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Tectonic History of Midcontinental United States

Frank G. Snyder

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ABSTRACT

Metasediments of Middle Precambrian, and possibly some of earlier age, form an arcuate trending belt across Missouri, Kansas, and Nebraska. These were intruded by granites of several ages that appear to be part of a continuous wave of Late Precambrian igneous activity. Late Precambrian events that can be delineated include, besides the igneous activity and formation of iron deposits, development of a Keweenawan basin that extended from Lake Superior into eastern Kansas; igneous activity and metamorphism of Grenville age in the eastern Midcontinent; development of a major fault lineament extending northeastward from northeast Arkansas into the Canadian shield outcrop area and separating basement rocks of two distinct ages; and a long period of uplift and erosion during which sediments were deposited in interior and fringing basins.

A belt of volcanic rock, partly preserved as an erosional remnant, extended from Ohio into New Mexico and formed a continental divide during Late Precambrian and Early and Middle Cambrian time. Higher peaks in this belt form the present St. Francois, Eminence, and Spavinaw outcrop areas. This area of high volcanic rock is termed the "Ancestral Ozarks."

Paleozoic time was a transition from a positive to a negative to a stable area. It began with broad submergence followed by development of domes, arches, and basins. Continued development of lesser arches fragmented the Midcontinent into numerous small basins and highs. The final stage of activity, oscillation and accompanying cyclical sedimentation, was succeeded by stability.

Numerous cryptoexplosion structures are known in the Midcontinent. Some are associated with intrusive and extrusive igneous activity. Nearly all of them lie on a preexisting structural axis.

INTRODUCTION

The Midcontinent, which embraces the region from the Appalachians to the Rockies, is largely an area of subdued topography and flat-lying beds. In the field of structural geology, its history is summed up—and frequently dismissed—as the stable interior.

The low-lying surface and flat beds conceal, however, a long and complex history in which only the major elements can be outlined. Age dating of basement rocks indicates that the foundations of the Midcontinent came into existence far back in Precambrian time. The older rocks were intruded and largely engulfed by later periods of igneous activity. For half a billion years, erosion and denudation reduced the face of the continent; the area became the stable platform (Fig. 1) upon which a veneer of Paleozoic sediments (thin over positive areas, thick in locally subsiding basins) was deposited.

Objectives and Tools of Structural Geology

Structural geology seeks to decipher the character of the present geological situation, to define the events that led to development of that situation, and to integrate those events into a coherent tectonic history.

The character of the present conditions is well known and can be adequately portrayed on maps (Fig. 2).

The major elements include the Appalachian plateau, the Cincinnati arch with its branches, the Ozark uplift, the Sioux and Nemaha uplifts, the Michigan, Illinois, and Forest City basins, and the several western basins and intervening arches. The development of these features is the story of the Paleozoic era.

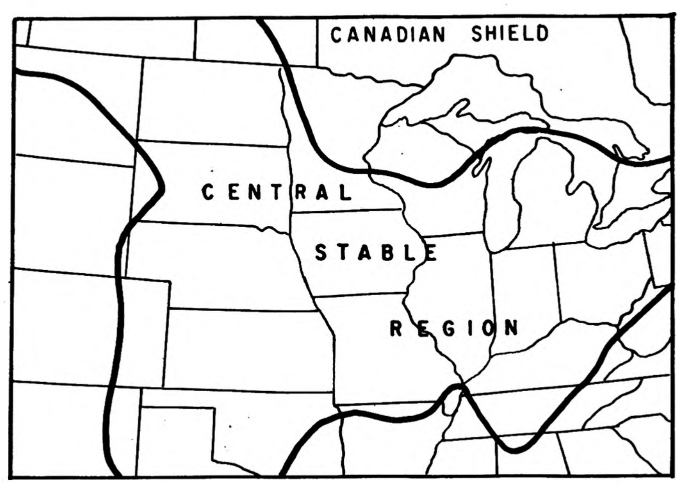

Fig. 1. Central stable region and Canadian Shield.

Folds and faults, the obvious and often spectacular features of structural geology, are the culmination of a long series of events, each related to and influenced by preceding events. The keys to deciphering these events are the sedimentary record and the dated ages of igneous and metamorphic episodes.

The sedimentary record reveals activity of both the source area and the depositional

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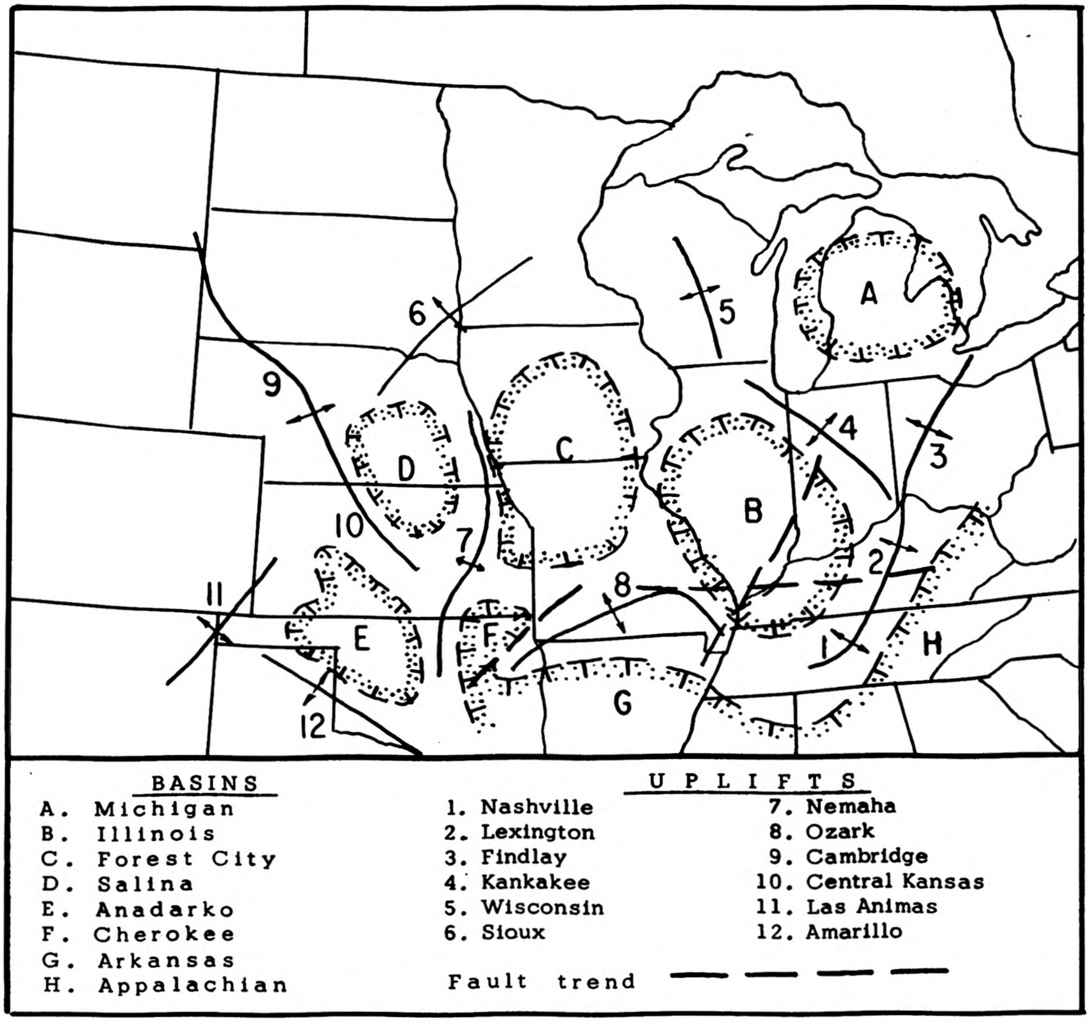

