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Basement Rocks of the Main Interior Basins of the Midcontinent

Edward C. Lidiak

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EDWARD G. LIDIAK*

ABSTRACT

The basement underlying the deeper basins in the Midcontinent is not well known because of the considerable thickness of overlying sedimentary rocks. However, gravity and magnetic surveys and sparse wells to basement suggest that deeper intracratonic basins are characteristically underlain by denser and more magnetic rocks than in adjacent areas. This correlation has important bearing on understanding the tectonic development and geologic history of Midcontinent basins.

The Michigan basin is underlain by prominent, linear gravity and magnetic highs that extend across the southern peninsula. A recent deep well to basement encountered basalt overlain by red clastic sedimentary rock. The combined geophysical and geological data support the idea that the basin is underlain by a Precambrian rift zone. The Illinois basin also contains prominent gravity and magnetic anomalies. The broad anomalies do not appear to correlate with any specific rock type at or near the top of the basement and may instead reflect intrabasement variation, such as major tectonic boundaries. The more local, closely spaced anomalies outline a complex reactivated rift zone that trends generally northeast through the deepest part of the basin. The Williston basin is another deep basin that is underlain by a linear gravity high. The gravity anomalies continue into Canada where they are associated with granulites and major fault zones that occur near the boundary between the Superior and Churchill provinces. The few wells to basement in the deeper parts of the Williston basin along the gravity high encountered granulites and other high-grade metamorphic rocks, suggesting that a major tectonic boundary similar to that occurring in Canada is present in the basement underlying the basin. The Forest City and Salina basins contain less distinct gravity highs, which occur on opposite sides and are partly obscured by the well known Midcontinent gravity high and rift zone. The remaining basin under discussion, the Arkoma basin, differs from those previously discussed in that it contains a large gravity low, which probably reflects the development of an extremely thick section of sedimentary rocks along the Ouachita structural belt. The Arkoma is, thus, more comparable to the Appalachian basin than to the other basins, which are totally within the craton.

The basins of the Midcontinent have apparently not all had the same tectonic development and are probably more complex than generally envisioned. A generalization which appears to be a useful working hypothesis is that intracratonic basins of the continental interior differ from foreland basins and originated by reactivation of older structures during periods of extensional tectonism. Consideration of basin development should take into account the Precambrian as well as the overlying Phanerozoic rocks.

INTRODUCTION

The origin and development of basins have long been an intriguing problem in the geology of continents. In general, the deep structures, rock units, and early history are particularly obscure. Work initiated by Muehlberger and others (1967) on general basement rock studies in the Midcontinent suggested that basins are different from arches and plains. Little direct knowledge on the lithology of the basement underlying the basins was available in this early study. Direct sampling of the basement in the deeper basins is still extremely limited. However, the increasing availability of regional and more detailed gravity and magnetic maps, seismic profiles, and geologic data provide a basis for interpreting the development of Midcontinent basins.

The purpose of this paper is to discuss the Precambrian framework of the Michigan, Illinois, Williston, Salina-Forest City, and Arkoma basins, to categorize basins according to type that occur in the Midcontinent and immediately adjacent areas, to contrast intracratonic basins from foreland basins and aulacogens, and to discuss the possible origin of intracratonic basins of the Midcontinent.

The location of the main basins in the general area of the Midcontinent is shown on Figure 1.

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MICHIGAN BASIN

Structural Framework

The Michigan basin is a prominent and well-documented cratonic basin that occupies the southern peninsula of Michigan. It contains an estimated maximum thickness of more than 15,000 feet of Phanerozoic sedimentary rocks that accumulated during subsidence dominated by flexure rather than by faulting (Cohee, 1945; Hinze and

*Department of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, Pennsylvania 15260.

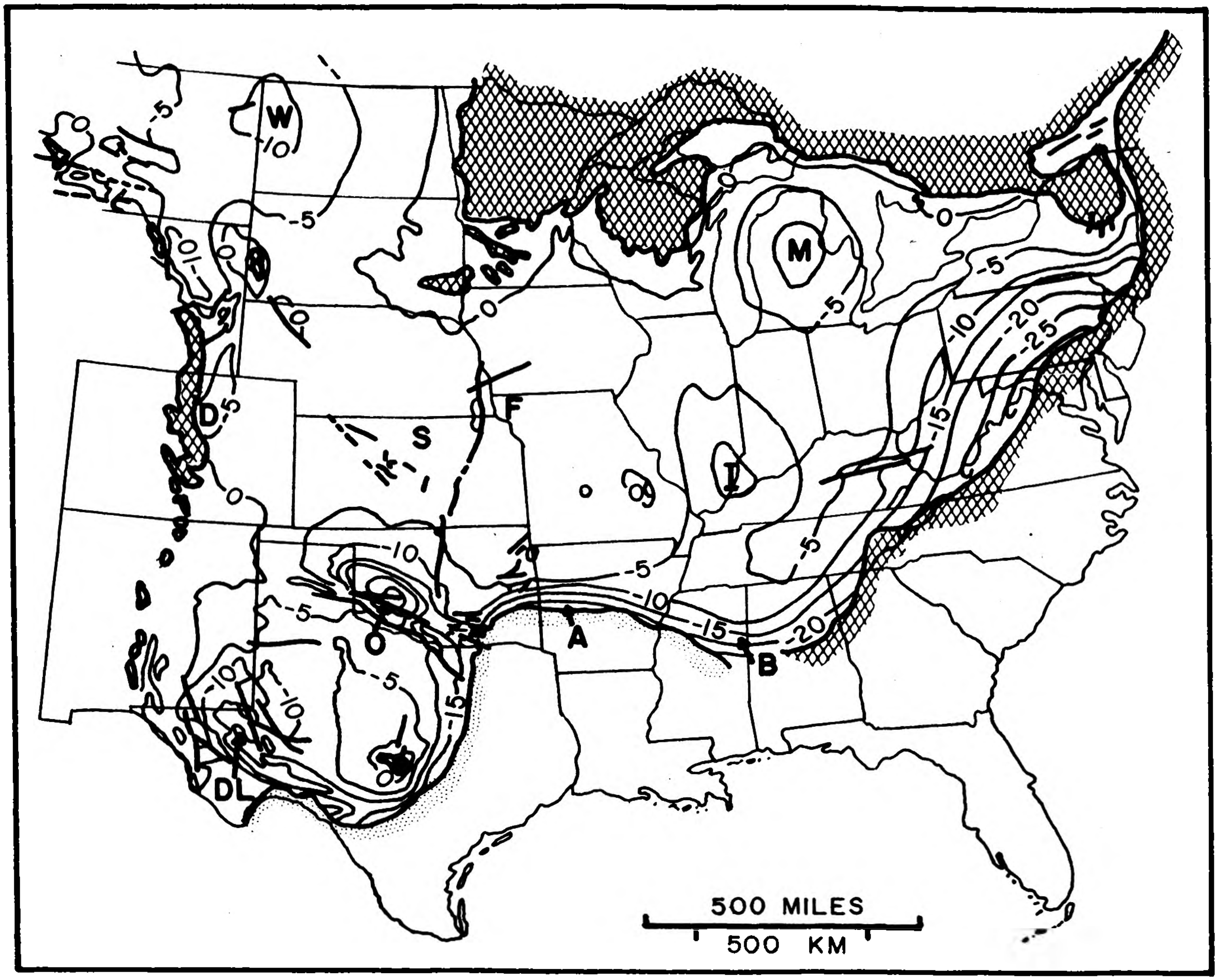

Fig. 1. Distribution of basins in the Midcontinent region, United States. Contours are in thousands of feet on the buried basement surface. Basin abbreviations: A - Arkoma, B - Black Warrior, DL - Delaware, D- Denver, F - Forest City, I - Illinois, M - Michigan, O - Southern Oklahoma, S - Salina, W - Williston. Exposed Precambrian, cross-hatched pattern. Ouachita system, dotted pattern. Adapted from Flawn (1967).

others, 1975; Sleep and Sloss, 1978). The Precambrian basement underlying these cover rocks is broadly oval in outline with little or no small-scale topographic relief (Fig. 2).

Basement Rocks and Regional Geophysics

Limited samples are available from the basement, which has been penetrated by a total of 22 wells. Most wells are in the southeastern part of the basin where depth to basement is generally less than about 7,000 feet. As a consequence, regional geophysical studies, mainly gravity and magnetic surveys, are the main source of information on the lithology and structure of the basement. The Michigan basin is an excellent example of the combined use of regional geophysical and limited basement well data in interpreting basement geology.

