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# Sturzstrom Deposit Caprocks


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## ABSTRACT

Split Mountain has world-famous subaerial and subaqueous sturzstrom deposits that have been carefully studied to learn their distinguishing characteristics (e.g. in Abbott and Seymour, 1996; Abbott et al., 2002). We consider here what caps the sturzstrom deposits. The upper Miocene subaerial-sturzstrom deposit is capped by aerial fallout found as thinly bedded, coarse sandstone. The lower Pliocene subaqueous-sturzstrom deposit is capped by tsunami erosion and deposition in discontinuous graded beds.


## INTRODUCTION

The Elsinore fault system is a prominent fact of life in southern California, soon to be realized by millions more people. One of the fastest growing housing markets in the United States is bringing hundreds of thousands of people to live in new houses built along the Elsinore fault zone ready to experience its next magnitude 6 to 7 earthquake. Over geologic time, the *en echelon* faults of the Elsinore system have created some interesting pieces of topography such as the pull-apart basin filled by Lake Elsinore and the push-up topography of Split Mountain.

Split Mountain lies south of the town of Ocotillo Wells on Highway 78 (see Thomas Bros. Map, p. 410, F10). Between the Vallecito and Fish Creek Mountains lies Split Mountain where Neogene basin-fill strata have been upwarped to expose some intriguing geologic history. The awe-inspiring Split Mountain outcrops of the catastrophic rock fall and flow masses known as sturzstroms were a prominent part of a recent South Coast Geological Society field trip (Abbott and Seymour, 1996).

In Miocene time, extension in the Salton Trough region was accommodated on linked normal faults. The extension created high-standing mountain blocks with pervasively fractured mountaintops such as the Vallecito and Fish Creek Mountains (Frost et al., 1996). The isolated mountains had intervening basins such as the Fish Creek-Vallecito basin, which contains a sedimentary fill that is 5 km thick (Kerr, 1982; Winker, 1987). The Fish Creek-Vallecito basin has undergone an inversion of topography as its sedimentary strata infill has been squeezed up to make Split Mountain. The exposed strata include both subaerial and subaqueous sturzstrom deposits.

## OVERVIEW OF STURZSTROM DEPOSITS

In latest Miocene time, the heavily fractured Vallecito Mountain top dropped a ~$300 \times 10^6 m^3$ volume of tonalite that fell more than 300 meters, shattered, and flowed eastward for 12 km down an alluvial fan and then up a braided stream valley as the Split Mountain sturzstrom (Abbott et al., 2002). In earliest Pliocene time, a heavily fractured mountaintop in the northern Fish Creek Mountains dropped a ~$300 \times 10^6 m^3$ volume of plutonic rocks, pegmatite, gneiss, and schist that fell, shattered, and flowed southward for several km along the seafloor as the Fish Creek sturzstrom (Abbott et al., 2002).

The sturzstrom deposits have very distinct and different features from strata deposited in other depositional environments. Yet, careful inspection of the subaerial and subaqueous sturzstrom deposits reveals no obvious textural or fabric differences between them despite the fact that one ran under air and the other ran underwater. In regard to both sturzstrom deposits:

1. They preserve the lithologic domains and rock distributions that existed in the original bedrock sources despite having fallen, shattered, and flowed for up to 12 km.
2. They are mostly unmixed.
3. They have jigsaw-puzzle fabric wherein the shattered pieces of bedrock are not scattered and can be visually put back together.
4. They have shattered pegmatites that step up in the direction of transport.

5. They have megaclasts concentrated at the top of the deposit.

The differences found when comparing subaerial and subaqueous sturzstrom deposits occur at the base of each deposit. Real differences occur when sturzstroms travel over a firm and dry surface versus a soft and wet surface. The subaerial sturzstrom had the following effects:

1. Boulders sitting on the ground were sliced through, thus decapitated stones were produced.
2. Basal surfaces were grooved and striated.
3. The substrate was disturbed for less than 1 m depth.

The subaqueous sturzstrom had profound effects on the substrate and within the basal sturzstrom deposit:

1. Muddy substrate was folded to depths >35 m.
2. Diapirs of substrate strata rose into the sturzstrom mass.
3. Lobes of sturzstrom material injected into the substrate.

In sum, the main bodies of subaerial and subaqueous deposits are identical, but marked differences are seen at their bases. What about the tops of sturzstrom deposits? Are there differences in the immediately overlying sediments? Are sturzstrom flow masses capped by genetically related sediments?