Fig. 2. Major structural features of the Midcontinent.

basin. Coarseness and composition of clastic sediments reflect periods of uplift and the type of rock which provided the sediments. Carbonates indicate inactive land areas and stable conditions; the sediments are those generated within the depositional basins. For Paleozoic and younger formations, the sedimentary record indicates times of subsidence and uplift, patterns of warping which gave rise to arches and basins, and nearly continuous deposition in some areas and intermittent subsidence and erosion in others.

Deciphering Precambrian history is a far more complex task because only the remnants of formations are preserved or known from drillhole records, and a great deal of interpretation must be based on limited data. In Missouri, for instance, age determinations from only 15 localities are available (Muehlberger and others, 1966). These data suffice to draw only the broad outline of the history of an immensely long period of time. Age dating methods are subject to errors in measurement and interpretation. They provide the only basis, however, for defining Precambrian orogenies and for relating subsurface areas to those orogenies.

An orogenic cycle begins with the development of a geosyncline and deposition of sediments. After a long period of sedimentation, the cycle culminates in a period of folding, usually, although not always, accompanied by igneous intrusion. Age dating of metasediments deposited during the geosynclinal stage would reveal the time of metamorphism and intrusion, not the time of deposition. Because of limitations in age dating methods and the long span of time involved in a period of igneous activity, the age given for an orogeny may represent a time span of up to 200 million years. Older rocks involved in a later metamorphic event would show the age of the younger event or, more likely, an age between the younger event and their true age.

Of particular importance to understanding Precambrian history is the recognition that petrographically similar granites in the Midcontinent may be considerably different in age (Muehlberger and others, 1966).

PRECAMBRIAN

Classification and Geochronolgy

During the period from 1840 to 1900, a subdivision of the Precambrian, based on rock types with age connotations for each, was developed. This classic "chronology", with periodic refinement, was accepted and used by most geologists. Age dating of orogenies and geologic provinces in the past decade (Goldich and others, 1961; Engel, 1963; Stockwell, 1964) has provided time points on the geologic calendar. The older terminology continues to be useful, however, in terms of *type* of sediment and depositional history (Table 1).

Table 1

Subdivision of the Precambrian

Series		*Types of Rock*
Keweenawan	Upper	Clastic
	Middle	Basic volcanic and intrusive
	Lower	Clastic
Huronian	Upper	Eugeosynclinal and volcanic
	Middle	Miogeosynclinal and shelf
	Lower	Miogeosynclinal and shelf
Timiskaming		Clastic
Keewatin		Eugeosynclinal and basic volcanic

An important part of the Precambrian, the Grenville, is not included in the table. The age of this thick sequence of marbles, gneisses, schists, and amphibolites was long disputed. Highly metamorphosed, the sequence was regarded by some as older than the less metamorphosed Huronian; others considered it Huronian equivalent or younger. Discussions of its position in the Precambrian cover many pages of literature.

Age dating has revealed three facets of great importance for interpreting the history of the Midcontinent: 1) The Grenville orogeny occurred in Late Precambrian time and correlates with Keweenawan igneous activity. Much of the eastern part of the Midcontinent was involved in this orogeny (Lidiak and others, 1966). 2) Beginning in Late Precambrian time, but earlier than the Grenville orogeny, the Midcontinent experienced a wave of igneous activity that became progressively younger southward and culminated in the Llano (Grenville) orogeny in central Texas (Muehlberger and others, 1966). 3) Although most of the recorded dates from the western part of the Midcontinent fit an early Late Precambrian time of igneous activity, scattered remnants of older rocks are present (Goldich and others, 1966b; Muehlberger and others, 1966). Age dating indicates that the St. Francois-Spavinaw-Nemaha type granites intruded a terrane of older granites which, in turn, had intruded and metamorphosed still older sedimentary rocks.

Table 2

Precambrian Geochronology

(adapted from Goldich and others, 1961; Stockwell and others, 1965)

Epoch	*Series*	*Orogeny*	*Approx. age, m.y.*
Late	Keweenawan	Grenville	1,100
Middle	Huronian	Penokean	1,700
Early	Timiskaming	Algoman	2,500
	Keewatin	Laurentian	?

The presently accepted geochronology, based on detailed stratigraphy (James, 1958) and age dating (Goldich and others, 1961), provides a threefold division of the Precambrian (Table 2).

Early Precambrian

Goldich and others (1966) define a belt of Early Precambrian which extends from the Lake Superior outcrop area southwestward across North and South Dakota to the Black Hills and westward into Wyoming. This belt includes (in Minnesota) the oldest known rocks in North America; granite gneisses dated by Catanzaro (1963) as 3,550 m.y. old.

South and east of this belt, no clear-cut evidence of an Early Precambrian terrane has been revealed. However, a few dated samples from Nebraska and eastern Kansas giving ages as old as 1,950 m.y. (Muehlberger and others, 1966) suggest that remnants of Early Precambrian, modified by later thermal events, still remain.

Middle Precambrian

Granites and gneisses of Middle Precambrian age are common in the Lake Superior outcrop area and in the subsurface across the northern part of the Midcontinent (Goldich and others, 1966b).

The oldest dated rocks in Missouri are from three St. Joseph Lead Company drill holes, one in Camden County, one in Audrain County, and one in Clark County. Basement rock in the Camden County drill core is a granite with an age of 1,520 m.y. (Muehlberger and others, 1966). In Clark County, the rock is a diorite with an age of 1,500 m.y. (Muehlberger and others, 1966). In neither case is the character of the intruded rock known.

