TECTONICS OF THE WOLF CREEK FAULT ZONE, SOUTHERN ILLINOIS:
A CONSEQUENCE OF LATE PALEOZOIC TRANSPRESSION AND TRANSTENSION
AT THE SOUTHEASTERN END OF THE STE. GENEVIEVE FAULT SYSTEM

BY

MARY JEAN SEID

THESIS

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Advisers:

Professor Stephen Marshak
Joseph A. Devera, M. S., Illinois State Geological Survey
The Ste. Genevieve Fault System (SGFS) is a 118-mile-long (190 km-long) belt of WNW-trending faults that extends from southwestern-most Illinois, across the Mississippi River, and into southeastern Missouri, in the central (Midwest) United States. East of the Mississippi River, in an area that lies in Jackson and Union Counties, Illinois, the SGFS is about three miles (5 km) wide, and is delineated by the Ste. Genevieve Fault on the SW, and the Pomona Fault on the NE. The region between these two faults is cut by several NNW- to NNE-trending normal faults that together comprise a zone here named the Wolf Creek Fault Zone (WCFZ). While normal faulting, indicative of local crustal stretching, dominates, the region also contains subtle structures indicative of local crustal shortening. Shortening structures, which include local anticlines, and a monocline formed over a buried thrust fault, have the same trend as the normal faults. New geologic mapping and shallow drilling in an 18 mile² (45 km²) region that includes the WCFZ indicate that normal faulting in the zone produced several tilted fault blocks of Mississippian strata; beds in these blocks now have dips of between 15° and 21°. This tilting occurred prior to deposition of the sub-horizontal beds of the Pennsylvanian-age Caseyville Formation, so the contact between Mississippian and Pennsylvanian strata in the WCFZ is an angular unconformity. Existence of this angular unconformity indicates that formation of the WCFZ took place in Late Mississippian/Early Pennsylvanian time (i.e., during the Late Paleozoic).
In detail, the WCFZ can be divided into three distinct structural domains—in the Western Domain, normal faults trend NNW; in the Central Domain, pre-Caseyville strata are horizontal and unfaulted; and in the Eastern Domain, normal faults trend NNE. The Western and Eastern Domains each contain two subdomains, one of east-dipping faults and one of west-dipping faults. Each pair of subdomains is separated by an anticlinal axis.

Construction of a new conceptual cross section supports the hypothesis that the WCFZ is not a set of paleo-slump blocks, as has been suggested previously, but rather formed due to tectonic stress at a stepover near the southeastern end of the SGFS. To explain the existence of both shortening and extensional structures, the stress state changed over time. First, transpression associated with left-lateral strike-slip on the SGFS produced shortening structures. Later, transtension associated with right-lateral strike-slip produced an extensional pull-apart zone. Similar episodes of deformation have been found in other continental-interior fault-and-fold zones (e.g., the Cottage Grove Fault System and the Sandwich Fault) in the Illinois Basin. The timing of activity in the WCFZ implies that it, and related zones, record a period of Alleghanian/Ouachita continental-interior fault reactivation and propagation, and thus are Midcontinent manifestations of the Ancestral Rockies event.
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General Statement

This thesis presents the results of new field mapping, and new analyses of shallow drill cores, designed to characterize an array of brittle faults, here named the Wolf Creek Fault Zone, that crop out along the southwestern edge of the Illinois Basin in southern Illinois. To provide a context for this study, I begin this chapter by characterizing the regional geologic setting of the study area. I will first introduce the basins and domes characteristic of cratonic interior platforms, and then I will describe the general nature of Midcontinent fault-and-fold zones. Then, I will provide additional detail concerning the delineation of the Wolf Creek Fault Zone as a portion of the larger Ste. Genevieve Fault System. This chapter finishes with a statement of the problem that my research addresses.

Regional Structure of the Midcontinent

North America can be divided into regional geologic provinces based on the overall character of the crust. Specifically, the eastern and western margins of the continent are Phanerozoic orogenic belts (the Appalachians and Cordillera, respectively). In between, in the region extending from the Appalachian front to Rocky Mountain front, lies the Great Plains
which, geologically, are underlain by a cratonic platform (Fig. 1). Here, Precambrian basement has been covered by a veneer of Phanerozoic strata that varies in thickness from a minimum of less than a few hundred meters to a maximum of about 7 km. Regions underlain by relatively thinner strata are known as arches and domes, whereas regions underlain by thicker strata are known as intracratonic sedimentary basins. The WCFZ occurs along the western boundary of one of these basins, the Illinois Basin, and the adjacent Ozark Dome. The Illinois Basin covers most of Illinois and portions of adjacent Indiana and Kentucky, while the Ozark Dome lies within Missouri. The sequence of strata filling the Illinois Basin thickens toward the basin’s interior, due to syn-depositional subsidence during the Paleozoic. The Illinois Basin is bounded on the east by the Cincinnati Arch, on the north by the Wisconsin Arch and Kankakee Arch, and, as noted already, on the west by Ozark Dome.

Numerous Midcontinent fault-and-fold zones locally cut the strata of the Midcontinent (e.g., Marshak et al., 2003). In the Illinois Basin, examples of these structures include the Rough Creek Graben and the Reelfoot Rift (Fig. 2). Each zone includes discrete faults as well as monoclinal folds that form above the tip-lines of faults. The principal faults of these fault-and-fold zones typically penetrate basement at depth. At shallower crustal levels, they bifurcate updip into splays, which together comprise a flower structure.

Within the continental-interior region of the United States, fault-and-fold-zones are kilometers to hundreds of kilometers long and fall into roughly two sets based on map-view trend—one set trends north-northeast (NNE), and the other trends west-northwest (WNW) (Marshak and Paulsen, 1997; Harrison and Schultz, 2002; Marshak et al., 2003). Midcontinent fault-and-fold zones affecting Phanerozoic sedimentary cover are likely due to reactivation of
Proterozoic basement-penetrating faults (Nelson and Marshak, 1996; Marshak and Paulsen, 1996; Harrison and Schultz, 2002). The specific timing of major reactivation events (during the Ordovician, Devonian, and Late Paleozoic) suggests that the events represent the cratonic response to stress generated by continental collisions on the margins of North America (e.g., Kolata and Nelson, 1991; McBride and Nelson, 1999).

**The Ste. Genevieve Fault System**

The Ste. Genevieve Fault System (SGFS) is one of the most prominent fault-and-fold zones in the Midcontinent. (Of note, Nelson and Lumm, 1985, referred to the structure as the “Ste. Genevieve Fault Zone.” I prefer to call it a “fault system” because of its dimensions; local assemblages of faults within it can be referred to as “fault zones.”) The SGFS strikes northwest (NW), and overall, its southwest (SW) side is upthrown relative to its northeast (NE) side. Nelson and Lumm (1985) state that the maximum observed vertical throw on the SGFS based on surface mapping is 3,000 feet (900 m). The fault system can be traced along the southwestern edge of the Illinois Basin for 118 miles (190 km), from southern Illinois into Missouri (Fig. 3), and in Illinois, it is about 3 miles (5 km) wide. The SGFS appears to be the surface manifestation of the crustal boundary between the Ozark Dome and the Illinois Basin, considering that it lies above a seismic zone and a zone that delineates two provinces that have different seismic-velocity structure (Chen et al., 2013; Pavlis et al., 2013). The significance of this boundary is emphasized by a shaded-relief structure-contour map of the top of the Precambrian basement, which shows that basement topography has relief of about 7 km across the boundary between the Illinois Basin and the Ozark Dome (Fig. 4).
The portion of the SGFS that lies in Illinois is located in the Shawnee Hills, a region that has relatively rugged topography, in comparison to the plains to the north. Its trace stands out in the topography, because the landscape to the south of the fault has notably smaller wavelength ridges and valleys than does the landscape to the north of the fault (Figs. 5A, B). This topographic contrast reflects the compositional contrast of bedrock units juxtaposed by the fault—cherty Devonian strata occur to the south and less resistant Mississippian and Pennsylvanian units lie to the north. Near Grand Tower, the Mississippi River channel follows the trend of the SGFS, making it clear that the fault has influenced the course of the river during the Cenozoic. Notably, the fault system influenced river courses during the Paleozoic as well. Specifically, a study of Pennsylvanian paleocurrents by George Desborough (1961b) showed that the “Rattlesnake Ferry fault” (his name for the Illinois segment of the SGFS) bounded a topographic high that diverted Pennsylvanian-age rivers.

The SGFS is one of several west (W)- to NW-trending fault systems in the Illinois Basin region. Other W- to NW-trending structures include the Rough Creek-Shawneetown Fault System, the Lincoln-Cap au Grès Monocline, the Sandwich Fault Zone in northern Illinois, and the Cottage Grove Fault System in southern Illinois. Of note, the Cottage Grove Fault System extends across southern Illinois and may link to the Rough Creek-Shawneetown Fault System (Nelson and Krausse, 1981). Notably, the existence of en echelon fault segments in the Cottage Grove Fault System, which can be seen in Fig. 5B, imply that a strike-slip component of displacement occurred within the system (Nelson and Krausse, 1981; Duchek et al., 2004).