## SPLIT MOUNTAIN STURZSTROM CAPROCK

The Split Mountain sturzstrom (SMS) deposit begins on the eastern side of Split Mountain at approximately the midpoint of Fish Creek Wash and extends eastward to, and partly around, the Fish Creek Mountains. A left-lateral fault runs subparallel to the wash and has provided the path for the erosional development of the gorge. The faults have offset portions of the SMS to the south as seen on the west wall of the gorge. Typically, the tributary canyon exposures on the west side of the gorge tend to be steeper, narrower and more difficult to explore. In the case of Fallout Canyon (Figure 1) and most of the other west-side tributary canyons, this can be attributed to the fact that steeper narrower canyons are younger, in the sense that they have suffered less from erosion than the wider, longer, less steep and more exposed canyons that are typical on the eastern side of the gorge. Fallout Canyon on the west wall of the gorge initially opens easily at the bottom but quickly becomes steep and narrow with increasing loose rock debris as elevation increases. This condition has fortunately protected a sensitive deposit of sandstone lying on the upper surface of the SMS. In other words, the overburden of material that has covered this deposit for millions of years has protected it while the recent erosion has, for the moment, exposed much of the deposit intact.

The SMS originated by fall of a huge mass of tonalite and granodiorite from high up the Vallecito Mountains west of the gorge. The fall shattered the plutonic rocks, producing broken rock and an accompanying aerial cloud of finer debris (Borron, 1999). Aerial fallout from the massive dust cloud associated with the SMS is clearly preserved in an east-flowing tributary canyon we call Fallout Canyon. Granular sand from the aerial fallout occurs in a 20 cm thick interval comprised of thinly bedded, coarse sandstone separated by thin biotite-rich layers (Figure 2) reflecting the complexities within the roiling cloud of shattered debris. The fallout beds are indurated and composed of individual grains of quartz, plagioclase, and plutonic rock detritus (Figure 3). The grain size varies from small gravel to silt and is a normally graded deposit. Grain-size analyses were completed on two samples retrieved from Fallout Canyon. The samples were soaked in an HCl solution to free the grains from cement. The grains were then sieved through a stack of 12 sieves to determine the grain-size distributions. A similar, but smaller, plutonic rock-fall event occurred at the Happy Isles Campground in Yosemite in 1996. The campground area was covered with shattered plutonic rock debris that was carefully sieved (Wieczorek et al., 2000). The grain-size distributions of the 1996 Yosemite samples are compared to the latest Miocene Fallout Canyon samples (Figure 4). Results of the sieve analyses are consistent, suggesting that the Split Mountain sturzstrom event was accompanied by roiling clouds of aerial debris. The curves show granular, silty, coarse sandstones that are very poorly sorted. The sediments are angular, reflecting their impact origin and short time of transport.

## FISH CREEK STURZSTROM CAPROCK

What sits on top of the Fish Creek sturzstrom? Winker (1987) defined a new stratigraphic unit called the Wind Caves member. He defined the member as sitting on top of the Upper Boulder Bed (our Fish Creek sturzstrom) and being discontinuous with thicknesses varying from 0 to 200 m of thin sandstone beds interbedded with gray claystone beds. Winker describes the lower Wind Caves as being dominated by "L" suite (Local) sediments derived from local sources and the upper Wind Caves as "C" suite

