

3.0 SUMMARY DESCRIPTION OF THE SITE GEOLOGY

3.1 REGIONAL GEOLOGY

3.1.1 Geomorphology

The Taum Sauk Plant is located in the Saint Francois Mountains, part of the Ozark Plateau geomorphic province and part of the Ozark Mountains. The Ozark Plateau province is located chiefly in southern Missouri and northern Arkansas, between the Arkansas and Missouri rivers. It is bordered on the south by the Ouachita Physiographic province, on the south and east by the Coastal Plain province, on the east by the Interior Low Plateau province, and on the north and west by the Central Lowlands province. The province is small, with a total area of about 129,500 km². The Saint Francois Mountains are characteristically well-rounded, heavily eroded ridges or rolling upland with thin soils.

3.1.2 Geologic History

The Saint Francois Mountains are an approximately 1.5 billion years old Precambrian terrane of anorogenic granites and rhyolites. The granites intruded the volcanic units that overlay and surround them. These mountains are part of the continental shield. This type of lithologic succession of volcanic rock overlying related intrusive rock has been found in other shield areas. The area has been deeply eroded leaving rhyolitec knobs as high points and exposed granitic plutons. In Early Paleozoic times this area was central to the Ozark dome uplift and probably sub-aerially exposed as islands in the Cambrian seas that covered the area. During this time the Cambrian Lamotte Sandstone and overlying Bonne Terre Dolomite were deposited around the edges of the granitic and rhyolitec highs. It is important to note that the younger Paleozoic units that now surround the Saint Francois Mountains are flat lying with minimal deformation. Presumably these sediments overlaid the volcanic-igneous suite and protected it from erosion.

From youngest to oldest the regional formations include:

- **Eminence Dolomite:** Dolomite with some druse-coated chert;
- **Potosi Dolomite:** Dolomite with an abundance of druse-coated chert;

- **Elvins Group:**
 - Derby-Doerun Dolomite: alternating thin dolomite, siltstone, and shale; and
 - Davis Formation: glauconitic shale with fine-grained sandstone, limestone, and dolomite;
- **Bonnaterre Dolomite:** Dolomite, dolomitic limestone, and limestone; glauconitic in lower part;
- **Lamotte Sandstone:** Sandstone with some dolomitic and shaly lenses, coarse-grained to conglomeritic and arkosic at base;
- **Diabase Dikes and Sills;**
- **St. Francois Mountains Intrusive Suite:** Subvolcanic alkali granite ring complexes; and
- **St. Francois Mountains Volcanic Supergroup:** Chiefly alkali rhyolite ash-flow tuffs with minor trachyte.

Several geologic features distinguish the Ozark Plateau province as a region. The faulting in the Ozarks is generally normal with most faults displaying a downward displacement on the southern side. Gentle folds are present, but these are generally of low amplitude. Surface rocks are older than those exposed in surrounding areas. This Province is distinguished from the Ouachita province by a less disturbed rock strata and a profusion of limestone and dolomite that when weathered from the parent rock accumulates at the surface. Streambeds contain abundant chert gravel washed from the hillsides.

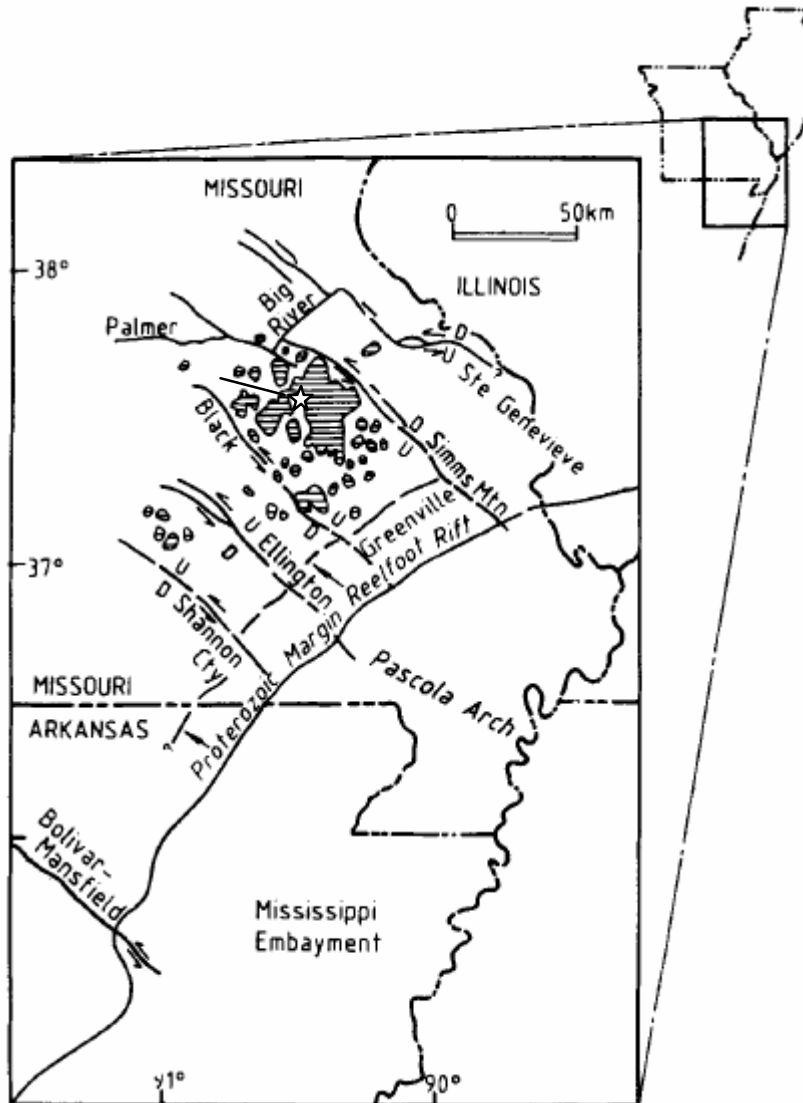
This area of Missouri contains a wealth of lead and iron mineral resources. The rhyolites of the Saint Francois Mountains host several high-grade magmatic and hydrothermal hematite and magnetite iron deposits. The Cambrian Bonne Terre Formation is host to the Mississippi Valley-type lead deposits that have made Missouri's Lead Belt and Viburnum Trend the most prolific lead mining districts in the United States for over 100 years. Significant occurrences of barite, silver, cobalt, and copper have also been mined in the area.

