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The Use of Ground Penetrating Radar for Mapping Rock Stratigraphy and Tectonics: Implications for Geotechnical Engineering

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ABSTRACT: This paper presents results from ground penetrating radar surveys using the SIR-10B GPR instrument (manufactured by Geophysical Survey System Inc., USA), with 400 MHz monostatic antenna (model 5 103). Survey was made over 3 excavation levels along the highway section at the Ras en Naqab escarpment area, Southwest Jordan. A total of 217 m along 4 profiles were covered in the winter of 2012. The objectives of the study are (i) to evaluate the resolution of the GPR technique in the field for detecting and locating anomalies caused by subsurface structures like cavities, fractures and faults, and (ii) to describe stratigraphic nomenclature of the subsurface rocks of the area. 2D interpretation of the obtained data and the geological information demonstrate a strong correlation between the GPR anomalies and the subsurface geology. Based upon the lateral and vertical velocity changes with depth, the thickness and orientation of the subsurface layers are outlined. Analysis of the exposed section shows good agreement between the estimated thicknesses of lithostratigraphic units and the quantitative assessment of the radar waves velocity inferred from GPR data.
KEY WORDS: ground penetrating radar, rock stratigraphy, rock tectonics, Ras en Naqab, Jordan.

1 BACKGROUND

Jordan is located on the northwestern edge of the Arabian Plate and has an area of about 96 000 km^2 (Fig. 1a). The landscape of Jordan is a fast semi-desert to desert plateau in the east. To the west is a mountainous region rising to a height of 800 to more than 1 700 m above sea level. Between two mountainous areas west of Jordan and east of Israel lies a north-south striking Dead Sea rift (DSR). The rift escarpment separates drainage into the Dead Sea Basin, ~430 m below sea level, from drainage into the plateau interior. The east bank of the DSR is controlled by the regional tectonics of the horizontally, northward-moving Arabian Plate. Therefore, the compressed structures are folded with a higher intensity of deformation close to the rift fault and decrease eastwards, thus leading to deformational belts which represent potential zones of weakness, characterized by displacements and stress release represented by major landslides, joints, fractures, rock collapses, local earthquakes, rock movements and caverns. Recent studies focused on the regional tectonics of the DSR and surrounding area are of the work of Diabat (2002), Zain Eldeen et al. (2002) and Diabat et al. (2004). The relative motion across the DSR has been estimated by both regional plate motion models and local slip rate considerations. The regional plate motion studies use the fault orientation, additional local observations, and constraints from the motion of neighboring plates to estimate 5–10 mm/yr of relative motion across the DSR (Chu and Gordon, 1998; Joffe and Garfunkel, 1987). Local seismic studies yield a wider range of slip motion of 1 to 10 mm/yr (Klinger et al., 2000; Shapira and Hofstetter, 1993).

Central Jordan surface morphology is dominantly characterized by flat lying. Rugged topography associated with the Ras en Naqab escarpment separates the northern Jordanian limestone area from the southern basement complex (Fig. 1a). A difference in altitude between these two geologic-physiographic provinces is in the order of 600 m. The escarpment area strikes in a northwest-southeast direction. A modern highway connecting north via central Jordan to the south was constructed 30 years ago. Because of the rugged terrain in the Ras en Naqab escarpment and it is considerably higher construction cost, works on this highway ceased in this area. However, a site on the escarpment was excavated up to five terrace levels (I through V, Fig. 1b). Each level is about 200 m long, 4 m wide and about 6 m high. These terraces have an east-southeast to west-northwest alignment. Fresh cutting and excavation work at the sites revealed the presence of localized zones of underground shearing, strike-slip faults, erosional surfaces, paleochannels, slickensides and different types of structural deformation and near-surface fractures. Detection and location of these features has become one of the major tasks in road and building construction and maintenance (Batayneh and Al-Diabat, 2002; Batayneh and Al-Zoubi, 2000; Batayneh et al., 1999; Smith, 1986).

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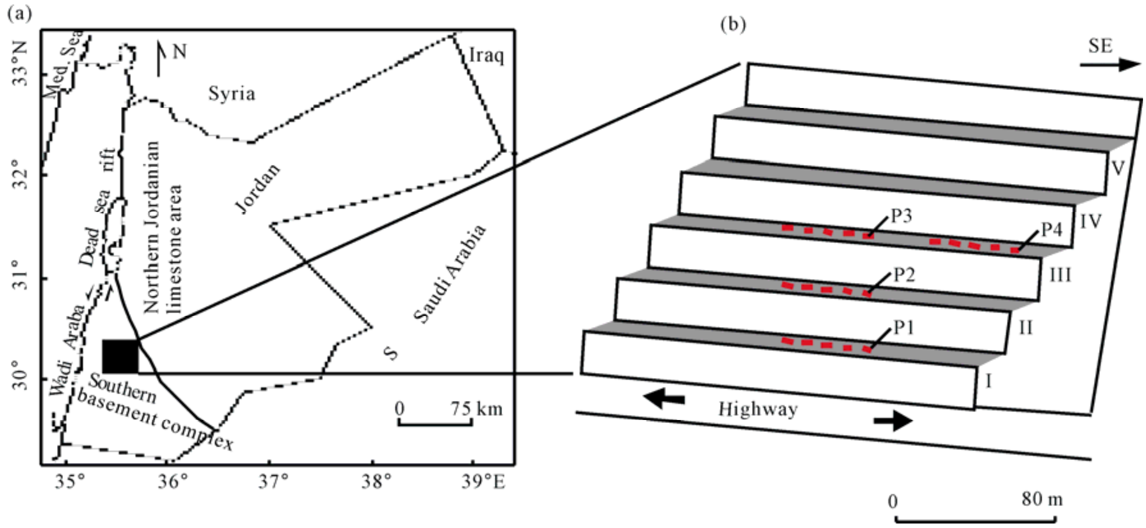

