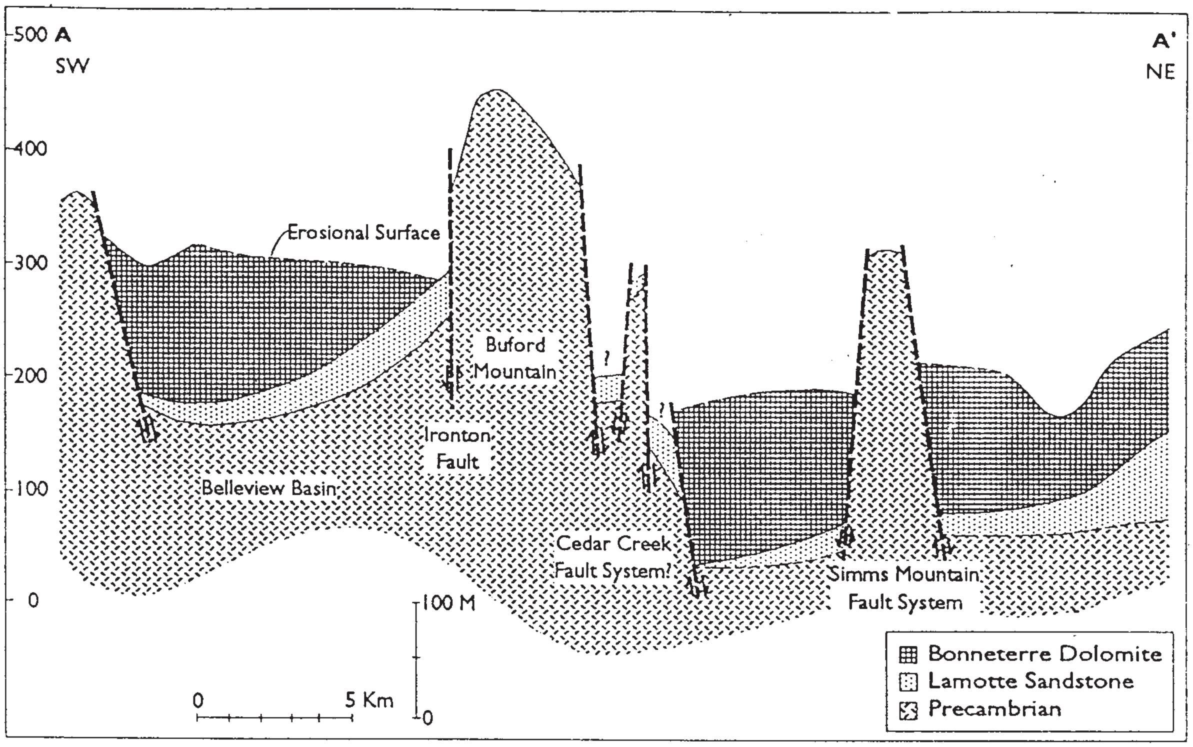
ASSOCIATION of MISSOURI GEOLOGISTS

SYNDEPOSITIONAL TECTONICS DURING THE LATE UPPER CAMBRIAN



Cross section of the Belleview basin

45th Annual Meeting and Field Trip

September 25 and 26, 1998
Farmington, Missouri

SYNSEDIMENTARY TECTONISM IN THE ST. FRANCOIS MOUNTAINS REGION, SOUTHEAST MISSOURI

AMG FIELD GUIDE
September 25 and 26, 1998

Cheryl M. Seeger and James R. Palmer
Missouri Department of Natural Resources
Division of Geology and Land Survey
P.O. Box 250, Rolla, MO 65402

Upper Cambrian synsedimentary tectonism in the St. Francois Mountains region, southeast Missouri, is illustrated in roadcut exposures and by subsurface data. Surface expressions of this tectonism include the Belleview and Sabula Basins and exposures of tectonically controlled facies in sedimentary rocks. This field trip will visit exposures of the Davis and Lamotte formations for discussions on tectonic control of depositional facies, and will give overviews on sedimentation in the Belleview and Sabula basins. The trip will also discuss new ideas on the evolution of the modern landscape (Elfrink and Siemens, this volume). The stop descriptions detail the lithology, petrology, and/or facies at the site, as well as the significance of the site in interpretation of the synsedimentary tectonic history of the region. For brief descriptions of the facies discussed in this paper, the reader should refer to Palmer and Seeger (this guidebook). Stops are located by mileage from known intersections and by legal description for use by readers of the guidebook.

Friday, September 25, 1998

Stop No. 1 - Davis - Derby-Doerun Formation Roadcut

(On Hwy 8, 0.6 miles west of intersection with Hwy M at Frankclay, Sec. 5, T36N, R4E, Flat River Quad.)

The Davis Formation has dramatic facies changes within short distances across fault zones. Two roadcuts near Farmington have very different lithologies and structures. The exposure at Stop no. 1 has evidence of local steepening illustrated by folding and abundant conglomerate. The second roadcut (Stop no. 4) has a simple gradual change from shales to oolitic dolomites.

Stratigraphy and Facies

The Upper Davis Formation and Lower Derby-Doerun dolomite (Fig. 1) represent the transition across the intrashelf basin - deep ramp margin, and show several periods of transgression-regression. The bioherms in the basal Derby have an apparent width of 24 feet, and contain mottled thrombolite boundstone and distinct columnar thrombolite. The base of the dolomite marks an eustatic event that coincides with the Pterocephalid-Ptychaspid Biomere boundary, and the introduction of Eorthis remnicha (Gregg, et al, 1989).

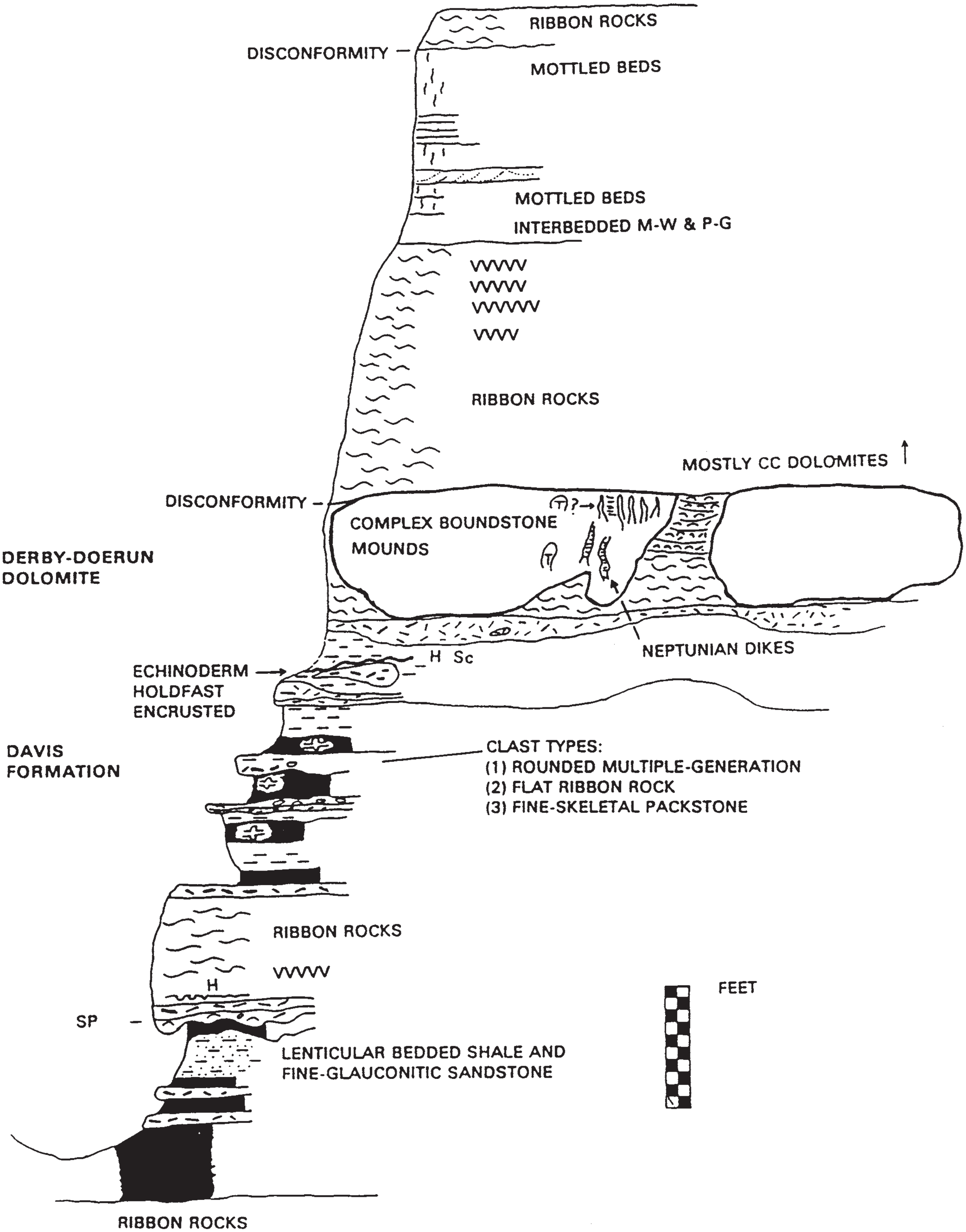


Figure 1. Upper Davis Formation and lower Derby-Doerun Dolomite. SP = sphalerite, H = hardground, Sc = scoured surface, VVVV... = rows of vugs.

The Davis and Derby-Doerun comprise the Franconian Stage, which in southern Missouri marks an abrupt sea level rise culminating in the widest development of intrashelf basins (Clendenin, 1989). This history is in stark contrast to the Late Upper Cambrian of the southern Appalachians, where the carbonate shelf shoals developed into peritidal conditions prior to the Franconian Stage. Intrashelf basins are common to carbonate shelves along passive margins. Such basins have a rim located along a sharp break in the shelf topography. A narrow or discontinuous rim (Fig. 2) leads to the development of intrashelf basins dominated by deep-water limestones. Wide, continuous rims trap more clastic sediment within the intrashelf basin area. The presence of an intrashelf basin requires the presence of a deep-water margin. In Missouri (Fig. 3) this rim is located along the northwest margin of the central graben of the Reelfoot Rift, leading to the suggestion that failed rifts may control the subsequent development of intrashelf basins within carbonate shelves.

Structural Significance

This exposure of Davis - Derby Doerun has several features suggestive of synsedimentary tectonism. Sediment-starved conditions combined with local steepening are supported by the presence of lithoclast conglomerate layers, ball and pillow structures at the base of some thicker dolomite beds, and a hardground encrusted with micrite, glauconite and pyrite. This Davis sequence represents a margin along a distally steepened carbonate ramp. Distally steepened ramps have slope breaks seaward of shoal or reef conditions. In areas where a ramp is steepened, sediment supply from the shallow ramp can be diverted. If sedimentation rates were otherwise slow, the setting would be sediment-starved. The location of a hardground containing crinoid holdfasts on a ropy, irregular surface eroded into conglomerate layers, visible on the surface of one bench, confirms local sediment-starved conditions. Currents across or through these areas develop channels that erode the basin margin. Preexisting sediments are eroded and redeposited, in part, as multi-generational lithoclasts. This sort of erosion/resedimentation cycle occurs when an area of the ramp is repeatedly steepened, possibly by faulting, and bypassed by sediment.

Early depositional deformation of beds is shown by wavy bedding present near the east end of the exposure. The wavy bedding is bounded above and below by similar lithologies which are undeformed. This suggests that local steepening or other fault movement caused folding of unlithified or slightly lithified units.

Further conformation of local tectonic control on deposition is provided by comparison of this roadcut with the Davis - Derby-Doerun exposure at Stop no. 4. The stop, which is only 4.5 miles away, has different facies and lithologies that are indicative of a homoclinal ramp (discussed below). There are two intrashelf basin cycles in the Upper Cambrian in Missouri. The first is represented by limestone-dominated Bonneterre Formation equivalent rocks, the second by shale-dominated Davis Formation and equivalent rocks. The regional implications of this pair of intrashelf basin cycles are at least fourfold:

(1) failed intracontinental rifts (aulacogens) and subsequent thermal subsidence can control the development of passive margin-like rimmed carbonate shelf sequences. Such

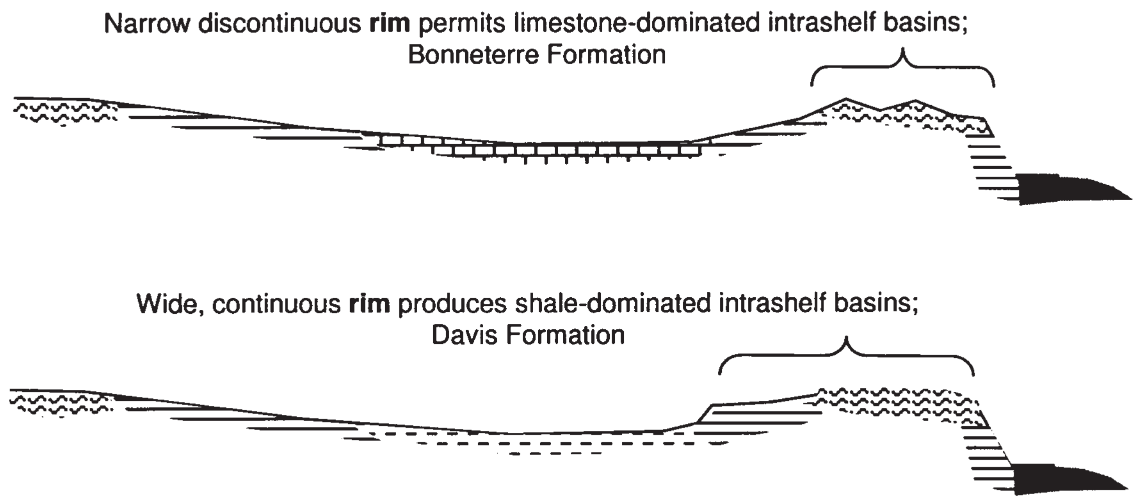


Figure 2. Diagram of intrashelf basin models. There are two periods of intrashelf basin development in the Upper Cambrian of southern Missouri, one during the early Dresbachian Stage, Bonneterre equivalent, the second during the Franconian Stage, Davis Formation.

Paleodepositional elements during the Upper Cambrian

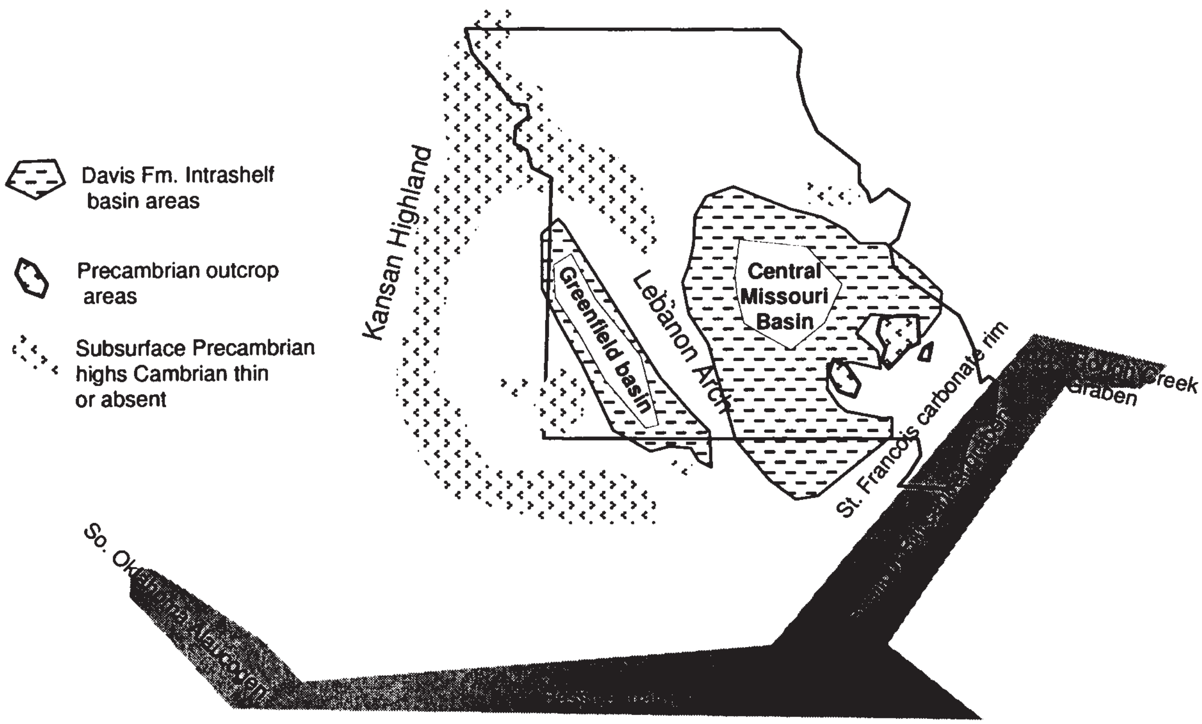


Figure 3. Diagram showing the regional setting during the late Upper Cambrian. The intrashelf basin areas are within the Davis Formation, and do not include Bonneterre Formation intrashelf basin areas.

sequences are not restricted to the continental margins;

(2) thermal driven and localized tectonic subsidence continued well into the late Upper Cambrian;

(3) the deep grabens of the Reelfoot rift were present during the Franconian stage (Davis Formation);

(4) subaerial redbed stage and thermal subsidence phase marine sedimentation are not often separated by many millions of years; therefore, the basal Lamotte redbeds are not only synrift, but are also probably no older than Middle Cambrian.

