REPORT OF INVESTIGATIONS NUMBER 52

CORRELATION OF CAMBRIAN STRATA

OF THE OZARK AND UPPER MISSISSIPPI VALLEY REGIONS

By Wallace B. Howe
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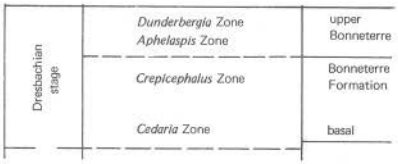
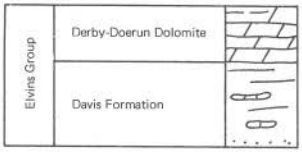
ERRATA

The following changes should be made to this publication:

p. 5 (Figure 2) Reference "Stitt (1970)" under "Continuous deposition" should read "Stitt (1972)".

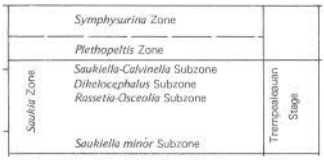
p. 8 (Figure 3) In zonation of the "Dresbachian stage", the *"Dunderbergia", "Aphelaspis", and "Cedaria"* Zones should be shown as indicated below (left). The "Elvins Group" should read as shown (right).





p.18 (8th line, 3rd para) should read: "However. . . .(of Gunter at. . . ."

p.20 (Figure 4) In subzonation of the *"Saukia* Zone", the *"Saukiella minor* Subzone" should be shown as:



p.54 "Bell, W.C., Robert Raymond Berg, and Clemens Arvid Nelson . . . . . Internatl. Geol. Cong. Symposium. . . . ." (instead of "Internatl. Geol. Eng. Symposim").

p.55 Delete the "s" on "Formations" under "Grant, R.E., 1965".

p.56 "Lochman-Balk, Christina, 1956 . . . . . Internatl. Geol. Cong. Symposium . . . . ." (instead of "Internatl. Geol. Eng. Symposium").

p.57 "Nelson, C.A., 1965" should read "Nelson, C.A., 1956".

p.58 "Raasch, G.O., ...change "cycle" to "cycles".

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CORRELATION OF CAMBRIAN STRATA OF THE OZARK AND UPPER MISSISSIPPI VALLEY REGIONS

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ABSTRACT

A principal problem inherent in regional correlation and isopachous mapping of Cambrian strata is that of recognizing major lithofacies elements and their relationship to or with locally applicable stratigraphic units. The relationship between the Cambrian section of the Ozark region in Missouri and that of the Upper Mississippi Valley region is an important example.

Lithostratigraphic and biostratigraphic correlation of Cambrian strata along a traverse connecting these areas indicates that 1) the concept of the general lithic equivalency of the Lamotte and Mt. Simon is valid; 2) the Bonneterre and Eau Claire formations are regionally correlative; however, difficulty in differentiation and correlation of upper Bonneterre and upper Eau Claire beds is a deterrent to satisfactory correlation in detail; 3) the term Eau Claire is preferable to Bonneterre in northeastern Missouri as the typical facies expression of the Eau Claire is represented in that area; 4) neither the Galesville nor the Ironton formations are present in Missouri; 5) divisions of the post-Ironton Franconian rock-stratigraphic succession such as the Birkmose, Tomah, and Reno are distinguishable and usable in northeastern Missouri; 6) of these, the Reno is traced the farthest and, as an attenuated unit, merges with the lower part of the Derby-Doerun Dolomite of the Ozark region; 7) traced northward, upper Derby-Doerun strata thicken and assume a facies relationship with the Potosi and the lower St. Lawrence, while Potosi strata undergo marked thinning apparently by facies substitution with the Derby-Doerun; and 8) the Momence Sandstone of northern Illinois is recognized in northeast Missouri where it underlies dolostone provisionally identified as upper Eminence. It is interpreted as the basal part of the Jordan-equivalent succession in Missouri.

Conclusions noted above are the basis for suggesting geographic limits to the practical application of many Missouri terms and are essential to satisfactory regional correlation of Cambrian strata.

INTRODUCTION

Cambrian strata in Missouri are part of an extremely widespread succession of rocks that retain persistent characteristics over areas peripheral to the Canadian Shield and prominent extensions that existed during Late Cambrian time. They are mostly if not entirely of Late Cambrian age, marine, and are almost entirely of shelf facies. These strata are related therefore to those of the Upper Mississippi Valley, Oklahoma and Texas, and the eastern Wyoming, Montana and Dakota regions, by strong paleontological ties as well as similarities in predominant lithologies and sequence of lithologic types. Essentially the same faunal zonation characterizes the entire region, and many of the lithostratigraphic units are correlated from state to state. Owing to the exposures in the St. Francois Mountain area, the Missouri section is one of the classic reference areas. This paper concerns relationships between the Cambrian strata of Missouri and the Upper Mississippi Valley region.

The typical succession of Upper Cambrian strata in the Ozark and Upper Mississippi Valley regions differs principally in that contrasting facies of regionally widespread units were developed in the two regions. The distance and lack of detailed subsurface information between the outcrop areas have been the principal deterrents to correlation of lithic and biostratigraphic divisions. The availability of diamond drill core data at suitable points across eastern Missouri and information gained through other current studies have made it possible to establish interregional correlation in more detail than has been feasible heretofore. Such correlation and comparison, along with attempts to suggest facies relationships, is the purpose of this study. Most of the Upper Mississippi Valley lithic units can be identified as far south as Clark County, in northeastern Missouri, and certain ones for some distance south. Ozark region units can be correlated into the same area. Northward facies changes are progressive and include pronounced vertical as well as lateral change.

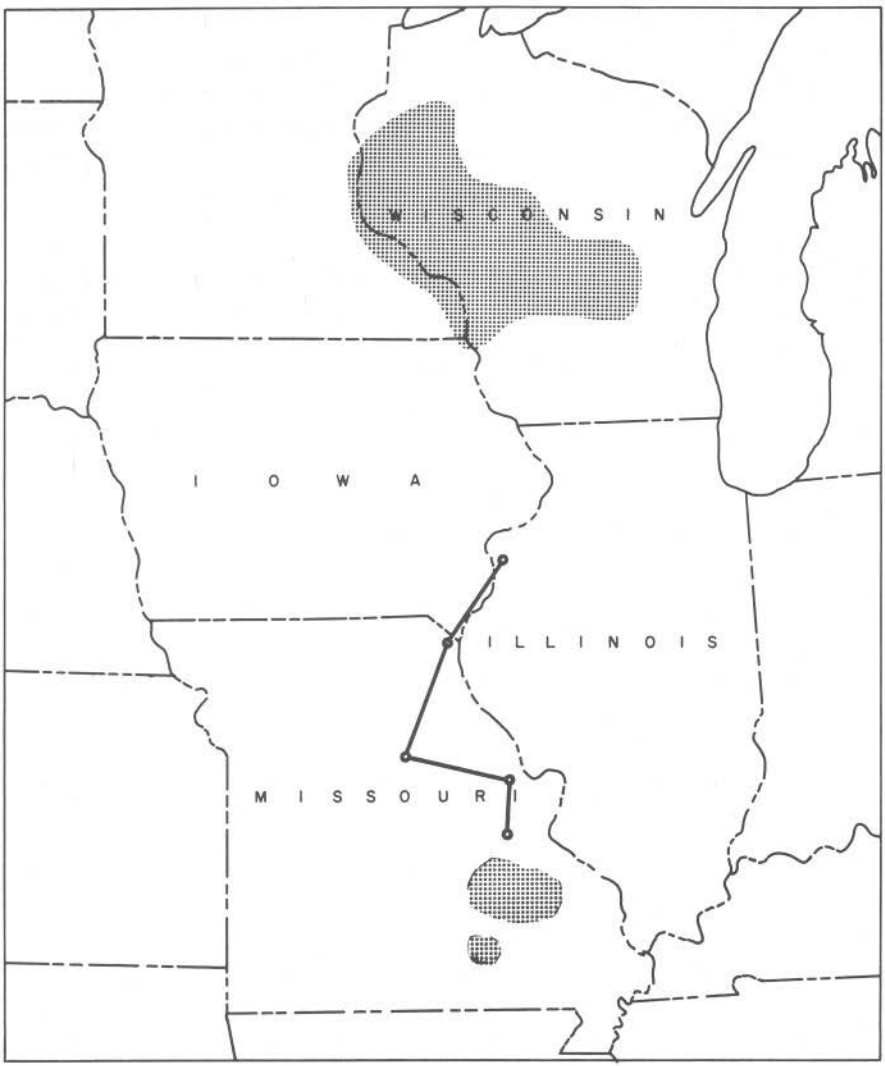

Figure 1

Outcrop areas in St. Francois Mountain and Upper Mississippi Valley regions and drillholes used in cross section.

One of the purposes of this report is that of illustrating the problem of limiting the extent of (or determining the limits of) usefulness of some formal stratigraphic names in the Cambrian succession as these strata are traced away from areas of typical expression and gradually become dominated by differing facies.

In this report, summary descriptions of the typical succession of two outcrop areas serve as the framework for discussion of the succession penetrated in drillholes located in northern Washington County, northwestern St. Charles County, central Audrain County, and northeastern Clark County, Missouri (fig. 1). A description of the Cambrian section from a well in Henry County, Illinois (Buschbach, 1965; Emrich, 1966), serves as an intermediate control point about midway between the Clark County hole and the Upper Mississippi Valley outcrop area.

As portrayed on plate 1 (Correlation Chart) the drillholes in Washington, St. Charles, Audrain, and Clark Counties, Missouri, are described and interpreted on the basis of core examination, sample and insoluble residue logging, and comparison with the sections in the outcrop area. The Henry County, Illinois, drillhole is illustrated and interpreted on the basis of information published by Buschbach (1965) and Emrich (1966).

General correlation of major divisions of the Cambrian in the two areas has been possible on a faunal basis for many years, as essentially the same cratonic faunizonal succession characterizes the Ozark and Upper Mississippi Valley Cambrian (fig. 2).

The advent of more detailed paleontological studies in Missouri, such as Kurtz's study of the Elvins (1960), allows considerable refinement in identification and utilization of biostratigraphic units. Current studies (Kurtz, 1971) of the fauna of the upper Bonneterre contribute to our understanding of some already well-defined problems in that part of the section. The record of the *Aphelaspis* Zone is now established in Missouri and the *Dunderbergia* Zone is also now recognized. Information on biostratigraphic zonation is presented in the discussion of the outcrop area succession and such information as is available from core samples is given in related discussions.

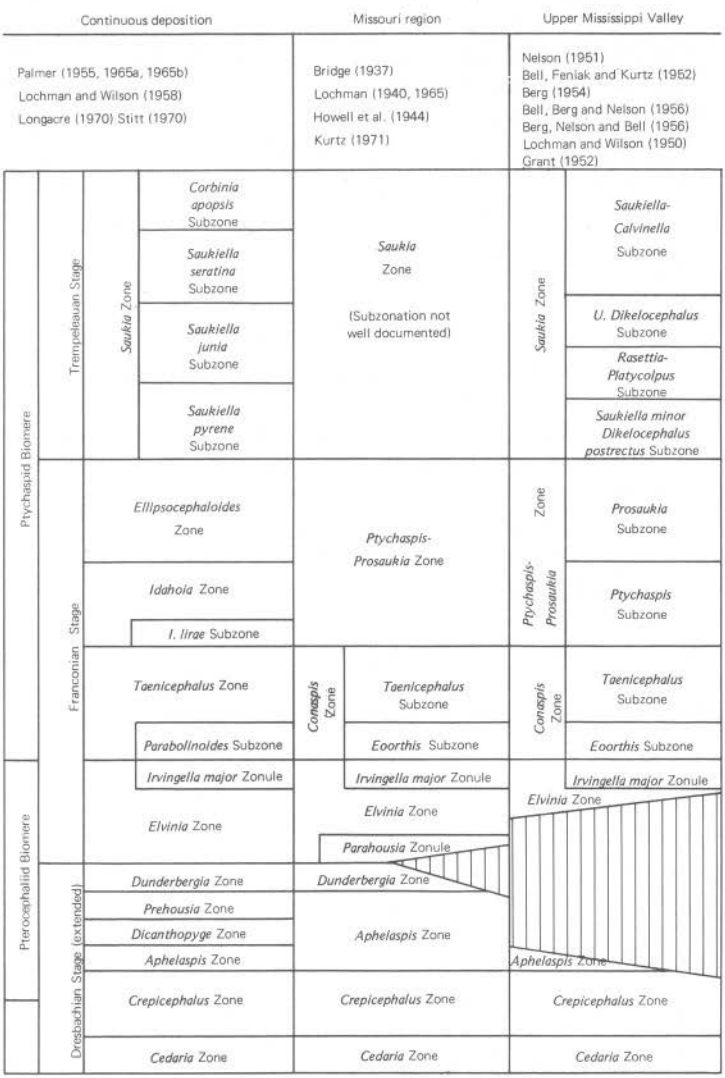

Figure 2

Late Cambrian biostratigraphic zonation.

