

## Chapter 8

# Geoarchaeology and Karst: A New Perspective

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**Abstract** In the context of karst-related research, the multidisciplinary approach is necessary and the paradigms of the emerging field of geoarchaeology provide a new perspective for completing studies that contains the human-element. Research completed at the Cave of Letters (COL) and the Qumran Archaeological Site in Israel and on the Vaca Plateau in Belize, utilizes the multidisciplinary approach endemic to geoarchaeology. By creating a series of digital, updatable maps for the COL and Qumran, spatial trends in and relationships between the physical and cultural landscapes become apparent. Additionally, through the use of geophysics (ground penetrating radar (GPR) and electro-resistivity tomography (ERT)), an ancient living surface (the Bar Kokhba layer) was delineated in the COL, and potentially collapsed caves, that may contain archaeological remains, were located at Qumran. GPR also delineated possible grave sites at the cemeteries of Qumran. In Belize, petrographic analysis of rock samples determined that the physical landscape is dominated by limestone breccias, which are mostly depositional in origin. Comparison of these results, with data collected related to quarried and cut stones used to face structures at the Ix Chel Archaeological Site, suggested some stones were quarried locally but, due to the sheer number of stones required to build the site, dictates that other regional sources were required. The studies detailed in this chapter point to the need for continued karst-based research within the multidisciplinary realm of geoarchaeology, because this marriage only enhances the quest for new knowledge and understanding.

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## 8.1 Introduction

Multidisciplinary and cross-disciplinary research is becoming the norm rather than the exception in many disciplines, including karst-based research. By pulling together the elements of several disciplines into one research design, a new, fresh perspective can be gained as new information is added to the existing base of knowledge. With respect to karst-related research, it has always drawn from the basic paradigms of many disciplines (e.g., geography, geology, biology, geochemistry, geomorphology, geophysics, hydrology), which were often melded together under the banner of undertaking a “karst-based” research project. This is still the case, but the scope has been further broadened to include other disciplines and sub-disciplines such as history, anthropology, archaeology, human ecology, climate and paleoclimate, environment and paleoenvironment, resource conservation and management, and the use of emerging technologies such as remote sensing, geographic information system science, and new approaches in geophysics.

Over the last 20 years the numerous karst-based projects I have been involved in have utilized multidisciplinary approaches. Some of these projects fall into the emerging cross-disciplinary field of geoarchaeology, which combines archaeological research with methods and concepts of the earth sciences (Butzer 1982). As stated by Fouache (2007), geoarchaeology can be more precisely defined as “the use of methods borrowed from geography and geosciences to reconstitute paleoenvironments and landscape dynamics from an archaeological perspective.” The archaeological perspective is a logical fit with the geosciences in that archaeology offers a deep time perspective on historical patterns and process that allows researchers to examine the intersection of long- and short-term sociological and natural phenomena, and to compare them across different spatial scales.

The research presented in this chapter utilizes the “tools” of disciplines often grouped together as the geosciences, which individually or collectively, within the framework of geoarchaeology can be applied to archaeological studies. A small body of literature merges methodologies and technology from archaeology and the geosciences to complete research that falls within the realm of geoarchaeology and karst studies. Many of these studies involved the use of geophysical techniques such as electrical resistivity tomography (ERT) (Gautam et al. 2000; Zhou et al. 2000; van Schoor 2002; Roth et al. 2002) and geographic information systems (GIS) to study karst features (Szukalski 2002; Lyew-Ayee et al. 2006).

Geography (both physical and human), geology, geomorphology, and geophysics, can be combined with archaeological methodologies to develop a multidisciplinary research design, within which new and innovative research can be conducted. The examples used in this chapter come from studies conducted at the Cave of Letters and the Qumran Archaeological Site in Israel (Reeder and Jol 2006; Reeder et al. 2004a, b; Jol et al. 2002, 2000) and on the Vaca Plateau in West-Central Belize, Central America (Colas et al. 1999, 2003, 2006; Reeder et al. 1996, 1998; Reeder 2003, 2009; Webster 2000; Webster et al. 2007; Polk et al. 2006, 2007).

By conducting these projects within the multidisciplinary framework of geoarchaeology, the full range of earth/geosciences was combined with archaeological

pursuits to infer past processes and events (Rapp Jr. and Hill 1998). Collecting and understanding physical and cultural data in a cross-disciplinary framework are major components within these project's research designs, as was understanding the intrinsic relationships that exist between the physical and cultural landscapes, and natural resources in these areas. It is the intent of this chapter to build upon the previous studies by further illuminating these relationships within the framework of a karst-based inquiry. First, the background of each project will be reviewed. This is followed by a discussion of the various research designs and methodologies. Then the salient results from the different projects will be presented and discussed, as will the conclusions drawn from the analysis of the data. Additionally, the contributions that these studies have made with regard to expanding the base of knowledge related to the karst-geoarchaeology of the Dead Sea area of Israel and the Vaca Plateau in Belize will be addressed.

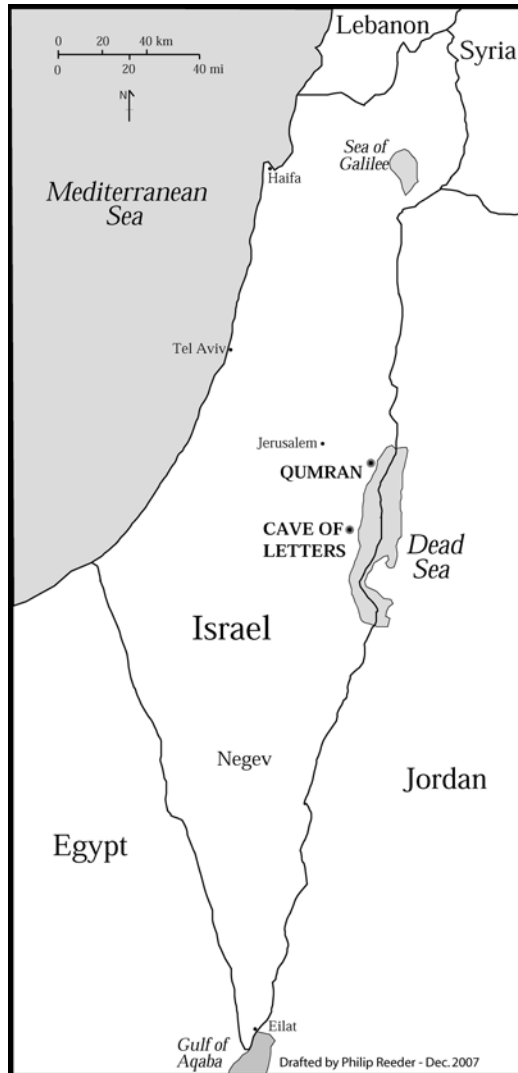
## 8.2 Background

### 8.2.1 *The Cave of Letters*

In 132 CE, the legendary Shimeon Bar Kokhba led the Second Revolt of the Jews against Roman rule. The First Revolt, which occurred 62 years earlier, ended with the famous resistance at Masada in the land of Israel. During the Second Revolt, Bar Kokhba's troops captured Jerusalem, and restored the Jewish state, but they were eventually defeated in 135 CE by the Roman general Julius Severus. Events associated with the First Revolt, recorded by Josephus Flavius, are part of the historical record for this period, but no such historian existed for the Second Revolt; so for nearly 2,000 years, Shimeon Bar Kokhba remained a mythical figure known mostly through Jewish folklore. All of this changed in 1960 and 1961 when archaeological expeditions headed by famed Israeli archeologist Yigael Yadin explored a Judean Desert cave in the Nahal Hever near the village of En Gedi (Aharoni and Rothenberg 1960; Yadin 1963) (Fig. 8.1). Rebel commanders, and their families, sought refuge in the cave near the end of the Second Jewish Revolt against the Romans (~135 C.E.). Research at the Cave of the Letters (COL) has yielded a priceless collection of artifacts.

Hall "A" (see Fig. 8.3), the first large chamber in the cave, contained a large cache of bronze objects. Excavations in Hall "B" (the second large chamber in the cave) led to the discovery of a fragment of a scroll that contained a rendering of an old psalm. In Hall "C" (the final large chamber in the cave), Yadin and his team discovered a bundle of leather, which later proved to be a goat waterskin that contained beads, perfume flasks, cosmetic tools, a hand mirror, and a bundle of papyri tied with string. Among the papyri were four wooden slats that were covered with writing, which were later determined to be letters from Shimeon Bar Kokhba to military commanders stationed at En Gedi. The first wooden slat contained the heading "Shimeon Bar Kokhba President over Israel". The goatskin belonged to

**Fig. 8.1** Location of the Cave of Letters and the Qumran Archaeological Site in Israel



Babatha, a young woman from a remote village in the Dead Sea area, and the wife of Yehonatan bar Be'ayan, one of Bar Kokhba's military commanders. When she fled to the cave, she had taken these items with her as part of her household belongings (Aharoni and Rothenberg 1960; Yadin 1963). The bundle of documents she left chronicles what life was like for a Jewish family at this important time in history. In all, approximately 70 documents written in Hebrew, Aramaic, Nabatean, and Greek were discovered in the cave, hence the name, Cave of Letters. About a dozen documents bore the name of Simeon Ben Koseva, the historical figure known as Bar-Kokhba.