Stop No. 2 - Belleview Basin
(Pull-off on Hwy 21, 0.4 miles south of the Hwy 32 – Hwy 21 intersection, Graniteville Quad)

The Belleview Basin is an orthogonal basin that has an asymmetric filling of Lamotte Sandstone. The basin is bounded on the northeast by Buford Mountain and on the southeast by a range of hills containing Elephant Rocks State Park, both visible from this location. The northwest and southwest sides are bounded by linear Precambrian hills, which can be seen while driving through the basin. Other hills are of Cambrian-Ordovician rocks. Bedrock outcrops in the basin are primarily Bonneterre Dolomite. Bedrock is eroded into a gently rolling topography with occasional small hills that have relief of 200-300 feet. Buford Mountain has a relief of greater than 750 feet from the basement floor beneath the basin to the crest of the mountain. There are also two nearby areas with Bonneterre Formation equivalent ultra-mafic lapilli tuffs, Dent Branch and Furnace Creek, located northwest along the strike of the southwest escarpment of Buford Mountain.

Structural Significance

Belleview Basin and the Sabula Basin (discussed at Stop no. 2, Saturday) resemble block-faulted valleys within rift settings. Subsequent deposition of basal alluvial fan and redbed sequences completes the analogy. Asymmetry in both the Lamotte and Bonneterre formations are evidence of tilting and faulting during deposition (Fig. 4). The Belleview Basin is bounded on the northeast by the Ironton Fault (strike NW). The upthrown side of the Ironton Fault (Buford Mountain) is a structural high and Precambrian basement outcrop area; the northeast side of this block is bounded by the Cedar Creek Fault (Fig. 4). Within the Belleview Basin, the Lamotte Sandstone is absent on the southwest side of the basin, and thickens to the northeast and Buford Mountain (Palmer and Seeger, this volume). This is the same direction of asymmetry in the Lamotte as that at the Simms Mountain Fault, discussed below and at Stop no. 3. The Lamotte continues to thicken to nearly 300 feet (90m) to the northeast in a paleovalley that extends past the southwest escarpment of Buford Mountain to an area of lower relief Precambrian knobs that are bounded on the northeast by a fault of the Simms Mountain Fault Zone. Across this Simms Mountain

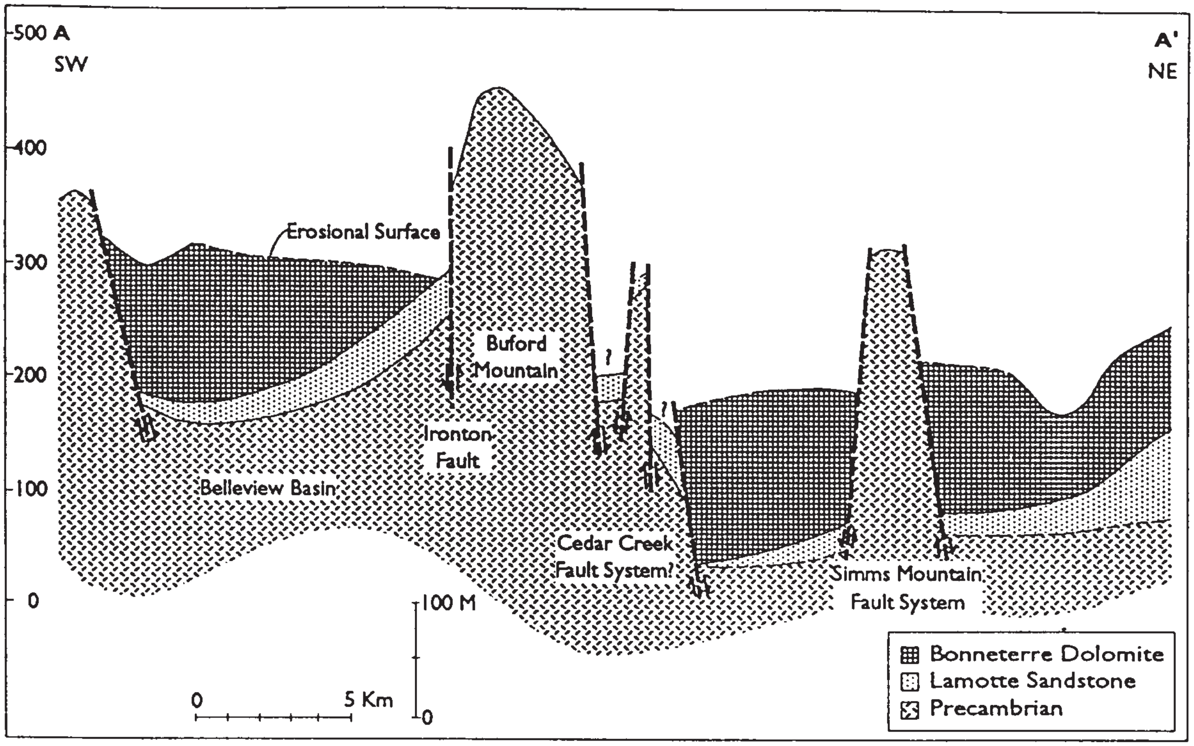


Figure 4. Cross-section of the Belleview Basin and region northeast, showing graben development and sedimentary expressions of synsedimentary deformation (after Kisvarsanyi, 1979; Thacker and Anderson, 1979).

structure, the Lamotte is as thin as 35 feet (10m) thick. Early northeast tilting is also indicated in the paleovalley and Lamotte outcrop patterns on the northeast side of Buford Mountain. Lamotte Sandstone in these valleys indicates that paleodrainage on Buford Mountain developed on a northeasterly sloping surface (Fig. 5). The overlying Bonneterre Formation is eroded along the east side of the basin, but is more than 500 feet thick along the southwest side of the basin, giving a tantalizing suggestion of a southwest dip reversal.

Northeast of the Cedar Creek Fault (Fig. 4), the Lamotte is thin to absent adjacent to the Cedar Creek Fault and thickens toward the Simms Mountain Fault Zone; the Bonneterre, however, thickens towards the Cedar Creek Fault and thins to the northeast, forming an apparent half-graben structure. This suggests a local dip reversal on the graben from Lamotte to Bonneterre deposition (Palmer and Seeger, this volume). The thickest Bonneterre Formation sequences are all near fault zones.

Stop No. 3 - Simms Mountain Fault Zone

(On both sides of Hwy 32, 2.7 miles west of the city limits of Elvins, Sec. 22, T36N, R4E, Flat River Quad.)

Lithology and Facies

Roadcuts west of Park Hills are excellent examples of faulted Lamotte Sandstone and the younger Derby-Doerun Dolomite. The Lamotte exposure will be discussed here; the Derby-Doerun exposure will be discussed at Stop no. 4.

The Lamotte Sandstone consists of basal, locally derived alluvial redbeds, middle quartzose-dominant fluvial sandstones, and upper marine sandstones. This exposure (Fig. 6) is comprised of arkose, quartz arenite, conglomerate, and shaly sandstones. Cross-bedding and channel cuts are notable in parts of the exposure. The majority of the roadcut is basal or near-basal Lamotte; the east end of the roadcut contains middle Lamotte that has been faulted downward relative to the lower Lamotte. The basal Lamotte rocks are dominated by rock-fragment and polycrystalline quartz grains, while the middle and upper Lamotte are mostly monocrystalline quartz. The basal to middle sequences are interpreted as a variety of alluvial fan facies which grade upward, and laterally, into rocks interpreted as part of a fluvial plain sequence.

Along the strike of the Simms Mountain Fault zone, on the east side of the St. Francois mountains, drillcores (Fig. 7) provide additional evidence of Cambrian syndepositional tectonism. Cambrian rocks comprise a series transgressive-regressive cycles (Fig. 8a) that begin with basal Lamotte alluvial facies and evolve to a series of carbonate ramp and intrashelf basins cycles; deposition culminated in a shelf with meter scale peritidal cycles in the Potosi Dolomite. The stratigraphic sequences and relationships along the line of cross-section (Fig. 8b) contrast areas that are dominated by intrashelf basin styles to the carbonate-dominant regional shelf rim that borders the central graben of the Reelfoot rift.

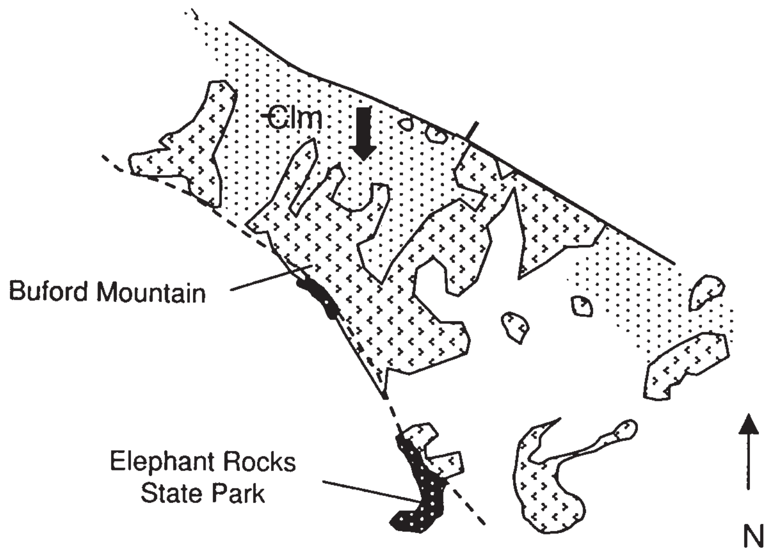


Figure 5. Asymmetric paleodrainages at Buford Mountain; Lamotte Sandstone outcrop patterns show extent of the paleovalleys (bold arrow) that developed in an asymmetric fashion on the northeast side of Buford Mountain. (Sketch map no scale)

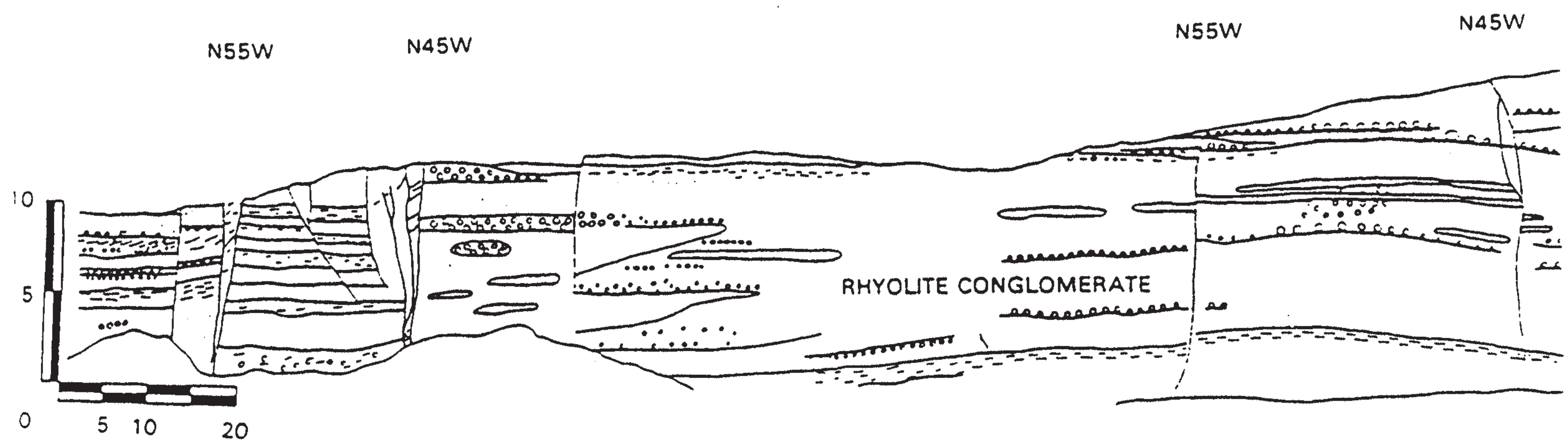


Figure 6. Part of a >300 foot lower Lamotte Sandstone section, south side of highway. Bases of rhyolite conglomerate beds are shown with associated thin lenses of fine-grained sandstone. The shales shown from center to far right are hematitic wackes. Bearings are fault strikes, scale in feet.

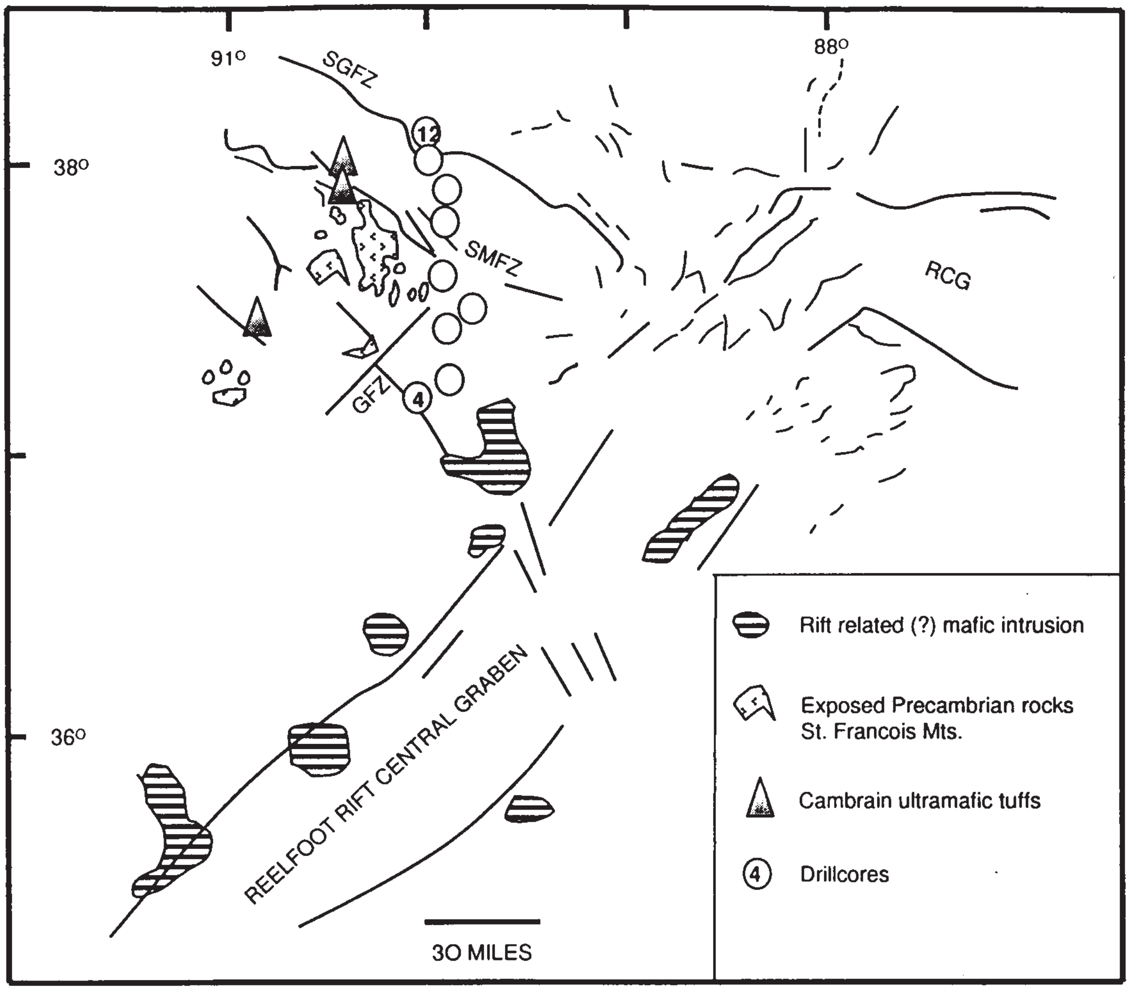


Figure 7. Selected regional faults in the Middle Mississippi Valley. GFZ - Greenville fault zone; SGFZ - Ste. Genevieve fault zone; SMZ - Simms Mountain fault zone; RCG - Rough Creek graben.