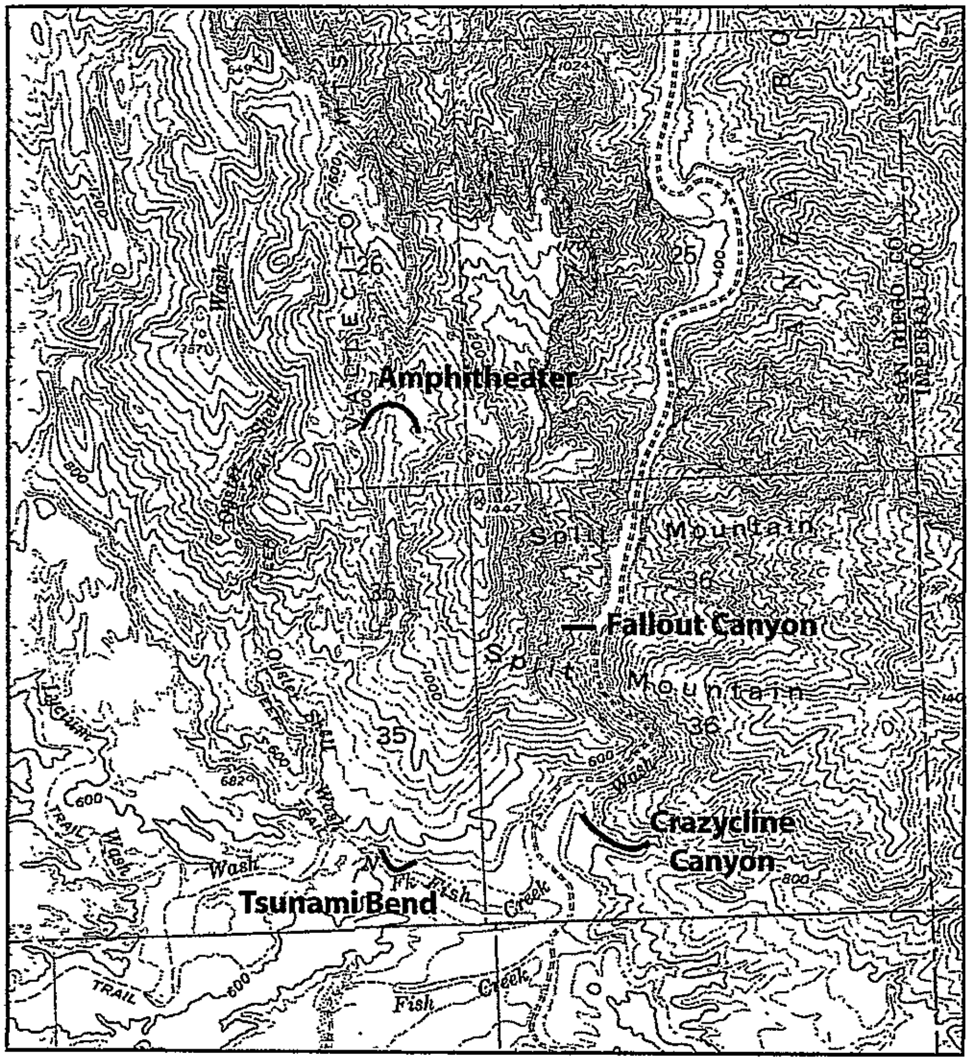


*Figure 1. Location map. Area studied is on four U.S.G.S. 7.5' topographic quadrangle maps: Harper Canyon (upper left), Borrego Mountain SE (upper right), Carrizo Mountain NE (lower right), and Arroyo Tapiado (lower left).*

(Colorado) sediments brought from a wide region by the Colorado River. Winker states (1987, p. 153): "No lithologic equivalents of the Wind Caves member are known to crop out elsewhere in the Salton Trough region." Winker tells of southerly directed paleocurrent indicators, and postulates a submarine-fan depositional system. Another cogent observation by Winker needs to be mentioned (1987, p. 149): "One boulder, exposed in lower Wind Caves Wash, consists of a large reworked clast of the underlying Upper Boulder Bed."

The Wind Caves member also can be studied via magnetic susceptibility. This is based on the original discovery by Gastil (1975) that the Peninsular Ranges have magnetite-bearing plutonic rocks on their western side and non-magnetite-bearing plutonic rocks on their eastern side. Thus, Salton Trough sediments derived locally from the eastern side of the Peninsular Ranges are nonmagnetic. This is in contrast to the magnetite-rich sediments delivered to the Salton Trough by the Colorado River. This difference in magnetite content allows recognition of the arrival of Colorado River-delivered sediment to the Split Mountain region (Gastil et al., 1996). Washburn (2001) used a magnetic-susceptibility meter to map the Wind Caves member (Figure 5). The Wind Caves member has a lower part (Pwl) made of locally derived nonmagnetic sediments and an upper part (Pwc) comprised mostly of sediments delivered by the Colorado River. The magnetic-susceptibility mapping clearly shows that all the sedimentary features immediately on top of the Fish Creek sturzstrom deposit were caused by local processes. The Colorado River could not have been involved; it arrived later in time.

