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SANDSTONE CYLINDERS AS POSSIBLE GUIDES TO PALEOMOVEMENT OF GROUND WATER

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INTRODUCTION

Geologic mapping of the Lees Ferry quadrangle, Coconino County, Ariz., has been undertaken by the Geological Survey on behalf of the Atomic Energy Commission. An interesting sidelight of the regional geology in this area is cylindrical bodies of sandstone that penetrate beds in the lower part of the Carmel formation. These cylindrical bodies and the enclosing strata of the Carmel formation are described from exposures at one place along the Echo monocline and several places along low terraces and benches bordering Judd Hollow (fig. 1). Several explanations have been advanced for the origin of these and similar features but to the writer's knowledge they have not been studied as clues to ground-water conditions at the time of their origin.

Many of the cylinders are inclined rather than vertical. The inclination may be due to slow basin-ward creep of the enclosing strata. However, if the cylinders were formed by the sudden release of hydrostatic pressure in the strata, then their direction of inclination might be explained by the refraction of flow lines at the interface between media of unlike permeability. (Hubbard, 1940).

CARMEL FORMATION

The Carmel formation (Gregory and Moore, 1931, p. 69) is Middle and Late Jurassic in age and in the Lees Ferry area is about 430 feet thick. In this area the formation is divided into three main units of generally contrasting lithology, a lower silty slump-deformed unit about 165 feet thick, a middle ledge-forming cross-stratified sandstone unit about 150 feet thick, and an upper mudstone unit about 110 feet thick.

The lower unit in the Carmel formation consists of medium- to dark-reddish-brown thin-bedded siltstone in strata 2 to 4 feet thick that alternate with grayish-yellow medium- to fine-grained sandstone in strata 2 to 15 feet thick. Beds in some of the sandstone strata are planar inclined and terminate against horizontal bedding planes above and below, but in most of the strata the bedding is horizontal. Locally in beds near the base of the formation coarse, angular grains of sand and angular pebbles are alined along bedding, are localized in small lenses or stringers, or are scattered at random in the sandstone. The units of siltstone are locally intercalated with thin beds of mudstone and fine-grained sandstone, but in most places they are massive. Where bedding is preserved in the siltstone it is contorted and broken by numerous intrastratal faults. Small concretions of calcite-cemented sandstone and spots of bleached sandstone ¼ to ½-inch in diameter also are scattered at random in the sandstone strata.

The middle unit of the Carmel formation is pale-gray brown to pale-yellow-brown medium- to fine-grained sanstone, massive and thick-bedded near the middle but interbedded with siltstone in the lowermost and uppermost parts. The massive thick-bedded sandstone weathers to round ledges with numerous potholes, but the interbedded sandstone and siltstone strata at the top and bottom of the unit weather to alternating ledges and smooth slopes. The sandstone strata in the middle unit are mostly horizontally bedded, and current lineation oriented northeast is locally apparent on the bedding surfaces. Festoon-type crossbedding is conspicuous in some strata, but in some the beds are planar inclined and terminate against horizontal bedding planes above and below.

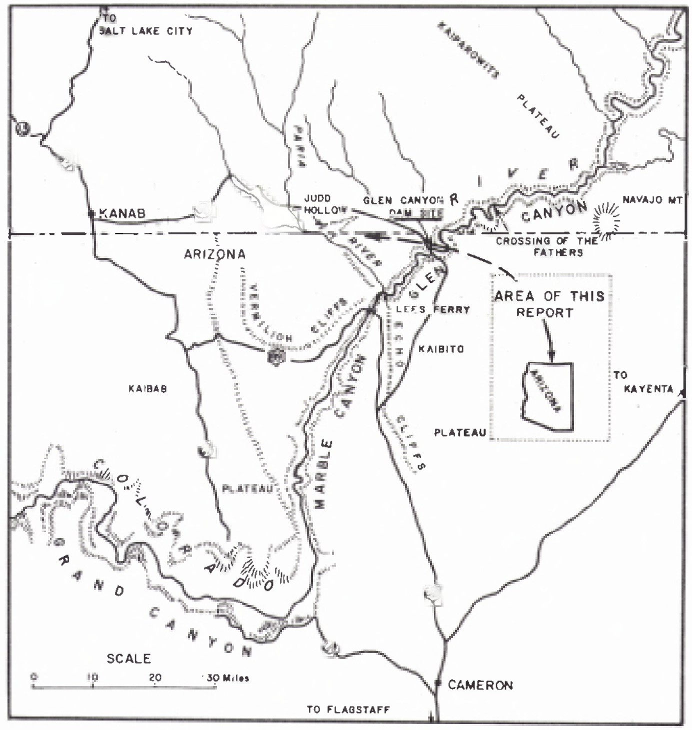

Figure 1. — Index map showing the location of Lees Ferry and nearby landmarks in Arizona and Utah.

The upper unit is reddish-brown thin-bedded siltstone and mudstone that contains local resistant beds of light-colored limy sandstone. The mudstone is blue-green for a distance of 1 to 2 feet below the Entrada sandstone; below this for about 5 feet it is mottled red and gray. The entire unit forms a dark-colored smooth slope broken here and there by thin but persistent pale-gray-green ledges of silty sandstone.

The Carmel formation rests with apparent unconformity upon the Navajo sandstone, for the contact is planar and truncates crossbeds in the Navajo sandstone. The hiatus represented by the unconformity probably was not long, however, for the two formations intertongue. The unconformity is believed to represent a simple encroachment of Carmel lithology upon the eolian crossbeds of the Navajo sandstone; truncation of the crossbeds is believed to have been accomplished along the shoreline of a slowly encroaching shallow sea.

