15 Quaternary Evolution of Caves and Associated Palaeoenvironments of the Southern Levant

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15.1 INTRODUCTION

Caves are extremely heterogeneous in morphology and development. The most studied ones are large, integrated conduit systems in wet regions. Their morphology has been used in some cases as a tool to identify the hydrologic setting under which cave formation took place (Ford & Williams 2007; Palmer 2009; Frumkin & Shroder 2013). Caves can also act as time-capsules, preserving within their voids geologic, biological, anthropogenic, and chronological records of the Quaternary in regions where erosion often destroys other evidence (e.g. Bar-Yosef & Kra 1994; Goldberg, Chapter 16, Bar-Matthews *et al*., Chapter 17, and other chapters in this volume).

In addition to being a terrestrial bridge between Asia and Africa (Fig. 15.1), the Levant is unique in its wide variety of caves over contrasting climates across the desert and Mediterranean ecotones. Consequently, both the natural evolution and anthropogenic attributes of the caves are different from other regions.

To focus on the Quaternary evolution of caves, the age of the voids and their fillings should be determined, where possible.

15.2 THE AGE OF EARLY EVOLUTION OF CAVES

15.2.1 PRIMARY CAVES

Primary caves are formed coeval with the rock surrounding them. They can be precisely dated by dating the enclosing bedrock. The most important type is the lava tube, also termed pyroduct, formed almost instantaneously during the emplacement of lava (Kempe 2013). The largest volcanic region of the southern Levant is Harrat Ash-Shaam (Weinstein & Heimann, Chapter 5 of this volume), covering parts of Syria, Jordan, Israel, and Saudi Arabia. Several lava tubes are known in its northeastern area, the Hauran; all of them are thought to be of Quaternary age (Razvalyaev 1966; Kempe *et al*. 2006; Tawk *et al*. 2009). Within this volcanic region, Harrat El Fahda basalt field of northeast Jordan (Ibrahim & Al-Malabeh 2006) is one of the most recent (~0.46±0.01 Ma; Tarawneh *et al*. 2000; Ilani *et al*. 2001) harrats of the Arabian plate. This is also the estimated age of the Khsheifa lava tube, formed within this basalt field (Frumkin *et al*. 2008) (Fig. 15.2). A Holocene 20.5 km long lava tube system has been identified in southern Syria (Frumkin 2016). Naturally, calcite speleothems deposited within such a cave are younger than the cave, as they are in karst caves.

A second type of primary cave is hollows formed in tufa or travertine sediments during deposition. These can also be potentially dated by determining the age of the enclosing calcitic bedrock. Such dating is yet to be attempted in the southern Levant. A unique cave of this type at Ein Gedi (Israel) is at least 2,700 years old, based on an Iron Age rupestrian inscription (Porat *et al*. 2015).

15.2.2 SECONDARY CAVES

Most caves in the Levant are secondary, i.e. formed after or mostly long after deposition of the rocks containing them. Of these, most Levant caves were formed by karstic dissolution within dense carbonate bedrock, whose depositional age is commonly Mesozoic to Eocene. Marly beds within the carbonate rocks retard early speleogenesis (cave formation) (Fischhendler & Frumkin 2008; Palmer 2009). The larger southern Levant caves are associated with long-lasting confinement and hypogenic flow (Frumkin & Fischhendler 2005; Klimchouk 2013; Frumkin 2015).

Dating such caves is difficult, and may be possible only if a feature relating to their early speleogenesis can be dated. The caves often contain pre-Quaternary sediments (Lisker *et al*. 2010), but dating these deposits commonly produces just a minimum age for the void. Three independent lines of evidence indicate speleogenesis (long?) before the Quaternary:

(1) The oldest age, 3–3.5 Ma, of vadose speleothems in Israel was determined using U–Pb on samples from Ashalim Cave and Ktora Cracks (Vaks *et al*. 2013). These speleothems were deposited on top of the host rock, indicating deposition following emergence of the cave above the water table.