Imbricated conglomerates in the southwesternmost exposure of the Fish Creek sturzstrom deposit yielded southerly flow directions to Washburn (2001). At two localities, imbricated clasts yielded average flow directions of 176° and 167° [Bed 1: n = 30, range = 150-196°; Bed 2: n = 15, range = 149-194°]. Apparently the Fish Creek sturzstrom began as a rock fall in the northern Fish Creek Mountains and continued as a sturzstrom flowing southward over the seafloor. The overlying lower beds of the Wind Caves member also contain southerly flow indicators. Grooved boulders in the FCS also provide some general idea of direction of transport (Figure 6).

## Sedimentary Features in the Basal Wind Caves Member

At the mouth of Crazycline Canyon (Figure 1), the top of the Fish Creek sturzstrom deposit has significant relief due to hummocky topography formed during slowing of the sturzstrom and/or erosion immediately after deposition of the sturzstrom (Figure 7). Against and on top of

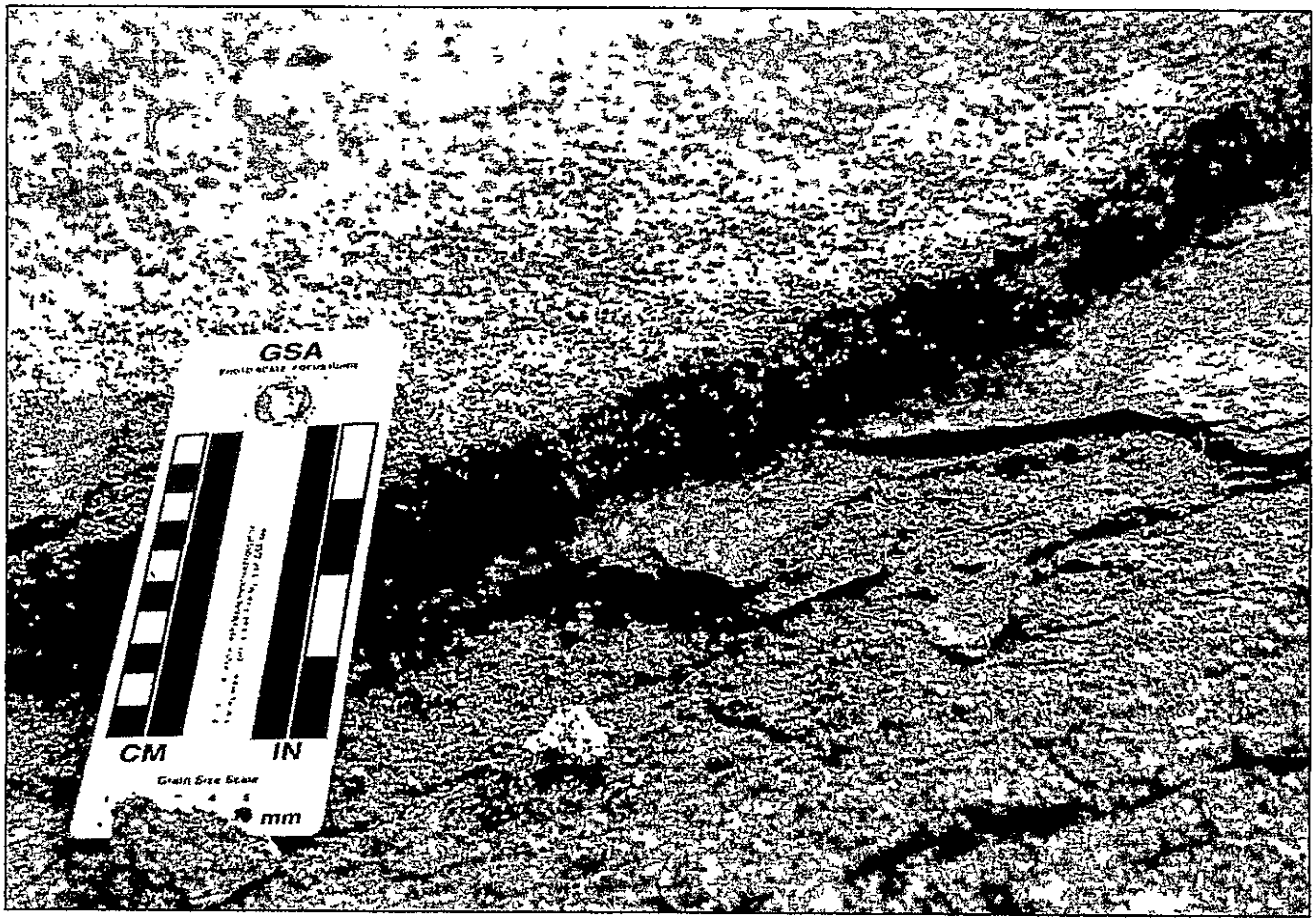


*Figure 2. Layers of fallout sandstone deposited on top of the Split Mountain sturzstrom from the accompanying cloud of aerial debris.*

this erosion surface is laminated coarse sandstone deposited quickly from a high-energy current.

