Chapter 4

GEOPHYSICAL INVESTIGATIONS

Since excavations were renewed at el-Wad in 1988, a number of geophysical investigations have been carried out whose purpose was twofold: to enable a reconstruction of the subsurface topography of the cave and to arrive at an estimate of the depth of the archaeological layers in Chamber III and in those areas of the cave that have not yet been excavated or tested, i.e., Chambers IV and V (in Chamber VI the bedrock is exposed). Two geophysical methods were employed: seismic refraction (Weinstein-Evron et al., 1991) and Ground Penetrating Radar (GPR) (Beck and Weinstein-Evron, 1997), which enabled cross-checking and validation of the data, thus making for more reliable results .

Seismic Refraction

The seismic refraction survey of el-Wad (Weinstein-Evron et al., 1991) consisted of 10 profiles (Fig. 26). Energy source was a 5kg hammer on a metal plate and receivers were 24 geophones with an internal frequency of 10Hz, arranged in 24 channels.

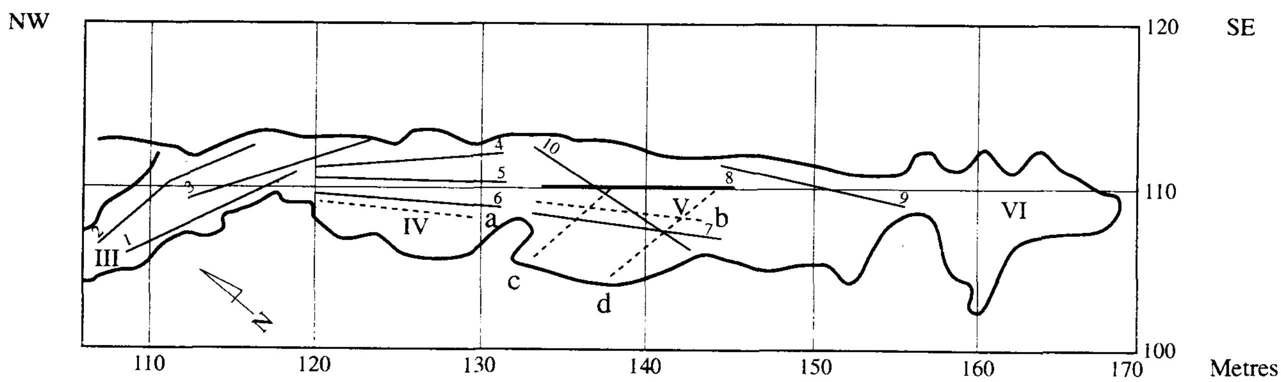

Fig. 26. Layouts of seismic refraction (_____) and GPR (- - - - -) profiles in el-Wad Cave. Coordinates are reference grid in metres.

To achieve high resolution, spacing between the geophones was kept to 0.5m. Shooting was done at both ends of the profile, i.e., where the external geophones were placed, and supplementary shooting was run at split profile configurations, where the energy was released in the centre of the profile.

Data processing was originally carried out according to the GRM method (Palmer, 1980), a procedure which guarantees reliable solutions of complex features, such as irregular configuration of seismic refractors, variable interval velocities or steeply dipping refractors. Reprocessing of the original data, using software introduced by the Institute for Petroleum Research and Geophysics (IPRG; Holon, Israel), and based on the same GRM method used before (Palmer, 1980), was done recently for selected profiles in Chambers IV and V. Both reprocessing and subsequent reinterpretation procedures have led to more reliable and refined results. These newly drawn profiles are dealt with in the following discussions. Introduced into the procedure was some basic input derived from geological and archaeological observations, such as the lithology of the underlying rock unit.

The original seismic refraction survey encountered two separate lithological layers easily distinguishable because of the varying seismic velocities that were obtained for them, the upper layer showing seismic velocities of 500 to 750m/sec, while in the second layer these range from 2140 to an anomalously high 2550m/sec. Even higher seismic velocities, exceeding 3000m/sec, were encountered at the northern edge of the surveyed part of the cave. At this stage it is difficult to determine whether these high velocities are associated with lateral lithological variation in the bedrock or with a sub-outcrop of a deeper geological layer. The slower seismic velocities in all likelihood point to unconsolidated sedimentary fill while the faster ones probably indicate bedrock.