SOUTHERN MISSOURI CAMBRIAN DISCONFORMITY BOUND SEQUENCES; Intrashelf basin vs. Platform

(Eminence Dolomite not shown)

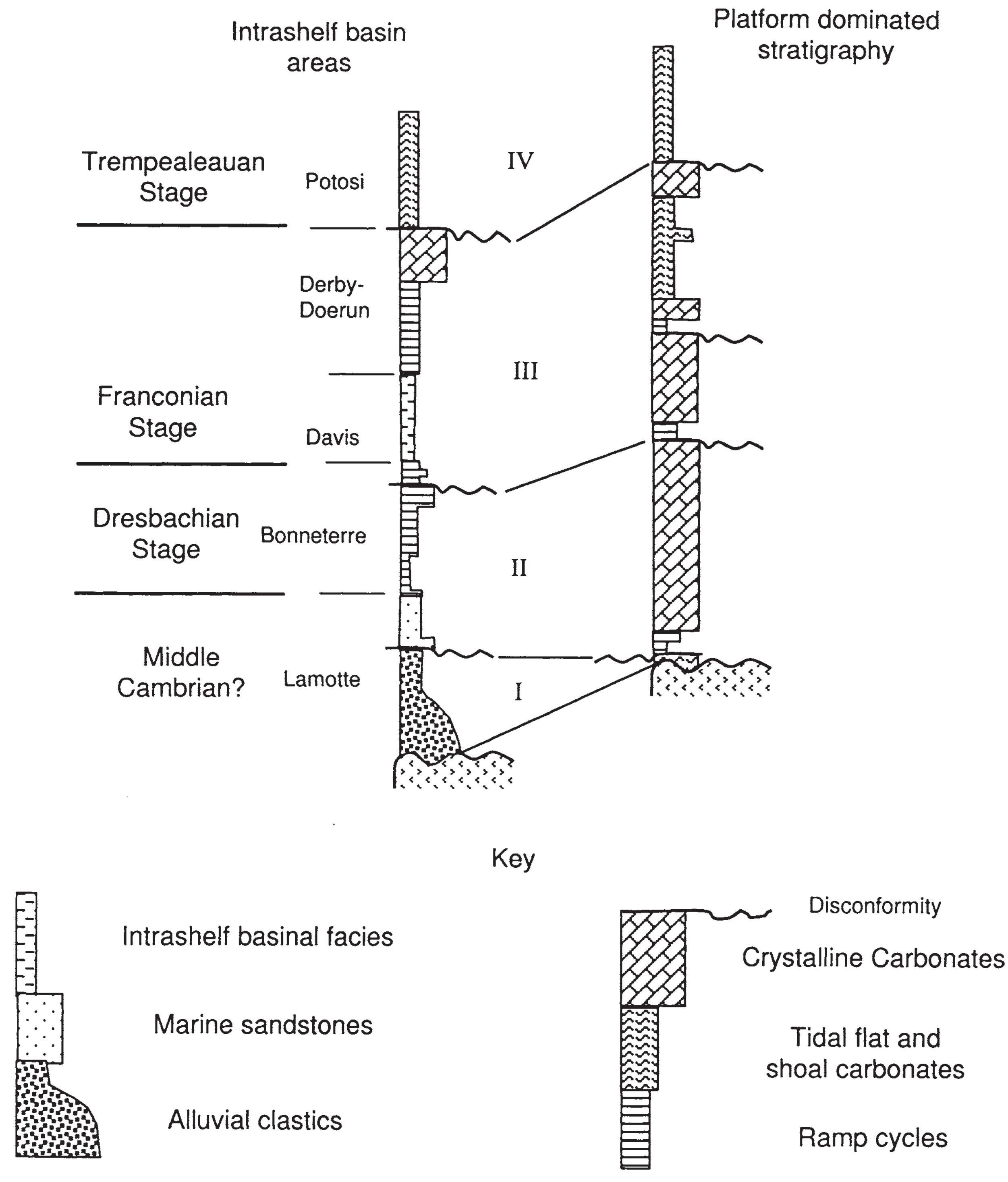


Figure 8a. Generalized stratigraphy of the upper Late Cambrian. Upper Cambrian sequences can be divided into large scale transgressive-regressive cycles. The accompanying cross-section (Figure 8b) shows in Sequence I the alluvial phase of sedimentation, Sequence II the Bonneterre equivalent sedimentation and deformation, Sequence III the Davis - Derby Doerun equivalent sedimentation.

Structural Significance

The main trace of the Simms Mountain Fault system is to the immediate northeast of the Lamotte outcrop, along Dry Creek. The fault exhibits approximately 800 feet of throw in this location; the downthrown side is to the northeast. The roadcuts visible just to the east are Derby-Doerun. The Simms Mountain Fault Zone extends more than 40 miles to the southeast, and may link with northwesterly striking faults in Cape Girardeau County.

The Lamotte exposure is cut by several faults of the Simms Mountain Fault system (Fig. 6). The large fault on the eastern end of the outcrop displaces middle Lamotte sediments several hundred feet downward in relation to the near-basal Lamotte sands and conglomerates comprising the rest of the exposure. The strike of the faults matches that of the northeast and southwest margins of the Belleview and Sabula Basins. Subsurface data show that the Lamotte Sandstone is thinner adjacent to the northeast side of the fault (Fig. 4), and thickens to the northeast away from the fault zone. The overlying Bonneterre Formation is thickest close to the northeast side of the fault and thins to the northeast. This asymmetry suggests that fault blocks were tilted in opposite directions during Lamotte and Bonneterre deposition in the Late Cambrian.

Subsurface data (shown on Fig. 8b) show along-strike deformation during a time frame that spans Bonneterre and Davis deposition. The cross-sections are constructed with a level datum that represents a disconformity that can be correlated in both intrashelf basin and carbonate rim areas.

Sequence I represents the alluvial phase of sedimentation. Few drillcores fully penetrated the alluvial sequence, but those that did provide a baseline for subsequent comparisons. Redbed sequences are located near Precambrian highs, while areas remote from knobs have more distally derived quartzose sandstones.

Sequence II has two striking features. 1) The first marine sediments south of the Simms Mountain Fault Zone comprises a deep-water intrashelf basin limestone. North of the fault zone the first marine sediments include peritidal and paleokarsted red limestones; further to the north sediments are cross-bedded quartzose sandstones of the upper Lamotte. 2) Neither facies nor sediment thicknesses in the sequence indicate that the Ste. Genevieve Fault Zone was active during the same period.

Sequence III, which includes Davis and Derby-Doerun equivalent strata, suggests that the Simms Mountain Fault Zone remained a largely positive feature. The basal portion of the sequence consists of a shallow ramp shoal and tidal flat sequence. This grades northward to ribbon carbonates in the deeper ramp and intrashelf basin shales recognized as the Davis Formation.

Sequence IV, while not shown, includes platform shoaling and the development of shelf-wide meter-scale peritidal cycles. Did regional faulting, isolating and rejuvenating rim and intrashelf basin areas end following Sequence III? We suggest a shelf rim adjacent to the central graben of the Reelfoot rift persisted until the end of the Franconian (Clendenin, 1989).

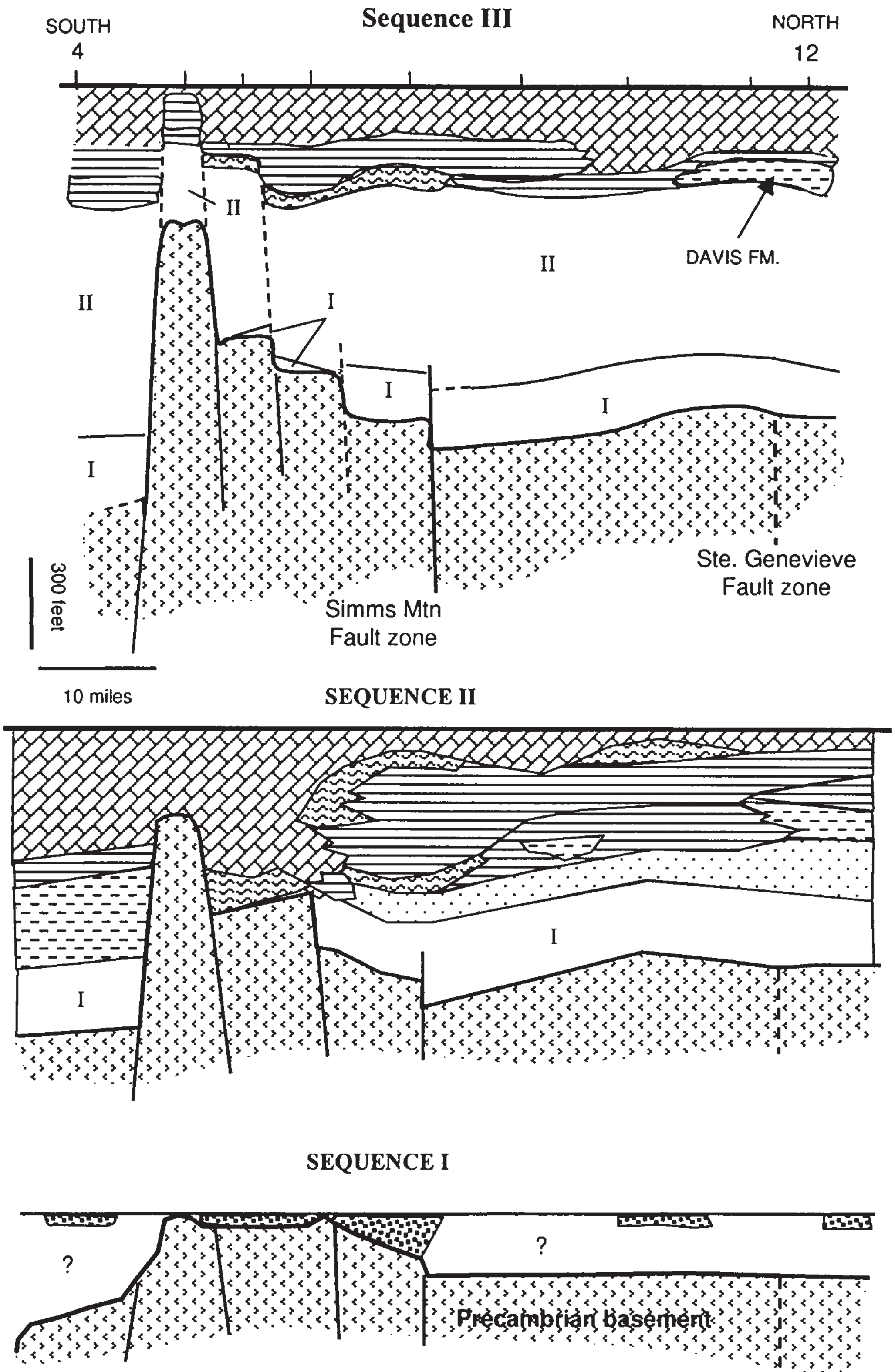


Figure 8b. Cross-section showing the progressive development of alluvial to carbonate sedimentation. The datum for the cross-section is the disconformity at the top of each labeled sequence. Key to lithologies is on Figure 8a.

Stop No. 4 - 2nd Davis - Derby-Doerun Roadcut
(On Hwy 32 west of the city limits of Elvins, Sec. 23, T36N, R4E, Flat River Quad.)

The Upper Cambrian Davis - Derby-Doerun formations (Fig. 9) crop out on the northwest side of the road, just northwest of the Lamotte outcrop at Stop no. 3. This area is located adjacent to a north-northwest trending low Precambrian ridge. In general, Cambrian carbonate platform sequences in southern Missouri are thought to have nucleated around basement highs and prograded to more basinal areas. Thus, the sequence at this stop likely represents a sequence older than the sequence at Stop no. 1. The upper part of the Davis Formation at this exposure is primarily shale, in contrast to Stop no. 1 with its abundant lithoclast conglomerates, hard grounds, and wavy bedding. The Derby-Doerun Dolomite consists of shaly ribbon rock and grades upward to thinly interbedded coarse dolomites and large-scale trough cross-bedded dolomites. Some areas of the roadcut have small paleokarst cavities filled with reddish colored dolomite; these cavities may represent a brief emergence during the Cambrian.

Structural Significance

This sequence represents a transition from the Davis Formation intrashelf basin to a barrier shoal along a simple homoclinal ramp. Homoclinal ramps have transitions from basinal areas to peritidal areas along gradual, unbroken slopes. This is in marked contrast to the distally steepened ramp at Stop no. 1. If the sequence at Stop no. 2 is somewhat older than Stop no. 1, then the ramp profile evolved as it prograded towards the north. A homoclinal ramp at this stop is representative of stable local conditions, free of tilting. The differences between the two exposures, which are only 4.5 miles apart, support tectonism as a depositional control at Stop no. 1.

Saturday, September 26, 1998

Stop No. 1 - Roadcuts in Butler Hill Granite and overlying distal alluvial plain facies.
(5.3 miles south of the junction of Hwy 67 and S.R. W, SE 1/4, NW 1/4, SW 1/4, Sec. 29, T35N, R6E, Wachita Mountain Quad.)

The Precambrian Butler Hill Granite is exposed in roadcuts in this location, with overlying coarse-grained sandstones of the lower Lamotte in a nonconformable contact onlapping from the south.

Igneous Petrology and Lamotte Facies

The Butler Hill Granite and its granophyric roof facies, the Breadtray Granite, are the most extensively exposed granites in the St. Francois Mountains. They comprise an epizonal, subvolcanic massif that produced a comagmatic suite of rhyolitic ash-flow tuffs; the tuffs are now largely removed by erosion. Rhyolite roof pendants are locally preserved within the massif and

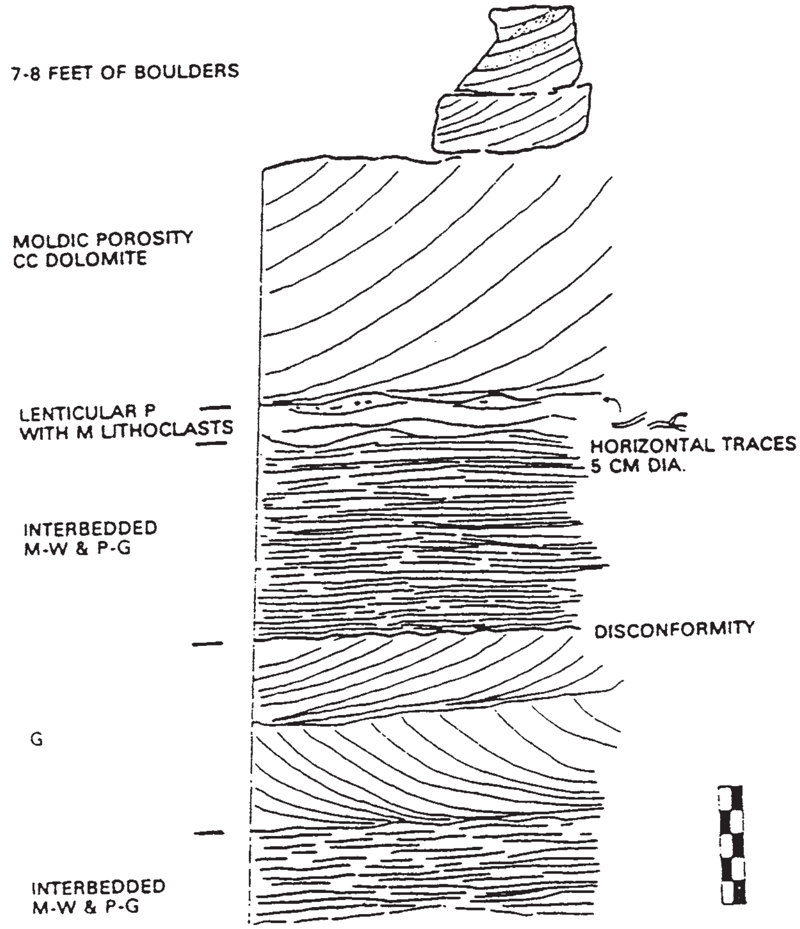


Figure 9. Derby-Doerun Dolomite. Upper large trough cross-bedded set has molds of grains up to 2 cm. CC = crystalline carbonate, M = mudstone, W = wackestone, P = packstone, G = grainstone. Scale in feet.

along its southwestern periphery. The Butler Hill Granite at this locality has well-developed rapakivi texture; ovoidal, pink alkali feldspars (orthoclase-microperthite) up to 3 cm in diameter are mantled by a thin white rim of oligoclase. The granite has prominent joint sets (Kisvarsanyi, et al, 1981).