In the Amphitheater (Figure 1), the top of the Fish Creek sturzstrom has a 7 m deep, concave-up channel either formed as a swale between hummocks and/or erosion by a high-energy current (Figure 8). The channel is filled by a normally graded sequence of coarse sediments deposited by a strong but rapidly ending current.

As described by Winker (1987), a large rip-up clast of Fish Creek sturzstrom sits within the lower Wind Caves member. A high-energy, short-lived current was necessary to erode and move this penecontemporary block of sediment.

*Figure 3. Fallout sandstone. An angular, very poorly sorted, granular, silty, coarse plutonic litharenite.*

At Tsunami Bend (Figure 1), the modern stream has carved a meander that provides an excellent 3D exposure of the basal Wind Caves member. A basal layer of cobble conglomerate of 1.5 m thickness is overlain by a 1.84 m thick graded bed of granular conglomerate — coarse sandstone, laminated medium sandstone, rippled sandstone, and mudstone. The 3.34 m thick section is a Bouma sequence of coarse sediments deposited from a short-lived, powerful current. The clasts in the conglomerate are polylithologic, indicating erosion from the Fish Creek sturzstrom deposit. If the conglomerate had been washed down the Vallecito Mountains alluvial fan/fan delta after a heavy rain, it would have produced a nearly monolithologic conglomerate.

