



Association of Missouri Geologists Field Trip Guidebook

50th Annual Meeting

Springfield, Missouri
September 26-27, 2003



**Missouri Department of Natural Resources
Geological Survey and Resource Assessment Division**

DEDICATION

This volume is dedicated to the memory of

Dr. Kenneth C. Thomson
1940-2004

Ken Thomson was a member of the geology faculty at Southwest Missouri State University from 1968 until his untimely death in an automobile accident on March 28, 2004. Ken was born and raised in Utah and received his education in geology at the University of Utah. Originally trained as an economic mineralogist, Ken rapidly adapted to his relocation to the Ozarks by becoming an expert in carbonate stratigraphy, karst geomorphology, and environmental problems associated with karst groundwater systems.

At SMSU, Ken taught Environmental Geology, Speleology, Air Photo Interpretation, and Field Geology, and he developed a program for training professional land surveyors. Ken loved to teach, and he especially loved to expose his students to geology in the field. He led countless field trips for his introductory courses, and he required field projects in all his advanced courses. The published geologic maps for Greene County and many of the surrounding counties in southwestern Missouri are based on detailed field mapping conducted by Ken and his SMSU geology students over the past three decades.

Ken was an avid caver, and he and his students mapped numerous caves throughout southwestern Missouri. Ken founded a caving club for SMSU students, the Heart of the Ozarks Grotto, and he remained the faculty sponsor for that organization until his death. He was also active in the Ozarks Highland Grotto and the Missouri Speleological Survey (MSS). He served as president of the MSS for thirteen consecutive years -- the longest anyone had ever held the post. At the time of his death, he was the Government Liaison for the organization.

Ken had a long-term commitment to helping preserve the water quality in Springfield and Greene County. Toward that end, he developed numerous very effective working relationships with governmental officials and members of the private sector throughout the area. He never tired of explaining the environmental challenges and responsibilities associated with living in an area of karst geology.

Ken was a Registered Professional Geologist in Missouri and an active member of the American Institute of Professional Geologists (AIPG) and the Association of Missouri Geologists (AMG). He served as President of the Missouri Section of the AIPG in 1992 and as President of the AMG in 1984. Ken's most recent contribution to the geology of southwest Missouri, in addition to his contributions to this guidebook, involved the discovery, exploration, and preservation of Riverbluff Cave in southern Greene County.

Ken's wife, Edda May, was killed in the same tragic accident. Ken and Edda May are survived by their four children and five grandchildren.

ASSOCIATION OF MISSOURI GEOLOGISTS 50TH ANNUAL MEETING

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GUIDEBOOK TO FIELD TRIPS:

*The Weaubleau-Osceola Structure:
Evidence of a Mississippian Meteorite Impact in Southwestern Missouri*

The Rader Spring Karst System, Greene County, Missouri

*Ordovician and Mississippian Stratigraphy and Structural Geology
of the Springfield-Branson Area, Southwestern Missouri*

*Engineering Geology of the U.S. 65 and Missouri Route 465 Corridors,
Christian and Taney Counties, Missouri*

2004

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Southwest Missouri State University

**ASSOCIATION OF
MISSOURI GEOLOGISTS**

50TH ANNUAL MEETING AND FIELD TRIPS

**SEPTEMBER 26-27, 2003
SPRINGFIELD, MISSOURI**

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Association of Missouri Geologists

2003

***Field Trip I: The Weaubleau-Osceola Structure:
Evidence of a Mississippian Meteorite Impact in Southwestern
Missouri***

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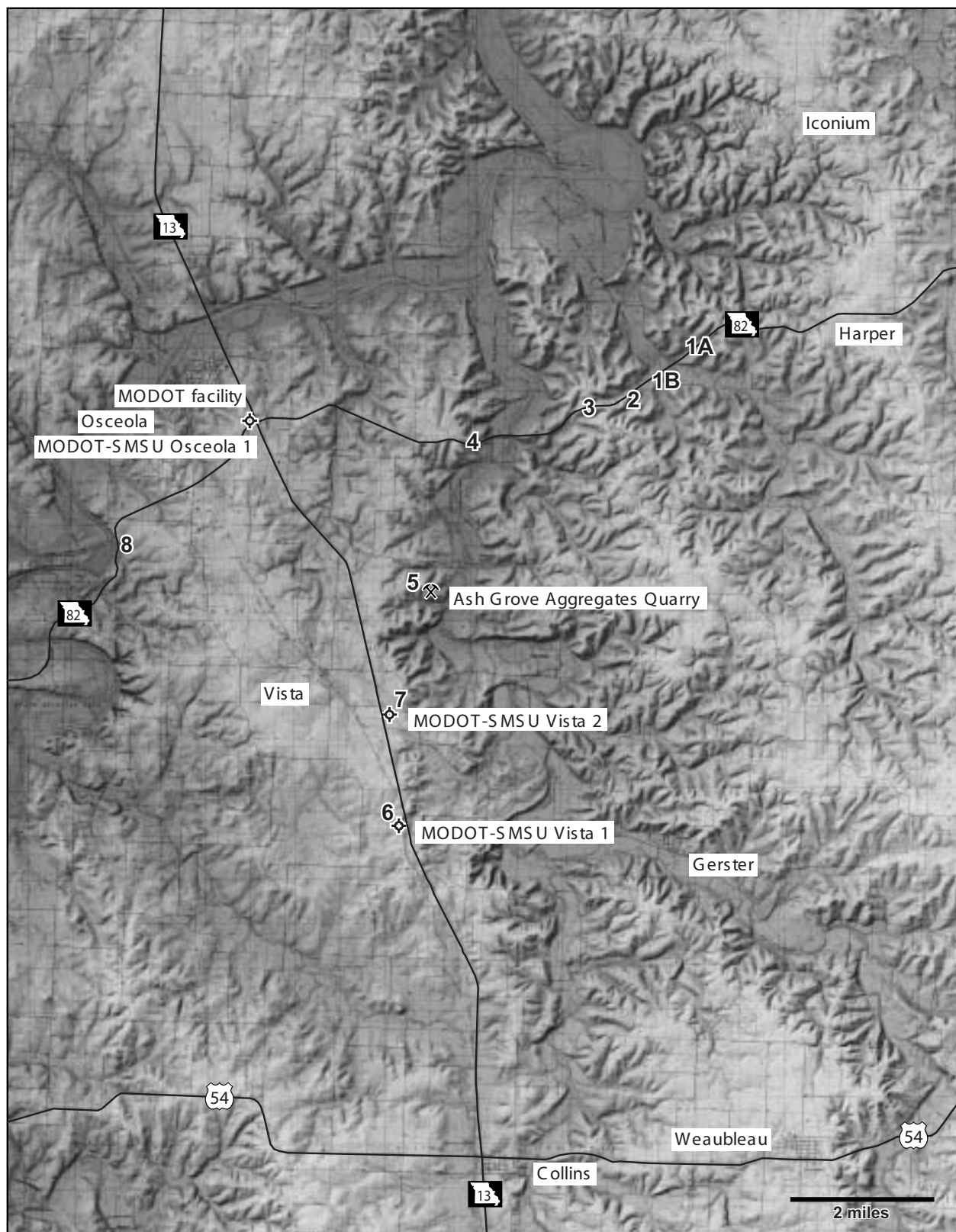



Figure I-1. Digital elevation model (DEM) overlain on topographic base map shows four 7.5 minute quadrangles: Osceola (upper left), Iconium (upper right). Weaubleau (lower right), and Vista (lower left). The 38th parallel runs through the middle of this map (top of map is north). Semicircular drainages, Coon Creek (southwest), Osage River (northwest), and Bear Creek (northeast), encompass an area of structural deformation. Points 1 through 8 are the field trip stops described in the roadlog. The  symbol indicates the location of the three sites drilled to date.

INTRODUCTION

Discovery of a 19-km-diameter circular topographic lowland in the vicinity of Osceola and Collins in southwestern Missouri (Figure I-1; Evans et al. 2003a) has placed new constraints on the dimensions of the Weaubleau structure of Beveridge (1951). This topographic feature outlines an area of deformed strata, and herein, we propose use of the name Weaubleau-Osceola structure to more accurately reflect the larger scope of this feature. In contrast to previous interpretations but in line with some previous speculations, we argue that this structure is a meteorite impact site (Evans et al. 2003b; Rovey et al. in press). This guidebook article records a provisional summary of results from reconnaissance-level investigations and a field trip road log that highlights a few of the extraordinary features of this site. Still, many questions with regard to the nature of this structure and its origin remain unanswered; much more work is needed to adequately describe and interpret the Weaubleau-Osceola impact site.

LOCATION AND GEOLOGIC SETTING

The Weaubleau-Osceola structure is located in southeastern St. Clair County, about 60 miles north of Springfield. Missouri Highway 13, the main artery between Springfield and Kansas City, crosses the western side of the structure (Figure I-1). Missouri Highway 82 crosses the northern part of it. U.S. Highway 54 runs south of the circular feature, but west of Collins the highway crosses an uplifted area that is part of the tectonic rim. The city of Osceola lies inside the northwestern perimeter of the structure, and the villages of Vista and Gerster are more centrally located within it.

The relatively flat uplands, low hills, dissected uplands, and narrow valleys of southeastern St. Clair County are at the northwestern edge of the Ozark Uplift, a gentle flexure across southern Missouri. Elevation in this area varies from approximately 700 to 950 feet, roughly 300 to 400 feet lower than the Springfield Plateau. Despite the difference in elevation, the stratigraphic succession in the area (Figure I-2) is broadly comparable to the Paleozoic bedrock of the Springfield Plateau. Broad upland areas generally are Pennsylvanian sandstones. These relatively flat areas are farmed extensively or are covered by prairie grasslands used for grazing. Valleys locally cut down to expose lower Ordovician Jefferson City-Cotter Dolomite. Where the Pennsylvanian has been removed by erosion, Mississippian and older strata provide for a rugged landscape of wooded hills and hollows.

PREVIOUS INVESTIGATIONS

Structural deformation along the Weaubleau Creek area has been known for more than fifty years. Thomas Beveridge's doctoral dissertation in the late 1940s at the University of Iowa and subsequently his work in the early 1950s documented the existence of complex folding and faulting in this area. He proposed the term "interthrust" to describe allochthonous exotic blocks of strata that were interposed with what appeared to be normally bedded strata (Beveridge, 1951). Beveridge recognized also an unusual "conglomerate" facies in the Burlington limestone. His initial interpretation, thrust faulting over a domal structure, relied on extant structural models of that era.

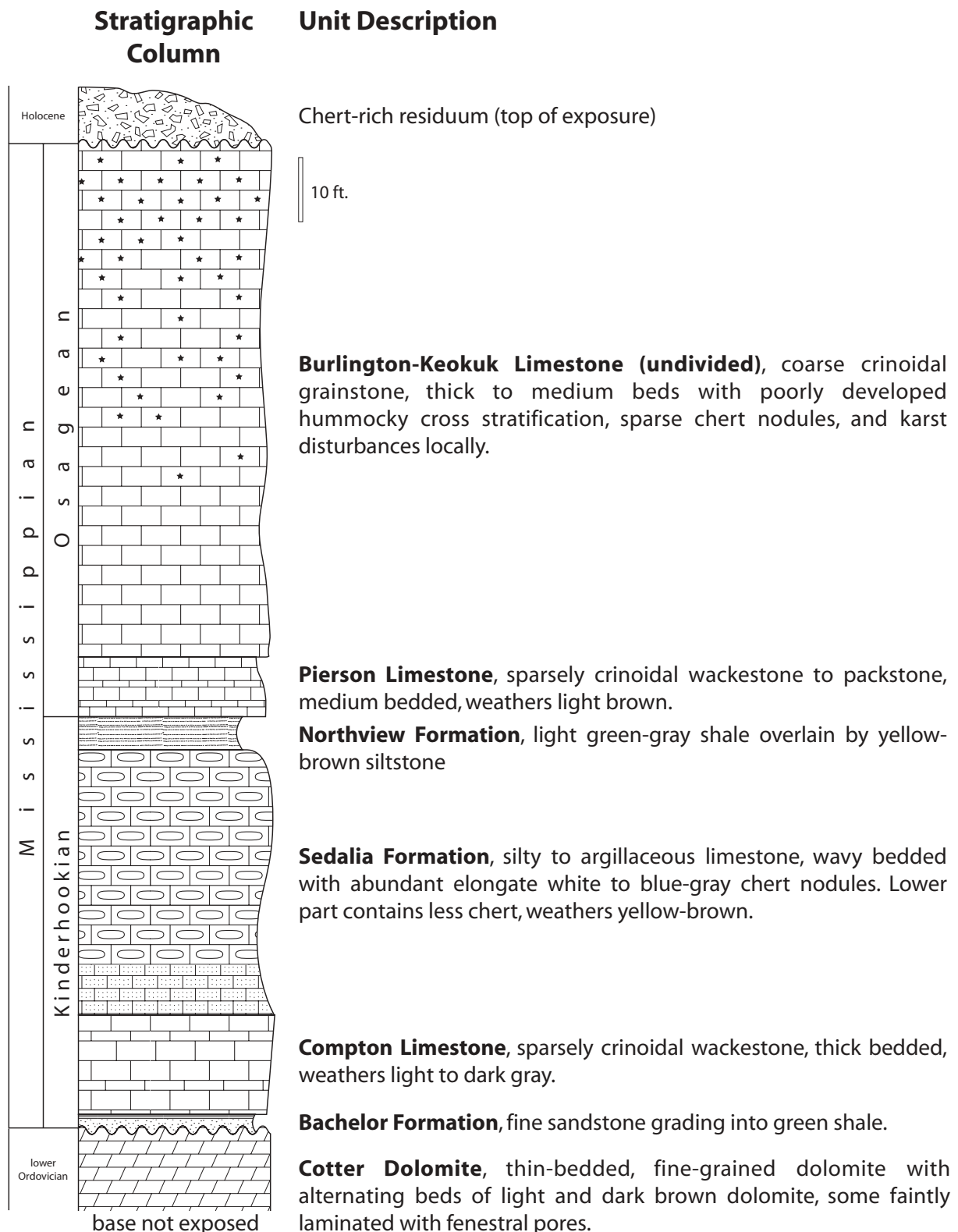


Figure I-2. Strata exposed at Stop 1A are not deformed, but this succession provides a useful reference for determining the provenance of clasts in breccias associated with the Weaubleau-Osceola disturbance. Lower units are better exposed on the east side of Weaubleau Creek on Missouri Highway 82. Rocks exposed at these two localities constitute most of the target rock affected by the impact. Units not exposed at this stop include the “Weaubleau Breccia” and Pennsylvanian Cherokee Group sandstones, shale, and breccia. A minor paleokarst feature is present in the Burlington-Keokuk interval.

Snyder and Gerdemann (1965) proposed a new mechanism for the formation of structures similar to that at Weaubleau; they called upon cryptoexplosive volcanism. These features had all of the hallmarks of deformation associated with volcanic explosions but commonly without volcanic rocks. Snyder and Gerdemann (1965) speculated that deformation around the Weaubleau area was attributable to these same processes, and they noted the linearity between eight of these supposed cryptoexplosive disturbances from southern Illinois, across Missouri, and into eastern Kansas more-or-less along the 38th parallel. That same year, a Geological Society of America field trip visited four of these localities, of which Weaubleau was one (Snyder et al. 1965).

Offield and Pohn (1979) published the first account of a 38th parallel disturbance. They interpreted the Decaturville structure as a meteorite impact site. Today, both the Decaturville and Crooked Creek structures are widely regarded as meteorite impact sites. Concerning the Weaubleau area, Offield and Pohn (1979) reported, “The Weaubleau area is like none of the others; it consists of an area 11 by 5 km intensively broken by thrusts and normal faults, and of adjacent areas of 44 km² containing unusual breccias.”

Since the efforts of Beveridge, Middendorf (unpublished map, 1984) prepared a reconnaissance-level geologic map of the Vista 7.5' quadrangle; his mapping shows uplift of the lower Ordovician west of Collins along U.S. Highway 54 and pinch out or erosional truncation of Mississippian strata below the Pennsylvanian. This map served as a base map for this area on the Springfield 1° x 2° geologic map (Middendorf et al. 1991).

Early studies of “cryptoexplosive” structures by Beveridge (1951), Snyder and Gerdemann (1965), and others have focused the efforts of those of us who have followed in their footsteps. By their recognition of areas with unusually complex geology and their description of them without genetic bias (despite their interpretations), the basic geology has proven to be sound and a useful point of departure for contemporary studies.

38TH PARALLEL STRUCTURES

Since 1984, the Weaubleau structure received mention only in passing as various authors speculated that it was either a cryptoexplosive or meteorite impact structure.

In 1994, impact of the Shoemaker-Levy 9 cometary bodies on Jupiter heightened interest in the idea that serial impacts may have occurred in Earth's geologic past. Rampino and Volk (1996) argued that the 38th parallel structures recorded such an event, spanning more than 500 km. Luczaj (1998) countered their argument, claiming that ultramafic volcanism or the release of volatiles along a zone of crustal weakness remained a viable mechanism for the deformation. He further contended that the ages of these structures could not have overlapped. From our understanding, given available data, the ages of many of these structures cannot be constrained adequately to support the idea that these are serial impacts. Many of Earth's known impact sites are deeply eroded, and it is impossible to infer age relationships where not only are impact products missing, so are would-be overlying undeformed strata that place an upper limit on the ages.

Neither is it possible to disprove the hypothesis that the 38th parallel structures record serial impacts. For example, the presence of angular fossiliferous chert clasts of possible Devonian age (see Snyder et al. 1965) in the so-called Avon “diatremes” does not place an upper limit on the age or ages of these breccia dikes. Any supposed impact would have post-dated this age. Ages from intrusive rocks in Hicks or Rose domes cannot constrain events if these were emplaced subsequent to hypothetical impacts. So, geochronological ages of isolated features cannot necessarily

serve as robust tests for the timing of events. Age constraints for the Weaubleau-Osceola structure are narrow indeed when compared to other structures along the 38th parallel.

The idea that serial impacts can occur on Earth has been challenged by planetary scientists. Serial impacts are presumably related to low-density asteroids that are held together by self-gravity. To have serial impacts (more than two impactors with some distance of separation) requires that these loose-knit accumulations be separated into individual bodies or clusters by the tidal forces of planetary bodies. For example, the comet Shoemaker-Levy 9 was broken apart and strung into 22 separate bodies by the influence of Jupiter's gravitational field in 1992, two years prior to collision. Recent attempts to model the tidal forces necessary to break apart an asteroid suggest that the probability of forming a crater chain on Earth is exceedingly small (Bottke et al. 1997; Richardson et al. 2002). Individual pieces would not be able to separate a sufficient distance to form anything other than a binary impact (for example, the Clear Lake structures of Quebec).

Certainly, crater chains are rare. Two unequivocal crater chains are known on the moon, where the likelihood of their formation is an order of magnitude greater than that calculated for terrestrial ones. Another is present on the Jovian moon, Callisto. Other than the 38th parallel structures, only the Aorounga impacts of Chad could potentially record serial impacts. If adequate age constraints can be placed on most of the 38th parallel impacts and these would tend to cluster around a middle to late Mississippian age, it would change our fundamental understanding of terrestrial impacts and their relationship to Earth-crossing asteroids.

DISCOVERY OF A 19-KM CIRCULAR FEATURE

Pursuant of his interests in understanding the geology of meteorite impacts, one of the authors, Evans, began mapping reported geological disturbances using digital elevation models. He generated maps of Decaturville, Crooked Creek, and other known impacts, noting their propensity to form circular features that have some sort of relict topographic expression. After focusing on the Weaubleau structure and examining the geologic maps of the Weaubleau and Vista 7.5' quadrangles (Beveridge, 1951, Middendorf, 1984), a couple of prospective areas of anomalous quasi-circularity were noted at Kings Prairie, north of Weaubleau, and along Highway 13 immediately west of Tanyard Branch, where the conglomeratic facies of the Burlington Limestone had been mapped by Beveridge. Not finding sufficient evidence to merit a drive to these localities, additional digital elevation model (DEM) data for the Osceola and Iconium 7.5' quadrangles were downloaded and merged with the existing maps to broaden the prospective region. Upon exporting this four-quadrangle DEM to a TIFF graphics file format and automatic generation of a desktop thumbnail icon by an Apple iMac computer, the large structure became apparent. Field studies began the next day. Refer to figure I-1.

CURRENT RESEARCH EFFORTS

Many collaborative studies of the Weaubleau-Osceola structure are advancing simultaneously. Recent core drilling, in July and August, 2003, geologic field and laboratory studies, and geophysical surveying support the idea that this structure was produced by impact. Abundant quartz grains with planar fractures (PFs) and apparent planar deformational features (PDFs), as yet unindexed, have been recovered from acid residues of a brecciated rock unit that we refer to informally as the "Weaubleau Breccia." These features indicate shock pressures that are known to

form only from nuclear explosions or meteorite impacts. Shatter cones, which are diagnostic of impact origins, have not been found in this structure, but unusual cone-like stylolites that formed at divergent angles likely will require description of a new type of pressure-solution feature that may be associated with impact processes. Mechanically twinned calcite clasts also are common in the “Weaubleau Breccia,” and while these are common in impact sites with carbonate target rocks, they can also form in orogenic belts. A student project by Chris Brocka and Matt Cosatt, directed by Tom Plymate of Southwest Missouri State University, has attempted to isolate coesite and stishovite, the high-pressure quartz polymorphs that are indicative of meteorite impact. So far, results have been unsuccessful, but refinement in procedural methods may yield results. The Weaubleau-Osceola impact site is coincident with complex Bouguer gravity and residual magnetic minima. New studies are helping to increase the resolution of these models. Many other facets of research, including new geologic field mapping, additional core drilling, geochemical analyses, detailed petrographic study, and seismic surveys need to be completed to more fully characterize this structure. From what we currently understand, a few statistics can be offered.

The Weaubleau-Osceola structure is among the fifty largest known in the world, and it is one of the four largest in the United States. Larger structures in the U.S. include the Chesapeake structure below Chesapeake Bay in Virginia, the Manson structure, which is buried below glacial material in northwestern Iowa, and the Beaverhead structure, which is exposed in a series of mountain valleys across southwestern Montana. Thus, the Weaubleau-Osceola structure *is the largest untectonized impact structure exposed in the United States*. Many impact sites are deeply eroded so that only traces of the original impact material are left, but the Weaubleau-Osceola structure is remarkably well preserved below a mantle of Pennsylvanian strata. Portions of a structural uplift on the outer margin of the circular feature are preserved, as are thick accumulations of impact-related breccia. Thus, this structure provides a unique opportunity to study aspects of impact geology that are not available elsewhere, and it serves both the scientific and local communities as a resource for education and research.

STRATIGRAPHY

Figures I-2 and I-3 provide a synopsis of both undeformed and deformed stratigraphic units in the Weaubleau-Osceola structure. Understanding the age and origin of the “Weaubleau Breccia” is the key to understanding this structure. It overlies the Burlington-Keokuk Limestone (undivided), is cut by paleokarst, and overlain by Pennsylvanian shales, chert breccia, and channel sands. Clast constituents of the “Weaubleau Breccia” include lower Ordovician and lower to middle Mississippian material as well as exotic clasts of granite. Cambrian rocks currently have not been recovered from the breccia, but presence of granite clasts indicates a minimum of 400 m of uplift in the central part of the structure. The age stratigraphy of this impact site is discussed in greater detail in the road log below. We consider this impact to be approximately 320-340 million years old.