No sanctioned research was conducted in the cave between 1961 and 1999, although it was postulated that a substantial amount of new information about this unique period in history remained to be discovered. Research expeditions to the Cave of Letters in July 1999 and July 2000 (the John and Carol Merrill Cave of Letters Expeditions) utilized state-of-the-art technology (ground penetrating radar (GPR), electrical resistivity tomography (ERT), a gradiometer, a high-resolution transient EM metal detector, and an endoscope), as well as traditional geologic, archaeological, and surveying techniques. Their purpose was to add a substantial amount of new information to the existing bases of knowledge about the Second Jewish Revolt, as well as the viability of geophysical research in caves. Because the COL is located in the tectonically active Dead Sea Rift Zone, and local limestone layers are being wedged apart by the growth of gypsum crystals, the cave floor is covered with roof fall that obscures the underlying archaeological deposits.

### 8.2.2 *Qumran*

The Qumran Archaeological Site, also in Israel, is located along the western shore of the Dead Sea (Fig. 8.1). This site is most famous for the caves located in the cliffs west of the site, where the Dead Sea Scrolls were discovered. In 1947, Arab shepherds found a cave whose contents were soon hailed as the greatest archaeological discovery of the twentieth century (VanderKam 1994). Approximately 800 manuscripts have been found in the 11 caves at Qumran (VanderKam 1994).

Data compiled by Roland de Vaux (1973), based on his excavations from 1953 to 1956 assert that Qumran was occupied by a group engaged in communal activities and religious rites (Schiffman 1995). In an attempt to understand the historical context of the Dead Sea Scrolls, scholars have tried to identify the group responsible for these documents (VanderKam and Flint 2002). Schiffman (1995) feels that the “Qumran Sect” was intrinsically linked to the scrolls found in the caves. The most widely adopted view of the “Qumran Sect” is that they were a small branch of the larger Essene movement (Sukenik 1955; VanderKam and Flint 2002), and that this sectarian group was responsible for gathering together, copying (mostly between 150 B.C.E and 68 C.E.) and depositing documents in area caves. After modern discovery, these documents came to be called the Dead Sea Scrolls (Schiffman 1995).

Another important facet of Qumran is the cemeteries located at the site. There are three cemeteries associated with Qumran, with the largest one located just east of the site, and smaller cemeteries found to the north and south (VanderKam 1994). In the main cemetery, de Vaux excavated 37 tombs out of the estimated 1,100 graves at the site, in the north cemetery two out of 12, and in the south four out of 30. Therefore, based upon de Vaux’s estimates, there are a total of 1,142 graves in the three cemeteries at Qumran.

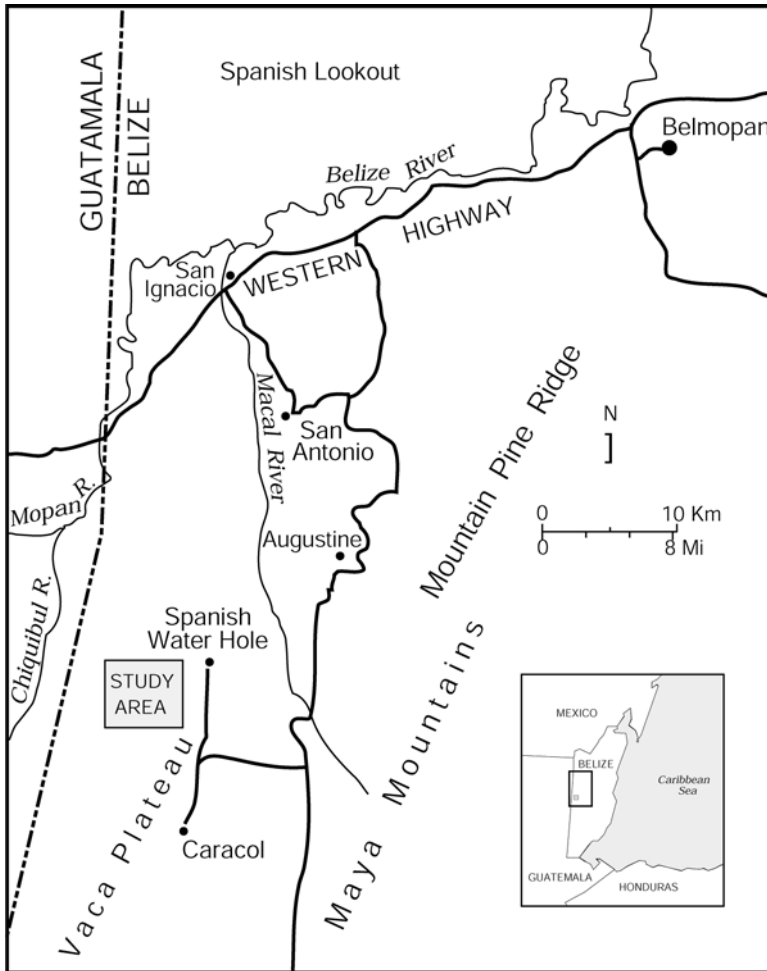
Past and present research efforts at Qumran have focused on the caves, the site, and the cemetery. Nine earlier reports, dating back as far as 1850 and continuing

through 1947, described various aspects of the Qumran Site, but no one had subjected the ruins to a thorough examination (VanderKam and Flint 2002). After the discovery of scroll material in cave one in early 1947, the site became of great archaeological importance. It was not until February 1949, because of political instability and hostilities that the first scholars began to work at Qumran. The 1949 excavation at cave one was directed by de Vaux and G. Lankester Harding. During this excavation, they also visited the ruins of Qumran and conducted a quick surface examination (VanderKam and Flint 2002). They returned in late 1951 and began to excavate portions of the surface ruins and cemetery. They returned again to work in newly found caves and at the surface ruins and cemetery in 1953. Additional expeditions were also staged in 1954, 1955, and 1956. After the final de Vaux-Harding expedition in 1956, Qumran received very limited archaeological attention. Little work was done with the archaeological remains at Qumran between the end of the de Vaux-Harding digs and the mid-1980s. Since then, several studies have been completed, in part supporting de Vaux's work and in part revising or refining his conclusions (VanderKam and Flint 2002). In 1995–1996, Magen Broshi (former curator of the Shrine of the Book at the Israel Museum in Jerusalem) and Hanan Eshel (Bar Ilan University) conducted a six-week season of excavation in an area of collapsed caves just north of Qumran. This was the last organized research effort at Qumran, until the John and Carol Merrill Excavations, which I was a part of, began at the site in July 2001.

### **8.2.3 *The Vaca Plateau in Belize***

Since 1990, the Northern Vaca Plateau Geoarchaeological Project (NVP GAP) has conducted 21 seasons of field research on the Northern Vaca Plateau in Belize, Central America (Fig. 8.2). The 25 km<sup>2</sup> study area is made up of mostly hilly, rugged terrain that exhibits landform features indicative of fluvio-karst topography, with the suite of landforms including an integrated system of dry valleys separated by residual hills and interfluves, single inlet and compound sinkholes, isolated cockpits, cutters, solution fissures and corridors, and caves (Reeder et al. 1996; Colas et al. 2008).

Petrographic analysis completed on rock samples collected in the study area concluded that the Campur Formation, the predominant geologic formation in the area, is a limestone breccia. Specifically, the study area is dominated by depositional breccias that formed in materials eroded off the Mountain Pine Ridge area of Belize just east of the Vaca Plateau, that were deposited and re-cemented in a shallow sea environment, and that now form the geologic materials we see on the Vaca Plateau today (Reeder et al. 1996). Geomorphic analysis in the study area has focused on relationships between structural elements of the areas bedrock, and the formation and evolution of area caves and the karst landscape. It was determined that planes of structural weakness formed in the Campur Limestone have similar orientations to contemporary karst landform features such as solution valleys, the long axis of sinkholes, and cave passages. These relationships suggest an important structural



**Fig. 8.2** Location of the Northern Vaca Plateau study area in Belize, Central America

control on the formation and evolution of area caves and the karst landscape. Furthermore, the dry-valleys and stair-step cave profiles indicate that the lowering of base level through time was interspersed with relatively stable periods when horizontal cave passages developed (Reeder et al. 1996).

The multidisciplinary research completed in the study area has provided a wealth of geologic, geomorphic, and speleologic data, as well as archaeological information about Late Classic Maya society and their usage of caves (Reeder et al. 1998; Colas et al. 2000, 2008), which are common in the rugged karst terrain of the Northern Vaca Plateau. As part of the cave-based component of the research, over 200 caves have been entered and explored, with maps created of the larger and/or more geologic or archaeological important caves. Although most of the research in the study area has

concentrated on caves, a large surface site, which was discovered in 1993, has been investigated as well (Colas 2001; Colas et al. 2006). The archaeological site of Ix Chel was discovered situated at the top of one of the many isolated hilltops in the study area. A sketch map of the Ix Chel Site was created in the mid-1990s, and in 2006, a detailed map of the site's core was produced (Fig. 8.12). Collected surface ceramics from Ix Chel suggest a Late Classic occupation, as do the artifacts in many of the caves that have been investigated thus far. Because these caves lie relatively close to Ix Chel, they may have been used by Ix Chel's inhabitants as ritual places (Colas et al. 2008).