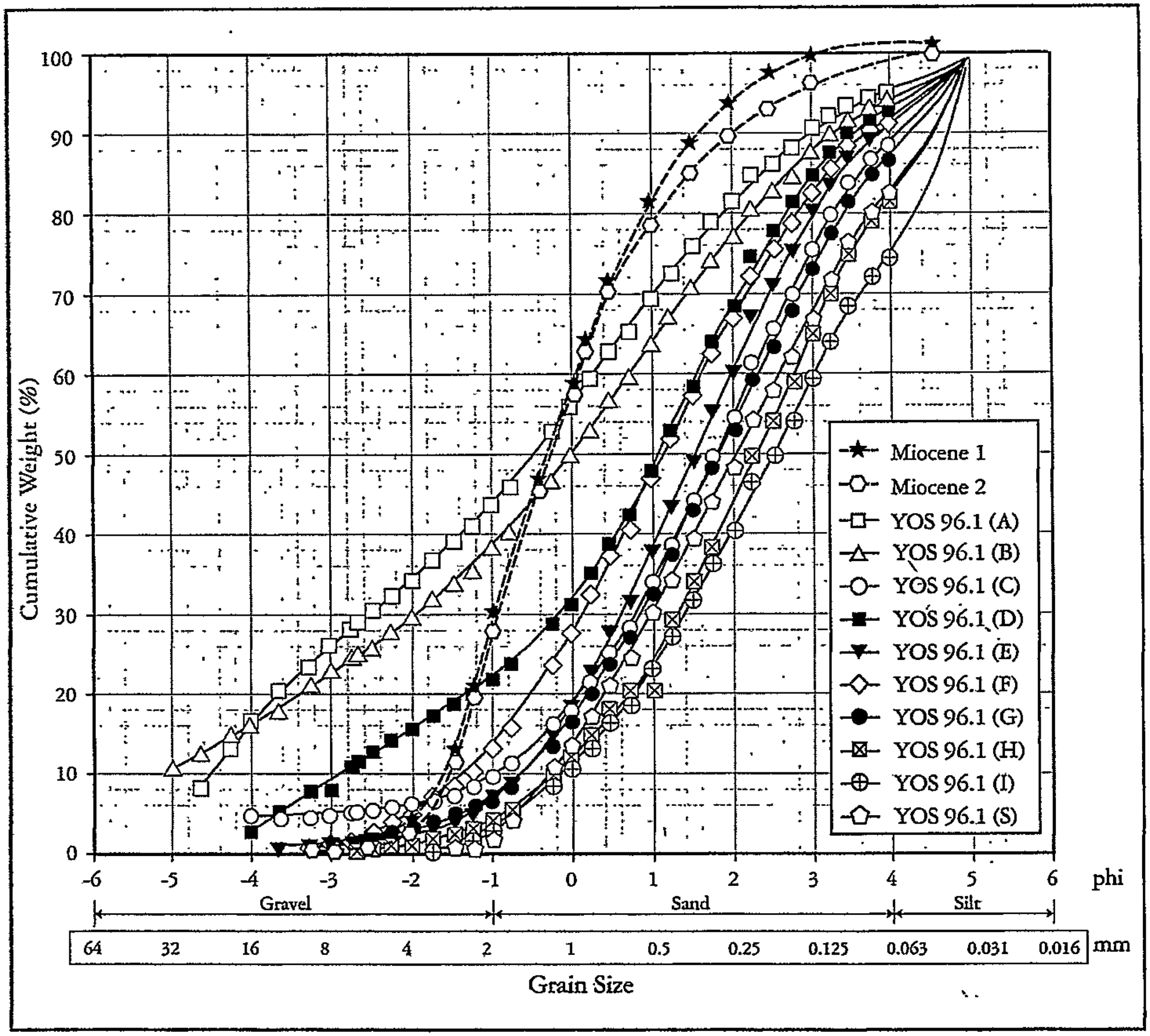


*Figure 4. Grain-size distributions for two uppermost Miocene sandstones from Fallout Canyon compared to sands from the 1996 Happy Isles rock fall in Yosemite analyzed in Wieczorek et al. (2000).*

What created the unique deposits that discontinuously cap the Fish Creek sturzstrom? The evidence points to tsunami caused by the passage of the Fish Creek sturzstrom into the sea.

Was it necessary for the rock fall that became the Fish Creek sturzstrom to drop directly into the sea in order to create tsunami? No, there are case histories of rock avalanches flowing over land and then creating tsunami after they reached the shoreline. For example, on 21 May 1792, a lava dome collapse from Mt. Unzen in Japan created a rock avalanche of 0.3 km$^3$ volume that flowed 6.4 km to the sea where it hit the water with enough impact to create tsunami that killed 15,000 people.

## CONCLUSION

The caprocks on top of sturzstrom deposits are markedly different. The subaerial Split Mountain sturzstrom deposit was sprinkled with poorly sorted, angular, plutonic rock sediment that moved as an aerial cloud above the flowing sturzstrom and then settled out on top of it in thinly bedded layers. The subaqueous Fish Creek sturzstrom deposit is cut by channels and had material eroded from its top; material was transported by high-energy tsunami that crowned the sturzstrom mass with rip-up clasts and filled concave-up channels with discontinuous masses of graded sediments.

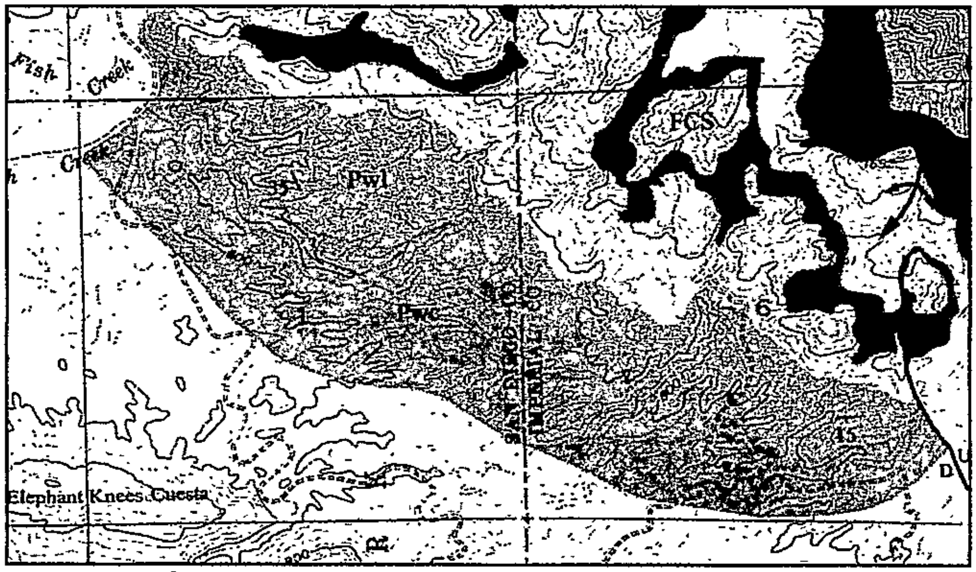


*Figure 5. Geologic map from head of Split Mountain Gorge (Washburn, 2001). The Fish Creek sturzstrom (FCS) is overlain by nonmagnetic, locally derived, lower Wind Caves member (Pwl). Upper Wind Caves member (Pwc) is magnetic and was eroded and delivered from a broad region by the Colorado River.*