The structural position of this Precambrian (1.48 Ga) volcanic-plutonic complex relative to the rest of the surrounding basement is due to its position at the crest of the Ozark Dome. The Ozark Dome is a structural high in the continental basement bounded by normal faults and strike-slip faults. Late Precambrian to Early Cambrian (Braile, et al., 1986) continental breakup gave

genesis to the Reelfoot Rift, an aulocogen or failed rift arm of a continental pull-apart basin to the southeast of the Ozark Dome. Late Pennsylvanian-Early Permian Alleghenian compressive stress uplifted the Ozark Dome and Saint Francois Mountains (Clendinen, et al., 1989).

Basement subsidence southeast of the Ozark Dome due to crustal thinning and sediment loading ensued as the Reelfoot and associated basement faults were reactivated during Late Paleozoic continental rifting. This process has contributed to the position of Ozark Dome as a structural and topographic high. In addition, isostatic rebound of the Dome due to denudation has contributed to the structural offset of the Ozark Dome from the surrounding areas. The Mississippi Embayment currently flanks the Ozark Dome to the southeast. The Mississippi Embayment contains a thick sequence of Phanerozoic sediments of marine, fluvial, and aeolian affinity which overlie the faulted basement associated with the Reelfoot Rift and New Madrid Rift Complex.

As shown on **Figure 3-1** there are a number of northwest trending faults associated with the Reelfoot Rift.



(Regional map showing relations of major faults in southeast Missouri and northeast Arkansas to Proterozoic margin of Reelfoot rift, from Clendinen, et al., 1989)

FIGURE 3-1

NORTHWEST TRENDING FAULTS ASSOCIATED WITH THE REELFOOT RIFT

The Black Fault is the closest of these named faults to the site.

3.2 SITE GEOLOGY

Pre-Cambrian rhyolite porphyry and granite porphyry characterize the geology of the site of the Taum Sauk Plant. The intrusive rock of the knob and ridge (i.e., Proffit Mountain), which accommodates the Upper Reservoir, is rhyolite porphyry, which is fresh high-compressive strength rock moderately to abundantly jointed. The 8th FERC Part 12 Independent Consultant

Safety Inspection Report, 2003, classifies the rock surrounding the Tunnel as granite porphyry, massive hard rock with infrequent and tight joints, and the bedrock at the Lower Reservoir Dam as hard, dense rhyolite porphyry cut by two closely-spaced sets of near-vertical joints, with only shallow weathering.

3.2.1 Lithology

The rock of the knob and ridge, which accommodates the Upper Reservoir, is rhyolite porphyry, which is described as fresh, high-compressive strength rock moderately to intensely jointed. This unit is mapped by Pratt, et al. (1992) Rolla 1° x 2° Quadrangle, as:

Alkali rhyolite: Mostly dark red, purple, or gray aphanitic porphyry containing phenocrysts of pink or flesh-colored potassium feldspar, and with or without quartz phenocrysts, in a cryptocrystalline felsic groundmass. Taum Sauk Mountain and Bell Mountain are divisible into individual map units.

The map unit for the alkali rhyolite at the Upper Reservoir is:

Tuff: Brick red, very well bedded, with sparse phenocrysts, equivalent to **Taum Sauk Rhyolite**.

Kisvarsanyi, et al., (1981) note prominent columnar jointing in the rhyolite adjacent to the Taum Sauk Plant. The tunnel is in granite porphyry, massive hard rock with infrequent and tight joints, mapped by Pratt, et al., (1992) as:

Amphibole-orthoclase granite, Slabtown-type: Medium to fine-grained gray granite characterized by sodic amphibole and (or) biotite, orthoclase microperthite, and minor plagioclase. Medium silica content (70-73 percent). The **fine-grained (hypabyssal) equivalent** was mapped at the site.

The bedrock at the Lower Reservoir Dam is mostly hard, dense rhyolite porphyry cut by two closely spaced sets of near vertical joints, with only shallow weathering. Pratt, et al., (1992) mapped four lithologies adjacent to the lower reservoir as follows:

Stromatolite/Mud Facies: Light gray to light brownish gray, finely crystalline limestone or dolomite. Plane laminated stromatolitic units averaging 0.3m thick grade upward into burrowed, largely pelletized and variably coquinoidal units averaging 0.8m thick; burrowed units may contain arkosic debris in upper parts. Also includes coarsely

recrystallized white vuggy dolomite (“white rock” of local usage). Includes stratigraphic equivalents ranging from Potosi Dolomite to Bonaterre Formation in age.

Ash-flow tuff: Red to dark maroon; contains a few percent phenocrysts of white feldspar with or without quartz; at top is about 25m of maroon air-fall tuff. Equivalent to Bell Mountain, Wildcat Mountain, and Russell Mountain rhyolites of Berry (1976). (subset of **Alkali rhyolite** unit)

Lava flow: Red to maroon; contains five percent phenocrysts of quartz and alkali feldspar; vividly banded red and white in many places. Equivalent to Royal Gorge Rhyolite of Berry (1976). (subset of **Alkali rhyolite** unit)

Tuff: Brick red, very well bedded; contains sparse phenocrysts. Equivalent to **Taum Sauk Rhyolite** of Berry (1976). (subset of **Alkali rhyolite** unit)

3.2.2 Geologic Structural Features

The geologic structure of the Saint Francois Terrane is marked by brittle deformation. Very little ductile deformation or metamorphism is documented. Contact metamorphism exists along the contact volcanic and intrusive units, but foliation and folding are not a significant part of the regional geology. Bedding due to debris, ash, and lava flow exists in the volcanic units and bedding structures are apparent in the Cambrian and Ordovician rocks.

The most significant geologic structural feature is an unconformity that separates the Upper Cambrian rocks and the Middle Proterozoic intrusive and volcanic rocks. This unconformity is marked by a basal boulder conglomerate described by Kisvarsanyi, et al., (1982) who also maps the unconformity at the Taum Sauk Plant as a contact of Taum Sauk Rhyolite and Davis-Doerun Dolomite (not mapped as such by Pratt, et al.). The unconformity is tilted, implying structural displacement of blocks of the Saint Francois Terrane. Lowell (2000) discusses subsidence structures related to caldera collapse and shift, and this process having an important role in existing structure. At the site, two narrow faults, or significant shear zones, were reportedly exposed during the excavation for the Upper Reservoir. No faults are reported near the Lower Reservoir Dam. Pratt, et al. (1992) did not map any faults on the site, however numerous faults are mapped five kilometers to the east in the same or comparable geologic units as encountered at the site. In addition, a northeast striking fault is mapped two kilometers to the north. The lack of mapped structures at the site may be due to immature mapping. Many of the faults in the Saint Francois Terrane terminate at the boundary of Cenozoic sediments, while others' continuation is inferred. It is not apparent whether any attempt to map faults across

unconsolidated sediment has been completed. The Black Fault exists seven to eight kilometers to the southwest. The Black Fault is a northwest striking feature exhibiting normal offset to the southwest. Strike slip motion along this fault is not recorded but is proposed by Clendenin, et al. (1989) based on orientation of slickensides. The Ellington Fault, 30 to 35 kilometers to the southwest, and the Sims Mountain Fault System, 40 to 45 kilometers to the northeast, exhibit similar strike to the Black Fault.