### 8.3 Research Designs and Methodologies

#### 8.3.1 *Cave of Letters*

The research design used at the Cave of Letters was cross-disciplinary and involved aspects of Geography, Geology, Geophysics, Archaeology, History, and Biblical Studies. The overall objective for the project was to better clarify some of the uncertainties associated with the Second Jewish Revolt, and the use of the cave by associates of the legendary Shimeon Bar Kokhba, who led the revolt against Roman rule. The research was conducted within the multidisciplinary framework of the emerging discipline of Geoarchaeology, and specifically it sought to: (1) Quantify the specifics of the area's geology and geomorphology, and to link it to the formation of the cave, the cave's setting in the Dead Sea Fault Zone, and the patterns of cave use by Bar Kokhba's followers; (2) Produce the most up-to-date and detailed maps of the cave that are digital and thus easily updatable; (3) Use geophysics to locate and then study the Bar Kokhba living surface layer in the cave; (4) Study the spatial and temporal nature of the microclimatic variations in the cave environment, and relate these variations to cave geology, geomorphology, and the patterns of cave use; and (5) Complete archaeological excavations in the cave to study the Bar Kokhba era living surface and the associated artifacts.

Much of the research conducted at the Cave of Letters and Qumran sites in Israel involved the collection of data to produce maps, and the collection of geophysical data to assess the nature of the near surface materials at these sites, and to designate the optimal sites for archaeological excavations. In order to create new, detailed maps for the Cave of Letters, surveys were completed using the traditional methods utilized in cave surveying, which included the use of the following hand-held survey instruments: (1) An optical compass, (2) an optical inclinometer, and (3) a nylon survey tape. More technologically advanced instruments, such as laser surveying devices (Lerma et al. 2010), were not available for use by the survey team; hence the traditional methods were used. A total of 82 survey stations were established within the cave. Data collected between each station includes azimuth, inclination, and distance. At each survey station, a sketch of that segment of cave passage was also produced. The survey data was plotted using the CAVEPLOT computer program,



and the plots were exported to Adobe Illustrator for map production. Plan view and cross-sectional maps were produced, as well as maps that depict the locations where geophysical and archaeological analyses were completed. A portable digital pulseEKKO™ 100 and 1,000 GPR system was used to obtain the GPR profiles. Four antennae frequencies, 100, 200, 225, and 450 MHz, were tested. To reduce data collection time in the rugged cave environment, a backpack transport system was employed. The digital profiles were processed and plotted using pulseEKKO™ software. The application of radar stratigraphic analysis, an approach for interpreting sedimentary environments (Beres and Haeni 1991; Jol and Smith 1991), provided the framework to investigate both lateral and vertical geometry of the reflection patterns. After processing, printing, and interpreting the GPR profiles while in the cave, archaeological probes were completed at selected locations using an endoscope, metal detector, and/or traditional archaeological excavation techniques.

The two-dimensional electrical resistivity and tomography (ERT) analysis in the cave involved introducing an electrical current into the ground with two electrodes, and measuring the voltage drop across the cave-floor with two other electrodes. Because electrical flow disperses throughout the surface of the geologic materials that make up the floor of the COL, these measurements provided information about the electrical character of materials below the surface of the cave floor.

ERT is a surface geoelectric technique for mapping the distribution of subsurface electrical resistivity in a cross-sectional format. Data are collected through a linear array of electrodes coupled to a DC resistivity transmitter/receiver and an electronic switching box. The collection process is driven by a computer that is also used for data recording. The entire dataset is then inverted using a two-dimensional (2-D) finite difference, smooth inversion routine. The final product is a 2-D geoelectrical cross-section, plotting “true” resistivity (in ohm-m) versus “true” depth. The acquisition hardware used in this program was the ABEM Lund Imaging System.

The locations of two of the ERT sections surveyed are presented in Fig. 8.4. For line # 1, a minimum electrode spacing of 1 m was used, providing a maximum depth of investigation of approximately 12 m below ground surface (mbgs). This line was 80 m in length and ran from Hall A, through the AB connection, through Hall B, and into passage BB (Fig. 8.4). ERT Line 2 was a 40 m line running from the northeast corner of Hall B, north through the Hall C Connection, and across the southwest corner of Hall C. The length of Line 2 was constrained by the geometry of the cave. A minimum electrode spacing of 0.5 m was used, providing a maximum depth of investigation of approximately 6 mbgs. While smaller minimum electrode spacing decreased the depth of investigation of Line 2, as compared to line 1, it increased the spatial resolution. In order to facilitate good electrode contacts (i.e., lower the contact resistance), approximately 200 ml of water was poured around each electrode placement. It is believed that the large amount of halite present on the surface, when saturated with water, significantly assisted in decreasing the contact resistance, making the ERT survey practicable in this extremely arid cave environment. Each of the electrodes used in each ERT spread were surveyed for relative relief along the line. The inverted (modeled) geoelectric sections account for any changes of relief along the lines.

Profiles were produced by modeling the data from a series of measurements with different depths and locations along a survey line (Reynolds 1997). In the COL, two electrical resistivity and tomography transect lines were established. A gradiometer and a high-resolution transient EM metal detector were also used in the COL, with limited success, to locate artifacts in and below the rubble.

### 8.3.2 *Qumran*

The multidisciplinary research project completed at the Qumran Archaeological Site was focused on efforts to uncover new information about the site by (1) finding new caves using geophysics, (2) expanding the base of knowledge about Qumran by studying the cemetery, and (3) producing maps that depict the site, caves, cemeteries, and the spatial relationships between these features. My main area of focus during this 2 year project (2001 and 2002) was to complete the most detailed maps to date of the Qumran Cemeteries and surrounding areas, from which we began to assess the spatial relationships between the cemeteries, caves, the Qumran site, and the physical and cultural landscapes of the area. One physical/cultural landscape feature that received special attention was the aqueduct system at Qumran. The sectarians that occupied Qumran spent a large amount of time engaging in activities associated with ritual purity (Schiffman 1995). Among the most striking features at the Qumran ruins are the cisterns and baths at the site. A growing population made it necessary to provide a plentiful and constant supply of water for the settlement; so, an aqueduct was constructed to carry water provided by winter rains (de Vaux 1973). This segment of the research sought to determine (1) how the Qumran Sectarians manipulated their water resources, and (2) what role the local geologic conditions played in the manipulation of area water resources.

It has been previously noted that accurate maps of the Qumran cemeteries are pivotal in understanding the archaeological evidence collected thus far at Qumran (Schiffman 1995). The detailed maps produced as part of this research allowed the spatial aspects of the databases developed for Qumran to be assessed, compared, and contrasted. Past mapping efforts by de Vaux and others did not produce a complete, accurate depiction of the site and surrounding area. At Qumran, a Total Station Surveying instrument was used to map the cemeteries, as well as the Qumran Aqueduct system, the Qumran Archaeological Site, and the location of ERT lines, and GPR lines and grids. A Total Station is a surveying instrument that utilizes a laser to measure distance, and x and y coordinates are collected relative to a known point of reference (a benchmark), so that a map can be created.

Most graves in the cemeteries were located visually, but additional graves, or what are suspected to be graves, were located using ground penetrating radar (GPR). Location and elevation data were collected for each grave using the total station, then the data was entered into spread sheets, and transferred to a plotting program (CAVEPLOT), and the plots were then exported into a graphics program (Adobe Illustrator 10.0) for map production.

A Noggin GPR system mounted on a cart for increased mobility was used to explore the cemeteries at Qumran. The system emits radio waves into the ground and then collects these waves as they reflect back from the underlying geologic materials. In a known cemetery, GPR can look for locations where the materials had been disturbed, indicating a grave location with no surface expression. GPR surveys in some parts of the cemetery indicated undisturbed flat-lying layers of geologic materials while other places had obviously been disturbed. The GPR plots for these locations indicated a v-shaped pattern indicative of a site that had been dug and then refilled with the same material. Suspected graves, located using GPR, were identified in all of the cemeteries at Qumran. Additionally, 2-D resistivity, and EM were used to search for subsurface voids at Qumran with the intention being to better understand the burial practices of the people of Qumran, and to locate potentially collapsed caves that may or may not contain written materials.