The erosional contact between Butler Hill Granite and the Lamotte Sandstone is best exposed in the cut on the west side of the road. The uppermost weathered granite is overlain by dark-maroon, shaly, thin regolith or paleosol derived from weathering of the granite. Bedding styles in these sandstones are consistent with those of alluvial or fluvial plains (Houseknecht and Ethridge, 1978; and Yesberger, 1981). These rocks have fewer basement rock fragments than alluvial fan sequences and are dominated by poly-crystalline quartz grains (Houseknecht and Ethridge, 1978; Yesberger, 1981).

Structural Significance

Cross-bedding directions in outcrops of basal alluvial Lamotte Sandstone (primarily on the east side of the St. Francois Mountains) show that areas some distance from basement highs had sediment transport directions toward the southeast (Houseknecht and Ethridge, 1978; Yesberger, 1981). Paleocurrents were deflected around Precambrian knobs; paleocurrent show the influence of the high. Where were these sands being transported? We suggest that the depocenter for this early period of alluvial sedimentation was graben(s) in the Reelfoot rift. If this is true, the redbed and other alluvial sequences in the lower Lamotte are synrift. Subsequent marine sandstones and the overlying pair of intrashelf basin – carbonate ramp sequences in the Bonneterre and Davis formations represent a stratigraphy comparable to those of the rifted passive margins in the southern Canadian Rockies and the southern Appalachians.

Stop No. 2 - Crane Mountain and Sabula Basin
(From Hwy E, 3.7 miles south on Iron Co Road 131, then east on U.S. Forest Service Road 2192 to top of knob, SE 1/4, SE 1/4, NE 1/4, Sec. 8, T32N, R4E, Des Arc NE Quad.)

Crane Mountain is located along the northeast side of the Sabula Basin. Locally known as Crane Mountain, due to the siting of Crane Lookout Tower on the top of the knob, the mountain is often confused with Crane Mountain proper, located 6 miles to the north on the Ironton and Lake Killarney quadrangles. The southeast rim of the mountain provides an excellent view across the Sabula Basin to the southwest, and of the surrounding mountain range of which Crane Mountain is a part. The large stacks visible in the valley belong to the Glover Lead Smelter. Looking northwest, Ketcherside and Hogan Mountains (which bound the northwest side of the Sabula Basin) are visible, and on a clear day, the top of Taum Sauk Mountain, some 7 miles distant, may be seen.

Igneous Petrology

Massive outcrops of Precambrian trachyte porphyry form step-like cliffs along the southwest face of Crane Mountain. The trachyte (identified by thin section) is dark-reddish-brown with abundant phenocrysts of sodic plagioclase and orthoclase in a holocrystalline groundmass. The groundmass has fine-grained trachytic texture characterized by fluidal arrangement of tabular feldspar microlites, and contains abundant magnetite grains (Kisvarsanyi, et al, 1981).

The rock is fractured, sheared, and locally mildly propylitized. Quartz, epidote and clinozoisite fill microfractures, and completely replace former ferromagnesian minerals. Development of calcite, chlorite, iron oxide, and sericite accompanies the alteration (Kisvarsanyi, et al, 1981). Veins of epidote and hematite 1 to 2 inches thick occur in highly fractured zones near the base of the outcrop at Stop no. 2.

Near the top of the outcrop, the trachyte porphyry contains conspicuous xenolithic masses of a dense, dark-gray rock. The xenoliths range in size from a few inches to several feet, are frequently twisted and contorted, and have sharp contacts with the enclosing rock. Traces of relict bedding are faintly discernible on slabbed surfaces, and microscopic observations indicate that the inclusions represent fragmented and recrystallized vitric-tuff beds that were caught up in the trachyte-porphyry flow (Kisvarsanyi, et al, 1981).

Sabula Basin

The Sabula basin is a down-dropped block, similar to the Belleview basin located to the north. It is separated from the Belleview Basin by extensive basement highlands. The basin is filled with Cambrian sediments and bounded by northeast- and northwest-trending lineaments. The northeast boundary is a steep scarp consisting of a narrow, northwest-trending mountain range coincident with the West Belleview-East Sabula lineament as defined by Kisvarsanyi and Kisvarsanyi (1976). Crane Mountain forms the southeastern abutment of this range, and Ketcherside Mountain its northwestern part. The northwestern boundary of the Sabula Basin is defined by a northeast-trending scarp consisting of Hogan and Vickery Mountains, and corresponds to the Hogan Lineament of Kisvarsanyi and Kisvarsanyi (1976). The southeast and southwest boundaries of the basin are less well defined, but remote-sensing imagery indicates that the southeast boundary is coincident with the Annapolis lineament (Kisvarsanyi, et al, 1981). This lineament may be a lesser structure subdividing two separate blocks between the St. Francois Mountains and the Eminence area knobs.

The Cambrian formations of the basin are dissected by stream erosion into a relatively rugged topography; the topography is considerably more rugged than that of the Belleview Basin. Drillholes indicate that the Precambrian surface at Glover is approximately 250 feet above sea level; on Ketcherside Mountain, Precambrian rocks are exposed at 1700 feet above sea level. The overall relief of the Precambrian surface is 1450 feet from the deeper portions of the basin to the highlands forming the margins. Faulting at the southwest base of Crane Mountain displaces basement rocks by more than 1400 feet. The Sabula basin is inferred to be underlain by one of the central plutons of the St. Francois Terrane (Kisvarsanyi, 1980).

Structural Significance

The Sabula Basin has numerous features that suggest synsedimentary tectonism affected deposition of Cambrian sediments in the basin. The northeast margin of this basin is along the strike of the southwest margin of the Belleview Basin. The northwest striking Black Fault bisects the basin and exhibits down-to-the-southwest post-Upper Cambrian displacement. The basin is generally considered to be bounded by faults on all four sides, supported by the differences in elevation of the Precambrian surface between the basin and the rimming hills. Faulting that occurred during the Upper Cambrian is thought to represent reactivation of an older pre-existing basement structure.

The major fracture traces in trachytes exposed on Crane Mountain strike northwest and are subparallel to the West Belleview-East Sabula lineament. The combination of fracturing, straight-line relationship of the mountain scarp and the Sabula basin, differences in elevation of the Precambrian surface along the mountain-basin boundary, and configuration of the total magnetic-intensity map of the area suggests that the northeast boundary of the Sabula basin is a normal fault and that Crane Mountain forms part of the relatively uplifted northeast block.

Figure 10, a southwest-northeast cross-section of the basin, illustrates known thickening and thinning of Upper Cambrian formations. Within the basin, upper Cambrian rocks have dramatic changes across the Black Fault. The basal Lamotte is primarily a conglomerate at the southwest and northeast basin margins; this material was probably shed from the adjacent high areas. The unit thins toward the center of the basin and changes from sandstone to fine-grained red clastics. The overlying Bonneterre and Davis formations also thin towards the center of the basin. The centrally located Precambrian high and hinge structure may have allowed the northeast and southwest halves of the basin to act as separate basins, or half-grabens, during Upper Cambrian deposition.

The Sabula Basin experienced progressive deformation during Upper Cambrian (post-Precambrian) deposition (for descriptive figures, see Palmer and Seeger, this volume). The central part of the basin had an initial upwarp of the Precambrian basement during deposition of the Lamotte Sandstone and equivalent sediments. From available data, it appears that basal Lamotte conglomerates were deposited on the basin margins and on the flanks of the uplift. Upper Lamotte clastics grade from quartzose sandstones in the southwest to red hematitic and gray clays in the northeast.

Deformation during deposition of the Lamotte-Bonneterre transition (sandy dolomite) was similar to the early stages of development of a hinge-like structure. Continued basement uplift, as well as sagging of the center of the northeast half of the basin, led to deposition of a thicker, lens-shaped sandy dolomite body, as opposed to the more sheet-like dolomite body in the southwest half of the basin. This depositional style is indicative of a half-graben (Leeder and Gawthorpe, 1987)

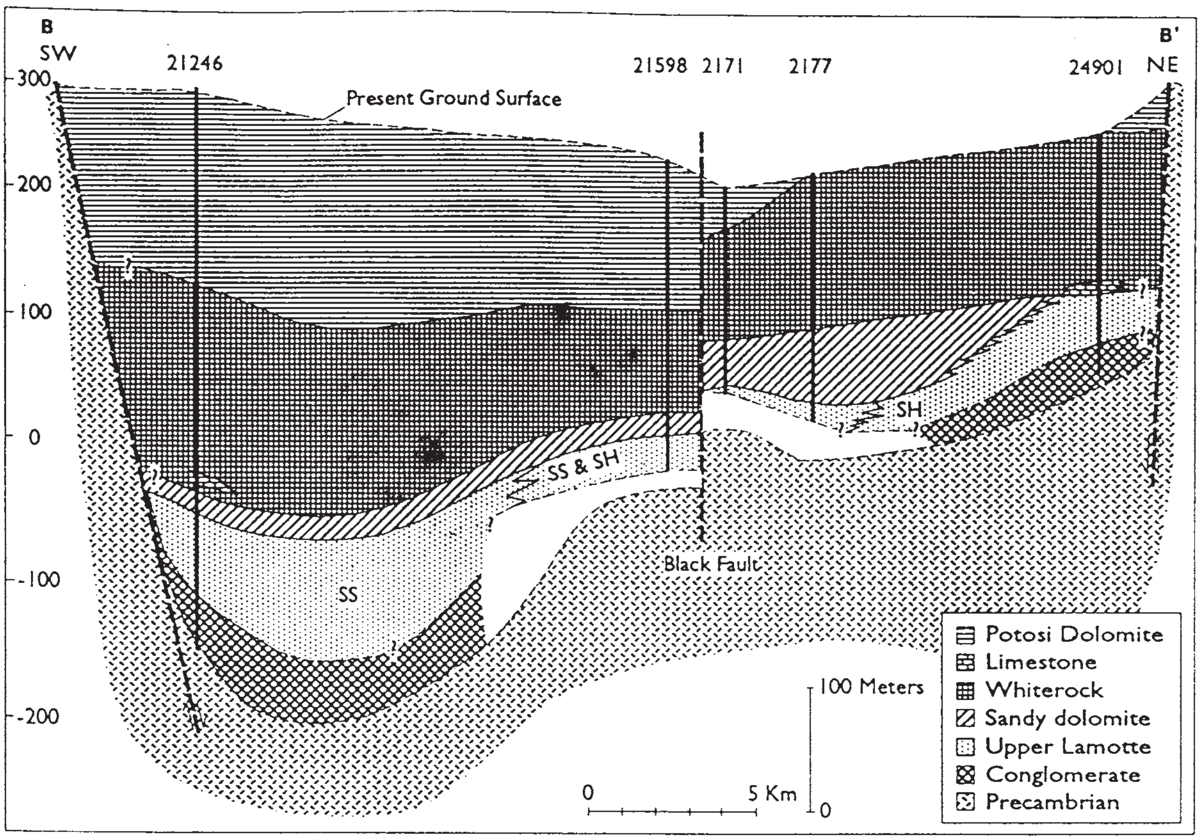


Figure 10. Cross-section of the Sabula Basin (after Kisvarsanyi, 1979). Datum is mean sea level. Well locations are in Palmer and Seeger, this volume.

formed by movement on the Black Fault.

Deposition of the whiterock facies (a coarse crystalline dolomite that had originally been red limestone and locally supplants all or parts of the late Upper Cambrian) was accompanied by continued uplift of the center of the basin and pronounced development of a hinge structure. The northeastern half of the basin may have been downdropped even further than may be inferred (Fig. 9, Palmer and Seeger, this volume), as the uppermost part of the whiterock sequence has been eroded in this part of the basin, and original whiterock thickness is not known.

Later movement on the Black Fault reversed direction, giving the down-to-the southwest sense of throw present today.

Stop No. 3 - Oak Grove Lamotte Sandstone Roadcut
(West on Hwy 72 3.4 miles from the junction with Hwy 67, NE 1/4, NE1/4, NE 1/4, Sec 9, T33N, R6E, Rhodes Mountain Quad.)

Alluvial fan sediments associated with the basal Lamotte Sandstone are evidence of dramatic local relief on the Precambrian surface during deposition. These sediments, referred to as redbeds, are commonly associated with continental rift faulting. We will observe transitions from fan conglomerates to distal braided stream sandstones in these roadcuts west of Fredericktown.

Stratigraphy and Facies

Lamotte Sandstone includes a basal alluvial sequence of hematite-rich conglomerates, sandstones and shales. The upper Lamotte consists of cross-bedded and burrowed marine quartzose sandstones. The initial Cambrian marine transgression in much of southern Missouri is at this alluvial clastics/marine sandstone contact. This may represent a late Middle Cambrian transgression. The roadcut on the south side exposes a thick section of coarse boulder conglomerate that mantles a Precambrian diabase knob; the intrusive body of diabase is present at the east end of the cut. This exposure is now difficult to find due to growth of vegetation. The diabase is deeply weathered, with large in situ exfoliated masses surrounded by disintegrated diabase. The largest of the exfoliated boulders is 10 feet in diameter (Kisvarsanyi, et al, 1981). Thin sections from its interior indicate fresh olivine diabase with ophitic texture. A thick boulder bed directly overlies the Precambrian diabase erosion surface; many of the boulders are weathered red granite. The center of the cut is dominated by a large angular block (20 feet wide by 5 feet high) of pale pink, partly recrystallized, porphyritic amphibole granite. This block lies on the west flank of the diabase knob and is part of the boulder bed (Kisvarsanyi, et al, 1981).

On the north side of the highway, 10 to 12 feet of coarse boulder conglomerate are exposed in the upper face of the roadcut (Fig. 11). This matrix-supported conglomerate contains rhyolite boulders up to 9 feet in length, in beds more than 6 feet thick. Parallel laminated shaly sandstone forms very irregular contacts with the conglomerate, suggesting deposition by water. This

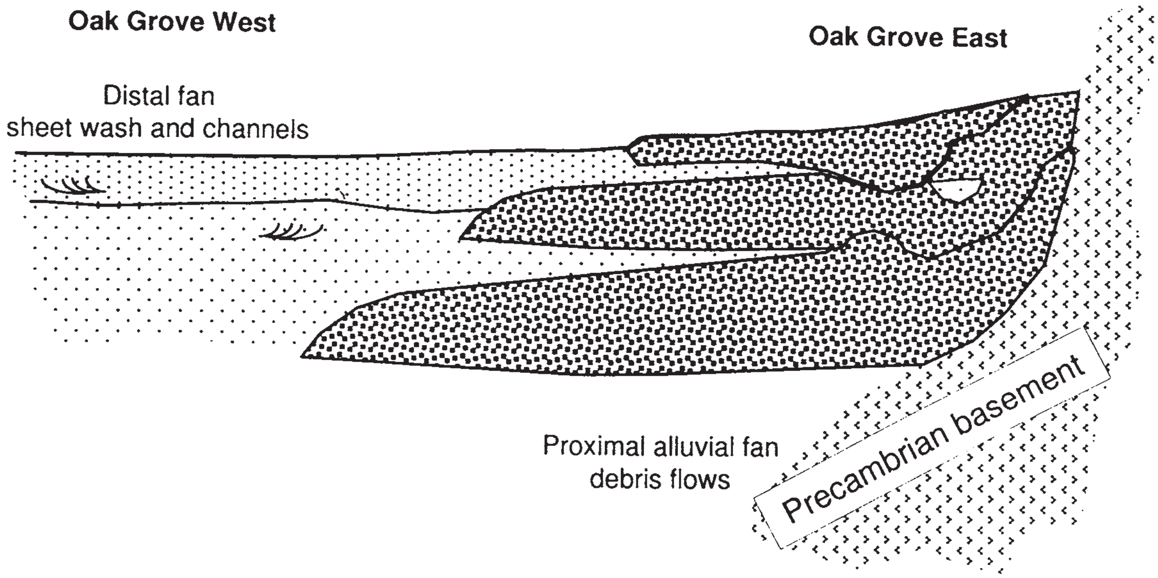


Figure 11. Diagram illustrating facies relationships in the basal and lower Lamotte at Oak Grove. These boulder bonglomerate represent a series of alluvial fan debris flows. The distal portions of the fan comprise finer-grained hematitic sandstones and shales.

sandstone sequence has been interpreted as conglomerate-dominated alluvial fan deposits. Near the western end of the lower cut, a part of the fan deposit is underlain by a water-deposited sedimentary sequence 4 feet in maximum exposed thickness and consisting of very thin-bedded siltstone and silty shale (the exposure is now partially covered by vegetation and debris). Its irregular contact with the boulder bed suggests that this material is a channel fill. This may represent an alluvial channel, common on alluvial fans (Kisvarsanyi, et al, 1981). Houseknecht and Ethridge (1978) attribute the deposition of the conglomerate to a series of high-viscosity debris flows that formed an alluvial fan in a paleotopographic valley. Lenses of horizontally bedded, fine-grained sediments within the conglomerate represent channel-fill or overbank sediment deposited by fluvial systems on the surface of the fan (Houseknecht and Ethridge, 1978). In the upper portion of the exposure there are contrasting types of matrix between boulders, which apparently two separate debris flows. The lower bed has a matrix consisting of coarse-grained and hematitic sandstone; matrix in the upper bed is sandy hematitic clay.