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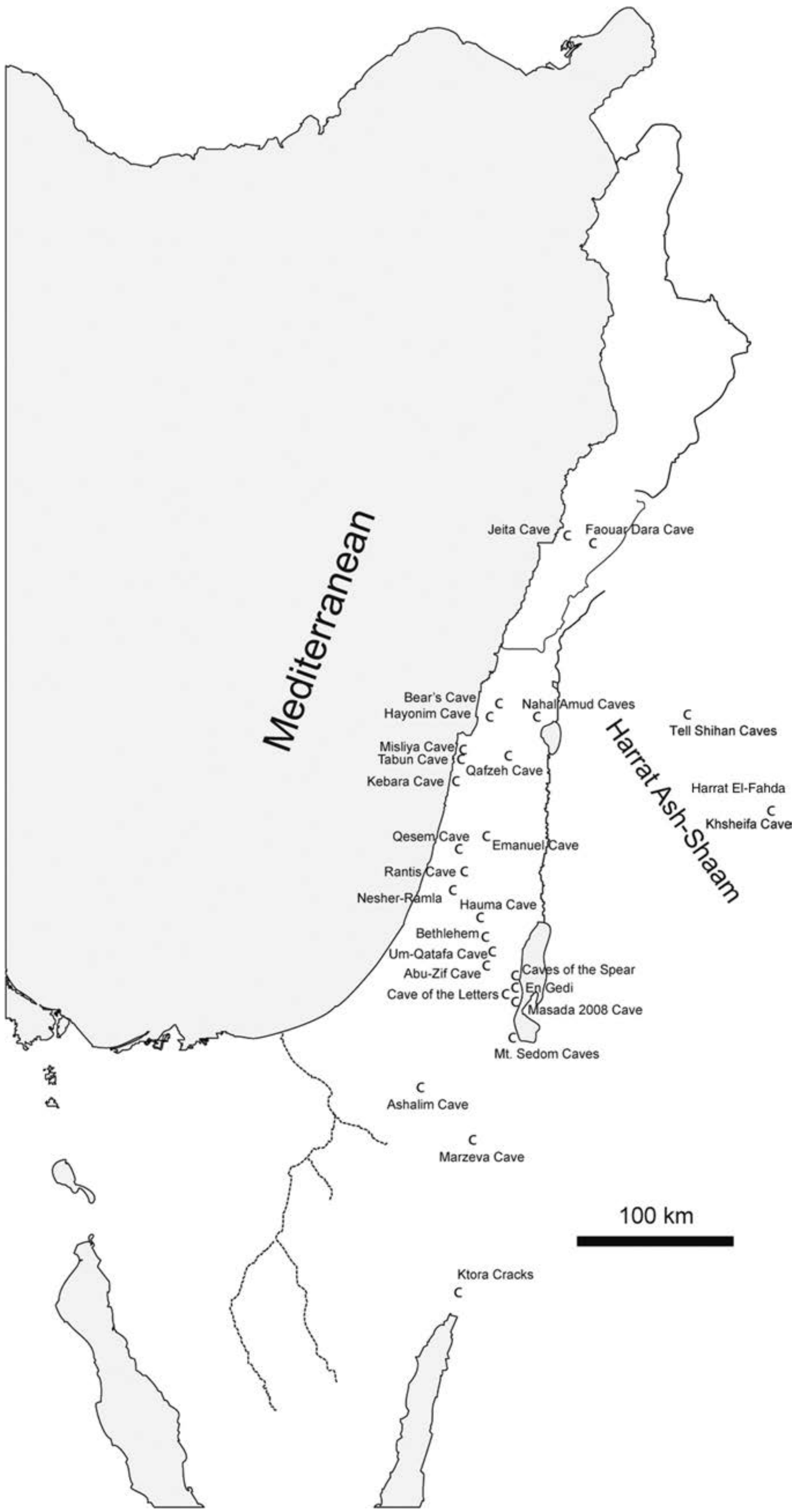

Figure 15.1 The southern Levant with sites mentioned in the text.

