maximum. Another example of negative correlation is provided by the basement trough and positive gravity anomaly centered in Kane County. Evidently, the pattern of gravity anomalies in northeastern Illinois primarily reflects basement density contrasts. A comparison of magnetic and gravity maps for the area might then be expected to define certain geophysical units within the basement, based on systematic differences in density and magnetic properties.

Figure 2 was prepared from the aeromagnetic map by outlining areas of clearly similar magnetic expression. Boundaries for areas of uniformly high or low magnetic intensity were located at the steepest portion of their flanking gradients; boundaries for areas of high magnetic relief are largely subjective. Regional simple Bouguer gravity contours have been superimposed on these magnetic units, and the resulting map permits a generalized discussion of the physical properties and possible lithologies of much of the crystalline basement underlying the Chicago area.

Several areas of excellent correlation between the gravity and magnetic data are outlined by this process. Particularly conspicuous is the band of strongly magnetic, high-density material that trends north-northwest and northwest across the south-central part of the map. This unit, which may continue with slight interruption to the southern border of the area, is flanked to the east by a broad low of similar trend. The low is clearly defined on the aeromagnetic map, but is only suggested, through deflection of contours, by the gravity data. In a very generalized way, this low is associated with the postulated basement topographic prominence underlying the Hersher anticline, described above. To the southwest, a similar geophysical low, with similar orientation, trends across the southwest corner of the map.

To the north lie two areas of great magnetic relief, characterized by numerous small, sharp anomalies. These areas are centered near the axis of the Ashton arch, and are approximately bounded on the northeast by the Sandwich fault zone. These magnetic features exhibit strong correlation with the gravity data; however, their associated gravity anomalies are of opposite sign. Centered in the larger magnetically prominent area, near the west-central border of the map, is a conspicuous 15-milligal gravity minimum, whereas the small magnetic unit to the southeast is correlative with an equally prominent 10-milligal gravity maximum.

Finally, north of the Sandwich fault two magnetic units are distinguished. The northernmost consists of a broad area of low and uniform magnetic intensity, which correlates in a general way with a similar broad gravitational low extended southward from the Wisconsin border. Immediately south of this unit an irregular magnetically prominent area is discerned, characterized by steep gradients, numerous closed anomalies, and an overall high magnetic intensity. To the west this unit is well defined, and appears to correlate with a large gravity maximum, but in passing eastward it widens, transgresses the gravity pattern, and loses its identity.

Tentative lithologies may be assigned to these geophysical units on the basis of their physical properties, shape, and a knowledge of the Precambrian crystalline rocks of surrounding areas. Grogan (1949) and Suter and others (1959) summarized available well data pertaining to the basement complex underlying northeastern Illinois. Six wells were discussed, all of which are reported to have penetrated granitic rocks. Three of these lie within units of high magnetic relief, although not directly over closed positive anomalies, suggesting that the magnetically-prominent pattern stems from rock bodies of composite lithology. Where these are associated with gravity highs they may represent injection complexes, with mafic material intimately intruding a quartzo-feldspathic country rock. This explanation is inadequate when applied to the large magnetic unit located in the west-central part of the map area. This unit is characterized by the presence of closely spaced, high-amplitude magnetic anomalies, but correlates precisely with a marked gravity low. It is penetrated by two wells, both of which encountered rocks described as granite. The geophysical evidence suggests a low-density rock at least part of which is strongly magnetized, whereas the well data point to a granitic lithology. As it is unreasonable to impute so high a magnetization to rocks of granitic composition, perhaps what is indicated is an injection complex much as described above, but with a highly feldspathic country rock.

The three geophysical units in the southern third of the area are more readily explained. They closely parallel regional structural trends, and thus conform to the pattern of basement topography. Furthermore, the central, geophysically high unit is correlative with a sharp basement trough, and its flanking geophysical low may correspond to crystalline topographic prominences underlying the La Salle and Herscher anticlines. These geophysical characteristics possibly originate in parallel belts of erosion-resistent quartzite, separated by a Precambrian lowland underlain by mafic rocks, possibly amphibolite.

Finally, the relatively uniform, geophysically low unit located along the northern border of the map suggests the presence of a large, homogeneous body of granitic rock.

DES PLAINES DISTURBANCE

Nothing in the foregoing discussion casts much light on the origin of the Des Plaines disturbance, as this structure does not seem to be reflected in basement topographic features or associated with any particular geophysical unit. However, Pemberton (quoted by Emrich and Bergstrom, 1962) noted an 8 milligal negative Bouguer gravity anomaly associated with the feature, and his conclusions are supported by the regional gravity contours. Emrich and Bergstrom (1962, p. 968) concluded that the feature does not owe its origin to an underlying intrusion. The absence of a magnetic anomaly over the Des Plaines disturbance supports their conclusion only to the extent that it indicates that no mafic intrusion is present, but does not preclude the possibility of a granitic intrusive mass.

SUMMARY

The basement complex underlying northeastern Illinois consists of diverse rock types bevelled by an undulating erosional and structural surface. This surface slopes to the southeast and south from the Wisconsin border, where it lies at less than 2,000 feet below sea level, and attains a maximum depth of approximately 6,500 feet below sea level in Livingston County, from which point it plunges south of the surveyed area into the Illinois basin.

Several geophysical units are chosen by a comparison of aeromagnetic and gravity data. These units probably correspond to definite lithologic types within the basement, and their diversity indicates that a considerable compositional range exists within the Precambrian of northeastern Illinois. In the southern half of the area, geophysical units, basement topographic features, and structures within the Paleozoic sedimentary rocks all have the same north-northwesterly trend.

Structures within Paleozoic strata, in particular the La Salle and Hersher anticlines, may have arisen in a variety of ways. The geophysical evidence suggests that they somehow are related to Precambrian structural trends. They may be due to a renewal of deformation along Precambrian fold axes during the Paleozoic, or the Paleozoic fold axes may have arisen from differential compaction over basement topographic features, themselves the direct or indirect products of Precambrian deformation. These sedimentary structures might then have served to localize subsequent compressional stresses, thus producing anticlinal folds situated over basement ridges, without the necessity of flexure in the crystalline rocks themselves. Comparatively minor structures, such as the Hersher anticline and Ashton arch, conceivably might have originated in this way. The La Salle anticline, however, is a major element in the regional structural pattern, and as such probably owes its existence to a renewal of activity along Precambrian structural trends.

The Sandwich fault zone does not show up on the basement contour map, possibly owing to its lack of great displacement. Nevertheless, it seems to have localized several mafic intrusions, and also appears to have affected the distribution of several basement geophysical units. Thus, there is reason to believe that the Sandwich fault zone also originated in Precambrian time, and has been rejuvenated.

ACKNOWLEDGMENT

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