### ***8.3.3 The Vaca Plateau in Belize***

The multidisciplinary research design implemented for the Vaca Plateau in Belize includes (1) exploration and mapping of caves and surface ruins in the study area, (2) studying area geology, geomorphology, hydrology, and speleology to better understand the study area's physical landscape, (3) mapping, collecting, and analyzing soils from archaeological sites and terraces, (4) collecting sediment and speleothems from caves for physical, chemical, and paleo-climate/paleo-environmental analysis, (5) collecting rock samples from outcrops, caves, archaeological sites, and possible quarry sites, (6) determining the usage patterns of caves via archaeological excavation and interpretation, and (7) determining relationships between cave formations (speleothems) and long-term changes in climate, vegetation, and land use patterns. This manuscript will focus on two subtopics within the projects' multidisciplinary research design. These subtopics revolve around the theme, how aspects of the physical landscape affect the cultural landscape. Examples will be presented and discussed regarding how the area's geology has affected and influenced the Maya cultural landscape that developed on the Northern Vaca Plateau. Specifically, local geology will be quantified to develop an overall understanding of the areas physical landscape, and this knowledge will be compared with geologic evidence related to area quarrying activities and the stones used in monumental construction, thus establishing a linkage between the physical and cultural landscapes.

Data regarding the petrology of the geologic formations in the study area were obtained by analyzing thin sections prepared from 25 rock samples. Rock specimens were collected at five general landscape positions and were grouped as follows: (1) Residual hilltops (7 samples), (2) residual hillside slopes (9 samples), (3) dry valley bottoms (2 samples), (4) cave entrances (4 samples), and (5) cave walls (3 samples). Three of the cave entrance samples were collected in dry valley bottoms, and one was from a residual hillside slope. The cave passages from which samples were collected have entrances located on a residual hilltop (1 sample) and

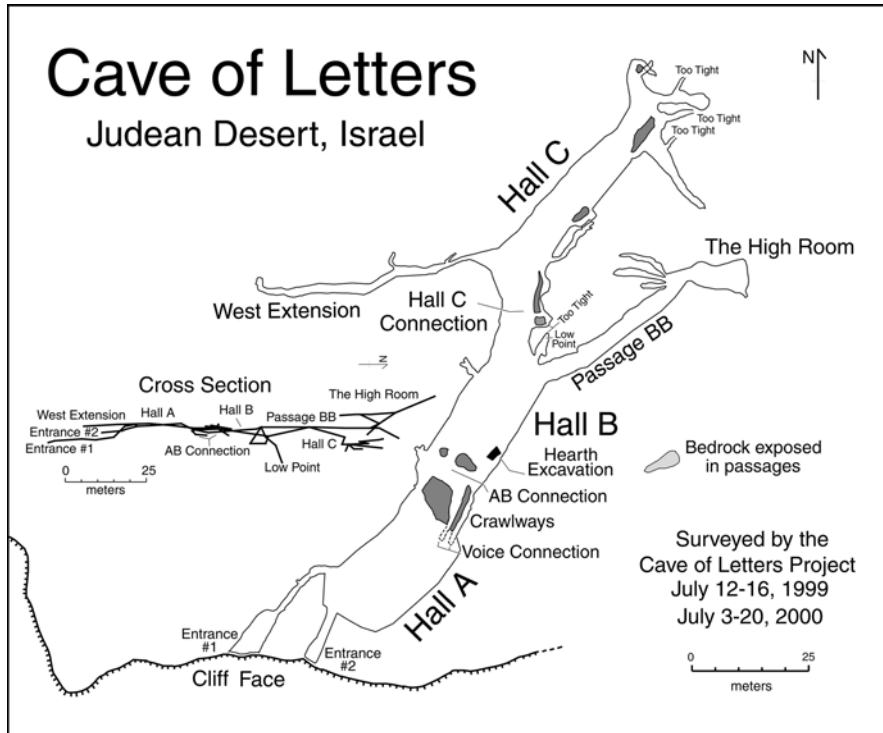
on a residual hillside slope (2 samples). Thin section analysis was used to identify rock constituents. Initial investigation indicated a large degree of heterogeneity, making the point count method of analysis (Folk 1962) inadequate. On brecciated rocks, the point count method may be misleading because of variations in lithology of the clasts, and the type and amount of cement. The relative abundance of sparite, micrite, fossils, or other characteristics becomes meaningless in these rocks, and it is more appropriate to classify the rock by using field relationships, stratigraphy, and petrographic analysis. The samples were therefore classified first using systems described by Pettijohn (1975), and then by methods described by Blount and Moore (1969).

Additionally, 32 rock samples were collected in and around the Ix Chel, with these samples coming from the surface of ruined buildings at the site, suspected quarry sites, and area outcrops. The purpose of this inquiry was to determine similarities and differences between stones used to face the buildings at Ix Chel, and area rocks from outcrops and suspected quarries. The determinations that were made, based upon this research, assisted in establishing a better understanding of the use of local resources versus using resources, in this case quarried stones, from the broader region. Analysis of the samples allowed a determination to be made regarding whether the sample was a breccia or non-breccia (Pettijohn 1975), and non-breccias samples were further analyzed using methodology utilized by Folk (1962), and breccia samples were described using the criteria outlined by Blount and Moore (1969). The brecciated rocks in the area cannot be quarried and carved because of their physical structure (large clasts embedded in a matrix of sparite or micrite), and extreme hardness. Once identified, the non-brecciated building stone samples were compared with non-brecciated samples from the suspected quarry sites to determine if the quarries were indeed the source for the building stones used at Ix Chel.

## 8.4 Results and Discussion

### 8.4.1 *Cave of Letters*

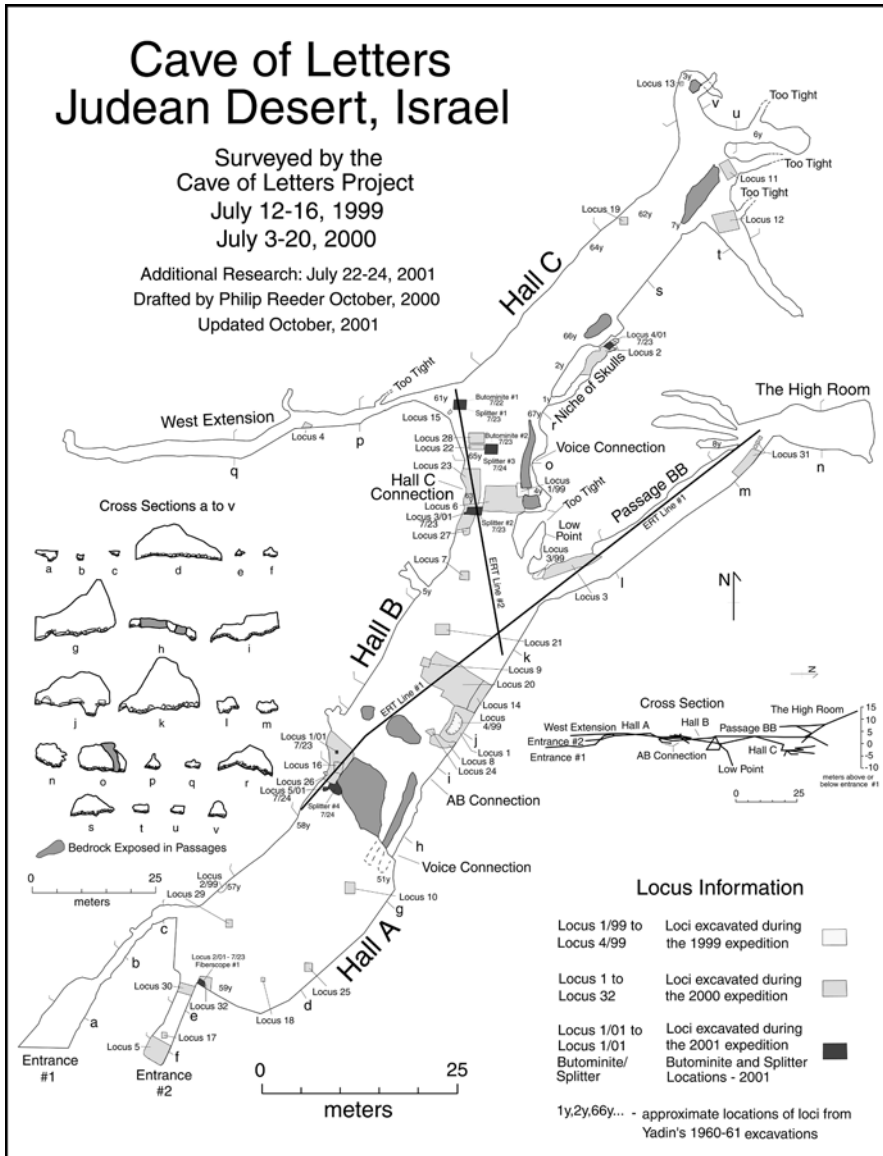
The mapping of the Cave of Letters (Fig. 8.1) was a major component of the project's overall research design because (1) it facilitated the creation of a new base map of the cave, and this map could be stored in a digital format and was thus easily updated, (2) layers of data could be added to the map in real-time, (3) the mapping process in the cave facilitated a thorough exploration of all passages, and (4) detailed maps could be created which highlighted the various components of the research (i.e., geophysics, geology, and archaeology). The collection of survey data, and the eventual production of a series of maps related to the 1999 and 2000 research completed in the cave, took place as a series of steps that included (1) data collection and acquisition, (2) data entry, storage, and manipulation, (3) plotting, (4) data export to a graphics program and de-construction of data plots created in the plotting program using this graphics program, and (5) map production using the graphics program. By combining the



**Fig. 8.3** The 2002 base map from the Cave of Letters, Israel

plotting program output that plots the cave walls, and the map sketch that was produced during the survey of the cave, a general base map of the Cave of Letters was produced in 1999, and updated after the 2000 expedition (Fig. 8.3). Based on the 1999 base map, the length of the Cave of Letters, based upon the most direct route through the cave, was estimated to be 335 m. The 474 m surveyed length of the cave reflects the distance between the 66 survey stations which were used to produce the map. In the three large chambers in the cave (Halls A, B, and C), the layout of survey stations meandered through chambers, not taking the most direct route. Hence, the 474 m distance value is an over-estimation, although it does reflect the surveyed length of the cave. The addition of the 16 survey stations from the year 2000 survey added 65 m to the surveyed length of the cave.