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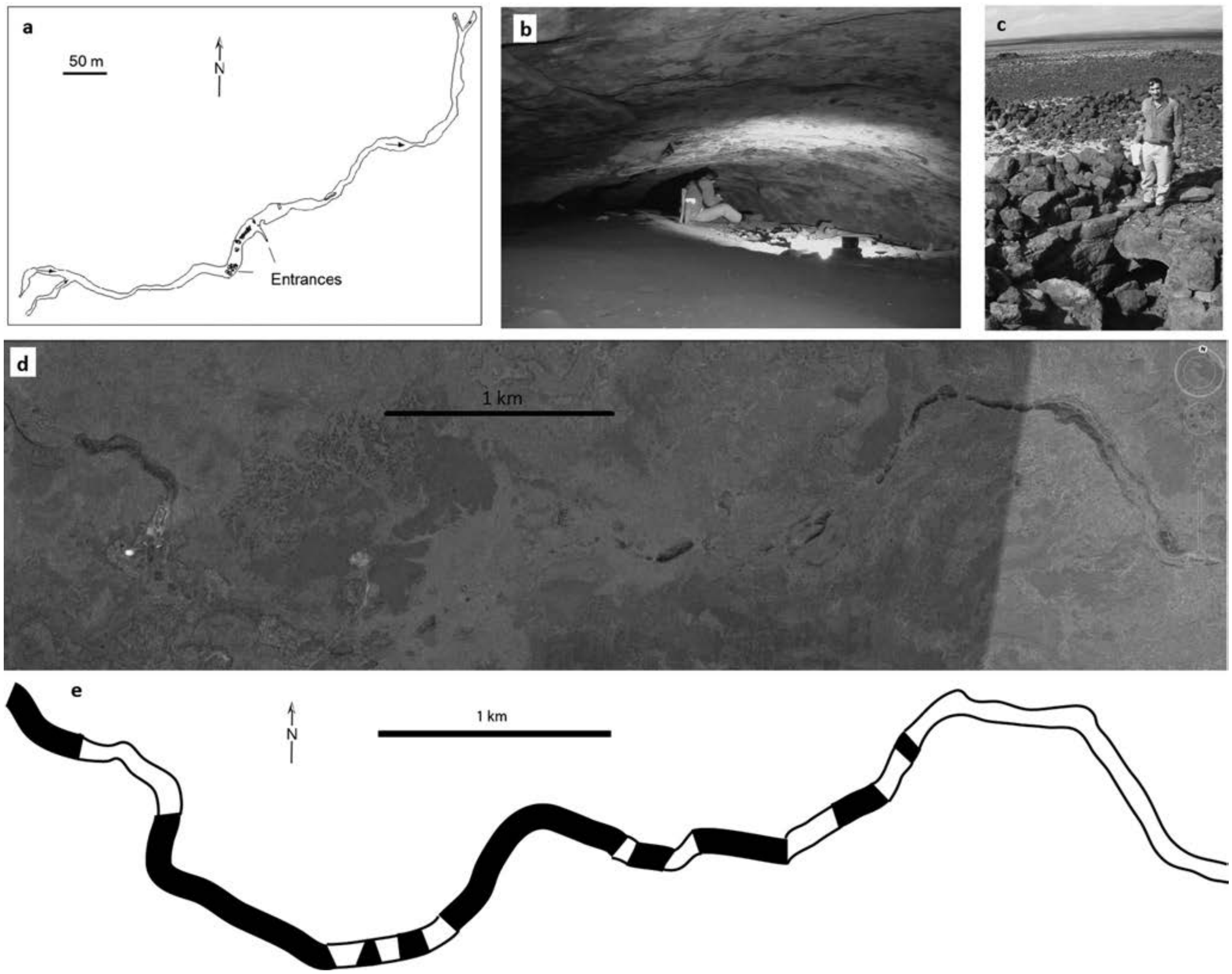

Figure 15.2 Lava tube systems are the largest Quaternary-age caves in the Hauran, eastern desert of the southern Levant. a: Plan of Khsheifa Cave lava tube in El-Fahda lava of Jawa, Jordan (modified from Frumkin *et al*. 2008, survey by Israel Cave Research Center). b: Central part of Khsheifa Cave: the original basalt ceiling is intact, while intruding run-off gradually fills the bottom of the void with fluvial loess. Striped hyaena (*Hyaena hyaena syriaca*) introduced bones and coprolites (illuminated) (photo: A. Frumkin). c: Collapsed ceiling, termed 'cold puka' (bottom), of Khsheifa Cave provides the main entrance which allows run-off to intrude the cave (photo: A. Frumkin). d: Google Earth view of the largest lava tube system in the southern Levant, which carried late Quaternary lava from Tell Shihan volcano westward, southern Syria (Razvalyaev 1966). e: Schematic plan of the Tell Shihan lava tube system, showing collapsed sectors (white) versus intact parts (black). The width is exaggerated (surveyed from Google Earth by A. Frumkin).

(2) Burial ages obtained using cosmogenic isotopes of allochthonous fluvial sand and silt at the Judean Desert Cave of the Letters and Masada 2008 Cave are 3.6–3.4 Ma. They indicate initial relief and incision of canyons flowing into the Dead Sea shortly before this time, cutting through the pre-existing caves (Frumkin 2001a; Matmon *et al*. 2014; Matmon & Zilberman, this volume).

(3) Terrestrial megafauna fossils filling a collapsed cave at Bethlehem, Judean Mountains, were correlated with Villafranchian (3.0–2.0 Ma) faunal assemblages in Eurasia (Hooijer 1958; Belmaker, Chapter 41 of this volume). Similar to the previous cases, the cave must have been developed and destroyed not later than the early Pleistocene.