3.2.3 Upper Reservoir Dike and Upper Reservoir Construction

The foundation rock at the Upper Reservoir Dike, being the flattened top of Proffit Mountain, is generally fresh to slightly weathered, hard, moderately to abundantly jointed. Joints are generally steeply dipping, open, and some were filled with clayey products of weathering such that seepage would occur without proper measures to seal the reservoir floor. During construction, the overburden was observed to vary from a few feet to as much as 65 feet thick (MWH, 2003). Several significant clay seams, gently dipping, and up to four inches in thickness were encountered. Under the dike, the seams were treated either by excavating and backfilling with concrete or covering with smaller-sized compacted rockfill. The upstream (or inside) 70 feet of the base of the dike was specified to be prepared such that not more than two-inches (average) of soil were left in place. A filter zone and several layers of compacted rock were placed over questionable areas where piping of the foundation might be possible. Outside the 70-foot zone, the weathered rock was left in place where its competence was judged equivalent to the rockfill. Low areas or depressions in the natural topography were filled with compacted rock. Drainage to the outer slopes was reportedly provided for all foundation areas.

Jointed rhyolite porphyry was encountered in the upper 125 feet of the vertical shaft. Open joints, weathered rock, and infiltration of ground water were observed in the upper 20 to 25 feet of the shaft. Consequently, the shaft was lined with shotcrete and wire mesh where it passed through the rhyolite porphyry to the underlying massive granite porphyry. The shaft and tunnel are unlined through the granite porphyry. The horseshoe tunnel has been unwatered several times and the in the unlined portion, return water was been negligible and no rockfalls were reported (MWH, 2003) (Cooke and Strassburger, 1968).

Construction of the Upper Reservoir was accomplished by practically “shaving off” or flattening the top of Proffit Mountain, using the broken rhyolite and excavated residual soil to construct the Upper Reservoir Dike. Our findings based on forensic observations indicate that little or no effort was used to segregate the soil fines from the rock. The construction resulted in a Dike that

was not typical of concrete-faced rockfill dams. Soil materials are prolifically mixed with the rock and the rock itself appears to have a wide range of particle sizes, ranging from gravel sizes to as large as four to five feet in diameter. For the most part, the rock is not slabby and is characterized as generally three-dimensional. Limited filters and special drainage features were reportedly included in the design to deal with questionable rock conditions on the upstream 70 feet of the dike foundation.

3.2.4 Lower Reservoir Dam

The bedrock at the Lower Reservoir Dam is hard, dense rhyolite porphyry with only shallow weathering. The foundation rock is fresh, dense, moderately but tightly jointed. Although the abutments have been subjected to high flows during spillway discharge, the rock shows little susceptibility to erosion due to high water flows.

Logs of three pre-construction borings are available for locations along the axis of the Dam. DH-15, on the left abutment, encountered 13 feet of "broken rhyolite" overlying 37 feet of "rhyolite." DH-14 on the right edge of the river encountered 10 feet of "sand and gravel" overlying "rhyolite." DH-16 on the right abutment encountered 49 feet of "rhyolite." The same drawing shows the depth of excavation along the upstream face to vary from 5 feet to about 30 feet. The broken rhyolite and sand and gravel encountered in the borings were reportedly removed, resulting in an irregular rock surface, typically varying one to three or more feet across the base of a block. The bedrock was reported as hard, dense rhyolite cut by two closely-spaced sets of vertical joints, the main set striking true North and the secondary set striking North 70° East. After cleaning, the exposed rock reportedly showed no evidence of alteration in either the joints or the exposed surface.

3.3 GEOLOGIC MAPPING OF THE BREACH AREA

As part of the overall field investigation associated with this forensic investigation, geologic mapping of the Breach Area was conducted on January 20 and 21, 2006. Lithology, fractures, orientation of rock fabric (banding), and any linear features such as shear zones and faults were mapped on a 1:600 scale. In addition, zones having soil cover were mapped. Field mapping included use of Global Positioning (GPS) equipment to accurately locate features.

The rock in the breach area is rhyolite as described in the legend of the Upper Reservoir Breach Area Geologic Map (*Plate 3-1*). Numerous fracture sets were mapped and are described in

Table 3-1. The dominant fracture sets are FS-1, FS-2, FS-12, and FS-14. Stereonet analysis of these data lead to the conclusion that fracture sets FS-2, FS-12, and FS-14 are likely the same set that strikes N40-60E and dips 85-90 NW and SE. These fractures are very continuous (greater than 100 feet in length) and are the dominant structural feature in the rock mass. Most of the fracture sets are too steeply dipping to present planar failure potential given the geometry of the slope of Proffit Mountain. However, less dominant, shallow dipping sets such as FS-7 may present the potential for localized planar failure.

TABLE 3-1**TAUM SAUK PLANT UPPER RESERVOIR BREACH GEOLOGIC DATA**

FEATURE	DIP DIR.	DIP	DESCRIPTION
FS-1	310	76	Fracture set, closely to moderately spaced, very continuous(>100 ft.), moderately to slightly open, smooth to slightly rough, planar, partially to mostly healed with 1mm thick firm greenish gray coating, fractures occur throughout the entire rock mass.
FS-2	155	88	Fracture set, widely spaced(1 -3 ft.), very continuous, slightly to moderately open, mostly healed with firm to hard greenish gray coating, significant iron staining, fracture are prevalent across rock mass.
	145	90	
FS-3	240	78	Fracture set, widely spaced, very continuous, slightly open, moderately rough (R3), mostly healed with hard to firm greenish gray coating, moderate iron staining.
	243	73	
FS-4	105	72	Fracture set, very closely to closely spaced (<0.1-.03 ft.), slightly continuous (3-10 ft.), slightly open (<1mm), moderately healed with very thin (<1mm) hard to firm greenish gray coating, moderate iron staining.
FS-5	140	65	Fracture set, moderately continuous, planar, slightly to moderately rough, moderately open, partially healed with very thin (< 1 mm) firm greenish gray coating.
FS-6	87	28	Fracture set, widely spaced (1 -3 ft.), moderately continuous (10-30 ft.), slightly open, planar, slightly rough (R4), mostly healed with hard, very thin (<1mm) coating.
FS-7	262	38	Fracture set, widely spaced (2-3 ft.), moderately continuous, slightly open, moderately rough (R3), slightly undulatory.
FS-8	270	8	Fracture, slightly continuous, rough (R2), undulatory, partially healed, widely spaced.
FS-9	58	18	Fracture, slightly continuous, rough (R2), partially healed.
FS-10	346	28	Fracture set, moderately continuous, moderately spaced (0.3-1 ft.), moderately open to open (1-10mm), slightly to moderately rough (R4-R3), completely healed with very thin (<1mm) hard pale green coating.
	345	25	
FS-11	225	83	Fracture set, moderately continuous, widely to very widely spaced (2.5-4.5 ft.), planar, slightly rough (R4), moderately open.
FS-12	138	89	Fracture set, very continuous, closely to moderately spaced (0.2-1 ft.), slightly to moderately open, slightly to moderately rough, slightly undulatory. Fracture set occurs throughout rock mass.
	131	83	
	311	88	
FS-13	197	83	Fracture set, slightly continuous.
	202	87	
FS-14	318	85	
FS-15	160	88	Fracture set, highly continuous, moderately spaced (0.3-1 ft.), moderately open, moderately rough (R3), planar.
	135	90	