The main geophysical feature of the Michigan basin is a prominent linear Bouguer gravity (Fig. 3) and magnetic high that trends north to northwest across the southern peninsula (Hinze, 1963; Hinze and others, 1975). The magnitudes of these anomalies clearly indicate that they originate from lithologic and structural variations in the basement rather than from sources in the overlying sedimentary rocks. Hinze and co-workers (Hinze, 1963; Oray and others, 1973; Hinze and others, 1971, 1975) have correlated these anomalies with middle Keweenawan basalts and associated upper Keweenawan clastic sedimentary rocks and postulated that the rocks accumulated in a continental rift zone of Keweenawan age, similar

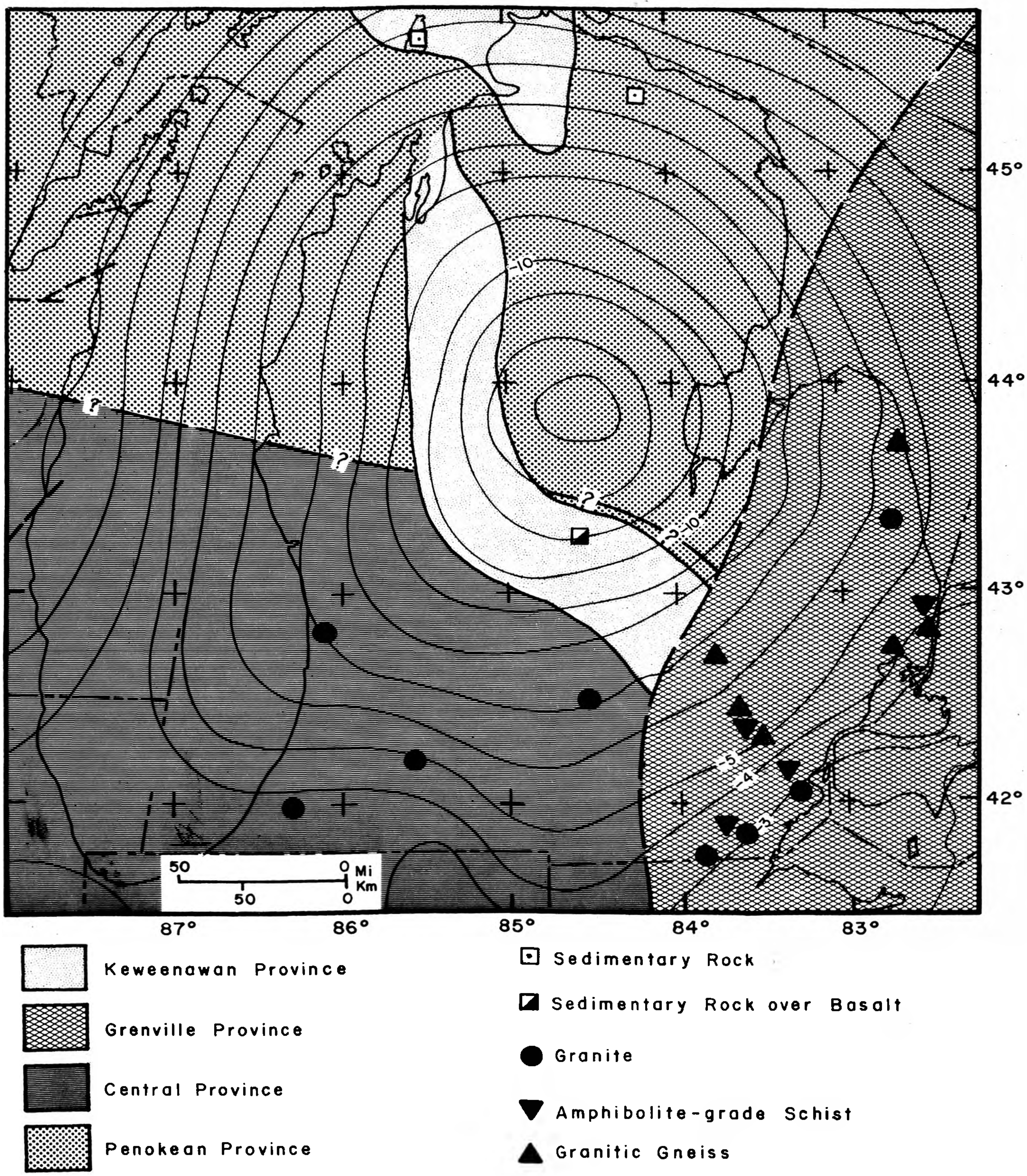

Fig. 2. Geologic map of basement rocks in the Michigan basin. Basement configuration contours, in thousands of feet, from Bayley and Muehlberger (1968).

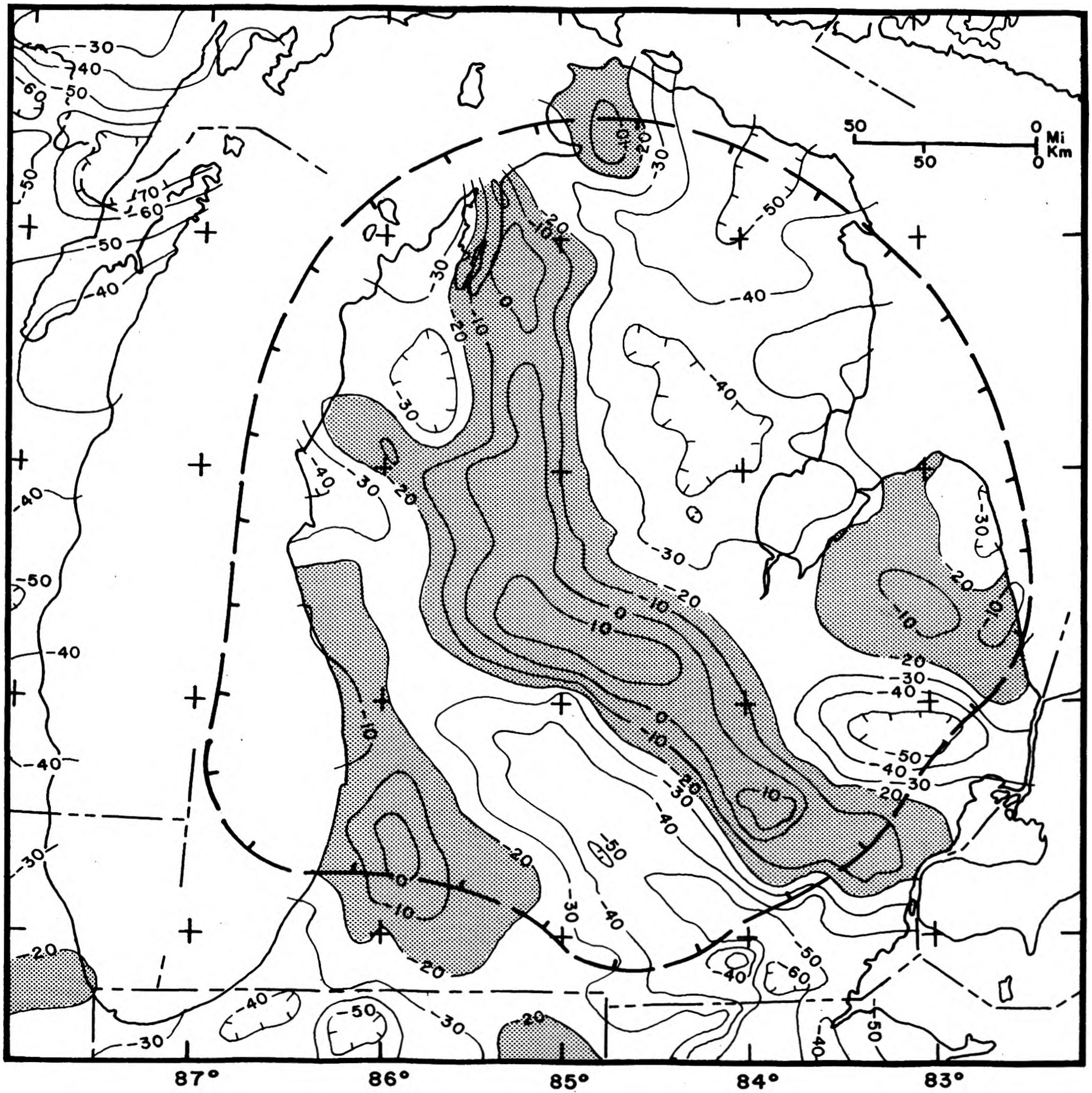

Fig. 3. Bouguer gravity map of the Michigan basin. Contour interval is 10 mgal. From Am. Geophys. Union and U.S. Geol. Survey (1964). Gravity highs - stippled pattern. Dashed hachure line outlining the Michigan basin is the -5,000 ft. contour of Figure 2.

to the rift that developed along the Midcontinent gravity anomaly (King and Zietz, 1971; Ocola and Meyer, 1973).

The main basement provinces and the lithology of available basement well samples are shown on Figure 2, which is adapted from Hinze and others (1975). Recent wells to basement have been added. Delineation of the provinces is based on lithology of basement well samples, isotopic ages, and extrapolation of geologic trends from the exposed Precambrian shield to the immediate north and west of the Michigan basin. Four main provinces are recognized. The presence of the oldest province, the Penokean province, in the northern part of the basin is based entirely on extrapolation of geophysical and structural trends. Inferred rock types are mainly metasedimentary rocks, metavolcanic rocks, and gneisses. These rocks were probably deformed and metamorphosed 1600-1800 m.y. ago, during the Penokean orogeny.

The Central province occupies the southwestern part of the basin, and is widespread in the northern and eastern Midcontinent of the United States (Lidiak and others, 1966). The main rock types consist of granite, rhyolite, and related rocks; metasedimentary rocks and gneisses are subordinate. Isotopic ages in the range of 1200 m.y. to 1500 m.y. have been obtained on samples from adjacent areas.

The third province, the Keweenawan province (1050-1150 m.y.), coincides with the prominent gravity (Fig. 3) and magnetic anomalies that transect the Michigan basin. A recent deep drillhole on the gravity anomaly in Gratiot County, Michigan, encountered pre-Mt. Simon (Upper Cambrian) lithified red mudstone and interbedded arkosic sandstone underlain by coarsely ophitic metabasalts (Sleep and Sloss, 1978; McCallister and others, 1978; Fowler and Kuenzi, 1978). Two other deep wells on Beaver Island in Lake Michigan on the western flank of the linear gravity anomaly also encountered a similar red-bed sequence (Fowler and Kuenzi, 1978). The pre-Mt. Simon rocks in these three wells are strikingly similar to the middle Keweenawan basalts and upper Keweenawan sedimentary rocks of the Lake Superior region. The combined geological and geophysical data thus strongly suggest the presence in the Michigan basin of Keweenawan-age rift zone.