These five caves at central to southern Israel were elevated above their respective water table (at least) during the Quaternary. Similarly, the present positions of most known caves that originally formed below the water table are now up to hundreds of metres above the water table. Many caves are located high above local or regional base levels, indicating intensive tectonic and geomorphic activity since their development. For example, the 'Caves of the Spear' (Fig. 15.3) are located today high in the Dead Sea western escarpment, 480 m above the Dead Sea shore (Porat *et al*. 2009). The lack of any genetic connection between these caves and the Dead Sea Transform indicates that most of these caves had already been formed before the development of the Dead Sea escarpment, which started to develop during the Miocene (e.g. Frumkin 2001a;

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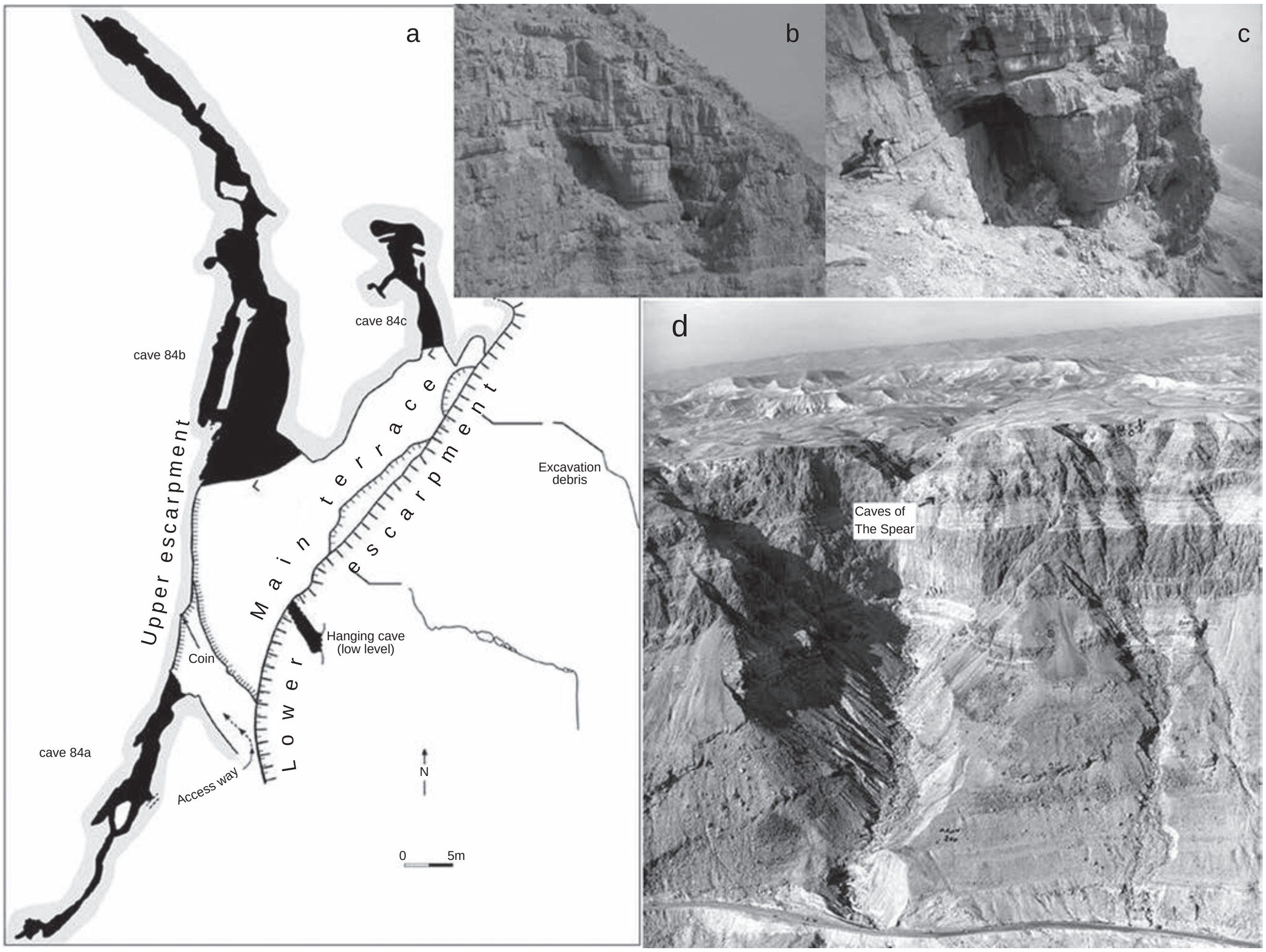