The Audrain County occurrence is the most revealing in that a pegmatite dated at 1,460 m.y. by Muehlberger and others (1966) cuts a steeply dipping Huronian *type* sequence containing quartzite, slate, and schist. A large diorite stock, similar in character to the Clark County diorite, lies within a mile of the dated pegmatite and associated metasediments.

Three of the 15 dated Missouri samples are approximately 1,500 m.y. old. The igneous rocks could represent waning stages of the Penokean orogeny. More likely, the diorites are of early Late Precambrian age and are the first representatives of a wave of intermediate to mafic intrusives that invaded Missouri and adjacent areas.

The intruded metasediments are part of an arcuate metamorphic belt (Fig. 3) that crosses Missouri, Kansas, and Nebraska and continues to the north and west. From presently available evidence, the Missouri metasediments appear to have been folded and metamorphosed prior to the 1,500 m.y. old igneous activity. The metasediments, at least in part, are probably Middle Precambrian in age.

The metamorphic belt, interrupted and broken in numerous places by later intrusives and sediments, is the preserved remnant of what was once a vast depositional basin. The sediments appear to have been dominantly sandstones and shales; no limestones nor volcanic rocks have been observed.

Late Precambrian

By far the largest number of holes drilled to the basement in the Midcontinent encounter rocks dated as Late Precambrian. Sufficient information is available (geological, geophysical, and chronological) to broadly define specific provinces and events of this period. These include: 1) a long period of igneous activity in the central Midcontinent that embraces widespread extrusion of rhyolitic to andesitic volcanic rock, intruded granitic and mafic rock, and formation of the Precambrian iron deposits; 2) development of the Keweenawan basin with its thick sequence of sedimentary clastic and basic volcanic rocks; 3) the igneous activity of the eastern Midcontinent that accompanied the Grenville orogeny; 4) Late Precambrian faulting and development of a major fault lineament that divides the central and eastern Midcontinent; and 5) a long period of uplift and erosion during which sediments were deposited in interior and fringing basins.

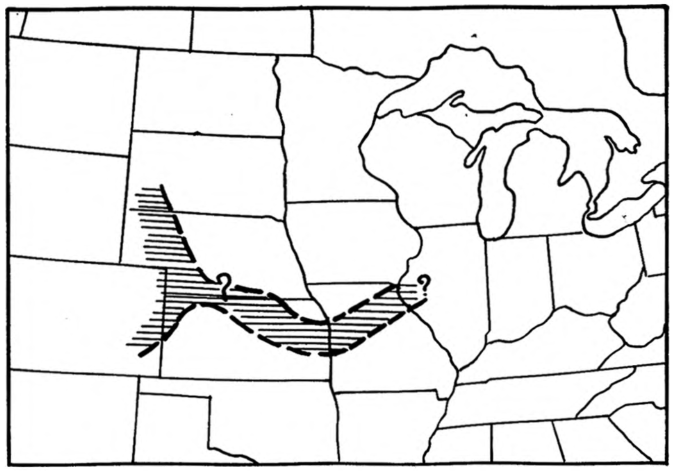

Fig. 3. Metamorphic belt in part intruded by igneous rocks of early Late Precambrian age (after Grenia, 1960; Merriam, 1963; Goldich and others, 1966; Muehlberger and others, 1966).

Central igneous activity.—Large parts of the central Midcontinent are floored by igneous rocks from 1,100 to 1,450 m.y. of age that become progressively younger to the south. The igneous activity responsible appears to be unrelated to any orogenic cycle. Muehlberger and others (1966) define geographic areas of igneous activity, including the Nemaha (1,350-1,450 m.y.), the St. Francois (1,200-1,350 m.y.), the Spavinaw (1,150-1,300 m.y.), and the Panhandle (1,100-1,200 m.y.).

Age determinations on samples from the St. Francois igneous outcrop area and nearby basement cut by drill holes show ages of 1,260, 1,290, and 1,330 m.y. for rhyolites and 1,120, 1,190, 1,210 (pegmatite in quarry wall), and

1,220 m.y. for granites (Muehlberger and others, 1966). Two stages of volcanic activity and two stages of granitic intrusion have been recognized by field studies (Hayes, 1961; Snyder and Wagner, 1961). The granite intrudes the volcanic rock. The younger granite and rhyolite are regarded as products of the same magma; and this sequence of extrusion of volcanic rock and intrusion of granitic rock was essentially continuous (Snyder and Wagner, 1961).

The extensive iron mineralization in Missouri appears to be derived from this igneous activity. Samples taken from the Pea Ridge iron mine give an age of 1,290 m.y. for host rock rhyolite and 1,310 m.y. for an aplite dike that cuts the ore body (Snyder, 1966; Muehlberger and others, 1966). The measurements, within the limit of error, are essentially the same. The iron mineralization appears to be a unique phase of the igneous activity.

Numerous intermediate to mafic intrusive rocks are known, both in outcrops and in the subsurface. The rock types range from diorite to gabbro, including norite. Body forms range from large stocks and bosses to thick layered sills and small dikes of diabase. The oldest dated rock is the 1,500 m.y. old Clark County diorite. The youngest is diabase that cuts all other igneous rocks as well as the iron ores. Probably several distinct stages of this phase of intrusive activity are present.

The Sioux Quartzite.—The Sioux Quartzite crops out in southeastern South Dakota, northwestern Iowa, and southwestern Minnesota and is present in the subsurface over much of southern South Dakota and part of northern Nebraska (Fig. 4). The formation consists largely of silicified sandstone but contains thin beds of shale.

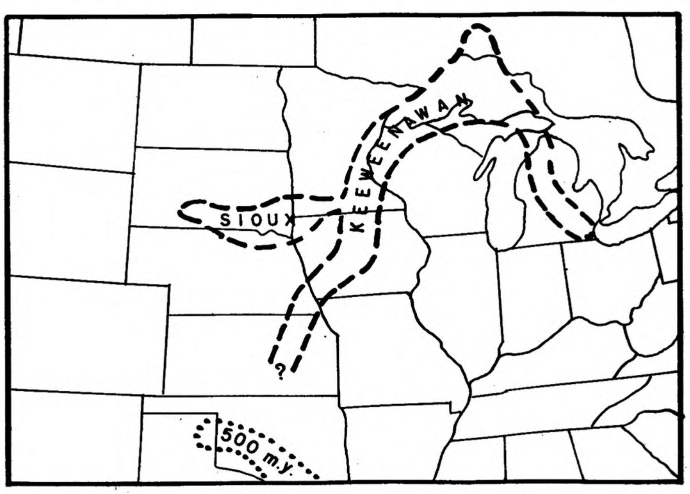

Fig. 4. Late Precambrian basins, probably not equivalent in age, and 500 m.y. old volcanic rocks (after Lidiak, 1964; Ham and others, 1964; Woolard, 1966, Goldich and others, 1966).