The writers acknowledge the cooperation of the St. Joe Minerals Corporation, through Paul Gerdemann, in making core from holes in Audrain and Clark Counties, Missouri, available for examination and sampling as a part of the study. Additionally it should be noted that samples from the holes in St. Charles and Washington Counties were made available to the Missouri Geological Survey by the National Lead and Missouri (Cleveland) Cliffs Mining Companies, respectively, as part of the Survey's activities of data acquisition and assistance to mining interests.

M.E. Ostrom reviewed the manuscript at an early stage of preparation and offered many comments which were helpful to the writers in completing the report. Kurtz reviewed and discussed the Upper Mississippi Valley section with Ostrom, G.S. Austin, and R.A. Davis, Jr. during the Cambrian-Ordovician field trip preceding the annual meeting of GSA in November 1970. Also, at that time, Gilbert O. Raasch discussed with Kurtz the now-inaccessible Sunset Point type locality and fossil collection made there some years earlier. Appreciation is also extended to Joseph Emielity, Curator of the Milwaukee Public Museum, for arrangements allowing Kurtz and James Stitt to inspect the Upper Cambrian collections housed at the museum. A late-stage draft of the manuscript received a considerate and constructive review by T.C. Buschbach, Elwood Atherton and Charles Collinson of the Illinois Geological Survey. This assistance is gratefully acknowledged.

Howe assumed most of the responsibility of organization of this report and prepared the section on "Cambrian strata in the St. Francois Mountain region". Kurtz supplied information on the faunas collected from samples from two of the drillholes, prepared the section on "Cambrian formations of the Upper Mississippi Valley region", and was principally responsible for identification of Upper Mississippi Valley rock-stratigraphic units in the cross section; Anderson prepared the individual graphic presentation of the four drillholes portrayed on plate 1 and contributed to the interpretation of the cross section developed from that information. The authors also wish to express general acknowledgment to the Missouri Geological Survey staff for the wide variety of support required in the preparation and publication of this report.

CAMBRIAN STRATA IN THE OZARK REGION

The St. Francois Mountain region, because of its abundant exposures and their accessibility, has become a classic area for study of Upper Cambrian rocks of the Central Interior region of the United States. Type sections for units that are recognized over hundreds of thousands of square miles in over a half-dozen states are located in this region. Cambrian sedimentation in southeastern Missouri began on an erosional topography, characterized by high local relief with prominent highland masses such as the St. Francois Mountains and associated valley systems. Some valleys were exceptionally deep and narrow. Total relief exceeded 2,000 feet. Ultimately, nearly all of this rather complex and poorly known paleotopographic surface was buried by early Paleozoic sediments. Peaks and ridges persisted for varying lengths of time as islands in an archipelagic complex. The section includes transgressive and regressive elements comprising dominantly carbonate and detrital facies respectively; however, carbonate facies make up most of the rock column above the Lamotte Sandstone. Aggregate thickness (allowing an average of 200 feet for the Lamotte) of the Cambrian succession peripheral to the Precambrian core area of the St. Francois Mountains ranges from 1,200 to 1,400 feet. Time and rock-stratigraphic classification of Cambrian strata in the Ozark area are shown in figure 3. A brief discussion of the Cambrian formations follows.

LAMOTTE SANDSTONE

The Lamotte is a basal Paleozoic sandstone that typically is mature in petrologic character but contains more or less locally derived arkosic material at and near the base. The name Lamotte, from the occurrence of the sandstone in exposures and mines in the vicinity of Mine La Motte in Madison County,

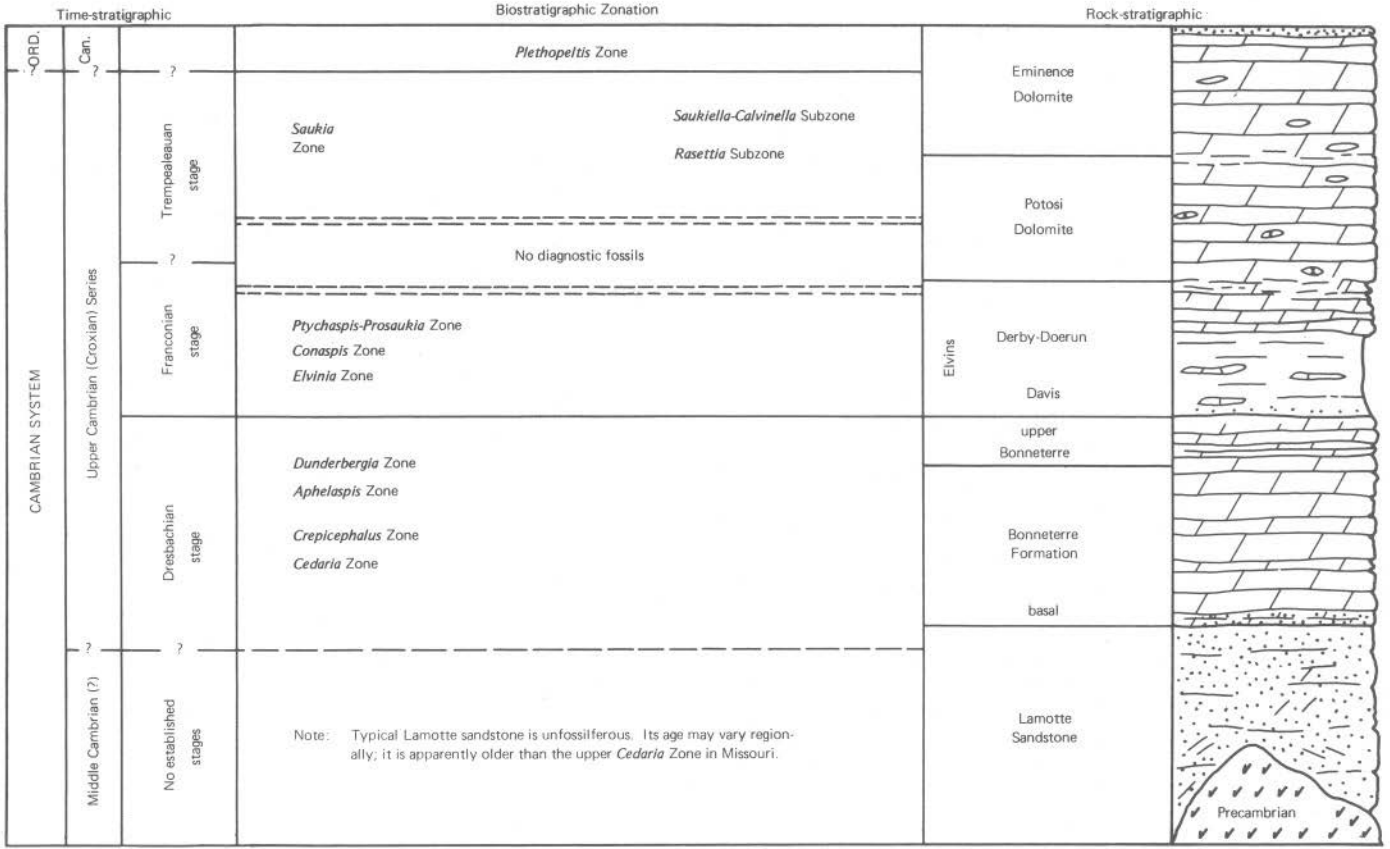

Figure 3

Time- and rock-stratigraphic classification of Cambrian strata in the Ozark region.

Missouri, was applied to this sandstone by Winslow in 1894 (p. 347), long before its regional extent came to be appreciated. Winslow's description and definition of the Lamotte was not comprehensive; however, it appears (p. 649-659) that his intent was to exclude strata currently identified as "transitional" and to refer them to the overlying formation. Usage in Missouri, as in James (1949), has been consistent in placing the boundary below the "transition zone". The Lamotte consists almost entirely of rounded fine and medium to coarse quartz grains. The overall color varies from white or gray to strong hematitic red and brown with variegated and/or alternating red and gray beds present in transitional zones. The Lamotte is a complex deposit and may include fluvial and aeolian as well as beach and shallow marine sediments.

The age of the Lamotte is not known – it may represent sand accumulation during part or all of Early, Middle and/or early stages of Late Cambrian time. Overlying strata (Bonneterre) contain representatives of the upper *Cedaria* Zone. No representatives of middle *Cedaria* and *Bolaspidella* Zone faunas have been reported. It is probable that some of the Lamotte is pre-Upper Cambrian.

Typically, in southeast Missouri, the boundary between the Lamotte and overlying Bonneterre is marked by a fossiliferous, glauconitic, texturally and compositionally variable "transition zone". In central and western Missouri, subsurface data indicate that basal Paleozoic strata are overlapped by younger Cambrian units with a comparable "transition zone", representing reworked Lamotte sand and other available material, developed above typical Lamotte (where present) and beneath overlapping strata. This relationship is interpreted as possibly representing a regional unconformity. In that part of the state where the Bonneterre is typically developed, the "transition zone" is comparable in most respects to the "poorly sorted lithotope" of Ostrom (1964) as applied to strata in the Mt. Simon-Eau Claire succession in the outcrop area of Wisconsin. It is a characteristically diachronous unit with much variation in thickness and lithology. The term "Shawtown" (Raasch and Unfer, 1964, p. 435) has been applied to a part of the "poorly sorted lithotope" described by Ostrom and the term Elmhurst (Buschbach, 1964, p. 32) appears to have been applied to similar transitional strata in the subsurface of northeastern Illinois. Both terms were introduced as member-rank divisions of the Eau Claire. Neither term appears to be directly applicable in Missouri.

Distribution of the Lamotte is essentially state-wide in Missouri except in the Mississippi embayment area of southeastern Missouri where basinal rather than shelf conditions are assumed to have prevailed. Positive identification of Lamotte in that area below a much thickened and poorly understood Cambrian section has not been possible as no drillholes have penetrated to the basement. Regionally, the formation thins to the west and north in Missouri from a maximum of over 400 feet in the southeastern part of the state. Local thickness variation associated with the pre-Lamotte topography on the Precambrian surface is a regional characteristic of the Lamotte.

BONNETERRE FORMATION

The Bonneterre typically comprises fine to coarse and variable shaly calcarenite, mostly dolomitized and including well-defined oolitic and stromatolite facies. Most of the medium-grained and coarser-textured rock is oolitic. The formation includes the "transitional" beds above the basal contact with the Lamotte Sandstone. Current use of the term is essentially the same as that of Buckley (1908) whose definition evolved in the type area of central and northern St. Francois County, Missouri. Original application of the term by Nason (1901) and later usage by Bain and Ulrich (1905) included the Bonneterre of current connotation plus a considerable thickness of strata now assigned to the Davis.

In much of the Ozark region it appears practical to distinguish and to refer Bonneterre strata to "lower and middle Bonneterre" and "upper Bonneterre". In the type area and elsewhere, three interrelated but distinctive divisions of the Bonneterre constitute the lower and middle parts of the formation. Each such division comprises more than one rock type but may be described in terms of dominant and subordinate facies. The principal divisions include 1) a basal "transitional" division that is strongly quartzose and commonly glauconitic; 2) intermediate variable oolitic and shaly to stromatolitic strata; and 3) broadly extensive, prevailingly oolitic carbonate that was deposited during the period of greatest Dresbachian transgression. The widespread oolitic material is identified

as middle Bonneterre because of its prominence and persistent stratigraphic position. A lower "volcanic debris facies" of the Bonneterre is known to have developed in some sharply restricted localities.

Upper Bonneterre strata are differentiated generally west of the Fifth Principal Meridian in the St. Francois Mountain region but, thus far, have not been identified or differentiated as a separate entity in the outcrop area proper. Beds classed as upper Bonneterre include a basal silty and shaly zone that is a prominent and well-defined element of the Bonneterre in central and south-central Missouri. Calcarenitic carbonate typically occurs above the silty and shaly zone and extends to the base of the Davis. The upper Bonneterre rests with seeming disconformity on middle Bonneterre strata and attains thicknesses of as much as 50 feet or more.

Biostratigraphic zonation of the Bonneterre has not been completed in detail, although the essential information has been made available. Lochman (1940) determined that the *Cedaria* Zone was represented in Bonneterre exposures in St. Francois, Ste. Genevieve and Madison Counties. Later (1956, p. 451) Lochman notes that the basal Bonneterre fauna is assignable to the upper part of the *Cedaria* Zone. It is probable that no material from upper Bonneterre beds was included in Lochman's studies. As much as 50 feet of siltstone, shale and dolostone that are assigned to the Bonneterre are present above rocks containing *Tricrepicephalus* and other fossils of the *Crepicephalus* Zone in a belt peripheral to the St. Francois Mountains on the west. This succession is referred to the *Aphelaspis* and *Dunderbergia* Zones on the basis of trilobite and brachiopod material, as noted by Kurtz (1971). Kurtz, using brachiopod zonation, recognized an *Angulotreta missouriensis* Zone (in part equivalent to the *Aphelaspis* Zone) and the *Apsotreta expansa* Zone (equivalent to the uppermost part of the *Aphelaspis* Zone, the *Dunderbergia* Zone, and lower part of the *Elvinia* Zone) in samples from diamond drill cores in the area. The trilobite zone definitions used in this paper are the same as those used by Kurtz (1971), i.e., the *Aphelaspis* and *Elvinia* Zones are defined by the ranges of the respective genera with the *Dunderbergia* Zone between the foregoing zones. The question of the presence of beds of this age in the outcrop area of the type Bonneterre has not been resolved, as possible equivalent strata of that area are dolostones from which no diagnostic fossils have been reported.