**TABLE 3-1
(CONTINUED)**

FEATURE	DIP DIR.	DIP	DESCRIPTION
FS-16	270	88	Fracture set, moderately continuous, moderately spaced.
	273	88	
	270	86	
FS-17	155	89	Likely same set as FS-2.
	154	88	
FS-18	57	87	Fracture set, moderately continuous, moderately to widely spaced (0.4-1.5 ft.), moderately open (1-2mm).
	54	87	
FS-19	135	90	Fracture set, moderately continuous, slightly to moderately open, planar, slightly rough (R4).
	135	84	
FS-20	143	88	Likely same set as FS-2.
	148	86	
	155	90	
FS-21	120	85	Fracture set, moderately continuous, closely to very closely spaced, slightly undulatory, slightly to moderately open.
	127	87	
	121	82	
	312	84	
FS-22	239	76	Fracture set, slightly to moderately continuous, closely to very closely spaced.
	244	76	
FS-23	220	15	Fracture set, moderately continuous, closely to very closely spaced.
	225	18	
FS-24	20	10	Fracture set, slightly continuous, closely to moderately spaced (0.1-0.4 ft.), slightly open.
	25	12	
FS-25	63	15	Fracture set, moderately continuous, closely spaced (0.1-0.3 ft.), slightly rough (R4).