Figure 15.3 Caves of the Spear, Dead Sea western escarpment, modified after Porat *et al*. (2009). The pre-Quaternary maze cave system formed below the ancient water table is gradually destroyed by surface erosion following the downfaulting of the Dead Sea depression. a: Plan showing collapsed sectors of the cave (main terrace, white) versus uncollapsed parts (black) (survey: R. Porat). b: The entrances of Spear Caves 84b and c within the vertical escarpment undermined by a nearby wadi. The upper right slope is the fault escarpment beyond the influence of the wadi (photo: R. Porat). c: Spear Caves 84b and the collapsed part, now forming the main terrace (foreground, note persons for scale) (photo: R. Porat). Oblique air photograph showing the Caves of the Spear hanging ~480 m above the Dead Sea (bottom road runs along the shore). The canyon in the centre increases gravitational erosion of the caves.

Matmon *et al*. 2014; Frumkin 2015; Matmon & Zilberman, this volume). These caves must have ceased to expand well before the Quaternary. During the Quaternary they have experienced mostly aging processes, such as filling, destruction, or formation of sinkholes into lower levels.

15.3 PROCESSES IN AGING CAVES

The type and rate of aging processes depend on the type of cavity and its evolutional stage, its connection with the surface, and subaerial environments.

The morphology of most caves in the drier parts of the Levant indicates that: (1) they had been formed under the water table; (2) the caves can be termed ‘isolated caves’, i.e. while forming they were not connected by a major opening to the surface – rather, they were connected to the surface only via tiny flow routes (less than ~5 mm wide), supporting diffuse, laminar flow (Frumkin & Fischhendler 2005); (3) the isolated caves were formed by a local boost of aggressivity in the groundwater within the saturated zone, without achieving a hydraulic breakthrough to the surface input or output of the water (Frumkin & Gvirtzman 2006).

Such isolated caves are also modified by natural processes after emergence above the water table. However, at this stage these processes commonly tend to fill and destroy the cave, and only rarely do they continue to expand within the vadose zone. The time range for final destruction of a cave and its traces depends mainly upon the original depth of the cave and subaerial denudation rate.

For the Mediterranean zone of the southern Levant, the regional long-term denudation rate is ~21±7 mm ka^{-1} (Ryb *et al*. 2014; Matmon, Chapter 46 of this volume). Assuming this rate for the 2.6 Ma of the entire Quaternary, a total denudation of ~55 m

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would destroy and remove most caves that were within a few tens of metres from the surface at the Plio-Pleistocene transition. Therefore, the surviving caves in the Mediterranean zone may have formed deeper below the surface, depending on their age. Indeed, the caves still existing in the desert zone of Israel, where denudation rate is low, are generally larger and more abundant than those in the Mediterranean zone (Frumkin & Fischhendler 2005; Frumkin 2015). However, other factors may influence the abundance of existing voids, such as the original hydrogeologic conditions during speleogenesis.

Autochthonous sediments, common in unbreached caves, mainly comprise residual clay, decomposed fragments of the walls and ceiling, as well as speleothems. These speleothems serve as important archives for palaeoenvironmental reconstructions (e.g. Bar-Matthews *et al*., this volume). The age of some speleothems is used to date associated archaeologic finds (e.g. Barkai *et al*. 2003; Gopher *et al*. 2010).

Allochthonous fills in southern Levant caves, common in caves which are well-connected to the surface, are mostly associated with gravitation, water, wind, or biological or anthropogenic agents. Fluvial deposits are common in river caves, which are common in the wetter regions of northern Levant, from Mt Lebanon northward. A special type of river caves with abundant fluvial deposits is the salt caves of Mt Sedom (see below; Frumkin 2013). Biogeochemical processes affect caves even before they are breached by subaerial erosion. After an opening to the surface is established, biogenic and anthropogenic processes commonly increase, combined with other natural processes. As the cave entrance enlarges, the variety of sediments and the rate of filling by allochthonous sediments commonly increase, depending on the relative role of intruding colluvium, alluvium, and aeolian sediments and biogenic-anthropogenic agents. When the cave is close to the surface, it becomes prone to destruction by collapse of the thin ceiling or by hillslope retreat.

Cave sediments are commonly inclined and deformed. The deformation may be associated with several causes, such as their initial depositional dip; subsidence and sagging into deeper voids; collapse of cave roof; introduction of subaerial materials through an upper entrance; internal irregular accumulation and deformation processes; tectonic deformation; seismic tilting and collapse; diagenetic chemical processes; gravitational compaction of loose sediments or of partly dissolved material. Many of these processes are controlled by gravity. Some affect only the internal cave sediments, while some gravitational deformations affect the bedrock skeleton of the karst system as well.