The relationship of the Bonneterre to the underlying Lamotte Sandstone is interpreted as possibly being one of regional unconformity with the variable thick basal Bonneterre "transition" zone representing reworked Lamotte sand incorporated with marine sediment during Bonneterre transgression. This reworked zone is commonly several tens of feet thick. Thickness of the Bonneterre ranges from 350 to 400 feet throughout the St. Francois Mountain area except in those localities where it laps upon Precambrian uplands.

ELVINS GROUP

The term Elvins is applied to strata between the Bonneterre Formation below and the Potosi Dolomite above in areas of their typical development in Washington and northern St. Francois Counties in southeastern Missouri. The name was originally proposed by Bain and Ulrich (1905, p. 23-26) for beds in St. Francois County "between the shaly top of the underlying Bonneterre Limestone and the cherty limestone of the Potosi group above" (p. 23). As originally defined, Bain and Ulrich's Elvins was somewhat thinner than the present connotation indicates because those authors included in the Bonneterre a significant portion of the section now assigned to the Davis Formation. The type section of the Elvins is in the vicinity of Elvins along Flat River in western St. Francois County, Missouri. This is also the region of typical development of the Davis and Derby-Doerun Formations.

The Elvins is a useful division of the Missouri Cambrian section throughout the southeastern Missouri area, although usage of the term has been inconsistent since its introduction. Its original application was as a formational name; however, Bridge (1937) in expanding or extending the base of the unit to its present boundary elevated the term to group status including in it the Davis and Derby-Doerun formations. Kurtz, in unpublished studies (1960), was the first to indicate the facies relationships and his concept of the unit as one of formational rank including several member rank divisions is accepted in principle by the authors of this report.

Biostratigraphic zonation of the Elvins is known in detail through the works of Kurtz (1960). Kurtz differentiated pre-*Elvinia*, *Elvinia*, *Conaspis*, and lower *Ptychaspis* – *Prosaukia* Zones in the Elvins of Missouri exposures. Upper beds of the type Derby-Doerun are unfossiliferous and collections at other places in the St. Francois Mountain area have not been satisfactory, with the result that well-defined zonation of upper Derby-Doerun strata has not been accomplished.

The Davis and the overlying Derby-Doerun Formations are practical divisions of the Elvins in its type area but a number of other facies, regarded as atypical and possibly not requiring formal stratigraphic identification, are developed within the St. Francois Mountain area, where they have been studied by Kurtz (1960) and Howe (1968). Among these are 1) an oolitic and coquinoidal calcarenite facies probably having vertical extent from near the base of the Elvins upward to a horizon within the Derby-Doerun; 2) planar stromatolite and burrowed carbonate mud facies described by Howe (1968); and 3) substitution of typical Derby-Doerun facies for significant portions of the Davis.

DAVIS FORMATION

The lower and thicker division of the Elvins is called the Davis. The name was applied in 1908 by Buckley (p. 33-44) for exposures in the Bonne Terre – Flat River area.

The Davis consists of repeated sequences of burrowed silty to sandy shale and slabby impure limestone or dolostone that are terminated by the development of irregular zones of mud-chip breccia, the "edgewise conglomerate" of authors. The mud-chip breccia zones are discontinuous and variably developed but consist mainly of disrupted angular to rounded tabular clasts that are locally derived from the substrate. Matrix in the breccia or conglomerate units consists of silt and sand-sized particles derived along with the clasts plus highly varied but generally distinguishable amounts of crinozoan and other fossil debris. Small algal bioherms, constructed largely of girvanellid limestone and associated *Epiphyton* colonies, are common in the Davis, particularly in the upper part.

Much of the silt and sand-sized fraction of the material present in the Davis originated as carbonate mud and sand rather than as terrigenous debris. Relative percentages are impossible to determine by field observation. The typical Davis locally is represented by, or may include, significant amounts of predominantly calcarenitic strata; however, the typical development in the northern Ozark region is of the shaly and silty to sandy glauconitic facies. Basal Davis beds are typically shaly with interbedded coquinoidal material and generally abundant pellet glauconite.

The contact of the Davis with the underlying Bonneterre Formation in the type region is sharp and appears to be one of unconformity, although the relationship is difficult to demonstrate. Thickness of the Davis in the type region is approximately 160 feet.

DERBY-DOERUN DOLOMITE

The upper division of the Elvins is a distinctive unit called the Derby-Doerun Dolomite. The terms "Derby" and "Doerun" were originally conceived by Buckley (1908) as names for what appeared to be distinctive lithic units within the interval above the easily differentiated Davis shale and below the Potosi dolomite. Consistent application of the individual terms proposed by Buckley has not been practical and the combined term Derby-Doerun has been, and is being usefully applied to the shallow marine shelf deposit complex that is characteristic of the upper Elvins over wide areas. The lower Derby-Doerun typically comprises thin and irregularly bedded (commonly burrowed) shaly to silty and glauconitic dolomitized calcarenite with locally important stromatoitic "reef" facies. In the Ozarks region variable abundant fine quartz sand and silt and glauconite characterize the lower part of the Derby-Doerun. The uppermost occurrence of this material is identified informally as the "top of the Cambrian clastics" and serves as a useful datum in the area. Upper Derby-Doerun strata consist mostly of rock that is essentially calcarenitic (often oolitic) in character. Uppermost Derby-Doerun beds consist of dense fine- to medium-crystalline dolomite at most outcrop localities and in most core records in the Ozark region. The relationship of the Derby-Doerun to the underlying Davis is one of

rather abrupt transition. In outcrop and in core description the contact is generally placed above the highest occurrence of green and gray shale and the mud-chip breccia or "edgewise conglomerate" that is typical of the Davis. This contact coincides with a marked decrease in the amount of clastic material. Thickness of the Derby-Doerun is about 115 feet in the type region.

POTOSI DOLOMITE

The Potosi consists of mostly medium crystalline brownish gray dolomite with more or less drusy quartz distributed throughout. Earliest application of the name Potosi was that of Winslow (1894a, p. 311-351); however, current connotation is that given the term by Buckley who in 1908 (p. 51) restricted its application. The name Potosi is taken from the town of that name in Washington County, Missouri. Good exposures occur at many points in the Potosi region. Dake (1930) supplied a comprehensive account of the development of the term Potosi and, in his discussion of stratigraphic units of the Potosi and Edgehill quadrangles, presented the most detailed description of the Potosi available to later workers in the St. Francois Mountain area.

Efforts by a number of workers indicate that *Rasettia* and *Scaevogyra* are important lower *Saukia* Zone fossils found in the upper Potosi.

The principal lithic components of the Potosi are 1) dolomitized oolitic calcarenite, 2) digitate stromatolites and 3) planar stromatolites. Typically the Potosi comprises repeated hemicyclic sequences consisting of prominent layers of medium to coarse crystalline brownish-gray oolitic dolarenite with associated digitate stromatolites, and less well-defined thinner layers of fine to medium crystalline dolostone characterized by more or less distinct lamination ascribed mostly to planar algal stromatolite development (Howe, 1966).

The relationship of the Potosi to the underlying Derby-Doerun Dolomite has not been well documented. The regional relationships described in this report illustrate facies substitution with the Derby-Doerun as the succession is traced northward. In the Ozark area the relationship of the Potosi to the Derby-Doerun is interpreted as being conformable, with either typical Potosi or time-equivalent planar stomatolite and burrowed carbonate mud facies present above the Derby-Doerun. In practice the boundary has generally been placed within or below an insoluble residue zone characterized mostly by green dolomite shale in subsurface work and below correlative green shaly dolomite in outcrops. The green dolomoldic shale "marker zone" noted here probably is either sharply time-transgressive or occurs at more than one horizon in some areas and thus may prove to be a misleading datum. Quartz druse, which is characteristic of the Potosi regionally, is associated with both the digitate and planar stromatolite structures. Thickness of the Potosi is from 300 to 350 feet around the northern periphery of the St. Francois Mountain area. The formation is somewhat thicker to the southwest in the south-central Missouri region, as interpreted from subsurface information.

EMINENCE DOLOMITE

The Eminence comprises predominantly calcarenitic strata (apparently universally dolomitized) above the Potosi and below the Ordovician Gasconade Formation. The name Eminence, from the town of that name in Shannon County, Missouri, was introduced in 1911 by Ulrich (p. 630-631). The Eminence is interpreted as a facies complex with (as primary material) oolitic to coquinoidal calcarenite as the dominant element and the principal secondary facies being burrowed coquina sand and mud. A wide variety of stromatolitic structures are present in the Eminence and tend to effect considerable control of its expression in exposures. Extensive silicification and formation of chert is characteristic of both the calcarenitic and burrowed carbonate (burrow-structured) types; this feature has been of particular importance in petrologic interpretation of the Eminence. The fauna of the Eminence was reported by Bridge (1930) and

Ulrich, Foerste and Bridge (in Bridge, 1930) as including, among the trilobites, *Calvinella, Euptychaspis, Triarthropsis* and *Plethometopus*, characterizing what was identified as the "main faunal zone", and, in an "upper zone", *Plethopeltis* and *Entomaspis.* No important work has been done on the Eminence fauna since that of Bridge and his colleagues. Recent studies in Wisconsin and Oklahoma (Davis, 1970; Stitt, 1971) refer *Plethopeltis*-bearing strata to an early Ordovician age; thus more detailed work may result in clarification of a relationship that appears to suggest assignment of upper Eminence strata to the Ordovician System and lower and middle parts of the formation to the Cambrian. Beds called "Sunset Point", more recently referred to the lower part of the Stockton Hill Member (Davis, 1970) of the Oneota Formation of the Upper Mississippi Valley region, contain the *Plethopeltis* fauna as noted by Berg, Nelson and Bell (1956). Stitt (1971) finds *Plethopeltis* low in the *Missisquoia* Zone of earliest Ordovician age in Oklahoma. The traditional definition of the Eminence is followed in this report because of the lack of detailed information that would confirm the indicated assignment of upper Eminence strata.

Although the Eminence is regarded as a formation of strictly carbonate affinity, quartz sand as discrete grains and as thin beds occurs in one or more zones in the upper part of the formation at a number of localities in southern Missouri. One or more such quartzose zones have been mistaken for the Gunter in outcrop studies and such sandstones are present in many drillhole records in southern Missouri. Probably the first to note the occurrence of quartz sand in the Eminence was McQueen (1931), who reported a thin sandstone or sandy dolomite at the base of the "Proctor" in western Missouri. The name Proctor, for upper Eminence beds (Winslow, 1894; Ulrich, 1911), has not received consistent usage and is not used currently. At least one of the upper Eminence "sands" in south Missouri occurs at the base of an uppermost part of the Eminence that is characterized by low insoluble residue content.

The Eminence Dolomite is, with the exception of the Lamotte Sandstone, the most widely distributed of the Cambrian formations in Missouri. The basal contact with the Potosi appears to be transitional everywhere in the Ozark region, commonly through a rather broad interval in which rock typical of both

units occurs and where the placement of the contact may be arbitrary through necessity. The Eminence-Potosi relationship seemingly is different in northeastern Missouri where strata provisionally assigned to the upper Eminence rest on thin sandstone and quartzose dolostone correlated with Momence Sandstone Member (Buschbach, 1964, p. 41) of northern Illinois.

Thicknesses of the Eminence range from 150 to 200 feet in the outcrop area peripheral to the St. Francois Mountains. Thicknesses of as much as 300 feet are common in the subsurface in south-central Missouri.

The Gunter sandstone is involved in this study of Cambrian stratigraphy even though it has been assigned to the Ordovician (as the basal member of the Gasconade) since its initial recognition by Ball and Smith in 1903. The type locality of the Gunter is in the Lake of the Ozarks area in Camden County, Missouri where it attains thicknesses of as much as 40 feet. Ball and Smith's definition of the Gunter (1903, p. 26-29) was poor in that much of the sandstone referred by them to the Gunter was later proven to have been the Roubidoux. However, their designation of a typical exposure (at Gunter of Hahatonka Spring) was appropriate and remains an eminently satisfactory type section. The common and quite correct understanding of the Gunter as a "zone" that includes up to one hundred percent quartz sand but more commonly comprises quartz sand and oolites in a dolomitic and presumably clastic carbonate matrix appears to be an appropriate working definition of the Gunter over most of central and southern Missouri. This is the connotation expressed by the lithofacies map published with the Knight (1954) paper. The sand zones present in the upper Eminence of Shannon and Reynolds Counties would appear to represent part or parts of this zone. The identity of the Gunter in this area probably can be established with reasonable certainty only at localities where the basal Gasconade carbonate strata are a part of the exposed succession.

Considered in the light of its position in the stratigraphic succession and its apparent post-*Plethopeltis* "zone" age, the Gunter appears best regarded as of early Ordovician age.

CAMBRIAN FORMATIONS OF THE UPPER MISSISSIPPI VALLEY REGION

INTRODUCTION

The Upper Mississippi Valley is the type area for the Upper Cambrian (Croixan) of North America. Croixan sediments accumulated to thicknesses of 800 feet in the area of outcrop and are now exposed as nearly horizontal strata along the valley sides of streams now dissecting the surface. Classification and nomenclature of Upper Cambrian strata in the Upper Mississippi Valley area have undergone many stages of refinement since the early efforts of Winchell (1872, 1884, 1886), Berkey (1898), Ulrich (in Walcott, 1914), and others. Publications by Raasch (1935) and Twenhofel, Raasch and Thwaites (1935) record the details of what became known as the "Conference Classification" and represent an important period of intense study of these rocks.