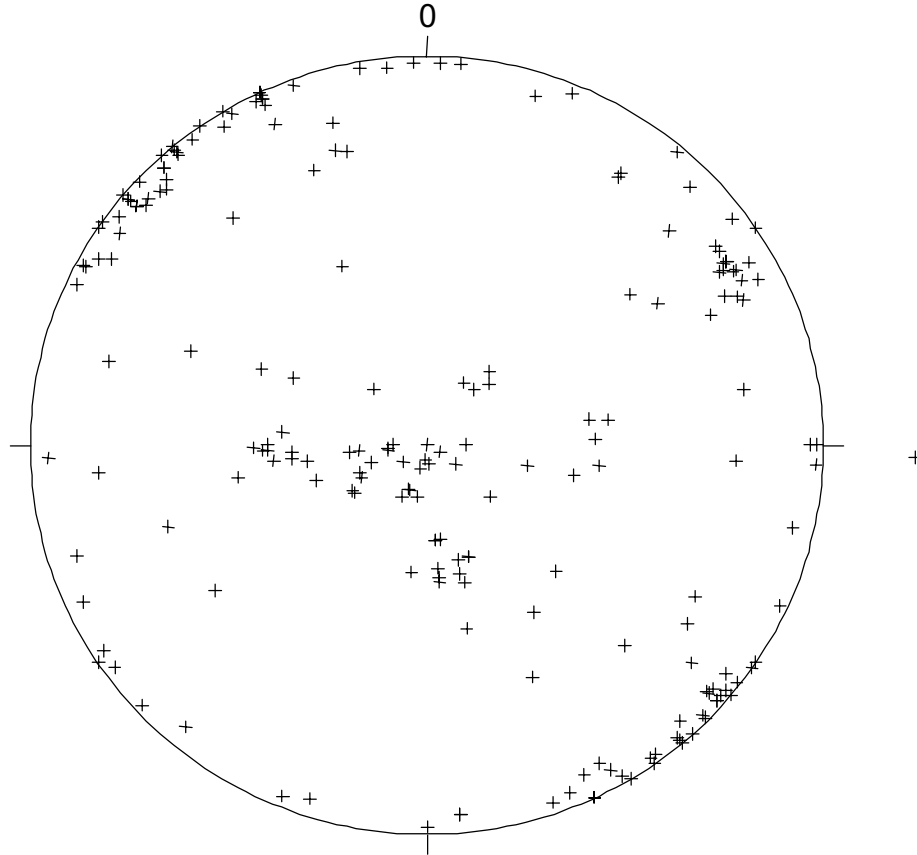


FIGURE 3-2

STEREONET OF FRACTURES: LOWER HEMISPHERE, POLE TO PLANE, N=193

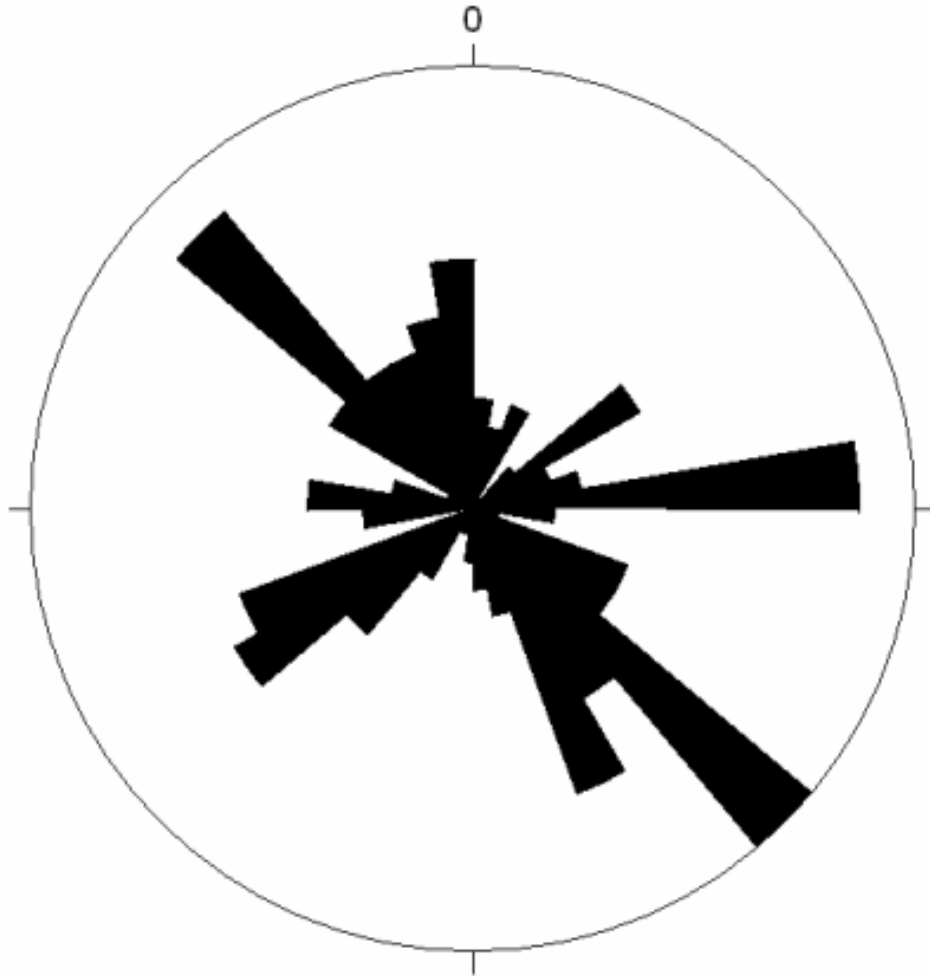


FIGURE 3-3

ROSE DIAGRAM OF FRACTURES, N=193

In locations where other fracture sets are prevalent, these sets are presented on the geologic map with a fracture symbol oriented by dip direction with dip of the fracture plane presented at the edge of the symbol. **Plate 3-1**, Breach Area Foundation Geology, presents significant geologic features of the rock mass at the breach. Several sets of shallow dipping fractures are present that dip both upstream and downstream. A description of these sets is included in **Table 3-1**.

Figures 3-4 through **3-7** show some of the prevalent fracture sets in the breach area foundation.



FIGURE 3-4
FRACTURE SETS FS-1, FS-2, AND FS-6



FIGURE 3-5
FRACTURE SETS FS-9 AND FS-25



FIGURE 3-6

FRACTURE SET FS-10

In addition to fractures, shear zones and faults exist with the breach area. Five roughly east-west striking, steeply dipping shear zones are noted and presented on *Plate 3-1*. These shear zones are linear, very continuous, and cut all other features. Rock within these shear zones is very broken. *Figure 3-7* shows shear zone SZ-2 from *Plate 3-1*. A sense of offset on this feature could not be determined.



FIGURE 3-7
SHEAR ZONE SZ-2

Two fault zones with slickensides were mapped in the breach zone area. These faults strike N80-85E, exhibit shallow dip (20-30 degrees) to the NNW, and have slickensides that rake north to N10E and dip 15-20 degrees (*see Figure 3-8*).



FIGURE 3-8
LOW ANGLE FAULT WITH SLICKENSIDES

In the vicinity of the toe of the Dike in the Breach Area, a contact of rhyolite and granite was observed. The granite body is shown on the *Plate 3-1*. Fracture patterns do not appear to change across the contact zone, implying that the mechanical behavior of the granite is similar to the rhyolite that it intrudes. A narrow zone of contact metamorphism exists at the contact of the two rock types exhibiting fine grained equivalents of the rhyolite and granite. The contact zone does not exhibit differences in fracture patterns.

Rock mass classification of the breach area is presented on the *Plate 3-2*, Breach Area Foundation Rock Mass Rating. The majority of the rock mass is classified as “fair” with sections of “poor” rock and “good” rock. Zones of soil cover are also depicted on *Plate 3-2*.

3.4 FAULTING

Two narrow faults, or significant shear zones, were reportedly exposed during the excavation for the Upper Reservoir. Mapping of the breach area revealed shear zones and fault features as discussed in *Section 3.3*. No faults are reported near the Lower Reservoir Dam. The nearest major fault zone is in the New Madrid Fault Zone, about 160 kilometers Southeast. Associated with the New Madrid Fault are a number of northwest trending faults. The closest of these faults is the Black Fault. As shown on *Figure 3-9*, the Black Fault is at least 25 miles long and at its closest point approximately 8 kilometers from the Upper Reservoir. This fault has both strike slip and normal offset. It is mapped as Cretaceous and possibly younger sediments in one location and is mapped as bounding the relatively young sediments in other area. The Quaternary-age sediments are colored yellow on *Figure 3-9*. The shears mapped within the Breach Area are oriented such that they may be Riedel Shears associated with the Black Fault.

New Madrid Seismic Zone extends from northeast Arkansas, through southeast Missouri, western Tennessee, western Kentucky, and to southern Illinois on the northwest limb of the Mississippi Embayment. Historically, the New Madrid Seismic Zone has been the site of some of the largest earthquakes in North America. Four earthquakes, with magnitudes greater than 7.0 occurred in December, 1811 through February, 1812. Hundreds of aftershocks followed over a period of several years. The largest earthquakes to have occurred since then were on January 4, 1843 and October 31, 1895 with magnitude estimated to be in the range of 6.0. Additional earthquakes with magnitudes greater than or equal to 5.0 have occurred in the area. Braile, et al., (1986), attribute seismicity to the New Madrid Rift Complex, a series of northeast and west-northwest striking fault zones related to reactivation of the Reelfoot Rift.

In addition to the New Madrid Seismic Zone, Langenheim and Hildenbrand (1997) identify the Commerce Geophysical Lineament and Commerce Fault, a zone in strike with and northwest of the New Madrid seismic zone as potential sources of seismicity. Anderson (1997) relates the Commerce Geophysical Lineament to Quaternary faulting. **Figure 3-10** shows the location of the Commerce Geophysical Lineament relative to the Taum Sauk Plant site and the New Madrid Seismic Zone.