GEOPHYSICAL MAPPING

Geophysical modeling of gravity and magnetic data has proven useful for determining the lateral extent and subsurface geometry of impact sites, and a gravity and magnetic analysis was initiated in late 2002. Gravity data were obtained from the National Imaging and Mapping Agency

A

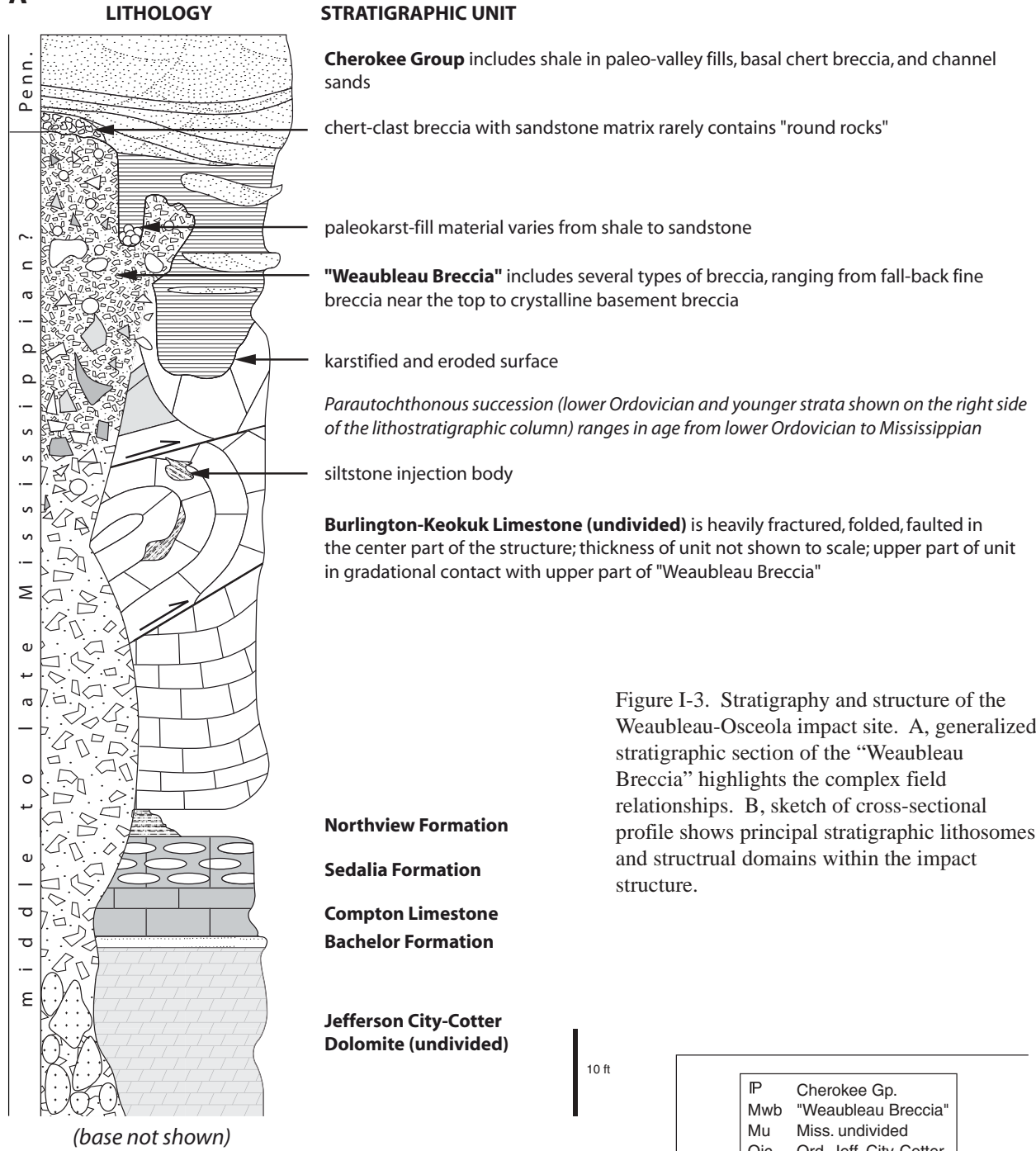
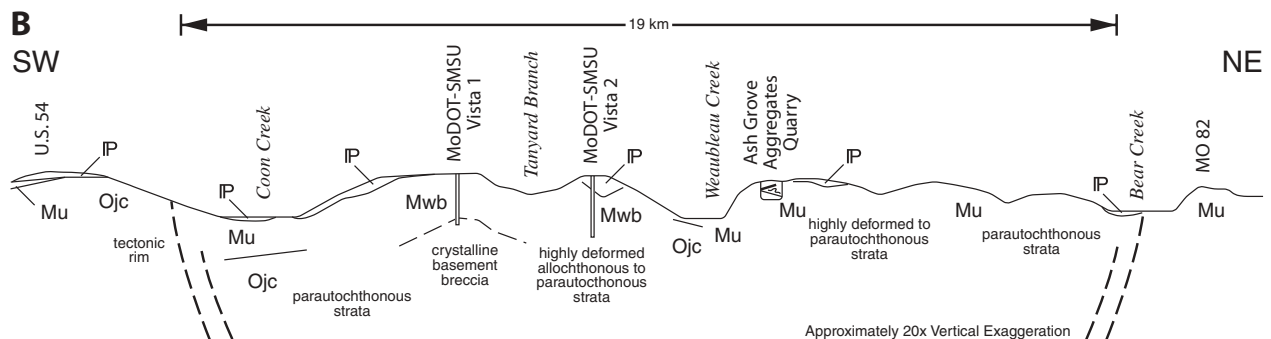


Figure I-3. Stratigraphy and structure of the Weaubleau-Osceola impact site. A, generalized stratigraphic section of the "Weaubleau Breccia" highlights the complex field relationships. B, sketch of cross-sectional profile shows principal stratigraphic lithosomes and structural domains within the impact structure.



(NIMA), but the amount of data was insufficient to perform a detailed analysis. So, a new survey was undertaken and 210 gravity stations were obtained within the proposed boundaries of the structure. These new data were merged with the existing data and processed into simple Bouguer gravity anomalies (Figure I-4A). Residual aeromagnetic anomaly data were obtained from the USGS (Bankey et al. 2002), where existing flight line data were merged into a grid with a spacing of 0.5 km (Figure I-4B).

Both the gravity and magnetic anomaly maps indicate a similar trend in the regional anomaly pattern, where northwest-trending anomalies reflect mainly the topographic and lithological changes within the Precambrian surface. The Weaubleau-Osceola impact structure lies on the southwest portion of a regional northwest-trending gravity and magnetic minimum. This trend is probably due to greater depths to the Precambrian granites, but may also be attributable to a southeastern extension of the Forest City Basin that is present in Kansas and far western Missouri.

Within the Weaubleau-Osceola structure, the gravity and magnetic anomaly patterns are more complicated with at least two small-amplitude gravity and magnetic minima that may reflect greater depths to the Ordovician surface (Figure I-4C). The corresponding gravity and magnetic maximum occurs where recent drilling indicates an uplift of Precambrian granite to within 200 feet of the surface. This maximum may be extended to the southeast on both anomaly maps by the slight bending of the contour lines. Further drilling in this region will determine if the anomalies are caused by uplifted Precambrian granite.

CORE DRILLING

The Missouri Department of Transportation (MoDOT) drilled three localities in the Weaubleau-Osceola structure between July 14-17 and July 21-24, 2003. Each hole was located on MoDOT right-of-way, including the maintenance lot at the MoDOT Osceola Maintenance Building. Sites were level with sufficient room for support vehicles, so Failing 1500 drills manufactured by the George E. Failing Company of Enid, Oklahoma were chosen for use. Normally employed for geotechnical sampling and characterization by the department, these drills may also be used for water well installation, coring for quarry investigation, and other highway-related tasks as needed.

For this task, two different Failing 1500 rigs were used. The first was equipped with a wire-line coring system and penetrated to a maximum depth of 247.8 feet for the MoDOT-Osceola Vista 1 borehole. A high-speed bit designed for limestone, dolomite and chert was employed, and coring bit pressures ranged from 150 to 200 psi. Water was the only drilling fluid necessary. With this system, it was not necessary to remove rods and “trip” the hole every time the core barrel was filled with an additional five feet of core. A winch brought up the inner core barrel, another was dropped into place, and coring resumed after each run. The use of two core barrels expedited the process, as coring resumed even before the previous core barrel had been emptied. Core recovery was nearly perfect, with only 0.56 percent loss (1.2 feet) over the entire cored interval of the first borehole. Greater depth was not possible, as only 250 feet of wireline rods were available and owned by the department. With additional rods, it is thought that over 800 feet of core might have been obtained.

The second Failing 1500 used a 10-foot core barrel, but had to trip the hole after every run. Greater core loss was experienced as the core barrel penetrated soft Pennsylvanian shale and sandstone until limestone breccia was reached. This second drill rig used a surface-set diamond-

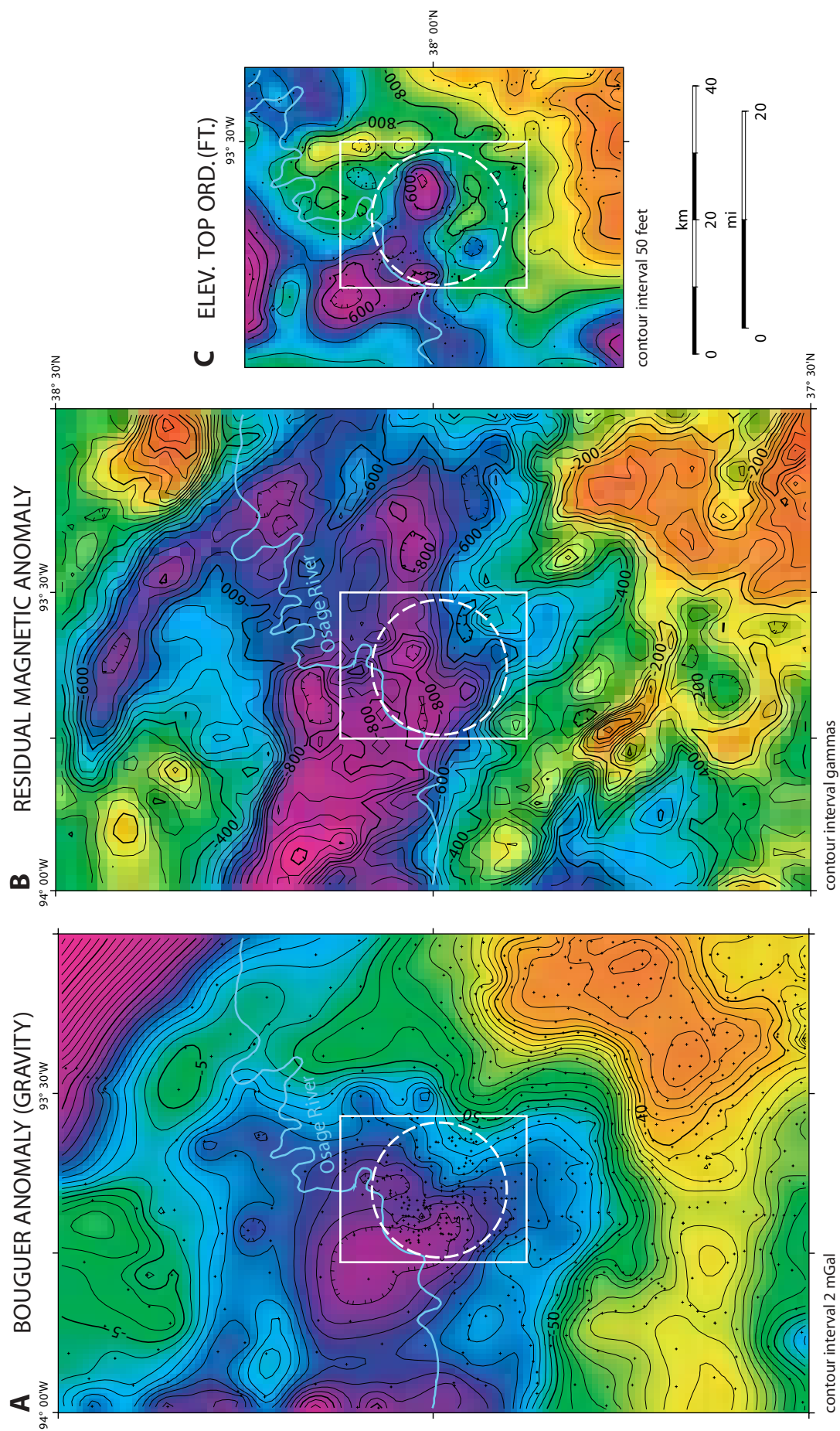


Figure I-4. Gravity (A) and magnetic (B) anomaly maps, and a subsurface structural contour map (C) of the Weaubleau-Osceola structure and surrounding areas. The (+) symbols represent station locations on the Bouguer gravity anomaly map and drill hole sites penetrating Ordovician units on subsurface structural contour map. Outline of the four-quadrangle area shown with solid white line and outline of circular feature shown in broken white line.

coring bit designed for a variety of rock types and conditions. Coring bit pressures ranged from 150 to 250 psi. Both drill rigs were using NX core barrels obtaining 2-inch diameter rock cores. Bentonite use was minimal for both rigs, using a fifty pound bag or less to seal the recirculation sump from the ground surface. The second drill rig used Baroid EZ-Mud sparingly. A total of less than 1/2 gallon was used for the 2400 gallons of water used in the fractured and brecciated rock encountered.

Drilling operations were successful due largely to the efforts of the two professional drilling crews. More than 600 feet of core was retrieved and selected samples were slabbled, polished, and hand transported to Nördlingen, Germany for display at the Third International Conference on Large Meteorite Impacts (Evans et al. 2003b). With this initial exploratory drilling and collection of core samples, we can begin to formulate tests for better understanding the morphology and details of this structure.

DISCUSSION

No impact site is typical; most have nuances that require explanation. Figure I-3B is a southwest-northeast cross-sectional sketch of the structure; it will, no doubt, become increasingly inaccurate as we learn more. We consider the tectonic rim (boundary fault) to be just outside of the 19-km circular feature. Uplifted strata on the southwestern flank are 150-200' higher than strata in the trough of the circular depression (ring moat). Deformation is gentlest around the periphery and more intense near the center. The outer portions are parautochthonous, whereas the central part is allochthonous. Granitic clasts currently are only known in the central uplift area, but gravity and magnetic data suggest that the structure is not symmetrical.

The distribution of impact breccia spans the structure because “round rocks” are found in and around all of the upland areas, assuming they were not transported as clasts. The thickest and best preserved outcrops of the unit are in the southwest, where the structure is not as deeply eroded. The depth of brecciation may reach thousands of feet in the central part of the structure.

The Weaubleau-Osceola structure is relatively large, but the level of structural deformation, although currently poorly known, seems gentle compared to structures of comparable or slightly larger diameter (e.g. Ries Crater). Several impact-related parameters could explain this discrepancy, including the velocity and density of the impactor. Another possibility is that the Weaubleau-Osceola impact records the impact of a “contact binary” asteroid. Within the 19-km relict feature are two smaller circular features. At least one of the smaller circles, the one in the southwest, is coincident with the breccia outcrop that originally was mapped as conglomerate. If two impactors struck simultaneously or nearly so, they could still have generated a large circular feature. Complex compressional and tensional shock-waves could have developed and the resulting distribution of central uplift material might seemingly resemble that shown in Figure I-4. A series of complex criss-crossing faults are reported upstream along Weaubleau Creek, to the southeast, on the Springfield 1° x 2° geological quadrangle. These are speculations, but ones worth noting as our concepts of the morphology evolve.

QUESTIONS REMAINING

For any one subdiscipline necessary to characterize this impact site, there are innumerable questions. This is just a sampling:

Biogeochronology:

What is the precise age of the impact?

Is it correlated with a major series or system boundary?

Paleontology:

Did the impact affect the fauna?

Did it result in biological extinction of species, genera, or families of organisms?

Paleoenvironmental Studies:

Did the impact strike land or a shallow epicontinental sea, where tsunamis may have been generated?

Can we correlate the impact event with strata in surrounding areas that may have recorded distal effects of the event, either sedimentologically or geochemically?

Sedimentology and Structural Geology:

What is the nature of the polymict breccia? How was it deposited or emplaced?

Are impact melts present among the granites?

Does emplacement of siliciclastic material along fault planes indicate acoustic fluidization?

What controlled the brittle-ductile structural zonation exposed in local quarry walls?

Field Mapping and Geophysics:

What is the distribution of the breccia?

What is the overall morphology of the structure?

How deeply eroded is the crater?

What are the details of gravity and magnetic field anomalies?

Planetary Geology:

Are serial impacts possible on Earth?

Is this impact site related to other known impacts along the 38th parallel?

Can we relate the morphology of the impact to a so-called contact binary impactor?

Can we correlate breccias from the Weaubleau-Osceola structure with the Decaturville structure using remnant paleomagnetism or geochemistry?

What impact modeling parameters can be derived from observations?

SUMMARY

Impact cratering is one of the fundamental processes of our solar system. From the accumulation of planetesimals during the origin of the solar system to the devastating effects of large terrestrial impacts on living organisms such as the K-T boundary event (Alvarez et al. 1980; Kring, 2000), impacts have played a crucial role in the development and evolution of life on Earth. Further exploration of the Weaubleau-Osceola impact provides a great opportunity to understand better the processes and products associated with a “middle-sized” impact and the effects of this event on Earth’s inhabitants. Our efforts also provide an opportunity to help develop the economic, cultural, and educational resources that such scientific discoveries can bring to local communities.

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The authors also wish to thank the following companies, organizations, agencies, and institutions: Ash Grove Aggregates; Association of Missouri Geologists; Missouri Department of Transportation; Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division; and especially Southwest Missouri State University, which provided faculty research funding to Chuck Rovey.

ROAD LOG (distances in miles)

Please note stops and points of departure are indicated in bold face and specific driving directions are shown in all capital letters. Distance shown in miles. Locations are provided in UTM grid coordinates for Zone 15S, using the WGS 84 datum.

- 0.0 From **Lamplighter Inn and Convention Center North**, Springfield, Missouri, DEPART at 8:45 am (UTM 4122416 mN 476920 mE). TURN LEFT onto Evergreen Street.
- 0.1 TURN RIGHT onto Glenstone Avenue.
- 0.4 TURN RIGHT onto entrance ramp for westbound Interstate Highway 44 toward Joplin, Missouri.
- 0.8 Burlington-Keokuk Limestone (undivided) is exposed along both sides of highway for the next few miles. The Burlington-Keokuk Limestone is Mississippian (Osagean Series) in age, and this unit typically is the uppermost strata of the Springfield Plateau. It is dominantly coarse-grained crinoidal grainstone.
- 1.4 Cross National Avenue overpass.

- 2.6 Cross Grant Avenue overpass.
- 2.9 Cross Broadway Avenue overpass.
- 3.1 TURN RIGHT onto exit ramp for Kansas Avenue (Missouri Highway 13 north) toward Bolivar, Missouri.
- 3.4 TURN RIGHT (north) onto Highway 13.
- 3.5 At signal, proceed through intersection on Highway 13, crossing Norton Road.
- 5.3 Cross Fantastic Caverns Road.
- 5.6 Large roadcuts expose Burlington-Keokuk Limestone on both sides of highway. Strata consist of thick to massive beds of crinoidal grainstone with a minor amount of chert. These are typical bedding characteristics for this unit in the Springfield Plateau.
- 6.0 Cross bridge over Little Sac River.
- 6.4 More large roadcuts expose Burlington-Keokuk Limestone.
- 7.9 At signal, proceed through intersection, crossing Highway O.
- 9.4 Cross intersection with Highway WW (to east). A short distance north, the northbound and southbound lanes of Highway 13 diverge.
- 13.7 Begin descent from Springfield Plateau. Exposures of siltstone on west side of road are mapped as Northview Formation (Mississippian, Kinderhookian). This area locally is known as Noble Hill. The Northview is fairly thick in this area, but reaches a maximum thickness of approximately 80 feet farther to the north in the Stockton Lake area. Thicknesses of 3-5 feet are common in the vicinity of Osceola and in the vicinity of Branson (Field Trip III).
- 14.2 Cross junction of Highway CC (east), and Highway BB (west).
- 15.5 Northbound and southbound lanes of Highway 13 rejoin and run parallel for a short distance.
- 15.8 Enter Polk County.
- 16.4 Cross bridge over North Dry Sac Creek.
- 18.6 Enter village of Brighton.
- 18.7 Missouri Highway 215 joins Highway 13 northbound.

- 19.7 Highway 215 exits left, to west. Proceed on Highway 13.
- 22.2 Cross T-road intersection with Highway KK (east).
- 24.2 Enter village of Slagle.
- 24.8 Northbound and southbound lanes of Highway 13 rejoin and run parallel.
- 26.0 Cross intersection with highways U (west) and Y (east).
- 26.8 Missouri Highway 83 detour exits right (east) toward the city of Bolivar. Proceed on Highway 13. New construction will widen Highway 13 to four lanes between Bolivar and Humansville.
- 27.4 Divided highway ends and construction zone begins.
- 27.6 Overpass, under construction, will be the future intersection with Highway 83.
- 29.9 Cross bridge over highway under construction.
- 30.3 At signal, cross intersection with Highway T.
- 31.3 At signal, cross intersection with Missouri Highway 32.
- 32.7 New roadcuts expose lower Ordovician Cotter Dolomite (Ibexian).
- 34.3 Entrance to Ash Grove Aggregates Bolivar quarry on right.
- 35.6 New roadcut on west side of highway exposes Northview Formation. For the next few miles, new roadcuts provide fresh exposures that have not been studied in detail. Stratigraphic units include the lower Ordovician Cotter Dolomite through Mississippian Pierson Limestone.
- 35.9 Cross intersection of highways B (east) and BB (west).
- 43.0 Older roadcut through Cotter Dolomite.
- 43.8 Cross intersection of Missouri Highway 123. Business 13 exits to right (east) toward Humansville.
- 44.1 Low roadcuts for the next few miles cut through Cotter Dolomite.
- 45.9 Enter city of Humansville.
- 46.4 Cross intersection of Highway N (west); Business 13 rejoins Highway 13 (east).

- 49.3 Enter St. Clair County. The broad flat valley we are following is a linear topographic low that stretches 35 miles (50 km), roughly centered on and bisecting the circular feature of the Weaubleau-Osceola structure. We informally refer to this topographic element as the Humansville-Weaubleau Creek lineament. Comparable linear physiographic features appear to be common in impact and suspected impact sites, but their origin remains enigmatic.
- 50.2 Cross bridge over Panther Creek.
- 51.4 Cross intersection of Highway UU.
- 53.4 Enter village of Collins.
- 53.7 At signal, cross intersection with U.S. Highway 54.
- 55.0 Approximately 300 feet (100 m) west of the road is a bridge over Coon Creek. This creek, which runs from southeast to northwest, forms the southwestern part of the “ring moat” associated with the Weaubleau-Osceola structure (Figure I-1). Coon Creek is both a topographic and structural low. Undeformed or mildly deformed beds of Burlington-Keokuk Limestone are exposed along the creek, but Mississippian strata are cut out on the hill tops just to the southwest, where Lower Ordovician strata have been uplifted and truncated below Pennsylvanian sandstone. Pennsylvanian sandstone and shale also are found along the creek. Beveridge (1951) interpreted this feature as a Pennsylvanian paleo-valley, and he was probably accurate in his assessment. We think that these exhumed paleo-valleys trace the inner part of an impact structure, just within the tectonic rim.
- 56.1 Divided highway begins on Highway 13.
- 57.3 Roadcuts on both sides of highway expose cross-bedded sandstones that are mapped as Pennsylvanian Krebs Group or its equivalent, the Cherokee Group.
- 58.7 Light yellow-weathering limestone breccia crops out in isolated roadcuts at left. We refer to this unit informally as the “Weaubleau Breccia.” This will become the type locality for the unit, and one of these exposures will be proposed as a reference section when it is described formally. A continuous core from the MODOT-SMSU Vista 1 borehole, which was located directly above the roadcut, likely will be designated as the type section for the unit per provisions of Article 16 in the North American Stratigraphic Code (NACSN, 1983). The MODOT-SMSU Vista 1 borehole spudded-in on July 15, 2003, and completed on July 22. After penetrating red clay and residuum for 29.5 feet, breccia was encountered at roughly the elevation of the rock exposed in the top of the roadcut, and after reaching total depth 247.8 feet, maximum depth for the wire-line drilling rig, breccia composed of crystalline basement clasts was still being recovered (see Figure I-7). This indicates a minimum thickness of at least 218 feet for the “Weaubleau Breccia.”