Bell, Berg and Nelson (1956) summarized and integrated all previous work done on Croixan strata and rendered the first rational interpretation of the various lithostratigraphic and biostratigraphic units. Their work is based heavily on paleontology by Bell, Feniak and Kurtz (1952), Berg (1953), Nelson (1951) and lithostratigraphy by Berg (1954) and Nelson (1956).

Terminology utilized in this report (fig. 4) is a composite of that recently expressed in publications of the Illinois, Minnesota and Wisconsin Geological Surveys and adheres to the philosophy that the terms Dresbach, Franconia and Trempealeau (with appropriate additional endings) are best reserved for use as stage names, except that in the Upper Mississippi Valley area Franconia is also applied to only part of the Franconian succession as a formation name. Inasmuch as some elements of the bases for establishing the terms Wonewoc and Lone Rock (Ostrom, 1966) as new formation names for the Galesville-Ironton and Birkmose-Tomah-Reno successions, respectively, are not accepted by the authors, these terms are not used in this report.

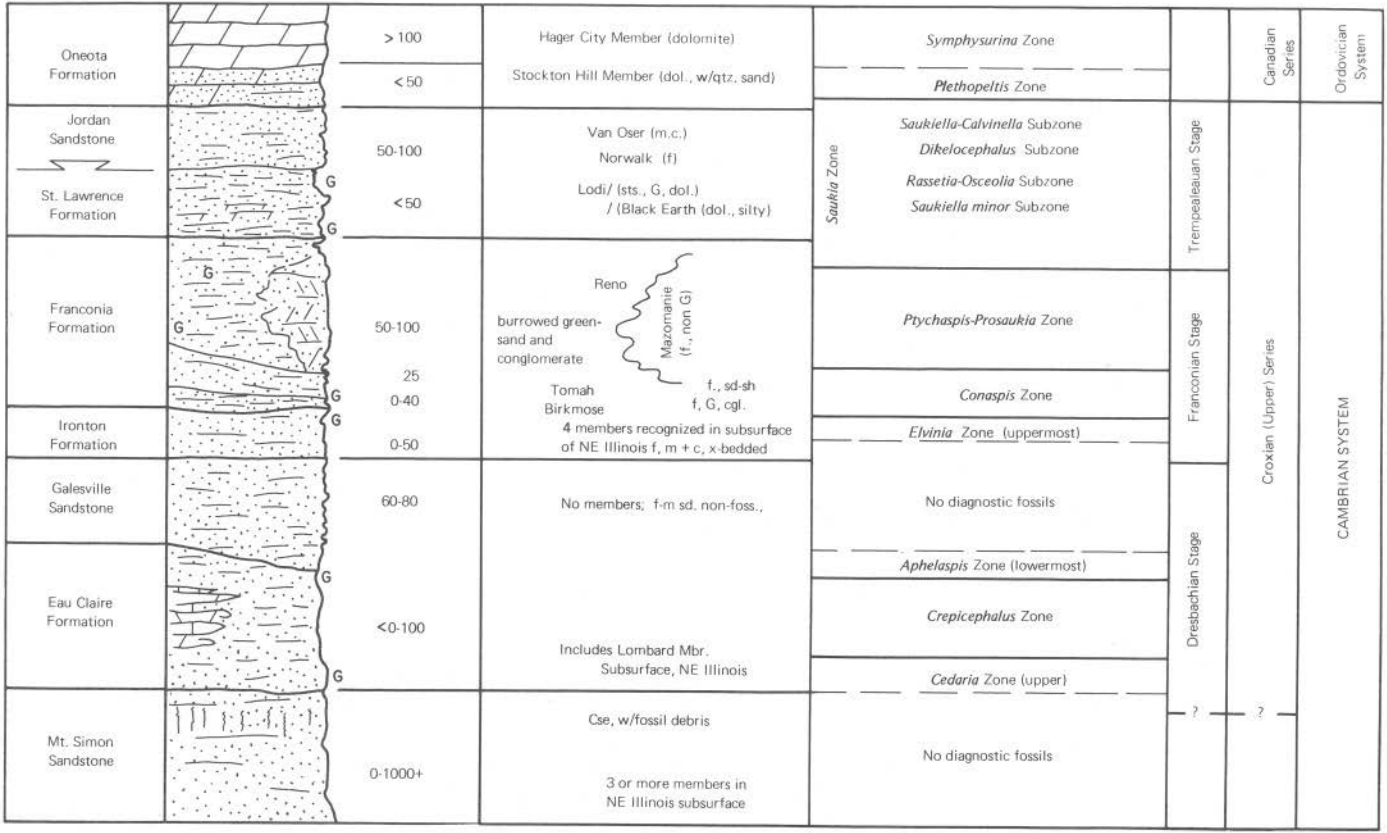

Figure 4

Time- and rock-stratigraphic classification of Cambrian strata in the Upper Mississippi Valley region.

The lower part of the upper Cambrian biostratigraphic succession in the Upper Mississippi Valley is incomplete, thereby posing problems in correlations of other areas. Apparently only the uppermost *Cedaria* Zone is represented, while in more basinward sections elsewhere, such as Texas (Palmer, 1955) and the Rocky Mountain area (Lochman-Balk, 1956), older *Cedaria* Zone faunas are present. Palmer (1955, p. 713) would place a disconformity between the *Cedaria* and *Crepicephalus* Zones as developed in the Upper Mississippi Valley because of the well-defined contrast between the two faunas. Elsewhere (Lochman-Balk and Wilson, 1958; and Palmer, 1955), the *Cedaria* fauna grades upward into the *Crepicephalus* fauna.

In this report the *Aphelaspis* and *Dunderbergia* Zones are referred to the Dresbachian Stage with the implication that it is extended or expanded in comparison to its original connotation. This concept is an alternative to one calling for the recognition of an intermediate stage comprising the *Aphelaspis* and *Dunderbergia* Zones and occurring above the Dresbachian and below the Franconian Stages.

The *Aphelaspis* Zone is known from only two localities in western Wisconsin from uppermost Eau Claire strata (Bell, et al., 1956). Apparently this is the lowest part of the zone. The succeeding *Elvinia* Zone is represented only by the uppermost part in western Wisconsin. The strata lying between the occurrence of *Aphelaspis* and *Elvinia* are the Galesville and lower Ironton sandstones. The lack of fossils casts some doubt on the age assignment. In the Great Basin (Palmer, 1955) and south of Llano uplift in Texas (Palmer, 1955), deposition was continuous and the complete *Aphelaspis* Zone (including *Dicanthopyge* and *Prehousia* Zones), *Dunderbergia* Zone (not represented in the Upper Mississippi Valley), and *Elvinia* Zone are present. Thus, the Galesville Sandstone could be of *Aphelaspis* and/or *Dunderbergia* or early *Elvinia* Zone age. It is generally agreed among Cambrian workers that the Ironton Sandstone represents continuous sedimentation up to the appearance of late *Elvinia* Zone age fossils near the top and is, therefore, considered *Elvinia* Zone age.

Serious and as yet unresolved problems are involved in the biostratigraphy and lithostratigraphy of sediments encompassing the Cambrian-Ordovician boundary. The sandy dolomite transition beds (Stockton Hill Member, Oneota Formation, Davis, 1970), between the Cambrian Jordan Sandstone and the

Ordovician Hager City Member (Davis, 1970) of the Oneota Formation evidently contain representatives of the *Saukia* Zone (Raasch, 1964), *Saukiella serotina* Subzone (Stitt, 1970, personal communication), *Plethopeltis* "Zone" (Raasch, 1950), and *Symphysurina* Zone (Raasch, 1964). These three faunas have not been found in succession at any one locality. An additional problem is that the range of the key genus *Plethopeltis* is not settled. Longacre (1970) finds *Plethopeltis* from the *Saukiella pyrene* Subzone, well down in the *Saukia* Zone in Texas. *Plethopeltis* recurs in earliest Ordovician *Missisquoia* Zone time in Oklahoma (Stitt, 1971). Finally as mentioned earlier in this paper, *Plethopeltis* occurs high in the Eminence in Missouri and seems to be above a typical high *Saukia* Zone fauna.

MT. SIMON SANDSTONE

Ulrich (in Walcott, 1914) proposed the term Mt. Simon for "235 feet of coarse sandstone and grits". The type section is exposed on Mt. Simon near Eau Claire, Wisconsin, and the unit is placed at the base of the Croixan Series. Ostrom (1970) presents a remeasured type section and the following comments are based on his descriptions. The base of exposures at the type section is 31 feet above the Precambrian. The lower 178 feet of exposures are a medium- to very coarse-grained, crossbedded feldspathic quartz sandstone and are regarded by Ostrom (1964) as made up of beach deposits. The next 37 feet of section is a fine- to coarse-grained, generally poorly sorted and vertically burrowed unit with some crossbedding. This latter unit is the "poorly sorted lithotope" of Ostrom (1964) and is included by him in the Mt. Simon. The upper part of this unit, i.e., Ostrom's "poorly sorted lithotope", is assigned to the Eau Claire Formation by Raasch and Unfer (1964) who identified it as the Shawtown Member. The uppermost 10 feet of the section is a coarse grained, slightly glauconitic crossbedded unit containing *Obolus namouna*. Twenhofel, Raasch and Thwaites (1935) and Raasch and Unfer (1964) assign this bed to the Eau Claire. Ostrom (1970, p. 51) assigns it to the Mt. Simon. The Mt. Simon-Eau Claire contact is not exposed at the foregoing section, but is probably nearly coincident with the top.

EAU CLAIRE FORMATION

The term "Eau Claire" was first applied by Wooster (1882) to all beds of Croixan Series exposed in west-central Wisconsin. This included strata from the Mt. Simon to the base of the Oneota dolomite. Ulrich (in Walcott, 1914) first applied the name Eau Claire in its present usage. The type section crops out on Mt. Washington in Eau Claire, Wisconsin. Twenhofel, Raasch and Thwaites (1935) define the Eau Claire as a fossiliferous unit, including the ***Cedaria, Crepicephalus*** and *Aphelaspis* Zones. This definition generally coincides with the occurrence of very fine-grained, silty and shaly glauconitic sandstones. Thickness of the Eau Claire in outcrop ranges from a featheredge to 150 feet (Raasch, 1935). These clastics make up marine transgressive and regressive phases of the Eau Claire. Maximum transgression is marked by a 20-foot unit of carbonate not observed in outcrop but present in the subsurface of southern Wisconsin (Ostrom, 1964, p. 392).

GALESVILLE SANDSTONE

Trowbridge and Atwater (1934, p. 45) proposed the name Galesville for the upper sandstone unit of the Dresbach Formation and gave a type section located on the "bluff above Beaver Creek at the mill dam at Galesville, Wisconsin". They assigned 86 feet of "poorly sorted sandstone with white and blue calcareous clay" to the member.

Emrich (1966, p. 78) remeasured the type section of the Galesville. His measurements of Trowbridge and Atwater's Galesville amount to 79.2 feet. However, Emrich assigns the top 28 feet of the type Galesville to the overlying Ironton Sandstone and adds 37 feet of what Trowbridge and Atwater considered Eau Claire to the base of the Galesville.

Ostrom (1970, p. 66, 67, 114, 115) also presents a remeasured type section and assigns from 39 to 52 feet to the Galesville, the variation in thickness due to relief on an erosion surface at the base. Ostrom's definition is accepted for the purposes of this report.

Kurtz visited the type section of the Galesville in late 1970 and agrees with Ostrom's (1970) measurements, description of the lithic units and conclusion that an erosion surface marks the Galesville-Eau Claire contact. The lower part of the Galesville is a generally medium-grained, prominently crossbedded, unfossiliferous sandstone, while the upper Eau Claire is a generally fine-grained glauconitic sandstone containing *Crepicephalus*. Emrich's redefinition of the Galesville at the type section to include the upper Eau Claire strata is rejected. Furthermore, the upper Eau Claire strata that Emrich would assign to the Galesville at its type section do not contain *Aphelaspis* Zone fossils (Emrich, 1966, p. 9), but rather *Crepicephalus* Zone fossils.

In the subsurface, on the other hand, Buschbach (1964, p. 35) finds the Galesville-Eau Claire contact transitional with no evidence of unconformity in northeastern Illinois. Austin (1970) makes a point of the transitional nature of the contact and the presence of regressive sediments immediately below it in south-central Minnesota.

IRONTON SANDSTONE

The term "Ironton" is applied to poorly sorted fine- to medium- and coarse-grained sandstone above the Galesville and below strongly glauconitic shale and sandstone of the lower part of the Franconia Formation. This usage follows Willman and Templeton (1952) and Emrich (1966). Original application (Thwaites, 1923, p. 5) of the term was to the basal unit of the "Franconia Formation" with the description as "below the shale are a few feet of hard calcareous sandstone, the Ironton Member." Ulrich (1924, p. 93) describes it as the coarse-grained sandstone which lies unconformably on the Dresbach Formation. He goes on to say that the presence of *Camaraspis hemisphericus* (=*C. convexa*) confirms the identification of the member. Twenhofel, Raasch and Thwaites (1935) equate the Ironton Member with the *Camaraspis (Elvinia)* Zone. Berg (1954) rejected the name "Ironton" as a member name because of the faunal connotation which had clouded the name. He proposed the new name "Woodhill", with exclusively lithic definition, as the basal sandstone of the Franconia.