Along its length, the SGFS includes many subsidiary faults. Some of these trend parallel to the main fault. But others merge and bifurcate to define an anastomosing pattern, or are
arranged in an *en echelon* pattern and intersect the main NW-trending fault trace at an angle (Biddle and Christie-Blick, 1985).

To avoid confusion, I will use the label SGFS to refer to the entire array of related faults at the boundary between the Ozark Dome and the Illinois Basin in Missouri and Illinois. In the segment of the SGFS of Illinois, the name “Ste. Genevieve Fault” will be used in reference to the major fault that delineates the southwestern edge of the SGFS, and the name “Pomona Fault” will be used for the major fault that delineates the northeastern edge of the SGFS (see Fig. 5B). The Pomona Fault is 13 miles (20 km) long (Desborough, 1961a; Nelson, 1995), and the northeast side is downthrown. I will not use the name "Rattlesnake Ferry Fault," which Desborough (1961a; 1961b) applied to the Illinois portion of the Ste. Genevieve Fault.

The SGFS has undergone at least two periods of movement (Nelson, 1995). The first episode occurred during the middle Late Devonian and resulted in normal-sense down-to-the-southwest (SW) displacement. The second episode occurred in Late Mississippian to Early Pennsylvanian time and resulted in high-angle reverse-sense top-up-to-the-northeast (NE) displacement. Structural analysis indicates that the last phase of faulting included a component of strike-slip displacement, visible in the Missouri portion of the SGFS (Schultz et al., 1992).

**The Wolf Creek Fault Zone**

The Wolf Creek Fault Zone (WCFZ) is an 18 mi² (45 km²) rhombohedral area of faulted strata that crops out near the southeastern end of the SGFS in southern Jackson and northern Union Counties, Illinois (Fig. 6). It was named for a ravine in the Gorham 7.5-minute Quadrangle along which mapping revealed four repetitions of the stratigraphic section (Seid et
The WCFZ covers portions of four 7.5-minute quadrangles—the Pomona, Gorham, Wolf Lake, and Cobden quadrangles (see Fig. 6). Faults within the zone extend from the Ste. Genevieve Fault on the south to the Pomona Fault on the north.

The WCFZ is a fault array containing NNW- to NNE-trending normal faults that are oblique to the overall trend of the SGFS. Displacement on the faults tilted Mississippian strata by an average of 15° to 20°, although steeper dips occur locally. The Pennsylvanian Caseyville Formation unconformably overlies the tilted fault blocks, which suggests that much of the displacement occurred prior to Pennsylvanian deposition, although a few faults may cut upward and displace Pennsylvanian strata.

The northeastern edge of the WCFZ is delineated topographically by a 200-foot-high (60 m) escarpment, which extends west-to-east across southernmost Illinois from the Mississippi River to the Ohio River. This escarpment exposes resistant Pennsylvanian clastic strata, so geologists refer to it locally as the "Pennsylvanian escarpment". The southwestern edge of the WCFZ is bounded by steeply dipping Mississippian and Devonian rocks uplifted along the NW-trending Ste. Genevieve Fault. The western edge of the WCFZ occurs where the deformed strata have been removed by erosion along the Big Muddy River, a tributary of the Mississippi that runs along the eastern edge of the main Mississippi flood plain. The structures of the WCFZ likely continue beneath the alluvial Mississippi floodplain, but this concept cannot be confirmed without drilling and/or seismic data. The eastern edge of the WCFZ is placed at the location where Chesterian strata are flat-lying and are covered by Pennsylvanian rocks, about one mile (1.6 km) east of State Route 127.
Statement of the Problem and Goals of this Research

The motivation for this thesis research evolved from quadrangle mapping of the Gorham and Altenburg 7.5' quadrangles as part of the U.S. Geological Survey’s STATEMAP contract with the Illinois State Geological Survey (Seid et al., 2009a; Seid et al., 2009b). The quadrangle mapping led to the identification of a fault array, the WCFZ. Developing an overall picture of the WCFZ was problematic for several reasons: (1) the zone covers the corners of four different quadrangles, (2) the quadrangles had been mapped using slightly different stratigraphic groupings, and (3) the dimensions and displacements of faults within the WCFZ were too small to be expressed at the 1:24,000 scale of the quadrangle maps. The quadrangle mapping, however, made it clear that a detailed study of the area may provide insights on the kinematic evolution of the southeastern end of the SGFS.

The pattern of the WCFZ, as characterized by the initial quadrangle mapping, was intriguing because it could be interpreted in two different ways: (1) the faulting could be a consequence of localized crustal trans-tension in a pull-apart basin within the SGFS, or (2) the faulting could be due to localized slumping along a paleo-river valley that had formed in Early Pennsylvanian time. Unfortunately, the quadrangle mapping did not provide sufficient detail to permit the validity of these models, or to identify other models to be tested.

With these questions in mind, it became clear that more detailed mapping focused on the WCFZ was needed, and that alternative models needed to be tested by the production of cross sections. This research, therefore, was designed to characterize the geologic structure of the WCFZ in detail. I did high-resolution field mapping of complex areas in the WCFZ, interpreted shallow drill cores that provide subsurface constraints on the WCFZ, collected bedding-attitude
data, and correlated strata across quadrangle boundaries. The geologic map and interpretive cross sections produced for my study lead to a new, alternative structural interpretation of the WCFZ and its relation to the SGFS, and provide insight into the nature of Midcontinent fault-and-fold zones in general.
Figure 1. Geologic map of the USA Midcontinent platform showing locations of basins and domes (from Marshak, 2009, p. 263). Wisc.=Wisconsin; Cin.=Cincinnati; Missi.=Mississippi.
Figure 2. Major structural features of the U.S. Midcontinent (from Kolata and Nimz, 2011, Fig. 2-2; modified from Buschbach and Kolata, 1991). Light yellow shading shows the areal extent of the Illinois Basin based on the –500-foot (–152-m) contour on top of the Ordovician Kimmswick (“Trenton”) Limestone. Shaded blue area is the Mississippi Embayment of the Gulf Coastal Plain.
Figure 3. Fault map of the Ste. Genevieve Fault System and other major structural features in the Illinois Basin (after Nelson, 1995).
Figure 4. Structure-contour of the top of Precambrian for the Illinois Basin / Ozark Dome region of Missouri, Illinois, Indiana, and Kentucky (Marshak et al., in prep, Map 8). Contour interval is 1,000 feet. The basement reaches its deepest point (29,000 feet below mean sea level) in Kentucky. The Illinois Basin is the depression covering most of Illinois and parts of southwestern Indiana and western Kentucky. The area in red indicates the center of the Ozark Dome, where the Precambrian outcrops at the surface.
Figure 5A. A digital elevation model of the Wolf Creek Fault Zone and vicinity, shown with only the Missouri-Illinois state boundary. Brown is higher elevation; blue is lower elevation. Map was produced in ArcGIS using digital terrain data with 10 m resolution.
Figure 5B. A digital elevation model (same as Fig. 5A) with an overlay of fault traces to show the location of the Ste. Genevieve Fault System and Pomona Fault. Note that the faults influence topography and drainage systems in this unglaciated area.
Figure 6. A digital elevation model (same as Figs. 5A, B) showing the location of the Wolf Creek Fault Zone study area (stippled pattern), county boundaries (large type; all capital letters), and an index of the USGS 7.5-minute quadrangle boundaries (rectangles outlined in purple; quadrangle name labeled in center).
General Statement

Below, I describe the various steps that I utilized in my study of the Wolf Creek Fault Zone (WCFZ). The work began with a compilation and assessment of previous geological research in the area, and then progressed to the collection of new data, both by field mapping and by shallow drilling. The final stage involved map compilation using modern digital mapping techniques, as well as construction of cross-sections.

Previous Studies of the WCFZ Region

The first studies of the geology of Jackson and Union Counties, the region in which the WCFZ lies, were part of county-scale geological surveys carried out after the Civil War. These studies established the basic stratigraphy and structure of the region (Worthen, 1868). Little further work was conducted in the region until the era of World War I, when Stuart St. Clair recognized the potential for the region to contain oil, and in the course of his study, discovered an the angular unconformity between Chesterian strata and overlying Pennsylvanian strata (St. Clair, 1917, p. 52). A few years later, George E. Ekblaw and his field partners mapped the Alto Pass 15' Quadrangle and found abundant evidence for post-Chesterian, pre-Pennsylvanian faulting in the north-south trending Cave Creek Valley (Fig. 7). Continued mapping efforts
resulted in the completion of a portion of the Alto Pass 15' Quadrangle (Weller and Ekblaw, 1940). This map included faults mapped previously by Ekblaw (1925) in Cave Creek, but did not include the western part of the WCFZ.