Using the base map created after the 1999 and 2000 surveys, more detailed, and sometimes topic specific maps were created. One map generated provides details related to the location of roof fall on the cave floor, holes in the cave floor, the topography of the cave floor, and features in the cave ceiling. A line plot of the cross-section of the cave was also created which could be added to maps, as were 25 individual cross-sections from throughout the cave, hence allowing the maps to depict both the plan view and cross section view of the cave on the same map sheet. Data related to archaeological finds in the cave were plotted on a version of the map



**Fig. 8.4** A detailed 2001 map of the Cave of Letters that depicts cave cross-sections, the location of archaeological excavations and selected geophysics transects in the cave

as well (Fig. 8.4). Because the map data was in digital format, it could be stored in a hand-held touch screen computer and information related to the archaeological loci and associated baskets could be added to the map database in real-time. This process greatly facilitated updating the archaeology research map of the cave. In addition, utilizing the same base map and the detailed physical and archaeology

maps, maps were created that depict the location of Ground Penetrating Radar or ERT survey lines, as well as the locations where rock splitting efforts were concentrated in 2001.

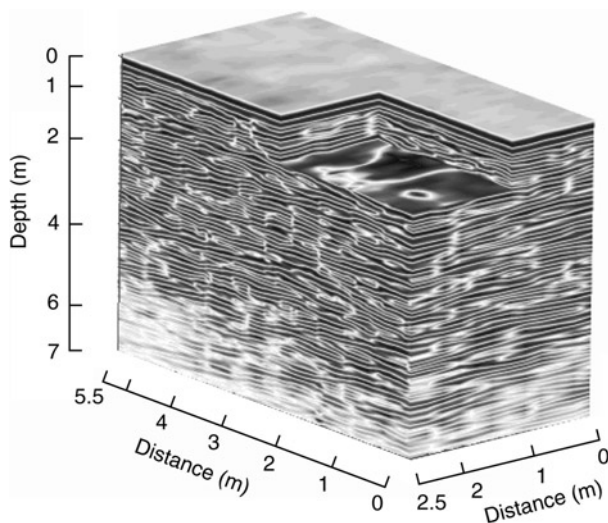
The set of maps that were produced as a result of this research provide a mechanism for understanding the spatial complexities/inter-relationships of the research, as well as a means of visually conveying this information. Very few researchers, or members of the general public, have been privileged to visit the Cave of Letters, but the set of maps produced as part of this research have contributed to establishing a better understanding of the geography of the Cave of Letters.

With regard to the use of GPR in the Cave of Letters, parallel transects were collected in each of the three rooms in the cave, as well as all the passageways that connect the rooms. In all, over 50 GPR transects were completed in the cave over the two field seasons (1999 and 2000). The lowest GPR antennae frequency used in the Cave of Letters was 100 MHz. A 27 m long 100 MHz profile was collected in Hall B, with the antennae separation of 1.0 m and a step size of 0.25 m. The upper area of the profile is similar in appearance to the underlying area, but it is separated by a near continuous, undulating reflection. The interpretation for this assemblage is that the upper area of the profile is the most recent roof fall (dislodged by the frequent earthquakes that occur in the area) which has accumulated on the hypothesized Bar Kokhba habitation layer.

Additional GPR transects were completed to further corroborate the existence of this layer. A 19 m long transect using 200 MHz antennae, with a separation of 0.5 m and a step size of 0.1 m, was completed in Hall B. This transect was at a 45° angle to the 100 MHz transect and crossed that transect in the southwestern part of the cave room. The reflection patterns in this transect were very similar to the first transect, with the upper levels of the profile in more detail because of the use of a higher resolution 200 MHz antennae and a closer step size (0.1 m). Again, the nearly continuous, undulating reflection that separates the two layers in the upper profile is interpreted as the Bar Kokhba floor. Additionally, above these reflection patterns, which became apparent using the higher resolution 200 MHz antennae, are several reflection patterns which were interpreted as additional material from more recent roof fall events that occurred since the cave was abandoned during Bar Kokhba times. Other 200 MHz survey transects were completed in various parts of the cave and they were able to image the undulating bedrock surface (original cave floor) and the hypothesized Bar Kokhba habitation layer. In addition, the first 4 m of the 19 m long transect discussed above was examined using an even higher frequency antennae (450 MHz) with a separation of 0.17 m and a step size of 0.05 m. With the increase in frequency to 450 MHz, the profile shows a decrease in depth of penetration (to approximately 3 m), but an increase in the resolution of the upper layers, with more details of the roof fall material apparent including the internal stratigraphy of the materials that the survey crossed.

A three-dimensional (3D) dataset was also developed for the Cave of Letters (Fig. 8.5). These type of datasets are useful for interpreting the framework of the subsurface materials and they provide a more detailed view of the geometry of individual units within the stratigraphy. In the Cave of Letters, three-dimensional datasets were collected in each large room in the cave to assist in the detailed





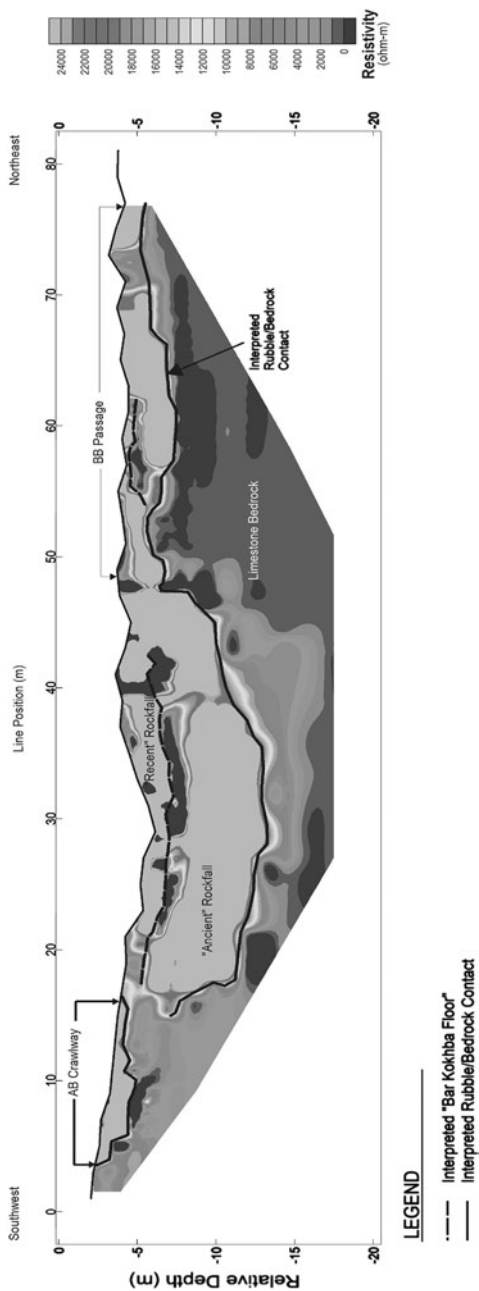
**Fig. 8.5** A three-dimensional GPR depiction cut away to the suspected Bar Kokhba habitation layer

interpretation of the cave deposits, and to possibly indicate optimum locations for archaeological excavation. A dataset for eventual three-dimensional depiction was collected in Hall B with the 200 MHz antennae with an antennae separation of 0.5 m and a step size of 0.1 m. The grid, the data was collected from, was 5.5 by 2.5 m. The reflections discussed in the previously cited two-dimensional examples are also visible in a 3-D perspective, wherein the three-dimensional cube created by the software is sliced and the Bar Kokhba habitation surface is exposed. The more continuous reflections in the cube below the Bar Kokhba layer may be former cave floors that pre-date the Bar Kokhba layer. The success in locating this surface beneath the roof fall materials provided locations for further exploration beneath the rubble using an endoscope, and pinpointed locales for possible excavation.