The "Woodhill" -Galesville contact is well-defined at Berg's type Woodhill section. Buschbach (1964) rejects the name "Woodhill". Ostrom (1965, p. 16,

17) also rejects "Woodhill" and maintains that the Ironton was defined on a lithic basis by Thwaites (1923). Emrich (1966, p. 11, 16) also rejects the name "Woodhill" but proposes that the new reference section for the Ironton be Berg's type section of the Woodhill. The *Elvinia* fauna occurring in the upper part of the Ironton may continue upward into the overlying Birkmose Member of the Franconia Formation.

FRANCONIA FORMATION

Berkey (1898, p. 373) first applied the name Franconia to about 100 feet of brown and yellow sandstone exposed at Franconia, Minnesota. This unit was considered by Berg (1954) as part of the Mazomanie Member of the expanded Franconia Formation of Twenhofel, Raasch and Thwaites (1935) in which they include in the Franconia all sandstone between the Dresbach below and the St. Lawrence Dolomite above. The divisions of the Franconia that were included in the "Conference Classification" (see Raasch, 1935 and Twenhofel, Raasch and Thwaites, 1935) were largely differentiated on faunal bases. In a major revision of Franconian stratigraphy, Berg (1954) identified five lithic divisions of the Franconia Formation: a basal fine-coarse sandstone (Woodhill-Ironton); a near-shore, non-glauconitic, fine-coarse sandstone facies (Mazomanie); three off-shore facies units consisting of two highly glauconitic fine sandstones (Birkmose and Reno Members) and an intervening shaly, silty and very fine sandstone facies (Tomah Member). Ostrom (1967) recognizes the above members but includes the Ironton in his Wonewoc Formation and the remaining members in his Lone Rock Formation.

In this report the restricted definition of the Franconia used by Buschbach (1964), Emrich (1966) and Austin (1969) is utilized. The formation includes the Birkmose, Tomah and Reno Members as well as their near-shore facies equivalent, the Mazomanie Sandstone Member. The rock-stratigraphic subdivisions of the Franconia Formation, excluding the Ironton, (as proposed by Berg in 1954) are easily observable in the field and are traceable into the subsurface. Since they are independent of faunal zones as rock stratigraphic units should be, these subdivisions are used in this paper.

Raasch and Unfer (1964) suggest numerous faunal zones and present their evidence for numerous hiatuses in the Croixan section. The evidence for the numerous faunal zones and for the numbers and magnitude of many of the hiatuses are subject to question. However, the post-*Aphelaspis*-pre-*Elvinia* hiatus is well known and the near absence of post-*Elvinia*-pre-*Ptychaspis* offshore deposition is well documented by Berg (1954, p. 870 and cross-sections A-A', fig. 4). He shows the *Conaspis* Zone thinning from 90 feet at Taylors Falls, Minnesota, southward in thirty miles to only 2.5 feet at the type section of the Birkmose at Hudson, Wisconsin, by the progressive pinching out of lower subzones; i.e., first the *Eoorthis* Subzone and then *Maustonia nasuta* Subzone. This leaves only the upper *Taenicephalus altus* Subzone present at both localities; it is much reduced in thickness at the latter. The *Ptychaspis* Subzone, on the other hand, may be absent at Taylors Falls but thickens to about 80 feet at Hudson. A similar pronounced thinning of the *Conaspis* Zone occurs from Dallas-Ridgeland southward forty-five miles to Arkansaw, Wisconsin (Berg, 1954, p.872, fig. 5). A complementary thickening occurs in the *Ptychaspis-Prosaukia* Zone (10 feet at Dallas-Ridgeland and about 60 feet at Arkansaw). It is apparent that at least locally "starved basin" conditions with stillstand of sea level existed at the end of *Elvinia* Zone time, persisted throughout *Conaspis* Zone time and into *Ptychaspis* Subzone time. The faunal zones document the prograding of sands southward and bypassing of sediments above wave base until the edge of the undaform platform was reached. The finer-grained sediments continued on to come to rest in clino- and fondo-form deposits to the south. It would appear from Berg's cross sections that more or less areally uniform rates of deposition were attained late in *Ptychaspis* Zone time.

Raasch (1951) places the top of the Franconian Stage at the top of the *Ptychaspis-Prosaukia* Zone and not at the top of the Franconia Formation. A basal *Saukia* Zone fauna (*Saukiella minor* Subzone) occupies up to 35 feet of the upper part of the formation (Bell, et al., 1956). The foregoing adjustment places the Franconian-Trempealeauan Stage boundary at a regionally correlatable faunal zone boundary.

Bell, Berg and Nelson (1956, p. 427, fig. 3) show the Franconia Formation to thin markedly to the southwest from more than 200 feet where the Mazomanie Member makes up a significant portion of the formation to less than 100 feet in south-central Minnesota and northeast Iowa, 150 miles distant,

where the dominant lithologies are the basinal Birkmose, Tomah and Reno Members. Also shown by isopach map (p. 437, fig. 4), the St. Lawrence Formation thickens to a maximum of 150 feet where the Franconia is the thinnest. The St. Lawrence thins to zero northeastward where the Franconia is thicker. The two units maintain a thickness very close to 250 feet. Contours of both units butt against the Sioux uplift, indicating that the units were more extensive to the west.

BIRKMOSE MEMBER

Berg (1954, p. 862) named the Birkmose Member from Birkmose Park in Hudson, Wisconsin. Here it consists of 27 feet of highly glauconitic (40 percent) sandstone, fine-grained and burrowed in the lower part with dolomitic lenses and conglomeratic dolomite in the upper part. The upper 2.5 feet contain the *Taenicephalus altus* Subzone of the *Conaspis* Zone immediately preceded by the *Elvinia* Zone. The *Eoorthis* Subzone and *Maustonia nasuta* Subzone are absent at this locality, perhaps because of lack of deposition or partly because of subaqueous scouring and possibly associated with the development of intraformational conglomerates. The Birkmose is thickest along the Mississippi and St. Croix Rivers, but thins to less than a foot eastward toward the Wisconsin arch.

The Birkmose is overlain by the Tomah Member in most of the area of outcrop. The Mazomanie Member is the succeeding lithology in nearshore localities.

TOMAH MEMBER

Berg (1954, p. 863) named this unit from the Tomah Quadrangle, Wisconsin. The type section is at Maynard Pass where 28 feet of a very fine-grained micaceous essentially non-glauconitic laminated sandstone, interbedded

with gray-green shale, is exposed. Berg also notes that the sandstone has been feldspathized, the feldspar occurring as overgrowths on quartz crystals and as cement. The composition, according to Berg (1952), includes 48 percent feldspar. The top of the member is drawn at the highest occurrence of interbedded shale. In most areas the Tomah contains a *Conaspis* Zone fauna, but in the area from Minneiska to Hudson the upper part of the Tomah contains the lower part of the *Ptychaspis* Subzone.

RENO MEMBER

The type section of the Reno is exposed in Hell Hollow near Reno in extreme southeast Minnesota. Berg (1954, p. 865) assigns 116 feet of fine-grained, mostly glauconitic, laminated and crossbedded and burrowed sandstones between the Tomah and St. Lawrence at this locality to the Reno. The laminated sandstones are similar to the Birkmose Member. The non-burrowed, non-laminated glauconitic sandstones of the Reno are crossbedded. Discontinuous greensand intraformational conglomerates occur within the upper 40 feet of the member. The top of the Reno is marked by a 6-foot conglomerate layer of sandstone pebbles imbedded in a fine-grained glauconitic dolomite matrix. Outside of the type area this terminal conglomerate is thinner and ranges from 6 inches to 2 feet in thickness. Twenhofel, Raasch and Thwaites (1935) place this conglomerate at the base of the St. Lawrence Formation. It is the Reno Member which represents a basinal facies of, and intertongues with, the Mazomanie Member.

Faunas in the Reno may include the upper part of the *Conaspis* Zone, the whole of the *Ptychaspis-Prosaukia* Zone, and the lower *Saukia* Zone or *Saukiella minor* Subzone in the upper part (recorded as much as 35 feet below the top).

MAZOMANIE MEMBER

The term "Mazomanie" was applied by Ulrich (1920) to the approximately 100-foot thick, calcareous sandstone which crops out in the vicinity of

Mazomanie, Wisconsin. Ulrich believed that the Mazomanie was younger than the Franconia. Trowbridge and Atwater (1934) recognized the temporal equivalance of the Mazomanie and the Franconia. Twenhofel, Raasch and Thwaites (1935) abandoned the "Mazomanie" because Franconia fossils were found in it. Berg (1954, p. 866) revived, expanded and redefined the Mazomanie as a lithic term to include the non-galuconitic and dolomitic sandstones that intertongue with the glauconitic Reno Member. He gave a section located on Ferry Bluff across the river from the town of Mazomanie. A total of 116.5 feet was measured. The Tomah Member at the base and the Reno Member at the top bound the formation. With the exception of the *Elvinia* Zone, the remaining Franconian fossil zones are found in the Mazomanie.

The Mazomanie is a near-shore facies and is not present in southeastern Minnesota, northeastern Iowa or northern Illinois.

ST. LAWRENCE FORMATION

Nelson (1956) ably summarized the involved nomenclatorial history of this formation. He (p. 173) defines it as "essentially dolomitic sediments between the sandstones of the Franconia and Jordan Formations". The thickness ranges from less than 15 feet in shoreward areas to 63 feet in more basinal exposures. It is subdivided into two members: 1) the Black Earth Member – sandy dolomite, interbedded dolomitic siltstone and fine-grained sandstone with local development of algal structures; and 2) the Lodi Member – siltstone, generally dolomitic, and dolomitic sandstone. In basinal exposures the Black Earth dolomite is said to rest directly on the Franconia. However, in such areas basal Black Earth sediments are silty and frequently sandy and shaly and could be considered an offshore facies of the Lodi. Shoreward the Black Earth becomes more silty and sandy and occurs as a wedge-edge within the Lodi Member, the Lodi is then in contact with the Franconia. Raasch (1951, p. 147) calls this tongue of pre-Black Earth Lodi the Arcadia Member and bounds it with unconformities. Bell, Berg and Nelson (1956, fig. 1) indicate that the Lodi, in turn, wedges out shoreward and the Jordan then overlies the Franconia.

Nelson (1956, p. 174-176) finds the following zones in the St. Lawrence, in ascending order: *Osceolia*, *Rasettia*, upper *Dikelocephalus*, *Calvinella-Saukiella* Zones. All of these zones, except *Rasettia*, extend laterally from the Lodi into the Jordan Formation, demonstrating the facies relationship between the two.

The *Osceolia* fauna (Zone) is thick in nearshore sections but pinches out basinward. The *Rasettia* Zone is the lowest faunal zone in the St. Lawrence in more basinal exposures. Nelson (1956, p. 172) suggests that these zones are, in part, laterally equivalent biofacies. His cross sections (figs. 4, 6, 8) demonstrate the clinoform attitude of the younger upper *Dikelocephalus* Zone, *Calvinella* Subzone and lower part of the *Saukiella* Subzone. It appears that in the lower Trempealeau as well as in the post-Ironton Franconia "starved basin" conditions existed. Older biostratigraphic units pinch out basinward and younger zones exhibit a clinoform relationship documenting the basinward (southwestward) progradation of sands during significant spans of time.

JORDAN SANDSTONE

The Norwalk (Thwaites, 1923, p. 544-548) and Van Oser (Stauffer, Schwartz and Thiel, 1919, p. 1240) are names applied to the lower fine-grained and upper coarse-grained portions, respectively, of the Jordan Formation. Bell, Berg and Nelson (1956, p. 440) note that the contact between these two units is gradational and the fine sand (Norwalk) facies thickens shoreward as the subjacent St. Lawrence thins. Ostrom (1966, fig. 2) used these terms and also included at the top the Sunset Point Member which, as described by Raasch (1952), consists of sandy dolomite, sandstones and shaly dolomite. Ostrom (1967) and later Davis (1970) refer the Sunset Point to the lower part of Stockton Hill Member of the Oneota Dolomite Formation. These sandy dolomite transition beds are evidently time-transgressive inasmuch as *Saukia* Zone, *Plethopeltis* Zone and *Symphysurina* Zone trilobites are recorded from it at different localities. Thus, the Stockton Hill includes both Cambrian and Ordovician age strata.

DISCUSSION OF CROSS SECTION

The conclusions reached during this study were drawn mostly through interpretation of the succession penetrated in each of five critically located drillholes and analysis of their relationship to one another and to the section present in outcrop in the Ozarks and in the Upper Mississippi Valley region. Figure 1 (repeated on pl. 1) illustrates the location and distribution of the five drillholes. With the exception of the northernmost hole, in Henry County, Illinois, the depiction of the holes on the cross section is basically that provided by insoluble residue logging techniques, augmented by core-logging data in some holes. The record of the Henry County hole is adapted from a sample log prepared and published by the Illinois Geological Survey (Buschbach, 1965). The primary mode of identifying the drillholes is by county and state on the cross section as well as in the text.