Grenville-like rocks compose the fourth province, which extends southwestward from the Canadian Shield across the eastern margin of the basin and continues southward into Ohio. The province is characterized by medium- to high-grade metamorphic rocks, gneisses, and granites. Anorthosites and calc-silicate rocks are present locally. Prominent gravity and magnetic anomalies parallel the Grenville trend along most of its extent. The youngest major period of metamorphism and igneous activity occurred about 1100 m.y. ago. K-Ar and Rb-Sr ages of 800-1100 m.y. on micas reflect later tectonic or thermal disturbance and probably deep burial and subsequent uplift. An important aspect of the Grenville front in this region is that the front appears to crosscut the Keweenawan rift zone. Hinze and others (1975) have noted that there is no correlative positive magnetic anomaly associated with the southeast-trending gravity anomalies east of about longitude 83° 45'W, which is near the boundary between these two provinces. The absence of a magnetic anomaly suggests that basalt is not present at or near the basement surface east of this boundary, probably because of erosion and uplift during Grenville orogenic activity. The eastward continuation of the gravity feature is attributed to an intrabasement anomaly, perhaps reflecting metamorphosed Keweenawan mafic intrusive rocks at depth.

ILLINOIS BASIN

Structural Framework

The Illinois basin occupies most of southern and central Illinois and adjacent parts of Indiana, Kentucky, and Tennessee. The basin is moderately elongate in a north-northwestern direction and is bounded by the Ozark uplift to the west, the Pascola arch to the south, and the Nashville dome to the east. The basin has a maximum depth of about 15,000 feet in southern Illinois (Fig. 4).

Complex structures occur in the deeper parts of the basin at the intersection of the extension of the New Madrid seismic zone and the 38th-Parallel lineament (Heyl, 1972; Braile and others, in press). This region is centered on the most intensely faulted area in the central cratonic United States. The other major structure in the basin is the La Salle anticlinal belt, the western edge of which is a monocline that slopes steeply westward (Wilman and others, 1975). Many smaller structures are present throughout the basin.

Basement Rocks and Regional Geophysical Setting

Approximately 18 wells have been drilled to basement or to pre-Mt. Simon (Upper Cambrian) sedimentary rocks in the general area of the Illinois basin. Their distribution and lithology are shown on Figure 4. The main rock types are granite, rhyolite, trachyte, basalt, and unmetamorphosed sedimentary rock. The felsic igneous rocks are petrographically similar to the granites, rhyolites, and trachytes of the St. Francois Mountains, which formed 1400-1500 m.y. ago. These rocks are part of a great elongate northeast-trending anorogenic felsic igneous province that is extensively developed in the central craton of the United States (Engel, 1963; Goldich and others, 1966; Lidiak and others, 1966; Muehlberger and others, 1966, 1967; Silver and others, 1977; Emslie, 1978; Denison and others, in press).

Regional geophysical anomalies indicate that dense and magnetic rocks are also common at the basement surface or in the basement infrastructure beneath the Illinois basin. A Bouguer gravity map of the basin (Fig. 5) shows a broad high that has a regional northwest trend and along which occur more local highs. Similar trending aeromagnetic anomalies are also present (Lidiak and Zietz, 1976). More detailed maps (Braile and others, in press) confirm these anomalies, show

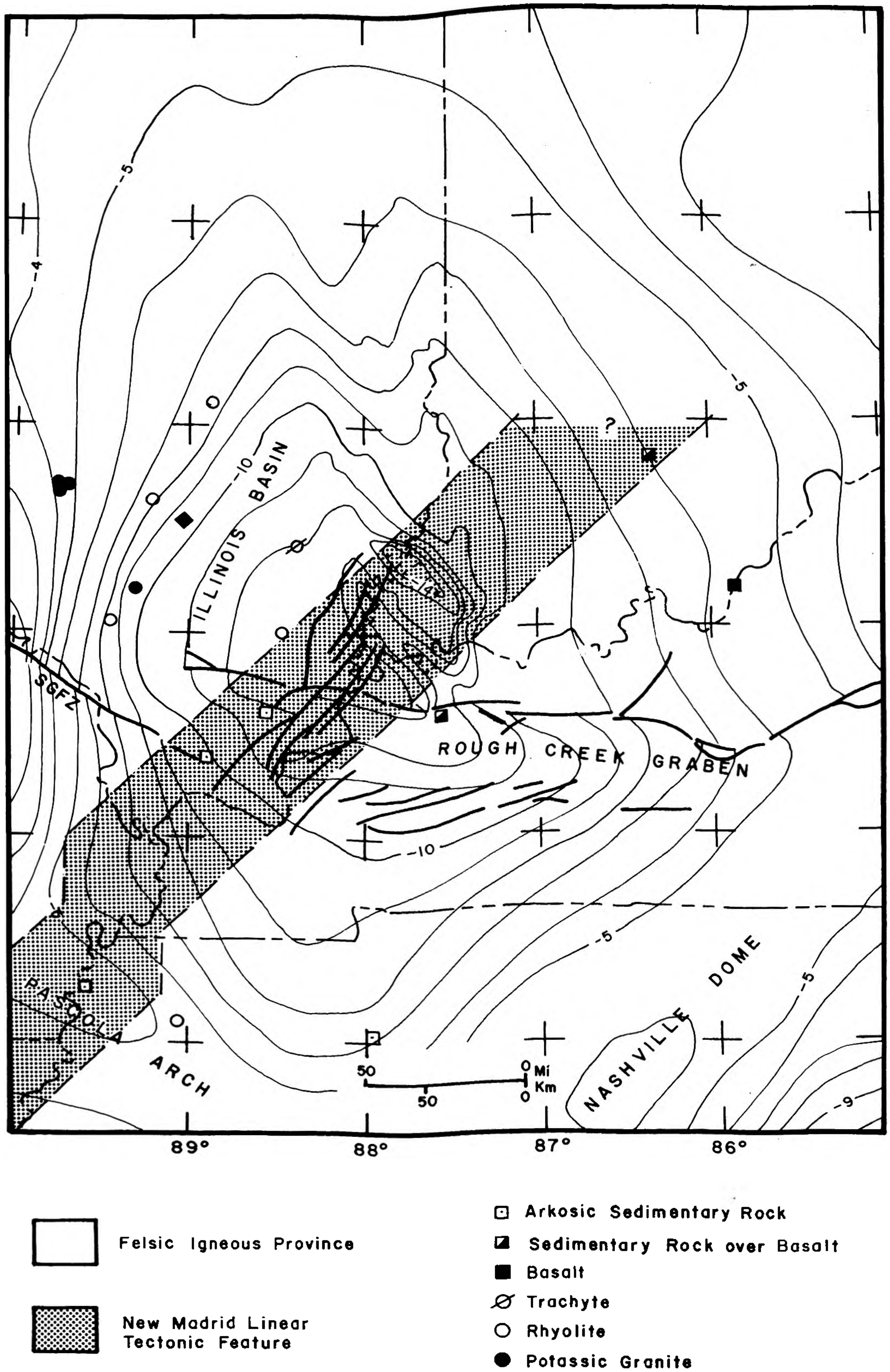

Fig. 4. Geologic map of basement rocks in the Illinois basin. Basement configuration contours, in thousands of feet, from Bayley and Muehlberger (1968). SGFZ - Ste. Genevieve fault zone.

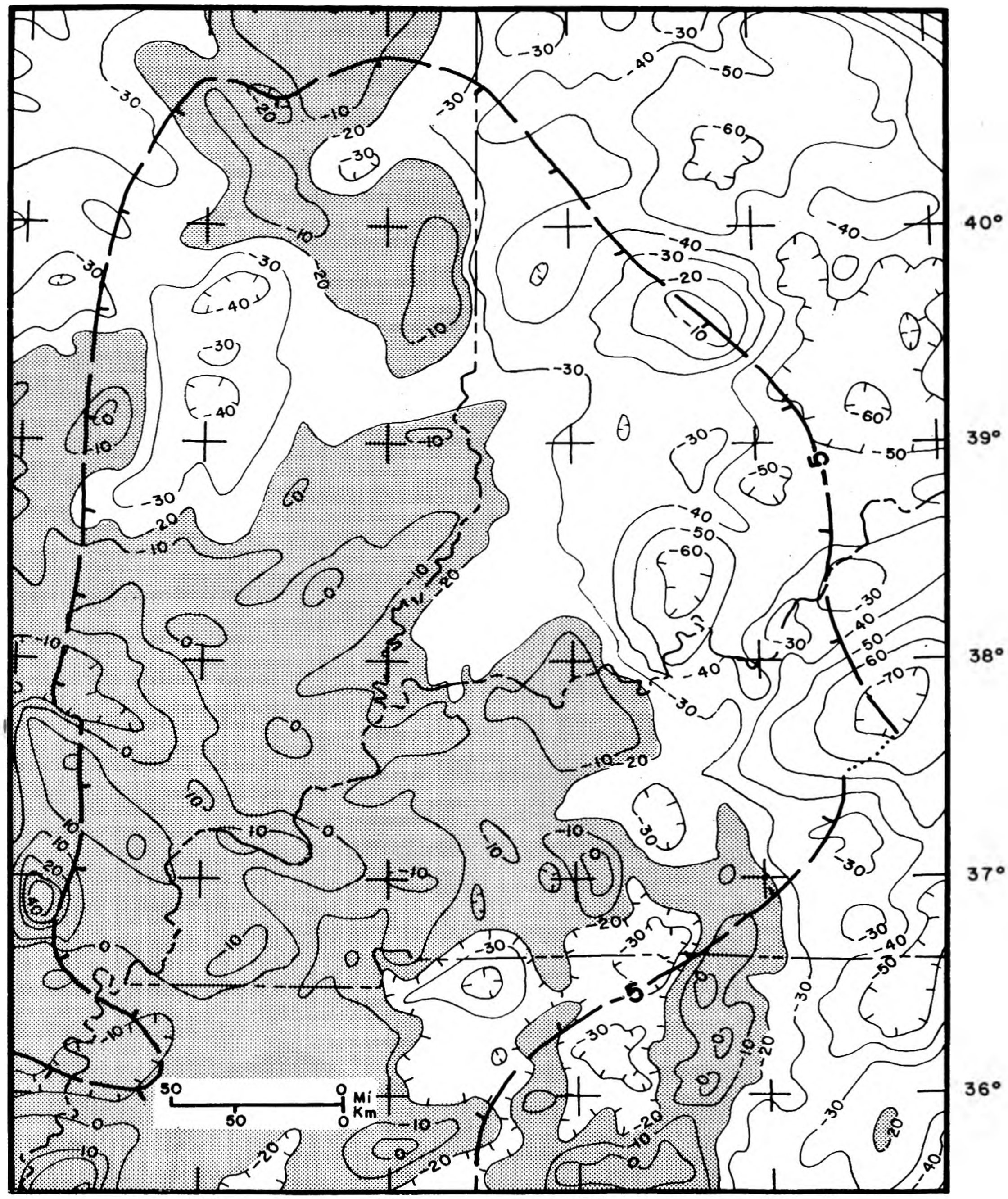

Fig. 5. Bouguer gravity map of the Illinois basin. Contour interval is 10 mgal. From Am. Geophys. Union and U.S. Geol. Survey (1964). Gravity highs - stippled pattern. Dashed hachure line outlining the Illinois basin is the -5,000 ft. contour of Figure 4.