The seismic profiles (Fig. 27) were set to measure the thickness of the upper sediment layer in three segments, corresponding to Chambers III, IV and V. The first segment (Chamber III, profile 1, Fig. 27a) is characterized by steep slopes and numerous outcrops of probable bedrock. The profiles suggest sediment thickness of less than one metre, deepening to the south, and anomalously high seismic velocities in the bedrock. The lack of readings towards the north can be explained by the fact that since this area had been excavated by Garrod only thin relics of lithified breccia were left containing archaeological remains adhered to the exposed bedrock. Moreover, that it would be difficult to interpret this segment was expected because parts of the profiles had been measured along recently excavated areas, which had somewhat distorted the natural configuration of the surface. Because of these problematics we have chosen not to reprocess the data obtained from this segment, and the profile in Fig. 27a is the original one (Weinstein-Evron et al., 1991).

The reprocessing of the second segment of the survey (Chamber IV, spread 4, Fig. 27b) enables the identification of three layers. The upper layer, 0.5m thick, with a velocity of 380m/sec, can be interpreted as consisting of loose material of unconsolidated fill. The second layer, with a seismic velocity of 1050m/sec and thickness varying between 1 to 3m, probably represents a more compacted, unconsolidated fill. At the base of the second layer lies carbonatic bedrock, the third layer, with a velocity of 2550m/sec and an irregular surface, revealing a large pit in the centre of the structure. There is a shallowing of the surface of the bedrock layer toward the interior part of the cave.