The “Weaubleau Breccia” is interpreted as an impact breccia. The facies exposed at the surface is thought to be the fall-back component of the breccia. Overall, the “Weaubleau

Breccia” is remarkably heterogeneous, but a crude sort of stratigraphy mimics the local rock succession. We will return to this location for Stop 6.

- 58.8 Cross County Road SE400.
- 60.3 Roadcut on right exposes chert residuum of Pennsylvanian age and onlapping cross-bedded sandstones.
- 60.4 Cross intersection of County Road SE250. A second core drilling site, MODOT-SMSU Vista 2, was located on top of the sandstone near the southeastern corner of this intersection. This borehole was a test of the stratigraphic relationships of the breccia and sandstone. Approximately 300 feet of core was recovered. The yellow-weathering fall-back component of the breccia is missing and presumed to have been removed by erosion at the base of the sandstone, which is more than 70 feet thick. We will return to this location for Stop 7.
- 60.9 Cross intersection of highways V (west) and T (east)
- 62.4 Cross intersection with Highway TT (east).
- 63.1 Cross bridge over Brush Creek.
- 64.9 Intersection of highways 13 and 82. TURN LEFT on Missouri Highway 82 and Business 13 toward Osceola.
- 65.0 TURN RIGHT onto Business 13 toward Osceola.
- 65.2 TURN RIGHT and enter the **MODOT Osceola facility** (UTM 4210625 mN 439881 mE). This is the starting point for the field trip. Brief introductory material will be presented at this stop.

RETURN to intersection of highways 13 and 82.

The southeast corner of the MODOT facility was the location for the third core drilling site, MODOT-SMSU Osceola 1. Pennsylvanian sandstone crops out in the ditch along Highway 82. Drilling encountered Pennsylvanian sandstone, chert breccia, and shale, before reaching a lower(?) part of the “Weaubleau Breccia.” These strata were only mildly deformed relative to other cores, and the hole was completed after approximately 80 feet of core was recovered at a depth of 102.8 feet.

- 65.4 PROCEED east on Highway 82, crossing Highway 13.
- 65.5 Low exposures of sandstone are present along the south side of road. Note the gently rolling topography that has developed on top of the Pennsylvanian. The structure is more heavily eroded on the eastern and northern portions, where relatively rugged hills are mostly wooded and narrow creek valleys and hollows dissect the landscape.

- 65.7 Sandstone is exposed in the roadcut on south side of road.
- 66.3 Begin descent into valley of Brush Creek. Roadcuts expose weathered Burlington-Keokuk that dips gently to the north. These strata are mostly normal in appearance, but the east end of the roadcut exposes irregularly bedded limestone that contains large angular chert clasts and rare exotic clasts of lime mudstone.
- 66.7 Cross bridge over Brush Creek.
- 68.5 Roadcut exposes Burlington-Keokuk Limestone and other stratigraphic units. We will return to this location for Stop 4.
- 69.2 Cross bridge over Weaubleau Creek.
- 69.4 Pass roadcuts that expose Mississippian succession. We will return to these for Stop 3.
- 70.3 Pass roadcuts that will be discussed on the return trip (Stop 2).
- 71.5 Pass roadcut that exposes the Cotter Dolomite. This will be Stop 1B.
- 71.8 Cross bridge over Bear Creek.
- 72.2 Pass roadcuts that expose the Mississippian succession.
- 72.7 At intersection of Highway 82 and County Road NE 320, TURN LEFT AND TURN AROUND to return to roadcuts approximately 0.5 miles to the west.
- 72.8 Roadcut exposes Burlington-Keokuk Limestone (undivided).
- 73.2 **STOP 1A** (UTM 4212179 mN 450185 mE). This stop highlights the undeformed stratigraphic succession in this area (Figure I-2). A key marker unit for understanding the Mississippian stratigraphy of southwestern Missouri is the Northview Formation. At this locality, and at most other areas in southwestern Missouri, the Northview forms either a recessive slope or undercut ledge (Figure I-5A). It is dominantly a green-gray siltstone that commonly weathers to a yellow-gold color. This unit varies greatly in thickness across the region, and here it is approximately 4 feet thick. The Northview Formation and underlying Mississippian strata are Kinderhookian in age.

The Pierson Limestone, which overlies the Northview, is not typically differentiated from the overlying Burlington-Keokuk Limestone (undivided) in this area, but, for reference on Figure I-2, this unit is indicated because it probably correlates with the Pierson Limestone of the Springfield Plateau. Carbonate strata above the Northview Formation are Osagean in age (approximately 340 Ma). The Pierson, Burlington, and Keokuk formations are shallow subtidal carbonates that accumulated on a shallow carbonate platform (Thompson, 1986). The lower 10-12 feet are mostly lime wackestone, but crinoidal material is more

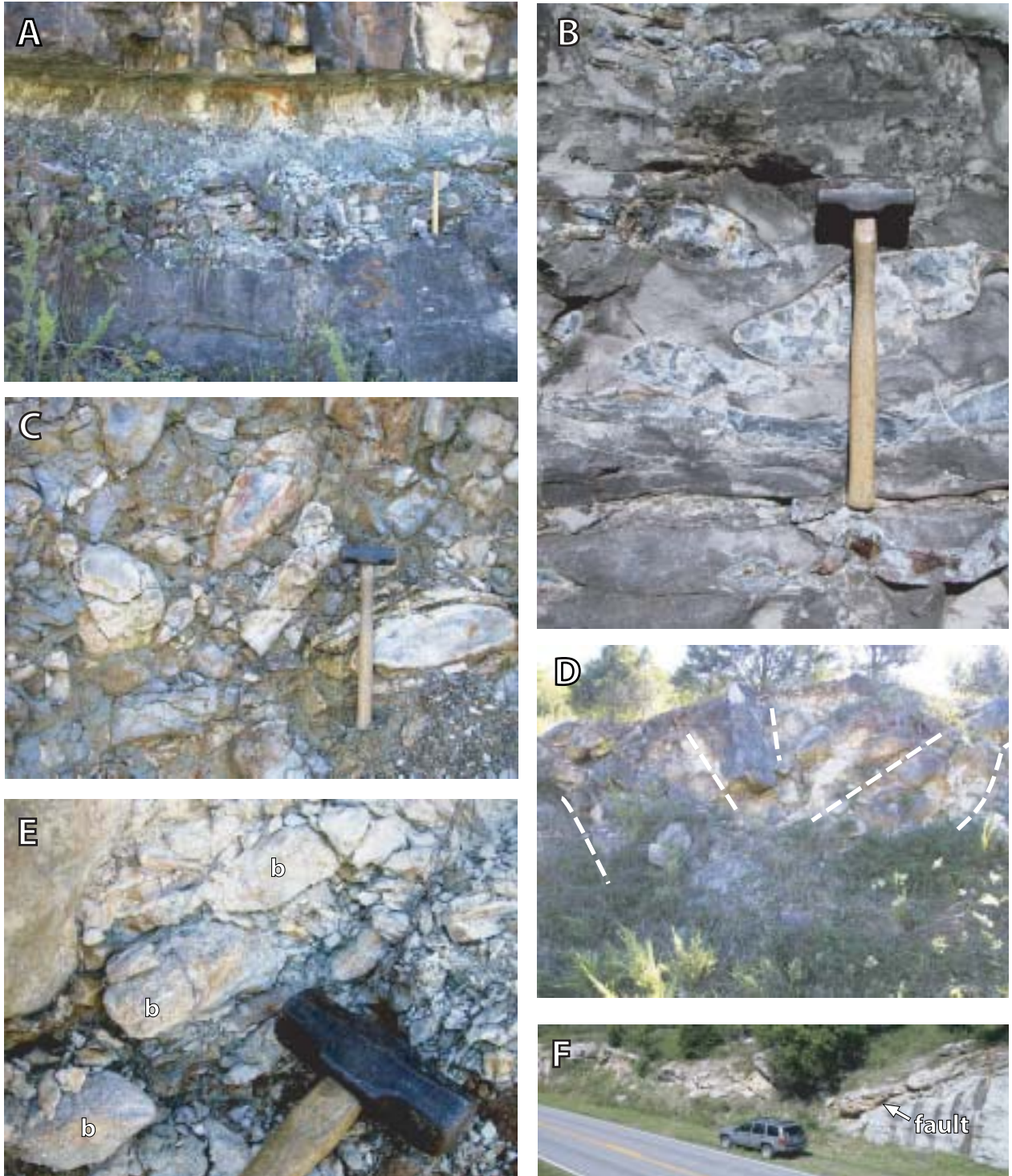


Figure I-5. Photographs of roadcuts along Missouri Highway 82. A, undeformed, normally bedded succession from Stop 1A shows the typical expression of uppermost Sedalia Formation overlain by the recessive Northview Formation, which is overlain by the Pierson Limestone. B, the Sedalia Formation at Stop 1A consists of chert and lime mudstone to wackestone. C, chert clasts in a paleokarst fill at Stop 2 are imbricated. D, at the same locality, large blocks of limestone form keystone-like arrangement of blocks (indicated by broken white lines) that records roof-collapse of the cave. Large block in upper middle part of exposure is approximately 6 feet long. E, clasts of breccia (b) in paleokarst fill material at Stop 2 indicate that karstification post-dated the impact event. F, thrust(?) fault and small roll-over anticline at Stop 3 show that deformation was relatively gentle along the northern reaches of the impact. The northern area was more deeply eroded, so this area would have been somewhat lower structurally than areas where impact breccia is preserved.

common upward and comprises the bulk of rock in the uppermost Burlington-Keokuk. White chert nodules are common accessories in these units.

The Sedalia Formation is immediately below the Northview Formation. It is approximately 40 feet thick and contains silty lime mudstone to calcisiltite interbedded with abundant white to blue-gray chert (Figure I-5B). In fresh exposures it sometimes has a slightly reddish gray appearance. Although its bedding is usually thick to massive, the Sedalia commonly contains thin laminations and small channels that are filled with low-angle cross-stratified mixed mudstone and packstone couplets. It is interpreted as an intertidal to shallow subtidal carbonate platform unit.

The Compton Limestone, the lowermost part of the Mississippian succession, contains only rare chert. This unit is dolomitic in some localities but distinguishable from Cotter because of its lenticular appearance in weathered exposures.

The lower Ordovician Cotter Dolomite (Ibexian) is better exposed at Stop 1B and below the bridge abutment on the east side of Weaubleau Creek.

73.6 Cross bridge over Bear Creek.

74.0 STOP 1B. Cotter Dolomite is exposed in roadcut on south side of highway. The Cotter is a silty dolomitic mudstone. It weathers brown or yellow gray and commonly develops a dusty gray magnesium oxide coating, and it develops very blocky weathering characteristics. At the east end of this roadcut, Pennsylvanian sandstone overlies the Cotter, suggesting that this, too, was a Pennsylvanian paleo-valley. Like Coon Creek, Bear Creek probably is near the tectonic rim. Very little deformation is evident in the bedded strata of these roadcuts, but the Cotter has been uplifted approximately 35 to 40 feet relative to beds on the other side of the creek. The sense of motion on this boundary fault differs from that expressed around Coon Creek, but this area has not been mapped in detail. Cuttings from a water well on the east side of Bear Creek indicate a partial duplication of the Mississippian succession. Seemingly, it is the relatively recent re-excavation of Pennsylvanian paleo-valleys by modern drainage systems that has provided the topographic expression of the circular anomaly.

74.4 STOP 2. On the south side of the highway, a fault cuts exposures of the Sedalia through Burlington-Keokuk formations, and a large channel-form paleokarst feature lies between the fault blocks. A drag fold on the east fault block dips gently to the west and is cut at the channel boundary. The Northview Formation is downthrown approximately 15 feet on the west side of the fault.

Paleokarst fill material consists mostly of friable sandstone and large imbricated lenticular cobbles of chert (Figure I-5C). Apparent inverse grading with large limestone blocks in the uppermost part of the exposure suggests that they collapsed to form this keystone-like wedge (Figure I-5D). A couple of the clasts in this filling are composed of fine-grained limestone breccia that bears clasts of Northview composition (Figure I-5E). This indicates that karstification occurred subsequent to the brecciation event.

Karst features resembling the ones at this stop and elsewhere on this field trip generally are assigned a Pennsylvanian age. Fault control of paleokarst development is a common phenomenon, and we interpret this particular feature as a collapsed cavern.

- 74.7 Roadcut of Burlington-Keokuk is exposed on south side of highway.
- 75.1 Roadcuts of Burlington-Keokuk are exposed on both sides of highway.
- 75.3 Roadcut of Burlington-Keokuk, gently dipping to the northwest, is exposed on right side of the highway. The low exposures on the left side are more-or-less flat lying.
- 75.9 **STOP 3.** The Burlington-Keokuk shows little deformation on east end of roadcut, but a low-angle reverse(?) fault cuts these strata; the fault trace is exposed on both sides of the road, indicating a more-or-less north-south orientation that roughly parallels Weaubleau Creek (Figure I-5F). It is difficult to determine the amount of offset along the fault because the Burlington-Keokuk limestones are on both the hanging wall and footwall. On the hanging wall side of the fault plane, rocks above the fault plane appear to be a normal crinoidal limestone with abundant angular chert clasts and downslope beds dip steeply to the east forming a small roll-over anticline. A few limestones in the upper part of the succession and around the periphery of the structure show little disruption except for angular chert clasts and apparent lack of uniform bedding, and these commonly are found near faults. We propose two alternative hypotheses: (1) these are fault breccias that have little apparent comminution or disruption, whereas the angular chert clasts within them show marked brittle deformation, or (2) some limestones were not lithified or were poorly lithified prior to the event, and silicification of the chert nodules was an early diagenetic process.

The significance of this fabric has some bearing on the interpreted age of the structure. How can coarse-grained limestones exposed at the surface not be lithified? It is possible that the impact occurred in shallow epeiric seas, prior to the subaerial exposure that would have lithified these strata. Karstification clearly post-dated the event, as we have seen and will see in subsequent stops. These aspects of the stratigraphy of the Weaubleau-Osceola structure suggest an age as old as Osagean for the event.

- 76.2 Roadcut near bridge abutment on south side of highway exposes Sedalia Formation. Cotter Dolomite is exposed near base of bridge.
- 76.8 TURN LEFT onto gravel road and park.

STOP 4. The Burlington-Keokuk ranges from undeformed to highly deformed in this locality. The uppermost strata of the roadcut are weathered, but lower strata are well preserved. One small tight fold and numerous broad folds and small thrust(?) faults are exposed in these roadcuts. A small paleokarst channel cuts deformed strata on both sides of the highway. Thin beds of rippled sandstone, shale, carbonaceous plant debris, and marcasite or pyrite are found in the channel (Figure I-6A). The sandstone shows only



Figure I-6. Photographs of roadcuts along Missouri Highway 82 (A), Ash Grove Aggregates quarry exposures (B, C), and roadcuts on Highway 13 (D-F). A, undeformed paleokarst channel at Stop 4 is filled with sandstone and shale. Arrows indicate the base of the channel. B, folds and fault in the high wall of Ash Grove Aggregates Osceola quarry (Stop 5) formed during formation of the transient crater. C, striae resembling stylolites are oriented in two directions on this boulder at Stop 5. D, roadcut through "Weaubleau Breccia" at Stop 6 contains a cobble of angular siltstone (n) derived from the Northview Formation. Other clasts include crinoid debris and angular pebbles of dark red chert. This facies of the breccia is interpreted as a fall-back product. E, nest of "Weaubleau eggs" or "round rocks" accumulated in a shale-filled paleokarst pocket at Stop 6, indicating that silicification preceded karstification. These spherical nodules commonly nucleate around clasts of siltstone from the Northview Formation. F, sandstone (s) laps onto a pod of angular chert breccia (c) of Pennsylvanian age at Stop 7. Hammer, for scale, is below left "s."

slight deformation, probably from differential compaction. Other smaller paleokarst features are present in these exposures, but they mostly are concentrated along the axes of synclines or along fracture zones in the deformed carbonate strata. The development of paleokarst clearly post-dates the deformational event.

- 80.1 TURN LEFT (south) onto Highway 13.
- 82.6 TURN LEFT (east) onto Highway TT.
- 83.8 TURN RIGHT onto gravel road and enter Ash Grove Aggregates quarry. Proceed to scale house. Please note, this is private property and special permission is required to visit this facility. *Do not attempt to visit this facility without prior authorization.*

We wish to maintain our excellent working relationship with Ash Grove Aggregates, so please heed a few rules: (1) *wear a hardhat in the quarry*, (2) *wear appropriate footwear*, (3) *wear protective eyewear for hammering and collecting rock samples*, (4) *do not walk or stand below the high walls of the quarry because they are heavily fractured and very dangerous*, (5) *be careful where you step because of the unstable nature of many of the loose blocks on the quarry floor*, (6) *no horseplay or unsafe practices will be tolerated*, and (7) *you must sign safety briefing statement of understanding in the scale house to proceed to the quarry*. One or more portable toilets are available only near the scale house.

STOP 5. The walls at the Ash Grove Aggregates Osceola quarry provide the single most extraordinary exposures of deformed strata in the entire Weaubleau-Osceola structure. Rockfalls are common in the quarry. To accommodate picture takers, one of the trip leaders will pose for scale, but for everyone else, we request that you remain at least 20 feet back from the high walls.

The east-facing high wall exposes two types of deformational fabrics: an upper brecciated and brittle, sheared carbonate domain overlying a ductily deformed zone of tight folds and thrust faults (Figure I-6B). The timing of brecciation in the upper domain remains sketchy. Fracturing and *in situ* brecciation may have briefly preceded development of the transient impact cavity. The uppermost sloping layers above the quarry walls are highly weathered and karstified, and we have not been able to confidently identify a fall-back component of the “Weaubleau Breccia.”

Silty shale and siltstone that appears to be derived from the Northview Formation are found along décollement surfaces and injected into pockets between broken layers. Yellow-weathering injection breccia is found throughout these exposures. It is somewhat coarser grained but bears remarkable resemblance to exposures of the “Weaubleau Breccia” that we will see at Stop 6. Is this then “Weaubleau Breccia?” Where can we place boundaries between rock units? The lower structural domain exposed on the high wall appears to have been compressed laterally and was likely deformed during formation of the transient cavity. Some of the faulting may be related to rebound and relaxation during the modification phase.

A few other features are worth noting. A poorly defined tight fold is exposed in the south quarry wall. In the western extension of this face, a steeply dipping stratum is inclined to approximately 40°W, a thin bed is tightly folded and faulted, and a monomict fault(?) breccia has been emplaced below the bed. On the quarry wall opposite the high wall, a lower pit exposes strata that are dipping gently to the north. The attitude of these strata may be related to formation of a rebounded central uplift that formed during the modification phase. Some pyrite and calcite mineralization pockets are found in loose blocks around the quarry. Multi-directional stylolitized cobbles are common throughout the quarry as well (Figure I-6C).

We will take a 30 minute break in the quarry for lunch.

86.1 TURN LEFT onto Highway 13.

87.4 TURN LEFT onto Highway T.

88.8 TURN LEFT into driveway and proceed to back of building. *Do not attempt to visit this private residence without prior authorization.*

Optional Stop. This house site overlooks the geometric center of the 19-km circular feature. We have yet to determine definitively if this was ground zero for the impact. The Humansville-Weaubleau Creek lineament runs north and south from the field below, and the face of the bluff to the northeast forms an east-west lineament that spans the structure. The intersection of these lines is approximately a quarter of a mile to the northwest.
RETURN TO MAIN ROAD.

89.1 TURN RIGHT onto Highway T and proceed west.

90.5 TURN LEFT onto Highway 13.

92.6 TURN RIGHT on County Road SE400 (west) and proceed to intersection with old Highway 13 [THIS IS A DANGEROUS INTERSECTION. CROSS-TRAFFIC DOES NOT STOP]. TURN LEFT (south) onto old Highway 13.

92.7 **STOP 6.** The “Weaubleau Breccia” is a polymict breccia exposed in a series of roadcuts along the west side of Highway 13. Only the uppermost part of the unit is exposed here, but it does not show any structural deformation other than minor irregular fractures. We interpret this stratigraphic unit as a fall-back component because lower levels of the breccia, recovered as core, contain smaller populations of exotic clasts and appear to have been more-or-less deformed and brecciated *in situ*. The “Weaubleau Breccia” is minimally a 210-ft-thick event bed that may have formed and accumulated over the course of a few minutes.

In collecting specimens from this exposure, we request that you sample float or slumped blocks that are out-of-place, because we have not fully documented the sedimentological characteristics of this unit. This roadcut provides a rare glimpse at an extraordinary type

of breccia, and although it is found over a few square miles, these are the only good exposures. We also respectfully request that you do not disturb the nest of “Weaubleau eggs” that lie at the base of a small shale-filled paleokarst pipe.

The characteristic yellow color in these exposures is due to weathering of iron-rich minerals. In part, these consist of octahedral pseudomorphs of hematite and goethite after magnetite(?). Other constituents include centimeter-sized angular clasts of white, red, dark brown, yellow-brown, and black chert; angular to subangular clasts of white, light yellow, and light gray-green siltstone; disarticulated crinoid and blastoid ossicles and rare calices; rare horn corals; rare dark carbonate clasts up to 5 cm long; tan dolomite clasts; and rounded quartz sand that ranges from fine to coarse grains with some granule-sized clasts. Some quartz grains appear to be yellow brown, and typically are referred to in impact literature as “toasted” grains. Clasts are dominantly supported by a matrix of fine lime mudstone to calcisiltite (Figure I-6D).

Conodonts from the “Weaubleau Breccia” include lower Ordovician (Ibexian), lower Mississippian, and middle Mississippian species as young as “Keokuk” (James F. Miller, 2003, personal communication). Blastoids and crinoids include middle Osagean to uppermost Osagean forms. In North America, blastoids experienced a major reduction in generic diversity at the Osagean-Meramecian boundary, so it is possible that this impact (and perhaps other impacts) occurred in shallow epeiric seas. Such an impact may have affected fauna on a regional to continent-wide scale (James F. Miller, 2003, personal communication).