the linear trends more definitively, and outline an important cross trend of local anomalies toward the northeast. The presence of both steep and broad gravity and magnetic gradients suggest that both shallow and deep sources are involved. The most probable causes of the shallower anomalies are a series of associated mafic (and ultramafic?) volcanic and intrusive rocks that have been emplaced along a major northeast-trending rift complex that is discussed in the next section. The presence of basalts in the basement of southern Indiana and western Kentucky (Fig. 4) represent examples of these mafic rocks that occur at the basement surface. The broader anomalies may represent the deeper manifestations of these mafic rocks. The considerable regional extent of the broad northwest-trending gradient suggests more probably that the anomalies may reflect a major crustal province boundary along which contrasting rock types are juxtaposed.

Pre-Upper Cambrian sedimentary rocks are also present in the Illinois basin (Lidiak and Hinze, 1980; Schwalb and others, 1980). An excellent example occurs in the Texas Pacific No. 1 Farley well, Johnson County, Illinois. The well penetrated 774 feet of white to red quartz sandstone and arkosic sandstone with thin layers of red siltstone beneath the Mt. Simon Formation; crystalline basement was not reached. Lidiak and Hinze (1980) have proposed that the sedimentary rocks are mainly preserved in ancient northeast-trending grabens associated with rift complexes.

Tectonic Interpretation

The Illinois basin is both a depositional and a structural basin. Its present configuration dates from late Paleozoic-early Mesozoic time (Bond and others, 1971; Wilman and others, 1975). Extensive basinal sedimentation began in Cambrian time during development of the Reelfoot basin, which encompassed an area including both the present-day Illinois basin and Mississippi Embayment (Schwalb, 1969). The Illinois basin, open to the south and the site of sedimentation during most of Paleozoic time, was closed by uplift of the Pascola arch, near the end of the Paleozoic era (Bond and others, 1971). The arch connects the Ozark uplift with the Nashville dome. The modern Mississippi Embayment developed as a structural trough in Last Cretaceous and Tertiary time.

Ervin and McGinnis (1975) proposed that the Reelfoot basin is underlain by a Late Precambrian aulacogen (Reelfoot rift) that formed by emplacement of anomalous mantle material and local intrusives into the crust. They regard this structure to be part of a period of widespread rifting that occurred prior to the formation of the Appalachian-Ouachita mountain belt. According to Ervin and McGinnis (1975), the rifting was followed by subsidence in Paleozoic time and by reactivation of the rift in Mesozoic time to form the modern Mississippi Embayment. Hildenbrand and others (1977) have used a linear series of circular positive gravity and magnetic anomalies, which presently delimit the seismic activity in the New Madrid area, to outline this buried rift zone. They regard the rift zone as having been active periodically since the Precambrian. Evidence for the extension of the rift zone northeastward through the deepest part of the Illinois basin has been presented by Braile and others (in press) and is referred to by them as the New Madrid Linear Tectonic Feature. The trend of this structure through the basin is shown on Figure 4. An eastward extension of this rift zone continues into western Kentucky and forms the Rough Creek graben. Soderberg and Keller (1981) regard this graben as a reactivated structure that formed in Late Precambrian-early Paleozoic time.

The most prominent features on the gravity (Fig. 5) and magnetic maps of the Illinois basin are west-northwest-trending anomalies. These anomalies are particularly evident on magnetic maps (Lidiak and Zietz, 1976; Braile and others, in press) where a pronounced magnetic gradient trends through western Kentucky, southern Illinois, and eastern Missouri. The gradient and associated anomalies closely parallel the Ste. Genevieve fault zone (long. 90°W, lat. 38°N) but are much more extensive and can be traced across Missouri and into Tennessee. Preliminary modeling of the anomalies suggests that the causative bodies have a significant depth extent (Braile and others, in press). The gradient thus probably largely reflects a major lithologic province boundary. The Ste. Genevieve fault is regarded as a reactivated fault along an older Precambrian structure.

The Illinois basin is an excellent example of a Phanerozoic intracratonic basin that has developed in part along the site of an older, larger structure, the Reelfoot basin. This correspondence suggests that the Illinois basin is a superposed structure. The older Reelfoot basin represents a preexisting zone of weakness that exercised control on the younger Illinois basin and Mississippi Embayment. Reactivation served to localize the younger structure but did not produce an identical feature, presumably because the stress fields were different. Stresses are obviously generated by a variety of tectonic forces, and forces producing a younger structure may be completely alien to those responsible for an older structure (Hinze and others, 1980).

WILLISTON BASIN

Structural Framework

The Williston basin, which occurs near the junction of the international boundary and the North Dakota-Montana line, occupies western North Dakota and adjacent parts of Montana, South Dakota, Manitoba, and Saskatchewan (Fig. 6). It is both a structural and a sedimentary basin, which dates back to the Cambrian. The present basin was shaped in Late Cretaceous-early Tertiary time by Laramide orogeny. The basin is bounded on the northwest, west, and southwest by a series of domes and anticlines; on the southeast and northeast it merges gradually with the slop-

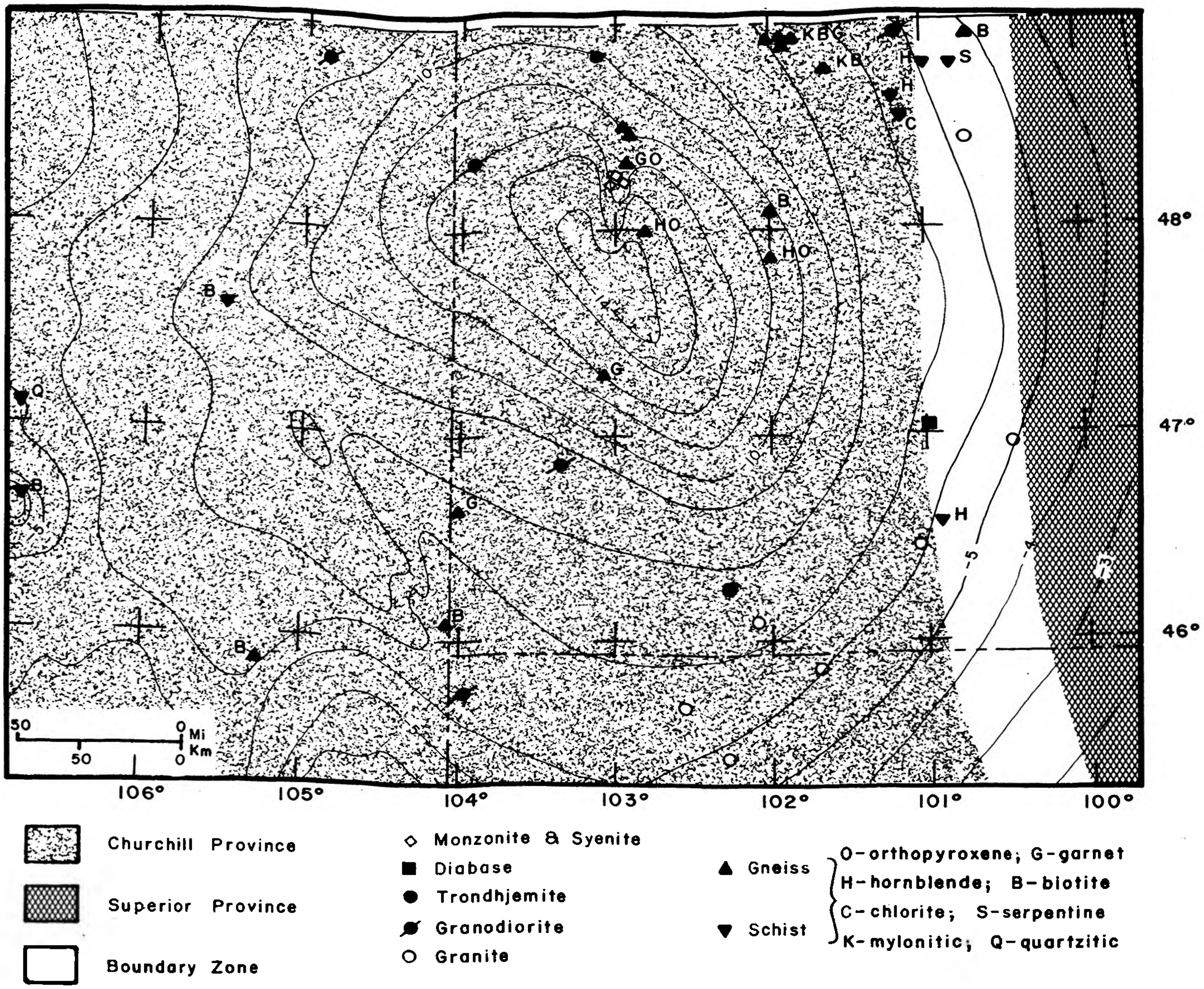

Fig. 6. Geologic map of basement rocks in the Williston basin. Basement configuration contour, in thousands of feet, from Bayley and Muehlberger (1968).

ing Precambrian shelf. Within the basin proper is the north-trending Nesson anticline at long. 103°W, lat. 48°N. The flanks of these anticlines and domes dip gently, on the order of several degrees only. The Precambrian surface is characterized by a relatively gentle slope; maximum depth to basement in the Williston basin is about 16,700 feet (Gerhard, this volume).