Stop 3a - Lamotte Sandstone distal fan deposits
(West of the preceding road cut, 1.2 miles on Highway 72, SE 5)

This roadcut is an exposure of sand-dominated fan deposits of the Lamotte Sandstone. These are thin, massive bedded, trough and planar cross-bedded lithic arkosic sandstones with locally abundant hematite cement (Fig. 11). Small mottled patches within the shaly portions of sandstones may represent paleosol mottling. These sandstones have been interpreted as alluvial fan deposits derived from granitic source rocks; however, they have bedding styles more consistent with distal fan, braided stream and sheetflood deposits.

Structural Significance

These two exposures of the Lamotte are probably temporally equivalent facies, and represent a period of uplift, denudation and alluvial sedimentation. This basal stratigraphy is identical to the redbed sequences associated with continental rifting. Modern alluvial fans and fan deltas are found at fault scarps, such as the huge fans forming today in Death Valley; these fans serve as a model for alluvial rocks observed in the subsurface. Both the Belleview and Sabula basins have basal clastics sequences indicating they began as closed depressions; this suggests that the St. Francois Mountain highlands could not have been a simples series of monadnocks, as has been postulated in the past. The Lamotte Sandstone thins against a northeast trending subsurface Precambrian ridge between the southwestern edge of the St. Francois Mountains and the Eminence area knobs; the Sabula basin is on the north and east parts this ridge. During subsequent marine transgression, many of these highland areas continued to produce locally derived clastic sediments that were poured out into standing water; this gave rise to a sequence consisting of interbedded sandstones and dolomites, as in the series of low roadcuts between the two Oak Grove stops. These are referred to as fan-delta sequences.

The alluvial fan deposits contain large boulders of rock types (such as granite and granophyre) which could not have been weathered in place; the igneous bedrock at the site is diabase. The nearest granites are a Silvermine-type granite exposed 1/2 mile to the southeast, and the Breadtray granophyric granite, located a mile away at its nearest current surface exposure. The distances involved make simple erosion unlikely as the method of deposition. Transportation of large boulders requires considerable local steepening, suggesting that the material may have been eroded from nearby fault scarps, and deposited, via debris flows, as long run-out landslides. The deep weathering and erosion of the diabase (including the large weathered and exfoliated diabase boulder), along with the overlying alluvial fan deposits, suggests that fault movement was contemporaneous with lower Lamotte deposition.

Stop No. 4 - Knob Lick Mountain and Land Form Discussion
(West at junction of Hwy 67 and Knoblick Tower Road, follow 60 feet and turn north, follow to top of knob, NE 1/4, NE 1/4, SE 1/4 Sec. 8, T34N, R6E, Wachita Mountain Quad.)

The view from Knob Lick Mountain will be the background for a discussion of the evolution of the modern landscape. Are the landforms truly ancient and represent a continuum of erosion and climate-controlled base level? Or, has significant uplift during the Quaternary played a greater role in landform development?

Igneous Petrology and terrain

The Grassy Mountain Ignimbrite (rhyolitic ash-flow tuff) is exposed at the top of Knob Lick Mountain, along its southern slope, and in a narrow belt for about 10 miles southward. The ignimbrite is a roof pendant in the Butler Hill-Breadtray granites, which are exposed to the west; the Knoblick and Slabtown Granites are exposed to the east of the outcrop (Kisvarsanyi, et al, 1981).

The view to the southwest is of a large area of relatively low topographic relief. This area, called the Flatwoods, and the distant surrounding knobs, illustrate the strikingly different topographic expressions of granite and volcanic terrains in the St. Francois Mountains. Granite areas tend to be gently rolling, whereas the more resistant rhyolites are commonly expressed as knobs or areas of dramatic high relief. The Flatwoods is underlain by the Butler Hill and Breadtray granites; all of the prominent knobs in the distance are comprised of more resistant volcanic rocks.

REFERENCES

Clendenin, C. W., 1989, Influence of a rigid block on rift-margin evolution: Geology, v. 17, p. 412-415.

Gregg, Jay M., Palmer, James R., and Kurtz, Vincent E., 1989, Field trip stop descriptions: in Gregg, Jay M., Palmer, James R., and Kurtz, Vincent E., eds., Field Guide to the Upper Cambrian of southeastern Missouri: stratigraphy, sedimentology, and economic geology, Department of Geology and Geophysics, University of Missouri, Rolla, p. 117-124.

Houseknecht, D.W., and Ethridge, F.G., 1978, Depositional history of the Lamotte Sandstone of southeastern Missouri: Journal of Sedimentary Petrology, v. 48, p. 575-586.

Kisvarsanyi, Eva B., 1980, Granitic ring complexes and Precambrian hot-spot activity in the St. Francois terrane, Midcontinent region, United States: Geology, v. 8, p. 43-47.

Kisvarsanyi, Eva B., and Hebrank, Arthur W., 1987, Roadcuts in the St. Francois Mountains, Missouri: basalt-dike swarm in granite, Precambrian-Paleozoic nonconformity, and a Lamotte channel-fill deposit: in Biggs, Donald L., ed., Centennial Field Guide Volume 3, North-Central Section of the Geological Society of America, Denver, Colorado, p. 161-164.

Kisvarsanyi, Eva B., Hebrank, Arthur W., Ryan, Richard F., 1981, Guidebook to the geology and ore deposits of the St. Francois Mountains, Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey Report of Investigations Number 67, 119 p.

Kisvarsanyi, Geza, and Kisvarsanyi, Eva B., 1976, Ortho-polygonal tectonic patterns in the exposed and buried Precambrian basement of southeast Missouri, in Hodgson, R.A., Gay, S.P., and Benjamins, J.Y., eds., Proceedings of the First International Conference in the New Basement Tectonics: Salt Lake City, Utah Geological Association Publication no. 5, p. 169-182.

Leeder, M.R., and Gawthorpe, R.L., 1987, Sedimentary models for extensional tilt-block/half-graben basins, in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental Extensional Tectonics: Geological Society of London Special Publication No. 28, p. 139-152.

Yesberger, W.L., 1982, Paleoenvironments and depositional history of the Upper Cambrian Lamotte Sandstone in southeast Missouri: unpublished M.A. thesis, University of Missouri at Columbia, 287 p.

SYNSEDIMENTARY TECTONIC FEATURES IN SOUTHEAST MISSOURI

James R. Palmer and Cheryl M. Seeger
Missouri Department of Natural Resources
Division of Geology and Land Survey
P.O. Box 250, Rolla, MO 65402

ABSTRACT

Upper Cambrian synsedimentary tectonism in southeast Missouri is considered to be related to development of the Reelfoot rift. Large-scale, unconformity bounded, transgressive-regressive sequences, sedimentation patterns and basin geometry show failed rift structures as controls on Late Cambrian sedimentation. Studies show decreasing numbers of transgressive-regressive cycles with distance from the rift margin. In the St. Francois Mountains region, Precambrian basement is cut by a series of northwest- and northeast-trending faults, creating a series of rectangular grabens or synsedimentary tectonic basins. The Belleview and Sabula basins represent locally formed grabens, filled with a succession of alluvial to marine Cambrian sedimentary rocks. These sequences thicken and thin as an expression of synsedimentary basement deformation.

INTRODUCTION

The Cambrian succession in southeastern Missouri contains features common to early Paleozoic shelves along passive margins, as well as both large and small scale features which suggest that synsedimentary tectonic activity influenced many depositional features. Features visible region-wide include syn-rift basal alluvial redbeds and post-rift thermal and differential subsidence phases represented by large-scale transgressive-regressive (t-r) cycles with evidence of growth faulting. Synsedimentary tectonic basins, filled with a thickening/thinning succession of alluvial to marine Upper Cambrian rocks, are found in the St. Francois Mountains area and suggest that deformation related to the Reelfoot rift affected sedimentation patterns.

GEOLOGIC HISTORY AND STRATIGRAPHY

Regional Geologic Setting

Paleozoic sedimentation in southeast Missouri was dominated by the Ozark Uplift. This broad, asymmetrical uplift is expressed by the St. Francois Mountains (Fig. 1), a region of exposed Precambrian knobs and Paleozoic sediments which dip a few degrees away from the uplift. The Ozarks were uplifted repeatedly throughout the Paleozoic, as evidenced by unconformity-bounded sequences between and within nearly every Paleozoic System.

The Precambrian complex which comprises the St. Francois Mountains is the exposed portion of an extensive anorogenic terrane of granite ring complexes and associated rhyolites that underlies most of southeastern Missouri. This terrane is characterized by the predominance of silicic rather than mafic rocks, and by the distribution of alkalic-intermediate rocks (Kisvarsanyi, 1981). The St. Francois terrane is bracketed by suggested dates of 1.3 to 1.5 Ga (Bickford and Mose, 1975).

Palmer (1989) suggests that the St. Francois Mountains formed as rift mountains in a northeast-trending series of blocks that parallel the Reelfoot Graben. Erosional relief on this surface in southeast Missouri may have exceeded 760 m, increasing from the southwest to the northeast, and becoming abruptly less rugged north of the St. Francois Mountains. Theories of formation of the St. Francois Mountains include: 1) local highs formed as part of the rift border fault system; 2) an accommodation zone between the Reelfoot and Rough Creek grabens; 3) an uplifted rift shoulder behind the rift border fault system; or 4) some combination of several or all of the three.

Portions of the St. Francois Terrane probably underwent extreme erosion before deposition of Upper Cambrian alluvial and marine sediments; as much as 700 million years of geologic record was removed in the southern Ozarks before syn-Reelfoot rift deformation was imposed on the basement complex. The failed Reelfoot rift is thought to be related to continental separation and rifting during the late Precambrian or early Cambrian (Ervin and McGinnis, 1975; Braile et al., 1984). The 70 km wide Reelfoot Graben is in the central part of the rift area, and has been described as a full graben by Hildebrand et al. (1977); Paleozoic sediments in the graben may exceed 7 km in total thickness (Schwalb, 1982).

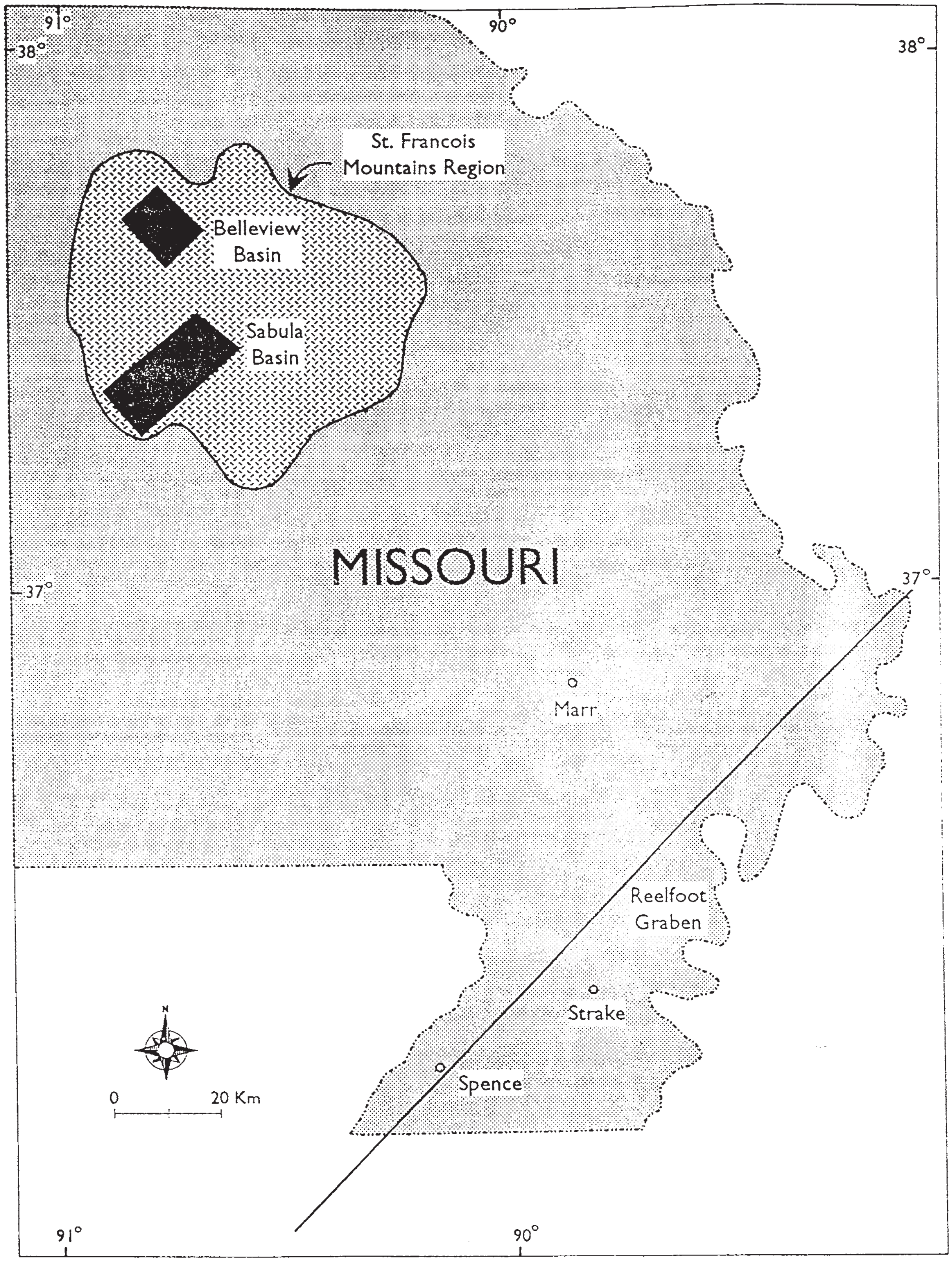


Figure 1. Map of southeastern Missouri showing locations of Ozark Uplift, Reelfoot Graben, and the Belleview and Sabula basins. Locations of wells used in transgressive-regressive correlations are included.

Basal Cambrian, pre-Dresbachian, deposition is comprised of alluvial and fluvial clastics, grading upward to marine sandstones and carbonates. The paleodepositional framework is reflected in four distinct stratigraphic sequence types: 1) rift graben basin, 2) graben margin and carbonate shelf margin, 3) intrashelf basin-carbonate ramp in the northern part of the outcrop belt, and 4) carbonate platform interior which dominates the St. Francois regional shelf. These facies are discussed in greater detail in Palmer (1989).

Stratigraphy and Lithologic Descriptions

Summaries of the formations and lithologies discussed in this paper are listed below. Primary lithologies of the Precambrian in this region are noted above. Palmer (1989) contains a detailed discussion of the lithologic framework of the Cambrian rocks of the St. Francois Mountains area and southeast Missouri.

Lamotte Sandstone

The basal to lower part of the Lamotte Sandstone of the St. Francois Mountains is comprised of alluvial fan-dominated deposits, debris- and mud-flows, fining-upward conglomerate based sandstone channel deposits, and sheet-flood deposits; these represent the first stage of post-rift sedimentation. Fan-dominated deposits grade upward and away from uplifted areas to aggradational braided fluvial plain facies of fining-upward sequences of trough and planar cross-bedded quartzose-dominated sandstones (Houseknecht and Ethridge, 1978; Yesberger, 1982).