The formation could be equivalent in age to the metasediments of central Missouri. However, Goldich and others (1961) place the time of folding of the Sioux Quartzite at 1,200 m.y., while the central Missouri metasediments appear to have been folded prior to the 1,500 m.y. old igneous activity. Because of the differences in the probable age of folding and in the character of the sediments, the two areas appear to be separate depositional basins, distinct in time and in sedimentary sequence.

The Keweenawan basin.—The Keweenawan basin, as defined by outcrop studies and subsurface projections based on geophysical data, is shown in Figure 4.

The lower Keweenawan Series is represented in the Lake Superior outcrop area by a thin clastic sequence.

The middle Keweenawan consists of up to 30,000 feet of basic lava flows. White (1960) regards this series as one of the world's great plateau basalt flows. The flows thicken toward the center of the basin. Closely related to the flows is the intrusion of the Duluth gabbro. Goldich and others (1966) date the time of igneous activity as approximately 1,100 m.y.

Following the volcanic episode, the geosyncline continued to subside. The upper Keweenawan sequence consists of up to 20,000 feet of sandstone and shale.

The Midcontinent gravity high, which extends southwestward from the Lake Superior area across Minnesota, Iowa, and into Kansas, is the largest positive gravity anomaly in North America (Thiel, 1956). The narrow gravity high is flanked on both sides by gravity lows. The high density belt consists of basic volcanic rock; the low density belts are interpreted as clastic sedimentary rock. Gravity data across the Keweenawan outcrop area substantiate this interpretation (Thiel, 1956). A southeastward extension of gravity data indicates that the Keweenawan basin continued across the present Michigan basin.

Igneous activity of the Keweenawan area was not an orogenic phase, although it was closely related in time to the Grenville orogeny. The Keweenawan igneous activity was dominated by the extrusion of basic lavas and intrusion of mafic rocks. The numerous mafic intrusive rocks of southern Missouri that are younger than the 1,200-1,300 m.y. old granites and rhyolites probably belong to this period.

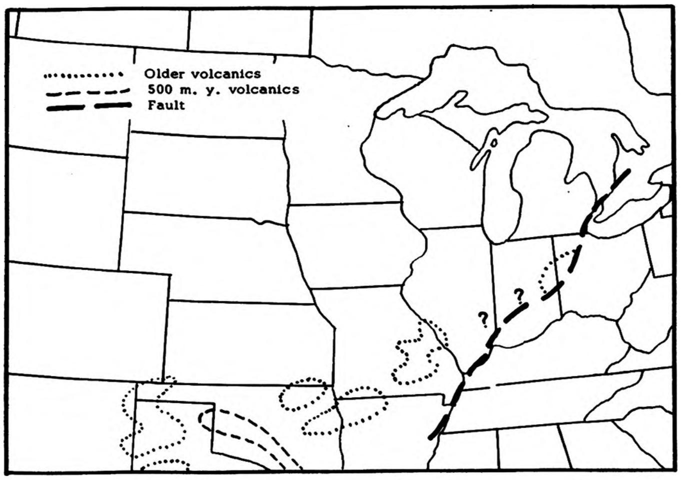

Fig. 5. Belt of preserved volcanic rocks (Ancestral Ozarks). Generalized after Ham and others, 1964; Muehlberger and others, 1966; Lidiak and others, 1966; unpublished drillhole data.

The Grenville orogeny.—The Grenville Series, exposed in the Adirondacks and eastern Canada, differs markedly from other North American Precambrian sequences. The thousands of feet of metasediments represent limestone interbedded with sandstone, shale, anhydrite, and even small amounts of hydrocarbon. The sediments indicate a time of shallow water geosynclinal conditions with reworking of sediments and long periods of carbonate deposition. Time of deposition is unknown. Intense deformation accompanied by igneous intrusion is dated at 800 to 1,100 m.y. (Lidiak and others, 1966).

Age dating of basement rocks from the subsurface in the eastern Midcontinent shows that large areas were affected by this orogeny. On the Precambrian shield, the Grenville is in fault contact with older Precambrian and appears to have been thrust from the southeast over the older basement. The fault can be traced southward and southwestward from the outcrop across Ohio, Kentucky, and Tennessee by the age determinations of the basement rocks.

Woolard (1958) suggested extension of the New Madrid fault zone northeastward into the St. Lawrence Valley and considered this one of the great fault lineaments of North America. The fault projected by Woolard from geophysical data apparently coincides with the boundary between two distinct ages of basement rocks. The fault developed in Late Precambrian time. Continued activity along this zone is indicated by a belt of earthquake epicenters (Woolard, 1958).

Uplift and denudation.—Following the central igneous activity and the Grenville orogeny, Precambrian history of the Midcontinent was largely restricted to uplift and erosion. Over most of the area, deroofed granites, granite gneisses, and mafic intrusive rock form the Precambrian subcrop; the volcanic rocks and the sediments intruded were largely removed.

Intermittent remnants of volcanic rock, forming Precambrian outcrops and subcrops, are known to be present in western Ohio, southern Missouri, northeastern Oklahoma, and western Texas (Fig. 5). Gaps in the belt are due in part to lack of information. This belt is termed the "Ancestral Ozarks". It appears to have been a continental divide in Late Precambrian time. Erosion on the southeastern side supplied sediments to the southern Appalachian basin, that on the northwestern side contributed sediments to the Keweenawan basin.

Local peaks on the divide form the Precambrian highs of southeastern Missouri and northeastern Oklahoma. In some areas, over 2,000 feet of local relief is present (Snyder and Wagner, 1961). The northeast-trending belt of sharp high peaks is narrow. Away from the belt, particularly on the northwest side where extensive drilling provides subsurface control, a broad rolling to flat surface with occasional subdued highs of a few hundred feet relief is present. Except for the Ozark divide, the broad, flat to gently rolling surface covered most of the Midcontinent at the beginning of Late Cambrian time.

PALEOZOIC

Upper Cambrian sandstones form the first unquestionable Paleozoic sedimentary rock over most of the Midcontinent. However, Early to Middle Cambrian igneous activity is recorded in Oklahoma (Ham and others, 1964), (Fig. 5). The igneous episode includes extrusion of volcanic material followed by intrusion of the Wichita granite.