The Williston basin had been deformed only during Phanerozoic time. The Precambrian rocks have thus remained a structural entity since the Precambrian, and their present distribution reflects mainly Precambrian structural trends.

Basement Rocks and Regional Geophysics

Approximately 42 wells have been drilled to basement in the general area of the Williston basin (Fig. 6). Most of the wells are located on the shallow eastern flank; only about 12 wells have penetrated the basement in the deeper parts of the basin at depths greater than 10,000 feet. The main rock types are medium- to high-grade sialic metamorphic rocks, granites, and granodiorites. Their distribution is shown on Figure 6.

The combined use of the sparse lithologic data, isotopic age determinations, and regional geophysical maps permits the recognition of two main geological provinces in the area. The boundary between the subsurface extension of the Superior and Churchill provinces trends southward across the eastern flank of the Williston basin (Fig. 6) along an abrupt change in the trend of Bouguer gravity anomalies. To the east, they trend east-northeast and are associated with greenstones, granites, and high-grade gneisses of Archean age; to the west the anomalies have a general northerly trend and are associated with medium- to high-grade metamorphic rocks, granites, and granodiorites of lower Proterozoic age (Peterman and Hedge, 1964; Goldich and others, 1966; Muehlberger and others, 1967; Lidiak, 1971).

One of the more striking features of the Williston basin is the large gravity high in the interior of the basin. As shown on Figure 7, the anomaly is broad and reaches values as high as about -30 milligals. The anomaly continues in Canada where it bifurcates into two prominent linear highs separated by a low (cf. Am. Geophys. Union and U.S. Geol. Survey, 1964; Observ. Branch, 1964). The eastern of these highs merges with the Nelson River high of Innes (1960). The western anomaly may also join the Nelson high via an arcuate path, but evidence for this trend is less compelling because of a complex anomaly pattern in central Saskatchewan. Wilson and Brisbin (1961, 1962) report that the Nelson River gravity high is underlain mainly by a high-grade gneiss zone and that a gravity low immediately to the northwest coincides with a zone of faulting, amphibolite-grade gneisses, and serpentinized peridotites. Bell (1964; 1966; 1971), Patterson (1963) and others have shown that the rocks in the immediate vicinity of the Nelson River consist mainly of granulites, charnockites, and retrograde gneisses. Bell (1964) further reported that granulites underlie the Nelson River gravity high, in agreement with studies by Gibb (1968 a, b) who found excellent correlation between surface Precambrian rocks, their densities, and the Bouguer anomalies. Gibb demonstrated that the granulites, having an average density of 2.73 ± 0.15 gm/cm^3, can account for the Nelson River gravity high. The main fault zones in the region are regarded by Gibb (1968 b) and Kornik (1969) as being major dislocations that extend deep into the crust.

The boundary between the Churchill and Superior provinces in northern Manitoba has been located at different places in the immediate vicinity of the Nelson River gravity high (Bell, 1966, 1971; Cranstone and Turek, 1976; Weber and Scoates, 1978; Green and others, 1979). Green and others (1979) recognized a broad boundary zone that includes the Nelson River gravity high and adjacent gravity low. They extend the boundary southward beneath the overlying Phanerozoic sedimentary rocks by using a newly-compiled regional magnetic map. This boundary lines up with the Superior-Churchill boundary in the northern United States (Goldich and others, 1966; Muehlberger and others, 1967) and occurs along the east flank of the broad gravity high. The deeper parts of the Williston basin thus lie immediately west of this prominent Precambrian boundary.

Twenty-two wells have been drilled to basement along the broad gravity high (Fig. 7) in western North Dakota. The main rock types are granulite-grade hypersthene gneiss, amphibolite-grade garnet, hornblende, or biotite gneiss, granodiorite, and trondhjemite. The latter two rock types are clearly suggestive of orogenic derivation. These metamorphic and igneous rocks are clearly insufficient to characterize completely the basement under the broad anomaly. The relations are, however, consistent with those reported from the Nelson River zone in Canada and suggest that the gravity high in the Williston is at least partially attributable to granulite and amphibolite facies rocks and igneous rocks of intermediate composition at and near the basement surface. The metamorphic rocks formed deep in the crust and would be expected to have a higher density than rocks metamorphosed at shallower depths. For example, a cylindrical bottom hole core from a granulite in McKenzie County, North Dakota has a measured density of 2.74 gm/cm^3. Similarly, the granodiorites and trondhjemites are typically denser than more granitic rocks.

Monzonites, syenites, and Nesson horst. - Monzonites and syenites also occur in the Williston basin, and their presence poses an interesting problem of distribution and age. The three known occurrences are on the Nesson anticline, which is regarded here as being a horst. The monzonites and syenites are overlain by Upper Cambrian-Lower Ordovician rocks, which contain lithic fragments of these felsic rocks. Feldspathic igneous bodies of this type are typically small and occur mainly as stocks, laccoliths, dikes, and sills. The only other feldspathic rocks in the general region of the Williston basin are in the Little Rocky Mountains of Montana and in the northern part of the Black Hills of South Dakota and Wyoming. These rocks were emplaced and uplifted to their present position along tectonic highs in late Mesozoic-Tertiary times. Peterman and Hedge (1964) dated K feldspar by Rb-Sr methods from one of the monzonites along the Nesson horst and obtained an apparent Late Precambrian age. The basement high, which the monzonites compose, is regarded by them as having been a center of post-Middle Precambrian igneous activity. The monzonites and syenites probably have limited extent in the Williston basin. Their presence along the Nesson horst and in the adjoining

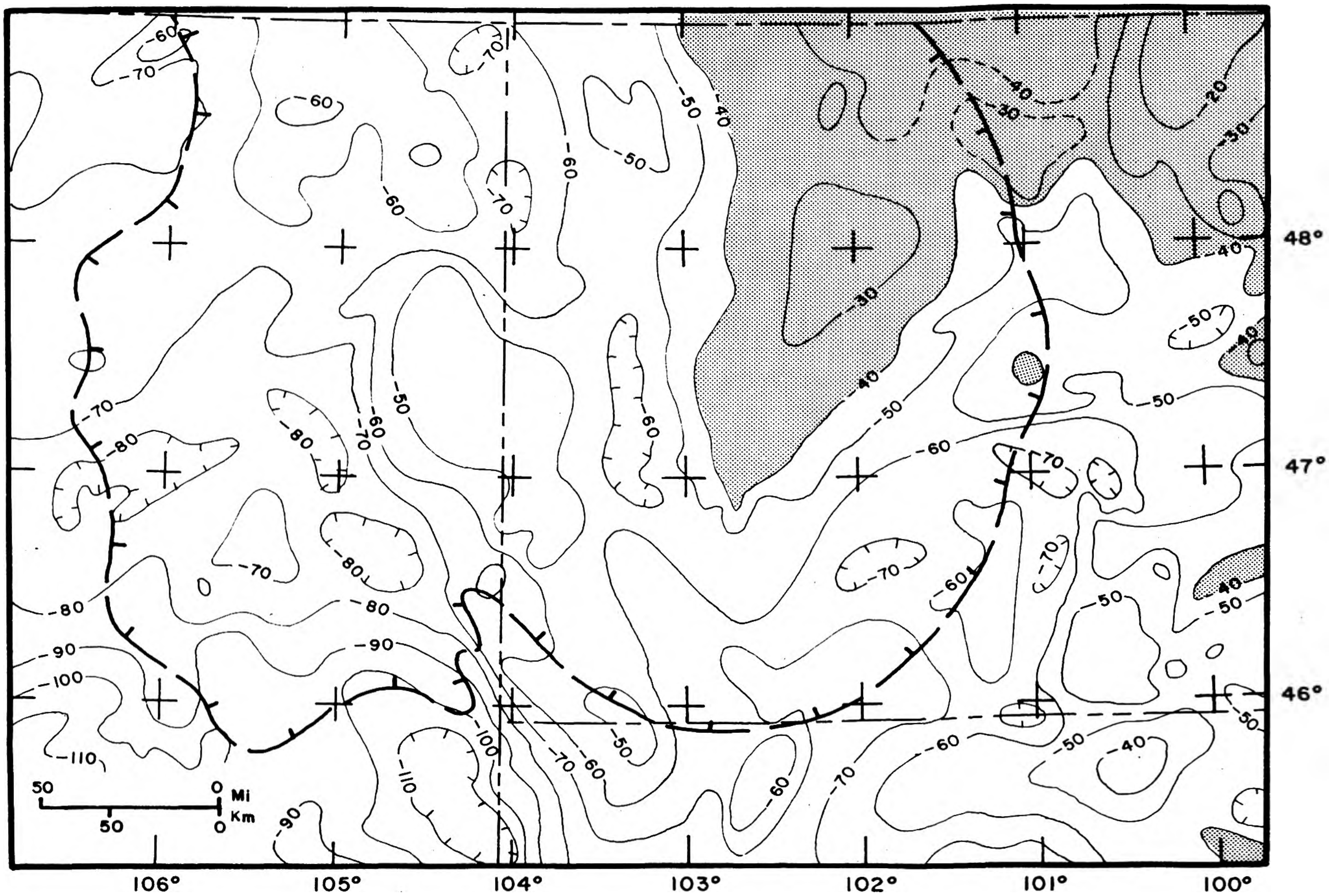

Fig. 7. Bouguer gravity map of the Williston basin. Contour interval is 10 mgal. From Am.Geophys. Union and U.S. Geol. Survey (1964). Gravity highs - stippled pattern. Dashed hachure line outlining the Williston basin is the -7,000 ft. contour of Figure 6.

exposed areas indicates that felsic igneous activity occurred in the region during more than one period of time. The Nesson horst may thus represent an resurgent structure within the Williston basin.