Between 1940 and 1960, no known geologic studies were carried out in the WCFZ. Then, beginning in the 1960s, several students at Southern Illinois University at Carbondale pursued geologic mapping projects at the 1:24,000 scale (or larger) for their Master’s theses. Desborough (1961a) mapped the geology of the Pomona Quadrangle, and Pickard (1963) mapped part of the Gorham Quadrangle. (Pickard’s map could not be examined because it was reported as lost by the library at Southern Illinois University Carbondale.) Joseph A. Porter (1963) produced a 1:12,000-scale map of the southeastern quarter of the Gorham Quadrangle and the northernmost edge of the Wolf Lake Quadrangle. Porter was the first to depict “hypothetical cross sections of the evolution of structure C1” (on his Plate 3). He depicts a simple two-stage mechanism: a shallow, vertical block fault offsets Chesterian strata and the faulted strata are overlain by unfaulted Pennsylvanian Caseyville sediments. Satterfield (1965) produced a geologic map of the Cobden Quadrangle, which included the faults in Cave Creek that were mapped four decades earlier by Ekblaw. These thesis maps show the geologic relationships and major fault zones, but the authors struggled to correlate the Chesterian formations consistently across all map areas. Specifically, they had difficulty distinguishing the Degonia Sandstone from the Palestine Formation. In addition, at that time, the role of strike-slip faulting had not been recognized in Illinois.

A renewed interest in geologic mapping of the WCFZ region began in the early 1990s. Several mapping projects of this area were supported by a cooperative agreement between the
U.S. Geological Survey (USGS) and the Illinois State Geological Survey (ISGS). In 1993, Joseph A. Devera (1993) mapped the Wolf Lake Quadrangle, which includes Devonian through Pennsylvanian strata exposed along the Ste. Genevieve Fault System. Devera and Nelson (1995) mapped the adjoining Cobden Quadrangle, which includes the faulted Chesterian strata in Cave Creek. About a decade later, I joined the ISGS mapping team of Devera and Nelson, and with them mapped the Pomona Quadrangle (Seid et al., 2007). We found that the faulting in Cave Creek extended northward from Cobden into the southernmost portion of the Pomona Quadrangle. Based on the map view pattern of these numerous sub-parallel faults in the Pomona Quadrangle, Seid et al. (2007) proposed that the WCFZ was an en echelon fault array that developed as a result of extension due to right-lateral strike-slip displacement on the Pomona Fault. In an effort to complete the mapping of the four adjacent quadrangles that included the WCFZ, we also completed the Gorham Quadrangle (Seid et al., 2009a). The WCFZ zone crops out on portions of four quadrangles—Wolf Lake, Cobden, Pomona, and Gorham. These four 1:24,000-scale geologic maps, which have been published during the past two decades, helped advance my understanding of the area by providing consistent correlation of Chesterian rock units across quadrangle boundaries. The maps also provide the basic data (e.g., strike and dip measurements, stratigraphic offset) necessary to begin characterizing the complex system of faults within the WCFZ.

In addition to the four quadrangle maps, a number of other studies have addressed the structures in the WCFZ. Desborough (1957) titled his study “Faulting in the Pomona area,” which covered the eastern portion of the WCFZ (Fig. 8A, B). He proposed that the faulting was related to the Ste. Genevieve Fault (his “Rattlesnake Ferry Fault”). Nelson and Lumm (1985)
called these structures the “Faults near Alto Pass” (Fig. 9), and attributed the faulting to slumping of unconsolidated sediments in response to tectonic movements on the SGFS.

**New Field Mapping and Shallow Drilling**

This project builds on a foundation of observations obtained during ISGS mapping projects in 2007 and 2009 in the Pomona and Gorham quadrangles. I carried out new field work for this thesis study during the 2010 to 2011 winter field seasons. The new mapping covers an area 2.65 mi- (4.25 km)-long by 1.9 mi- (3 km)-wide, between latitudes 37°36’00”N and 37°39’00”N and longitudes 89°22’00”W and 89°25’30”W. This area is centered at the corners of four USGS 7.5-minute quadrangles—Gorham, Pomona, Cobden, and Wolf Lake. An initial compilation of these four maps (Fig. 10) provided context to guide the study. In addition to my own field observations, I obtained insight into outcrop details concerning the Wolf Lake and Cobden quadrangles from the archived field notes of W. John Nelson and Joseph A. Devera; these notes are on file at the ISGS Library. I also had extensive discussions with Nelson and Devera concerning observations and interpretations in the field area.

The mapping was carried out between 2007 and 2009 using standard field methods (e.g. Compton, 1985). Working primarily during the winter, when the leaves were down, I located outcrops on a 1:24,000 USGS topographic base map and systematically recorded observations including measurements of bedding attitudes, mesocopic structures (faults, folds, and joints), lithologic descriptions, and stratigraphy for each note location (Fig. 11). In 2010, I began using a GPS unit (Garmin GPSmap76CSx) to provide a digital coordinates and began to compile data.
on a digital map using *ArcGIS 10.0* software, produced by ESRI. The data compilation process is discussed in more detail in the following section.

In addition to mapping, I examined core recovered from four new 83- to 410-foot-deep (25 to 125 m-deep) drill holes obtained in the map area. The GG hole (410 feet total depth) was designed to penetrate faulted Chesterian rocks beneath Pennsylvanian strata. The Sanders hole (230 feet total depth) was drilled to characterize the contact between the Menard Limestone and Pennsylvanian strata. The Allison (265 feet total depth) hole was drilled in order to identify the subsurface orientation and character of the Pomona Fault. The HRW hole was drilled with the goal of characterizing the stratigraphic section in an undeformed portion of the WCFZ, although karst at the Mississippian-Pennsylvanian boundary caused circulation problems and the total depth of the hole was only 83 feet. Drill hole observations are discussed in greater detail in Chapter 4.

**Compilation of Geologic Data**

New mapping and borehole data was compiled with the GIS data from the Gorham, Pomona, Cobden, and Wolf Lake quadrangles using *ArcGIS*. *ArcGIS* was used for map compilation because it creates a georeferenced database in which note locations can be linked to the details that are recorded in field observations (i.e. bedding attitude, joint orientations, descriptions of faults and folds, notes on the character of contacts). The geologic map data management structure (abbreviated “GMDM”) currently in use at the Illinois State Geological Survey was used as a template for creating the database. *ArcGIS* has limited graphics capabilities, so all data compiled in *ArcGIS* were then exported at a scale of 1:12,000 to a
graphics program, *Adobe Illustrator CS5*. *Illustrator* tools are well suited to adding map legends, editing lines, and manipulating word or number locations. Thus, *Illustrator* made it possible to produce a final publishable-quality map. The specific steps in my mapping procedure are described below:

- The four different 7.5' geologic quadrangle maps containing the WCFZ were resized to the 1:12,000 scale and compiled in *Adobe Illustrator* from their original .pdf files. This preliminary map was useful for identifying important outcrops and for checking the locations of faults (see Fig. 10).
- *ArcGIS* software was used to compile data from hundreds of closely spaced field locations and drill holes at various scales for interpretation. My observations were supplemented with field notes from other mappers, notably those of W. John Nelson and Joseph A. Devera. In *ArcGIS*, I began by building a map document (.mxd) to which I imported the USGS 7.5-minute topographic maps from the ISGS database.
- I added the geologic data in GIS format (shapefiles and feature classes of the geologic contacts, map unit polygons, and drill hole data) for the Pomona, Gorham, Wolf Lake, and Cobden quadrangles from the ISGS database. New field note locations and drill hole data were then added to the digital map.
- I made decisions regarding the placement of geologic unit contact lines, faults and folds, and applied a consistent color scheme to the geologic units.
- The map was exported *Adobe Illustrator* for symbolization, labeling, final editing and completion of the map layout.
Constructing the map and cross sections was an iterative process. Once the final map began to take form, I constructed cross sections. The sections were made with no vertical exaggeration in order to convey the true angles of fault and bedding dips. The cross sections had to be constructed initially on paper at a larger scale than the geologic map in order to convey the detail of the fault array. I determined that the ideal scale for the cross sections was 1:3,000 (one inch = 250 feet), so units that were only 50 feet (15 m) thick could be portrayed without vertical exaggeration. The hand-drawn cross sections were then digitized and edited in Illustrator.
**Figures**

![Map of faults in the vicinity of Alto Pass (Ekblaw, 1925)](image)

**Figure 7.** A map showing some of the faults in the vicinity of Alto Pass (Ekblaw, 1925).
Figure 8A. Areal pattern of faults in the Pomona area (Desborough, 1957).
Figure 8B. Areal geologic map of the Pomona area (Desborough, 1957).
Figure 9. Distribution of faults composing the Wolf Creek Fault Zone, which occurs between the Ste. Genevieve and Pomona faults (Nelson and Lumm, 1985).
Figure 10. Initial compilation of the Gorham, Pomona, Cobden, and Wolf Lake quadrangle maps. Faults are shown with bold black lines.
Figure 11. Joe Devera and I doing fieldwork in ideal field conditions during the winter, when the vegetation is down and visibility is better. The nature of a typical outcrop can be seen on the hillside in the background. Photo credit: Stephen Marshak, December 2009.
--- CHAPTER 3 ---

STRATIGRAPHY OF THE WCFZ

General Statement

Exposed strata in the map area comprise six stratigraphic units that range in age from Mississippian to Pennsylvanian (Fig. 12). Mississippian units attain a total thickness of 305 to 415 feet (93 to 126 m) and consist of the Menard Limestone, Palestine Sandstone, Clore Formation, Degonia Sandstone, and Kinkaid Limestone; all of these units are assigned to the Chesterian Series of the Elviran Stage. An unconformity exists at the Mississippian-Pennsylvanian boundary. This unconformity, which can be traced across the entire Illinois Basin (Siever, 1951; Bristol and Howard, 1971; Bristol and Howard 1974), is one of the major sedimentary sequence boundaries that Sloss (1963) identified in the Midcontinent. He referred to it as the “sub-Absaroka unconformity,” and it marked a time of widespread erosion in Illinois. Above the unconformity is the Early Pennsylvanian Caseyville Formation (Morrowan Series). The above units are described below in sequence, from oldest to youngest.

