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# A geotechnical study of evaporitic, lacustrine sediments in the saline environment of the Dead Sea area

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ABSTRACT

This paper is the third by the authors relating to the geotechnical properties of the evaporitic, lacustrine sediments of the saline environment in the Dead Sea area. The earlier papers identified difficulties involved in establishing the water content of sediments in a saline environment. A different approach was adopted whereby fluid content, rather than water content was used to define geotechnical properties. The present paper expands on the geological background presented in the previous papers, and discusses additional geotechnical aspects of the materials' behavior. The three major sediment types encountered in the region are fluvial granular soil, cohesive lime carbonate deposits and granular to massive halite sediments. The granular soils, composed predominantly of sand and pebbles of dolomite with minor chert and limestone, have gradations which vary widely both with depth and laterally. Shear wave velocities are higher than those estimated from common existing correlations with standard penetration test, SPT, blow counts. While compression indices, Cc, and cyclic shear response of the saturated lime carbonates are consistent with behavior of clay soils, their effective friction angle of about 34° on average, is significantly higher than that of clays. The geotechnical properties of the rock salts encountered in the region are shown to be intimately related to the extent of diagenesis and burial, with very significant difference between the younger, more porous deposits of Holocene age, and the older, Mt Sdom diapiric salt wall of Upper Miocene age. The latter are seen to have properties consistent with those of older rock salt deposits at greater depths, reported in the literature.



## 1. Introduction

The Dead Sea area has become an important industrial and tourist centre, both on the Israeli and Jordanian sides. As development and building increases in the area, it becomes more important to correctly understand the geotechnical properties and engineering behavior of the local sediments, as related to foundation engineering. The authors (Charrach et al, 2007; Frydman et al., 2008) have previously reviewed Dead Sea soil behavior; the present paper extends those reviews, focusing on geotechnical properties relevant to foundation design and construction, including additional data that was not available at that time, and also referring to engineering properties which were not previously discussed. Although the paper refers to the specific sediments of the Dead Sea area, the approaches presented could be useful in other areas such as the developments being planned or undertaken in playa lake environments worldwide, or for understanding the geotechnical behavior of salt filling of nuclear and hazardous waste repositories.

All reported laboratory testing performed in Israel was carried out in the Building and Infrastructure Testing Laboratory, Haifa, in the framework of ongoing engineering projects. Consequently, these tests were always performed according to accepted international standards (generally ASTM), but they were not usually research oriented. The present paper should be viewed in this context – as an attempt to collect and interpret a significant bank of geotechnical information resulting from routine, commercial testing of these special deposits.

### 1.1. Geological setting

The Dead Sea Basin (Figure 1) is an intracontinental basin located within the Dead Sea Transform that separates the Arabian and Sinai plates. It is the lowest point on earth and is tectonically subsiding. The basin is part of an active plate boundary that connects the Red Sea to Turkey. It formed during the late Cenozoic period by the breakup of the once continuous Arabian - African continent (Garfunkel and Ben Avraham, 2001). The basin is bordered by steep normal/strike slip fault scarps and by longitudinal intra-basinal faults. These faults delimit the interior graben from the less subsiding marginal blocks. The stratigraphy of the graben fill is up to 13 km (Ginzburg and Ben Avraham, 1997), of which the lower section consists of clastic sediments, mainly

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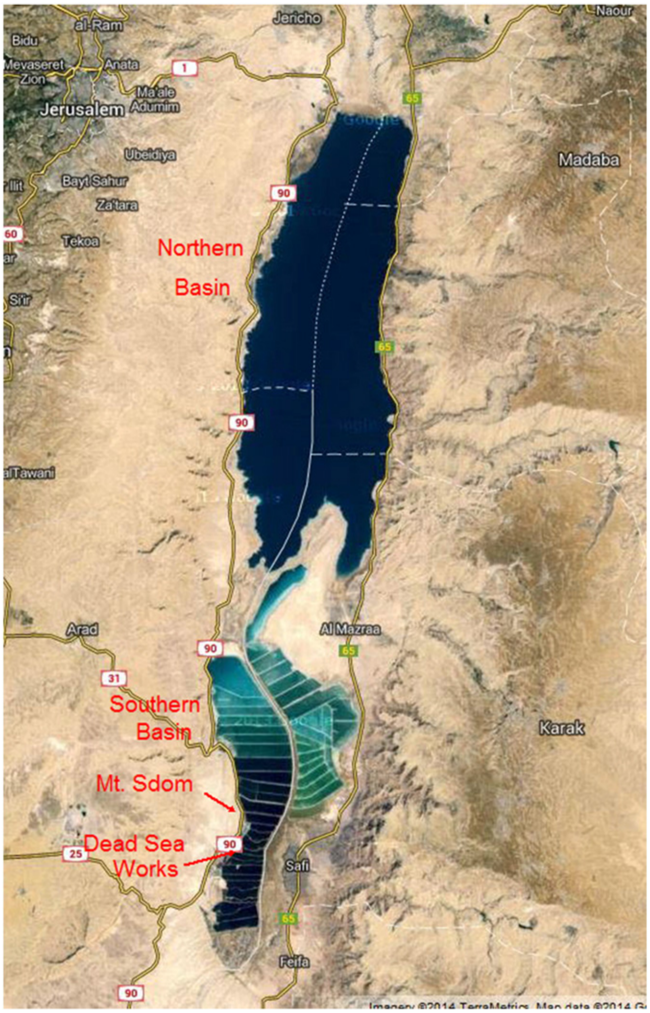


Fig. 1. Map of the Dead Sea area.