Cryptoexplosion structures. - Probable astroblemes or fossil meteorite craters have been identified within the Williston basin in the subsurface of Saskatchewan, Manitoba, and North Dakota (Sawatzky, 1972, 1975). The structures are circular in outline and contain local intensely deformed strata. Shatter cones have been recognized in cores from McKenzie County, North Dakota (Sawatzky, 1975). Commercial hydrocarbon production occurs along the rims of some of the structures. One of these probable astroblemes in Renville County, North Dakota, has deformed the basement. The basement rocks encountered in several deep holes to the Renville County structure are highly deformed amphibolite-grade garnet and biotite gneisses. Superimposed on the earlier gneissic foliation are irregular, generally sub-horizontal shear planes, cataclastic and mylonitic surfaces, and brecciated zones, all of high complexity. The amphibolite-grade foliation has been largely disrupted. Most of the secondary surfaces are closely spaced. Rounded rock fragments predominate over angular fragments in the brecciated matrix. Definitive meteorite impact features have not yet been recognized in the basement rocks. These local structures probably have no direct relation to the tectonic development of the basin.

Tectonic Interpretation

The presence of granulite-grade and amphibolite-grade gneisses and igneous rocks of intermediate composition near the basement surface has an important implication for the tectonic development of the Williston basin, which is commonly regarded as dating back to the Cambrian at which time subsidence began. Its history, however, is more complex. The basin probably owes its early development to processes operating in Precambrian time. An explanation of the gravity highs and the high-grade gneisses in the Williston basin seemingly requires major crustal uplift and accompanying erosion in the area now underlain by the gravity feature. The time to uplift cannot be stated precisely; it probably began after the widespread 1800 m.y.-old metamorphism, and may have continued into Late Precambrian or Early Cambrian time. Fault zones containing dense crustal rocks, such as the granulites, were brought to the basement surface. A gravity high could be produced by the juxtaposition of deep and shallow crustal rocks. The possibility of portions of the Williston basin being underlain by a complex orogenic boundary similar to that occurring along the Nelson River area in Canada will require further more detailed studies.

SALINA AND FOREST CITY BASINS

Structural Framework

The Salina and Forest City basins are structural and depositional basins. Both are shallow basins, having a depth to basement of about 4000 feet. Configuration of the basement surface is shown on Figure 8. The two basins are separated by the prominent north-trending Nemaha uplift, a Late Mississippian (pre-Desmoinesian)-Early Pennsylvanian structure (Merriam, 1963; Adler and others, 1971). Prior to that time, a single basin, the North Kansas (or Iowa) basin was present.

The Salina basin is limited on the north by the Siouxana arch, on the east and southeast by the Nemaha ridge, on the west by the Cambridge arch, and on the southwest by the Central Kansas uplift. Secondary structures within the basin are outlined by Cole (1962) and Carlson (1967). The geologic history of the Kansas portion of the basin is summarized by Lee (1956). The Nebraska part is summarized by Reed (1954) and Carlson (1963).

Structural features that outline the Forest City basin are the Thurman-Redfield fault to the north, the Mississippi River arch to the east, the Nemaha ridge to the west, and the Bourbon arch to the south. Within the basin are two opposing structural trends, an older northwest trend and a younger northeast trend. Anderson and Wells (1968) discuss the geologic history of the basin.

Basement Rocks and Regional Geophysics

Numerous wells to basement have been drilled along the arches and ridges that encircle the two basins. The basement geology in these contiguous areas are described elsewhere (Muehlberger and others, 1967; Lidiak, 1972; Kisvarsanyi, 1974; Denison and others, in press; Bickford and others, 1981). In contrast to the uplifts, only a few wells to basement have been drilled in the basins proper. As in the other basins, interpretation of the basement geology thus requires not only study of the available wells to basement but also an evaluation of the regional geophysical anomalies.

The wells to basement in the Salina and Forest City basins are shown in Figure 8. The available data suggest that the main rock types in the northern part of the Salina basin are gneissoid rocks of granite and granodiorite composition, nonfoliated anorogenic granite and granodiorite, and minor silicic metamorphic rocks (Denison and others, in press). The southern part of the basin is underlain by Keweenawan basalts and associated immature sedimentary rocks. There are no wells to basement near the center of the basin.

The type of basement rocks in the Forest City basin is also poorly known. Gneissoid granitic rocks have been encountered along the western flank and near the center of the basin. Keweenawan basalts and associated sedimentary rocks occur in a northeast-trending belt in the northern part of the basin. The lithology of the basement in the remainder of the basin is unknown because of the complete lack of well control.

Gravity anomalies suggest that additional mafic rocks may be present within the basement of both basins. Figure 9 is a Bouguer gravity map of the two-basin area. The pronounced northeast-trending gravity high and flanking low are part of the well-known Midcontinent gravity anomaly These anomalies coincide with a major continental rift zone in which a thick sequence of Keweenawan basaltic and associated sedimentary rocks accumulated (King and Zietz, 1971; Lidiak, 1972; Ocola and Meyer, 1973). Other gravity highs are also present within both basins. In the east-central part of the Salina basin at longitude 98°W along the Kansas-Nebraska state line is a broad gravity high. Two other broad highs occur to the south-southwest, forming an apparent trend that parallels the Midcontinent gravity anomaly in Kansas. In the Forest City basin at lat. 40°N, long. 95°W is a small gravity high that occurs immediately south of the deepest part of the basin. The low amplitude and broad gradients associated with these basinal anomalies suggest that the source is buried at depth within the intrabasement. Their proximity and the parallelism of the anomalies in the Salina basin to the Midcontinent gravity anomaly suggest a relationship. The anomalies possibly reflect the intrusion of gabbroic igneous rock at moderate depth within the sialic crust. Steeples (this volume) shows that an anomalous mantle occurs along a broad zone beneath both the Salina and Forest City basins and is centered on the Midcontinent gravity anomaly.

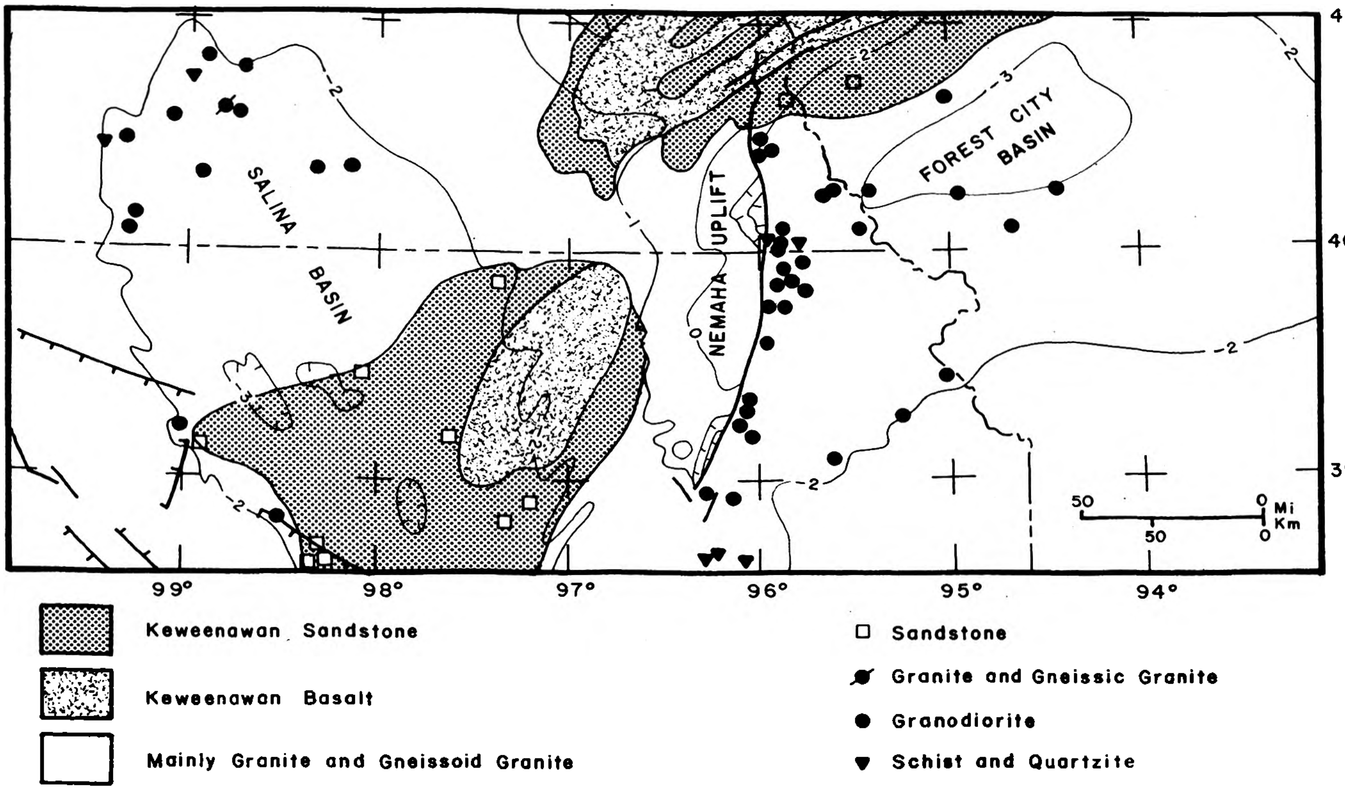

Fig. 8. Geologic map of basement rocks in the Salina and Forest City basins. Basement configuration contours, in thousands of feet, from Bayley and Muehlberger (1968).