In the case of an archaeological cave, these processes usually affect diagenesis, geometry, distribution, and interpretation of archaeological finds, so they must be seriously considered (Frumkin *et al*. 2009; Karkanas & Goldberg 2013; Goldberg, Chapter 16 of this volume).

The caves that we can enter today are those which have been breached by subaerial processes or by recent anthropogenic intervention, such as quarrying or construction. The anthropogenic breaching is ongoing rapidly as infrastructure is developed, so several previously unknown caves are discovered every year. These serve as confirming evidence for the initial isolation of similar caves which were breached naturally. Some newly discovered caves contain archaeological and archaeozoological evidence indicating previous opening to the surface, followed by blockage and re-opening of the entrance. Such modifications can indicate changes of surficial processes such as hillslope erosion and accumulation.

Ultimately, the life of a cave void ends by complete filling, or collapse, or both. While the void ceases to exist, the fill of pre-existing caves can be still excavated and studied. Until recently, prior to intensive construction works, such filled caves were rarely observed. An example is the mid-Pleistocene Bear's Cave in northern Israel (Tchernov & Tsoukala 1997). The remains of the cave, which was exhumed by natural subaerial denudation, included deposits of stalagmitic breccia and carnivore remains. However, such rare cases reported in the past do not reflect the true distribution of filled caves, as inferred by recent finds.

Recent construction works reveal filled caves at an ever-increasing rate. For example, during a few years of quarrying and construction works in the early twenty-first century, four filled caves (or collapsed caves) with mid–late Pleistocene archaeozoological and anthropogenic remains were discovered within an area of 35 × 10 km in southwestern Samaria (Barkai *et al*. 2003; Marder *et al*. 2011; Goder-Goldberger *et al*. 2012; Zaidner *et al*. 2013). Located on moderate hillslopes, these sites (respectively: Qesem, Rantis, Emanuel, and Nesher Ramla; Fig. 15.4) were not observed in the field or air-photographs before being artificially breached. This camouflaging of caves can be attributed to intensive colluviation during the late Quaternary, which completely filled the voids to their upper openings, eventually smoothing the overlying surface. The intensive alluviation is associated with severe environmental changes and anthropogenic interference causing rapid deterioration of vegetation and soil erosion during the late Quaternary (Frumkin *et al*. 2000; Bar-Matthews & Ayalon 2005; Enzel *et al*. 2008). The climate-dependence of these processes implies that they are more active in the Mediterranean zone than in the desert. In the desert, where soils are thinner on hillslopes, direct aeolian deposition in cave entrances may be more important than colluvial fill; still, unlike the Judean Desert and the western escarpment of the Dead Sea, the density of caves in the Negev is small.

The filling rate of an open cave depends largely on its relation to the adjacent surface. Rapid filling by colluvium is favoured in a cave with a large opening located on a hillslope. On the other hand, caves with a small or horizontal opening, e.g. Tabun and Hayonim, in a vertical cliff are relatively protected from colluvial filling. Such caves may support longer periods of hominin usage with thicker anthropogenic deposits compared with caves filled by colluvium. A cliff also protects the cave entrance from rainfall, wind, and direct sunshine. Consequently, most studied prehistoric caves are in cliffs, e.g. Abu Zif, Amud, Hayonim, Kebara, Misliya, Qafzeh, Tabun, Um-Qatafa (Hovers *et al*. 1995; Ullman 2013; Frumkin 2015; Ullman & Frumkin 2015; Ronen, Chapter 24 of this volume; Bar-Yosef *et al*., Chapter 26 of this volume). When denudation opens a hole or a chimney in the roof of such caves, the colluvial fill rate may increase and overshadow other fill processes (e.g. Tabun Cave; Ronen, this volume).