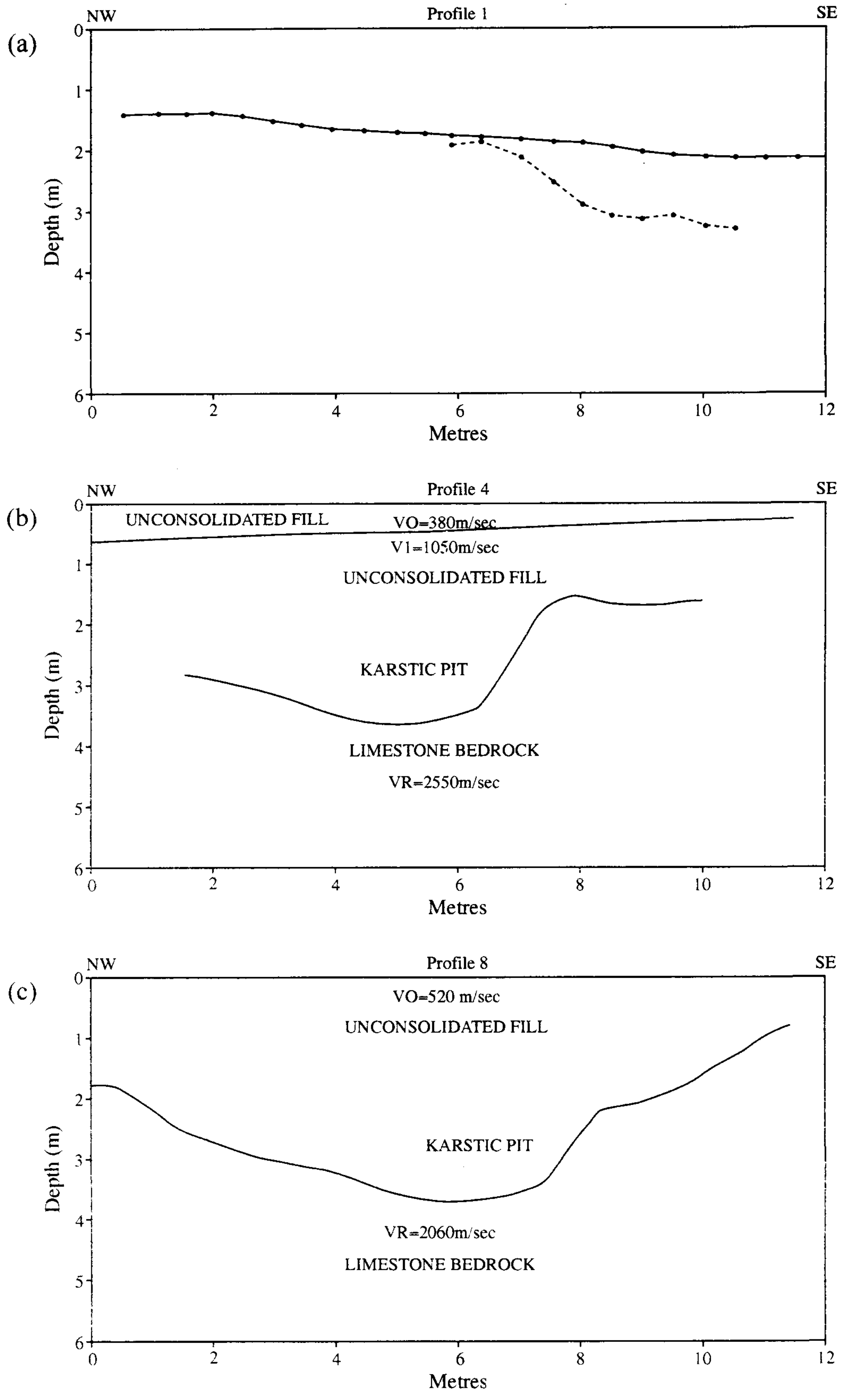

Fig. 27. Interpreted seismic refraction profiles in el-Wad Cave, showing measured depth below surface (see Fig. 26 for location): (a) represents the original interpretation (Weinstein-Evron et al., 1991); (b) and (c) are reprocessed.

The third segment surveyed is Chamber V. Profile 8 (Fig. 27c) represents this part of the corridor, showing two layers. Seismic velocity of the first layer is 520m/sec, interpreted as unconsolidated fill. The underlying bedrock shows a seismic velocity of 2060m/sec. Thickness of the sedimentary fill exceeds three metres and the microtopography of the sediment/rock contact surface seems irregular, with a large pit in the centre of the chamber. At the southern edge of the chamber measurements show a shallowing of the bedrock layer whereas further southwards the Cenomanian bedrock crops out.

Ground Penetrating Radar

In October 1994 a Ground Penetrating Radar (GPR) survey was conducted to interpret the subsurface configuration and to correlate the new findings with the results of the earlier seismic refraction surveys (original and reprocessed).

Profiles were located as close as possible to the seismic refraction profiles in Chambers IV and V (Fig. 26), but because a path (of concrete) had meanwhile been laid down for visitors, not in all cases could the exact same tracks be followed. Because the layout of the GPR profiles was restricted to the open spaces left in the relevant chambers, only Chamber IV and V could be surveyed for GPR analysis.

The GPR method is based on electromagnetic waves that are transmitted into the subsurface through an antenna. The centre frequency used in this case was 500MHz. Much like seismic refraction, electromagnetic waves are reflected from interfaces between layers. Here, however, reflections are caused by differences in the electrical properties of the layers, mainly the dielectric constant — the greater the difference the higher the amplitude of the reflection signal. The attenuation of electromagnetic waves in the subsurface is also a function of the centre antenna frequency and the conductivity of the subsurface materials: the greater the centre frequency and the conductivity the higher the attenuation of the electromagnetic signal.

The GPR survey in el-Wad consisted of four profiles each between 8 and 15m long (Fig. 26). A GSSI-10 system, with antenna frequency of 500MHz, was used. The GPR sections are presented in coloured line scan format (Figs. 28, 29), where low amplitudes are brown-red and high amplitudes are yellow-blue.

The first GPR section (Fig. 28) was carried out in Chamber IV, overlapping seismic refraction spread 6 (Fig. 26) and c. 2-4m south of spread 4. The surface is clearly marked in black-purple at the top of the section. The undulating black marker at a depth of 2-3m below surface indicates the bottom of the unconsolidated fill or the top of the bedrock. The bedrock itself is characterized by high amplitude (blue-purple) signals. As expected from the layout of the geophysical profiles, the first GPR spread (a) accords well with seismic refraction spread 6 (Weinstein-Evron et al., 1991). However, reprocessing of the seismic refraction data could be performed only on spread 4, due to the geometrical parameters of the field acquisition. Thus, this spread is used for comparing the two sets of data. The structure of the subsurface is quite similar to that indicated by the seismic-refraction spread 4 (Fig. 27b), with discrepancies no larger then 0.5-1m. The base of the pit lies at a depth of 2.5-3m, as indicated by the calculated dielectric constant value of $\varepsilon r = 9$.