At the beginning of Late Cambrian time, the Midcontinent surface consisted of the narrow highland belt of volcanic rock flanked by broad, low, gently undulating plains which sloped toward the Keweenawan and Appalachian basins. Except for the igneous peaks, most of the present relief on the basement surface was developed after the beginning of Late Cambrian time by differential subsidence and uplift.

Slow epeirogenic movements led to the formation of basins and arches. Some of these features played an important role throughout the Paleozoic; others were short-lived and in-

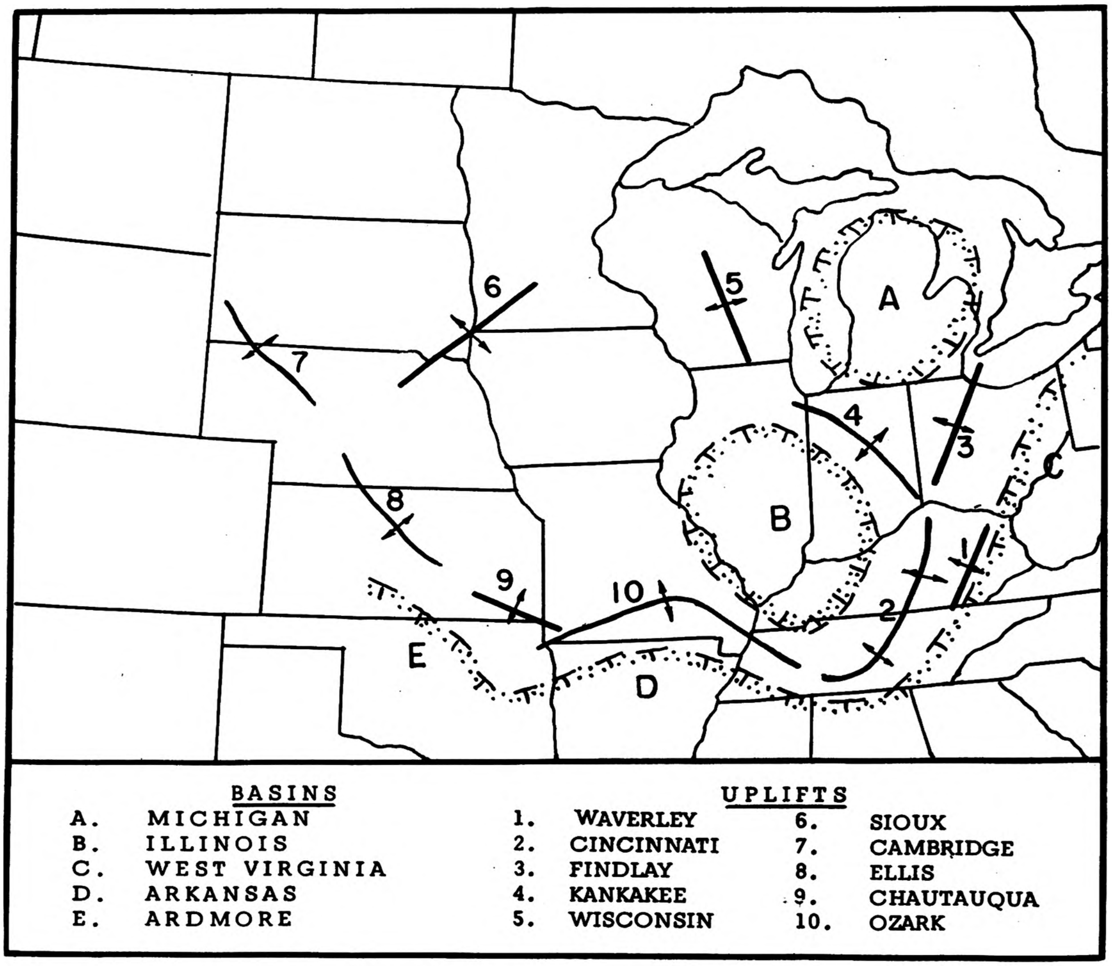

Fig. 6. Early structural features.

fluenced the sedimentary record only for a brief time. The major arches and basins began to develop in the latter part of Late Cambrian time and Early Ordovician time. The arches essentially were areas of less subsidence than the adjacent basins; they received sediments, but thinner blankets of sediment than were deposited in the basins. Only intermittently were the arches above sea level and subjected to erosion.

The transition from the Late Precambrian positive area undergoing erosion to the Paleozoic negative slowly subsiding area receiving sediments to the present stable area was a major tectonic change, the cause of which is not yet understood. The major elements in the transition which followed the broad uplift and deep erosion of Late Precambrian time include successively: 1) slow subsidence of the entire Midcontinent, 2) development of major arches and basins with intermittent subsidence and uplift, 3) fragmentation of the region through subdivision of the basins by short-lived or minor arches, 4) oscillation leading to cyclical deposition, and 5) final uplift and stability.

Another major element of the Paleozoic is the resurgence of carbonate deposition. Carbonate rock reflects warm shallow seas, an abundance of marine plant and animal life, and the absence—or only minor influx—of clastic sediments. Apparently, these conditions had not existed in the Midcontinent in over a billion years, not since Middle Huronian time.

Basins

The basins and arches which form the dominant structural features of the region (Fig. 2) developed gradually throughout the Paleozoic. At the beginning of Late Cambrian time, broad submergence prevailed and a blanket of sediment covered all but the higher peaks. The Eastern Interior basin, comprising much of Michigan, Indiana, and Illinois, subsided more rapidly than adjacent areas. Aside from this basin, only the fringing Appalachian and Ardmore basins received more than a thin veneer of lower Paleozoic sediments.