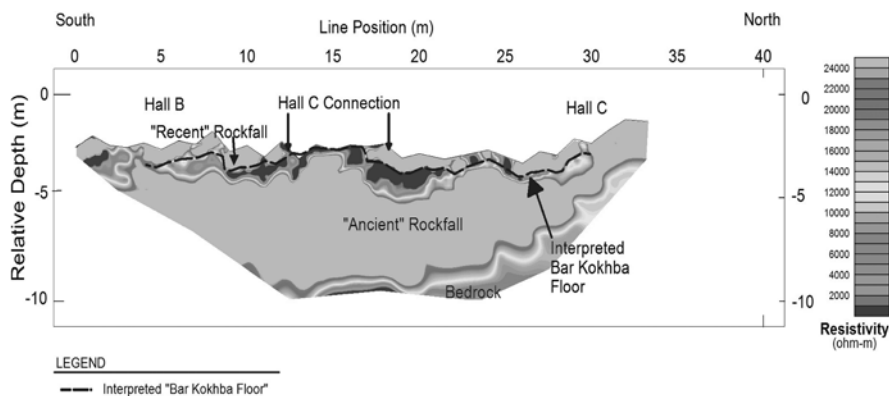
Interpretation of the data collected along ERT Transect 1 identified two distinct layers in the profile. An upper layer is thought to be composed of various sized roof fall material. The deeper and thicker layer is believed to be limestone bedrock. There is no evidence of internal layering within the roof fall materials. If a packed earth floor exists, as was interpreted using the GPR data, this layer should appear as a less resistive layer within the roof collapse debris. One explanation for the absence of this horizon is that it is too thin to be detected using ERT.

Similar to ERT 1, ERT 2 has two prominent layers, consisting of a highly resistive layer of roof collapse debris, which overlies a moderately resistive layer interpreted to be limestone bedrock (Fig. 8.6). Different from Transect 1, ERT 2 contains a mostly continuous, lower resistivity layer that cuts almost completely across Hall B and partially through the floor materials in the BB Passage. This layer varies from just below the cave floor surface to approximately 3 m below the cave floor. Similar to the interpretations made based upon the GPR data, this layer is hypothesized to be the remains of the Bar Kokhba period surface. This layer was detected





**Fig. 8.6** An ERT cross-section from the AB passage, though Hall B and down the BB passage, which highlights the Bar Kokhba habitation surface, locations of ancient roof fall materials, as well as recent rock fall



**Fig. 8.7** An ERT cross-section from Hall B, through the BC passage and into Hall C, which highlights the Bar Kokhba habitation surface, the location of bedrock, locations of ancient roof fall materials, as well as recent rock fall

in the ERT 2 Transect and not ERT 1, because ERT 2 crossed the center of the room, and ERT 1 traversed along the wall. Most of the activities in the cave would have taken place more in the open areas of the cave toward the center of the rooms and not along the walls.

As with ERT Line 1 and 2, Line 3 contains two layers, including a highly resistive ( $>20,000$  ohm-m) layer of roof collapse rubble overlying a moderately resistive (1,000–9,000 ohm-m) layer interpreted to be limestone bedrock. Only a relatively small thickness of the limestone bedrock is imaged as the depth of investigation of the 40 m long section is only 6 m below the cave floor. The roof collapse rubble reaches a thickness of about 6 m in Hall B and in the Hall C Connection. The rubble reaches at least 5 m below the cave floor in Hall C.

Similar to Transect 2, ERT 3 contains a continuous, lower resistivity layer that exists for almost the entire extent of the 40 m line (Fig. 8.7). The depth of this layer varies from just below the cave floor surface to approximately 1.5 m below the cave floor. This interpretation corroborates interpretations based on the GPR data that this layer is the Bar Kokhba habitation surface. In the C Connection Passage, excavation revealed a densely packed surface of fine grained material which required a digging tool to penetrate. Excavation of this layer revealed a Vespaian coin (in conjunction with metal detection surveys), 72 pieces of Roman period pottery, and a pointed wooden stick that was possibly a writing instrument.

### 8.4.2 Qumran

The Dead Sea Scrolls are approximately 900 different manuscripts discovered in eleven caves in the vicinity of Qumran between 1947 and 1956 (Fig. 8.1). The scrolls contain every book of the Hebrew Old Testament except the Book of Esther, with the scrolls predating any other version of the Bible by more than 1,000 years. Thus,

the Dead Sea Scrolls are often referred to as the most important archaeological find of the last century, and Qumran is perhaps the most important archaeological site in the world from the perspective of the development of Judeo-Christian civilization.

An intriguing aspect of the Qumran Site, along with the ruins, caves, and aqueduct system, is the cemeteries (Fig. 8.8). Qumran is arguably one of the premiere sites from

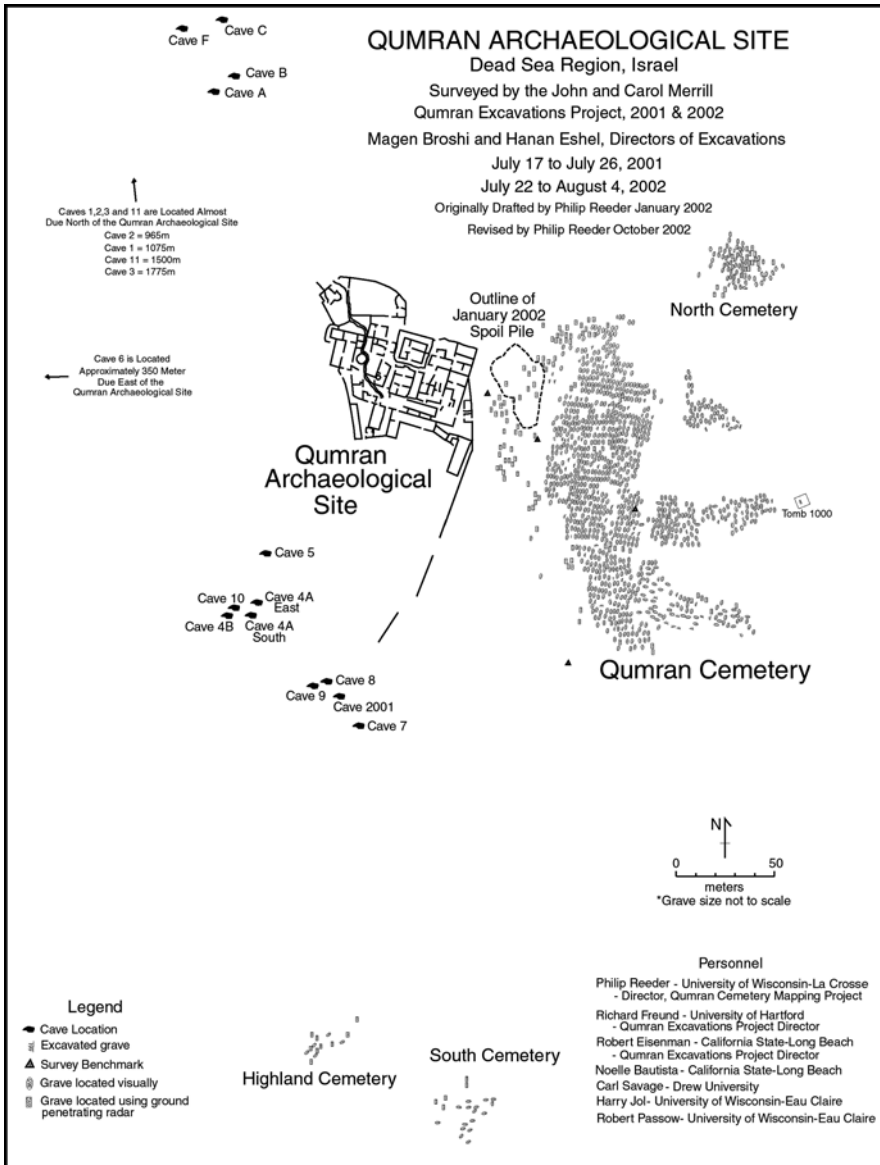


Fig. 8.8 A map of the Qumran area depicting the spatial relationships between the caves, the archaeological site, and the cemeteries, with tomb 1,000 highlighted

antiquity in Israel, but the cemetery had never been thoroughly studied and systematically mapped. The 2001 and 2002 surveys of the cemeteries at Qumran found 1,056 graves with surface expression in the main cemetery, fingers and North Cemetery (978 were located visually). Seventy-eight of these graves had been previously excavated. Records indicate that there are 46 legally excavated graves in the cemeteries, so it can be assumed that the other 32 are the result of illegal excavations. If the South and Highland Cemeteries are included, four additional excavated graves (for a total of 82) and 17 additional visual graves (for a total of 995) are added, producing a total of 1,077 graves in all of the cemeteries that have some visual expression.

To non-intrusively assess the subsurface of the cemeteries at Qumran, a Noggin GPR system mounted on a cart for increased mobility was used to explore the cemeteries. In a known cemetery, GPR can look for locations where the materials had been disturbed but have no surface expression. GPR surveys in some parts of the cemetery indicated undisturbed flat-lying layers of geologic materials, while in other locations v-shaped patterns indicative of a site that had been dug and then refilled with the same material were located. Suspected graves, located using GPR, were identified in all of the cemeteries at Qumran, with 84 located in the main cemetery, one in the Middle Finger, six in the South Finger, 22 in the North Cemetery, five in the South Cemetery, and nine in the Highland Cemetery. A total of 122 GPR anomalies were found.