Descriptions of Stratigraphic Units

**Menard Limestone:** The Menard Limestone is 105 to 115 feet thick (32 to 35 m) and consists of limestone and shale. The limestone portion is medium brownish-gray packstone, with local variations in bioclastic content. Shale and calcareous shale beds of the unit are
interbedded with both limestone beds that range between one inch (2 cm) to eight feet (2.5 m) in thickness. Medium-gray to greenish-gray shale beds that range in thickness from one inch (2 cm) to three feet (1 m) occur locally in the section but are poorly exposed. The formation contains two Õolithic and cross-bedded horizons—one is 25 feet (8 m) below the top of the unit, and the other is 25 feet (8 m) above the base of the unit. The Menard contains a variety of fossils, including brachiopods, bivalves, myalinids, and crinoids.

**Palestine Sandstone:** The Palestine Sandstone is 40 to 50 feet thick (12 to 15 m) and consists of interbedded shale, siltstone, and sandstone. The lower 30 feet (10 m) of the unit consists dominantly of light brown very-fine-grained quartz arenite sandstone, and the upper 10 feet (3 m) of the unit consists of micaceous gray silty shale. Beds are one inch thick (2.5 cm) or less, and contain ripple marks and load casts on bedding surfaces. The Palestine is very poorly exposed in the study area.

**Clore Formation:** The Clore Formation (Fig. 13) is 80 to 90 feet thick (24 to 27 m) and is dominated by shale but also contains limestone, with minor amounts of interbedded sandstone. The unit can be divided into three members—the basal Cora Member, the middle Tygett Member, and the upper Ford Station Member. The Cora and Ford Station Members consist of limestone and shale; the Cora contains relatively more shale with lenticular limestone whereas the Ford Station contains relatively more limestone. In the Cora and Ford Station Members, the limestone is brownish-gray crinoidal wackestone. Locally, the basal part of the Ford Station is Õolithic. Õolite beds are only known from this area of the basin within the Clore Formation. Shale horizons of the Cora and Ford Station Members are dark gray, non-fissile, and non-calcareous. The middle Tygett Member consists of dark gray, thinly laminated, non-fissile silty
shale, and contains the trace fossil *Teichichnus ichnosp.* (a horizontal, gutter-stacked trace fossil). Fossils in the Clore Formation include myalinids, crinoids, fenestrate bryozoans (*Archimedes* sp.), rhomboporid bryozoans, pelmatozoa, *Composita subquadrata*, *Anthracospirifer increbescens*, and productid brachiopods. A three-foot-thick (1 m) bed of shaly limestone with abundant brachiopods serves as a marker bed within the basal 20 feet (6.5 m) of the Clore.

**Degonia Sandstone:** The Degonia Sandstone (Fig. 14) is 80 to 100 feet thick (27 to 30 m) and consists dominantly of sandstone, and lesser amounts of siltstone, shale, and mudstone. The sandstone is white to light brown, fine-grained, well sorted, quartz arenite. This rock is generally very thinly bedded but locally crops out as a 20- to 40-foot-thick (6 to 12 m) massive bed which forms bluffs in the landscape. Siltstone beds in the Degonia are light brown, wavy bedded, and rhythmically laminated with dark to light gray shale. Shale within the unit is generally very dark gray to black, non-fissile, non-calcareous, and non-fossiliferous. Mudstone occurs within the upper 40 feet (15 m) of the unit and may be gray, green, red, olive, or purple, and non-calcareous. In outcrop, the sandstone tends to be well exposed, whereas siltstone and shale tends to be covered. A marine zone in the upper Degonia was discovered during the course of this study—it is a three- to five-foot-thick (1 to 2 m) bed of sandstone that contains brachiopods, fenestrate bryozoans, bivalves, nautiloid and goniatite cephalopods and gastropods. Though sandstone in the Degonia is typically more thinly bedded and contains more prevalent small-scale primary sedimentary structures (i.e. wavy bedding, herringbone cross-bedding and stacked ripple-laminated sheets) than does the Caseyville, it proves difficult to distinguish the Degonia from the Caseyville in field exposures of faulted areas.
**Kinkaid Limestone:** The Kinkaid Limestone (Fig. 15) is typically 140 feet thick in this part of the Illinois Basin, but significant pre-Pennsylvanian erosion reduced its thickness to about 60 feet (20 m). The unit contains limestone and shale and can be divided into the basal Negli Creek Member, the middle Cave Hill Member, and the upper Goreville Member (where preserved). The Negli Creek Limestone is gray to dark gray micrite, which fractures conchoidally, and contains Bellerophonid gastropods and *Girvanella* sp. This unit contains irregularly shaped dark gray chert nodules up to three or four inches (3 to 6 cm) in diameter. The Cave Hill is gray crinoidal wackestone to packstone and can include shale beds a few feet (1 m) thick. The upper Goreville is a ledge-former and consists of gray to light gray lime grainstone with abundant crinoids and fenestrate bryozoans (*Archimedes* sp.). Fossils throughout the Kinkaid include brachiopods, crinoids, and *Chaetetes* sp.

**Caseyville Formation:** The Caseyville Formation (Fig. 16), of Pennsylvanian age, is 0 to 200 feet thick (0 to 70 m) and forms an erosion-resistant cap atop the succession of Chesterian rocks. Sandstone in the upper part is highly variable in thickness. It forms a topographic bluff that is 20 to 40 feet (6 to 12 m) thick at the Pomona Natural Bridge (to the NE), 100 feet thick at Horseshoe Bluff (to the NW), and 10 to 20 feet thick along the east bank of Cave Creek (to the east). The unit’s composition is extremely variable, both laterally and vertically.

The basal contact of the Caseyville is a major unconformity, and channeling is well developed in Mississippian rocks across the entire Illinois Basin (Fig. 17). In local channels, the basal Caseyville can contain conglomerate. This basal conglomerate contains gray and black rounded limestone clasts, rounded to sub-angular chert pebbles up to two feet (40 cm) across in a matrix of quartz sand with limonite cement. It is mostly matrix-supported and massive to
crudely stratified. A study of clast composition suggests that the clasts were derived from nearby Silurian, Devonian, and Mississippian strata (Poor, 1925).

The conglomerate is overlain by beds of sandstone, siltstone, and shale. The sandstone is a quartz arenite, which is white to light gray where fresh, and light brown to reddish brown where weathered. It is very fine- to coarse-grained, sub-angular to sub-rounded, and well to poorly sorted and typically contains only about 1% mica. In the field area, sandstone is non-calcareous. Bedding in the sandstone ranges from thinly laminated to massive—the thin to medium beds can be flaggy and ripple-marked, and the massive beds are commonly cross-bedded. The siltstone is gray, laminated, and carbonaceous, and locally contains pyrite and micro-crossbedding. In places, the sandstone of the Caseyville is interbedded with medium-grained sandstone, gray shale, calcareous bands, and coal seams; the coal seams are locally 14 inches (25 cm) thick. Shale in the Caseyville is light to dark gray, silty, weakly fissile, and locally micaceous and/or calcareous.
Figures

Figure 12. Stratigraphic column of the geologic units mapped in this study.
Figure 13. Outcrops of the Clore Formation. A. Clore dipping 20° west in Caney Creek; April 2011. Photo looking south-southwest; B. Brachiopod-rich layer in the basal Cora Member on the north side of Macedonia Road, about 2,100 feet NW of junction with Bobcat Road; January 2011; C. Yellowish-orange bed commonly found in the Clore; December 2011.
Figure 14. Outcrops of the Degonia Sandstone; April 2011.  
A. Bluff of Degonia Sandstone horizontal and undeformed on the east side of the east branch of Wolf Creek.  
B. Close up of the bluff.  
C. Ripple marks on underside of Degonia float block.  
D. Brachiopod mold from brachiopod sandstone layer in the upper part of the formation in the west branch of Wolf Creek.
Figure 15. Outcrops of the Kinkaid Limestone in the west branch of Wolf Creek; March and April 2011. **A.** A relatively good exposure of Kinkaid Limestone, beds dip 23° east-northeast. Photo looking north-northwest. **B.** Dark brownish gray flattened chert nodules in limestone, typical of the Kinkaid. **C.** Bellerophonid gastropod, a common fossil in the basal Negli Creek Member.
Figure 16. Outcrops of the Caseyville Formation at the head of the west branch of Wolf Creek, March 2011.  

A. Bluff-forming sandstone of the Caseyville Formation.  

B. Basal lag deposit consisting of sub-rounded chert and quartz pebbles in a sandstone matrix, a diagnostic feature of the Caseyville Formation.  