WASHINGTON COUNTY, MISSOURI

Missouri Cliffs, Inc. No. 1-32-37N-2E (MGS No. 19971)

This exploration hole was selected as representative among many that have been drilled in central and northern Washington County, Missouri, where the typical Ozark region divisions of the Cambrian section can be readily identified. No fossils were obtained from this core, but the Davis Formation in the Missouri Cliffs, Inc. No. 3-32-37N-2E (MGS No. 21181) is fossiliferous; these data were utilized in the interpretation of this hole.

LAMOTTE SANDSTONE

The Lamotte of this well is typical of that formation in the Ozark region, consisting mostly of medium to coarse quartz sand grains and characterized by pronounced cross-bedding. Although it is thin (54 feet) in the selected drillhole, it is recorded as 370 feet thick in a drillhole only a few miles to the north. Such local variation is characteristic of the Lamotte, owing to the irregularity of the underlying Precambrian surface.

BONNETERRE FORMATION

The Bonneterre section in this well consists mostly of massive to shaly oolitic dolomite, with increasing percentages of glauconitic silt and medium to coarse quartz sand in the basal part. In this region, the lower and middle parts of the Bonneterre tend to be shaly, with the carbonate rock represented by limestone and dolomitic limestone. Fine to medium crystalline vuggy dolomite in the 895 to 910 foot interval above the oolitic facies and below shaly Davis strata is referred provisionally to the "upper Bonneterre". The 302 feet assigned to the Bonneterre are as much as 30 feet less than thicknesses encountered elsewhere in northern Washington County. The unconformable relationship at the top and difficulty in consistent identification of the base are both factors in the thickness variation.

DAVIS FORMATION

Description of core from nearby holes and the typical expression of the insoluble residue logging of the 735 – 895 foot interval in the selected well together suggest that the Davis here is comparable in most, if not all, respects to that of exposures in the type area 15 to 20 miles to the southeast. A sandy slightly glauconitic zone in the 870-880 foot interval in insoluble residue logs of

this hole and a comparable zone in other nearby holes and on the outcrop is correlated with somewhat thicker and better defined similar zones in wells to the north, where it is identified as the Birkmose Member of the formation.

Shale beds with thin layers of glauconitic coquinoidal limestone containing phosphatic shell and trilobite debris, occurs beneath the sandy zone and is included as the basal part of the Davis. An early species (not reported from exposures in the type area) of *Linnarssonella L. costa* was collected from basal Davis shale at about the same stratigraphic position in a core-hole located less than a mile away from the reference well. This occurrence corroborates Kurtz's conclusion (1970) that the Davis in the subsurface peripheral to the St. Francois Mountain area on the west includes basal beds that are slightly older than those of the outcrops in the type area.

The upper boundary of the Davis is placed at a color change in the shale from *green* in the Davis to *brown* in the overlying Derby-Doerun. In this well this color boundary coincides rather closely with a pronounced decrease in the percent of insoluble residue. Typically the insoluble material in the uppermost Davis is shale; the preponderance of silt in this hole is anomalous but probably reflects the location of the hole on the northern edge of the St. Francois Mountain area.

DERBY-DOERUN DOLOMITE

In this part of Missouri, the Derby-Doerun averages 100 to 110 feet in thickness. The lower one-third to one-half consists of mostly thin and irregularly bedded, shaly, fine- to medium-grained dolomite, that contains very fine sand or silt-sized quartz and glauconite grains. The upper limit of the quartz and glauconite mark the "top of the Cambrian clastics", which is a useful datum in the Ozarks region, but which is shown to rise markedly in this part of the geologic section as associated units are traced northward. Upper Derby-Doerun beds tend to be more or less massive, and commonly are oolitic dolomite. The contact between the Derby-Doerun and Potosi is not sharply defined in this hole, but is placed below the occurrence of significant amounts of quartz druse and brown, medium-crystalline dolomite typical of the Potosi.

POTOSI DOLOMITE

The Washington County hole is essentially in the type area of the Potosi, and the characterization of the formation in the insoluble residue log on plate 1 is its typical expression. The presence of more or less quartz druse associated with medium to coarse crystalline brownish-gray dolomite typifies the unit. The thickness of the Potosi in this well (310 feet) is within the limits of its average range in the northern Ozark area. The Potosi-Eminence contact, which has been assumed to be conformable if not gradational throughout the Ozarks area, is differentiated both in core and in well samples on the basis of increased coarseness and medium to light gray color of the dolomite and presence of white oolitic and stromatolitic chert in the Eminence.

EMINENCE DOLOMITE

The characteristic Eminence lithology was noted in connection with the discussion of the Potosi and Eminence stratigraphic relationships. The northward thinning from 300 feet in this well to about 200 feet in St. Charles County is also expressed in the No. 1 Wynn-McAlpin test, in NW¼, NE¼ Sec. 20, T. 50 N., R. 12 W., Bonne County, Missouri, where the Eminence is 175 feet thick and the Potosi is from 50 to 60 feet thick. One, and perhaps two, thin quartzose sandstone zones have been noted as occurring some 40 to 50 feet below the top of the Eminence in widely scattered exposures and in many drillholes in the Ozark region. Although this zone was not logged in the Washington County hole (possibly because of a sample gap in the mostly residual material in the upper part of the interval), its approximate position is shown on plate 1 because of its possible importance in the interpretation of holes farther north in the traverse. It may represent the Momence sandstone of northern Illinois, which is identified in the drillholes comprising the northern part of this traverse.

ST. CHARLES COUNTY, MISSOURI

National Lead Co. (now NL Industries, Inc.), XT-1 (MGS No. 19247)
Sec. 34, T. 48 N., R. 1 E.

This exploration hole was drilled on a magnetic anomaly near Wentzville, Missouri. It provides an important link in the traverse described in the present

study. An insoluble residue log (prepared by J.S. Wells of the Missouri Geological Survey staff) to a depth of about 2,610 feet is the only detailed record available. Total depth and depth to the top of the Precambrian are also known. No paleontologic information is available, however.

LAMOTTE SANDSTONE

It is assumed that the Lamotte is typical in this well and is essentially monomineralic quartzose sandstone. Assuming that the estimated top of the Lamotte is correct at 2,661 feet as indicated, the sandstone is 459 feet thick at this location. The thickest Lamotte recorded in Missouri is along the eastern border of the state, near the edge of the Illinois basin.

BONNETERRE FORMATION

The Bonneterre section in this hole is comparable in thickness (361 feet) with that of the Washington County well, but is characterized by significantly higher percentages of silt and shale throughout with most of the carbonate rock preserved as limestone. As compared with the Washington County hole, the quartzose dolostone "transition" zone at the base is considerably thicker. Silty shale in the 2,300-2,310 foot interval is referred to the "upper Bonneterre" and occurs above predominantly carbonate oolitic facies typical of the Bonneterre section, and below a persistent sandy zone in the lower Davis. This shale is unlike the basal Davis shale noted in the Washington County hole, and is provisionally (lacking fossil evidence) correlated with the "upper Bonneterre silt" of south-central Missouri counties. The admittedly tenuous correlation of the 2,300-2,310 foot interval in this hole with the 895-910 foot interval in the Washington County hole is suggested because of similar stratigraphic position. Neither lithic nor time equivalency is implied.

DAVIS FORMATION

In this well, the 2,120-2,300 foot interval is referred to the Davis. The distinctly sandy lower 20 feet of the Davis section may represent the Birkmose. Relatively little glauconite was logged in this interval, however, and it appears inappropriate to carry the term this far south into Missouri. The Davis top is placed above a green shale "kick" that appears to correspond to the same point in the Washington County well. An alternative interpretation, placing the contact some 60 feet higher, is judged to be inappropriate following recognition that this point (the top of Cambrian clastics) falls within the Derby-Doerun in areas to the south, and appears also to be the top of a flood of post-Davis clastics that extend into the area from the north.

DERBY-DOERUN DOLOMITE

Insoluble residue characteristics suggest assignment of the anomalously thick 1,920-2,120 foot interval to the Derby-Doerun, and this is supported by the still greater expansion of the member in the Audrain County well to the northwest. The authors' interpretation is that the marked increase in thickness is mostly if not entirely at the expense of the Potosi. The lack of any basis for suggesting an unconformity, coupled with the compensatory thickness relationship, lends strength to the concept of rapid facies change as responsible for the marked thickness changes noted between the Potosi and upper Derby-Doerun. Accordingly the interpretation is that the lower part of the Derby-Doerun in this well is equivalent to and might be identified as an extension of the lower part of the Reno Member of upper Mississippi Valley classification. It is well defined in this drillhole and in the Audrain County well.

POTOSI DOLOMITE

In the St. Charles County well, only 100 feet of strata are assigned to the Potosi reflecting marked thinning, apparently by facies "shift" to the north.

This thinning relationship is emphasized further in the Audrain County well. Since the entire interval changes thickness but very little, and the difference in thickness of the component lithologic units appear to have been the result of facies relationships, it is assumed that the St. Charles County area had a depositional environment related to that of Audrain and Clark Counties, Missouri. The Potosi of the Henry County, Illinois, well is considerably thicker and presumably represents deposition in an environment comparable to that existing in the Ozark region into which northern clastics did not extend.

EMINENCE DOLOMITE

In his preparation of the log of the St. Charles County hole, Wells referred the 1,630-1,820 foot interval to the Eminence Dolomite. As shown on plate 1, the Eminence in this hole is about 100 feet thinner than in Washington County, Missouri, and undergoes further thinning in the Audrain County hole to the northwest.

A rather limited understanding of the Eminence and of its relationship to the Potosi is illustrated by the difficulty encountered in objective discussion of the formation as represented in the St. Charles County well and others along the traverse to the north. As noted in the preceding pages, the northward thinning of the Potosi is inferred to have resulted through facies substitution with the Derby-Doerun. The northward thinning of the Eminence is seemingly not explained by facies relationships and requires other mechanisms to be considered. Insoluble residue zonation suggests that the Eminence of northeastern Missouri should be correlated with the lower part of the substantially thicker succession that occurs in the Ozarks region. Attempts to trace and correlate insoluble residue zones of the Eminence in detail have not been made. Under this interpretation, only lower Eminence is present in northeastern Missouri where it is underlain by sandstone (the Momence) and overlain by sandstone correlated with the Gunter. The latter relationship would seem to require recognition of a hiatus representing middle and upper Eminence rocks and a demonstration of the mechanism and loci of "pinch out" of the middle and upper parts of the formation. An alternative and preferred interpretation is that the thinning

occurred with some facies changes and successive northward overlap of lower and middle parts of the Eminence, the upper part being of considerably broader extent than the Eminence as a whole. Under this interpretation the Momence sand would represent relatively slow deposition that took place while significantly thicker carbonate deposits were accumulating in the Ozarks region to the south. Also, under this interpretation, the Jordan Sandstone of the Upper Mississippi Valley would be the general correlative of the upper Eminence rather than of the total Eminence as developed in the Ozarks area. A quartzose sand zone observed 40 to 60 feet below the top of the Eminence at various points in the Ozarks may represent the Momence and tends to substantiate the view that the Eminence of northeastern Missouri is properly identified as upper Eminence.

AUDRAIN COUNTY, MISSOURI

St. Joseph Lead Co. (now St. Joe Minerals Corp.), No. 63-25 (MGS No. 25355)
NE¼ NE¼ Sec. 6, T. 50 N., R. 7 W.

This exploration hole is important because of its location in an area of little or no deep drilling data and because a log of the core and considerable paleontologic information are available (tbl. 1). In this area some of the Ozark region terminology becomes difficult to apply and northern terms can be utilized.

LAMOTTE SANDSTONE

In this well the Lamotte is 245 feet thick, is mostly medium- to coarse-grained with pebbly zones, and is strongly hematitic. Overall, it is not significantly different from the Lamotte of the Ozark region. The contact with the overlying Bonneterre was placed below the dolomitic and strongly glauconitic basal beds of that formation, coinciding with the lowermost occurrence of phosphatic shell material.

TABLE 1
List of fossils from St. Joseph Lead Co. exploration hole 63-25, Audrain, Co., Mo.
(Prepared by V.E. Kurtz)

Ptychaspis – Prosaukia Zone

Lower part Ptychaspis

1783.9	*Billingsella* sp.
1784.1	*Billingsella* sp.
1786	*Billingsella* sp.
1788	*Monocheilus* cf. *M. micros* (Walter)
1792.8	*Saratogia* cf. *S. fracida* Grant, *?Idahoia* sp.
1793.7	*Wilbernia* cf. *W. halli* Resser
1794	*Saratogia* sp.
1796.1	*Sinuella* sp.
1796.5	*?Saratogia* sp.
1796.7	*Pseudagnostus* sp.