The total number of graves in all the cemeteries at Qumran, including suspected graves found using GPR, is 1,199. Of the 995 graves located visually in all the cemeteries (not including excavated graves), 14 (1.4%) were in excellent condition, 164 (16.5%) were in good condition, 424 (42.6%) were fair, 301 (30.3%) were poor, and 92 (9.2%) were in very poor condition.

Two graves located on the middle finger of the east extension of the main cemetery took on a special significance (Figs. 8.8 and 8.9). In 2002, a skeleton was discovered in a grave that has been designated Tomb 1,000, the same site where the remains of two women from the first century AD were found during the summer of 2001. Prior to the discovery of the two women in 2001, an anomaly was found at the site using GPR. Excavation revealed a building that was eventually determined to be a mourning enclosure, and the skeletal remains of the two women. In 2002, the floor of the mourning enclosure was again surveyed using GPR and another anomaly was located which proved to be the location of a skeleton. This skeleton was discovered 1.5 m below the surface, and approximately 1.0 m below the remains of the two women. This building (mourning enclosure) is situated in a prominent elevated position on the periphery of the cemetery. The positioning of this burial chamber may indicate that a person of some importance was buried in this location, and a ceramic dated to the first century CE was found alongside the skeletal remains (Jacobson 2002). The skeleton was found facing east and the first rays of the rising sun would strike the burial chamber. This burial chamber is one of the most elaborate in what is otherwise a very simple place (Jacobson 2002). The east–west orientation is generally thought to coincide with Muslim burials that have taken place in the cemetery over the last several hundred years, but the presence of the first century pot confuses this issue. Scholars generally agree that the other east–west burials in the

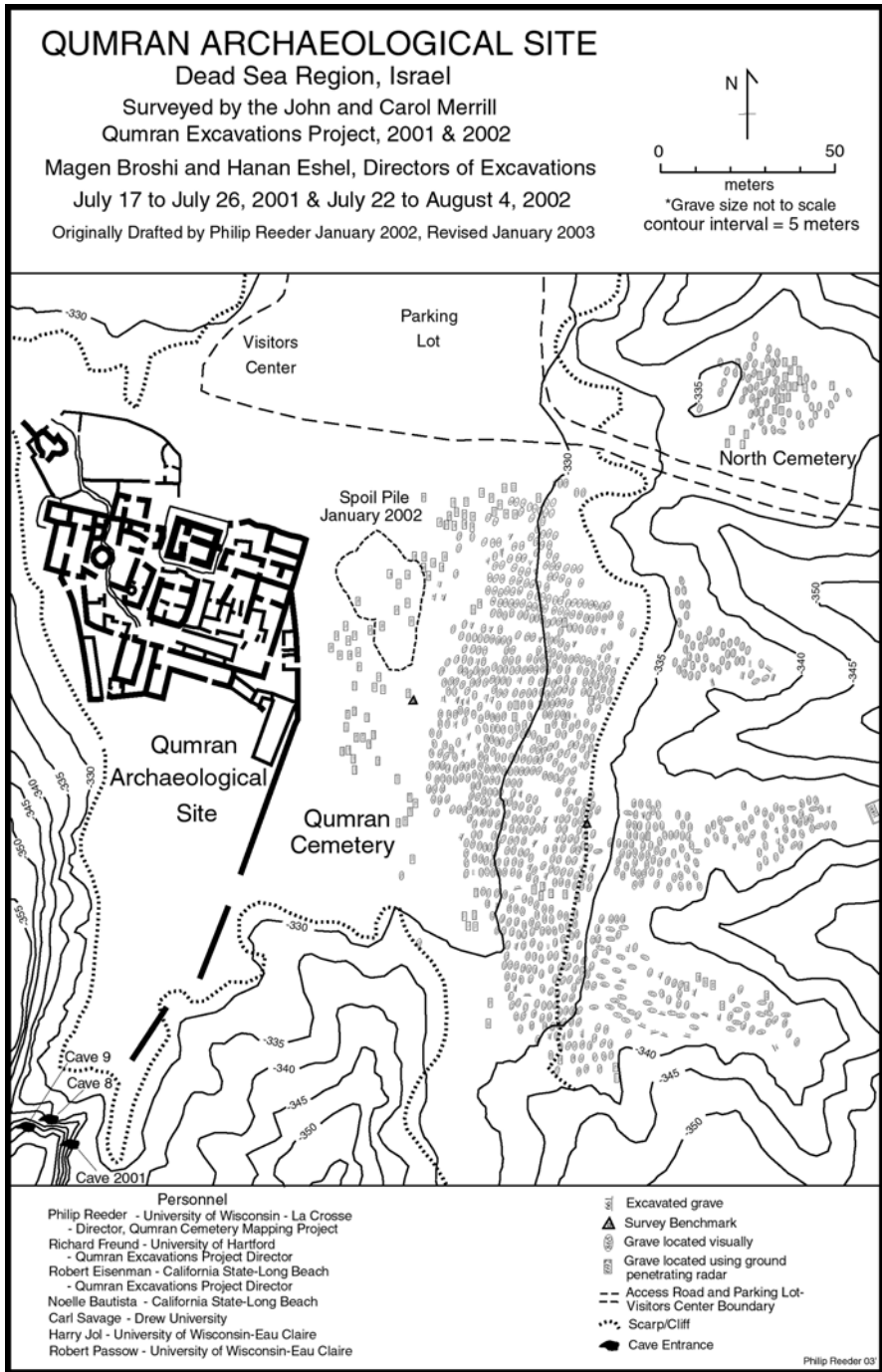


Fig. 8.9 A more detailed map of the Qumran Archaeological Site, with the caves and cemeteries close to the site included, as well as the areas topography

cemeteries are either Christian or Muslim (Bedouin) dating to the last few centuries (Zias 2000; Eshel et al. 2002), but the Tomb 1,000 burial remains a mystery.

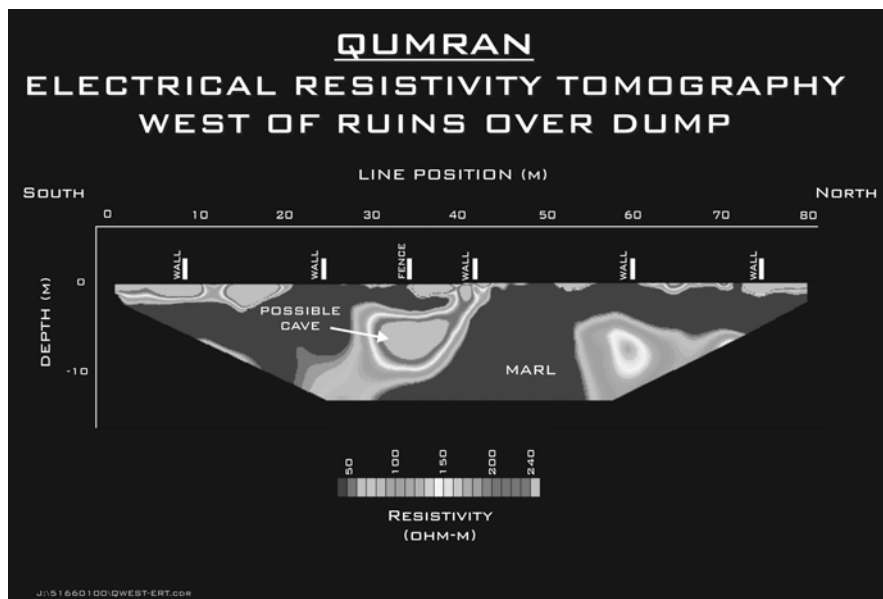
Another mystery in the cemeteries at Qumran is grave 978, which contains the remains of a zinc coffin. This grave was likely excavated by looters, and portions of the zinc coffin were damaged or removed. This grave is oriented north–south, which is interpreted as a burial from the era of the Qumran Sect (Schiffman 1995; VanderKam and Flint 2002). The zinc coffin may have been used to transport a body from another location for burial at Qumran.

A map of the aqueduct in the vicinity of the Qumran Site was also completed. A growing population made it necessary to provide a constant supply of water for the settlement (de Vaux 1973). A narrow canyon extends from the mountains west of Qumran, connecting with the upper reaches of Wadi Qumran. Structures were created in the lower portions of the canyon to move water toward the site, rather than down the wadi into the Dead Sea. At some points, the aqueduct going through tunnels cut into the rock, and in other places the water flowing through channels excavated into surface exposures of bedrock. Once out of the rocky canyon, the aqueduct was dug into the marl terrace that slants toward the settlement (Schultz 1960). Upon reaching the settlement, the channel was coated with plaster and, for some part of its winding course between buildings it was covered with stone slabs (de Vaux 1973). The difficult and elaborate construction of the aqueduct is a testimonial to the importance of water to the Qumran Sect.