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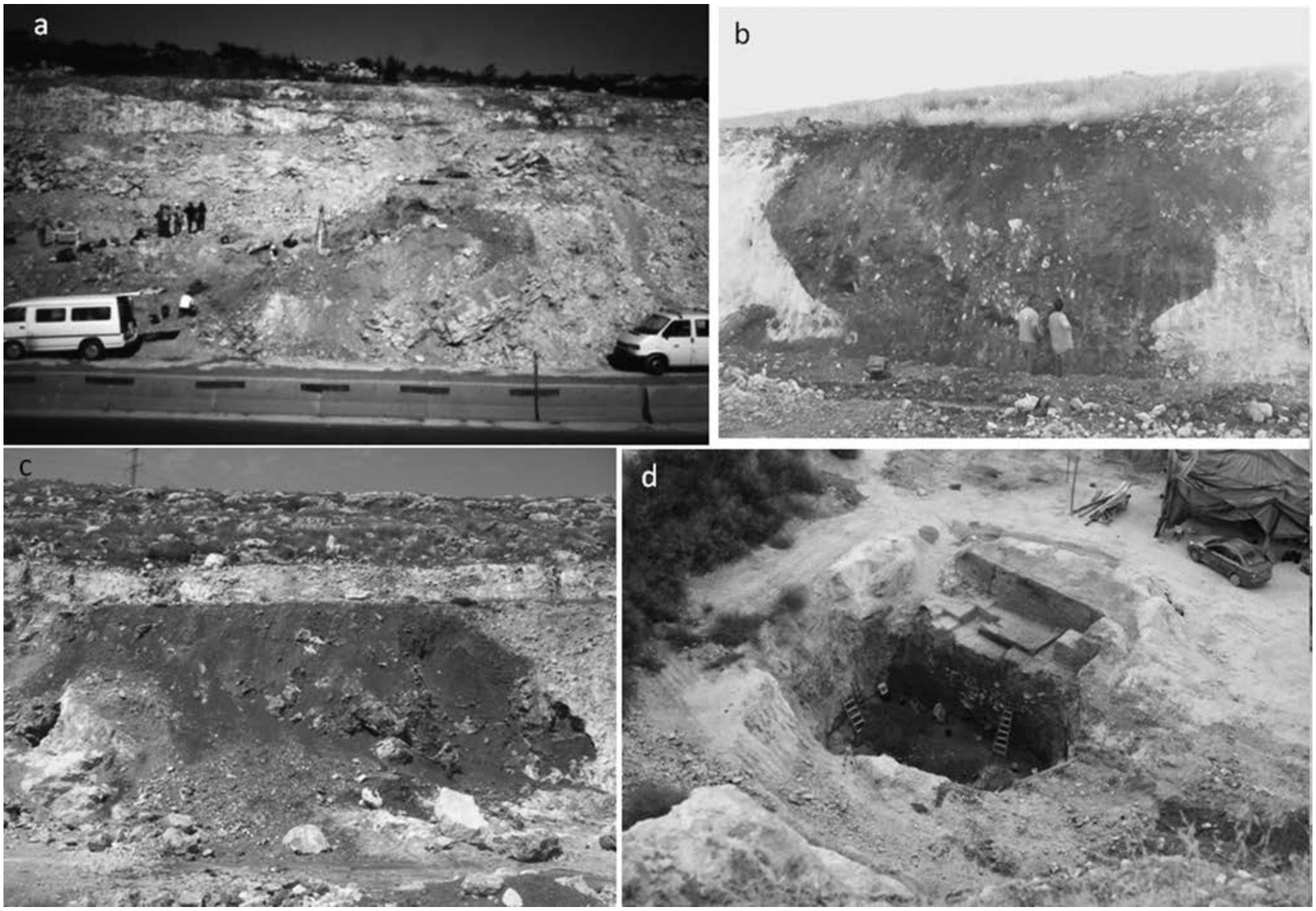

Figure 15.4 Four archaeological sites which have acted as voids during mid–late Quaternary, attracting hominins and/or animals. During the late Quaternary the voids were ultimately sealed by sediments, mostly of reworked terra rossa soils transported as colluvium. The surface around the sites has only thin soil remnants, an indication of erosion which transported the soil into the topographic sinks. The sites were exposed during early twenty-first century construction. a: Qesem Cave, photo by A. Frumkin (Barkai *et al*. 2003); b: Rantis Cave, photo by O. Marder (Marder *et al*. 2011); c: Emanuel Cave, photo by A. Frumkin (Goder-Goldberger *et al*. 2012); d: Nesher Ramla karst depression, photo by Y. Zaidner (Zaidner *et al*. 2013).

Caves with cliff entrances are prone to destruction by hillslope retreat and collapse, so the present area of the cave is smaller than during its occupation. Misliya Cave (Weinstein-Evron, Chapter 25 of this volume) has been completely destroyed by the retreat of western Carmel cliff since the middle Palaeolithic (Weinstein-Evron *et al*. 2012). Um-Qatafa and Amud caves have lost most of their ceiling area by collapse since their respective early and late Palaeolithic main occupation. In addition to hillslope-retreat, the susceptibility to collapse is controlled by several geologic factors, such as cavity size, as well as roof thickness, lithology, and fractures.