Conaspis Zone

1824.0	*Unident. Acrotretid* frag. ventral valve (not *Angulotreta*)
1832.5	*Billingsella* sp.
1841.2	*Billingsella* sp.
1846.0	*Angulotreta* cf. *A. tetononsis* Grant
1846.5	*Billingsella coloradoensis* (Shumard)
1847.3	*Billingsella* sp.
1854	*Billingsella* sp.
1854.0	*Angulotreta* sp.
1859.5	*Billingsella coloradoensis* (Shumard)
1859.8	*Kendallina* cf. *K. biforota* (Berg)
1860	*Billingsella coloradoensis* (Shumard)
1862.5	*Angulotreta* sp.
1863.5	*Billingsella coloradoensis* (Shumard)
1863.5	*Angulotreta* cf. *A. tetonensis* Grant
1865.5	*Taenicephalus* cf. *T. gouldi* (Frederickson)
1867	*Eoorthis remnicha* (Winchell)

Elvinia Zone

very thick shells abraded

1883	*Ocnerorthis* sp.
1883.9	*?Ocnerorthis* sp.
1885.5	*Pterocephalia sanctisabae* (Roemer) *Cliffia* sp., *Elvinia roemeri* (Shumard)
1885.7	*Pterocephalia sanctisabae*, (Roemer) ? *Pseudagnostus* sp. *Cliffia wilsoni* Lochman
1885.8	*Pterocephalia sanctisabae* (Roemer)
1899.7	*Burnetiella* sp.
1905	*Housia* cf. *H. varro* (Walcott)
1934.2	*Linnarssonella girtyi* Walcott
1959.0	*L. girtyi*, Walcott *L. costa* Kurtz
1961.0	*L. girtyi*, Walcott *L. costa* Kurtz
1965.2	*L. costa* Kurtz
1966.6	*L. girtyi* Walcott

mod. thick shells abraded

1967.5	*L. costa* Kurtz
1968.5	*L. costa?* few v. water worn & frag. specimens
1972.3	*L. costa* Kurtz abund. mostly v. water worn

very thick shells very abraded

1974.1	*L. costa* Kurtz *Apsotreta expansa?*
1974.2	*L. costa*, Kurtz *Apsotreta expansa* Palmer (reworked) *Apsotreta stricta?* (reworked)
1974.5	*L. costa*, Kurtz *Apsotreta expansa* Palmer (reworked) *Apsotreta stricta* Kurtz (reworked)

Dunderbergia Zone

single pop. not abraded

1977.1	*Apsotreta expansa* Palmer (high) *A. stricta*

mixed pops. partly abraded

1979.0	*Apsotreta expansa* Palmer (int.) thick shelled several highly apsoconical ventral valves of mixed thick and thin shelled variants, *A. stricta* Kurtz (high) thin shelled, mostly small forms
1981.5	*Apsotreta expansa* Palmer (low) specimens uniform in size, not abraded

Crepicephalus Zone

2008	*Coosina* cf. *C. ariston* (Walcott)
2010	*Tricrepicephalus* sp.
2012.5	*Llanoaspis* sp., *Tricrepicephalus* cf. *T. coria* (Walcott) *Meteoraspis* cf. *M. metra* (Walcott)
2016	*Coosina* cf. *C. ariston* (Walcott)

BONNETERRE FORMATION

The 1,975-2,300 foot interval is referred to the Bonneterre in the Audrain County hole. The formation is comparable in most respects (including its thickness of 325 feet) to its development in St. Charles County. Oolitic limestone and dolomitic limestone are the dominant lithologies, constituting nearly 200 feet of the upper, lower and middle parts of the succession. *Crepicephalus* Zone fossils occur between 2,008 and 2,016 feet. Shaly to silty dolomite and siltstone in the 1,975-2,008 foot interval are provisionally assigned to the "upper Bonneterre". This unit occurs immediately beneath the sandy, heavily glauconitic zone of the Davis. It is well-defined in the Clark County hole to the northeast, but is absent in the St. Charles County and Washington County holes. These strata contain fossils (*Apsotreta expansa*) near the top (1,977.1-1,981.5 feet) that suggest assignment of that part of the interval to the *Dunderbergia* Zone (Kurtz, 1971). Although no fossils were collected in the 1,981.7-2,008 foot interval, provisional assignment to the *Aphelaspis* Zone is reasonable, as this interval lies between ones containing *Crepicephalus* and *Dunderbergia* Zone fossils. Core samples from comparable strata in the south-central Missouri area contain *Aphelaspis* (Kurtz, 1971). The 1,987-2,008 foot interval is correlated with the "upper Bonneterre silt" of south-central Missouri. Basal Bonneterre beds in the Audrain County hole were described briefly in the discussion of the Lamotte-Bonneterre boundary. A significant percentage of the sand and silt in the basal Bonneterre is feldspar of mixed varieties.

DAVIS FORMATION (LOWER FRANCONIA FORMATION)

In Audrain County, Missouri, and northward, problems arise both in the interpretation of meaningful boundaries and in the selection of appropriate stratigraphic terminology, especially in post-Bonneterre and post-Eau Claire strata. In the Audrain County hole, the term Davis is usefully applied to the 1,815-1,975 foot interval, as the rock therein is of typical Davis lithology and upper and lower boundaries are determined with confidence. Silt-sized residue throughout the entire interval in this well is partly authigenic feldspar which

does not occur above 1,815 feet. Because of the significant carbonate rock content, the term Davis is best used for the rock in the log of the Audrain County well, but the essential lithic equivalence of the Birkmose (1,935-1,975 feet) and Tomah Members (1,815-1,935 feet) of Upper Mississippi Valley terminology to the Davis of this hole is clearly indicated by plate 1.

RENO MEMBER (FRANCONIA FORMATION)

Ozark region terminology does not apply well to the approximately 125 feet of glauconitic sandy and silty dolomite and dolomitic siltstone present above the Davis in the Audrain County hole. The lower 45 feet (1,770-1,815 feet) of this material is a lithic correlative of the lower part of the Derby-Doerun and because it can be differentiated, it is informally identified as "lower Reno". Upper Reno beds (in the 1,694-1,770 foot interval) are substantially different from typical upper Derby-Doerun strata. They were logged in core as fine-grained to silty, glauconitic, dolomitic sandstone; however, insoluble residue percentages indicate that they are properly described as sandy dolomite. A thin zone (1,692-1,694 feet) of irregularly-bedded dolomite containing abundant pellet glauconite was recorded at the top of the Reno in core description. It is of interest to note that 115 feet of strata that should be assigned to the Reno were logged in the No. 1 Wynn-McAlpin well, in Boone County, Missouri, 30 miles away, thus adding further dimension to the area in which the term Reno appears to be useful.

DERBY-DOERUN DOLOMITE

The interval extending from 1,490 to 1,690 feet in the Audrain County hole is provisionally identified as the Derby-Doerun Member. Some doubt as to the desirability of using the term in this area remains, and it is possible that referral of the included strata to the Potosi or to the St. Lawrence might be preferable. Core logging suggests assignment of the 1,445-1,544 and 1,544-1,690

foot intervals to the Potosi, with the notation that the rock in the latter interval resembles the Derby-Doerun. Insoluble residue breaks in the succession occur at 1,535 and 1,640 feet. The section extending from 1,490 to 1,535 feet is described (residue logging) as silty dolomite with granular quartz masses in the lower part and containing some green shale. The 1,535-1,690 foot interval is generally like the lower Derby-Doerun of the Ozark region. Uncertainty arises from the fact that in this area there is a strongly emphasized upward shift in facies development. Most of the facies in this part of the section are sharply time-transgressive in this area.

POTOSI DOLOMITE

The 1,445-1,490 foot interval in the Audrain County well is assigned to Potosi. Considerable difficulty was encountered in establishing the lower boundary as much of the upper part of the section referred to the Derby-Doerun is transitional. Residue logging indicates that the 1,445-1,490 foot interval should be included in the Potosi. Either interpretation involves thinning of this unit as compared to its expression the St. Charles County well, and pronounced northward thinning from the Ozarks region.

EMINENCE DOLOMITE

Only 92 feet (from 1,353 to 1,445 feet) of rock are assigned to the Eminence in the Audrain County hole. Core logging indicates a basal zone consisting of sandstone and sandy dolomite in the lower 15 feet, with typical Eminence lithology above. The basal sandy zone is identified as the Momence sandstone (Buschbach, 1964, p. 41) of Illinois, and is seemingly developed at or near the same horizon occupied by thin quartzose dolostone and sandstone zones in the upper Eminence in the Ozark area. On the assumption that this is correct the Eminence in the Audrain County hole is identified as upper

Eminence, and the pinchout of older Eminence strata between St. Charles and Audrain Counties is attributed to regional thinning with the basal relationship with the Potosi shown as generally transitional. Alternate interpretations are noted in discussion of the St. Charles County core hole.

The Eminence above the Momence is sparingly quartzose through a thin transition zone. Sandstone and quartzose dolomite in the 1,345-1,353 foot interval are identified as the Gunter sandstone. The upper Eminence, including the Momence sandstone in its lower part, appears to represent the Jordan Formation of the Upper Mississippi Valley.

CLARK COUNTY, MISSOURI

St. Joseph Lead Co. (now St. Joe Minerals Corp.) and Meramec Mining Co., SF-1 59-M-1 (MGS 18404) Sec. 5, T. 65 N., R. 6 W.

This exploratory hole, drilled to investigate a prominent magnetic anomaly, has provided much information about the Cambrian section of northern Missouri. Many of the stratigraphic units can be correlated with strata in the Henry County, Illinois, drillhole to the north and with the Audrain County, Missouri, drillhole to the south. Overall, the Cambrian section here is far more amenable to the application of upper Mississippi Valley classification and nomenclature than to that of the Ozark area. Core description and insoluble residue logging is available for most of the Cambrian succession along with some information on the generally sparse fossils.

LAMOTTE (MT. SIMON) SANDSTONE

The mostly medium and coarse quartzose sandstone below the glauconitic and fossiliferous shaly sandstone of the Eau Claire of the Clark County drillhole appears to be appropriately identified by either term—Lamotte or Mt. Simon.

The upper 107 feet of the formation consist mostly of medium and coarse white and locally hematitic red sandstone, while the lower and middle parts consist mostly of medium-sized grains, with granular to pebbly arkose zones at and near the base. A thin zone of igneous pebbles and very coarse sand at 2,586 feet marks the base of the upper 107-foot unit. The upper unit may correspond to the Charter Member of the Mt. Simon as defined by Templeton (1950).

EAU CLAIRE FORMATION

The term Eau Claire seemingly is more appropriate than Bonneterre in this part of Missouri, and the 2,231-2,479 foot interval is referred to that formation. Laminated shale and fine sandstone typical of the Eau Claire are well represented in the core. Arthropod coquina limestone is present as a minor constituent in an essentially shaly succession extending from 2,251 to 2,359 feet. *Tricrepicephalus* and *Kingstonia* were noted at 2,324 feet, *Crepicephalus* at 2,299 and *Aphelaspis* at 2,256. Maroon and grayish-green shale with interbedded thin arthropodal limestone and dolomitic limestone is the principal lithology from 2,349-2,395 feet. Shaly glauconitic sandstone, generally characterized by burrow structures and containing a few thin layers of strongly dolomitic sandstone, extends from 2,395 to 2,463 feet, and contrasts sharply with the generally coarse, strongly glauconitic and hematitic sandstone that occurs at the base of the unit. Phosphatic shell debris is abundant in the basal beds. Silty shale extending from 2,255 to 2,285 feet is correlated with the silty portion of the "upper Bonneterre" of south-central Missouri. The 2,231-2,255 foot interval is in part equivalent to the section differentiated as "upper Eau Claire" in the Henry County, Illinois drillhole and is overlain unconformably by the Birkmose. Under this interpretation the Galesville is regarded as absent in Missouri as is the Ironton. Core logging indicates that the base of the upper interval should fall at 2,251, at the base of a strongly glauconitic zone. Sample logging at 5-foot intervals (shown on pl. 1) indicating that the base of the zone extends to 2,255 feet is probably in error to the extent of the 4-foot discrepancy.

BIRKMOSE MEMBER (FRANCONIA FORMATION)

Beds in the 2,183-2,231 foot interval are referred to the Birkmose. As logged from samples, the material consists mostly of medium-grained, strongly glauconitic, coquinoidal to shaly sandstone. The Ironton is apparently not represented in the Clark County drillhole and the Birkmose rests unconformably on the shaly strata referred to the "upper Eau Claire" in this report.

TOMAH MEMBER (FRANCONIA FORMATION)

Strata, consisting mostly of burrowed, fine- to medium-grained, generally slightly glauconitic sandstone with considerable interbedded and interlaminated shale and subordinate amount of carbonate in the 2,055-2,183 foot interval, are referred to the Tomah Member. Although more glauconitic than typical Tomah, we regard the abundant interbedded shales as primary criteria for identification of this unit as Tomah. *Linnarssonella* (at 2,155 feet) and *Eoorthis remnicha* (at 2,117 feet) were the only fossils recovered and identified from the Tomah beds.

RENO MEMBER (FRANCONIA FORMATION)

Finely glauconitic and dolomitic siltstone and fine sandstone within the 1,896-2,055 foot interval are assigned to the Reno. "Lower" Reno beds (1,960-2,055 feet) contain some interbedded shale and are less certainly differentiated in this than in drillholes to the south. There was essentially agreement among two core logs and one sample log with respect to the placement of the upper boundary which, although transitional, falls above beds described as consisting of very fine-grained sandstone and below silty to sandy dolomite.