Alluvial and fluvial sandstones are locally overlain by burrowed and cross-bedded marine sandstones that are interbedded with local fan delta deposits derived from nearby high-standing igneous knobs. The initial transgression represented by the marine part of the Lamotte is either latest Middle Cambrian or earliest Dresbachian.

Lamotte-Bonneterre Transition

The contact between the Lamotte and Bonneterre formations is described as conformable; it is generally a transition zone comprised of a series of interbedded sandstones and dolomites, or is a sandy dolomite. Interbedded Lamotte-Bonneterre sandstones and marine carbonates (0.3-1 m thick in sequences up to 66 m) are found in areas where fan deltas were still active during Bonneterre deposition, and discharged into tidal flat or shallow marine area (Hayes and Knight, 1961; Yesberger, 1982).

Bonneterre Dolomite

The Bonneterre Formation in southern Missouri consists of shales, thin sandstones and siltstones, and carbonates. Dolomites in the Bonneterre host the majority of the Mississippi Valley-type ores of southeast Missouri. Depositional facies which make up the Bonneterre are varied; they range from transgressive drowned shelf and intrashelf basin to shallow water buildups, shoal complexes and platform interior facies. A detailed discussion of Bonneterre facies is in Palmer (1989).

Davis Formation

This unit is an intrashelf basin facies comprised of a series of shales interbedded with shaly limestones, clean limestones, and local dolomites; in the basal to lower parts of some sections, shales are interbedded with thin glauconitic fine-grained quartzose sandstones. In the area of the Sabula Basin, discussed below, the Davis is represented by coarse crystalline dolomite (whiterock facies).

Derby-Doerun Dolomite

The Derby-Doerun Dolomite is a series of brown to gray, thinly- to thickly-bedded dolomites which overlie the Davis Formation within and at the margins of intrashelf basin areas. This slightly to very vuggy dolomite contains only minor megaquartz and chalcedony cement.

Potosi Dolomite

The Potosi Dolomite consists of a series of thick to massively bedded, brown to gray dolomites that overlie the Derby-Doerun; locally, it contains large amounts of megaquartz and chalcedony cement in vugs and solution enlarged fractures.

Whiterock facies

The term "whiterock" has been used in the Southeast Missouri Mining district to refer to coarse-crystalline white, light-gray, or light-brown dolostone. For the most part these rocks have no apparent preserved primary depositional fabrics; some ghost textures are present (Howe, 1968) which suggest that they were deposited in the very shallow platform interior. Whiterock is found at the top of shallowing-upward cycles, and thins in off-platform directions. Reddened hematitic patches remain in many whiterock sequences and grade outward to pale olive-green clay-rich coarse-crystalline dolomite, suggesting that reddened limestones were the precursor to whiterock dolomite (Howe, 1968).

SYNSEDIMENTARY TECTONIC BASINS

Pre-rift St. Francois Terrane igneous rocks are faulted into large orthogonal blocks along the southwest side of the Precambrian outcrop area (Fig. 1). These blocks locally formed grabens, and were filled with a succession of alluvial to marine Cambrian rocks. Two of these grabens, the Belleview (13 by 11 km) and Sabula (29 by 11 km) basins (Fig. 2), have partial rims of Precambrian igneous rocks oriented in northwest and northeast striking directions consistent with regional structural grain.

Sedimentary patterns of the Lamotte, Bonneterre, Davis and Derby-Doerun formations in these two basins are evidence of the influence of tilting of basement blocks on sediment deposition, and suggest that some paleotopography on the nonconformable Precambrian-Cambrian contact is the result of faulting, rather than simple erosion. Evidence from these basins further indicates that early Paleozoic rift-style deformation was not restricted to the Reelfoot rift area, and that early Paleozoic basement-involved deformation (which included local dip reversals) was widespread in the southeastern Ozarks.

Belleview Basin

The Belleview Basin and region to the northeast contains evidence of synsedimentary tectonism in the Lamotte and Bonneterre formations (Fig. 3). The Belleview Basin is bounded on the northeast by the Ironton fault (strike NW). Within the basin, the Lamotte Sandstone (Fig. 4) and overlying Bonneterre Formation (Fig. 5) thicken to the northeast toward this fault, suggesting

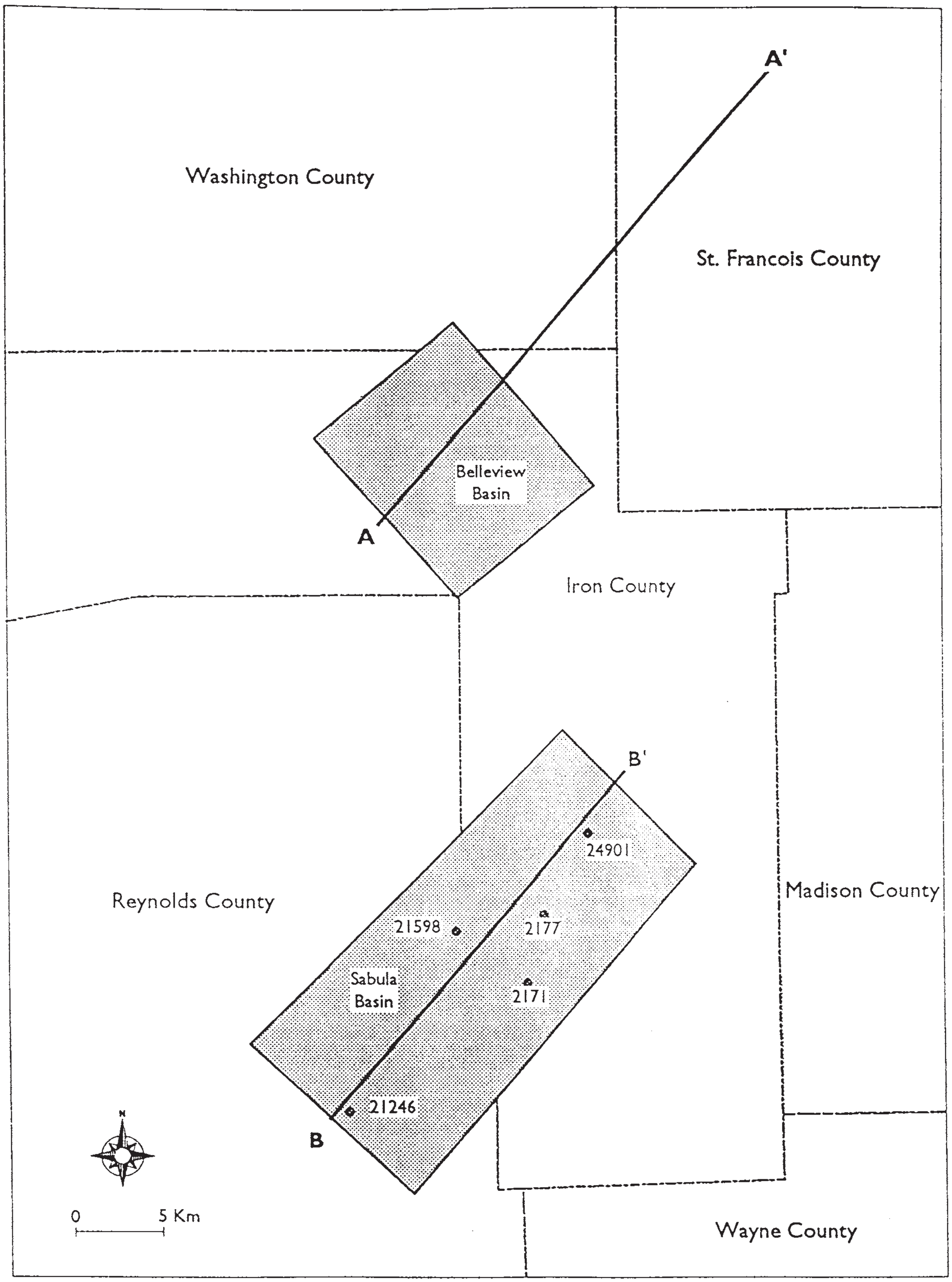


Figure 2. Map showing locations of cross-sections of the Belleview and Sabula basins. Locations of wells used in the Sabula Basin cross-sections are included.

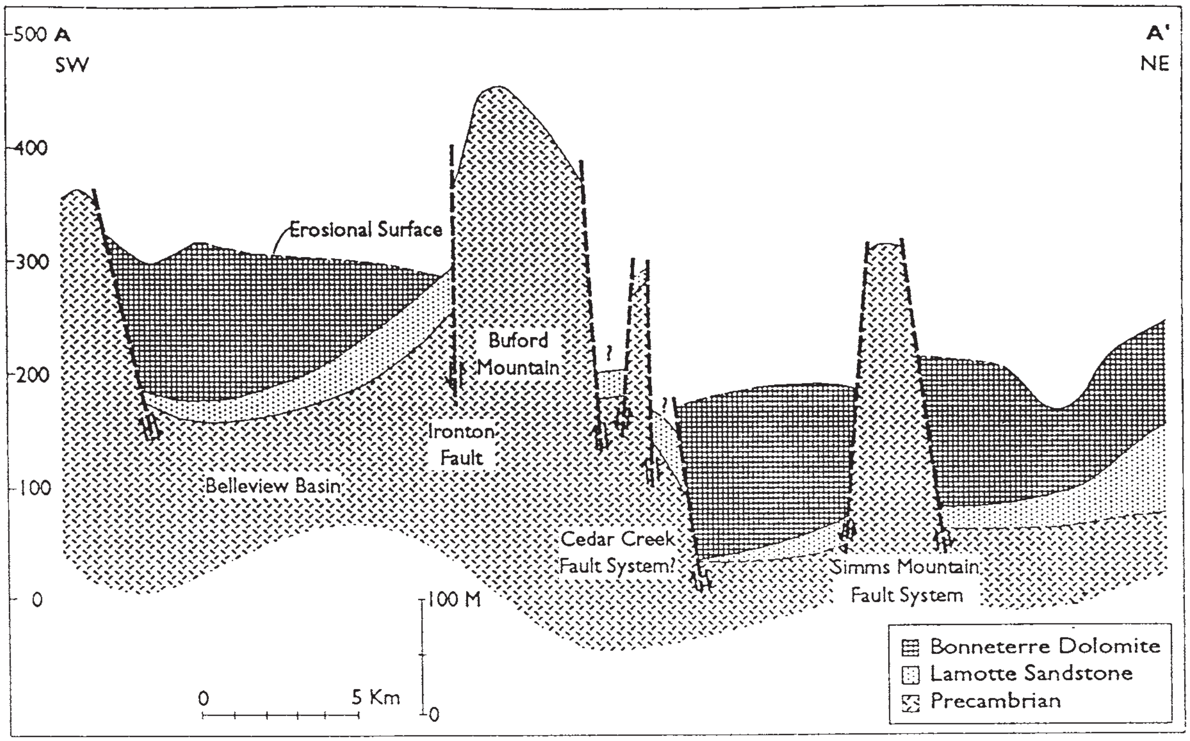


Figure 3. Cross-section of the Belleview Basin and region northeast, showing graben development and sedimentary expressions of synsedimentary deformation (after Kisvarsanyi, 1979; Thacker and Anderson, 1979) .

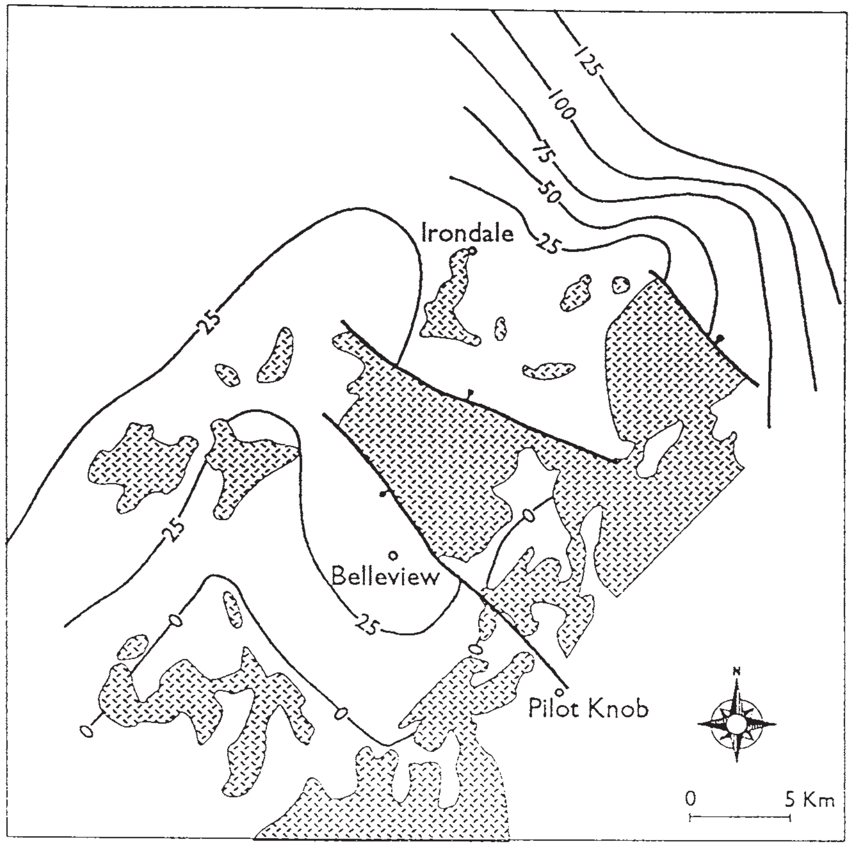


Figure 4. Isopach map of Lamotte Sandstone for the Belleview Basin and region northeast; the map includes locations of Precambrian outcrops (after Thacker and Anderson, 1979). Contour interval is 25 m.

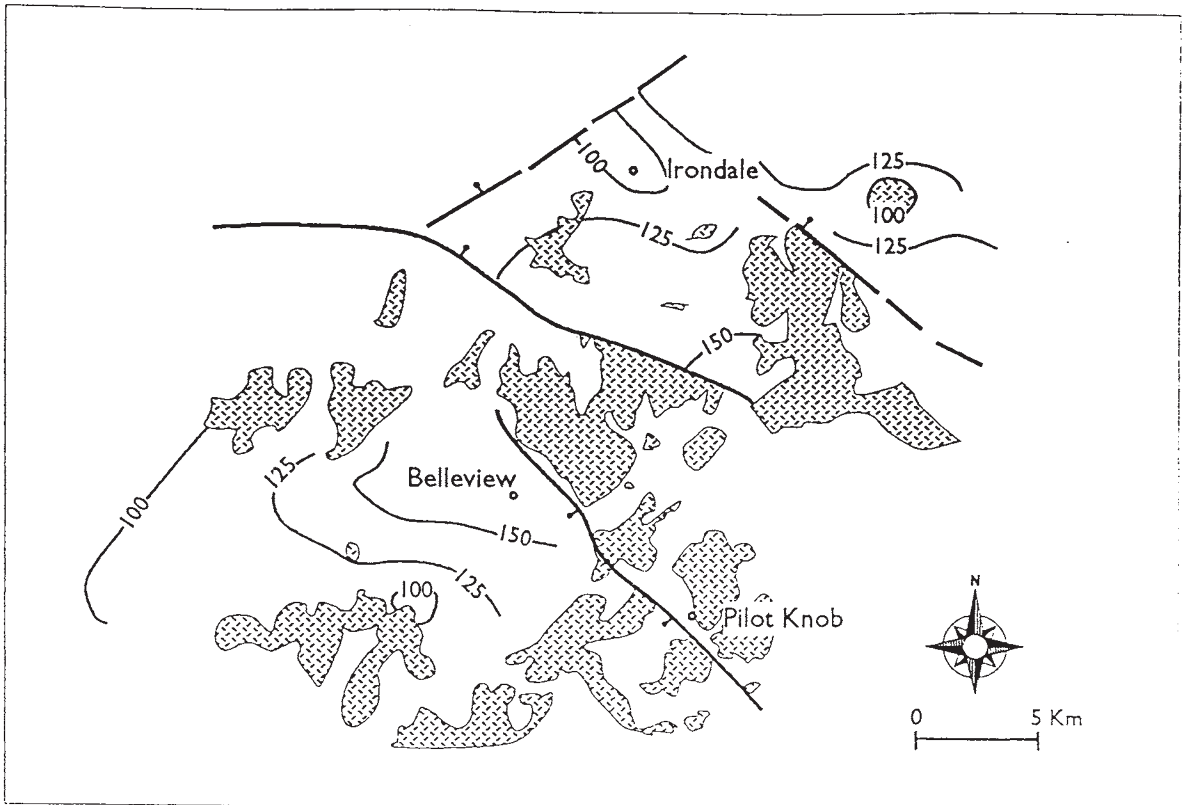


Figure 5. Isopach map of Bonneterre Dolomite for the Belleview Basin and region northeast; the map includes locations of Precambrian outcrops and exposed Lamotte Sandstone (after Thacker and Anderson, 1979). Contour interval is 25 m.

continued tilting of the graben to the northeast during Upper Cambrian deposition. The upthrown side of the Ironton fault (Buford Mountain), is a structural high and Precambrian basement outcrop area; the northeast side of this block is bounded by the Cedar Creek fault (Fig. 3). Northeast of the Cedar Creek fault, the Lamotte is thin to absent adjacent to the Cedar Creek fault and thickens toward the Simms Mountain fault (Fig. 4); the Bonneterre, however, thickens towards the Cedar Creek fault and thins to the northeast (Fig. 5), forming an apparent half-graben structure. This suggests a local dip reversal on the graben from Lamotte to Bonneterre deposition. In addition, thinning in the Bonneterre northeast of the Simms Mountain fault system (Fig. 3) suggests that there may have been a pronounced Precambrian high in this area during Bonneterre deposition.