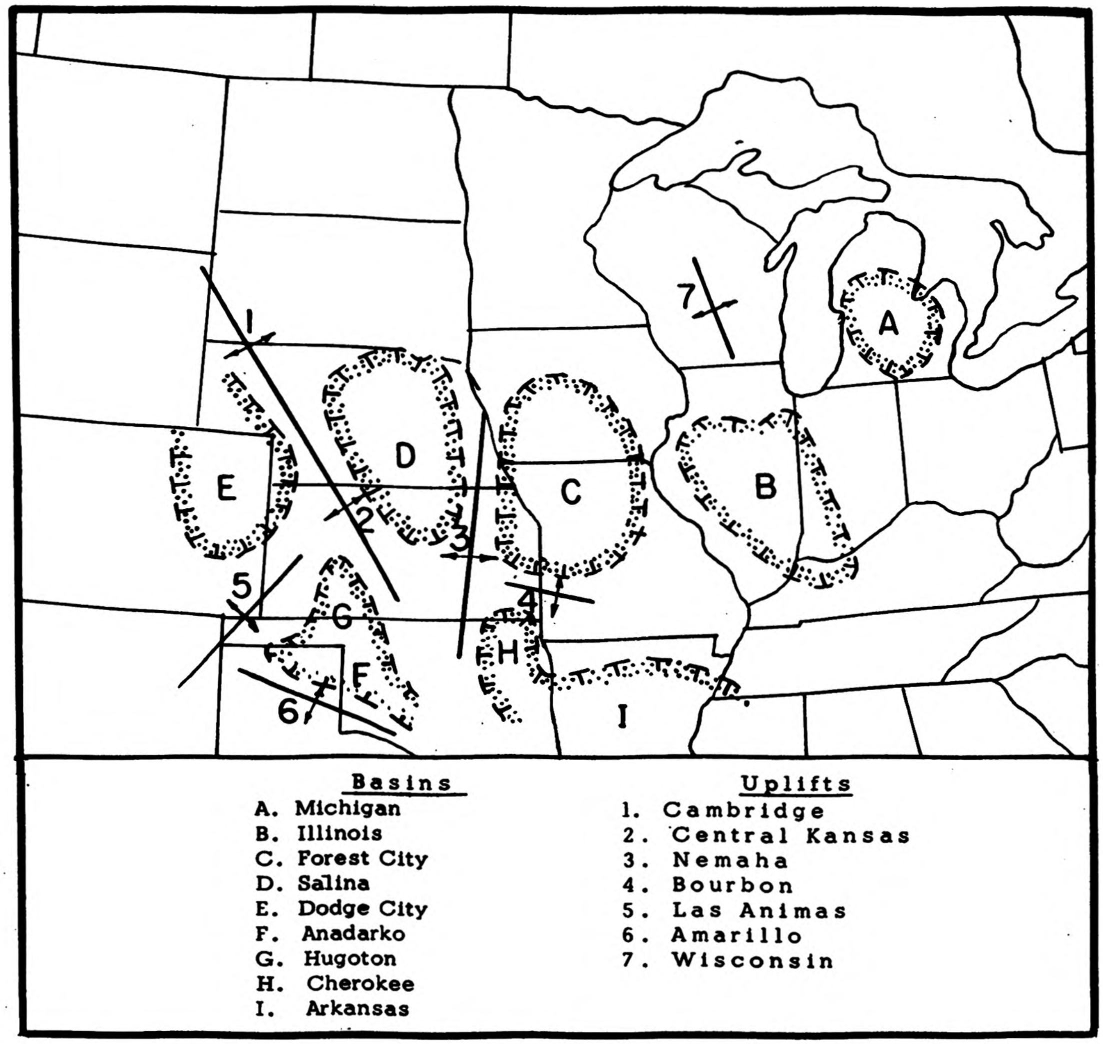

Fig. 7. Upper Paleozoic structural features.

In the latter part of Late Cambrian and in Early Ordovician time, the major arches began to appear. Continued differential subsidence, with periodic uplift and erosion, developed a number of basins. The appearance of the Cincinnati arch, the Ozark uplift, and the Wisconsin dome led to a basin-arch relationship (Fig. 6). The Kankakee arch, active in Devonian time, divided the Eastern Interior basin into the Michigan and Illinois-Indiana-Kentucky basins.

The western part of the Midcontinent contains a number of arches and basins. A large basin in northern Kansas and adjacent states began to develop in Middle Ordovician time. Concurrent with its development was the rise of the Chautauqua arch that linked the Ozark uplift and the Central Kansas uplift. By Mississippian time, the Chautauqua arch was no longer active. The North Kansas basin was divided into the Forest City and Cherokee basins by the appearance of the short-lived Bourbon arch in post-Mississippian—pre-Desmoinesian time. The Forest City basin became separated from the Salina basin through the development of the Nemaha uplift (Fig. 7).

West of the Central Kansas uplift lay the Dodge City basin with several embayments. This was separated from the Ardmore basin by the Las Animas arch. By Late Pennsylvanian time, the Kansas and Oklahoma arches had become inactive, and again a large area was merged into a single unit called the Anadarko basin.

The basins show a wide range in time of activity and amount of subsidence. The Michigan basin contains over 14,000 feet of sediment; the Illinois basin slightly less; the Forest City basin about 4,000 feet; the Salina basin about 4,500 feet; and the Cherokee basin about 3,500 feet. The Hugoton embayment of the Anadarko basin has about 9,500 feet of sediment and is the deepest basin in Kansas (Merriam, 1963).

Arches and Uplifts

Epeirogenic activity can be described more specifically by considering the development of individual arches. Their appearance subdivides basins and defines basin limits. During much of their history, they were submergent. During intermittent emergent periods, they were actively eroded while adjoining basins may have been receiving sediments.

The Ozark uplift.—As indicated earlier, this was a high—an erosional remnant—during Late Precambrian time. The present uplift embraces a large part of southern Missouri, northern Arkansas, and northeastern Oklahoma. It is reflected as a broad area of Cambrian, Ordovician, and Mississippian rocks which dip outward from a Precambrian core.

During Late Cambrian and Early Ordovician time, the area slowly subsided and sediments transgressively overlapped the higher peaks. Minor disconformities indicate brief interruptions in deposition, but the first major unconformity is that on the Jefferson City surface.

The Jefferson City—St. Peter unconformity signaled a reversal of tectonic activity; the Ozark uplift became a positive element. Sediments deposited in adjacent basins had thin or no counterparts over the uplift. Uplift and widespread erosion occurred at the close of the Silurian; preserved remnants of Silurian formations are known only from a few small areas in northeastern and south-central Missouri (Snyder and Gerdemann, 1965). Silurian formations around the uplift are beveled. Devonian strata rest unconformably on Silurian and are, in turn, truncated by post-Devonian erosion.

Widespread submergence during the Mississippian Period again led to deposition of sediments over the uplift. Probably even the highest peaks were covered. Uplift and removal of Mississippian sediments was followed by another period of submergence, and Pennsylvanian sediments were deposited on the Jefferson City karst surface.

The Wisconsin dome.—Like the Ozark uplift, the Wisconsin dome slowly subsided during the early Paleozoic and was covered with a veneer of sediment. Following deposition of the Prairie du Chien (Beekmantown), the area was uplifted and eroded. Renewed deposition was again followed by erosion.

A southeastward extension of the Wisconsin dome joins it with the Kankakee arch which began to develop in pre-St. Peter time. Renewed activity of the Kankakee arch in Devonian time separated the Eastern Interior basin into the Michigan basin and the Illinois-Indiana-Kentucky basin.

The Cincinnati arch.—The Cincinnati arch, which can be subdivided into the Nashville and Lexington domes, extends northeastward as the Findlay arch and northwestward as the Kankakee arch. By Middle Ordovician time, the Nashville and Lexington domes exerted a strong influence on deposition; they probably became active in Early Ordovician time.