ST. LAWRENCE FORMATION

Shaly to silty and in part glauconitic dolostone of the 1,797-1,896 foot interval is referred to the lower St. Lawrence Formation. These beds resemble the Derby-Doerun Formation of the Ozark area in most respects. Dolostone in the 1,763-1,797 foot interval in the Clark County drillhole is correlated with and identified as the Potosi on the basis of insoluble residues.

EMINENCE DOLOMITE

Poor samples and the possibility of solutional loss within the Eminence are cause for some doubt about the usefulness of the insoluble residue log of this part of the drillhole; however, no other information is available. On the basis of the available information, the 1,652-1,763 foot interval is referred to the Eminence. It includes the Momence Sandstone Member.

HENRY COUNTY, ILLINOIS

Ralph E. Davis Assoc., No. 1 E.A. South SW¼ SW¼ SW¼

Sec. 30, T. 16 N., R. 1 E.

This important drillhole was the subject of an Illinois Geological Survey report by Buschbach (1965). In addition, the Ironton-Galesville succession received more detailed attention in a report by Emrich (1966). Because of the availability of the two reports on this well, the authors did not examine the samples and relied entirely upon the description published by Buschbach plus the interpretation of the gamma ray, focused electrical and sonic log information published with that report and information included in Emrich's study. As portrayed on plate 1, the log of the E.A. South well is a stripped version of the sample description given by Buschbach with some additional detail added from interpretation of the foregoing logs in the "Franconia", "Ironton-Galesville" and Eau Claire sections. Recognition of the possibility of unit correlation between the E.A. South well and Clark County, Missouri, drillhole led to the initiation of the present study.

MT. SIMON SANDSTONE

The Mt. Simon in this well is far thicker (1,270 feet) than equivalent sandstone in any of the other wells included in this cross section, and comparable in thickness and general character to the Mt. Simon of northeastern Illinois as described by Buschbach (1964). Conceivably it may include sandstones which do not have time equivalents in the section represented by other drillholes in this traverse. Buschbach did not attempt to differentiate or recognize Templeton's (1950) divisions of the Mt. Simon in this well. The present authors differ with Buschbach with respect to the placement of the Mt. Simon – Eau Claire boundary, placing it at 2,585 feet rather than at 2,600 feet. The boundary was placed at this point because of a discontinuity in each of the several logs published in Buschbach's report.

EAU CLAIRE FORMATION

Strata in the 2,306-2,585 foot interval are referred to the Eau Claire. Buschbach (1965) described the formation in this well as a "variable unit of sandstone, siltstone and shale". The Eau Claire includes in its upper part 72 feet (2,306-2,378 feet) of shaly siltstone and sandstone that is differentiated in this report simply as "upper Eau Claire" and which is interpreted as being correlative with the "upper Bonneterre" of wells to the south. The lower 38 feet of this division of the Eau Claire are tentatively correlated with the silty portion of the "upper Bonneterre" in the drillholes in Clark, Audrain and St. Charles Counties.

IRONTON-GALESVILLE SANDSTONE

In his report on the Henry County hole, Buschbach (1965) referred the strata within the 2,177-2,306 foot interval to the Ironton-Galesville Sandstone. Emrich (1966) referred this interval solely to the Ironton. On the basis of the experience of Kurtz in the upper Mississippi Valley outcrop section, the writers suggest restriction of the Ironton-Galesville to strata within the 2,190-2,306 foot interval. In this restricted connotation the Ironton-Galesville consists mostly of white (light gray), medium-grained sandstone. It is seemingly absent in the Clark County, Missouri, well, substantiating Emrich's work (1966, fig. 7).

FRANCONIA BEDS ABOVE THE IRONTON

The upper 13 feet (2,177-2,190 feet) of the glauconitic and dolomitic sandstone included in the Ironton-Galesville of Buschbach is identified as the Birkmose Member of the Franconia Formation, on the basis of interpretation of the gamma ray log and sample description provided by Buschbach (1965). The unit is not as glauconitic as typical Birkmose but does occupy the same stratigraphic positions. Apparently this is the same unit that was identified as the upper part of the Mooseheart Member of the Ironton by Emrich (1966). Beds within the 2,160-2,177 foot interval are assigned to the Tomah Member, and those within the 2,048-2,160 foot interval are assigned to the Reno Member. The top of the Franconia is placed at the base (2,048 feet) of sandy glauconitic dolomite that is referred to the lower St. Lawrence in this report. Buschbach included the latter in the upper part of his Franconia Formation, which he did not subdivide. The Franconia section in the Henry County well, according to the writers' interpretation, extends from 2,048 to 2,190 feet, including 142 feet of strata lying above the mostly white, medium-grained sandstone of the upper Ironton and below sandy glauconitic dolomite assigned to the St. Lawrence Formation. As indicated in the cross section, each of the members of the Franconia retains its identity to the south far into Missouri, and strata provisionally identified as "lower Reno" can be correlated into the Ozarks region.

ST. LAWRENCE FORMATION

The authors identify the rocks in the 1,830-2,048 foot interval as the St. Lawrence Formation, comprising a silty and shaly (sandy and glauconitic) lower St. Lawrence (Lodi?) Member and the overlying Potosi (Black Earth) Dolomite. Buschbach (1965) assigned the succession in the 1,830-1,996 foot interval to the Potosi Dolomite, and referred the 1,996-2,048 foot section to the Franconia. The latter division has some of the characteristics of the Lodi Member of the St. Lawrence Formation and also of the Derby-Doerun Dolomite of the

Ozark region. The formational term St. Lawrence is recognized as most appropriate in this and the northeastern-most Missouri area where the Potosi is thin and can be identified and use of the term Derby-Doerun is not feasible. It is interesting that the somewhat greater and assumedly basinal thickening of the Potosi as expressed in this well is mostly at the apparent expense of the underlying lower St. Lawrence. The top of the Potosi is placed at 1,830 feet following Buschbach (1965). This point is above a 10-foot interval of lost circulation and poor samples. Whether or not the Momence Sandstone, which is referred to the basal part of the overlying Eminence Dolomite, extended down to the 1,840 foot level is a moot question. The base of the Momence, which is identified in two other wells in this traverse, is an important horizon in this part of the Cambrian succession. The basis for our correlation of the Potosi with the Black Earth and our provisional identification of the "lower" St. Lawrence or Lodi(?) is the discussion of the regional relationships of the Black Earth and Lodi Members presented by Ostrom (1966, p. 52).

EMINENCE (JORDAN) FORMATION

The Eminence Dolomite of the Ozark region is regarded as being in part correlative with the Jordan Formation of the upper Mississippi Valley region. Buschbach (1965) identified the Eminence (1,769-1,830 feet) in the E.A. South well. The writers consider that the sandstone and dolostone in the 1,769-1,790 foot interval represents the Gunter. The Momence Sandstone forms a lower part of the Eminence in this as well as two other drillholes to the south in this traverse. The Momence is probably a tongue of the Jordan, as suggested by Buschbach (1964, p. 41). One of the problems of interpretation of the Eminence-Jordan relationship is the question of whether the Jordan represents part of the Eminence or whether they are of equivalent age-span but of different thicknesses. As indicated in the discussion of the St. Charles County well, an Eminence "sand" encountered at points in the Ozarks probably is the Momence. Thus, the Eminence recorded in the Henry County, Illinois, and the Clark and Audrain County, Missouri, wells is provisionally referred to the upper Eminence.

CONCLUSIONS

Several broad conclusions are suggested by this study. They are summarized as follows:

1. Thickness and character of the Lamotte (Mt. Simon) appear to be unrelated to that of overlying strata. A "transitional" zone of reworked sediments is interpreted as basal Bonneterre or, in northeastern Missouri, as basal Eau Claire. Similar "transitional" strata have been identified in northeastern Illinois as the Elmhurst Member of the Eau Claire (Buschbach, 1964, p. 32), and, in Wisconsin, as the Shawtown Member (Raasch and Unfer, 1964). This material is referred to the Mt. Simon in recently published Wisconsin reports (Ostrom, 1970).

2. The Bonneterre and Eau Claire formations represent contemporary facies whose common boundary extends across northeastern Missouri. Along the line of cross section, the thickness of the Bonneterre or Eau Claire varies only slightly although the transition from the southern to the northern facies is well defined. Silty to shaly beds marking the base of an upper division of the Bonneterre in south-central Missouri are recognized in northeastern Missouri where they are included in the upper part of the Eau Claire Formation. The typical calcarenitic or oolitic middle portion of the Bonneterre thins somewhat to the north but is characterized by a pronounced facies change to silty shale in northeastern Missouri. The term Eau Claire is applicable in that part of Missouri.

3. The Galesville Sandstone is not developed in Missouri. The highly glauconitic and sandy Birkmose Member, Franconia Formation, is provisionally correlated with a highly glauconitic zone near the base of the Davis. In northeastern Missouri the Birkmose rests on shale and silty shale referred to the upper Eau Claire.

4. The Ironton Sandstone is not present in Missouri. The nature of the southern termination of the Ironton is not well understood, but may have been an undaform shelf edge.

5. General correlation of the Elvins of the Ozarks and the Franconia of the Upper Mississippi Valley region has been assumed for decades. However, correlation of specific parts of these units has not been consistent, principally because of rapidly-climbing facies that distort the upper boundaries of these units, particularly that of the upper Elvins, as identified in northeastern Missouri. Secondly, the comparatively extensive southward distribution of the Reno Member adds to the inconsistency. Principal lithologic characteristics of the Davis facies are applicable to the entire Franconian section in northern areas.

6. The Tomah and underlying Birkmose members are distinguishable in northeast Missouri and, together, are the lithic correlative of the typical Davis. Authigenic feldspar occurs in the Tomah and older units, but is lacking in the overlying Reno.

7. The Reno facies is distinguishable in northeastern Missouri, and occupies the stratigraphic position of the Derby-Doerun in Audrain County, Missouri. What is interpreted as the correlative of the lower part of the Reno is identified in the St. Charles County drillhole, where it is clearly equivalent to the lower Derby-Doerun. Differentiation of a lower part is suggested in the Audrain County hole, but the relationship is not as well defined. Regionally, the lower Derby-Doerun and the Reno are approximate correlatives.

8. The upper part of the Derby-Doerun and the Potosi are approximately correlative with the St. Lawrence Formation. Upper Derby-Doerun facies thicken northward seemingly at the expense of the Potosi Dolomite, and grade laterally into upper Reno and lower St. Lawrence strata in northeastern Missouri. In its northern extension the upper Derby-Doerun becomes atypically silty and glauconitic and, as it is beyond the area of useful application of the term Derby-Doerun, the term "lower St. Lawrence" is used. The Derby-Doerun and the lower St. Lawrence both appear to have a gradational relationship with the overlying Potosi. The "top of the Cambrian clastics", of considerable value as a datum in the Ozark region, appears to have lost most of its usefulness in Audrain County and to the north. The "top of Cambrian clastics" notation, made by many geologists on the basis of various techniques, marks the upper, time-transgressive boundary in what may be termed the Upper Mississippi Valley Cambrian facies, generally characterized by prevailing fine- to medium-textured thoroughly burrowed clastics, with generally abundant glauconite. This facies boundary

descends from near the top (in beds equivalent to the Potosi) of the upper Cambrian section in the north to an appreciably lower point (lower Derby-Doerun) in the Ozark region.

9. Other workers have suggested the correlation of the Potosi Dolomite with the Black Earth Member of the St. Lawrence Formation; this work supports this conclusion. The traverse suggests very pronounced thinning of this unit north-northwestward from the type area in Washington County, Missouri, with some increase along the traverse from northeastern Missouri into the Illinois basin. The relatively abrupt northward thinning in Missouri possibly is accountable entirely to substitution by Derby-Doerun and Reno facies. Both Potosi and Eminence thin rapidly to the north through progressive overlap and facies substitution. Current study reinforces the concept of a transitional rather than an unconformable relationship between the Derby-Doerun and Potosi.

10. The indicated approximate correlations suggest that the Trempealeauan/Franconian boundary probably follows the top of the Derby-Doerun facies, and is somewhat higher than as shown on plate 1. The early Trempealeauan *Saukiella minor* Subzone probably is represented in the strata identified as lower St. Lawrence.

11. Preparation of the traverse cross section and review of published data support the concept of a general correlation between the Jordan Formation (mostly sandstone and quartzose dolomite) of the Upper Mississippi Valley region and the Eminence Dolomite of the Ozarks. Sandstone at the base of Eminence strata in Audrain County, Missouri, is correlated with the Momence Sandstone of Illinois and appears to be the same as thin sandstone in the upper Eminence noted at points in the Ozark region. Eminence beds in Audrain County and to the north are consequently referred to the upper Eminence. Therefore, the regional concept of correlation of the Jordan and Eminence is true only in part.

12. Northward facies changes are, in general, progressive but some deviations are noted and can be related to variation in lithologic expression.

13. Many residue zones useful in the Ozark region are expanded beyond utility as the section is traced north; nevertheless they are an invaluable tool. The relationship of residue zonations to both the Ozarks and Upper Mississippi Valley section is demonstrated.

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CORRELATION OF CAMBRIAN STRATA

OF THE OZARK AND UPPER MISSISSIPPI VALLEY REGIONS

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