Sabula Basin

The Sabula Basin is south of the Belleview Basin (Fig. 2) and separated from it by extensive basement highlands. The northeast margin of this basin is along the strike of the southwest margin of the Belleview Basin. The northwest striking Black fault bisects the basin and exhibits down-to-the-southwest post-Upper Cambrian displacement. Figure 6, a southwest-northeast cross-section of the basin, illustrates known thickening and thinning of Upper Cambrian formations. The basal Lamotte is primarily conglomerate at the southwest and northeast basin margins; the unit thins toward the center of the basin and changes from sandstone to fine-grained red clastics. The overlying Bonneterre and Davis Formations also thin to the center of the basin. The centrally located Precambrian high and hinge structure may have allowed the northeast and southwest halves of the basin to act as separate basins, or half-grabens, during Upper Cambrian deposition.

The accompanying series of sections (Fig. 7-9) illustrates the progressive deformation of the Sabula Basin during Upper Cambrian (post-Precambrian) deposition. Figure 7 shows the initial upwarp of the Precambrian basement and deposition of the Lamotte Sandstone and equivalent sediments. From available data, it appears that basal Lamotte conglomerates were deposited on the basin margins and on the flanks of the uplift. Upper Lamotte clastics grade from quartzose sandstones in the southwest to red hematitic and gray clays to the northeast.

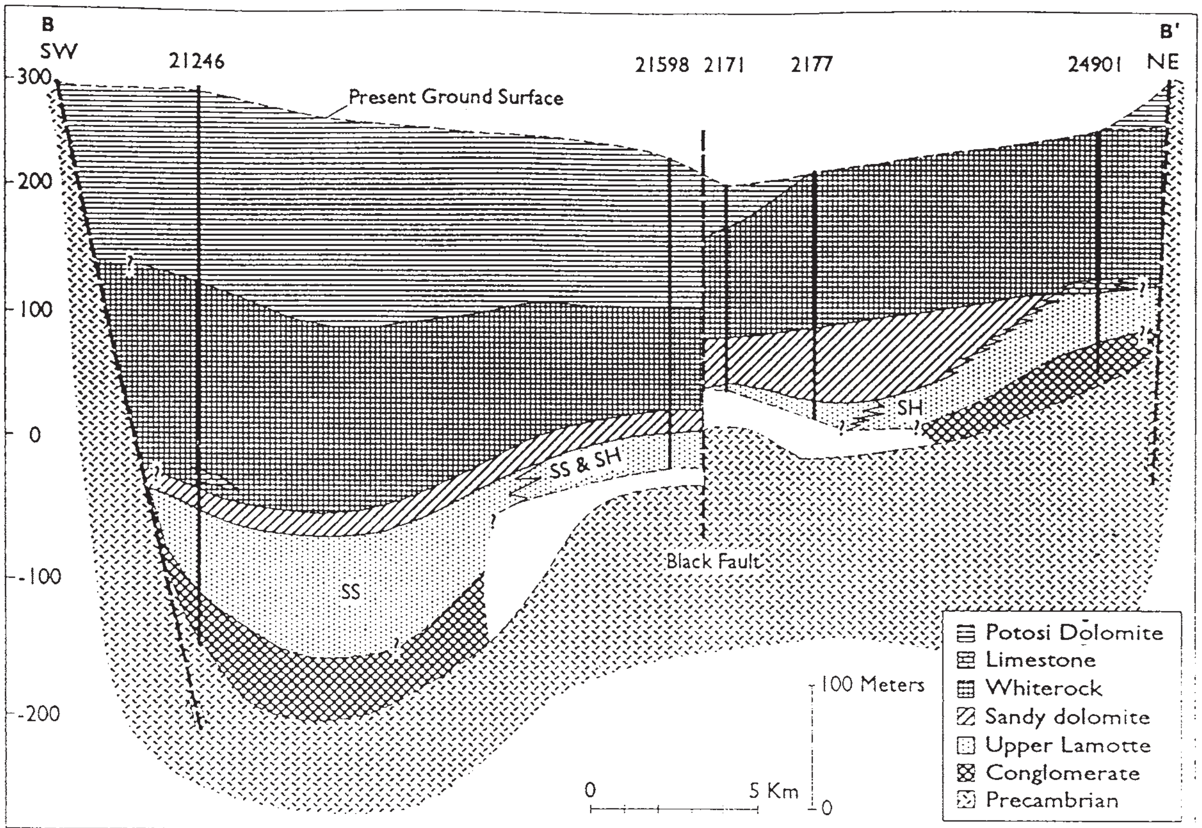


Figure 6. Cross-section of the Sabula Basin (after Kisvarsanyi, 1979). Datum is mean sea level. Locations of wells used are on figure 2.

Figure 8 illustrates conditions during deposition of the Lamotte-Bonneterre transition (sandy dolomite). Deformation of the Precambrian basement is, at this stage, similar to the early stages of development of a hinge-like structure. Continued basement uplift, as well as sagging of the center of the northeast half of the basin, led to deposition of a thicker, lens-shaped sandy dolomite body, as opposed to the more sheet-like dolomite body in the southwest half of the basin. This depositional style is indicative of a half-graben (Leeder and Gawthorpe, 1987) formed by movement on the Black fault.

Deposition of the whiterock facies (Bonneterre, Davis, and Derby-Doe Run formations) was accompanied by continued uplift of the center of the basin (Fig. 9), and pronounced development of a hinge structure. The northeastern half of the basin may have been downdropped even further than shown, as the uppermost part of the whiterock sequence has been eroded and original thicknesses are not known.

LARGE SCALE TRANSGRESSIVE-REGRESSIVE CYCLES

The failed Reelfoot rift produced a passive margin-like succession in southeastern Missouri (Fig. 10-11) beginning with alluvial and fluvial redbeds (pre-Late Middle Cambrian). This rim, and associated deposition, is believed to have been controlled by large faults. The initial early Paleozoic marine transgression probably occurred during latest Middle Cambrian. Deepest marine shelf sediments were deposited in the Mississippi Valley Graben (MVG) and a rimmed carbonate shelf sequence developed along the graben margin concurrently with an intrashelf basin-carbonate ramp system in the Ozarks (Fig. 10). The MVG rim, represented by the Spence well in figure 11, has eleven large-scale transgressive-regressive (T-R) cycles 35 to 185 m thick with a total thickness of more than 1435 m; within the graben, carbonate shelf equivalent black shales reach thicknesses of more than 490 m (Strake well, Fig. 11). Northwest of the MVG, in the carbonate shelf rim dominated by platform interior carbonates, only six t-r cycles (20-60 m thick) have been identified (Marr well, Fig 11), while in intrashelf basinal areas only four large t-r cycles are recognized.

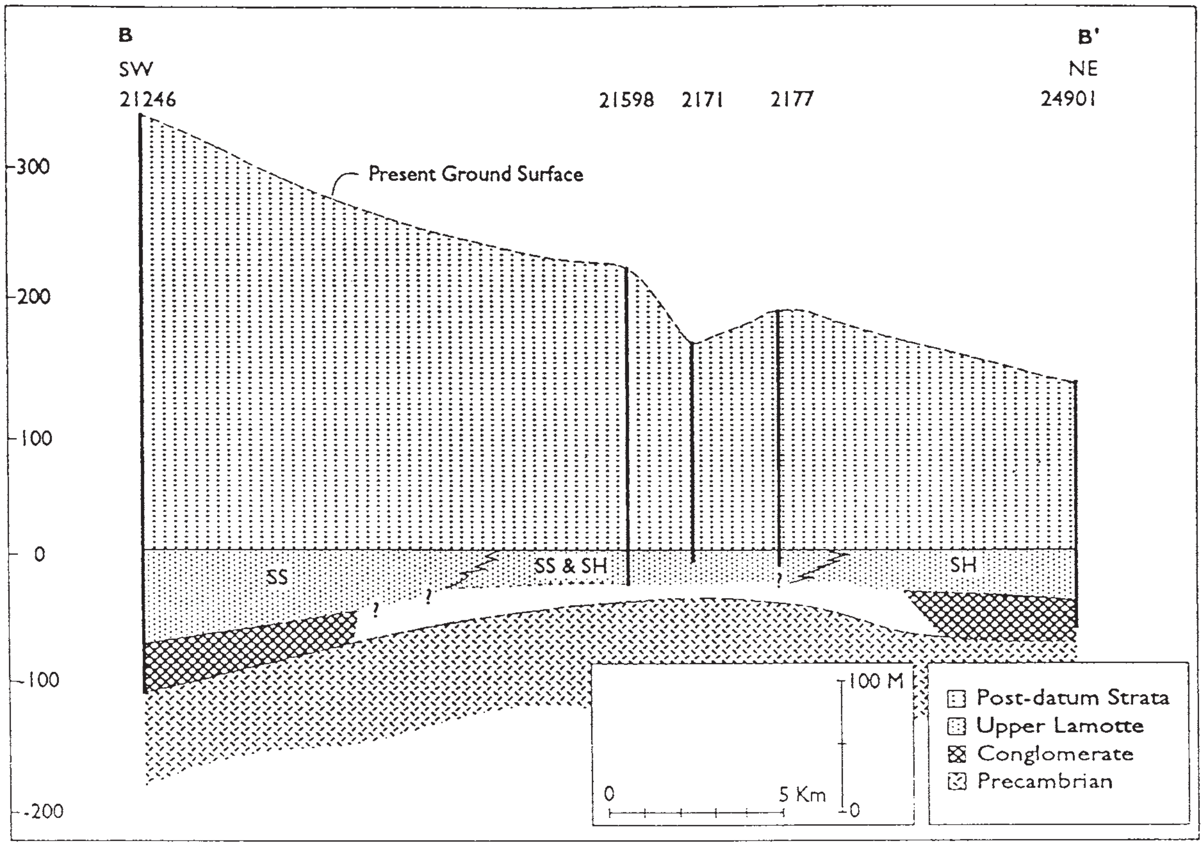


Figure 7. Cross-section of the basin during Lamotte deposition. Wells are located in figure 2. Datum is the base of the sandy dolomite (Lamotte-Bonneterre transition). After Kisvarsanyi, 1979.

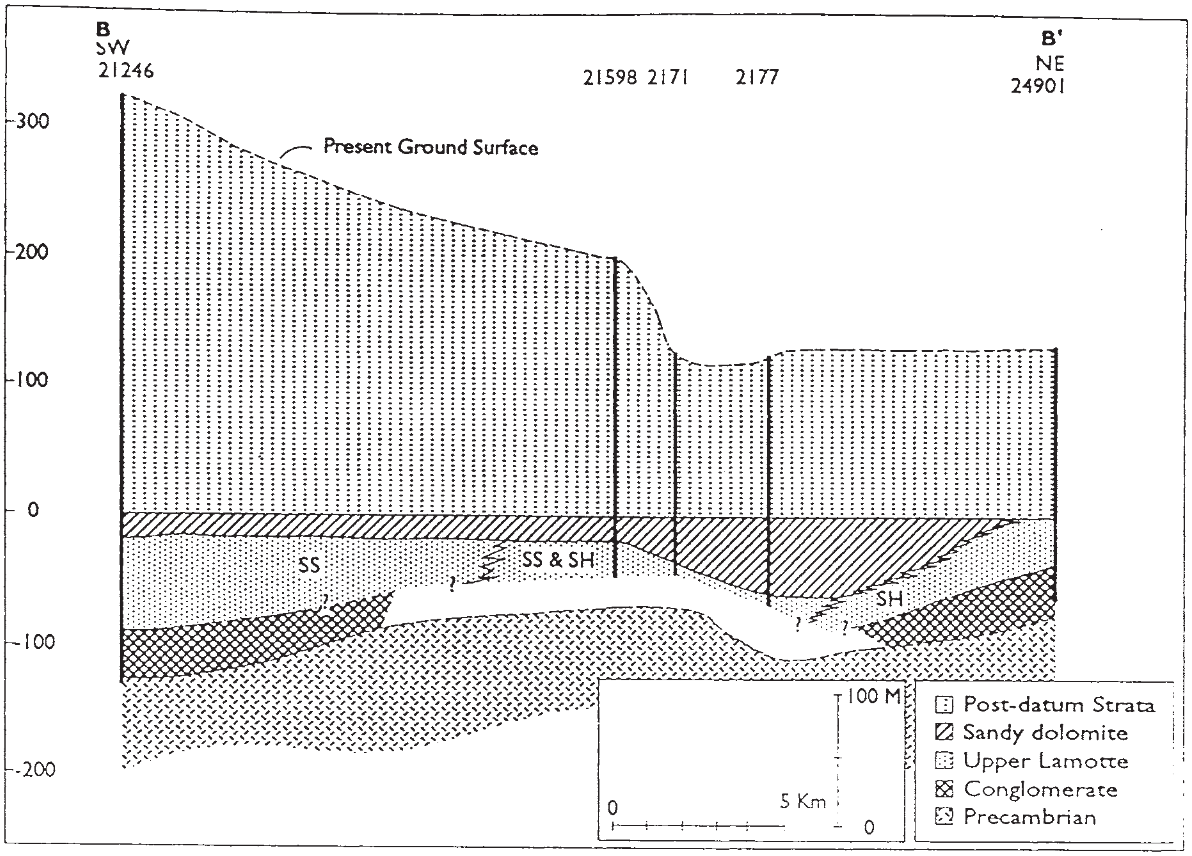


Figure 8. Cross-section of the Sabule Basin during sandy dolomite deposition. Datum is the top of the sandy dolomite. Wells are located in figure 2. After Kisvarsanyi, 1979.