C. Wedge-planar cross bedding dips SE, indicating deflection of SW-flowing early Pennsylvanian rivers by the SGFS.
Figure 17. Paleogeologic map of the sub-Pennsylvanian surface in the Illinois Basin. (Bristol and Howard, 1971, Plate 1). The deepest scouring, as evidenced by incision into the oldest Mississippian units (red and gray) occurred around the flanks of the Illinois Basin. The youngest sediments (pink and dark blue) were preserved in the deepest part of the Illinois Basin. The Pennsylvanian rivers carried sediments from the Appalachians, which were to the NE, and channels that flowed to the SW further scoured into the Mississippian surface.
General Statement

The final geologic map completed for this study is shown in Figure 18, at reduced scale, and on Plate 1, at full scale. This new map improves upon the compiled version of the existing geologic maps in three ways: (1) it traces faults identified in the Gorham Quadrangle farther to the south, (2) it represents the position of fault traces more accurately, and (3) it depicts stratigraphic formations with consistent colors across the entire map area. The map reflects the results of new mapping and drill-core analysis. Areas of the detailed mapping, and locations of drill holes, are shown in Figure 19.

In the area between the Pomona Fault and the SGFS, the WCFZ consists of a series of NNW- to NNE-trending normal faults that offset Mississippian (Chesterian) strata to form a set of cuestas (tilted blocks) in which beds dip between 15° to 21° (Fig. 20). The faults define an *en echelon* array relative to the Ste. Genevieve and Pomona faults, if the two bounding faults are thought of as enveloping surfaces. Resistant beds underlie the dip slopes of the cuestas, and partings along joints form the escarpment face of each cuesta. Displacements on the faults appear to range between 20 and 240 feet (5 to 70 m). Within each tilted block, there are mesoscopic (outcrop-scale) normal faults on which displacements range from less than one inch to a few inches (2 to 20 cm) (Fig. 21). Pennsylvanian strata unconformably overlie the
Mississippian strata, and are sub-horizontal (i.e., have dips of less than ~ 3°) indicating that most movement on the faults occurred between the Chesterian (~345 Ma) and the Early Pennsylvanian (~ 311 Ma). Younger faulting locally affected the Caseyville Formation (Fig. 22).

**Structural Observations**

Dipping beds of the Degonia Sandstone (see Fig. 20) are traceable across the mapping area and are particularly well exposed in Wolf Creek and Caney Creek. Using this unit as a marker horizon, I found that the Chesterian stratigraphic section is repeated four times along an east-trending traverse that begins at a Shawnee Forest access road at the north end of Black Pond Road (N 37.63103°, W 89.39100°) and follows the west branch of Wolf Creek. The continuation of these eastward-dipping panels can be found in the next unnamed tributary to the south, along a northeastward traverse beginning at N 37.62050°, W 89.38400°. The ridges of Degonia Sandstone, which were informally called "ribs" during my mapping, are cuestas. Once it was determined that each cuesta is a tilted fault block topped by Degonia Sandstone, it became possible to use the geomorphology of the WCFZ as a basis for mapping faults—fault traces delineate the base of each cuesta.

Not all of the cuestas dip eastward. A westward-dipping cuesta topped by Degonia Sandstone is exposed at the headwaters of Caney Creek, along a north-trending traverse beginning at N 37.62410°, W 89.39892°. This cuesta can be traced to the south across Macedonia Road. In a southward-flowing unnamed tributary to Hutchins Creek, south of Macedonia Road, this cuesta divides into three smaller cuestas, presumably because the underlying fault splays into three strands.
Mesoscopic normal faults (Fig. 23) were found in many outcrops. For example, an outcrop-scale negative flower structure occurs in the Degonia Sandstone (Fig. 24), and down-dip slip lineations (interpreted to be indicative of normal-sense displacement) were visible locally on fracture surfaces, indicating that the fractures are mesoscopic faults (Fig. 25). In two places, bedding appeared to thin plastically in the Degonia Sandstone, adjacent to a presumed fault, suggesting that the sediment was only partially lithified at the time of deformation (Fig. 26). The occurrence of mesoscopic structures supports the interpretation that the study area has been broken up by faulting.

Though the dominant slip on faults appears to be normal sense, not all faults in the study area display this type of movement. Specifically, at one locality I observed a faulted monocline in the upper Palestine (Fig. 27). Here, a 6 foot (2 m) long exposure of siltstone has been cut by a reverse fault whose attitude is 330°/28°NE; the fault dies out up-dip into a monocline. Beds in the hanging wall above the fault are horizontal, whereas beds in the footwall are overturned. In addition, a NNW-striking anticline occurs in the Kinkaid Limestone, in Secs. 25 and 36, T. 10 S., R. 3 W. This structure has a half-wavelength of 1700 feet (500 m). A fold with similar geometry occurs in the west branch of Wolf Creek. It is not clear if these structures are rollover folds related to normal faulting, or are buckles related to a separate phase of compression.

**Structural Domains**

The pattern of bedding strikes and fault trends in the WCFZ indicate that the zone can be divided into three structural domains, here named the Western, Central, and Eastern Domains (Fig. 28). Along strike, each structural domain can be traced for nearly the entire distance
between the Ste. Genevieve and Pomona faults. The Western and Eastern Domains each contain a set of west-dipping and east-dipping cuestas that are separated by a gentle anticline that is 300 feet wide (100 m). The Central Domain consists of flat-lying, undeformed strata.

In map view, the Western Domain is approximately two miles (3 km) wide, as measured across-strike, and four miles (6 km) long, as measured parallel to strike. Trends of fault traces and strikes of bedding planes are roughly NNW in the northern portion of the Western Domain and curve to a NW trend in the southern portion, where they are apparently deflected by slip on the NW-trending Ste. Genevieve Fault. Average strike and dip of bedding in the west-dipping panel of the Western Domain is $356^\circ/21^\circ W$ (**Fig. 29A**), whereas average strike and dip of bedding in the east-dipping panel is $338^\circ/20^\circ E$ (**Fig. 29B**).

The Central Domain is about 1.5 miles (2.5 km) wide, as measured across strike, and three miles (5 km) long, as measured parallel to strike, and has a triangular shape in map view—it is narrower to the south and wider to the north. Within the Central Domain, Mississippian and Pennsylvanian strata are sub-horizontal and have not been cut by faults.

The Eastern Domain is about two miles (3 km) wide, as measured across strike, and 3.5 miles (5.5 km) wide, as measured along strike. Faults and bedding planes within this domain generally strike NNE. The average strike and dip of bedding in the west-dipping panel of the Eastern Domain is $032^\circ/17^\circ W$ (**Fig. 29C**), whereas the average strike and dip of bedding in the east-dipping panel is $010^\circ/17^\circ E$ (**Fig. 29D**).
Data from Drill Holes

Six drill holes provided new information about formation thicknesses, bedding dip, depth to the Menard Limestone, and the extent and style of faulting. The drill holes are named after the localities in which they were drilled—GG, Sanders, Allison, Hickory Ridge Winery (HRW), Pomona Civilian Conservation Corps (Pomona CCC), Gorham (GH), Stearns, Hagler, and Godwin. **Figure 19** provides the locations of these wells. The GG, Sanders, Allison, and HRW holes were drilled specifically for this project by the Illinois State Geological Survey drilling team. They were drilled using standard two-inch- (5 cm)-diameter coring bits, and yielded continuous cores from the ground surface down to the base of the hole, and each took about two weeks to drill.

The GG hole was drilled in 2009 (total depth = 410 feet) for the purpose of testing whether the tilted fault blocks mapped in the northern portion of the study area extended to the south in Wolf Creek, where ground-surface outcrop consists of sub-horizontal Pennsylvanian strata. In the GG core, Chesterian strata intersected below the Pennsylvanian dip uniformly at about 20°. Unfortunately, since the core is not oriented, and downhole dip-meter or imaging techniques were not employed, the strike of bedding could not be constrained. The presence of tilted strata indicates that the tilted fault blocks exposed at the head of Wolf Creek indeed do extend southward, beneath the sub-horizontal Pennsylvanian strata. Also of note, the Clore Formation is only 41 feet (12 m) thick in the drill hole (i.e., is thinner than in the surrounding regions), and the Palestine Sandstone does not occur in the drill hole. A sheared shale lies at the base of the Clore. These observations—the absence of stratigraphic section and the presence of a sheared horizon—further suggest that the drill hole crossed a normal fault.
The Sanders well was drilled in 2010 (total depth = 230 feet) on Milligan Hill Road in Alto Pass. In the well, the Caseyville Formation rests unconformably on the Menard Limestone 41 feet below the surface. Just below the unconformity, the Menard Limestone is cut almost entirely by fracture planes that dip 80°. The lower half of the Menard Limestone has a dip that ranges between 10° to 15° and appears to be cut by mesoscopic fractures oriented at 40°, 75°, and nearly 90° to the horizontal. This observation contradicts the assumption that the Menard Limestone is flat-lying and undeformed (c.f. Devera and Nelson, 1995). In the well, at a depth of 153 feet, a mullioned, vertical, left-lateral strike-slip fault with fibrous calcite lineations was observed in the Menard Limestone. The Caseyville Formation dips about 3° and is cut by faults that dip 55° and 80° to the horizontal, although sense of slip was unclear. Such observations suggest that slip on the Ste. Genevieve fault affected the Caseyville.