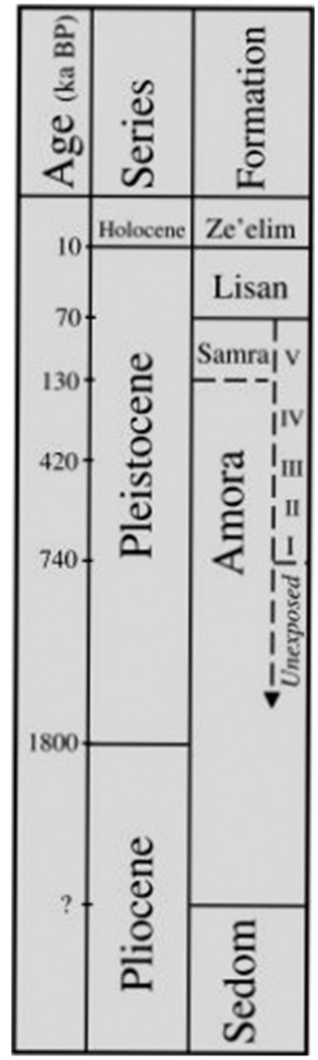


Fig. 2. Simplified stratigraphic column.

quartzose sandstones of the Miocene age. A simplified stratigraphic column is shown in Fig. 2. During the late Miocene to lower Pliocene, a 2 km thick evaporate sequence was deposited within the rift valley, which later formed diapirs and the Mt. Sdom salt wall (Zak, 1967; Tannenbaum and Charrach, 1993; Charrach, 2006a); an example of Mt Sdom salt is shown in Fig. 3A. This sedimentary sequence can be considered as non marine, firstly on account of the mineral assemblage, which is $MgSO_4$ poor (Hardie, 1990), and secondly, in view of the fact that the Messinian sediments wedge out, west of the Tivon – Mt. Carmel barrier, east of the present day Haifa Bay (Sagy and Gvirtzman, 2009), and are not found east of this barrier (Shaliv, 1991). The upper 4 km of sediments in the Dead Sea basin consists of continental fluviatile and lacustrine sediments, deposited from the lower Pliocene until the late Pleistocene.

During the late Pleistocene (70,000 to ~11,500 yr BP), lime carbonate and gypsum sediments were deposited from the terminal Lake Lisan, a precursor lake to the present day Dead Sea. The Dead Sea is a unique non marine, chloride lake with very high concentrations of dissolved magnesium and calcium chloride (Lerman, 1967; Hardie, 1984). Evaporate sediments precipitate when saturation of a mineral is reached, which only occurs when evaporation is greater than rainfall and when the relative humidity is low. Calcite precipitates when approximately 75% of sea water has evaporated and reached a specific gravity of 1.1, while halite (NaCl) requires greater than 95% of brine evaporation, with specific gravity reaching 1.235 for Dead Sea brines (Sonnenfeld, 1984). The Dead Sea Basin is in a rain shadow with low humidity. During the Holocene period there were major climatic

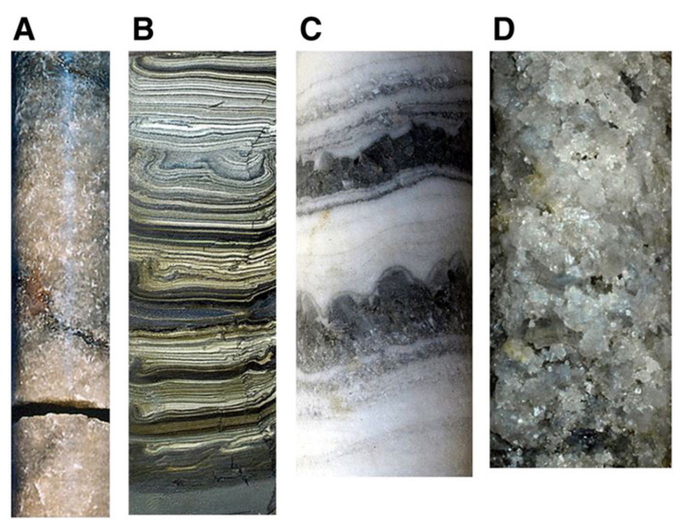


Fig. 3. A: Halite sediments from the Sdom Fm. Fine grained cloudy halite with the beds of carbonate and minor sulphate minerals. Scale: width 6.2 cm. B: Lime carbonate sediments. Laminated organic rich beds, clay to silt size clastic sediments (predominantly calcite) and authigenic aragonite. Note the seismites and unconformities Scale: width 10 cm. C: Halite sediments from the lower Holocene. Grey euhedral, bottom growth halite draped by white surface evaporated halite. Scale: width 10 cm. D: Halit sediments from upper Holocene. Recrystallized euhedral cubic halite. Note the porosity of the sediments. Scale: width 10 cm.