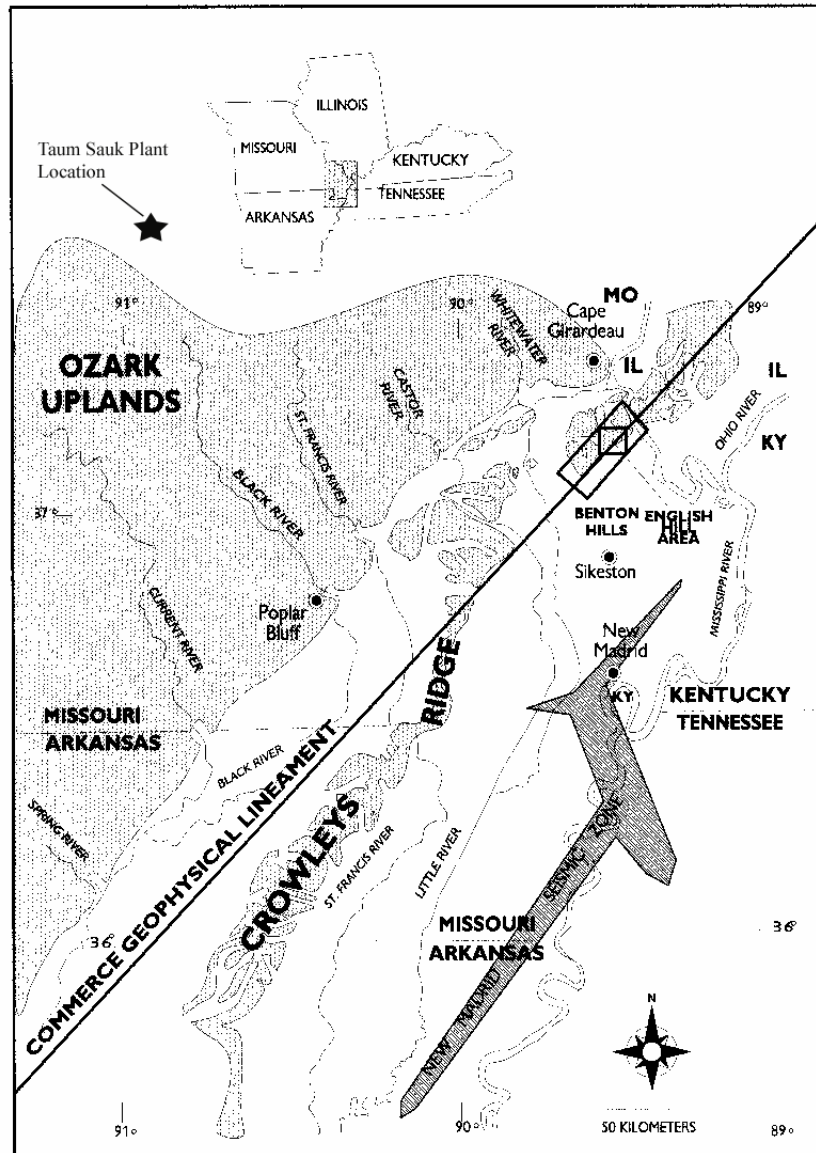


FIGURE 3-10

**COMMERCE GEOPHYSICAL LINEAMENT AND NEW MADRID SEISMIC ZONE
(FROM ANDERSON, 1998)**

In addition, Clendenin, et al., (1989) identify northwest striking faults, such as the Black Fault, Simms Mountain Fault, and Ellington Fault as having left lateral and dip slip components as part of a transfer system oblique to and structurally related to the northeast striking New Madrid and Reelfoot structures, and as zones of potential seismic activity based on present day east-west compressive stress fields. The northwest striking Simms Mountain and Saint Genevieve Faults are recognized by Lowell (2000) as the mechanisms for a subsidence structure within the Saint

Francois Terrane. Although faulting within the Saint Francois Terrane has been established, the relationship to current seismicity within the New Madrid Seismic Zone is not clear. Pratt, et al., (1992) map numerous faults within the Cambrian and Late Proterozoic rocks of the Saint Francois Terrane, including the northwest striking faults previously discussed. Many of these faults terminate in map view as they intersect Quaternary through Cretaceous sediments while others are mapped as inferred across the younger sediments.

Occurrence of earthquakes with epicenters in the Saint Francois Mountains is sparse. USGS Quaternary Fault and Fold Database has the nearest features 30 miles to the northeast as the St. Louis-Cape Girardeau liquefaction features, which includes portions of Washington and St. Francois Counties. The largest earthquake with the epicenter roughly in the St. Francois Terrane, according to a search of the USGS earthquake catalog is a magnitude 4.4. The nearest epicenter found is within ten miles of the site with a magnitude of 4.0 in 1965.

3.6 SEDIMENT MAPPING OF THE BREACH CHANNEL

3.6.1 Generic Definition

For this forensic investigation, we use the term “debris torrent” to describe the transport of the material down the Breach Channel, differing from debris flows that generally stop or stay close to the foothills where flow originated. From a generic perspective, debris torrents are characterized by long stretches of bare soil and unstable channel banks that are scarred by the extremely rapid movement of debris, a type of mass movement that involves water-charged, predominantly coarse-grained inorganic and organic material flowing rapidly down a steep confined, pre-existing channel. It moves as a fluid, and the material is being continually deformed. Depending on the amount of water involved and the steepness of the slope, the rate of movement can be slow to very rapid.

A debris torrent might begin as a debris slide or as a debris flow, to later become a debris torrent when channelized in streams and moving rapidly downstream. The terms channelized debris flow as well as debris avalanche have been used when referring to similar processes.

3.6.2 Debris Torrent Process

Three consecutive steps are used to describe this debris torrent occurrence, specifically, initiation, transport and deposition.

Initiation is where the mass movement is triggered at the source area headwaters. At Taum Sauk, this is the failure of the Rockfill Dike at the Upper Reservoir.

Transport of the debris occurs down the initial zone, scouring and widening, as the debris flow grows in size. A straight and uniformly steep gradient channel, like Taum Sauk, represents the most favorable transport condition. Initiation and initial transportation and erosion of the channel occurred on an average slope of 13 degrees.

The zone of depletion of the debris (the zone where the displaced material was below the original ground surface) is the area from the downstream toe of the Rockfill Dike to the break in slope. This area is characterized as having a few remnant patches of residual soil, no vegetation and no material derived from the Rockfill Dike (or facing concrete). Only a small concrete block is observed close to the top. *Figure 3-11* shows this area as it is seen from the slope break to the initiation area.



FIGURE 3-11

ZONE OF DEPLETION FROM THE INITIATION AREA TO THE SLOPE BREAK

3.6.3 Deposition

Deposition occurs where either the channel gradient flattens to the point that there is insufficient energy for continued movement, or when the channel becomes laterally unconfined. At Taum Sauk, partial deposition and remobilization occurred when the slope flattened to about 4 degrees. The deposited material is highly variable, covering a wide range of particle sizes from very fine sand to boulders. We also observed old construction material and drilling pipes/bits derived from drilling operations associated with the blasting operations.

The primary factors affecting the deposition patterns are:

- Loss of confinement of the debris, especially in those areas where creeks drained into the main channel.
- Impediments to flow including trees, large boulders, and previously deposited natural debris; these impediments were removed from the zone of depletion during the debris torrent.
- The flow rate versus time as the Dike failed; and
- The changing channel gradient.