The Allison hole was drilled in 2010 (total depth = 265 feet) with the intent of providing insight into the depth and character of the Pomona Fault in the subsurface. In the Caseyville Formation, sub-vertical faults with 1-2 mm of offset were common, and I observed a flower structure at 52-feet-depth. Beneath the Pennsylvanian strata, although stratigraphic relations are difficult to recognize, the Chesterian strata dip between 38° and 64°. Lineations on a combination of reverse and normal faults suggest dip-slip and oblique-slip displacements. The most intensely faulted zone occurs between 165- and 207-feet-depth, where the shale is sheared and has a scaly texture, and sandstone bedding is tilted as much as 67°. This hole confirmed that the Pomona Fault affects both Chesterian and Pennsylvanian strata, although Chesterian strata are more intensely deformed, indicating that major movement occurred post-Chesterian to pre-Pennsylvanian.
The Hickory Ridge Winery hole (HRW) was drilled in 2010 (total depth = 83 feet) on Hickory Ridge Road for the purpose of obtaining thicknesses of the stratigraphic section in the undeformed Central Domain. The hole bottomed in a karst horizon at the Mississippian-Pennsylvanian unconformity, and drilling fluids could not circulate with the large void space, so operations ceased. Only eight feet of core were recovered below the unconformity—a six-foot-thick reddish brown paleosol at the unconformity, and two feet of the Negli Creek Member of the Kinkaid Limestone at the base of the hole. The Pennsylvanian strata above the unconformity were sub-horizontal, except for two faults with unknown displacements at 38- and 55-feet-depth.

In addition to the new wells that were drilled, I also examined archived cores and drilling records obtained from older drill holes in the study area. These holes include the Pomona CCC, GH, Stearns, Hagler, and Godwin holes. The Pomona CCC hole (total depth = 645 feet) is a water well that was drilled for the Civilian Conservation Camp along Hickory Ridge Road in the 1930s. This vertical borehole penetrated the flat-lying, undeformed stratigraphic section in the Central Domain, which indicates that, in the Central Domain, Pennsylvanian strata and underlying Mississippian strata are sub-parallel, so that the sub-Absaroka unconformity is a disconformity. The GH hole was drilled in 1993 (total depth = 236 feet) on the north (downthrown) side of the Pomona Fault. The depth of the Kinkaid Limestone is about 300 feet (100 m) lower in this hole than it is in the HRW hole that lies north of the Pomona Fault. This observation indicates that the vertical throw across the Pomona fault is about 300 feet (100 m). The Stearns, Hagler, and Godwin holes were all drilled in the late 1940s in the floor of Cave Creek Valley. The Stearns (total depth = 961 feet) and Hagler holes (total depth = 2,565 feet) encountered horizontal Menard Limestone at 70 feet (23 m) below the surface, and the Godwin
hole (total depth = 925 feet) found horizontal Menard Limestone at 36 feet (10.5 m) below the surface. Based on this observation, Devera and Nelson (1995) suggested that a sub-horizontal detachment lies in the shaly upper part of the Menard Limestone, and that the tilting of fault blocks in the WCFZ is confined to the interval above this detachment. They interpreted the fault blocks to be rotational slump blocks.

Cross Sections

The locations of cross sections are shown in Figure 30. Two types of cross sections were constructed for this study—A-A’ is constrained by outcrop data (Fig. 31), whereas B-B’ (discussed in the next chapter) covers a broader area and is interpretative. Both cross sections are based on the map data on Plate 1.

Cross section A-A’ covers the east-dipping panel of the Western Domain along the west branch of Wolf Creek. It extends only down to a depth of 150 feet below the surface (45 m) and is intended to provide an image of subsurface fault geometry with a minimum amount of interpretation. This cross section emphasizes that the WCFZ consists of an array of normal faults that bound gently tilted blocks containing strata of the Menard, Palestine, Clore, Degonia, and Kinkaid Formations. Nearly flat-lying beds of Caseyville Sandstone were deposited unconformably over the tilted strata.
Figures

Figure 18. Geologic map of the Wolf Creek Fault Zone produced for this study (reduced-scale). Full-scale map is shown on Plate 1.
Figure 19. Locations of drill holes (orange dots with name of drill hole) and new mapping (area outlined in red) for this study. Latitude and longitude for each drill hole: GG—N 37.626104°, W 89.388372°; Sanders—N 37.580495°, W 89.342700°; Allison—N 37.625572°, W 89.320088°; HRW—N 37.634395°, W 89.365289°; Pomona CCC—N 37.635664°, W 89.365442°; GH—N 37.658579°, W 89.379825°; Stearns—N 37.62973°, W 89.339528°; Hagler—N 37.618384°, W 89.339271°; Godwin—N 37.61463°, W 89.339216°.
Figure 20. Beds of the Degonia Sandstone dipping toward the northeast in the west branch of Wolf Creek. Photo looking northwest; March 2011.
Figure 21. Outcrop-scale normal faults with small offsets (2 cm) in the Degonia Sandstone, exposed in overhang of outcrop in Figure 20. Photo looking southeast; March 2011.
Figure 22. Faulting in the Caseyville Formation; March and April 2011.  
A. Relay fractures associated with normal faulting at the head of the west branch of Wolf Creek.  
B. Normal fault exposed in old railroad cut on the east side of Cave Creek.
Figure 23. Mesoscopic normal faults; March and April 2011. A – G. Faults in the Degonia Sandstone. H. Fault in the Palestine Sandstone.
Figure 23. (cont.)
Figure 23. (cont.)
Figure 23. (cont.)
Figure 24. Outcrop-scale negative flower structure in Degonia Sandstone (N 37.61582°, W 89.40115°; April 2011).
Figure 25. Slip lineations (parallel to pencil) exposed on a fault surface in the Degonia Sandstone at the head of Caney Creek (N 37.62272°, W 89.39938°; April 2011). Orientation indicates dip-slip movement.
Figure 26. Bedding in the Degonia Sandstone is smeared out due to faulting of partially lithified sediment. A. Oblique view to fault plane. B. View straight down on fault plane.
Figure 27. Outcrop-scale monocline in Palestine Sandstone, view is SE. Location: N 37.6074°, W 89.3828°; 2,000 feet from the north line, 300 feet from the east line of Sec. 36, T. 10 S., R. 3 W. Photo credit: Stephen Marshak; December 2009. A. Photo of outcrop; white rectangle indicates the field of view of in C. B. Line sketch showing interpretation of photo in A. C. Close-up view of the fold hinge, showing horizontal beds on the left, a narrow zone of tight folding, and overturned beds on the right.
Figure 28. Division of the study area into three structural domains: the Western, Central, and Eastern Domains. A, B, C, and D refer to dipping panels (subdomains) of the structural domains and their corresponding stereonets in Figure 29.
Figure 29. Equal-area lower hemisphere stereonet plots of bedding orientations, shown by great circles and corresponding poles to bedding (small black dots). Average of all bedding planes is shown by a red square, with a 95% confidence cone indicated by the red circle around the square. Stereonet plots were made using OSXStereonet 1.3 by N. Cardozo and R. W. Allmendinger. A. Western Domain, west-dipping panel. B. Western Domain, east-dipping panel. C. Eastern Domain, west-dipping panel. D. Eastern Domain, east-dipping panel.
Figure 30. Locations of cross sections A-A’ and B-B’.
Figure 31. Cross section A-A’ covers the east-dipping panel of the Western Domain along the west branch of Wolf Creek. No vertical exaggeration. Numbers on the vertical scale are mean sea level (e.g. 500 = 500 feet mean sea level).
CHAPTER 5

DISCUSSION

General Statement

Mapping of the southeastern end of the WNW-trending SGFS in southern Illinois indicates that the region between the Ste. Genevieve Fault and the Pomona Fault is occupied by an array of en echelon NNW-trending faults. My use of the term en echelon refers to a stepped array of relatively short faults that are approximately parallel to each other, but oblique to two enveloping surfaces (Biddle and Christie-Blick, 1985 and references therein; van der Pluijm and Marshak, 2004). This array is here called the Wolf Creek Fault Zone (WCFZ). The WCFZ lies at the southeastern end of the Ste. Genevieve Fault System (SGFS). As evident from Figure 5B, the Pomona Fault dies out about 5 km SE of the WCFZ study area, whereas the SGFS dies out in a horsetail splay about 20 km to the SE of my study area.

Displacement on the faults of the WCFZ resulted in the formation of several tilted fault blocks involving Mississippian strata. Fault surfaces are not well exposed, but the few examples that were found display down-dip lineations. In drill holes, it is clear that faulting has resulted in loss of section. The geometry of the tilted blocks, the down-dip lineations, and the loss of section along fault planes together indicate that the faults of the WCFZ are normal faults, and as such, indicate that displacement on them has accommodated local extensional strain. As a result
of erosion, tilted fault blocks in the WCFZ now stand out as cuestas in the landscape—each cuesta is topped by a resistant layer of Degonia Sandstone.