Other accessory components include “round rocks,” which are actually spherical nodules of chert that have nucleated mostly around siltstone clasts from the Northview Formation. We colloquially refer to these as “Weaubleau eggs.” These nodules are common throughout the structure, serving as a proxy indicator for the presence of the fall-back component. Reports on CNN.com amplified a slight misquote from the Springfield News-Leader when it inferred that these “round rocks” were shot out like cannonballs by the impact. In our estimation, these do not represent large accretionary lapilli but rather formed diagenetically around siltstone particles that were blast products (along with the breccia matrix that later became silicified). The nest of “Weaubleau eggs” shows that silicification of the chert nodules preceded karstification of the unit (Figure I-6E). Gray clay shale fills many of the karst features.

Breccias from the MoDOT-SMSU Vista 1 core show a crude stratigraphic order that is similar to the undeformed strata, indicating that most of the upper rocks, below the fall-back component, were likely brecciated in place (Figure I-7). Some zones in the core appear to be composed of heavily sheared siltstone. Fluorite mineralization is present along some open fracture pores in the core. Just below the top of the Jefferson City-Cotter Dolomite, rounded granite clasts were encountered at about 220 feet depth. Normal depth to basement in this area is 1,400 feet. Granite was likely brought nearer the surface during resurgence of the central uplift during the modification phase. A small sample of this core will be available for inspection at the stop.

RETURN TO HIGHWAY.

92.8 AT INTERSECTION, TURN LEFT (north) on Highway 13.

94.4 **STOP 7.** Sandstones mapped as the Krebs Subgroup of the Cherokee Group are exposed in a low roadcut on the right. These undeformed, cross-bedded Pennsylvanian channel sands lap onto a white chert breccia unit that has a sandstone and red-clay matrix (Figure I-6F). Drilling of the MoDOT-SMSU Vista 2 borehole, less than 100 feet to the north, encountered approximately 70 feet of sandstone above chert breccia. Chert breccia overlies a gray shale unit that is similar to the karst-filling gray shales of Stop 6. Gray shale also fills the paleo-valley features north of Collins, where they are considered Dedrick Subgroup of the Cherokee Group. The ages of the Krebs Subgroup spans the Atokan through Desmoinesian. The shales, filling post-impact paleokarst and paleo-valleys, thus provide an upper limit on the age of the impact.

The highest deformed strata and youngest known fauna from the Weaubleau Breccia is Osagean in age. The oldest known rocks that are undeformed are either Atokan or Desmoinesian. Meramecian, Chesterian, and Morrowan are missing either by erosional truncation or non-deposition. If faunal ages are accurate, the age of impact would be very near the top of the Osagean. If karstification occurred only following sea level fall at the base of the Pennsylvanian, it would suggest a somewhat younger event. In round figures this provides an age of approximately 340-320 Ma. It is likely that strata correlative to this event will be found in more complete stratigraphic sections.

CONTINUE NORTH ON HIGHWAY 13.

95.0 TURN LEFT ON COUNTY HIGHWAY V.

95.7 Enter village of Vista.

95.8 TURN RIGHT on Highway V.

95.9 Sandstone outcrops on left.

97.2 Highway V exits to left and Highway WW continues on as main road. PROCEED ON HIGHWAY WW.

99.5 AT INTERSECTION, TURN LEFT on Highway 82.

101.0 **STOP 8.** Overlook at roadside park highlights the scenic beauty of this area. The confluence of the Osage and Sac rivers lies below towering bluffs of Osagean carbonates. “Round rocks” are found in residuum above the cliffs and below the Pennsylvanian sandstone beds that crop out at road level. Spherical chert nodules have been used as folk-art decorative elements in concrete statuary around the Osceola area. Note the very large nodules on the walking bridge and smaller ones set in mortar around the low bench with



Top=29.4'

Fall-back component

Dominantly Burlington Limestone material

Abundant Northview Formation siltstone emplaced(?)

Reddish carbonates and chert from the Sedalia Formation

Compton(?) Limestone material
Bachelor Formation sandstone
Dominantly Cotter Dolomite clasts

Mostly dolomite

Isolated melt(?) material

Granitic crystalline breccia

TD=247.8'

Figure I-7. MoDOT-SMSU Vista 1 core of "Weaubleau Breccia." The top is at the upper right, the bottom is at the lower left (247.8'), and each of these 44 segments is approximately five feet long. The crude stratigraphy of the "Weaubleau Breccia" mimics the normal succession. This indicates that clasts below the fall-back facies were not transported as ejecta, which would invert stratigraphy, but were brecciated virtually in situ.

the granitic inset with the north arrow and elevation. This is the last stop of the field trip, but additional information is provided below for the return trip to Springfield. TURN AROUND AND PROCEED EASTWARD ON HIGHWAY 82.

- 102.3 Cross intersection with Highway WW.
- 103.7 TURN LEFT at intersection onto Business 13.
- 103.8 TURN RIGHT into MODOT facility. This concludes the impact geology portion of this field trip. RETURN TO SPRINGFIELD via Highway 13.
- 127.5 To the left, a quarter- to half-mile-wide swath of broken and uprooted trees were hit by the devastating tornado that nearly flattened Stockton, Missouri, on May 3, 2003. Another tornado on the same evening destroyed much of Pierce City, Missouri, to the west-southwest of Springfield.
- 154.2 Roadcut on the left side of the highway exposes the contact between Cotter Dolomite and Compton Limestone. The angular discordance of two to three degrees below the unconformity may indicate that the earliest phases of uplift on the Ozark Dome preceded Kinderhookian time. Silurian and Devonian units were deposited across this area but had been removed by erosion prior to deposition of Mississippian strata.
- 154.7 Roadcuts on both sides of the highway expose a thick succession of resistant siltstone beds that constitute the Northview Formation. The thickness of this unit varies from a few feet to 80 feet. Thompson (1986) regarded the thick trough-like accumulations around Lake Stockton as the Northview Basin. The distribution of disparate thicknesses may reflect tectonism associated with early stages of the Ouachita orogeny. It is conceivable that the Northview accumulated in a back-bulge basin, while thick successions of mixed carbonates and siliciclastics were deposited in the more rapidly subsiding foreland basin that was developing in northern Arkansas.
- 165.0 MERGE INTO LEFT LANE, CROSS OVERPASS, AND TURN LEFT onto Interstate 44.
- 167.5 TAKE EXIT RAMP ON RIGHT to Glenstone Avenue.
- 168.0 MERGE INTO LEFT LANE AND TURN LEFT at signal onto Evergreen Street.
- 168.2 TURN RIGHT into Lamplighter Inn. END FIELD TRIP.

ADDENDUM February, 2004

Field trip guidebooks, even more than most other types of scientific publications, reflect works in progress. In the preceding pages we presented evidence for a meteorite impact site near the towns of Weaubleau and Osceola as we understood it in September, 2003. New evidence from Shuttle Radar Topography Mapping (SRTM) indicates that this feature is highly eccentric (Figure I-8, below). This new map has focused our efforts to more accurately describe the range of deformational styles across this feature. Undoubtedly, continued field mapping will reveal many additional nuances.

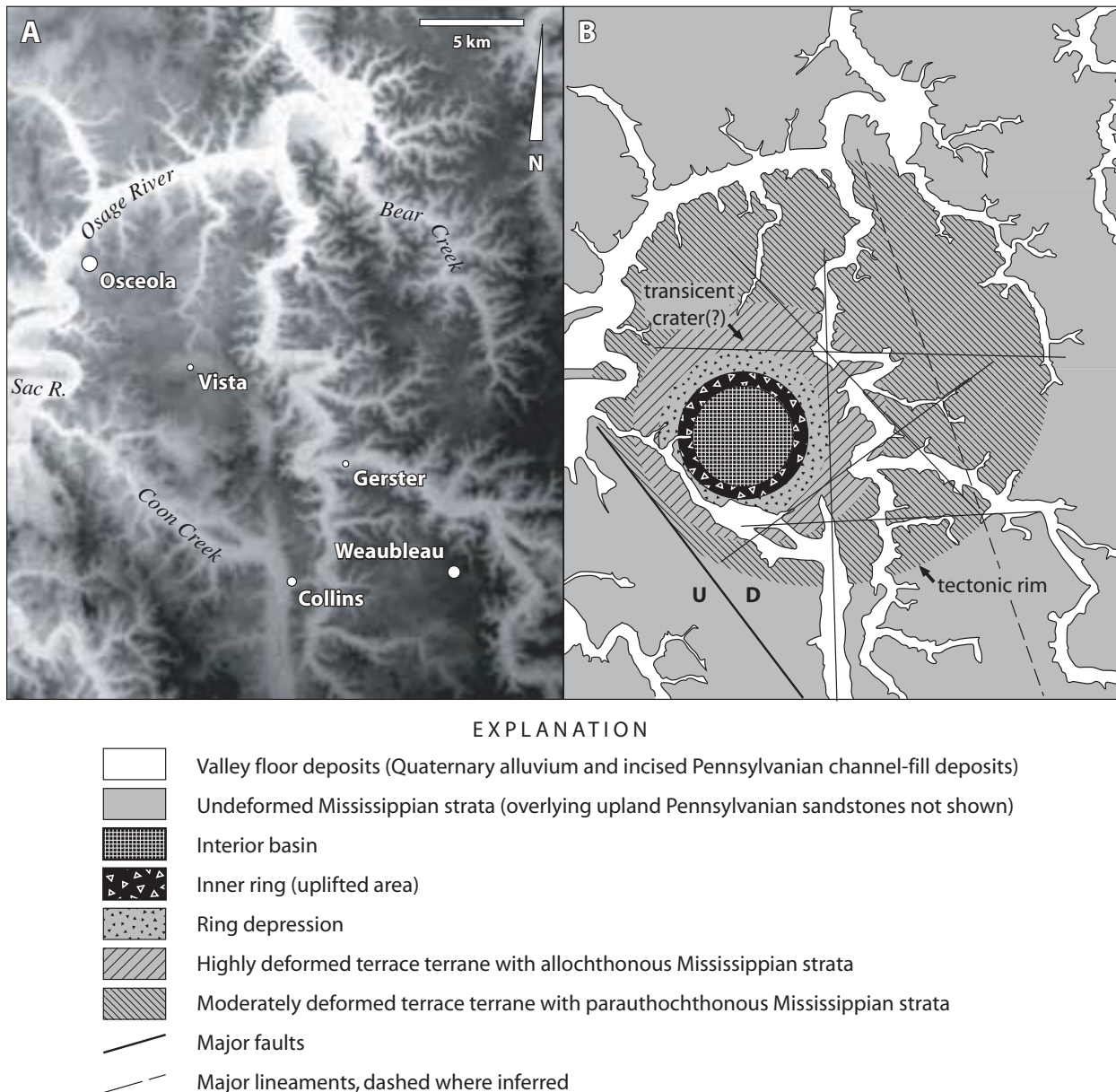


Figure I-8. A, Shuttle Radar Topography Mapping (SRTM) image of the Weaubleau-Osceola impact site. Topographic highs are shown in darker colors and lighter colors represent lower surface elevations. B, interpretive deformation map of the impact site. The far-field deformation extends from the semi-circular drainages of Coon Creek in the Southwest, Sac and Osage river valleys in the northwest, and Bear Creek in the northeast. Structural relief coincident with the circular feature defines the tectonic rim. The extent of the transient crater was probably near the outer margin of the ring depression.

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Association of Missouri Geologists
2003

***Field Trip II: The Rader Spring Karst System,
Greene County, Missouri***

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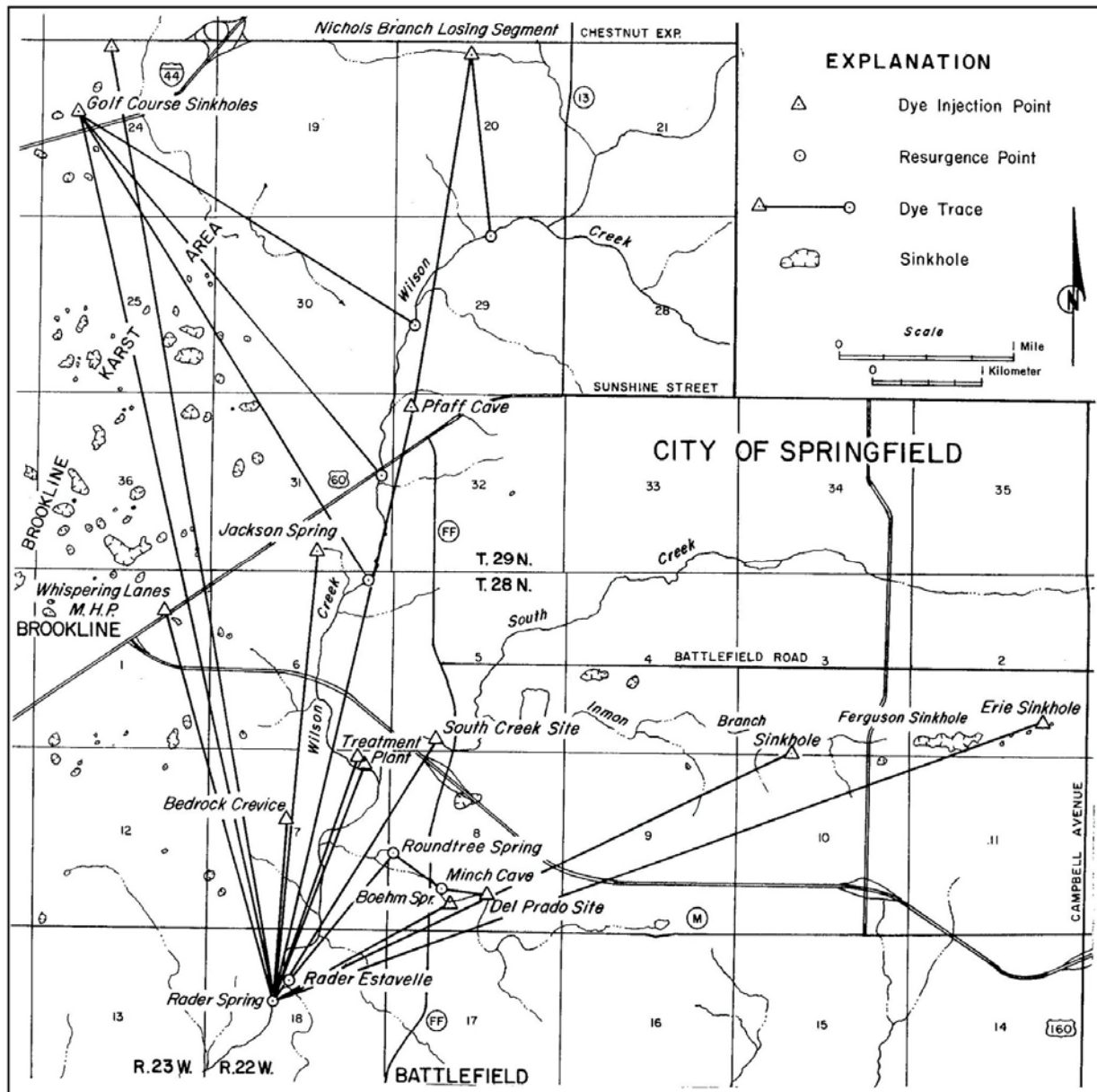


Figure II-1. Map of the area southwest of Springfield, Greene County, Missouri, showing water traces to the Rader Spring Karst System (from Thompson, 1997).

ROAD LOG (distances in miles)

This road log starts from the parking lot at the intersection of Hammons Parkway and Grand Street on the campus of Southwest Missouri State University in Springfield, Missouri. Proceed to the exit of the parking lot and TURN LEFT (south), proceed south on Hammons Parkway. (Distances are in miles.)

- 0.1 Grand Street, TURN RIGHT (west).
- 0.4 Kimbrough Avenue, TURN LEFT (south).
- 1.4 Sunshine Street, TURN RIGHT (west).
- 1.8 Campbell Avenue, TURN LEFT (south).
- 2.9 Crossing Sunset Street, continue south on Campbell.
- 3.4 Crossing Battlefield Street, continue south on Campbell.
- 3.7 Erie Street to the right, TURN RIGHT (west) onto Erie and proceed west.
- 4.0 Erie Street and Ertis Avenue.

STOP 1. ERIE SINKHOLE. This sinkhole has been traced to Rader Spring (Figure II-1), the largest spring in Greene County. In this sinkhole, soil has been cleaned out and provisions made to allow runoff from the east to gain easy access to subsurface conduits, in effect using the sink and subsurface as a portion of the storm sewer system for Springfield. During heavy rain events, Erie Street turns into a channel and carries water from channels that cross Campbell Avenue to the east. In addition, the runoff from the Wal-Mart parking lot to the south flows into a sinkhole detention basin and its overflow goes into this sinkhole. If the capacity of the sinkhole is exceeded, the water will flow down the valley and into Ferguson Sinkhole to the west. This happened during the 100 year storm event of September 24-25, 1993, and several homes were flooded. These homes have since been purchased and removed by the city to provide a floodway. Erie Sinkhole drains an area of 390 acres to the east. This area is also highly developed in both residential and commercial properties. Return to vehicles and proceed north on Ertis Avenue.

TURN RIGHT (north) onto Ertis.

- 4.1 Montclair Street, TURN LEFT (west) onto Montclair.
- 4.2 Dayton Avenue, continue west on Montclair Street.
- 4.3 Pinehurst Avenue, TURN LEFT (south) onto Pinehurst.

4.4 Rockwood Street, TURN RIGHT (west) onto Rockwood.

4.5 Danbury Avenue and Rockwood Street. Observe the sinkhole on the left, just to the west of a house. This is an unstable area in which subsidence of the sinkhole severely damaged a house. There was a house occupying the vacant lot which subsided enough that it was condemned and removed. The one on the left has been stabilized.

Continue west on Rockwood.

4.6 Parkhill Avenue and Rockwood Street.

STOP 2. FERGUSON SINKHOLE. This sinkhole extends to the west to Kansas Avenue. Ferguson sink is a very large solutional sinkhole which actually has several “eyes”. Three or four of these have been modified to maintain their openings and keep water flowing into the subsurface. The sinkhole is about 22 acres in size and drains about 281 acres, most of which has been developed into residential neighborhoods. The sinkhole has gentle sloping sides ranging from 8.75 percent to 1.33 percent. The sinkhole presently has been cleaned up and has grass growing in it. The western portion has had fill removed from it, and the southern portion has been filled in the past. At present this sinkhole is draining fairly well. Water does not stand very long.

The Erie-Ferguson complex actually takes water from about 670 acres of land. Several small sinkholes have been found within the large sinkhole on the south side quite near the sinkhole “eye.” At the low point in the sinkhole a vertical pipe has been placed to allow water to gain access into the subsurface. The pipe stands above the floor of the sink by several feet. A gravel area just to the west of Ferguson Avenue near the bottom of the sinkhole is an area which has been protected with shot rock to be able to accept water from storms. Another area like this has been modified in a similar manner on the west side of Parkhill Avenue. As previously discussed, Erie Sinkhole has been traced to Rader Spring and probably Ferguson Sinkhole is also connected.

During the 100-year storm event of September 24-25, 1993, Ferguson Sinkhole flooded to an elevation of approximately 1247.5 feet. About seventeen homes were flooded during this event. To protect the public, Springfield Public Works purchased twenty-two homes which have been removed. Ferguson Avenue has been terminated at the sinkhole as is Franklin Avenue. Now Ferguson and Franklin have been connected to Parkhill Avenue with Rockwood as a cross street. This will generally keep traffic off of the sinkhole floor. In addition, a storm channel has been constructed connecting Ferguson Sinkhole with Erie Sinkhole. A detention basin is also built on the south end of a city park north of and between the two sinkholes. The entire area is a Public Works Park and will be maintained in grass.

TURN LEFT (south) onto Parkhill.

4.7 Walnut Lawn Street. Stop, TURN RIGHT (west) with caution onto Walnut Lawn.

- 5.2 Kansas Avenue. Stop, proceed west with caution on Walnut Lawn.
- 5.3 Large sinkhole visible on the left side of the road. The area is being developed and the sinkhole is supposed to be protected. Observe large sinkhole to the south of Walnut Lawn Street, about 850 feet west of Kansas Avenue. This sinkhole is a classic solutional doline which has the low point 23.5 feet below the low rim elevation. The sinkhole is 350 feet by 250 feet and occupies 1.39 acres. A small collapse was observed in the northeast part of the sink in 1992. It was about 10 feet deep and about 12 feet in diameter. The sides of it were vertical and no bedrock was observed in the hole. This sink has drained well in the past and reports from the neighbors indicated that water seldom stands very long in the bottom. This sinkhole serves as the access to the shallow ground water system for water draining from 6.85 acres of land to the south. It is probably part of the Rader Spring System.

Just to the west of the large sinkhole is a smaller one which is currently being encroached upon, and because Walnut Lawn is to be enlarged, it will probably be modified a bit. Walnut Lawn was diverted on the north side of the sinkhole to protect it. The center of the sink is about 180 feet east of Kansas Expressway. The relatively flat floor of this roughly circular bowl-shaped depression is about 3 feet below the rim elevation. The diameter of the sinkhole is 175 feet by 110 feet and it occupies 0.34 acres. Prior to the construction of Walnut Lawn, the vegetation in and around this sinkhole was removed to expose it better. This sinkhole also serves as the access to the shallow ground water for runoff from 6.17 acres of surface area to the south.

- 5.4 Kansas Expressway. Obey traffic light, then TURN LEFT (south) onto Kansas Expressway.

It should be noted that another sinkhole was located at this intersection. It was filled during the construction of Kansas Expressway.

- 6.1 On-ramp to James River Freeway (US-60), TURN RIGHT (west) and enter the freeway.
- 8.4 Off-ramp to FF highway. Leave the freeway and follow the ramp to southbound FF.
- 8.7 FF Highway, TURN LEFT (south) and proceed with caution.

FF Highway Cave is located directly below the westbound lane of the James River Freeway, just to the west of FF Highway. It was discovered when exploration was done by drilling for the James River Freeway. Later the contractor working on the highway dug open the natural entrance to the cave. It was located in a sinkhole to the north of where the drill hole had gone into the roof of the cave. The cave is just over 500 feet long and extends nearly due south and then to the southeast from the entrance to a sinkhole which has since been removed because it is in the eastbound lane of the freeway. During the construction of the James River Freeway, 200 feet of the cave

was destroyed by the Highway Department by excavating the roof from the cave. The water flow route was preserved during construction as well as 300 feet of a relatively small cave near the old sinkhole.

- 8.9 Road into the Southwest Wastewater Treatment Facility. Entrance to Southwest Wastewater Treatment Plant. During construction of the facilities, several solutional features were found in the area of the facility, including three caves.
- 9.2 Farm Road 168, TURN RIGHT (west) and follow 168.
- 9.4 Junction of Farm Road 123 and 168, continue west on 168.
- 9.8 Greenway Trail, turn left into parking lot and park.

STOP 3. ESTEVELLE AND KARST WINDOW. We will walk south along the Greenway Trail to an estevelle along Wilson Creek. Here, during periods of low precipitation, water from Wilson Creek is diverted to the east and disappears into the ground at this location. No traces have been made, but the water probably flows to Rader Spring. Further along the Greenway Trail on the east side of Wilson Creek about 200 yards to the north of M Highway is a collapse in the floodplain revealing a karst window with water flowing through it. It too probably connects into the Rader Spring system.

Return to the vehicles and return to Farm Road 168, TURN RIGHT (east) and proceed east.