The zone of deposition extends downhill to Johnson Shut-Ins Park and into the Lower Reservoir, with some suspended sediments going over the Dam and further downstream. The degree of confinement for this flow ranged from confined to partly confined when traveling downhill, and unconfined when reached the foothill in Johnson Shut-Ins Park.

Once the availability of the source of material ended, i.e., when the Dike was fully breached, there was some local remobilization based on the fact that plugs of debris and banks were cut as much as 6 inches and boulders were remobilized from their original position. The height of the mix flow is shown to be at least 10 feet high, from overbank flows, based on marks left by rocks on trees left standing on the hillsides, where almost all minor vegetation was partially removed (*Figure 3-12*).



FIGURE 3-12

**FACIES S1/S3 DEPOSITS OVER SLOPE IN SW OF SECTION 1,
WITH MARKS ON TREES CAUSED BY ROCK PARTICLES**

When referring to the deposition process, it should be noted that all of the original deposits along the Breach Channel were scoured, removed and displaced by sediments derived from the Breach Area as well as the reworked original deposits. When the coarse-grained debris from a “channellized” debris flow stops, it can take many forms, depending on the character of the debris and the debris fan, and on the presence of natural or artificial impediments. These forms, as shown in *Figure 3-13*, include sheets or lobes of debris on the debris fan, plugs of debris deposited in the stream channel, and debris levees along the stream channel.

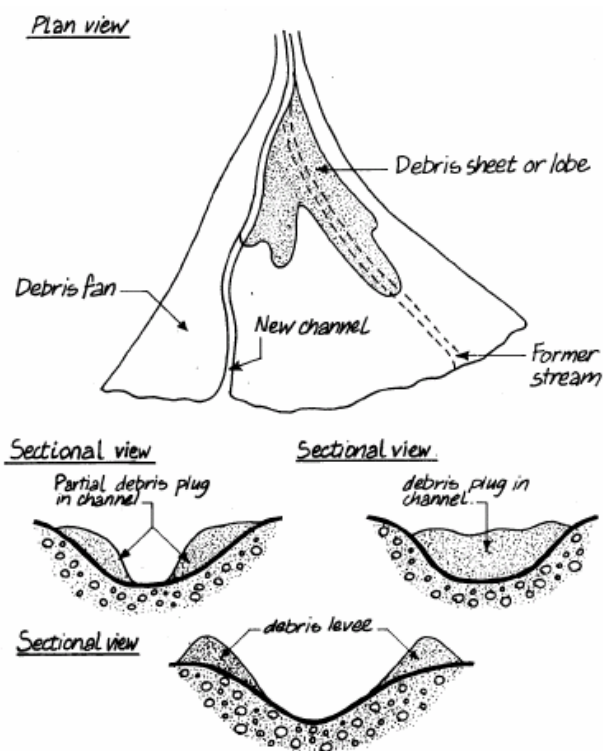


FIGURE 3-13

**FORMS OF CHANNELIZED DEBRIS FLOW DEPOSITION
(D.F. VANDINE, 1996)**

Debris sheets or lobes are usually deposited over an extended portion of the debris fan. They are often characterized by a number of arms. The thicknesses of the deposited debris sheets along the Breach Channel area were estimated using the elevations shown in the topographic map for this same region and the actual elevations for the top of the debris. Based on this information it is estimated that the as much as 25 feet may have been deposited in the deepest part of the original creek channel that ran through the valley. At the break in slope near the Breach Area shown on *Figure 3-11*, the thickness is estimated to be in the range of 15 feet.

The thickness decreases towards the borders of the channel with only minor variations due to the presence of levees. (Debris levees are steep-sided ridges that were found to be up to several feet in height. They lie outside and above the sides of a pre-existing stream channel, and can extend for many tens of feet along a channel.) Debris plugs were locally observed, as they tend to

usually partially or completely fill the stream channel, which often results in an abrupt change in flow direction

Figure 3-14 shows the location of the sections developed as part of the overall mapping effort.