Significantly, normal faults are not the only structures in the WCFZ. The normal faults cut the limbs of what appear to be gentle upright anticlines whose axes have the same trend, and at least at one location, the study area contains a distinct monoclonal fold with an overturned limb. The geometry of the monocline suggests that it is a fault-propagation fold formed beyond the tip line of a thrust ramp.

Pennsylvanian-age Caseyville Formation sandstone was unconformably deposited on top of the tilted fault blocks. (The Caseyville has also been cut by faults, but the displacement on post-Caseyville faults in my study area is significantly less than on pre-Caseyville faults.) Channels and basal conglomerates along the unconformity (Howard and Whitaker, 1988; Poor, 1925) indicate that the Caseyville filled a landscape that had significant topography, probably caused by fluvial incision. These stratigraphic relations indicate that the main activity of faults in the WCFZ occurred between Late Mississippian and Early Pennsylvanian time, and thus was roughly coeval with tectonic activity in the Alleghanian and Ouachita orogens.

Considering the above observations, the following three alternative working hypotheses are proposed to explain tectonic setting in which the WCFZ formed:

- **Hypothesis 1**: Deep river valleys cut during the Pennsylvanian created local unstable slopes. Eventually, slumping occurred along the margins of these slopes, resulting in the development of rotational slump blocks, namely the tilted fault blocks of the WCFZ. In this regard, the origin of the WCFZ is similar to the origin of the horst-and-graben terrane bordering the
Colorado River in Canyonlands National Park today (McGill and Stromquist, 1979). The upper shale horizon of the Menard Limestone could have served as a failure horizon for the slumping.

- **Hypothesis 2**: Transtension associated with regional strike-slip movement explains structures forming at oblique angles to the Ste. Genevieve and Pomona faults. The WCFZ could be the near-surface manifestation of a pull-apart basin (i.e. negative flower structure).

- **Hypothesis 3**: The WCFZ is the result of two periods of movement. The first movement was transpressional, and the second movement was transtensional.

To test these multiple working hypotheses, I examined existing cross sections and created a conceptual cross section to see whether the models could produce admissible structures at depth. Detailed discussion of each hypothesis follows.

**Hypothesis 1: Gravity Slumping into a Paleovalley**

The foundation of Hypothesis 1 ([Fig. 32](#)) is based in the fact that a widespread erosional unconformity occurs between Mississippian and Pennsylvanian-age strata throughout the Illinois Basin. The period of erosion and uplift that occurred between these periods carved deep river valleys into the upper Mississippian surface (Bristol and Howard, 1971; Bristol and Howard, 1974; Greb, 1989). The channels eventually filled with sediments from early Pennsylvanian rivers that flowed southwesterly from the Appalachian Mountain front (Siever, 1951), and eventually the ridges between valleys were overtopped by Pennsylvanian strata, but conceivably prior to this deposition, unstable slopes existed along the river valleys.
These valleys can be considered analogous to Cataract Canyon of the Colorado River Valley in the Needles District of Canyonlands National Park. Here, the area bordering the valley has become unstable, and slumps parallel to the valley axis have developed along the slopes. At the ground surface, slumping has led to the development of a horst-and-graben belt whose architecture closely resembles that of a small tectonic rift belt (McGill and Stromquist, 1979). Downward movement on listric slump failure surfaces has led to rotation of strata in the fault blocks.

Outcrop data, stratigraphic relations and cross sections from the Cobden Quadrangle (Fig. 33) were the basis for Hypothesis 1. Devera and Nelson (1995) observed outcrops of tilted Chesterian strata in Cave Creek Valley and had the drilling records of three boreholes in Cave Creek Valley (Stearns, Hagler, and Godwin; see Fig. 19) that indicated that the Caseyville Formation rests directly upon horizontal Menard Limestone. The tilted outcrops and drill holes, in addition to a subsurface borehole study that found slump blocks of the Negli Creek member of the Kinkaid Limestone beneath the Pennsylvanian cover (Howard and Whitaker, 1988), led Devera and Nelson to deduce that perhaps strata from the Palestine through Kinkaid interval broke off and slipped downslope on curving failure surfaces into a Pennsylvanian-age valley in response to seismicity on the SGFS. They deduced that this gravity-driven slumping occurred along listric normal faults, with a basal detachment in the upper shaly part of the Menard Limestone. Could the WCFZ have formed by slumping along the flanks of a Pennsylvanian-age river valley?

To test this model, I looked for possible accommodation space for the slump blocks. Specifically, Hypothesis 1 requires the existence of a Pennsylvanian-age paleovalley into which
in which the slump blocks moved. This valley should exist along strike of the faults. No such paleovalley can be found. If this hypothesis were correct, rotational fault blocks might occur along known Pennsylvanian paleovalleys, but none have been found.

Secondly, if the paleovalley model were correct, then it should be possible to construct an admissible cross section depicting the model. In an admissible model, the geometry of structures obeys standard relationships that have been well documented in outcrop and/or by seismic lines. In the case of Hypothesis 1, an admissible cross section would have to be able to accommodate the observed fault displacements above a detachment in either the lower part of the Clore Formation or the stratigraphically deeper upper part of the Menard Limestone. Construction of cross section A-A’ (see Fig. 31) indicates that Hypothesis 1 leads to a “room problem.” By this, I mean that it is not possible to fit the mapped array of tilted fault blocks, with the magnitude of displacement observed, into a region above a detachment horizon that lies in the upper part of the Menard Limestone.

**Hypothesis 2: Pull-Apart Basin**

In the second hypothesis, faults of the WCFZ develop during the formation of a small transtensional pull-apart basin between the Pomona and Ste. Genevieve faults, as shown in interpretative cross section B-B’ (Fig. 34A). In other words, the WCFZ is a negative flower structure (Fig. 34B; e.g., Woodcock and Fischer, 1986; Sylvester, 1988). At depth, the normal faults of a pull-apart basin merge with the major bounding strike-slip faults of the system. Pull-apart basins form at releasing bends or at a releasing step-over along a strike-slip fault system,
and their geometry reflects the overall sense of slip on the fault system. The orientation of normal faults in the WCFZ requires that the slip along the SGFS be right-lateral (Fig. 35).

Cross section B-B’, which crosses the Ste. Genevieve and Pomona faults and the WCFZ in between, depicts this interpretation down to a depth of 12,000 feet (3.65 km) (see Fig. 34A). In this cross section, the WCFZ appears as a series of normal faults rooted in a fairly shallow detachment, which in turn roots in a splay off of the Ste. Genevieve Fault. To test this model, I first examined the admissibility of the structures by comparing them to published cross sections of other pull-apart basins (Bürgmann, 1989). Similar geometries do occur. Next, I examined the model to determine if there is a “room problem.” None exists—it is possible to provide sufficient room for the tilted fault blocks in a pull-apart basin if the basal detachment is rooted in the SGF. Third, I looked for evidence of bending along the SGFS, and found that the SGFS does bend—its trend changes by about 45˚ at the western edge of the WCFZ. Specifically, to the west of the WCFZ, the SGFS has an east-west trend, whereas to the east, it has a NW-SE trend. I also note that the geometry of the WCFZ is somewhat similar to the horsetail splay at the southeast end of the Ste. Genevieve Fault (see Fig. 5B); the splay also has resulted in the development of a series of cuestas that can be thought of as tilted fault blocks associated with normal faulting. Finally, it is important to note that the WCFZ lies near the southeastern end of the SGFS, in an area near where the Pomona fault dies out while the Ste. Genevieve Fault continues further to the southeast; in this regard, the WCFZ may also be interpreted as accommodating the stepover from the Pomona to the Ste. Genevieve Fault as the SGFS lengthened to the southeast. Unfortunately, without deeper drilling data and/or collection of high-resolution seismic-reflection data, it is not possible to confirm Hypothesis 2.
Notably, strike-slip displacement on the SGFS is compatible with other studies suggesting that strike-slip components of slip occurred on other Midcontinent fault-and-fold zones in the U.S. Midcontinent during the Paleozoic. Clendenin and Diehl (1999) interpreted that right-lateral strike-slip displacement occurred on NE-striking faults in Paleozoic rocks in a quarry exposure near Grays Point, Missouri, a locality that is close to my study area. A study by Harrison and Schultz (1994) near Thebes, Illinois (New Madrid Seismic Zone) came to a similar conclusion—that right-lateral strike-slip displacement occurred on NE-trending faults during the Ordovician, Devonian, Cretaceous, and possibly as recently as the Cenozoic. Two studies interpreted that a right-lateral strike-slip component of displacement occurred on the WNW-striking Cottage Grove Fault System (Nelson and Krausse, 1981; Duchek et al., 2004). Marshak et al. (2003) describe many other fault-and-fold zones in the North American cratonic platform that display a strike-slip component of displacement, and they suggested that strike-slip displacements are fairly common yet generally hard to detect because they do not cause vertical displacement of marker horizons.