Distinct from but apparently related to the Cincinnati arch is the Waverly arch of eastern Kentucky. This became active very early in the Paleozoic and was a major feature during Cambrian and Early Ordovician time. By Middle Ordovician time, the Waverly arch became dormant (Woodward, 1961).

Wilson (1949, 1962) describes several periods of uplift of the Nashville dome. During Middle Ordovician time, it was a narrow belt of shallow water, called the Central Tennessee Bank, and was emergent for short periods. The arch was uplifted and truncated at the close of the Devonian. Chattanooga shale, overlain by Mississippian and Pennsylvanian formations, was deposited over the dome. The Lexington dome followed a similar history.

The Transcontinental arch.—The Transcontinental arch has been referred to as the "continental backbone" by Keith (1928). It is an impressive feature on paleogeologic maps of the middle Paleozoic (see Eardly, 1951). The arch extended from the Precambrian outcrop area of Lake Superior southward across South Dakota and Nebraska into New Mexico. Its present exposed counterpart is the Sioux uplift of southeastern South Dakota, northwestern Iowa, and southwestern Minnesota.

The arch probably became active before the deposition of Paleozoic sediments. However, during early Paleozoic time, it was low and contributed little coarse clastic sediment to the basins to the east. It became a positive feature during middle Paleozoic, and parts of it were eroded. Pennsylvanian submergence again covered the arch with sediments.

A northwestward trending prong of the arch which extends from western Kansas into South Dakota is known as the Cambridge arch; a southeastward trending prong is the Ellis arch. The Ellis arch is the pre-Mississippian development of the Central Kansas uplift with the latter term applying to the post-Mississippian-pre-Desmoinesian period of activity of this structure.

The Nemaha uplift.—The Nemaha uplift, which extends from Nebraska through eastern Kansas and into Oklahoma, developed in Early Pennsylvanian time. Mississippian and older formations were sharply tilted by the uplift and were eroded to expose the Precambrian core. The truncated sediments and basement were covered by Pennsylvanian deposits.

Most of the arches active during the Paleozoic developed as slowly moving, gentle, usually symmetrical features. The Nemaha uplift, in contrast, is a sharply defined, asymmetrical structure with a well-developed, high angle fault on the east side and a gently sloping west side. Eardley (1951) classes the structure as a *range* because of the difference in tectonic development.

Minor arches.—Numerous lesser uplifts that are classed as folds or anticlines are present throughout the Midcontinent. Probably the best known of these is the LaSalle anticline. This extends in a southeasterly direction across Illinois. It formed during Pennsylvanian time. The Lincoln arch and the Savanna-Sabula anticline and many others belong to this group. Like the LaSalle anticline, most of them developed in late Paleozoic.

Faulting

An east-west trending faulted area, which embraces the Palmer-Cottage Grove-Rough Creek-Shawneetown-Kentucky River fault zones, is one of the major features of the Midcontinent. Amount of displacement and type of movement vary along the zone. Uplift along the Rough Creek segment is as much as 2,500 feet in places (McFarlan, 1943).

McGuire and Howell (1963) associate the east-west system in Kentucky with a hinge line active since Early Cambrian. Intermittent igneous activity from Late Cambrian to Cretaceous time indicates that this was a zone of weakness throughout a long span of time (Snyder and Gerdemann, 1965). Although the zone appears to have been active periodically throughout the Paleozoic, the major displacement was post-Pennsylvanian.

In addition to the east-west faulting, both northeast- and northwest-trending faults occur. The northwest-trending Ste. Genevieve fault zone is a high angle thrust fault. The northeast-trending New Madrid fault zone, cited earlier as a Precambrian lineament, reveals extensive post-Paleozoic activity along the Illinois-Indiana boundary extending southwestward beneath the Tertiary sediments of the Mississippi River Embayment.

Frequent earthquakes, ranging in strength from minor tremors to the severe New Madrid series, indicate that these faults are still active. Heyl and others (1965) state that quakes in the vicinity of the St. Francois Mountains focus at depths of about 40 miles. They indicate that deep-seated adjustments are still taking place in the Ozarks.

On the western side of the Ozarks, deformation is expressed as a series of parallel northeast-trending faults, the largest of which is the Seneca fault which can be traced for over 100 miles. Faulting occurred as repeated movements during Pennsylvanian time and is probably related to the Ouachita orogeny.

Cryptoexplosion Structures

The Midcontinent contains a large number of structures that have been interpreted both as of meteoritic and deep-seated volcanic origin. Not all are of Paleozoic age, but all that are shown on Figure 8 occur in Paleozoic rocks. (A similar structure in Mississippi, not shown in Figure 8, occurs in Tertiary formations).

The structures show many similar features (Bucher, 1936). They have a circular form, a central uplifted area bounded by concentric faults and brecciated and displaced blocks. They range in size from one to ten miles in diameter. Many of them appear to be randomly distributed. Some are associated with intrusive and extrusive basic igneous rocks; others are not, so far as known.

Snyder and Gerdemann (1965) defined an east-west line along which eight such structures occur. Five of the structures have associated igneous rocks which have been dated by geological or geochemical methods as Late Cambrian (Furnace Creek and Hazel Green), Devonian (Avon), Permian (Hicks dome), and Paleocene (Rose dome area). The features are aligned along the east-west fault zone described earlier. The occurrence of intermittent, deep-seated igneous activity along this zone supports the geological conclusion that the fault zone has been active since early Paleozoic time and that other cryptoexplosion structures on this line are the result of subterranean forces.

The apparently random distribution of many of the structures cannot be related to known fault zones. However, comparison of Figure 8 with Figures 2, 6, and 7 indicates that many are located on Paleozoic positive areas. The