- 10.2 Farm Road 123, TURN RIGHT (south).
- 10.3 Roundtree Spring on the left. Roundtree Spring is a perennial spring. The owner, Mr. Ford Carr, states that he has been into the spring/cave and that it extended to the south and east. From the entrance a low water crawl was described to extend to the south and then to the east. The owner said that there were several rooms and some nice decorations. I asked about any cave life and he said that he only saw white crayfish. The direction seems logical because there is a 60-ft-diameter sinkhole to the east-southeast of the cave near the owner's house. This is a solutional sinkhole that shows no evidence of collapse at this time. It has been partially filled with construction demolition and soil.

Minch Cave can be found just east of FF Highway and 1,280 feet north of highway M. Entrance is through a well which drops initially 15 feet and then a climb down for a total of 24 feet to a stream bed below. The elevation of the stream channel is 1,160 feet, just a bit above the level of Roundtree Spring. Taylor (1970) describes the cave: "From the entrance, the cave extends to the north and then bears to the west at the end of the surveyed section. A stream flows from the south behind the north wall of the cave and exits to the west. A past fluorescein dye trace indicated that the water flows

out of Roundtree Spring, about 1,900 feet to the west. The cave has large breakdown boulders and is bounded on the south throughout its surveyed length by a wall of breakdown boulders and blocks. The passage extends both to the south and to the west along the stream, but with only 3 to 4 inches of air space it could not be explored further.”

A collapsed cave system was found along Roundtree Branch about 700 feet east of Highway FF. The feature was on the north side of the branch and consisted of an elongated shallow sinkhole with bedrock walls. Water tracing also indicates that Roundtree Spring connects to Rader Spring. Rhodamine WT was introduced into Boehm Spring just to the south of Minch Cave and was recovered in Rader Spring.

- 10.7 M Highway (Republic Road). Stop, TURN RIGHT (west) and proceed with caution.
- 11.5 Farm Road 174, TURN LEFT (south).
- 11.7 Locked gate. This property is owned by Tony Earl. For our AMG field trip on September 26, 2003, we have permission to unlock the gate and drive down the dirt road to Rader Spring. Anyone following this roadlog after September 26, 2003 should obtain permission separately before proceeding to Rader Spring.

STOP 4. RADER SPRING AND RADER ESTEVELLE. The following account is taken from Vineyard and Feder (1982) with additional comments added liberally throughout:

Rader Spring is on the west bank of Wilson Creek about 5 miles south-southwest of Springfield. The spring issues from a series of openings along enlarged joints in the Burlington-Keokuk Limestone. A pool has developed along the base of a low bluff and the spring branch empties into Wilson Creek a short distance from the spring.

The discharge of Rader Spring ranks third among the springs on the Springfield Plateau and second among those in the White River basin. A description of the spring and its relation to Wilson Creek and karst features of the area is given in a paper by Harvey and Skelton (1968). However, at that time only about one-half the flow of the spring was natural because the discharge of the spring was augmented by treated sewage effluent from the Springfield Southwest Treatment Plant. Subsequent improvements eliminated the effluent loss problem, with a corresponding decrease in the flow of Rader Spring and an improvement in the quality of its water.

Recent hydrologic investigations, including those of Harvey and Skelton (1968), Vineyard and others (1969), and Vineyard (1970), have revealed a remarkable underground drainage system in the Wilson Creek valley south and west of Springfield. Rader Spring is the master resurgence for an extensive area drained by sinkholes. Water tracing by Harvey and Skelton (1968) showed that, prior to the construction of a tertiary treatment lagoon below the Springfield Southwest Treatment

Plant, effluent from the plant was lost into a losing reach of Wilson Creek and reappeared in Rader Spring. Results of further dye tracing by Vineyard and others (1969, p. 25) showed that Rader Spring also receives increments of flow from several other sources on the limestone plateau in the vicinity of Springfield.

The City of Springfield occupies an upland region underlain by the Burlington-Keokuk Limestone and drained primarily by Wilson Creek and its major tributaries. Sinkhole drainage passes through a shallow groundwater system and resurges at Rader Spring. One large sinkhole (Erie Sinkhole) drains an area of approximately 200 acres. Storm water drainage is readily accepted by this sinkhole, although occasionally after heavy precipitation it fills with water and floods the surrounding residential area. Fluorescein dye injected into the sinkhole following approximately 2 inches of rainfall during the preceding 24 hours reappeared in Rader Spring—about 5 miles away—within 72 hours.

South Creek is a permanent stream until it begins to lose water in sinkholes in the streambed about a quarter mile above the point where it empties into Wilson Creek. The position of these swallow holes varies from time to time as small subterranean channelways are filled and others are opened by changing conditions imposed by floods on the stream. However, South Creek discharges into Wilson Creek as a surface stream only in times of plentiful rainfall; at other times, the water is pirated underground into channelways that resurge in Rader Spring. Three pounds of fluorescein dye was injected in South Creek (SW1/4, SE1/4, SE1/4, SE1/4, Sec. 6, T.28 N., R.22 W.) at a time when the entire flow of South Creek was being pirated to underground drainageways through a small swallow hole in the north bank of the stream. Most of the time South Creek is dry in the reach of the stream from FF Highway bridge over South Creek and the Southwest Treatment Plant. On October 29, 1968, the flow of South Creek entering the swallow hole was estimated to be 0.5 cfs. Charcoal packets were placed in several possible resurgences along Wilson Creek, in Rader Resurgence-Sink and in Rader Spring. At the time, Rader Resurgence-Sink was accepting a flow of about 0.3 cfs from Wilson Creek. The dye was visually detected in Rader Spring on October 31, 1968 at approximately 8:00 am. The dye was injected at 5:00 pm on October 29, 1968. The time of travel from South Creek to Rader Spring was approximately 39 hours to travel a distance of about 2 miles straight line. Dye was also introduced into a sinkhole along Farm Road 164 in Section 3, T.28 N., R.22 W. in July of 1986 and a weak recovery was indicated at Rader Spring 14 days later.

About 4 miles north of Rader Spring is Pfaff Cave, which has a sinkhole entrance about 500 feet east of Wilson Creek. A stream flows through the cave at a level about 25 feet below the bed of nearby Wilson Creek. This stream has been traced to Rader Spring. Fluorescein dye required approximately 39 hours to cover the 4 miles between Pfaff Cave and Rader Spring. This test was conducted during a time of high flow through the system, and during low flow periods the travel time would be expected to be somewhat less. Rhodamine WT was injected into a losing stream segment on Nichols Branch (SE1/4, NE1/4, NE1/4 Sec. 20, T.29 N., R.22 W.) and recovered in

both Pfaff Cave and Rader Spring to the south. A trace was done from Wilson Creek (SW1/4, SE1/4 Sec. 31, T.29 N., R.22 W.) and recovered at Rader Spring, a distance of 2.3 miles.

On October 18, 1988, Tom Aley introduced 5 pounds of 20% Rhodamine WT dye into a backhoe pit at the approximate site of a catastrophic sinkhole collapse that had formed in 1986 on a golf course just north of Interstate Highway 44. At the same time a second injection of fluorescein dye was made in another excavated catastrophic collapse on the golf course south of the first. The fluorescein was recovered in Rader Spring in 17 to 24 days. It was also recovered in several places along Wilson Creek to the north. The Rhodamine WT was recovered at Rader Spring in 24 to 32 days.

Harvey and Skelton (1968) recorded a travel time of approximately 5 ½ hours for treated sewage effluent to travel between the Springfield Southwest Treatment Plant and Rader Spring, a distance of 1.35 miles. Water traces were done by Harvey and Skelton (1968) from Rader Resurgence-Sink during periods of both high base flow and low base flow. In both cases the water passed underneath the creek and reappeared at Rader Spring. Rader Spring also receives increments of flow from the extensive sinkhole topography lying west of Wilson Creek and north-northwest of the spring. Sinking streams and sizable caves are known to exist in this area (Thomson, 1970). Tracing done by Bill Duley of the Department of Natural Resources from the Whispering Lanes Mobile Home Park in 1985 indicated dye introduced into the waste water treatment plant was recovered at Rader Spring eight to fifteen days later after traveling a distance of 2.5 miles.

Perhaps the most unusual characteristics of Rader Spring and its supply system are the reversible sinkholes or estavellas that occur in the Wilson Creek valley. These curious karst features accept water in drier seasons and discharge water as springs during rainy seasons. They are probably much more common than would be suggested by references to them in literature. Rader Spring rises along a prominent joint in the Burlington-Keokuk Limestone, aligned approximately N. 30° E. About a quarter mile away, in direct line with the joint forming Rader Spring, there is a reversible sink called Rader Resurgence-Sink. This small sinkhole is connected with nearby Wilson Creek through a small channel. During periods of normal flow on Wilson Creek, water flows from the creek down the channel and into Rader Resurgence-Sink, generally forming a small whirlpool. However, during rises on Wilson Creek the flow is reversed, a boil forms in Rader Resurgence-Sink, and water is discharged into Wilson Creek. Similar situations exist with regard to other reversible sinkholes farther upstream. There are two such features in the vicinity of the new tertiary treatment lagoon at the Springfield Southwest Treatment Plant. The most spectacular of these is at the toe of the north dike enclosing the lagoon. This feature is called Oval Sink. Oval Sink, being farther upstream, seldom reverses its flow, but when it does, it produces a sizeable spring that discharges into nearby Wilson Creek. At times of low flow, standing water is always observed in the Oval Sink at about the same level as water in Wilson Creek. That the creek and Oval Sink are hydrologically connected through

relatively open solution channels is shown by the occasional presence of river fish and turtles in the waters of the sink.

Analysis of the flow pattern of Rader Spring and the several reversible sinkholes along Wilson Creek gives insight into the functioning of this groundwater drainage system. The relative openness of the solution channels contributing flow to Rader Spring is shown by the rapid travel time of water traced by fluorescent dyes from various places in the Wilson Creek basin. The capacity or volume of the subterranean channel ways can be approximated by considering the sequential reversal of flow in the resurgence sinks. For example, a relatively small rainfall is sufficient to cause reversal of flow in Rader Resurgence-Sink, and this type of reversal is propagated sequentially upstream until the Oval Sink becomes the last in the series to reverse its flow. A large amount of rainfall in a relatively short time is required to cause Oval Sink to resurge. Pfaff Cave, several miles farther upstream, is a similar feature, but it has never been known to reverse flow because it is considerably closer to the headwaters of the stream and is much deeper than the reversible sinkholes in the lower reaches of the Rader Spring supply system.

Situations similar to that of the Rader Spring supply system may be expected in other parts of the Ozarks where similar geologic and hydrologic conditions exist. Further study of the system is likely to reveal more details of the spring supply systems and the functioning of the various segments of the system.

Return to Farm Road 174 and follow it north.

12.5 0.0 M Highway (Republic Road). Stop, TURN LEFT (west) and proceed with caution.

14.5 2.0 ZZ Highway, TURN LEFT (south).

16.0 3.5 Farm Road 182, TURN RIGHT (west).

17.2 4.7 Nau Farm on the left (south). This property is owned by Mary Nau. For our AMG field trip on September 26, 2003, we have permission to park in the barn lot and walk to Panther Cave. Anyone following this roadlog after September 26, 2003, should obtain permission separately before proceeding to Panther Cave.

STOP 5. PANTHER CAVE PIRACY. Panther Cave is at the bottom of a 40-ft-deep canyon which starts to descend at the road and continues to the east, then curves to the south and finally to the west. This sinkhole drains approximately 800 acres of land in the northeast portion of the city of Republic. Most of this land is developed as housing tracts and hence the amount of impervious area in the drainage basin has been substantially increased. Calculations for the drainage basin indicate that for the 100-year, 24-hour storm event, 378.89 acre feet of water would enter the sinkhole. The volume of the sinkhole was calculated and found to be 9.75 acre feet. This would be 2.6 percent of the 100-year, 24-hour storm event. Fortunately the sinkhole drains well

and very few storms will overflow the sinkhole basin. No water traces have been made from this site, but it is assumed that the water will be traced to numerous springs along Shuyler Creek and near Wilson Creek Battlefield to the east-southeast.

Return to the vehicles and follow Farm Road 182 back to the east, ZZ Highway to the north, Republic Road to the east, and Campbell Avenue to the north to return to Springfield. END FIELD TRIP

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Association of Missouri Geologists
2003

***Field Trip III: Ordovician and Mississippian Stratigraphy
and Structural Geology of the Springfield-Branson Area,
Southwestern Missouri***

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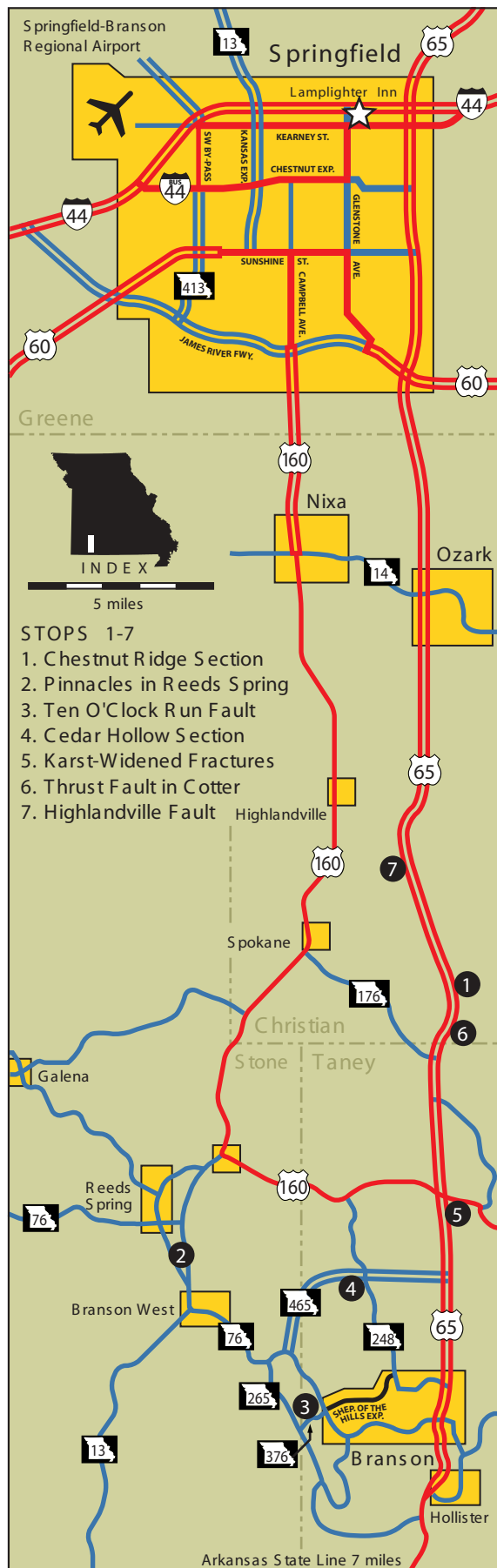


Figure III-1. Index map of the Springfield-Branson area showing route and location of stops for Field Trip III.

INTRODUCTION

Since the 1980s, tourism-driven development has prompted construction of several new sections of highway between Springfield and Branson, Missouri. New roadcuts provide exceptional exposures of the lower Ordovician and lower and middle Mississippian strata of this region. This field trip is designed to highlight some of the best new exposures along US Highway 65 and Missouri highways 13 and 465 in the area north of Branson (Figure III-1). Rock units to be examined include the lower Ordovician Cotter Dolomite, the lower Mississippian (Kinderhookian) Bachelor Formation, Compton Limestone, and Northview Formation, and the middle Mississippian (Osagean) Pierson Limestone, Reeds Spring Formation, Elsey Formation, and Burlington Limestone (Figure III-2).

MISSISSIPPIAN	Chesterian Series	Vienna Limestone Fayetteville Formation/Tar Springs Sandstone Glen Dean Formation Batesville Formation/Hardinsburg Formation Hindsville Limestone/Golconda Formation Cypress Formation Paint Creek Formation Yankeetown Sandstone Renault Formation
	Meramecian Series	Aux Vases Sandstone Ste. Genevieve Limestone St. Louis Limestone Salem Formation Warsaw Formation
	Osagean Series	Keokuk Limestone Burlington Limestone Elsy Formation /"lower Burlington" Reeds Spring Formation /Fern Glen Fm. Pierson Limestone
	Kinderhookian Series	Chouteau Group Northview Formation Sedalia Formation/"McCrane Limestone" "Chouteau Limestone" Compton Limestone Bachelor Formation /Hannibal Shale Horton Creek Limestone Bushberg Sandstone
ORDOVICIAN	Cincinnatian Series	Leemon (Noix Ls.) Formation Maquoketa Group Cape Limestone
	Mohawkian Series	Kimmswick Limestone Decorah Group Plattin Group "Pecatonica Formation" Joachim Dolomite Dutchtown Formation St. Peter Sandstone
	Whiterockian Series	Everton Formation
	Ibexian Series	Smithville Dolomite Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite

Figure III-2. Stratigraphic units of Ordovician and Mississippian age in Missouri (adapted from Thompson, 1986, 1991, 1995). Units exposed in the area of Field Trip III are indicated in bold type.

ROAD LOG (distances in miles)

- 0.0 Intersection of Interstate Highway 44 and U.S. Highway 65. Proceed south on US-65.
- 2.7 The Springfield metropolitan area (to the right) is located on top of the Springfield Plateau, a relatively flat, topographically high region underlain by the middle Mississippian (Osagean) Burlington Limestone. Much of the precipitation falling on this plateau drains into the subsurface, and karst topography is locally well developed (Field Trip II).
- 8.4 Intersection with U.S. Highway 60. Proceed south on U.S. Highway 65.
- 10.8 Enter Christian County.
- 15.5 Intersect Missouri Highway 14; the town of Ozark is just to the east. Proceed south on US-65.
- 16.0 Cross Finley River.
- 21.0 Intersect Christian County Highway EE; Highlandville is 3 miles to the west. Proceed south on 65.
- 23.0 At this point we are starting to descend off the south edge of the Springfield Plateau. From here to Branson we will be in the typical Ozark “hills and hollars” topography developed on the formations that underlie the Burlington.
- 28.2 Intersect Christian County Highways A and BB. Proceed south on US-65.
- 29.1 **STOP 1. ORDOVICIAN AND MISSISSIPPIAN STRATIGRAPHY, CHESTNUT RIDGE SECTION** (Day 7 ½’ quadrangle, SE ¼, SE ¼, Sec. 27, T 25 N, R 21 W; UTM-NAD27: 480450mE, 4076088mN; UTM-WGS84: 480440mE, 4076299mN)
- The major roadcut on the east side of the northbound lane of US-65 exposes a total of 170 feet of strata, the uppermost 110 feet of the Ordovician Cotter Dolomite and the lowermost 60 feet of the Mississippian (Kinderhookian and Osagean) section (Figures III-3 and III-4).
- Thompson and Fellows (1969, Section M) published a measured section for the Mississippian strata exposure on the west side of the highway at this location as it existed before the highway was widened to four lanes.
- Continue south on US Highway 65.
- 30.3 Enter Taney County.
- 31.1 Intersect Missouri Highway 176 west. Proceed south on 65/176
- 32.0 Missouri Highway 176 exits to the east (toward Rockaway Beach). Proceed south on US-65.
- 33.5 Cross Bear Creek.
- 33.9 Roadcut through Bear Mountain exposes a thick sequence of Cotter Dolomite on both sides of the highway. Thompson (1991, Figures 26A and 27) published a measured section



Figure III-3. Roadcut on east side of US-65, 1.3 miles north of Christian/Taney County line. The Ordovician/Mississippian unconformity is exposed as a prominent bench approximately 100 feet above road level.

for the exposure on the west side of the highway as it existed at this location before the highway was widened to four lanes. Davis discusses the special benching of the new roadcuts at this location to prevent rockfalls from reaching the highway. (See “Engineering Geology of the U.S. Highway 65 and Missouri Route 465 Corridors, Christian and Taney Counties” by George Davis, included later in this guidebook.)

- 34.8 0.0 Intersect US-160. TURN RIGHT (west) onto US-160.
- 38.6 3.8 Missouri Highway 248 enters from the left (south). Proceed west on 160/248.
- 40.5 5.7 Enter Stone County.
- 43.4 8.6 Reeds Spring Junction. Missouri Highway 13 enters from the north and US-160 exits to the north. TURN LEFT onto 13/248 and proceed southwest toward the town of Reeds Spring.
- 44.2 9.4 Missouri 248 exits to the right (west) to the town of Reeds Spring. Continue south on Missouri Highway 13.
- 46.2 11.4 Missouri Highway 76 enters from the right (west). Continue south on combined Missouri highways 13 and 76.
- 47.0 12.2 **STOP 2. KARST CUTTERS AND PINNACLES IN THE REEDS SPRING FORMATION** (Garber 7 ½' quadrangle, NE ¼, SW ¼, Sec. 1, T 23 N, R 23 W; UTM-NAD27: 466607mE, 4064012mN; UTM-WGS84: 466598mE, 4064218mN)

Cutters and pinnacles are well developed in the Reeds Spring Formation at this locality (Figure III-5). The Reeds Spring Formation contains abundant chert nodules

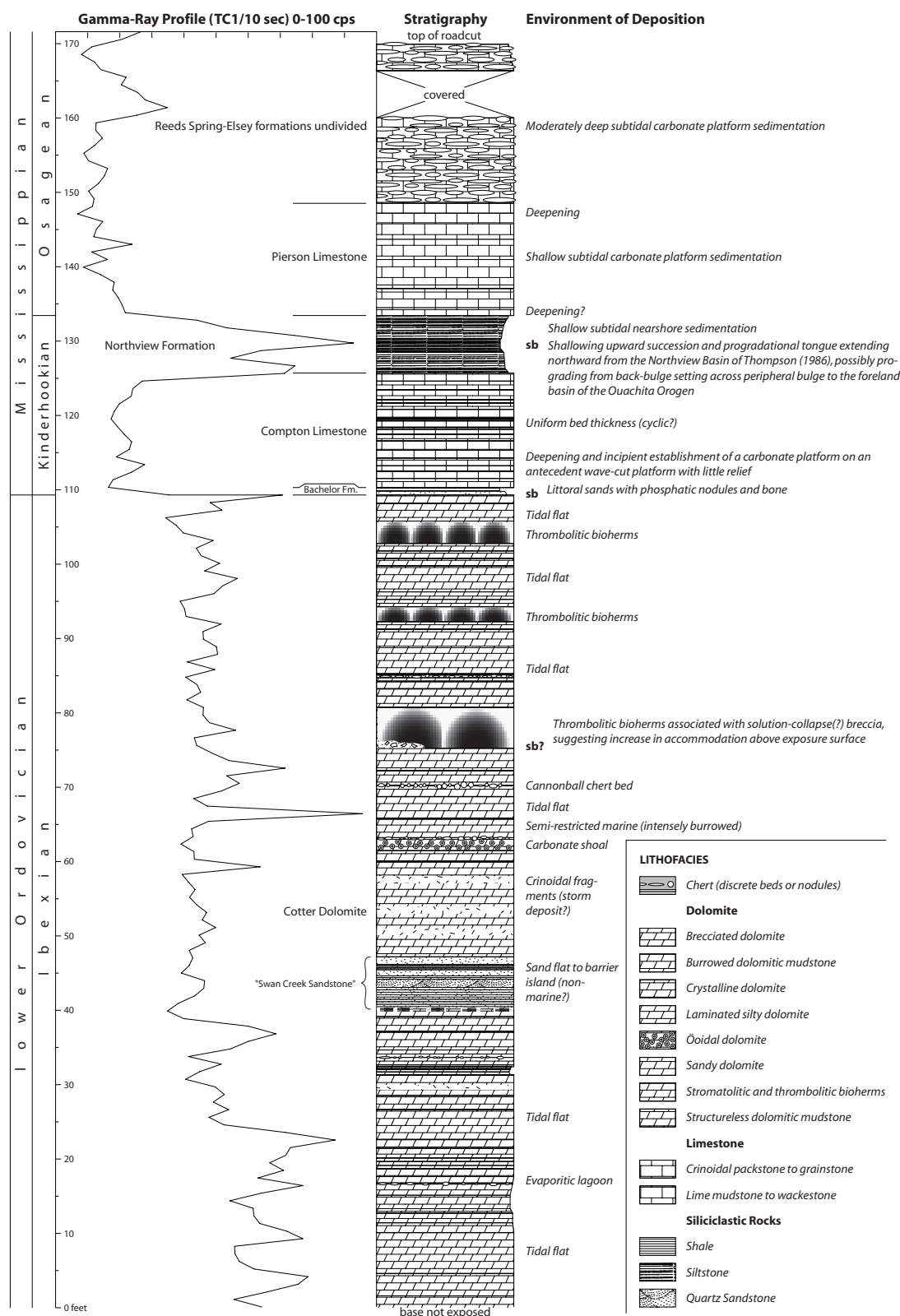


Figure III-4. Measured stratigraphic section on the east side of U.S. 65 Highway at Chestnut Ridge, Christian County, Missouri (Stop 1). The roadcut exposes the upper part of the lower Ordovician Cotter Dolomite and lower Mississippian stratigraphic units. A gamma-ray profile was recorded in total counts (TC1) units, and averaged over 10 seconds at one foot intervals. Tidal flat sediments of the Cotter Dolomite and the Northview Formation account for the highest radioactivity in these strata. The base of the Mississippian is a sequence boundary (sb); we provisionally interpret a sequence boundary within the Northview Formation. Sequences within the Cotter Dolomite are more difficult to identify because of the pervasive shallow-water sedimentation across this platform and the potential for dynamic patterns of sedimentation to have developed with minor or no fluctuations of sea level.