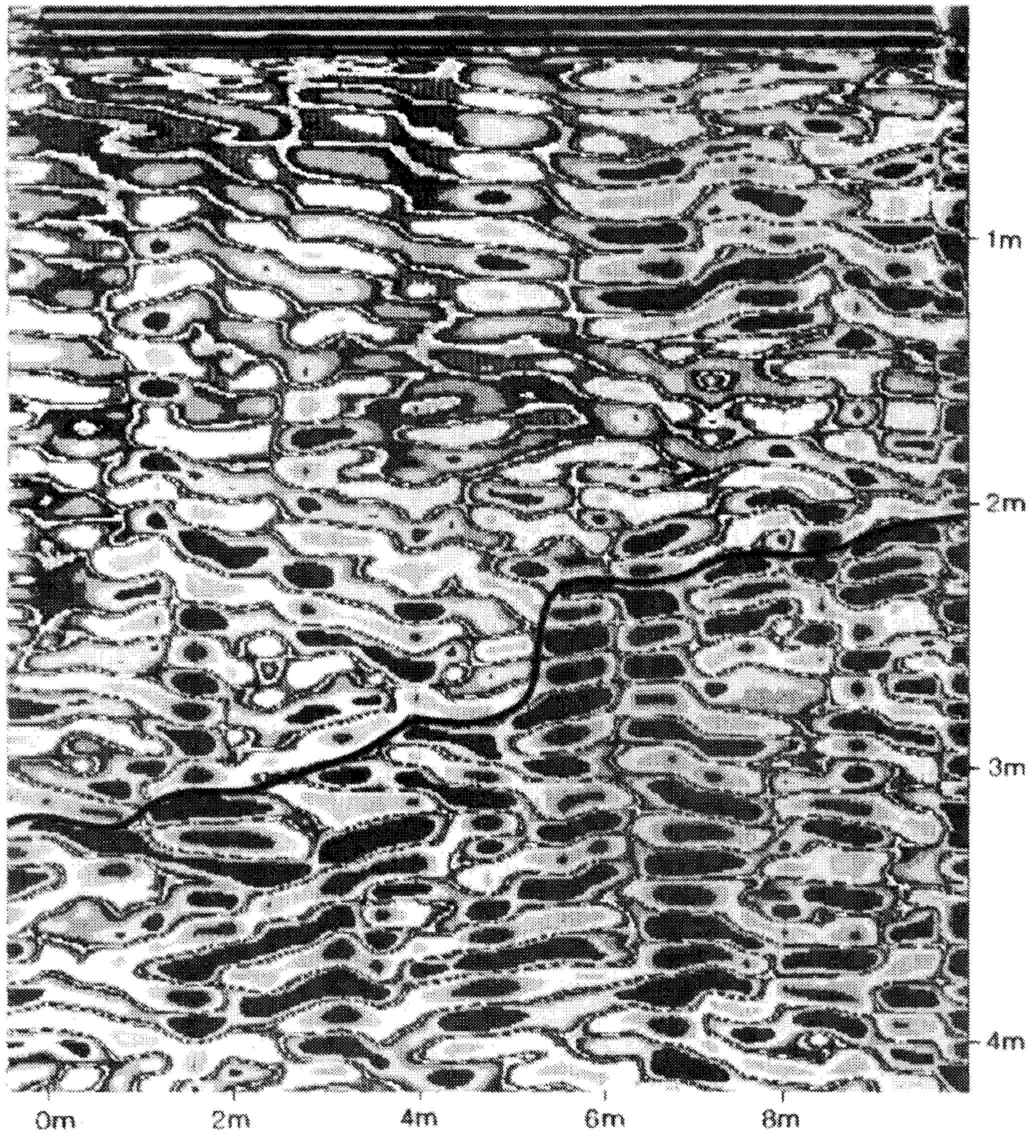

Fig. 28. GPR spread a, Chamber IV.