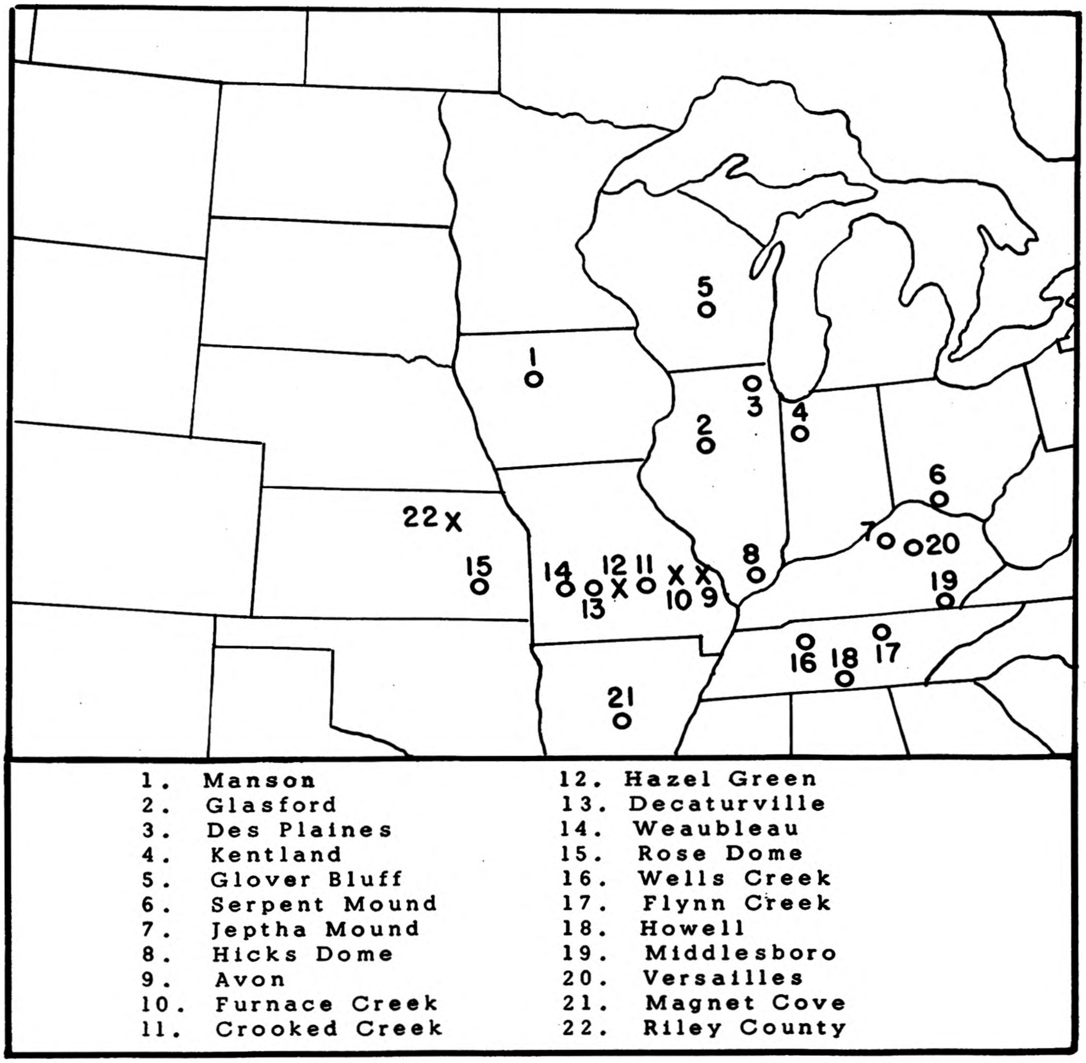

Fig. 8. Cryptoexplosion structures and igneous activity in the Midcontinent.

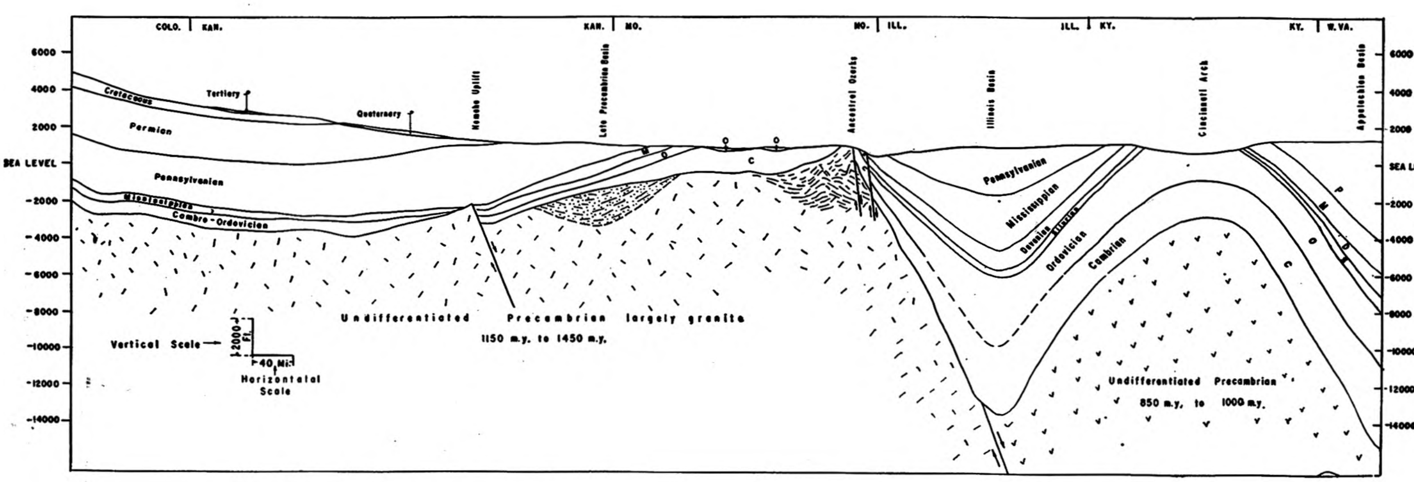

Fig. 9. Cross section approximately along the 38th parallel.

number that are not associated with preexisting structural axes are few.

MESOZOIC

The Mesozoic history of the Midcontinent is largely one of continued erosion. Except for the western part and the Mississippi River Embayment, the area never again subsided enough to be inundated by seas. The degree of stability reached can be illustrated by comparison of Paleozoic with later activity. During the Paleozoic, the Michigan basin subsided 14,000 feet more than adjoining areas; seas traversed the continent from Hudson Bay to the Gulf of Mexico during numerous submergences. The Cretaceous and Tertiary sediments in the Mississippi River Embayment reach only a few hundred feet above present sea level; the central Midcontinent did not subside enough to permit their deposition farther northward.

In the western part of the Midcontinent, the basins and arches that were active during the Paleozoic became dormant. The entire area as far east as Iowa and northwestern Missouri subsided slowly and received only a thin blanket of Cretaceous sediments before its final uplift.

Continued fault activity, particularly in the area of the Mississippi River Embayment, continued throughout the Mesozoic.

TERTIARY

From the beginning of the Tertiary to the present, the area, except for the westernmost part, has continued to be positive and has undergone erosion. Minor vertical movements have led to the development of numerous erosional levels, but no appreciable vertical movement has occurred. Deep-seated adjustments within the craton, relieved along old faults, continue to take place, but the region has become the *stable interior* (Fig. 9).

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