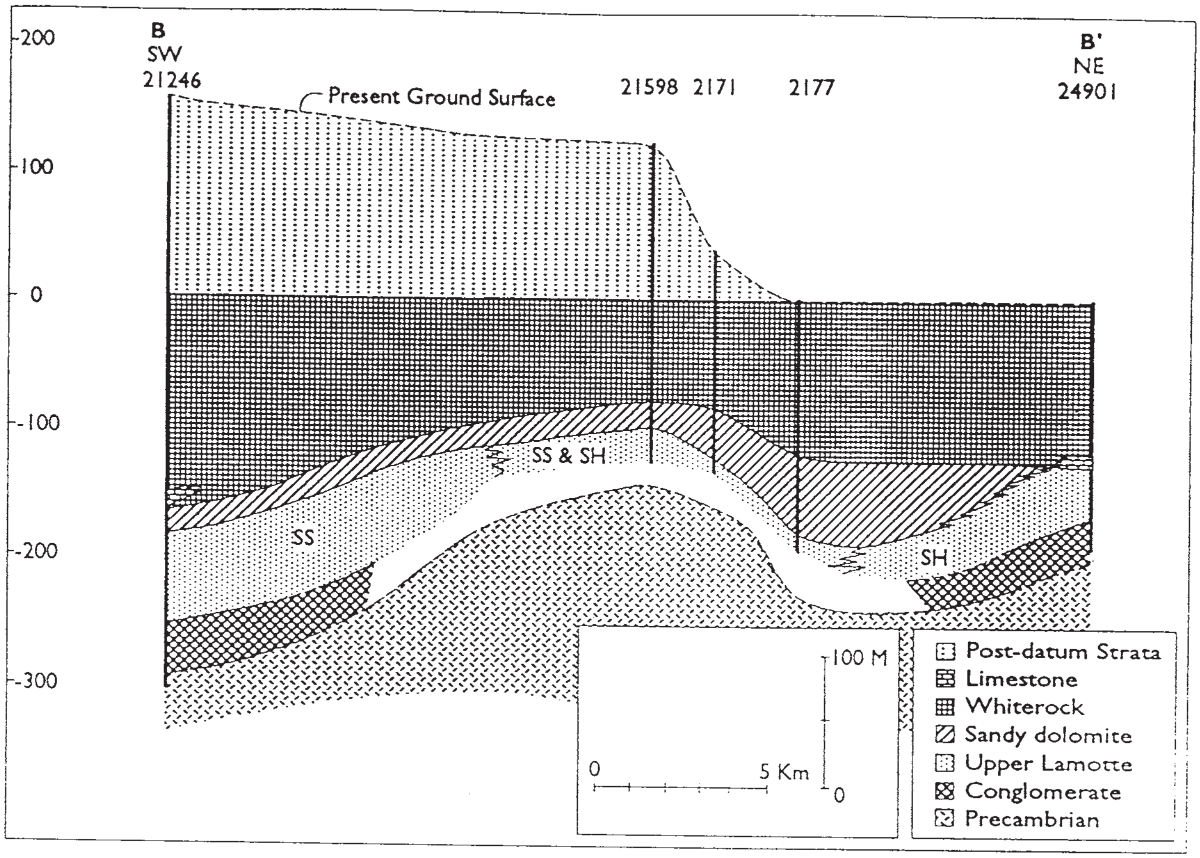


Figure 9. Cross-section of the Sabula Basin during whiterock facies deposition. Datum is top of whiterock. Wells are located in figure 2. After Kisvarsanyi, 1979.

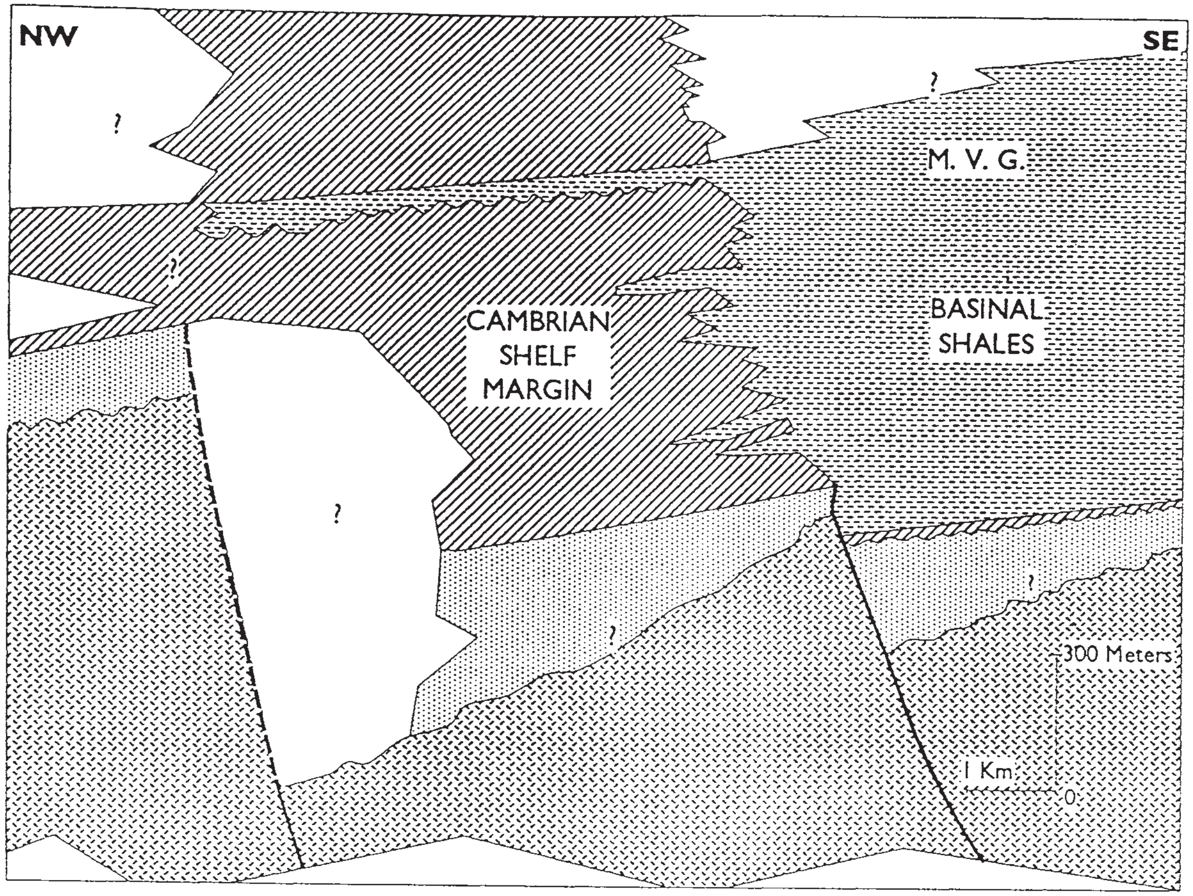


Figure 10. Conceptualized cross-section of graben rim showing comparative thicknesses and positions of major facies.

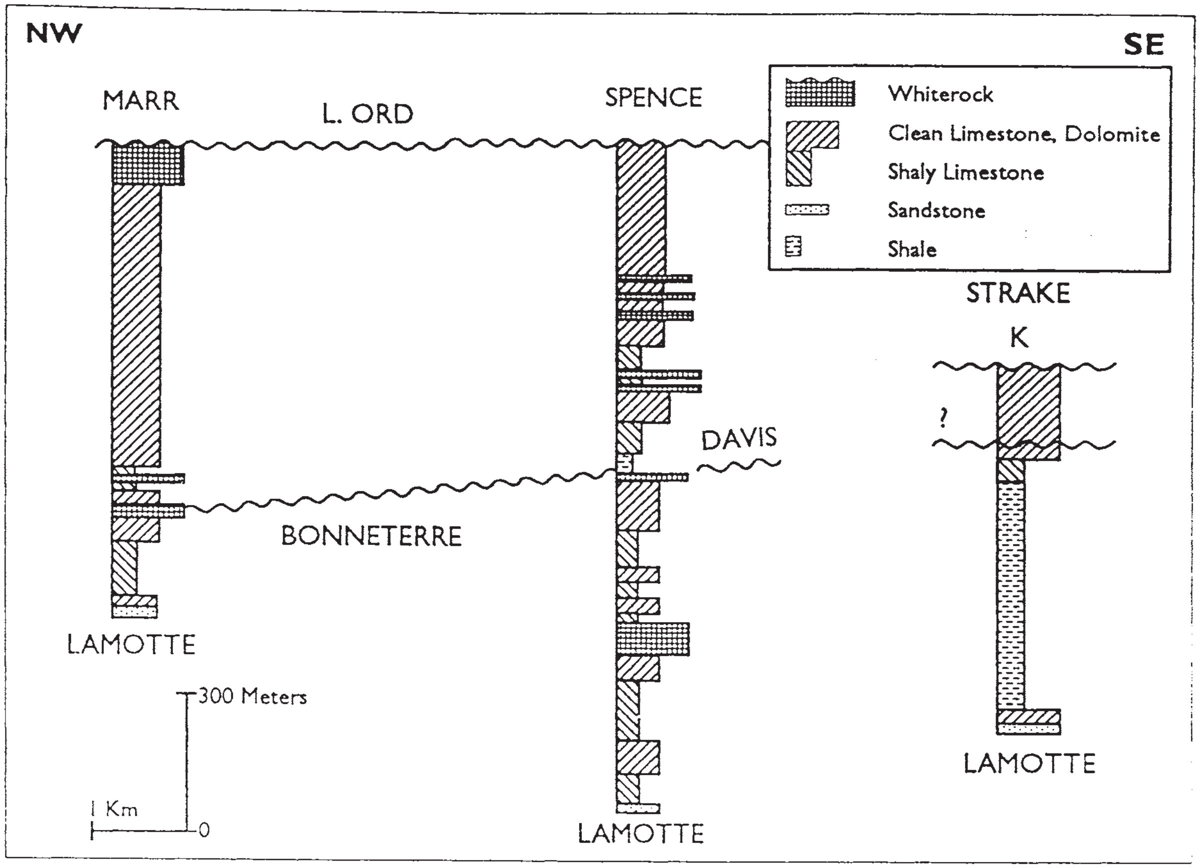


Figure 11. Cross-section of Reelfoot rift rim to Mississippi Valley Graben (MVG) basin showing lithologies and transgression-regression cycles.. Wells used are located on figure 1.

OTHER INDICATORS OF SYNSEDIMENTARY TECTONISM

Other indicators of synsedimentary tectonic activity include sedimentary depositional patterns suggestive of rifting and post-rift thermal subsidence. The first of these are stratigraphic sequences which contain conglomerates, composed of Precambrian clasts, stratigraphically above fine-grained quartz arenites or within platform carbonates. Clasts of rhyolite, containing probable primary specular hematite, are noted in the Bonneterre on the east flank of the Ozark Uplift (Seeger and Kisvarsanyi, 1992). Snyder and Gerdemann (1968) discuss the Hayden Creek Mine, in which MVT-stage ore is found in a granite boulder conglomerate in the Lamotte and lower Bonneterre formations; these conglomerates are near the flank of a granite knob. The conglomerate has a matrix of interbedded, undisturbed sandstone or dolomite; the majority of the boulders are a fresh red granite shed from the knob, rather than weathered reworked material, suggesting uplift of the knob during Lamotte and Bonneterre deposition. Bonneterre core overlying the Bourbon magnetite-hematite deposit, housed at the Missouri Division of Geology and Land Survey McCracken Core Repository, illustrates multiple episodes of clasts of PreCambrian igneous rock being shed from nearby faulted highlands (now buried knobs).

Several other features in the region suggest synsedimentary tectonism. The presence of deep-water, starved shelf limestones that correlate with nearby early paleokarsted tidal flat sequences and meter-scale fan delta cycles of sandstone and paleokarsted carbonates suggest that portions of the shelf were periodically uplifted and subaerially exposed, while others remained well below sea level. The change in characteristic facies of intrashelf basins from limestones (indicating a narrow, leaky carbonate shelf rim) during the middle Dresbachian Stage to shale-dominated facies (indicative of a wide, continuous rim) during Franconian Stage deposition is another likely indicator of tectonism. A middle Bonneterre sequence that thickens by 305 m across the Greenville fault in the southeastern edge of the St. Francois Mountains, similar to those discussed in the Belleview and Sabula basins, suggests continued movement on the fault during deposition.

IMPLICATIONS FOR MINERALIZATION

Syndepositional extensional-style fault zones probably opened fracture zones into the Precambrian basement, allowing MVT-stage mineralizing fluids to circulate within the iron-rich and, locally, sulfide-rich volcanic rocks and intrusives; this may have permitted leaching and deposition of base metals in both Cambrian and Precambrian sequences. Rift-style synsedimentary features enhance prospects in some growth fault locales for Mount Isa-type syngenetic base metal ore deposits.

CONCLUSIONS

The Upper Cambrian succession in southeast Missouri contains both large and small scale feature which suggest that synsedimentary tectonic activity influenced depositional features. Evidence of syn-Reelfoot rift deformation in the St. Francois Mountains region is typified by the Belleview and Sabula basins. Cambrian stratigraphic sequences in these basins exhibit thinning of units in response to tilting and uplifting of the basement, and dip reversals in formations which conformably overlie one another. Large scale transgressive-regressive cycles dominate the rim of the Mississippi Valley Graben, and decrease in frequency with distance from the Reelfoot rift. Conglomerates, comprised of Precambrian basement clasts cemented by Bonneterre dolomites, also indicate movement on basement-cutting faults during the Upper Cambrian. Other evidence suggesting synsedimentary tectonism during the Cambrian includes facies changes and development of paleokarst features in uplifted areas.

ACKNOWLEDGEMENTS

Some of the work presented in this paper was supported by an N.S.F. grant awarded to Jay Gregg, for which we are grateful. We would especially like to thank Bill Clendenin and Wallace B. Howe for many stimulating hours of discussion on faulting and stratigraphy in southeast Missouri.

REFERENCES

Bickford, M.E., and Mose, D.G., 1975, Geochronology of Precambrian Rocks in the St. Francois Mountains, Southeastern Missouri: Geological Society of America Special Paper 165, 48 p.

Braile, L.W., Hinze, W.J., Sexton, J.L., Keller, R.G., and Lidiak, E.G., 1984, Tectonic development of the New Madrid seismic zone, in Gori, P.L., and Hayes, W., eds., Proceedings of the Symposium on "The New Madrid Seismic Zone", Otto W. Nuttli convenor, Southeast Missouri State University, Cape Girardeau, Missouri, April 27-28, 1984: U.S. Geological Survey Open-File Report 84-770, 467 p.

Ervin, P.C., and McGinnis, L.D., 1975, Reelfoot rift: reactivated precursor to the Mississippi Embayment: Geological Society of America Bulletin, v. 86, p. 1287-1295.

Hayes, W.C. and Knight, R.D., 1961, Cambrian System, in Koenig, J.W. ed., Stratigraphic Succession in Missouri: Missouri Geological and Water Resources v. 40, second series, p. 14-20.

Hildebrand, T.G., Kane, M.G., and Stauder, W., 1977, Magnetic and gravity anomalies in the northern Mississippi Embayment and their spatial relation to seismicity: U.S. Geological Survey Miscellaneous Field Studies Map MF-914.

Houseknecht, D.W., and Ethridge, F.G., 1978, Depositional history of the Lamotte Sandstone of southeastern Missouri: Journal of Sedimentary Petrology, v. 48, no. 2, p. 575-586.

Howe, W.B., 1968, Planar stromatolite and burrowed carbonate mud facies in Cambrian strata of the St. Francois Mountain area: Missouri Geological Survey and Water Resources Report of Investigations No. 41, 113 p.

Kisvarsanyi, E.B., 1979, Structure contour map of buried Precambrian basement-rock surface, Rolla 1° X 2° quadrangle and adjacent areas, Missouri: U.S. Geological Survey Miscellaneous Field Studies Map MF-1001B, 1:250,000.

Kisvarsanyi, Eva B., 1981, Geology of the Precambrian St. Francois Terrane Southeastern Missouri (Contribution to Precambrian Geology No. 8): Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigations No. 64, 58 p.

Leeder, M.R., and Gawthorpe, R.L., 1987, Sedimentary models for extensional tilt-block/half-graben basins, in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental Extensional Tectonics: Geological Society of London Special Publication No. 28, p. 139-152.

Palmer, J.R., 1989, Late Upper Cambrian shelf depositional facies and history, southern Missouri, in Gregg, J.M., Palmer, J.R., and Kurtz, V.E., eds., Field Guide to the Upper Cambrian of Southeastern Missouri: Stratigraphy, Sedimentology, and Economic Geology: Department of Geology and Geophysics, University of Missouri at Rolla, p. 1-24.

Schwalb, H.R., 1982, Paleozoic geology of the New Madrid area; report prepared for the U.S. Nuclear Regulatory Commission: NUREG/CR-2909 RA, 61 p.

Seeger, Cheryl M., and Kisvarsanyi, Eva B., 1992, Potential for Magmatic-Hydrothermal Fe-REE-Cu-(Au?) Deposits in the Proterozoic Basement of the Paducah 1°x2° Quadrangle, in Goldhaber, M.B., and Eidel, J.J., eds., Mineral Resources of the Illinois Basin in the Context of Basin Evolution, St. Louis, Missouri, January 22-23, 1992: U.S. Geological Survey Open-File Report 92-1, p. 57-58.

Snyder, F.G., and Gerdemann, P.E., 1968, Geology of the southeast Missouri lead district, in Ridge, J.D., ed., Ore Deposits of the United States 1933/1967: The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, p. 327-358.

Thacker, J.L., and Anderson, K.H., 1979, Preliminary isopach maps of the Cambrian Lamotte Sandstone and Cambrian Bonneterre Formation Rolla 1° X 2° quadrangle, Missouri: U.S. Geological Survey Miscellaneous Field Studies Map MF-1002A, 1:250,000.

Yesberger, W.L., 1982, Paleoenvironments and depositional history of the Upper Cambrian Lamotte Sandstone in southeast Missouri: unpublished M.A. thesis, University of Missouri at Columbia, 287 p.