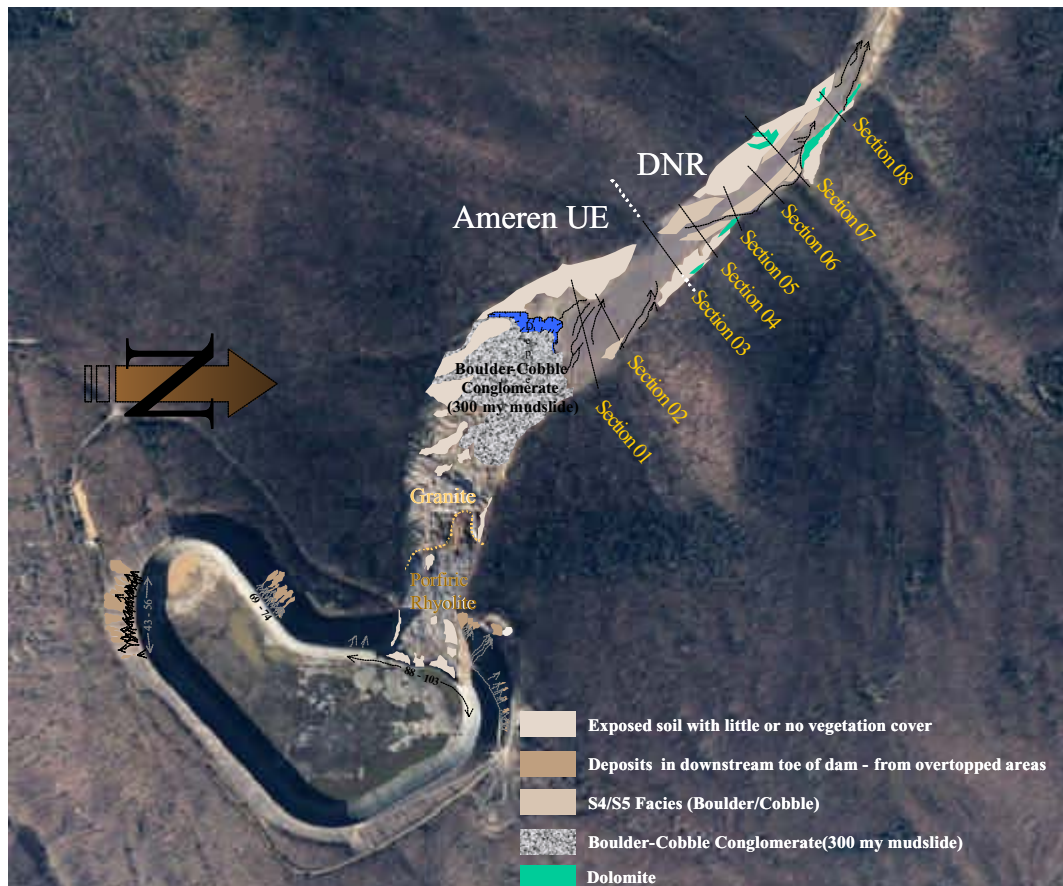


FIGURE 3-14

**GENERALIZED DISTRIBUTION OF DEPOSITS DERIVED FROM BREACH AREA
AND SUBSEQUENT DEBRIS TORRENT**

Somewhat in contrast to expectation, the debris is more stratified and well sorted/poorly graded deposits, possibly as a result of the very high water content of the mix. These effects are shown in **Figures 3-15 and 3-16** where a cut into a debris plug is shown. The stratification and gradation is evident and extensions of the debris sheet are well sorted accumulations of facies S4/S5 sediments. This is in accordance with a more fluid type of mass movement, enhanced by the availability of a large rapid water source.



**South end on section 3
S4/S5 facies levee**



North end on section 6



North end on section 4

FIGURE 3-15

**DIFFERENT LEVEES IN SIZE AND COMPOSITION
ALONG THE DEBRIS DEPOSITS**



FIGURE 3-16

STRUCTURED DEPOSITS IN A DEBRIS PLUG CUT








FIGURE 3-17

WELL-SORTED FACIES S4/S5 SHEET DEPOSIT, SECTION 6

3.6.4 Sediment Mapping

The sediment mapping conducted as part of the field investigation consisted of an assessment of the surface deposits, their characteristics and the evident processes associated with the actual location and distribution of such deposits. The volumes of these deposits was not estimated, only their character.

Referring back to *Figure 3-14*, the deposits shown in Breach Area are those distinctive facies S4/S5, with larger particle sizes as shown on *Figure 3-18*. The facies at the other sections indicated on *Figure 3-14* are shown on *Figures 3-18 and 3-19*.

Facies	Description	Size	Image
S1	Medium to very coarse Sand with granules and pebble.	< 1"	
S2	Pebble with granules and coarse sand	1" – 3"	
S3	Cobble with pebble, granules and very coarse sand	3" – 6"	
S4	Cobble	6" – 1'	
S5	Boulders	> 1'	

Most particles are angular to subangular, derived from the rhyolite, porfirc rhyolite and granite; with traces of particles smaller than a very fine sand

Measuring tape used as scale is always indicating 3 feet

FIGURE 3-18

CHARACTERISTICS OF FACIES TYPES USED IN DESCRIBING SUPERFICIAL SEDIMENTS



S 1



S 2



S 3



S 4



S 5

FIGURE 3-19

FACIES TYPES USED IN DESCRIBING SECTIONS NORMAL TO FLOW

The Sections located on **Figure 3-18** are shown below on **Figure 3-20** and the fraction of the various facies at each section is indicated on **Figure 3-21**.

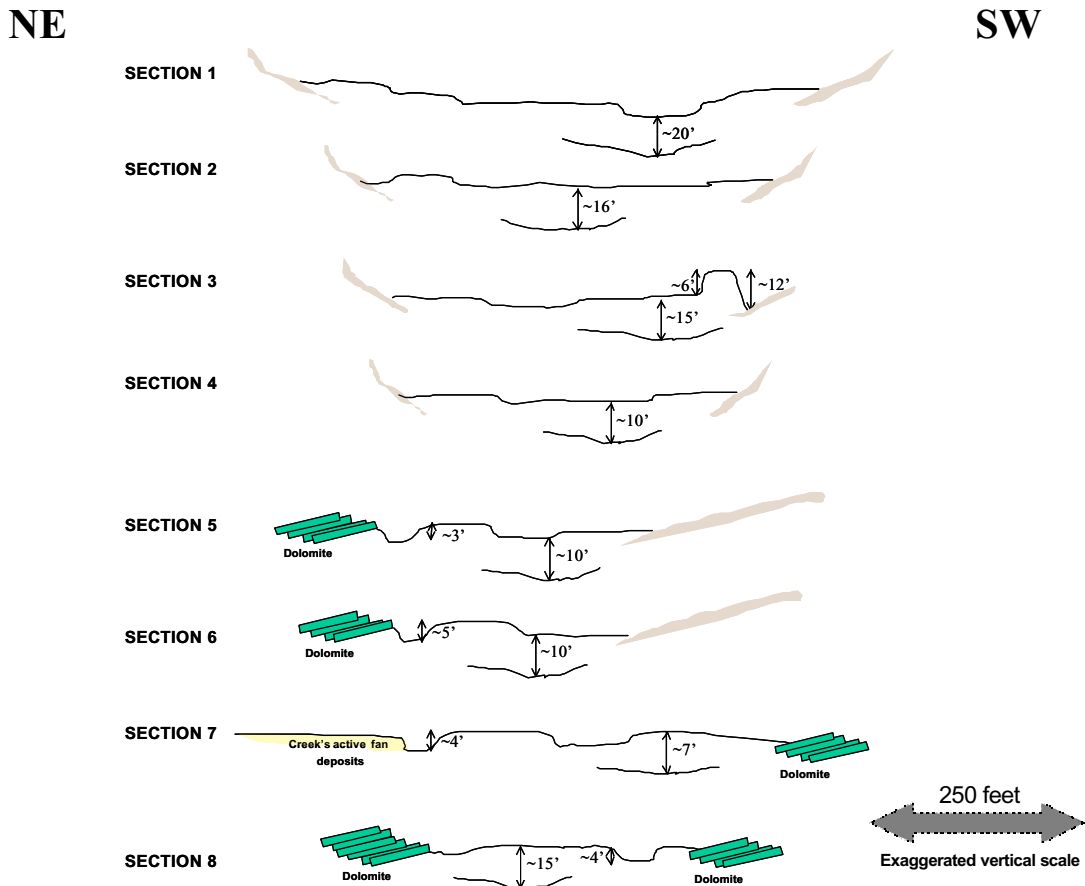


FIGURE 3-20
CROSS SECTIONS OF BREACHED CHANNEL

Facies (%)	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
S 1 (%)	15	10	5	5	5	10	15	5
S 2 (%)	25	30	35	15	15	20	15	15
S 3 (%)	30	35	40	15	30	20	20	25
S 4 (%)	20	20	15	40	20	30	35	40
S 5 (%)	10	5	5	25	30	20	15	15
Max Size (feet)	10	3	5	2	5	5	2	3

FIGURE 3-21
FACIES FRACTION AT EACH MAPPED SECTION