centrations. All of these characterize the clay. The yellowish sediment has an abundance of oxidized minerals, a diversity of grain sizes, and finely comminuted fossils. The clay is opposite in each of these characters. Clearly dark and light sediments accumulated under radically different environmental conditions. Yet both contain remains of Pleistocene elephantine mammals and both occur at approximately the same depth beneath a covering of identical soils (Figure 1).

The clay appears to be a subaqueous deposit, as evidenced by the uniform fine texture, the abundance of turtles, and the unoxidized carbon. The yellow gravelly sand appears to be a subaerial accumulation—as suggested by the absence of unoxidized material, and the absence of aquatic organisms. Apparently, clays accumulated beneath the surface of a sizeable water hole that was populated by turtles, plants, and other aquatic organisms. Relief was so low that most of the sediment entering the water hole was either clay-sized or the remains of organisms that died in, or near, the water. Organic remains were well preserved in poorly aerated bottom sediments. Adjacent to the water hole, sediments were moist and well aerated, leading to hydration and oxidation. Mastodon, ground sloth, and other large mammals trampled the ground, thus, bones of dead organisms were generally broken and delicate tissues were destroyed. While this environmental reconstruction seems compatible with all that is known of the Darks Mill Local Fauna, two lots of spoil bank sediments are not an ideal basis for environmental interpretation.

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THE PORT ROYAL, TENNESSEE DOLINE COLLAPSE — A CASE STUDY

PHILLIP R. KEMMERLY

Department of Geology
Austin Peay State University
Clarksville, Tennessee 37040

ABSTRACT

The collapse of a doline in the Port Royal area, Tennessee was investigated in terms of the:

1. bedrock and unconsolidated stratigraphy exposed at the site;
2. chemical weathering features and products contributing to instability;
3. engineering character of the soil bridge (overlying three solution chimneys); and
4. collapse mechanism.

The collapse mechanism is attributed to short-term dynamic loading and the modification of the doline to increase runoff storage capacity.

The overburden stresses acting perpendicular to the soil bridge prior to failure is estimated, using conventional soil mechanics principles, to have been 1.4 to 1.5 tons/ft^2.

INTRODUCTION

The occasional collapse of a doline on the Western Highland Rim certainly is not an uncommon event, yet such phenomena have in general gone undocumented. The lack of documentation can in part be attributed to the traditional notion that karst landscapes are a random, chaotic collection of solution and collapse dolines. Recent work indicates rather conclusively that such opinions are unfounded. Williams (1972) investigated several factors affecting the spatial distribution of dolines. McConnell (1972) utilized what he describes as a Modified Poisson Distribution to estimate the probability of occurrence of both solution and collapse dolines. Both studies indicate the paucity of geologic data concerning doline change with time, particularly collapse events.

In July 1973, a newly constructed stock pond on the Milton Moore farm, in extreme northeastern Montgomery County, collapsed (unfortunately a picture was not available, as the doline collapse was filled in shortly after field examination). The stock pond is located approximately 4.7 mi north and 0.2 mi east of Port Royal, Tennessee in an area where numerous dolines provided natural depressions for runoff collection. Two months prior to the collapse, a northeast-southwest trending doline was modified to increase runoff storage capacity for livestock. Approximately 2 to 4 ft of residuum was excavated from the doline bottom. The ellipse-shaped doline, after modification, measured approximately 225 ft (major axis of ellipse) by 125 ft (minor axis) with an estimated average depth of 8 ft.

Runoff, from abundant summer precipitation during the period of June 1 to July 15, filled the pond to capacity. Two days after reaching storage capacity, the northeastern end of the stock pond collapsed. The loss of unconsolidated deposits produced a funnel-shaped void approximately 60 ft long, 35 ft wide, and 30 ft deep (Figure 1). The purpose of this paper is to:

1. evaluate the surficial and subsurface (where exposed) geologic conditions at the site; and
2. describe the collapse mechanism.

GENERAL GEOLOGY

The study area, located in the east-central portion of the Sango Quadrangle (1:24,000), exhibits the typical karst terrane developed on the northwestern portion of the Western Highland Rim. Excellent secondary permeability is provided in the site area by three systematic joint sets oriented N.70-80°E., N.20-40°E., and N.20-30°W. The major axis of the doline is oriented parallel to the N.20-40°E. set. Bedrock stratigraphy in the Sango Quadrangle consists of, in ascending order, the St. Louis and Ste. Genevieve limestones both of Mississippian age. Examination of the bedrock stratigraphy in the immediate study area was limited to a single outcrop exposed, as a result of the collapse, in the bottom of the doline.