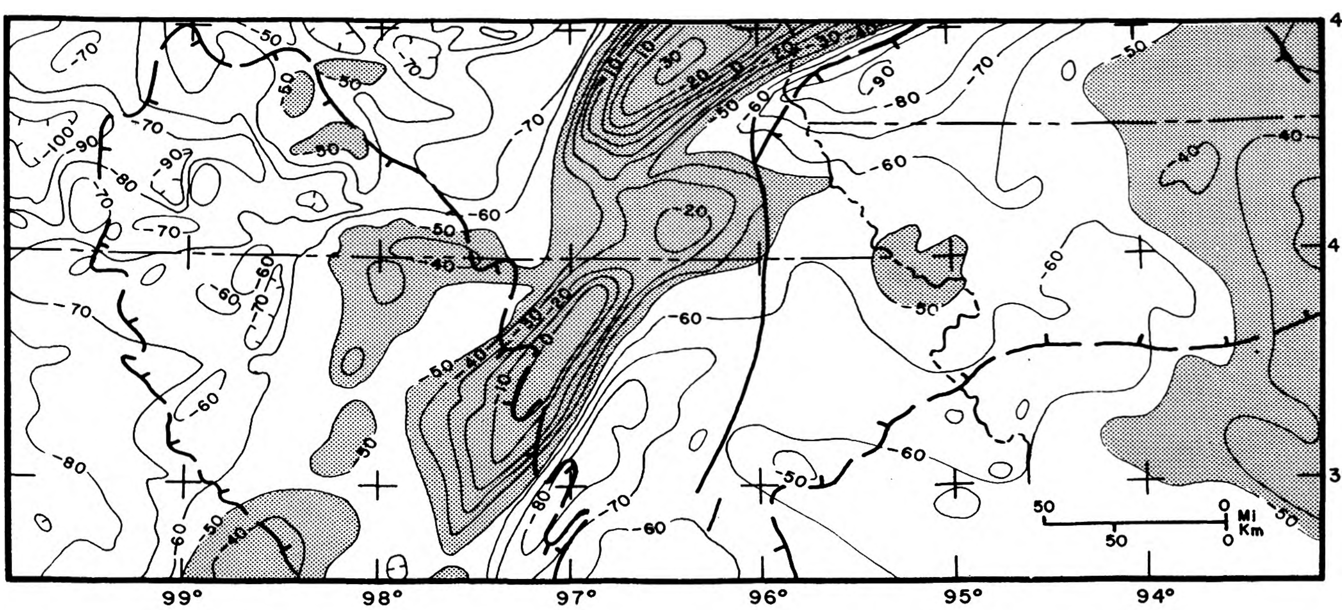

Fig. 9. Bouguer gravity map of the Salina and Forest City basins. Contour interval is 10 mgals. From Am. Geophys. Union and U.S. Geol. Survey (1964). Gravity highs - stippled pattern. Dashed hachure line for each basin is the -2,000 ft. contour of Figure 8.

ARKOMA BASIN

Structural Framework

The Arkoma basin is an elongate east-north-east-trending structural and depositional basin that is bounded on the north by the Ozark uplift and on the south by the Ouachita Mountain system (Fig. 10). The basin, once part of the larger Ouachita geosyncline, formed in late Paleozoic time during the Ouachita orogeny and contains over 30,000 feet of pre-Missourian Pennsylvanian strata (Flawn and others, 1961; Branan, 1968).

Two main structural patterns occur in the basin. To the south are numerous east-trending anticlines, synclines, and northward-thrust faults. The folds and faults occur with increasing intensity toward the Ouachita front. Maximum sedimentary thickness and the deepest part of the basin is adjacent to the Ouachita front in the region of greatest thrusting and folding. This structural style gives way toward the north to high-angle block faulting. These faults probably formed during basinal subsidence.

Basement Rocks and Regional Geophysics

Three wells have been drilled to basement in the Arkoma basin. All are located along the steep northern slope (Fig. 10). Two of the wells bottomed in metarhyolite porphyry and the other encountered a medium-grained two-feldspar hornblende granite (Denison, 1966, in press). Rb-Sr ages of 1270 m.y. on the metarhyolite and 1240 m.y. on feldspar from the granite indicate that the granite is younger than the rhyolite and may have metamorphosed it (Muehlberger and other, 1966; Denison, 1966, in press).

Figure 11 is a Bouguer gravity map of the Arkoma basin. A prominent -100 milligal gravity low strikes east-northeast through the center of the basin. The close similarity between the basement configuration (Fig. 10) and the gravity anomaly contours is due to the fact that the form and depth of the deep basin is based on the gravity data (Bayley and Muehlberger, 1968).

The most significant feature of Figure 11 is the -100 milligal gravity low that occurs in the area of

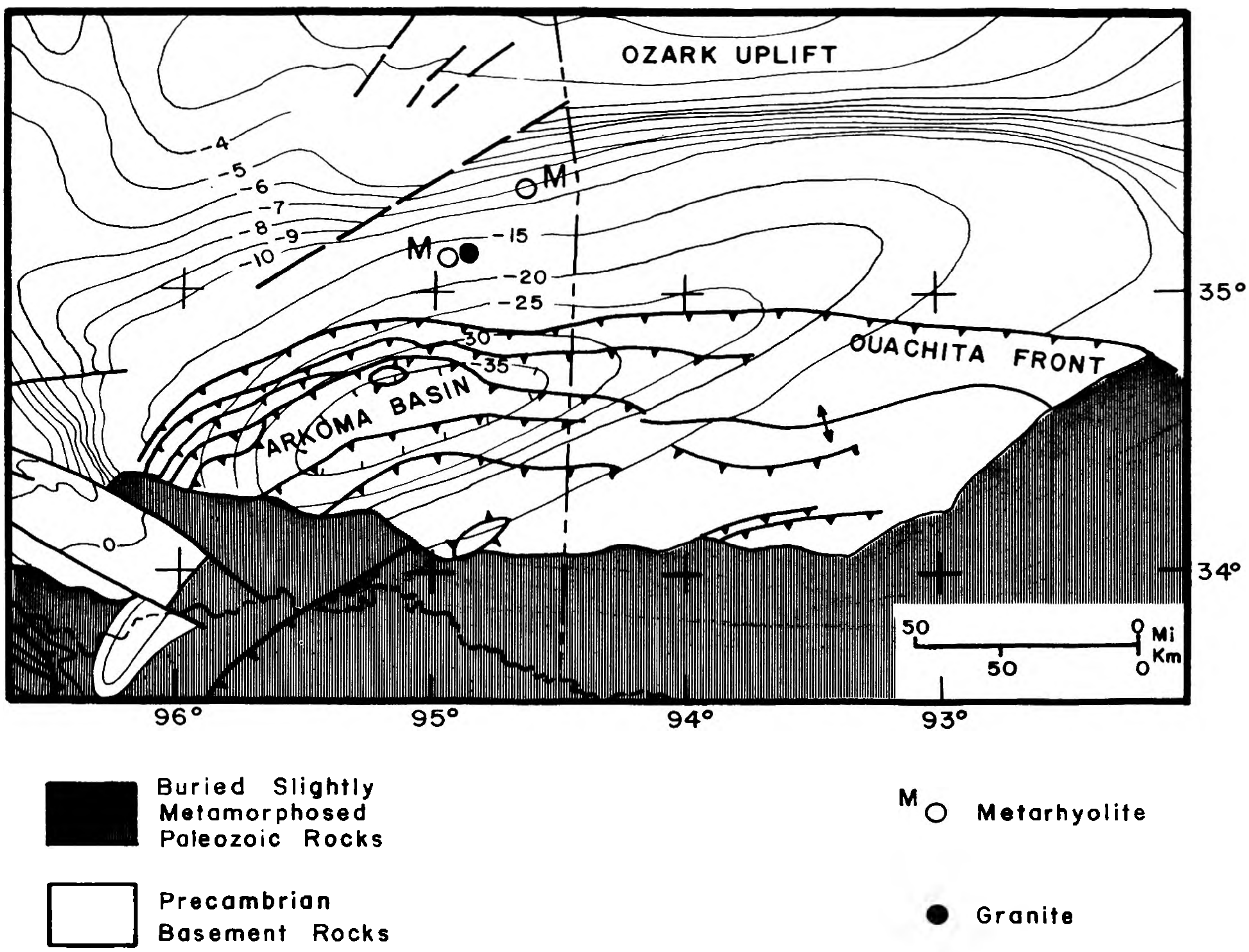

Fig. 10. Basement configuration map of the Arkoma basin. Contours, in thousands of feet, are from Bayley and Muehlberger (1968).