Origin

The origin of the Carmel formation was discussed by Harshbarger and others (1957, p. 43-56), who suggested that the Carmel formation was deposited in an environment that alternated between a low-lying flood plain and a marshy tidal flat. It seems likely that the Carmel environment was first introduced by conditions favorable to planation of the Navajo sandstone, such as an enroaching shoreline of a shallow sea. Sediments were subsequently deposited in quiet water or in an environment of sluggish streams. Sedimentary structures of various kinds in the sandstone strata of the middle third of the formation, including foreset and festoon bedding and current lineation, suggest that sediments were transported by directional currents that moved northeastward. The strata of thin-bedded mudstone, siltstone, and sandstone in the lower third of the formation were probably deposited in an environment of quiet shallow water. No trace of fossils was found in the beds in the Lees Ferry area to indicate their age or depositional environment.

COMPACTION STRUCTURES IN THE CARMEL FORMATION

Structures resulting from compaction are common in the Carmel formation of the Lees Ferry area and help to identify the formation. In the lower unit of the Carmel formation, about 40 feet above the base of the formation, cylinderical to cone-shaped and locally somewhat sinuous bodies of sandstone 4 to 18 feet high and 1 to 6 feet in diameter penetrate strata of fine-grained fluvial cross-bedded sandstone. Where these bodies of sand are cone-shaped the base may be either larger or smaller than the top; whatever their shape, however, these bodies are referred to here simply as "cylinders." Commonly, beds marginal to the cylinderical bodies sag downward or are offset 2 to 3 inches by near-vertical concentric faults; locally the cylinders are ringed by a series of faults so that beds 6 to 18 inches away from them are repeatedly offset. In such places, displacement along one fault may be upward and along an adjacent fault may be downward, as though pressure was reversed several times during formation of the faults. However, the cumulative displacement on the faults is inward and downward toward the base of the "cylinder". The cylindrical bodies of sandstone, generally, but not always, penetrate a stratum of massive medium- to fine-grained sandstone 10 to 15 feet thick. The base of the cylinder in most places begins in an underlying stratum of fine- to very fine-grained silty sandstone, and the sediments in this stratum are locally depressed below the base of the cylinder and are also offset by numerous intrastratal faults. In one area a bed of sandstone truncates the top of several cylinders. Generally, however, around the upper "lip" or edge of the cylinder and for an inch or two above and lateral to the edge of the cylinder the sandstone is indistinctly bedded, as though the top had been surrounded by a mound of sand. The sandstone within the cylinders rarely is bedded, but where it is, the bedding is horizontal.

Figure 2a. — Sandstone cylinders cutting 10-foot-thick bed of white sandstone in the lower third of the Carmel formation.

Figure 2b. — Closeup view of sandstone cylinders in 10-foot-thick bed of white sandstone in the Carmel formation.

Locally the cylinders are enclosed by shells of massive sandstone, as though a cylindrical cavity was filled with sandstone, then reexcavated and refilled. The outer shells commonly terminate at successively higher beds in the surrounding sandstone strata. The sandstone in the cylinders is like that in the host sandstone strata, but it is less well sorted and locally the cylinders contain angular pebbles similar to pebbles contained in the siltstone beds at their base. Likewise, some cylinders of sandstone are cemented to a greater degree than the surrounding rocks, so that they stand in relief (figs. 2a, 2b) At Judd Hollow, where the basal unit of the Carmel formation is well exposed, the cylinders are found at two localities, and in both places they occur in the same stratigraphic unit. At both localities they are mostly titled at angles of 5 to 10 degrees from the vertical, and the direction of this tilt is northeastward.

Pipelike features very similar to those in the Lees Ferry area were described by Hawley and Hart (1934) and by Gableman (1955). Those described by Hawley and Hart penetrate fluvial crossbedded sandstone of the Potsdam sandstone, which probably was deposited in shallow water; those described by Gableman pentrate fluvial crossbedded siltstone of Permian (?) age believed to have been deposited on a coastal mud flat. The cylindrical structures described by these authors are like those that penetrate fluvial crossbedded sandstone of the Carmel formation of Jurassic age, and the writer believes that they all have a similar origin.

Origin of sandstone cylinders

These cylinders are believed to represent loci of relief of hydrostatic pressure in the bed at the base of the cylinder, and the relief of this pressure is believed to have been contemporaneous with deposition of the sediments. The pressure needed to form the cylinders can be attributed partly to the load of overlying sediments and party to a lateral pressure gradient in the groundwater in the bed at the base of the cylinder. The extrusion of sand and water from the beds at the base of the cylinders probably first formed a cylindrical cavity. Subsequently the cavity was filled with sand derived partly from the walls of the cavity but mostly from beds above or below the cavity. In some cavities deposition was sufficiently orderly so that the filling sediments were bedded; in others, deposition within the cylinders took place too quickly for bedding to form. The surface manifestation of such cavities is believed to be similar to features described as shoreline spring pits by Quirke (1938) and to the numerous small springs that locally flow from tidal flats and from bottom sediments for short distances off-shore in shallow bays and estuaries.

Some of these features on Recent tidal flats may be "triggered" by the burrows of animals; however, the cylinders in the Carmel formation are not associated with and do not contain fossils, and the reason for the point of rupture is not known. If these cylindrical bodies are caused by a combination of lithostatic and artesian pressure, however, the direction of inclination of the cylinders will be an indication of past ground-water conditions in the beds. Hubbert, who examined the behavior of a liquid flowing through inhomogeneous media (1940, p. 844-847), pointed out that flow lines will be refracted at the interface between media of different permeability, according to the ratio of the permeabilities. Thus, in upward leakage from a confined bed the flow lines will be inclined. If pressures are great enough to cause rupture of the sediments, as is postulated in the case of the cylinders, then the direction of rupture should follow the flow line and also be inclined.

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