Figure III-5. Cutters and pinnacles in Reeds Spring Formation exposed on west side of Missouri Highway 13, 0.8 miles south of intersection with Missouri Highway 76.

concentrated along bedding planes, separated by 3- to 8-inch beds of lime mudstone to wackestone. The base of the Burlington Limestone is exposed near road level at the north end of the northernmost roadcut. The Elsey Formation is absent at this locality.

Continue south on 13/76.

47.9 13.1 Missouri Highways 413 and 265 enter from the northwest at the north edge of Branson West (formerly known as Lakeview). Proceed south through Branson West on 13/76/265.

48.9 14.1 At the south edge of Branson West, Highways 76 and 265 separate from Highway 13. TURN LEFT (east) and proceed southeast on 76/265.

51.0 16.2 Village of Notch.

51.9 17.1 Indian Point Road to Silver Dollar City on the right (south). Proceed east on 76/265.

52.5 17.7 Missouri Highways 76 and 265 separate. BEAR LEFT and proceed east on 76.

53.2 18.4 Cross Missouri Highway 465.

53.8 19.0 Enter Taney County. Shepherd of the Hills Farm and Inspiration Tower on the left.

55.8 21.0 Intersect Missouri Highway 376. TURN RIGHT (west) and proceed southwest on 376.

56.8 22.0 Note the large collapsed sink structure in the Cotter Dolomite on the right (west) side of the road.

56.9 22.1 **STOP 3. TEN O’CLOCK RUN FAULT**

(Garber 7 ½’ quadrangle, SE ¼, SW ¼, Sec. 34, T 23 N, R 22 W;
UTM-NAD27: 472803mE, 4055480mN; UTM-WGS84: 472796mE, 4055686mN)

The Ten O’Clock Run Fault extends through the valley of Fall Creek at this location. North of the valley, the Cotter Dolomite dips 15-20° southwest into the fault (Figure III-6). Strata in the quarry south of the valley are nearly horizontal (Figure III-7).

This fault is a major regional structure in this part of southwestern Missouri. From this location, the fault can be traced to the east-southeast for at least 15 miles, where it defines a linear section of the valley of Bee Creek near the Missouri-Arkansas state line. To the west of this location, the fault curves clockwise and can be traced for only approximately 3 miles before it dies out into a north-northwest trending monoclinical structure. Vertical displacement across the Ten O’Clock Run Fault approaches 160 feet at some locations.

Continue southwest on 376.

57.5 22.7 Intersect Missouri Highway 265. TURN RIGHT (north) and proceed northwest on 265.

57.7 22.9 Enter Stone County. Highway 265 follows the crest of Compton Ridge, a remnant of Mississippian strata surrounded by valleys cut into the lower Ordovician Cotter Dolomite. Views of Table Rock Lake to the left and the greater Branson area to the right.

60.6 25.8 Intersect Missouri Highway 76. TURN RIGHT (northeast) and proceed east on 76.

61.3 26.5 Intersect Missouri Highway 465 (the new “Ozark Mountain Highroad”). TURN LEFT (north) and proceed northeast on 465.

62.0 27.2 Enter Taney County

64.7 29.9 **STOP 4A. FACIES AND TIDAL CHANNELS IN THE COTTER**

DOLOMITE (Garber 7 ½’ quadrangle, NW ¼, NW ¼, Sec. 11, T 23 N, R 22 W;
UTM-NAD27: 474076mE, 4063154mN; UTM-WGS84: 474069mE, 4063357mN)

The roadcuts on the north side of the eastbound lane of Missouri Highway 465 expose cyclic facies and tidal channels within the lower Ordovician Cotter Dolomite. Major facies include laminated silty dolomitic mudstone, structureless silty dolomitic mudstone, and autoclastic breccia. Minor facies include fine quartz sandstone, shale, and burrowed dolomitic mudstone.

Spectral analysis of gamma-ray profiles through this interval shows a dominant cyclicity at a thickness of roughly 4.3 m, which corresponds to thick successions of relatively “clean” autoclastic breccias and stacked intervals of “hot” laminated silty dolomitic mudstone. The alternation of these facies constitutes cyclic succession of depositional environments across a peritidal carbonate platform, varying from a



Figure III-6. Roadcut on west side of Missouri Highway 376, 0.6 miles northeast of intersection with Missouri Highway 265, just north of the Ten O'Clock Run Fault. The Ordovician Cotter Dolomite is dipping southwest into the fault.



Figure III-7. Quarry face on west side of Missouri Highway 376, 0.3 miles northeast of intersection with Missouri Highway 265. South of the Ten O'Clock Run Fault, the Ordovician and Mississippian strata are horizontal.

shallow subtidal, near normal marine setting (burrowed dolomitic mudstone) to supratidal sabkha settings (autoclastic breccia and quartz sandstone).

The laminated silty dolomitic mudstone facies represents tidally influenced sedimentation from traction currents. Laminae range from a few millimeters to a few centimeters in thickness. Both erosional and constructional channels are found in the laminated silty dolomitic mudstone facies (Figure III-8). Channels vary in size but locally reach up to one meter in depth. Shale typically is preserved in channel-fills. Desiccation features are preserved in some of these terrigenous channel-fill deposits.

We interpret the autoclastic breccia as having formed from solution-collapse of mixed dolomite and evaporite beds. Fine-grained sandstone is commonly associated with these breccias and probably accumulated as terrestrial sediments encroached on the carbonate platform during a sea-level lowstand. The structureless silty dolomitic mudstone facies is a transitional facies between the evaporative deposits of the



Figure III-8. Roadcut on north side of the eastbound lane of Missouri Highway 465, 1.3 miles west of intersection with Missouri Highway 248. (Lower photo is a panoramic composite.) Scalloped bedding surfaces in the Cotter Dolomite are interpreted as tidal channels. Note that two different horizons show well developed channels.

autoclastic breccia and higher-energy deposits of the laminated silty dolomitic mudstone facies.

Continue east on MO Highway 465.

65.7 30.9 **STOP 4B. ORDOVICIAN AND MISSISSIPPIAN STRATIGRAPHY, CEDAR HOLLOW SECTION** (Garber 7 1/2' quadrangle, NW 1/4, NW 1/4, Sec. 12, T 23 N, R 22 W; UTM-NAD27: 475771mE, 4062972mN; UTM-WGS84: 475763mE, 4063176mN)

The five major roadcuts on Missouri Highway 465 just west of Missouri Highway 248 expose a total of 400 feet of strata, comprising the upper 240 feet of the Ordovician section and the lower 160 feet of the Mississippian (Kinderhookian and Osagean) section (Figure III- 9). The lower contact of the Cotter Dolomite with the underlying Jefferson City Dolomite may be exposed in this section, but the position is uncertain. The “Rockaway Conglomerate” which marks the top of the Jefferson City Dolomite cannot be confidently recognized at this locality, but it is possible that a thick evaporitic solution-collapse breccia unit near the base of this section correlates to the “Rockaway Conglomerate.”

Outcrop gamma-ray profiles record the natural radioactivity for this section and the Chestnut Ridge section 9 miles to the north (Figure III-10). With the exception of the Northview Formation, the Mississippian formations have significantly lower natural radioactivity than the underlying Cotter Dolomite.

Correlation of the Cotter Dolomite is notoriously difficult because of the lack of fauna and the similarity of the lithofacies. Close inspection of the dolomitic strata exposed in fresh roadcuts, however, reveals a complex pattern of sedimentation that arguably can be correlated at least locally. Unique successions of lithofacies provide some help. Burrow-mottled horizons are somewhat rare in both stratigraphic sections, but presumably these represent times when marine water circulation was somewhat less restricted.

Figure III-10 shows our provisional correlation of the Cedar Hollow section with the Chestnut Ridge section, 9 miles to the north. If this correlation is correct, at least 65 feet of the Cotter Dolomite has been cut out at Chestnut Ridge. Angular discordance of less than 1° below the unconformity at the base of the Bachelor Formation could account for the apparently thicker succession at Cedar Hollow. Such discordance is not detectable on the scale of outcrops in this area, but discordance, with sub-unconformity beds dipping northward, can be demonstrated in a roadcut north of Springfield. Upper Ordovician and younger strata that are present in northern Arkansas have also been cut out by erosion at the base of the Mississippian. Conceivably, many scenarios could account for erosional truncation, but one model synthesizes the available information.

We propose that beveling of the Cotter Dolomite around Springfield may indicate uplift associated with the onset of tectonism in the Ouachita orogen. In this model, the earliest phase of uplift on the Ozark dome may be associated with development of a peripheral bulge north of the Ouachita foreland basin in Arkansas. Ultimately,

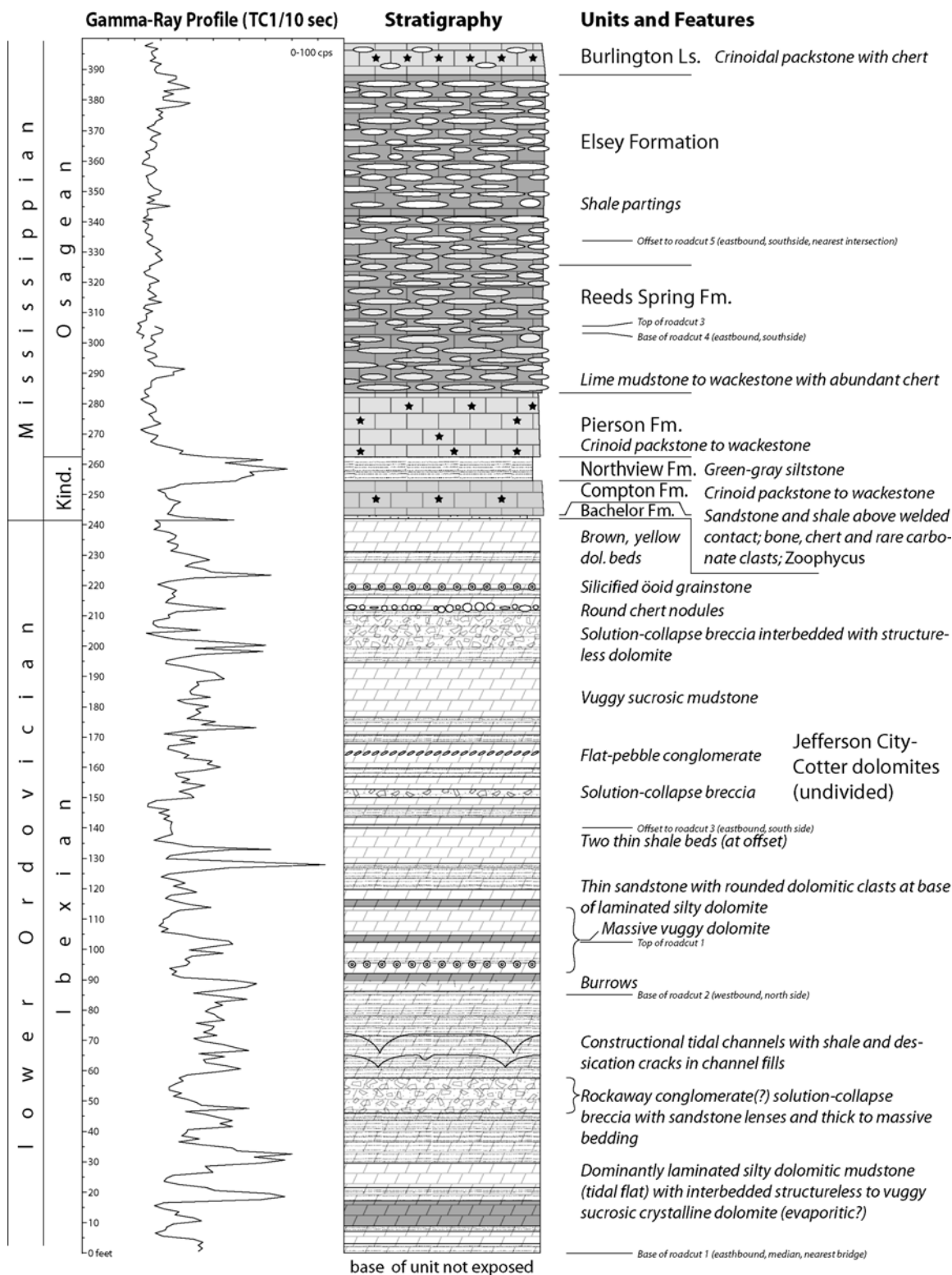


Figure III-9. Composite stratigraphic section at Cedar Hollow, Missouri Highway 465 west of Missouri Highway 248, Taney County, Missouri. See Figure III-4 for explanation of lithofacies symbols.

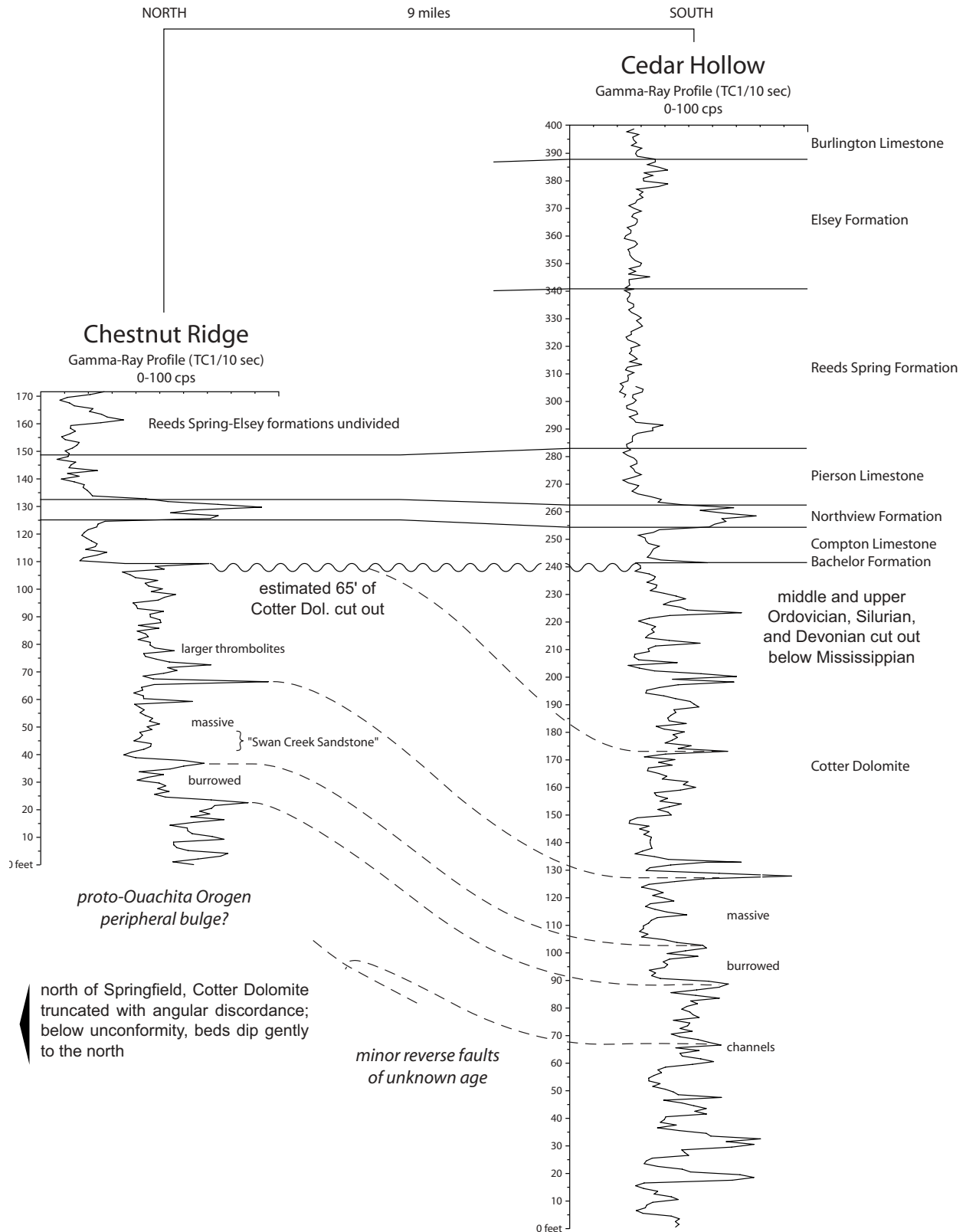


Figure III-10. Correlation of gamma-ray profiles and stratigraphic sections at Chestnut Ridge on US-65 (Stop 1) and Cedar Hollow on MO-465 (Stop 4B). Datum is base of the Bachelor Formation.

sea level rise inundated the beveled Lower Paleozoic succession, but in the back-bulge area, Kinderhookian siliciclastics of the Northview Formation may have accumulated in a shelf-parallel trough-like basin. Clearly, understanding the stratigraphy below the basal Mississippian unconformity will be crucial to understanding the geologic history of this interval.

Continue east on MO Highway 465.

- 65.9 31.1 Cross beneath Missouri Highway 248.
- 68.8 34.0 Intersection with U.S. Highway 65. TURN LEFT (north) and proceed north on U.S. Highway 65.
- 71.1 36.3 Take exit ramp to U.S. Highway 160 eastbound.
- 71.2 36.4 TURN RIGHT (east) onto U.S. Highway 160; immediately TURN LEFT (north) onto north access road (Hamilton Drive); TURN AROUND.
- 71.5 36.7 **STOP 5. KARST-WIDENED FRACTURES IN COTTER DOLOMITE**
 (Branson 7 ½' quadrangle, NE ¼, SE ¼, Sec. 29, T 24 N, R 21 W;
 UTM-NAD27: 480212mE, 4066821mN; UTM-WGS84: 480206mE, 4067026mN)
 The Cotter Dolomite in this area is extensively fractured. Solution-widening of these fractures presented numerous challenges in the construction of the highway (Figure III-11).
- 71.6 36.8 TURN RIGHT (west) onto U.S. Highway 160; immediately TURN RIGHT (north) onto entrance ramp to northbound U.S. Highway 65; proceed north on U.S. Highway 65.
- 74.5 39.7 Missouri Highway 176 enters from the east (right). Proceed north on 65/176.
- 75.4 40.6 Missouri Highway 176 exits to west (left). Proceed north on U.S. Highway 65.
- 76.2 41.4 Enter Christian County.
- 76.6 41.8 **STOP 6. THRUST FAULTS IN COTTER DOLOMITE**
 (Day 7½' quadrangle, NE ¼, SW ¼, Sec. 34, T 25 N, R 21 W;
 UTM-NAD27: 479832mE, 4074930mN; UTM-WGS84: 479826mE, 4075135mN)
 The south end of the long roadcut on the east side of the highway exposes a small thrust fault in the lower Ordovician Cotter Dolomite (Figure III-12). The fault plane can be traced for only a few tens of feet before it merges into bedding planes. An interesting feature of this exposure is that the terminus or leading edge of the overriding block can be seen in cross-section. The timing of thrust faulting in the Cotter Dolomite is unknown, but it is possible that it is related to distal compression during the Ouachita Orogeny.
- 78.2 43.4 Intersect Christian County Highways A and BB. Proceed north on U.S. Highway 65.



Figure III-11. Roadcut at intersection of US-65 and US-160 showing solution-widened vertical fracture.

82.5 47.7 **STOP 7. HIGHLANDVILLE FAULT**

(Selmore 7 ½' quadrangle, NW ¼, NE ¼, Sec. 4, T 25 N, R 21 W;
UTM-NAD27: 478493mE, 4083915mN; UTM-WGS84: 478487mE, 4084121mN)

The roadcut on the west side of the highway exposes the nearly vertical Highlandville Fault. The main fault plane is marked by a 1-meter-thick breccia zone. At road level, this fault plane juxtaposes the Mississippian (Kinderhookian) Compton Limestone to the north against the lower Ordovician Cotter Dolomite to the south (Figure III-13). The distinctive blue-gray silty mudstone of the Mississippian (Kinderhookian) Northview Formation serves as a convenient marker bed, revealing approximately 70 feet of vertical offset across the main fault plane at this location.

The main fault plane strikes approximately N67°W and intersects the southernmost part of the new roadcut on the east side of the highway. The new roadcut exposes several smaller, nearly vertical breccia zones, indicating that the movement associated with this structure was distributed across a fault zone at least a few hundred feet wide. At least one of these small breccia zones includes horizontal slickensides, suggesting the fault movement included a strike-slip component.