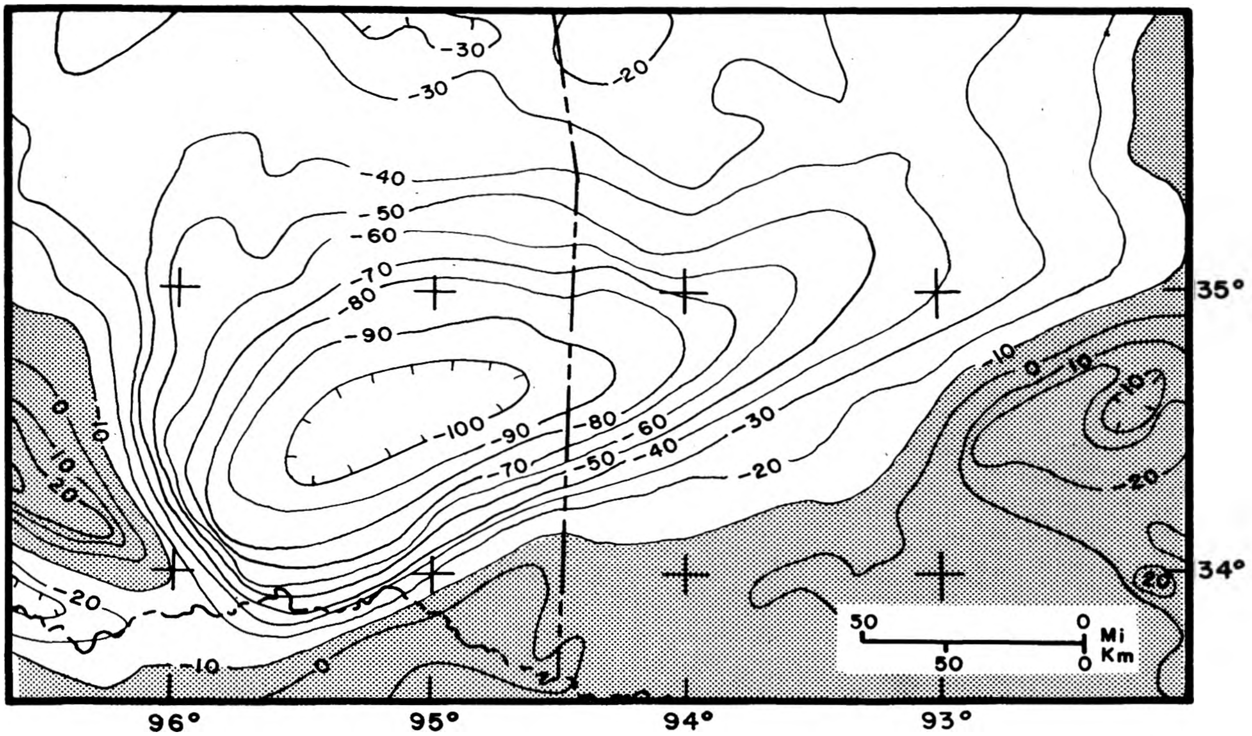

Fig. 11. Bouguer gravity map of the Arkoma basin. Contour interval is 10 mgal. From Am. Geophys. Union and U.S. Geol. Survey (1964).

the Arkoma basin. The basin thus differs from those previously described in this report in the absence of a gravity high and in the large magnitude of the gravity low. The gravity anomalies suggest that the basin is filled with a thick section of low-density sedimentary rocks. The absence of a gravity high implies that the basement consists of low or moderate density material. Consistent with this interpretation is the presence of rhyolite and granite along the north flank of the basin. Rocks of this type are probably widespread in the basement beneath the Arkoma basin. If denser basement rocks are present, they are evidently masked by the thick sedimentary sequence.

DISCUSSION

Types of Midcontinent Basins

The origin and development of basins in continental areas have long been controversial topics. Basins typically contain a thick accumulation of sedimentary rocks that accumulated over a long time span. Igneous rocks are sparse or absent; where present they occur as minor intrusions, dikes, sills, laccoliths, or as thin ash layers and were generally emplaced in the later stages of basin development. The rocks filling the basins are unmetamorphosed except the deepest parts where incipient effects may be present. Structures within basins are generally subtle and consist of minor folds and normal or strike-slip faults. In basins adjacent to orogenic belts, more complex folds, thrust faults, and listric faults may occur. The early history of most basins is imperfectly known because of deep burial.

Recently, several models have been proposed to account for the origin of major continental basins. These models involve essentially a prolonged one-stage process that includes the generation of a thermal anomaly followed by thermal contraction (Sleep, 1971; Sleep and Snell, 1976; Haxby and others, 1976) or extensional tectonism accompanied by a thermal anomaly (McKenzie, 1978; Jarvis and McKenzie, 1980). These theories account for many aspects of basin development but do not appear to be consistent with the general absence of thermal effects within most basins.

A second prominent problem involves the fact that not all basins have had the same origin. On regional geologic considerations alone, basins that form in foreland areas marginal to orogenic belts such as the Appalachian basin and the Arkoma basin are distinguishable from basins, such as the Michigan basin, that occur in intracratonic areas (Umbgrove, 1947; Kay, 1951; King, 1959). Foreland basins are closely associated with orogenic belts and are apparently compatible with an origin by a one-stage process. Characteristic features are the development of a deep downwarped basin parallel to the mountain front, orogenic sedimentary patterns, and orogenic structural styles. Basin development and deposition are in part synchronous with compressional folding in the adjacent orogenic belt (Cooper, 1968; Rodgers, 1970; Cloos, 1971). In contrast to these basins are intracratonic basins, which are removed from orogenic belts and occur in areas of subsidence. These basins are mainly nonlinear in outline, contain mostly mature sedimentary rocks, and are essentially undeformed except for minor block faulting. A third type of basin that is now widely recognized is an aulacogen. These are long troughs extending into continental cratons from fold belts (Burke and Dewey, 1973; Hoffman and others, 1974; Burke, 1977). Their properties include a long history as an active structure, a thick, gently folded sedimentary sequence, the emplacement of igneous rocks generally in the early stages of development, a complex of horsts and grabens within the aulacogen, and the occurrence of reactivated structures.

A compilation of basins of the Midcontinent and areas marginal to the craton reveals that all three types of basins are present. The basins are shown according to type in Table 1.

Table 1. Basins of the Midcontinent and Adjacent Areas, United States

A. Intracratonic Basins	
	Michigan Basin
	Williston Basin
	Illinois Basin
	Salina-Forest City Basins
B. Foreland Basins	
	Arkoma Basin
	Appalachian Basin
	Denver Basin
	Black Warrior Basin
C. Aulacogens	
	Southern Oklahoma
	Mississipi Embayment
	Delaware Basin

As discussed previously, intracratonic basins are underlain by distinct geophysical anomalies, either Bouguer gravity highs, magnetic highs, or both. Most of the anomalies are linear. They reflect old, mainly Precambrian structures, along which dense and (or) magnetic rock has been juxtaposed against more typical sialic material. The geophysical signatures and available basement geological data of each basin indicate that the anomalies are attributable either to old basaltic rift zones in the basement complex, or to major Precambrian tectonic boundaries. Muehlberger and others (1967) first recognized that a large proportion of dense (mainly mafic) rock underlies these basins, and McGinnis (1970) proposed that the basins are sites of collapsed one-stage rift systems.

In contrast to intracratonic basins, foreland basins do not appear to be associated with gravity or magnetic highs. These basins are underlain instead by gravity lows which, in part, reflect a thick accumulation of sedimentary material. A possible exception is the Black Warrior basin which contains a prominent gravity high in the northern part. However, the Black Warrior is a complex basin, occurring in a recess between the converging Appalachian and Ouachita fold belts. It is divisible into a southern structural province of thrust faults and a northern province of normal faults (Flawn and others, 1961; Thomas, 1972).

The three aulacogens listed in Table 1 have geophysical signatures that are more similar to intracratonic basins than foreland basins and are probably underlain in part by dense mafic rock. The southern Oklahoma aulacogen (Hoffman and others, 1974), which includes the Anadarko, Ardmore, and Marietta basins and flanking Wichita and Amarillo uplifts (Ham and others, 1964) contains linear gravity and magnetic highs and lows. Brewer and others (in press) present evidence for the existence of an earlier extensive Proterozoic basin in this area. They suggest that the aulacogen may have had a much longer history of subsidence or that it may represent a younger reactivated structure. The second-listed aulacogen, the Mississippi Embayment, also contains gravity and magnetic highs that form linear trends (Ervin and McGinnis, 1975; Hildenbrand and others, 1977). These workers suggest that the aulacogen formed in late Precambrian time and was reactivated during the late Mesozoic. Similarly, recent work by Keller and others (1980) has shown that the Delaware basin occurs adjacent to a gravity high and is also a probable aulacogen that had an origin similar to the southern Oklahoma aulacogen.

Origin of Intracratonic Basins

The presence of older structures in the basement underlying intracratonic basins is noteworthy and suggests that the sites where intracratonic basins developed have had complex histories. One-stage models have the inherent difficulty of not accounting for the lack of symmetry between the older structures and the overlying basin and the long time span of development. For example, the thermal contraction model proposed by Haxby and others (1976) attempts to relate the underlying 1100-m.y.-old linear Keweenawan rift with the formation of the circular Michigan basin, which began to subside in early Paleozoic time. As noted by Brewer and Oliver (1980), a direct relation is difficult to visualize.

A more complex sequence of events seems necessary to explain the development of these basins. Intracratonic basins apparently occur along sites of older structures. The first step appears to be the formation of a major fault zone or other tectonic boundary. These structures would presumably be of sufficient magnitude to modify the crust for tens of kilometers both horizontally and at depth. Possible structures would include rift zones, large strike-slip or transform fault zones, lithologic, tectonic, or metamorphic province boundaries, and local basement inhomogeneities in the form of mafic or ultramafic intrusions (Hinze and others, 1980).

The second stage would involve the development of the basin itself and would occur at some later but unspecified time. Subsidence is initiated in response to (new) tensional forces. The new strain field would be unrelated to earlier regimes and would produce a different type of structure. However, the tensional forces would be localized along the older structures, which represent old zones of weakness in the crust. Basins would thus tend to form along older reactivated structures.

It perhaps needs to be emphasized that a reactivated structure does not necessarily produce a basin. Extensional tectonism operating over a long period of time is apparently necessary, and reactivated structures are clearly not all extensional. A variety of reactivated structures are present in the Midcontinent, and models to explain their development are discussed by Hinze and others (1980).

The formation of intracratonic basins by reactivation of older structures during periods of extension is an example of intraplate tectonism. Development of these basins contrasts with tectonic processes operating along plate boundaries. The basins contain the accumulated products of long-term dynamic systems and encompass a considerable geologic record. Their formation along old zones of weakness by reactivation of earlier structures indicates that they have had a more complex history than generally envisaged. They are thus important in understanding the structure, behavior, and evolution of continents. A consideration of basin development must take into account the Precambrian as well as the overlying Phanerozoic rocks.

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