The bedrock at the site consists of 3.5 to 4.0 ft of intensely weathered, gray to buff, medium- to coarse-grained, thin- to thick-bedded limestone. Within the carbonate matrix, pebble- to cobble-sized chert nodules occur. Field examination indicated that the limestone outcrop in the doline is Ste. Genevieve. Three vertical chimneys, ranging from 18 to 26 in. in diameter, intersect the limestone outcrop providing major pathways for ground-water recharge. The chimneys occur in linear sequence parallel to the N.70-80°E. joint set in the area. Immediately above the limestone, approximately 30 ft of unconsolidated deposits are exposed in the northeastern corner of the collapse area.

Field examination of the unconsolidated deposits overlying the Ste. Genevieve indicates the presence of two distinct stratigraphic units consisting of a cherty residuum overlain by a silty colluvium. The unconsolidated deposit directly overlying the Ste. Genevieve at the site consists of 25 ft of highly weathered, buff to reddish, angular to blocky, porous chert pebbles and cobbles incorporated in a yellow to reddish, highly mottled clay matrix. The deposit is definitely residuum derived from the intense chemical weathering of the underlying Ste. Genevieve augmented by extensive leaching.

The colluvial deposit consists of approximately 5 ft of brownish- to tannish-yellow clayey silt within which minor quantities of pebble-sized chert occur. The silty colluvium was distinguished from the residuum primarily on the basis of a substantially higher silt content. Corgan (1970), in an unpublished loess map of Montgomery County, indicates that greater than 80 percent of the soils in the area surrounding the site are derived from loess. Field examination of the soils topographically higher than the doline confirmed this point. The area immediately adjacent to the doline has been so severely eroded that virtually all of the loess and loess-derived soils have been displaced and redeposited in the doline as a colluvial deposit. The presence of minor quantities of chert in the silty colluvium and the discontinuous nature of the loessial soils suggest that sheet wash and channelized flow did not remove uniformly the loess and loess-derived soils surrounding the doline. The soils reflect the discontinuous nature of the colluvium. The Baxter and Pembroke Soils occur in the immediate area of the site (Smith, 1974). The Baxter Series are residual soils developed from limestone and the Pembroke soils are derived from loess (Moneymaker, 1968).

COLLAPSE MECHANISM

A doline (commonly termed sink hole) can be broadly defined as a depression, generally elliptical to circular in shape, resulting from loss of unconsolidated surfical deposits through enlarged joints and chimneys produced by the solution of bedrock. The doline generally serves not only as a collecting basin for runoff, but a point source for primary recharge of ground water. Infilling of unconsolidated deposits such as residuum, alluvium, and colluvium not infrequently restrict swallet openings resulting in a temporary ponding of water.

The Port Royal doline developed under the same general conditions described above with the following three modifications. The rate of carbonate solution was accelerated differentially along the N.20-40°E. joint set. The abundance of chert in the residuum augmented the low permeability of the kaolinite-group clays allowing increased rates of subsurface ground-water recharge. Vadose ground water as well as phraetic ground water, on an intermittent basis, combined to produce three solution chimneys highly localizing ground water entry into the subsurface. All of the above factors would collectively combine to increase the rate of chemical weathering at the site. There are two factors that would reduce carbonate solution rates at the site.

The major chemical weathering product of the Ste. Genevieve limestone is a cherty clay residuum. The increase in thickness of the residuum with time would retard, at an unknown rate, the solution of limestone because of the low permeability of kaolinite. The redeposition of the loess in the doline would also tend to retard solution rates. Loess in an in-situ configuration commonly has a preferred particle orientation. As a result the vertical permeability of loess in-situ generally is greater than it would be after the loess structure was destroyed following redeposition in the doline.

Loess, loess-derived soils, and residual soils (surrounding the doline) were displaced and redeposited above the cherty clay residuum in the doline. The cohesive nature of the residual clay, the honey comb structure of the silt, and the redeposition of displaced residuum produced a self-supporting soil bridge of unconsolidated deposits over the three solution chimneys. Overburden pressures produced a partial reorientation of the silt normal to the direction of stress. The resultant grain-to-grain arch structure in a soil mass produces typically a rather high void ratio (commonly > 0.75).