The archaeozoological/anthropogenic remains found in a cave reflect a relatively short time window in the evolution of the cave: it often starts with the first breaching of the void by erosion, ending when the cave is totally filled or destroyed.

Some caves continue to attract animals and hominins even after destruction by collapse of the ceiling. This can occur if the collapsed cave becomes a doline (karst depression) accumulating water or acting as a natural trap for animals. This has probably been the case for the Bethlehem (Shaw 1961), Rantis (Marder *et al*. 2011), and Nesher Ramla sites (Frumkin *et al*. 2014) (Fig. 15.4). Such natural traps can also be observed today (e.g. Langford 2015).

15.4 QUATERNARY SPELEOGENESIS: FORMATION OF NEW CAVES

Some caves are actively being formed or continue to enlarge during the Quaternary. The main speleogenetic agent is water. Therefore, currently forming caves increase in size, depth, and abundance towards the northwest of the Levant, with the increase of precipitation from the desert towards Mount Lebanon (Frumkin 2001b). Faouar Dara, the deepest Levant cave, and Jeita Cave, the longest one (Chabert 1974; Hakim & Karkabi 1988), are both in the western flanks of Mt Lebanon. Vadose caves are also favoured in the northwest Levant because of the thickening of pure limestone, particularly of Jurassic age. On the arid side of the environmental spectrum, large limestone caves hardly form during the Quaternary owing to aridity and the thinner, less pure carbonates which were deposited in regions seldom ingressed by the Tethys Sea. Known limestone caves

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are mostly pre-Quaternary hypogene systems, such as Marzeva Cave in the Negev. Locally, a change in morphogenetic type with relief is observed, from hypogenic and phreatic caves dominating in lower hills, to more vadose shaft caves in high plateaus (Frumkin *et al*. 1998).

Active Quaternary flow of water enlarges voids in the vadose zone. This occurs in river caves, vadose canyons, and vadose shaft systems, or a combination of these. The southernmost long limestone river cave is Hauma Cave under the city of Jerusalem (Langford & Frumkin 2013). Caves of this type are more common in the wetter karst of Lebanon (Hakim & Karkabi 1988; Karkabi 1990).

Active vadose caves are common in the extremely arid salt karst of Mt Sedom, Israel (Frumkin 2013). The high solubility of the salt allows the entire karst system to develop under the dry climate of the Holocene (Frumkin *et al*. 1991). The solubility and erodibility of the salt promote rapid evolution of the caves in spite of the rarity of the run-off events which enlarge them (Frumkin & Ford 1995). The falling Dead Sea level induces even faster developments of voids along the lake shores, associated with collapse and sinkhole hazards (Frumkin *et al*. 2011).

Below the vadose zone, caves continue to form during the Quaternary within the phreatic zone and close to the water table, but they are rarely accessible (Laskow *et al*. 2011). Quarrying has allowed insight into water-table caves at Nesher Ramla, at the border of the coastal plane, formed by rising sulfidic water (Frumkin & Gvirtzman 2006; Frumkin *et al*. 2014).

In addition to the above-mentioned cave types, other speleogenetic processes can produce small local caves, sometimes with archaeological importance similar to karst caves. Such processes include physical disintegration of granular rocks by sea waves (e.g. Ronen *et al*. 2008) or flowing vadose streams in erodible materials, termed piping (e.g. Porat & Frumkin 2015). Tectonic deformation can also open voids beneath the surface. Temperature variations or salt crystallization (e.g. Lisker *et al*. 2007) can form and erode cavities that are more common in desert environments. These are usually widely open to the surface, sometimes in the form of notches (Shtober-Zisu *et al*. 2015). Such rockshelters were often favoured for prehistoric human habitation as they provide light and some protection from the elements (wind, rain, and direct sunlight), while allowing free usage of fire (e.g. Ullman *et al*. 2013).

15.5 CONCLUSIONS

Quaternary evolution of caves in the southern Levant is intimately associated with environmental conditions. Large river caves form during the Quaternary in the wetter regions, such as Mt Lebanon. In the Judean Desert, Quaternary-age carbonate caves are commonly smaller, and in the Negev Desert they are rare, developing mainly by physical processes. Large caves formed during the Quaternary in the desert under specific conditions, e.g. salt caves in Mt Sedom, and lava caves in the Hauran of Syria and Jordan.

All types of known caves experienced some aging processes during the Quaternary, including filling, collapse, and ultimately destruction. Until total destruction, the caves serve as natural time-capsules, preserving natural and anthropogenic deposits, with some of the best palaeoenvironmental and anthropogenic records in the elevated areas of the Levant, where erosion often destroys surficial records.

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