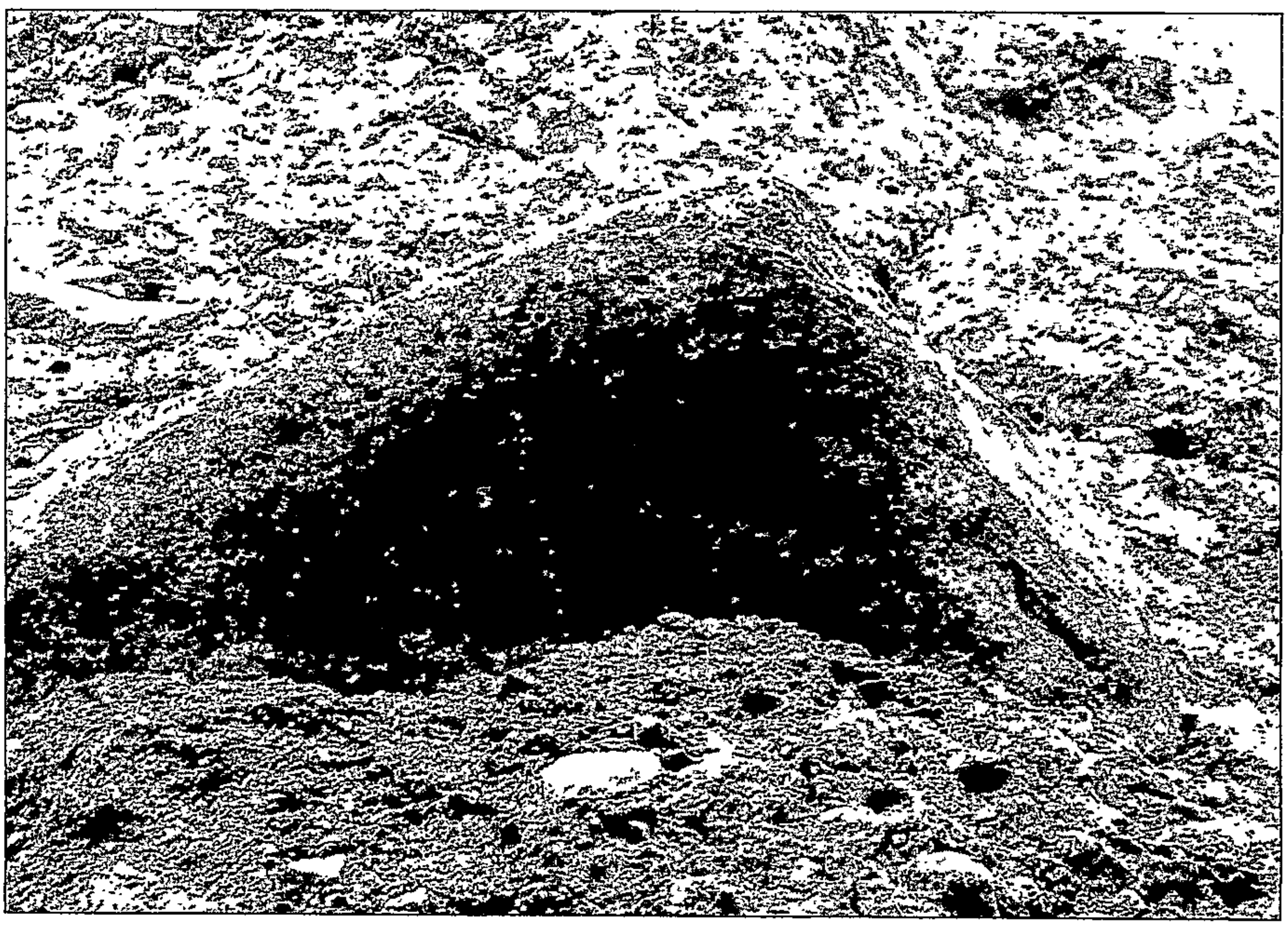

*Figure 6. Large boulder in the Fish Creek sturzstrom, showing grooves scratched during transport. Flow direction was southwest.*