**Hypothesis 3: Two Stages of Deformation**

Hypothesis 2 appears to explain the normal faulting of the WCFZ, but does not explain the occurrence of minor shortening structures (anticlines and fault-propagation folds) with the same structural trend. Thus, I propose Hypothesis 3, which involves two phases of deformation—the first is transpressional (Fig. 36) and the second transtensional (as in Fig. 35). The development of transpressional structures in the SGFS requires the occurrence of a left-lateral phase of displacement, so that the bend on the fault serves as a restraining bend.
Significantly, such a phase of left-lateral displacement on the SGFS has been suggested by previous researchers (Schultz et al., 1992; Clendenin and Diehl, 1999). If, at a later phase, the sense of slip on the SGFS reversed, so that it became right-lateral, the bend would become transtensional and, as described in Hypothesis 2, normal faulting in the same trend would form. Hypothesis 3 requires a reversal of slip sense on the fault. Such reversals have been proposed for other Midcontinent strike-slip faults, and may reflect changes in the geometry of the stress field in the continent (e.g., Marshak et al., 2003; Engelder and Geiser, 1980; Geiser and Engelder, 1983; Nickelsen, 1979).

**Regional Tectonic Implications**

Midcontinent fault-and-fold zones have been reactivated multiple times in response to orogeny along the continental margin (Nelson and Krausse, 1981; Harrison and Schultz, 1994; Clendenin and Diehl, 1999; Marshak et al., 2003), because as demonstrated by van der Pluijm and others (1997), orogenic stresses can be transmitted into the continental interior, over 2,000 km to the foreland of the Appalachian and Ouachita orogens. As discussed by McBride and Nelson (1999), a major pulse of reactivation, affecting the entire continent, happened at the end of the Paleozoic. This event was originally referred to as the Ancestral Rockies event because the evidence for it was found in the region that is now the Laramide-age Rocky Mountains, and has been attributed to transmission of Alleghanian/Ouachita stresses into the continental interior platform. But it is now clear that a similar style of deformation affected the entire cratonic platform, though east of the Rocky Mountain Region, the magnitudes of displacement are less. The Late Paleozoic episode of normal faulting that occurs in the WCFZ is broadly coeval with
Alleghanian/Ouachita deformation, and therefore likely represents a stage of reactivation and perhaps growth of the SGFS during the craton-wide Ancestral Rockies event (Fig. 37).

As noted by Marshak et al. (2003), many fault-and-fold zones in the U. S. Midcontinent have a strike-slip component of deformation because the zones are preexisting weaknesses that were reactivated in a stress field in which maximum compressive stress was not perpendicular to strike. Considering that the SGFS trends NW-SE, and the direction of maximum compression in the region is NW-SE, as defined by Craddock and van der Pluijm (1989) using calcite twinning data, it is reasonable for the SGFS to be reactivated with either a right-lateral or left-lateral component of strike-slip, depending on the variations in local stress trajectories.
Figure 32. Hypothesis 1: Schematic cross sections showing the step-wise development of rotational slump blocks into a Pennsylvanian-age valley.
Figure 33. Cross section from the Cobden Quadrangle, depicting curved normal faults accommodating slip on the upper part of the Menard Limestone. From Devera and Nelson (1995).
Figure 34. The concept of the WCFZ as a tectonic pull-apart. A. Cross section B-B’ is an interpretative cross section showing the Wolf Creek Fault Zone as a series of normal faults caused by simple shear on the Ste. Genevieve and Pomona faults. Numbers on the vertical scale are in mean sea level (e.g. 12,000 = 12,000 feet below mean sea level). Numbers on the horizontal scale indicate distance along the line of section. B. Three-dimensional block diagram of an idealized pull-apart basin (negative flower structure). From Woodcock and Fischer (1986).
Figure 35. Hypothesis 2: Map view showing the kinematics if the WCFZ is a pull-apart basin formed by transtension. Fault traces and trace of fold hinges are shown. Superimposed strain ellipses show progressive right-lateral simple shear on the WCFZ block.
Figure 36. Hypothesis 3: Map view model showing the kinematics if the WCFZ first underwent transpression in response to left-lateral oblique-slip motion on the bounding faults. Later right-lateral shear, as depicted in the previous figure, would be required to cause normal faulting with the same trend. Fault traces and trace of fold hinges are shown. Superimposed strain ellipses show progressive left-lateral simple shear on the WCFZ block.
Figure 37. Paleogeographic reconstruction of North America in the Middle Pennsylvanian (~308 Ma), from Blakey (2013). The SGFS is uplifted, and the Appalachian and Ouachita mountains are in the process of being built.
Geologic mapping and drill core analyses of a 45 km² area in southwestern Illinois were carried out to determine the tectonic setting of faulting in the Wolf Creek Fault Zone (WCFZ). The WCFZ is dominantly an *en echelon* array of NNW- to NNE-trending normal faults that lies between the Ste. Genevieve Fault and the Pomona Fault near the southeast end of the Ste. Genevieve Fault System (SGFS). Thus, the WCFZ represents a rhombohedral area of local extensional strain. My observations indicate that the zone can be divided into two domains (the Eastern and Western Domains) separated by an undeformed block (Central Domain). Kinematic indicators are rarely exposed in the study area, although two localities along a master fault suggest purely down-dip normal-sense displacement. The normal faulting produced a set of tilted fault blocks that are now exposed as a set of sub-parallel cuestas, whose top surface is a dip slope of Degonia Sandstone. In addition to normal faulting, the WCFZ includes a few structures indicative of local shortening strain; these include open anticlines, and mesoscopic monoclines formed at the tip of reverse faults. Notably, the shortening structures trend parallel to the extensional structures. Stratigraphic relations indicate that most of the displacement occurred prior to the development of the sub-Absaroka unconformity that separates Mississippian from Pennsylvanian strata, although outcrop and drill core observations indicated that some faults were reactivated post-Pennsylvanian.
Three hypotheses were proposed to explain the deformation of the WCFZ: (1) gravity-driven slumping into a paleovalley, using a shale horizon as a failure surface (Devera and Nelson, 1995); (2) formation of a pull-apart basin (negative flower structure) during a phase of right-lateral strike slip along a releasing bend or stepover in the SGFS; and (3) formation of minor shortening structures due to transpression along a restraining bend in the SGFS during a phase of left-lateral strike slip, followed by transtension along the same bend when the sense of slip on the SGFS later became right-lateral. I conclude that Hypothesis 1 cannot be supported, because it creates “room problems”—given the observed displacement on the normal faults, there is not enough room to accommodate observed extension above the proposed failure surface. Hypothesis 2 successfully explains the origin of normal faults in the WCFZ, but cannot explain the minor shortening structures. Thus, Hypothesis 3, which explains the WCFZ as a consequence of transpression at a restraining bend followed by transtension at a releasing bend, when the sense of slip of the strike-slip component on the SGFS changed from left-lateral to right-lateral, appears best supported. Based on stratigraphic constraints, almost all of this deformation happened during the Late Paleozoic, prior to or during the formation of the sub-Absaroka unconformity.

In sum, the results of this project imply that the WCFZ formed as a consequence of the following sequence of tectonic events:

1. The NW trend of the Ste. Genevieve Fault System (SGFS) was inherited from Precambrian faulting and had already been reactivated during the Devonian.
2. After Mississippian deposition was complete, but before the youngest Mississippian sediments were completely lithified, tectonic stress from early pulses of the Ouachita orogeny along the southeastern North American continental margin were transmitted into the continental interior, triggering movement on the SGFS.

3. Late Paleozoic movement on the SGFS had a significant dip-slip component, causing vertical displacement of stratigraphic markers, but it also had a strike-slip component of deformation. This component was initially left-lateral, so that at the bend and step over that existed at the southeastern end of the SGFS, there was a component of transpression that yielded NNW-trending folds and thrust faults.

4. Later, the sense of the strike-slip component of deformation on the SGFS changed to right-lateral, perhaps reflecting changes in the continental stress field as the main Alleghanian orogeny began. During this phase, the southeastern end of the SGFS became a releasing bend or extensional step-over and a pair of small pull-apart basins, separated by an unfaulted block, formed.

5. Relative sea level drop across the Illinois Basin led to widespread erosion of the Late Mississippian surface, locally cutting valleys down to the depth of the Menard Limestone within the WCFZ.

6. The Caseyville Formation and a thick succession of Pennsylvanian sediments were deposited
over the irregular topography, and eventually completely buried and lithified the structures of the WCFZ. Minor post-Pennsylvanian reactivation locally cut Pennsylvanian strata.

7. Post-Paleozoic erosion removed strata just above and below the Mississippian-Pennsylvanian unconformity. The Chesterian fault blocks are now exposed at the present-day land surface.

The above tectonic scenario is admissible, in the sense that it utilizes only tectonic events and structural styles that have been documented in the geologic literature, but it cannot yet be proven. It is testable, however. Future work could test the scenario by using seismic-reflection data and additional drilling to characterize the extent, orientation, style, and kinematic significance of the WCFZ. In particular, a seismic line along the flood plain of Big Muddy River could provide insight into the extent and deeper structure of the WCFZ.
REFERENCES


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APPENDIX: PLATE 1: GEOLOGIC MAP OF THE WOLF CREEK FAULT ZONE, NORTHERN UNION AND SOUTHERN JACKSON COUNTIES, ILLINOIS

The geologic map produced as part of this thesis may be found in a supplemental file named Geologic map of the Wolf Creek Fault Zone.pdf.