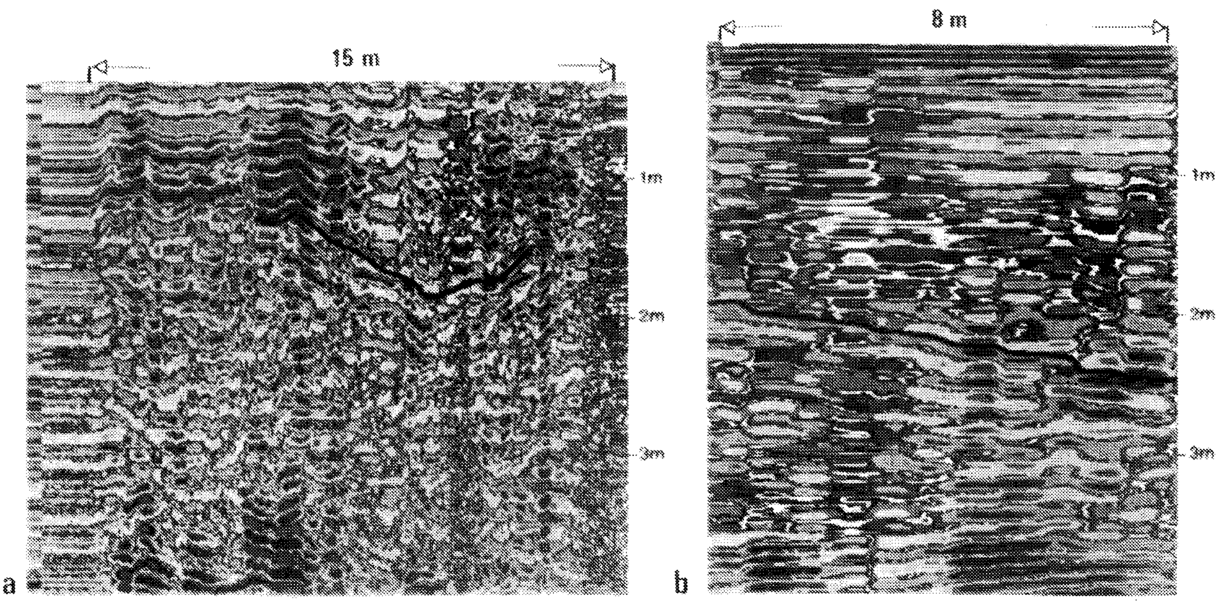

Fig. 29. (a) GPR b, Chamber V; (b) GPR spread d, Chamber V.

The second GPR section (Fig. 29a) was carried out in Chamber V. It is a NW-SE section, parallel to, and in very good concordance with, seismic refraction spread 7 (Weinstein-Evron et al., 1991). This section is compared to the reprocessed profile 8, 1-2m to the east, for the same reasons mentioned above. The black marker is interpreted as the base of the unconsolidated fill, and shows thc boundaries of the karstic pit quite clearly. The maximum depth of the bedrock surface is at 2-2.5m, about 1m less than the interface marker calculated for refraction spread 8. Such discrepancies may be explained by the 1-2m difference in the localities of the sections.

Two further GPR sections, each 8m long, were carried out in Chamber V semi-perpendicularly to the main profile (Fig. 26). The two sections exhibit very similar trends and only GPR spread d is given in Fig. 29b. These sections show dipping layers at a depth of 2-3m. The direction of the dip is W-E, indicating clearly that the structure is deepening towards the centre of Chamber V, which confirms the possible existence of a karstic pit there.

The seismic refraction survey suggests that the thickness of the sediment fill ranges between c. 0.5-3.5m. The 500-600m/sec seismic interval velocity range suggests dry, unconsolidated cave fill. On the other hand, moisture or lithification may be associated with locations where faster velocities were encountered. The more shallow deposits were found closer to the walls of the cave, while thicker layers were encountered along the axis of the cave.

A relatively shallow depression was found in the southern part of Chamber III. That there may be a pit here is also suggested by the tilting of the archaeological layers that was observed in the recent excavations. Another deepening, reaching a depth of two meters below surface, and oriented W-E, was found in Chamber IV. The most impressive pit, attaining a depth of nearly four meters, was encountered in the centre of Chamber V. Shallowing of the bedrock was measured further southwards, and the Cenomanian bedrock crops out at the southern tip of the cave (Fig. 27c).

The GPR profiles for Chambers IV and V correlate well with the seismic refraction sections of the same areas of the cave, both indicating deep pits in the two Chambers. Taking all the profiles together, the indications are of basin-shaped depressions in the two chambers. As mentioned above, the discrepancies in measurement results for the depths of the pits may be explained by the fact that the compared spreads could not be laid on the same lines exactly. The seismic refraction sections show the largest depth values probably because they were taken more in the centre of the chambers where the pits are deepest. The additional, semi-perpendicular spreads in Chamber V also indicate a dipping of layers towards the centre of the chamber.

As already mentioned, the occurrence of pits in the cave is corroborated by the occasional tilting of the archaeological layers, as brought to light by the recent excavations of Chamber III. That such pits, or swallow holes, evolved may have much to do with the karstic origin of the cave. An immense pit, at the bottom of which were two swallow holes of unequal depth, had already been unearthed in the outer chamber (Garrod and Bate, 1937: Plate III, Section VII-VIII). Similar pits or swallow-holes were found in the neighbouring Tabun (Garrod and Bate, 1937) and Jamal (Weinstein-Evron and Tsatskin, 1994) caves, and are common as well in other caves in the area, such as Kebara (Laville and Goldberg, 1989). The size of the chambers and the depth of the pits seem to be positively correlated.

The thickest sedimentary fill was found in Chamber V. Going by the results of former investigations in el-Wad and other caves, this is where we may expect to find the oldest archaeological layers, provided prehistoric people did make use of the inner parts of the cave which are immersed in almost total, perpetual darkness.