The Highlandville Fault was originally mapped by McQueen (1924) on the old 30 minute Forsyth Quadrangle and later Hayes (1960) made reconnaissance maps of the Highlandville, Hurley, Selmore, and Spokane 7 ½' quadrangles verifying the existence of the fault and extending it to Section 2, T.25 N., R.21 W. In RI37, a

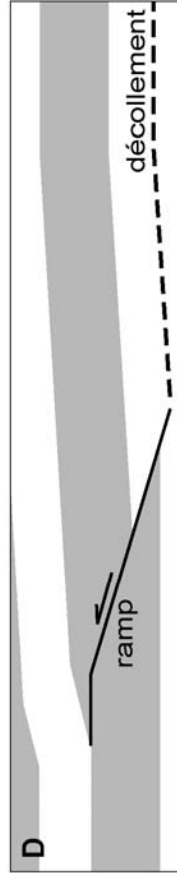
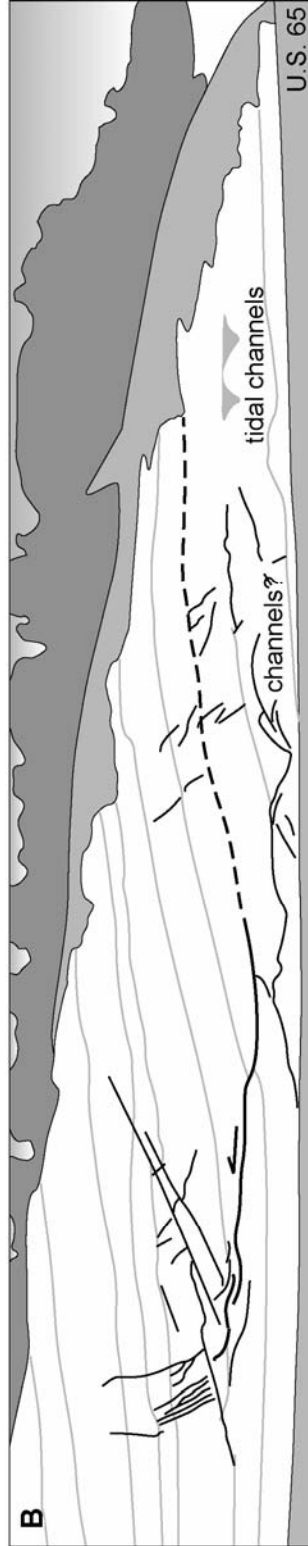


Figure III-12. Roadcut on east side of US-65, 0.4 miles north of boundary between Christian and Taney Counties. Offset bedding planes along a small thrust fault within the Ordovician Cotter Dolomite indicate at least 3 ft (1 m) of horizontal shortening due to compressional forces. A, photomosaic showing faulted strata. B, interpretive sketch showing main thrust horizon (bold black line), fracture surfaces (light black lines), and selected bedding planes (gray lines). C, close-up of central portion of structure. D, simplified model of fault and bedding relationships at this location.



Figure III-13. Roadcut on west side of US-65, 6.2 miles north of boundary between Christian and Taney Counties. Vertical offset along the Highlandville Fault is indicated by displacement of the Northview Fm.

Guidebook to the Geology between Springfield and Branson Missouri emphasizing Stratigraphy and Cavern Development, 1967, Jerry Vineyard and Larry D. Fellows described the Highlandville Fault as follows:

"The major fault exposed in these cuts strikes N55°W, is nearly vertical, and has breccia and gouge associated with it. Strata on the north side of the fault have moved downward with respect to those on the south. The Northview Formation, displaced approximately 60 feet, is in contact with the Cotter Dolomite. Numerous smaller faults, associated with the major fault, are present on the downthrown side. It is possible that Woods Fork flows along another major fault. This faulting might be the southeastern extension of the Chesapeake Fault."

Mapping for the DNR/USGS CUSMAP Project, Thomson (1982) was able to obtain more detailed information on the trend of the fault and mapped it from the Selmore Quadrangle on the east into the Republic Quadrangle to the northwest. It follows the same general trend as the Chesapeake Fault to the northwest and may possibly be part of that system.

In conjunction with the U. S. Geological Survey National Cooperative Geologic Mapping Program - Statemap, Jim Brown mapped the Selmore Quadrangle, Christopher B. Vierrether mapped the Highlandville Quadrangle and William K. Wedge mapped the Hurley Quadrangle. William K. Wedge (1998) in describing the Highlandville Fault System in the Hurley Quadrangle states:

"This structure extends approximately 3 miles to the northwest from the Highlandville Quadrangle through sections 7 and 18, T.26 N., R.22 W. and sections

1, 2 and 12, T.26 N., R.23 W. The width of the structure is approximately one-quarter of a mile within the Hurley Quadrangle and forms a graben structure. Displacement of up to 100 feet occurs in the northeast quarter of section 18, where the Pierson Limestone is adjacent to Burlington Limestone. To the northwest, the fault is apparent through an extended chert breccia zone within the Burlington Limestone.”

Christopher B. Vierrether (1998) describes the Highlandville Fault System in the Highlandville Quadrangle as follows:

“This structure, formerly known as the Highlandville Fault and described as a single fault, is now being upgraded to a fault system. The width of the structure varies from approximately one quarter of a mile to one and one-quarter miles. The system covers an 8 mile length on this quadrangle and extends into the adjoining quadrangles to the west and east. The system is segmented into three loosely constrained areas: the Jamesville Segment is the northwestern extension, the Montague Segment located in the middle and the Woods Fork Segment is the southeastern portion. The Highlandville Fault System is comprised of a complexed series of horsts and grabens. In general, the horsts are located south of the grabens. The horst consists of a series of uplifted and tilted fault blocks. Displacement appears to reach a maximum in the Montague and Jamesville segments. The fault block just east of the James River (NW1/4, Sec. 21, T.26 N., R.22 W.) has a minimum displacement of 160 feet and is steeply tilted toward the southwest. Cotter Dolomite forms the entire bluff and hilltop, while the Compton Limestone and the Pierson Limestone outcrop in the valley floor immediately to the north. In the Jamesville Segment, two other blocks are defined with the Cotter Dolomite outcropping at the surface. In the center of the SW1/4, Sec. 25, T.26 N., R.22 W., the Reeds Spring Formation outcrops at a spring merely 20 feet upstream from Cotter Dolomite outcropping in the stream channel. The Woods Fork Segment, contains a number of transecting faults that cut the graben as well as the horst, and is extremely complex. Chert breccia is commonly observed within this segment. A horst block steeply tilted to the south (NW1/4, SE1/4, Sec. 32, T.26 N., R.21 W) displaces the Cotter Dolomite about 100 feet. Almost immediately to the northeast (SE1/4, SE1/4, NE1/4, Sec. 32, T.26 N., R.21 W.) a downthrown block (approximately 150 feet of displacement) within the graben has placed Burlington-Keokuk Limestone adjacent to Compton Limestone. The upthrown- and downthrown-blocks total displacement is a minimum of 250 feet.”

James C. Brown, Jr. (1998) mapping in the Selmore Quadrangle describes the Highlandville Fault there as follows:

“The structure extends from the west onto the quadrangle in SW1/4, Sec. 33, T.26 N., R.21 W., and the name from a previously named fault near Highlandville. There are several complex downthrown semiparallel faults which create graben-like features along the majority of the Woods Fork and Moon Valley segments. It extends to the east onto the Chadwick 7.5' quadrangle and changes into semiparallel monoclinial

features along the Bull Creek Segment. The Woods Fork Segment extends from near the headwaters of Woods Fork to the common boundary of Sec.02 and 03, T.25 N., R.21 W. It has numerous subparallel and/or oblique fractures that indicate left-lateral displacement in exposures near U.S. Highway 65 and eastward to the NE1/4 Sec. 03, T.25 N., R.21 W. The relatively undisturbed beds adjacent to the structure and nearly flat lying concordant elevations of map units outside of the segment are remarkable. Bedrock in the segment is extensively brecciated and includes dolomitic limestone, silicified cherts, and sandy chert breccias. Vertical displacements vary from a few inches to 100 feet. A feature known as H'Doubler Cave Structure extends from the west and merges with the Woods Fork Segment near U.S. Highway 65 twin bridges crossing of Woods Fork in the SE1/4, Sec. 33, T.26 N., R.21 W. The Moon Valley Segment extends from NE1/4, NE1/4, Sec. 03, T.25 N., R.21 W. to Logan Ridge in the NE1/4, Sec. 01, T.25 N., R.21 W. It has structures similar to the Woods Fork Segment except some graben blocks in NE1/4, Sec. 02, and NW1/4, Sec. 01, are downthrown approximately 160 feet, and brecciated masses are numerous. The continuity of the system appears to diverge near Hancock Hollow with northeast trending monoclines, i.e., Logan Ridge and Hancock Hollow structures. The Hancock Hollow Structure has been extended to the Tuttle Mine Structure and Brown Spring Fault in Sec. 18, T.26 N., R.20 W. The Bull Creek Segment extends from Logan Ridge NE1/4, Sec.01, T.25 N., R.21 W, to Medlock Hollow in Sec. 33, T.26 N., R.20 W. Semiparallel monoclines occur within the segment, which dip to the south approximately 60 feet within 1 mile. The south branch diminishes in the small tributary to Bull Creek in NW1/4, SW1/4, Sec. 05, T.25 N., R.20 W. Several streams along the Highlandville Fault System receive recharge from losing segments of adjacent tributaries, with numerous large springs occurring along the northern graben-like features."

Continue north on US-65.

- 85.5 50.7 Intersection with Christian County Highway EE. Proceed north on US-65.
- 90.2 55.4 The northern end of the roadcut on the east side of the highway exposes the contact between the Elsey Formation (below) and the Burlington Limestone (above). From this point northward to Springfield, all roadcuts are in the Burlington. The deeply weathered Burlington roadcuts along US-65 and US-60 along the east and south edges of Springfield, respectively, provide some excellent opportunities to collect crinoids and other typical Mississippian fossils.
- 90.5 55.7 Cross Finley River.
- 91.0 56.2 Intersection with Missouri Highway 14. Proceed north on US-65.
- 95.7 60.9 Enter Greene County.
- 98.1 63.3 Intersection of US Highways 65 and 60. Proceed north on US-65.
- 106.5 71.7 Intersection of US-65 and Interstate-44. **END OF ROAD LOG**

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Association of Missouri Geologists

2003

***Engineering Geology of the U.S. 65 and Missouri Route 465 Corridors,
Christian and Taney Counties, Missouri***

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INTRODUCTION

The U.S. 65 corridor for many years has served as an adequate north-south artery between the cities of Springfield and Branson, both located in MoDOT's Springfield District. The road traverses hilly terrain through rugged and beautiful scenery from the Springfield Plateau into the heart of the Ozarks. Increased population and a demand for tourist access has led not only to the development of a four-lane access to Branson itself, but to the development of a rapid bypass around the city, and improved access within Branson. The geology of the area was probably the single most important factor influencing construction of additional lanes for U.S. 65 and for the new Ozark Mountain Highroad, now known as Missouri Route 465. Improvements to Route 65 ran south of the City of Ozark in Christian County, then into Taney County, and finally continuing into the City of Branson as a four-lane thoroughfare that was completed in 2001. The first section of Route 465 was completed and opened to traffic on June 16, 2003.

Route 65 followed the same route as the original two lanes that were constructed many years earlier. Beginning in Christian County, south of Ozark, Missouri, bridges were constructed for Hatem Creek, North and South Woods Fork Creeks, Camp Creek, and Cook Hollow. In Taney County, bridges were built at Bear Creek, North and South Fork Emory Creeks, at a crossing for an outer road several miles north of Branson, and for two interchanges. Major improvements were made at the junction with U.S. Highway 160, which continues east to West Plains and beyond, and west to Mindenmines, Missouri and on into Kansas. Major improvements were also made for the junction of Route 465 with Highway F and U.S. 65. This final location when purchased as right-of-way marked one of the few times in MoDOT's history where a motel was purchased to construct an interchange.

Originally known as Route 765 (Davidson, 1992), Route 465 was a triumph of state, local and federal cooperation. Various agencies including consultant firm Howard Needles Tammen and Bergdorff (HNTB) "fast-tracked" the approval process, completing a four-lane divided highway with 9 bridges and 8 miles of asphalt pavement in 8 years. Over 5.8 million cubic yards of dirt and rock were moved, the equivalent of a mountain a quarter-mile high that would completely cover the baseball diamond in Busch Stadium. The Federal Highway Administration awarded MoDOT and HNTB a special award for Environmental Excellence in 1995 for the design of this route. At one point, the route was even rerouted to avoid the safety hazard of a buzzard roost to the west of Branson. The potential hazard posed by up to a thousand of these flying "botulism factories" is unpleasant at minimum.

This article is intended to acquaint the reader with some of the unique engineering geology problems encountered during construction of these two routes and how these problems were solved in a manner that facilitated completion of the routes. A firm understanding of the soil and rock types occurring on this corridor is necessary to understand the unique problems that arose during planning and construction. The solutions arrived at are due in large part to the daily teamwork of design engineers, bridge engineers, and geologists at MoDOT addressing the problems both in advance and as they occurred.

SOIL TYPES

Soils that mantle the geology of the corridor are formed in residuum from limestone and dolomite of the area. Since these soils were formed from formations that contain chert in varying amounts, most also contain residual chert. Soils formed in the area are primarily of the Alfisol, Ultisol, Entisol, Inceptisol, and Mollisol orders of the National Soil Classification System promulgated by the U.S. Department of Agriculture (Allgood and Persinger, 1979). Inceptisols are not prominently mentioned in the USDA soil surveys of Taney and Christian Counties (Dodd and Dettman, 1996; Dodd and Aldritch, 1985). These soils are, however, more often present than not, indicated by the presence of cambic, or Bw horizons as seen in many soil pedons sampled by the author and others (Tummons, 1997). Soil series recognized by USDA and that were mapped at 1:24,000 quadrangle scale in Taney and Christian Counties are tabulated in Table 1 with their taxonomic classification.

The USDA soil series taxonomic classification provides many indicators of soil types to be encountered by excavation and grading. Alfisols possess an argillic horizon (clay increases within the soil profile as specified in Soil Taxonomy). Clay abundance may indicate the need for stabilizing agents to be added to high fills made from these soils to prevent future stability problems. Skeletal and clayey-skeletal particle-size classes indicate an abundance of chert or rock fragments. These chert fragments often make excavation more difficult, and may cause excess wear on tires and machinery during construction. Udalfs, Udolls, Udufts, and Udents are the udic moisture regime suborders of the Alfisol, Mollisol, Ultisol, and Entisol soil orders of Soil Taxonomy, respectively. As such, these soils are usually at or close to natural seasonal moisture content during both wet and dry years. Soils of the Captina and Creldon series, both belonging to fragic subgroups, have fragipans, or hard, clay-stripped subsurface root restrictive layers that are also extremely hard to excavate. These examples illustrate how knowledge of soil taxonomic nomenclature provides the geologist advance knowledge of route conditions prior to investigation of soils for route design.

Normally for design characterization, soils are grouped into associations as they appear on the General Soil Map of Missouri, also published by USDA, but appearing on a county basis in the soil survey for a particular county. Soil associations are a useful tool in the description of the engineering geological characteristics of the soil groups that are represented. They aid in delineating the location of the soils on the physical landscape and they identify the cataena (landscape geomorphology) that occurs in a particular area. A soils investigation planned with these parameters in mind generates useful information concerning soil depth over bedrock, soil drainage and/or the need for additional drainage, generalized slopes, and characteristics affecting management of the roadside following construction. Soil associations recognized from the corridors of Route 65 and Route 465 that were to be constructed in Taney and Christian Counties (Goessman, 1996 and 1997) comprise the following:

1. the Ocie-Gatewood-Gasconade association (Taney and Christian Counties)
2. the Rueter-Clarksville-Hailey association (Taney County)
3. the Britwater-Sandbur-Huntington association (Taney County)
4. the Clarksville-Doniphan association (Christian County)

All of these soils are formed in the residuum of cherty limestone and dolomite, which varies in chert percentage. The contribution of shale interlayers to the overall pedologic make-up of these soils is small to negligible. The soils range from shallow to deep, from nearly level to steeply sloping, and are well to excessively well drained.

Soil Series Name	Taxonomic Classification of the Series
Bardley	Very fine, mixed, mesic, Typic Hapludalfs
Bolivar	Fine-loamy, mixed, thermic, Ultic Hapludalfs
Britwater	Fine-loamy, mixed, mesic, Typic Paleudalfs
Brussels	Clayey-skeletal, mixed, mesic, Cumulic Hapludolls
Captina	Fine-silty, mixed, mesic, Typic Fragiudults
Cedargap	Loamy-skeletal, mixed, mesic, Cumulic Hapludolls
Clarksville	Loamy-skeletal, siliceous, mesic, Typic Paleudults
Credon	Fine, mixed, mesic, Mollic Fragiudalfs
Doniphan	Clayey, mixed, mesic, Typic Paleudults
Gasconade	Clayey-skeletal, mixed, mesic, Litic Hapludolls
Gatewood	Very fine, mixed, mesic, Typic Hapludalfs
Goss	Clayey-skeletal, mixed, mesic, Typic Paleudalfs
Hailey	Loamy-skeletal, siliceous, mesic, Typic Dystrochrepts
Huntington	Fine-silty, mixed, mesic, Fluventic Hapludolls
Kaintuck	Coarse-loamy, mixed, nonacid, mesic, Fluventic Hapludolls
Lecoma	Fine-loamy, siliceous, mesic, Typic Paleudalfs
Needleye	Fine-silty, mixed, mesic, Aquitic Fragiudults
Ocie	Loamy-skeletal over clayey, mixed mesic, Typic Hapludalfs
Peridge	Fine-silty, mixed, mesic, Typic Paleudalfs
Racket	Fine-loamy, mixed, mesic, Culmulic Hapludolls
Reuter	Loamy-skeletal, siliceous, mesic, Typic Paleudalfs
Secesh	Fine-loamy, siliceous, mesic, Ultic Hapludalfs
Sandbur	Coarse-loamy, siliceous, nonacid, mesic, Mollic Udifluvents
Tonti	Fine-loamy, siliceous, mesic, Typic Fragiudults
Viraton	Fine-loamy, siliceous, mesic, Typic Fragiudalfs
Wilderness	Loamy-skeletal, siliceous, mesic, Typic Fragiudalfs

Table 1. USDA-Recognized Soil Series of Taney and Christian counties.

GEOLOGIC FORMATIONS, STRATIGRAPHY AND AGGREGATE SUITABILITY

Formations occurring along the two routes are the Ordovician Jefferson City Dolomite and Cotter Dolomite, Mississippian Bachelor Formation, Compton Limestone, Northview Formation, Pierson Limestone, Reeds Spring Formation, Elsey Formation, and Burlington Limestone. Complete descriptions of these formations and their nomenclature can be found in Thompson (1986, 1991, 1995).

The Jefferson City Dolomite (Ordovician – Ibexian) occurs only in the bottom of the deepest valleys along the subject route. The overlying Cotter Dolomite (Ordovician – Ibexian) makes up many of the side slopes of the valleys and some of the valley bottoms. In this area, stromatolites and gastropods are the predominant fauna of these formations, which occur as brown, buff, or gray thin to medium bedded dolomite with shale seams and partings. The Jefferson City in this area is regarded as being unsuitable for road aggregate, except as fill, base, or asphalt rock due to its relatively low strength and its tendency in pavements to cause map cracking which is responsible for premature deterioration and failure of pavement. This may be caused by the presence of quartz silt particles finely dispersed through the dolomite, or by an alkali-carbonate reaction with Portland cement. There may be exceptions to this “rule of thumb.” One quarry that was operated by Doss and Harper south of the city of Houston, Missouri, had a twenty-five foot ledge of “Quarry Ledge” dolomite, an arenaceous burrowed mudstone of subtidal origin that after extensive testing was allowed for use as concrete aggregate.

By contrast, dolomite of the Cotter Dolomite is widely used in the area for asphalt, base, and (in selected instances where physical testing criteria have been met) for Portland cement concrete pavement. Much of the Cotter is oolitic. It is possible that this facies expression of the formation contributes to its overall durability in concrete pavements. Internal MoDOT studies have shown that a similar phenomenon exists for the Bethany Falls member of the Swope Formation in the Kansas City area. Where map cracking (also known as D-cracking because of the shape of the cracks) occurs when the Bethany Falls is used in concrete pavement, aggregate sizes larger than ¼ inch have shown increased susceptibility except where oolitic aggregate was used. Perhaps if more facies of the Jefferson City Formation were oolitic, it would be equally acceptable as an aggregate formation. The presence of quartz silt in the formation from tidal facies is an additional element that causes freeze-thaw problems. MoDOT geologists have found that this quartz silt increases in content in a northerly direction.

The Bachelor Formation (Mississippian – Kinderhookian) is predominantly calcareous shale to sandstone on these routes and had little effect upon construction or design in the area. During subsurface exploration of stratigraphy it was not unknown for drill bits, once breaking through the overlying Compton Limestone, to suddenly increase speed moving downward, becoming stuck in the sandstone. Similar occurrences have been reported where drill bits have been lodged and lost in the St. Peter Sandstone during exploration for the construction of Route 30 in Jefferson County (Linebach, 1992) to the south of St. Louis.

Overlying the Bachelor Formation in this area are the Compton Limestone and Northview Formation, both part of the Chouteau Group (Mississippian – Kinderhookian). The Compton Limestone is an excellent source of concrete aggregate with sufficient thickness to make mining profitable. The Northview Formation, atop the Compton, weathers readily and for this reason is not considered suitable for aggregate or base rock. In fact, its argillaceous character specifically precluded it from use in rock fill atop the subgrade and under the concrete pavement.

The Pierson Limestone, atop the Northview, is a Mississippian (Osagean) formation that in the Springfield area has been an excellent source of high quality aggregate for Portland cement pavement and is also useful for asphalt and base rock. Relatively chert-free, it possesses reasonably good porosity that is useful to prevent freeze-thaw failures, and provides adherence to asphalt oil. North of this area where the Pierson thins to less than three feet, particularly in the Sedalia area, pyrite in the formation can cause deterioration of the rock prematurely in pavements and as base and is not considered acceptable for use.

The Mississippian Osagean Reeds Spring Formation and Elsey Formation also occur in this area. The chert content of both the Reeds Spring and Elsey render them unusable as concrete paving stone, though they are used for asphalt, base, and fill material.

The Burlington Limestone is perhaps one of the largest aggregate-producing formations in the state of Missouri, with stone being produced in most areas where the Mississippian (Osagean) Burlington and Keokuk limestones are exposed. The two formations are difficult to map separately or delineate as different, thus in most circumstances they are considered as the same.

ENGINEERING PROPERTIES OF SOIL AND ROCK UNITS

Critical to the program of MoDOT construction was understanding the various types of rocks and soils in the project areas and their relationship to pavement, subgrade and rock and soil interactions with structural elements of highway design. Residual soils with admixed chert fragments were most common, with ASTM classification ranging from fat clay to gravelly fat clay. Some areas of lean clay were also present in the area. Field moistures were measured as slightly below the optimum moisture content for compaction and further construction. Geotextile was used to prevent scour at bridge ends where sand, lean clay, and gravel were encountered. The soils of the area have high concrete and steel corrosivity. Steel used in pavement should have epoxy coating to prevent rust and corrosion.

Rock in the project areas exhibited consistent characteristics that allowed for generalizations to be made in the design of slopes and bridge foundations. All bridge foundations across creeks had rock of the Cotter Dolomite at footing depth. Bridge foundation types were chosen with respect to rock depth and competency. Spread footings were chosen where competent rock was encountered at depths of ten feet or less. This footing type distributes the load of the structure on a prepared surface of the rock rather than concentrating it at one point. In cases where rock was encountered at depths greater than ten feet, H-pile foundations were used. The thin-bedded nature of the Cotter Dolomite yielded low or erratic Rock Quality Designation (RQD), often leading to recommendations of preboring for pile foundations.

Culvert floors were also added to culverts at Bee Creek, Cook Hollow, and an extension at South Fork Emory Creek due to the Cotter's thin bedding. At Bee Creek, exposed wavy-bedded stromatolitic dolomite caused a need for additional leveling by the pouring of a concrete floor. This was important since this culvert was under 125 feet of fill. Walls of this culvert were poured in place and had steel reinforced walls nearly three feet thick. Reinforcing bars were epoxy coated to prevent corrosion of the steel, which would in turn (if uncoated) corrode the concrete as they oxidized. At South Fork Emory Creek, extension of an existing arch culvert was undertaken.

Engineering characteristics of the extension made it necessary to use lightweight fill atop this culvert extension. After haydite and other types of lightweight fill were examined for possible use, a new method of using soil-encapsulated polystyrene foam in the fill was attempted. After an early failure during construction, this fill was reengineered with additional safeguarding parameters and functions adequately today.