Figure 1. (a) Site map of the study area; (b) locations of the four GPR lines (P1–P4) in Ras en Naqab area.

From a geological point of view, and during the Late Cretaceous Period, a major transgression of the Tethys Ocean resulted into carbonate facies deposition of the Ajlun Group (Cenomanian–Turonian) throughout Jordan. The rocks of this group, which disconformably overlies the Kurnub sandstone group of Lower Cretaceous age (Barjous, 1995), consists of the Na'ur limestone (NL), the Fuheis/Hummer/Shueib (F/H/S), and the Wadi Es-Sir limestone (WSL) formations. The base of the Ajlun group comprises siltstones and mudstones up to 10 m thick. These members form a transitional zone at the base of the NL Formation. Generally, NL Formation contains three horizons; the upper and the lower consist of massive, hard carbonate units each up to 20 m thick (Batayneh and Barjous, 2003), while the strata interbedded between these units comprise alternating thin beds of marl, dolomite and sandstone. The overlying marl, limestone, dolomitic sandstone, siltstone-mudstone, claystone and sandstone beds are equivalent, in upward sequence, to the F/H/S formations (Cenomanian–Lower Turonian). At the studied site, these formations are about 50 m thick (Batayneh and Barjous, 2003). The WSL Formation of the Turonian age is about 100 m thick and dominantly consists of massive dolomitic limestone. At the base it is composed of massive sandy dolomitic carbonate beds intercalated with marly limestone, silty mudstone and nodules of chert. The upper part of this formation is composed of a massive to bedded sandy and dolomitic limestone. Figure 2 shows a stratigraphic column from the studied site (after Batayneh and Barjous, 2003).

In the present study, we present results of ground penetrating radar (GPR) technique application to investigate subsurface geology in terms of environmental and engineering application. The study was performed at the Ras en Naqab escarpment area, southwest Jordan, in the winter of 2012. This site has a large existing geological data base, and thus is ideal for GPR technique in detecting and locating potential geologic features.

2 GENERAL PRINCIPLES AND DATA ACQUISITION

GPR is an electromagnetic profiling technique utilized for high resolution mapping of subsurface features. GPR technique has been used in geological (e.g., Carrozzo et al., 2003; Nobes et al., 2001; McMechan et al., 1998), hydrological and hydrogeological studies (e.g., van Overmeeren, 1998; Beres and Haeni, 1991), in aquifers investigations (e.g., Arcone et al., 1998), water contamination (e.g., Benson, 1995; Daniels et al., 1995; Annan et al., 1991), geotechnical engineering (e.g., Batayneh et al., 2002; Barnhardt and Kayen, 2000; Birken and Versteeg, 2000; Saarenketo and Scullion, 2000), and in archeological investigations (e.g., Bonomo et al., 2009; Imai et al., 1987; Vaughan, 1986).

In the GPR technique, a short pulse of high frequency (10–1 000 MHz) electromagnetic energy is transmitted by the antennae through the ground surface and then receives its reflection from boundaries between layers or from internal irregularities of different electrical properties. The amount of energy that is reflected back to a radar antenna by an interface is dependent upon the contrast in the relative dielectric permittivity (Er) of the two layers. Abrupt boundaries that separate contrasting materials reflect more energy than gradual boundaries that separate materials with similar Er. The Er of soil materials is principally dependent upon moisture content (Buynevich and Fitzgerald, 2003; Annan et al., 1991; Beres and Haeni, 1991) and varies with temperature (phase-dependent), density, and antenna frequency (Denizman et al., 2010; Daniels, 2004). The reflection is detected on the surface, and the time between transmission and detection at the surface is proportional to depth. The depth of penetration of a GPR system is highly site specific and is limited by attenuation of the outgoing pulse. The velocity of the GPR is dependent on a degree of saturation and hence recent rainfall patterns. Generally, greater penetration is obtained in dry, sandy, and rocky soils and little penetration is obtained from moist, clayey conductive soils (Batayneh et al., 2002; Wolf et al., 1998; Liner and Liner, 1997; Cai et al., 1996).

The GPR survey layout at the Ras en Naqab site was constrained by GPR cable length and accessibility problems of the upper levels due to difficult terrain, so the lower three levels (I through III, Fig. 1b) were used for survey layout. A total of