*Figure 7. Outcrop near mouth of Crazycline Canyon. Quadrant in lower left is Fish Creek sturzstrom. Note near-vertical erosional wall eroded by tsunami then abutted and buried by tsunami sandstone. White dashed line indicates channel base.*


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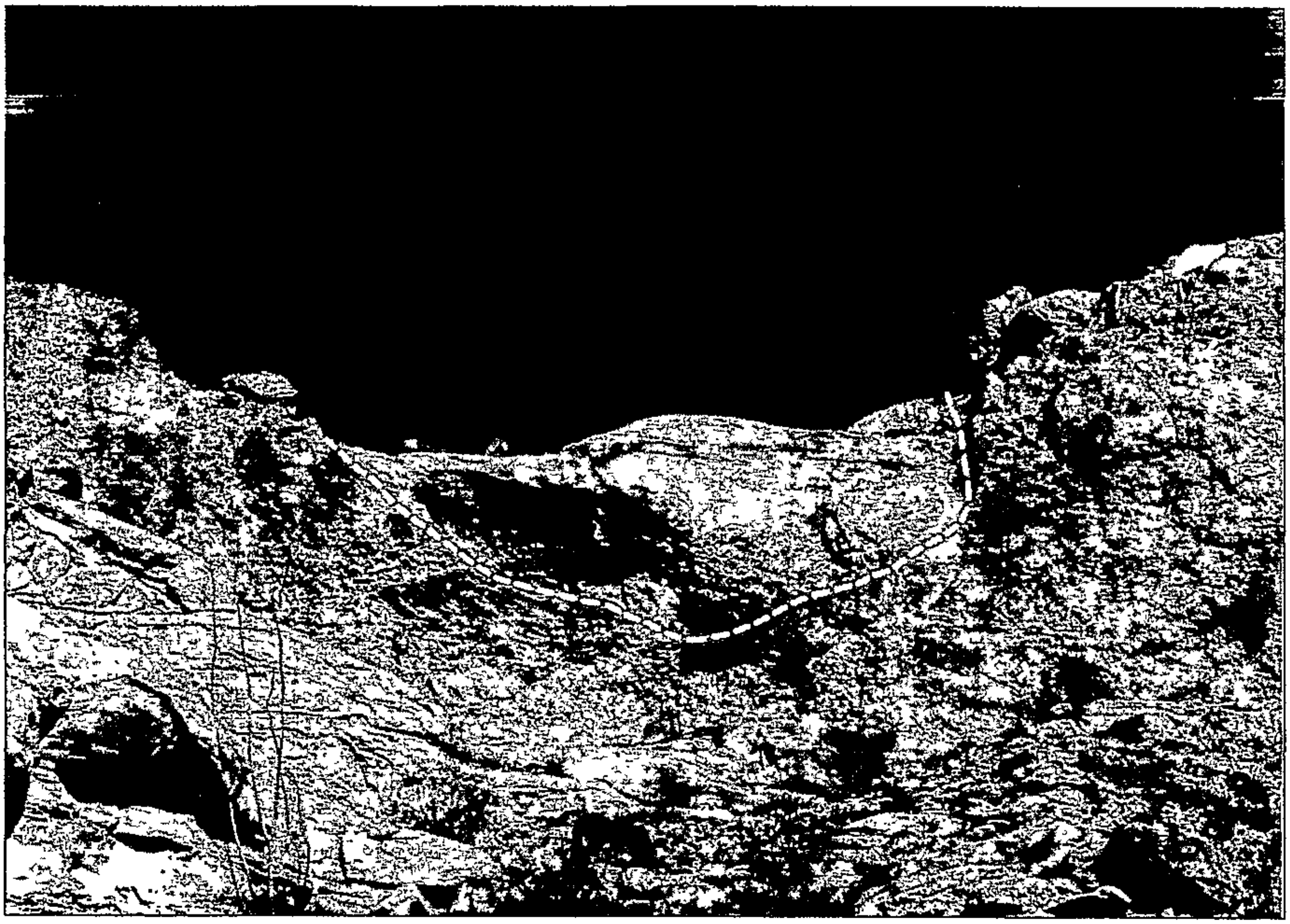

*Figure 8. In the Amphitheater. Note Fish Creek sturzstrom all the way up the right-hand side of the photo. See tsunami-carved channel in FCS filled with tsunami-deposited gravelly sandstone. White dashed line indicates channel base.*

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