STRUCTURAL FEATURES BEARING ON CONSTRUCTION

Faults were the most common structural features that had a bearing on construction in the U.S. 65 and Missouri Route 465 corridors. All of those examined by the author were normal; many had been mapped previously by Thomson (1982 a, b, c) in his 7½' quadrangle scale mapping south of the Springfield 1° x 2° sheet. Many faults found during route construction had not been previously mapped because they were of insufficient displacement or had insufficient surface expression to identify at the 7½' quadrangle scale. Most appeared to have a single factor of commonality: they were *en echelon* with the predominant fault of the area, the Ten O'Clock Run Fault. Another structural feature in the area, the Hollister Anticline, did not enter into consideration during routing or construction.

A fault found during final bridge soundings occurs at one location about 5 miles north of Branson. This fault was previously unmapped on the reconnaissance geologic map of the Branson 7½' quadrangle compiled by Thomson (1982 a), since it lacked surficial expression and had less than two feet of offset. Further examination revealed it to be a small rotational graben with approximately 18 inches to two feet of displacement. The fault was of high angle and could have led to a topple type failure during blasting for bridge foundation leveling. It was recommended that a hoe ram or hydraulically powered rock splitter be used instead of explosives at this location. Thus, the minimization of rock fall during and after construction was accomplished successfully. As will be explained in a later section, rockfall hazard recognition, classification, and mitigation (if necessary) is part of MoDOT's due diligence towards insuring the safety of the motoring public, and is a unique way in which knowledge of geology affects design and construction.

SPECIAL INVESTIGATIONS

A number of karst features were found along the subject routes. On Route 465 approximately 300 yards west of the intersection with Route 65 and Route F, a cave was found while a rock cut was being excavated. Named the Highroad Horror Cave, this cave dropped 50 feet under the road from a six-foot by two-foot entrance on the ditch line of the route. A small stream issues from an area just under the cave entrance with approximate discharge of 5 gallons per minute. This stream flows down the sides of the pit becoming a small waterfall about 8 feet below the entrance to the pit. As this pit does not seem to be endangering the highway, the current drainage path was preserved, and the project continued (Capps, 1997). Figure 1 is the actual map drafted by Capps in his preparation of a report to the Department.

Another solution feature that could have caused major problems was at the site of a bridge foundation at the junction of Highways 65 and 160. During final soundings for the bridge at this

FIGURE 1.

HIGHROAD HORROR HOLE

Taney Co., Missouri

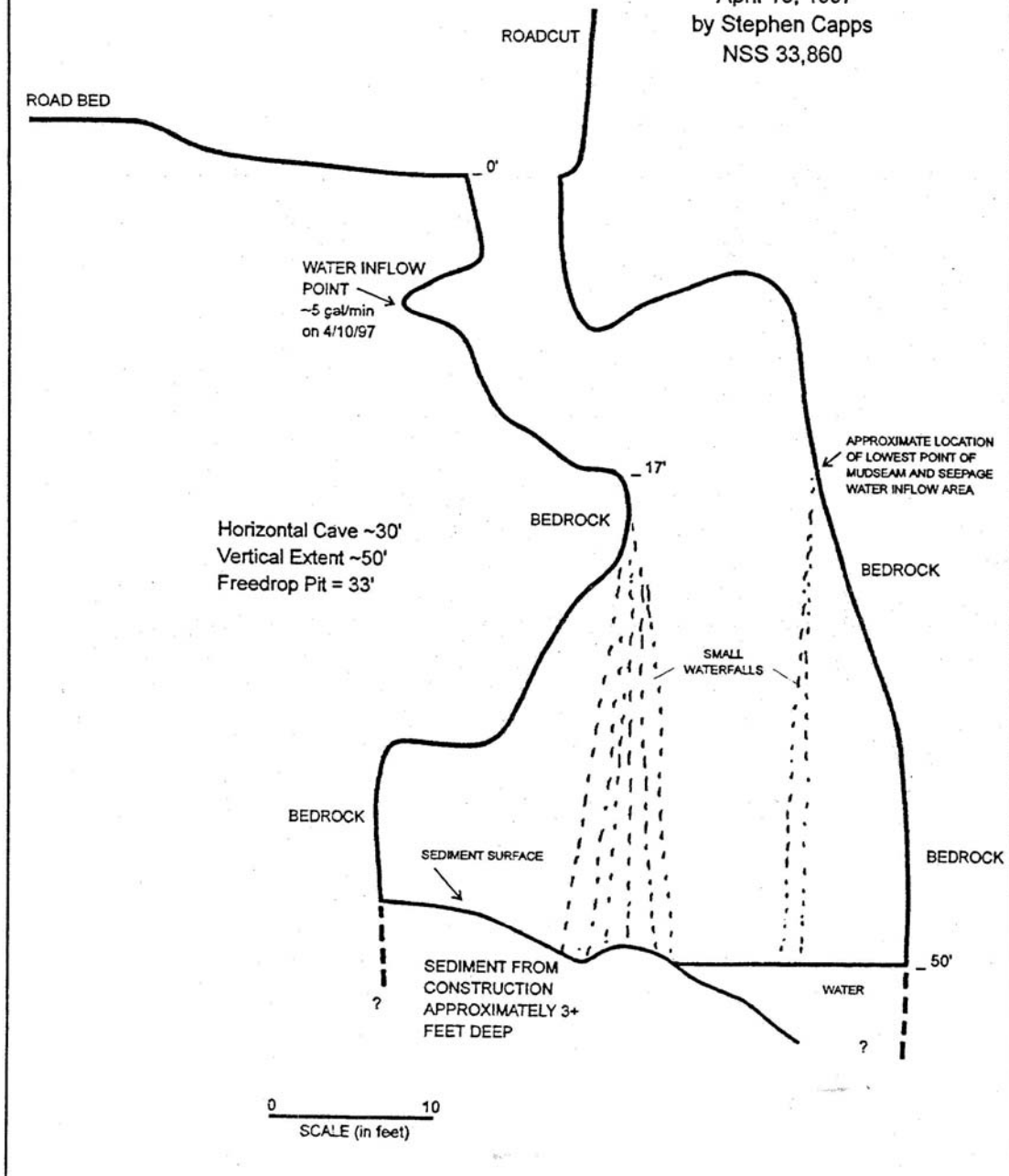
Grade 2 Survey

Compass and Tape

April 10, 1997

by Stephen Capps

NSS 33,860



GEOTEK



Figure 2. Soil Map of 23TA226 showing position of test holes (TH) 1 through 18, soil types, and Bents (piers) 7, 8, and 9 of Structures A-5441 and A-5442.

location a vertical joint feature was noticed which appeared to be a conduit for downward movement of water. Several subsidence features on the hillside were also examined in relation to a possible collapse hazard. The hillside and much of the adjacent terrain was removed to facilitate construction of a full interchange at this location, and no further relation with a collapse feature, solution cavity, cave, or karst hazard was found.

GEOARCHEOLOGY

On Route 465 where two bridges are currently planned to cross Lake Taneycomo below Table Rock Dam, is an archeologic site known as 23TA226. During the investigation of this feature a stratigraphic profile was developed of the soils occurring across the White River Valley based on a series of continuous sample borings completed to bedrock, which was the Cotter Dolomite. This investigation was to determine the geomorphology and pedostratigraphy of the site to determine if any deeply buried surfaces existed (as inferred by others) on which intact cultural remnants or remains could be found.

A soil map at a 1:600 scale was prepared, which revealed scour of a colluvial fan deposited by a valley near the site. This quickly illustrated that the site was subject to scour during periods of flooding and sheetwash over the site. Portions of the site that were tested revealed evidence of stratification in nearly every boring in the forms of platy soil structure, color banding, and grain size sorting. The soil map that was prepared is shown as Figure 2. It is notable that the names of the soil series presented on the map may not be the same as the “officially” recognized soils of Taney County. These soils may be inclusions in the series mapped in the county, but not of sufficient acreage overall to represent in the survey document.

Geologically, four separate phases of deposition occurred on this deposit. This is shown in the pedostratigraphic correlation of Figure 3. First, sandy loam and loamy sands with gravel were deposited upon the stair-stepped surface of the Cotter Dolomite in the White River Valley. This is shown as the first depositional phase. Following this, a period of relative quiescence occurred during which normal silt loams were deposited during flooding. These deposits were minimally bioturbated during the second phase of deposition. A bar of sand was deposited on this surface, creating a chute channel with the adjacent hillslope. This was followed by another depositional phase of silt loam and silty clay loam with slope colluvium in the form of a small fan prograding over the surface from the adjacent hillside.

ROCKFALL

Rockfall has become a cause for concern recently in other highway districts, most notably on a cut on Route 30 in Jefferson County south of St. Louis. On both Route 65 and Route 465, vertical rock faces have been given adequate setback and wide benching at critical levels. Currently, MoDOT has started to use the Colorado Rockfall Simulation Program, or CRSP (Jones, et al., 2000) to simulate rockfall down various slope configurations. Also, a research project is currently being conducted by Dr. Norbert Maerz of the University of Missouri-Rolla to determine a rapid and inexpensive method of cataloging potential rockfall hazards along Missouri state highways using the Department’s advanced video-equipped van normally used in route survey.

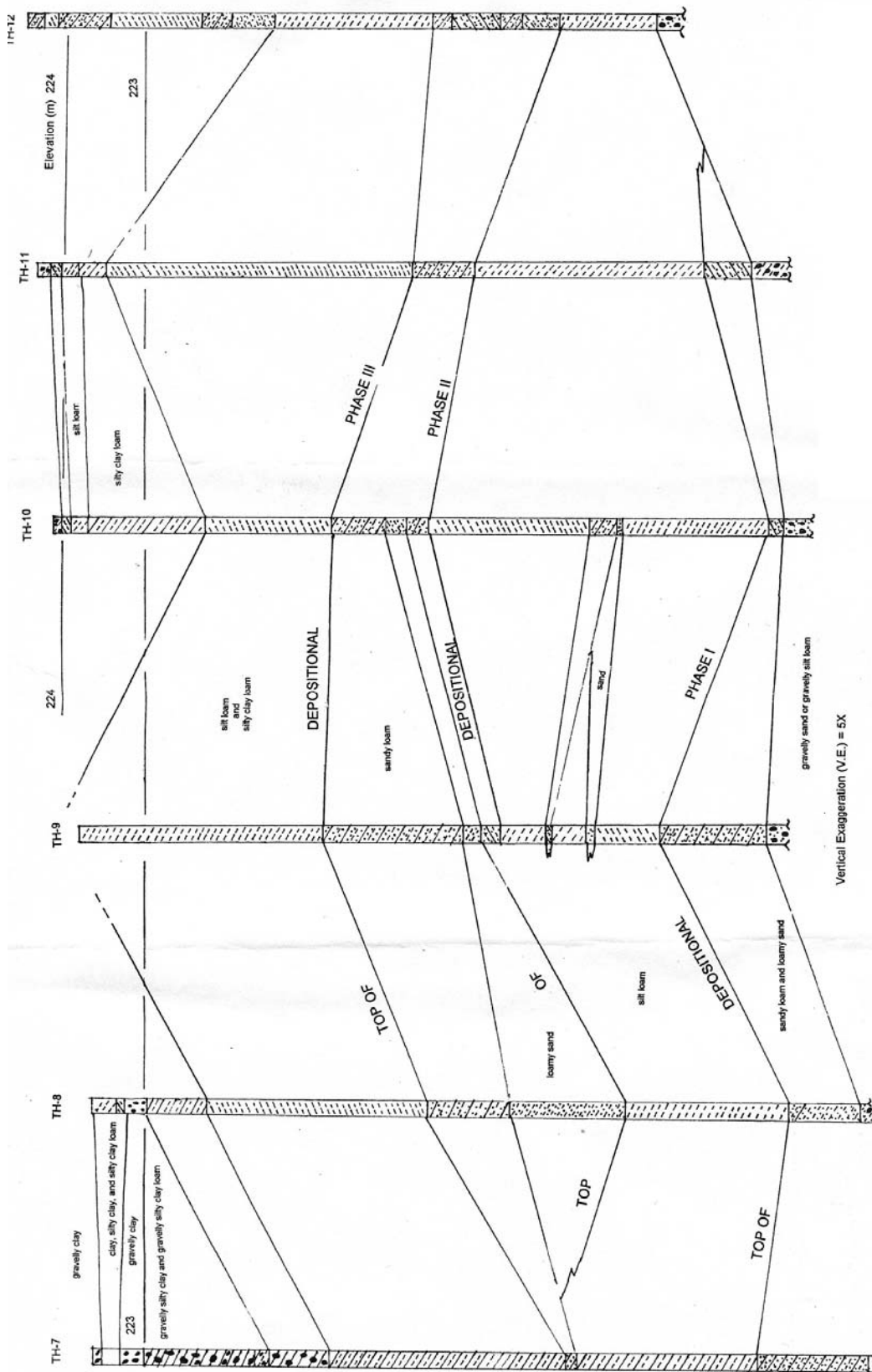


Figure 3. Pedostratigraphic correlation of Test Holes (TH) 7 through 12. Correlation in south-north direction. Correlation is not chronostratigraphic.

Rather than risk the lives and property of Missourians and others who use these routes, these software simulations of rock accelerating downslope save time and money in the design of rock slopes.

Bear Mountain on Route 65 in Taney County is one of the highest rock cuts in the state at over 165 feet high, and it serves extremely well as an example of how benched cuts prevent rocks from reaching the road. Two separate runs of the Colorado Rockfall Simulation Program were completed to illustrate ‘before’ and ‘after’ benching of Bear Mountain, using a theoretical 0.3 meter (1 foot) diameter boulder, assumed spherical. The ‘before benching’ run is shown as Figure 4. The ‘after benching’ run is shown as Figure 5.

A SUMMARY OF IMPORTANT CONSIDERATIONS IN HIGHWAY GEOLOGY

Route location, design, and construction all rely on a combination of successful geologic investigation with sound engineering principles. Highway geologists must be ready (once a route is proposed for construction) to offer their best judgment based upon their experience with similar and different terrain to aid the engineer in producing a quality product which is economical for the taxpayer. The finished product should also be safe, which requires the geologist to locate existing geological features such as faults, folds, karst features, and drainage features.

The geologist’s job is not finished once the project is started. The geologist should be available to solve special problems during and after the project is completed. Furthermore, the geologist should be aware of the location and quality of aggregate resources for asphalt, concrete, and shot rock for fill. After project completion, he/she should monitor areas of potential slope instability, bridge scour after flooding, and a hundred other details that do not confront geologists in minerals exploration and environmental work. MoDOT even has asked a geologist to become expert in the types and variability of salts used in de-icing of roads. Each project is unique and offers an unpredictable mélange of problems to be solved to insure that the taxpayer receives a safe, affordable, and high-quality transportation system.

ACKNOWLEDGEMENTS

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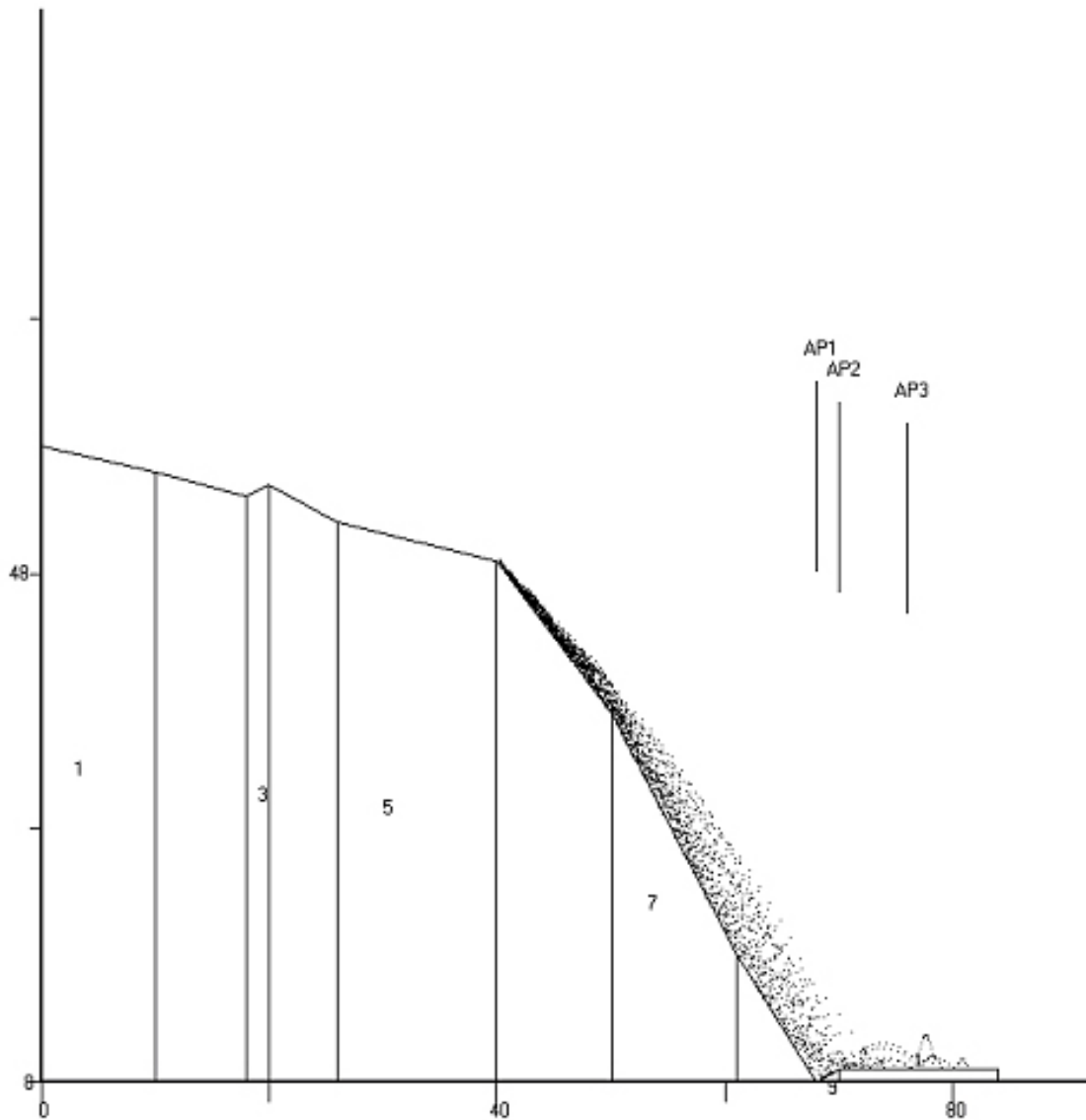


Figure 4. Colorado Rockfall Simulation Program (CRSP) slope diagram representing 100 rocks rolled from highest point on the Bear Mountain road cut before construction, southbound lane of Route 65, Taney County. Of 100 rocks rolled, 22 reached the pavement, with an average velocity of 16.0 meters per second. AP1, AP2, and AP3 are analysis points representing the base of the cut, the edge of the shoulder, and the edge of the pavement, respectively, where measurements were made using the program. This diagram illustrates the need for a properly benched road cut as illustrated in Figure 5.

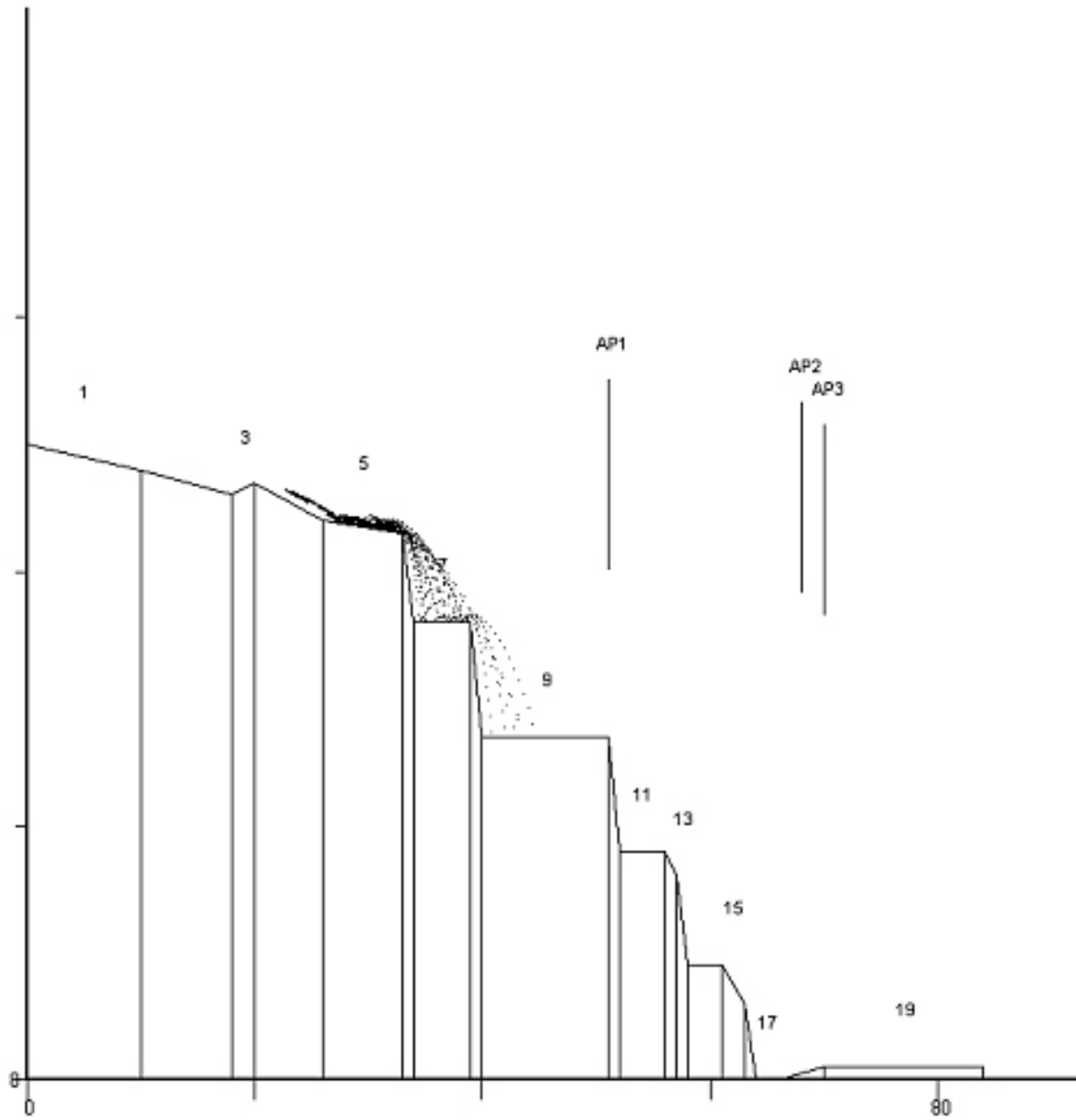


Figure 5. Colorado Rockfall Simulation Program (CRSP) Slope Diagram from highest point on the Bear Mountain road cut after construction, southbound lane of Route 65, Taney County. Line concentration between vertical cells 3 and 5 represents 100 iterations of rock rolled. None of the rocks reached the pavement at cell 19. Parameters used were the most flexible in allowing a spherical rock to roll downslope. AP1, AP2, and AP3 represent analysis points at the roadward edge of cell 9 (widest bench on slope designed to dissipate the greatest amount of energy), the edge of the shoulder, and the edge of the pavement respectively.

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