In addition to the use of GPR at Qumran, other geophysical techniques, namely two-dimensional electrical resistivity and tomography (ERT), were used as well. ERT can detect cavities in the subsurface that have no surface expression. The previously discovered caves that contained scroll material are in areas of rugged, exposed limestone cliffs, with many of the caves adjacent to the Qumran Site and others up to 1.8 km away. This limestone topography is very common in and around Qumran, the area is tectonically active, and there is a distinct possibility that earthquakes caused caves containing artifacts to collapse. ERT surveys in the vicinity of the Qumran Site were completed to pinpoint possible locations for excavation. The ERT surveys delineated several locations where possible voids (collapsed caves) existed (Fig. 8.10). These areas were probed with an auger (a portable hand-held drilling device), but no cavities were found. The original research design for this phase of the project called for the use of a power auger to drill into the voids, but this request was not approved, and only the use of a hand auger was allowed. No further research permits were submitted to continue this work at Qumran; so, we will never know if a more sophisticated drilling device would have been able to probe the suspected voids.

### ***8.4.3 The Vaca Plateau in Belize***

Geologic, geomorphic, speleological, and archaeological research has been conducted for the past 20 years within a 25 km<sup>2</sup> area of the Northern Vaca Plateau centered 6 km east of the border between Guatemala and Belize, 15 km south-southeast of



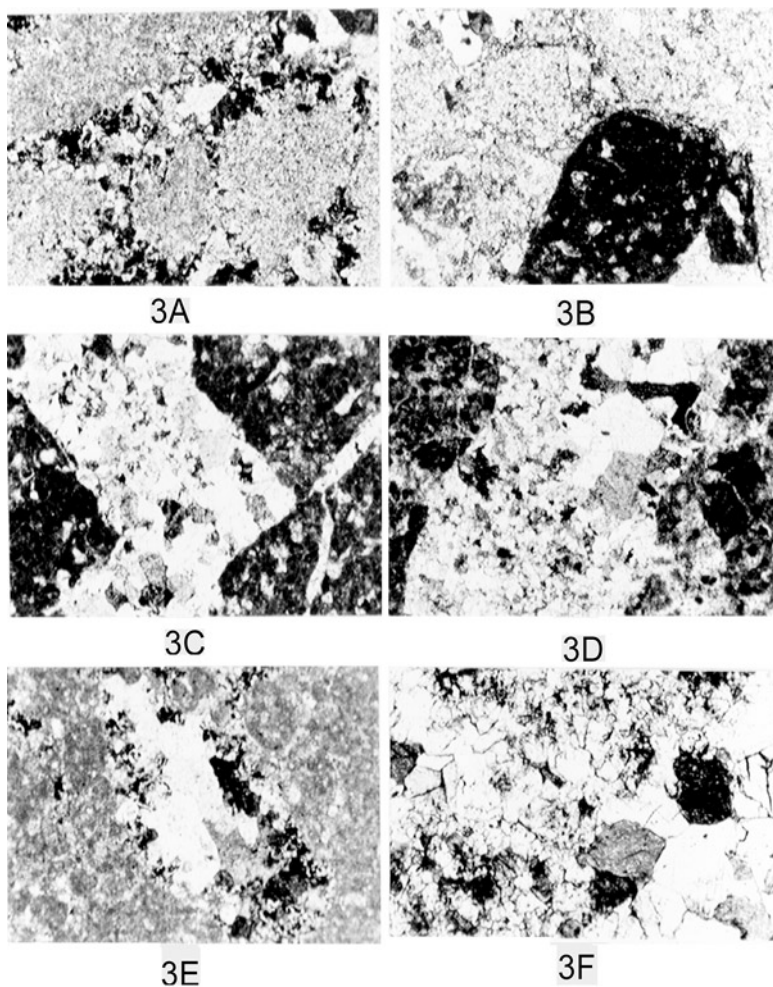
**Fig. 8.10** An ERT cross-section from Qumran from near the archaeological ruins to an area called the dump site, with the location of a possible cavity (cave) included, as well as some subsurface geological features

the Augustine Forestry Station, and 8 km north of the Caracol Archaeological Site, the largest archaeological site in Belize (Fig. 8.2). One component of this research was to quantify the physical landscape characteristics of the Northern Vaca Plateau (i.e., limestone petrology, structure, geomorphology, and hydrology) and to relate these parameters to landscape and cave formation and evolution, and the development and evolution of the Maya cultural landscape. A beginning point in this study was a detailed analysis of the area's geology. Specific research regarding the physical landscape in this portion of Belize has not been conducted prior to the onset of our (the Northern Vaca Plateau Geoarchaeology Project) work which began in 1990. The only sources for physical geography and geology information were very general country-wide or regional assessments, citations in publications regarding the Mountain Pine Ridge and Maya Mountain section of Belize, or detailed studies in other areas with similar geologic characteristics.

What follows is a small segment of the research completed on the Vaca Plateau that deals with quantifying the study area's geology. Once a firm understanding of the area's geology was obtained, an additional study was completed that assessed the petrology of the building stones used at Ix Chel, and the relationship between these stones and rocks from suspected quarry sites in the area.

The petrology of 25 samples collected from outcrops in the study area was analyzed. Twenty-one samples were classified as breccias, and four were classified as non-breccias. Using Pettijohn's (1975) system, the breccias were classified into





**Fig. 8.11** Thin sections depicting six different types of rocks found on the Vaca Plateau in Belize

four types: (1) 12 samples were micrite clasts dominate, sparite cement (Fig. 8.11a); (2) 3 samples of sparite clasts dominate, sparite cement (Fig. 8.11b); (3) 3 samples were fossiliferous micrite clasts dominate, sparite cement (Fig. 8.11c); and (4) 3 samples of pelletal micrite clasts dominate, sparite cement (Fig. 8.11d). The non-breccias were classified as follows: (1) 2 samples of micrite dominates with some pellets (Fig. 8.11e); and (2) 2 samples were sparite (Fig. 8.11f). The four breccia types were further classified using Blount and Moore's (1969) system, which is based upon the origin of the breccias as determined from field relationships, stratigraphy, and petrographic analysis. All 21 breccia samples are lithoclastic (reworked fragments of an older lithified limestone). They consist primarily of pre-existing limestone fragments with

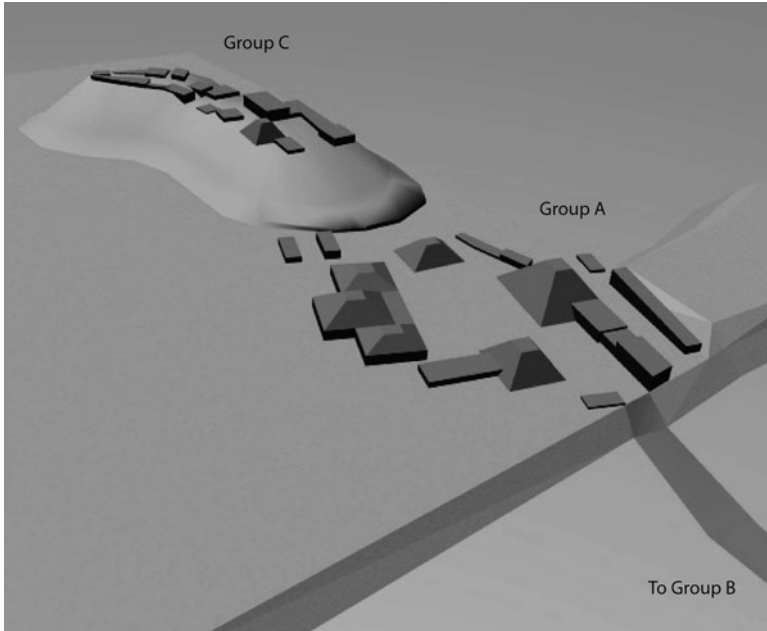


some samples containing rudistid (a bivalve mollusk) fossil fragments and/or pellets (probably mollusk feces). The clasts are considered lithoclasts, rather than intraclasts (penecontemporaneous, usually weakly consolidated carbonate sediment that eroded from adjoining parts of the sea floor) (Folk 1962), because the lithoclastic interval is over 200 m, based upon the elevation difference between breccias found deep in vertical caves and on the highest hilltops.

In 12 samples, micrite clasts dominate and the matrix is sparite. The lithology of the lithoclasts is similar to non-lithoclastic limestones from the same formation, indicating they are intraformational (from the same geologic formation). Based upon these characteristics, and criteria outlined by Blount and Moore (1969), these samples are designated depositional breccias. In three other breccia samples, sparite clasts are embedded in a secondary matrix of sparry calcite cement and these specimens were classified as tectonic breccias (Blount and Moore 1969). In three samples, fossiliferous micrite clasts dominate within a sparite cement. The fossils appear to be broken rudistid fragments and the lithoclasts are intraformational. These specimens were classified as depositional breccias as well. In three samples, pelletic micrite fragments are cemented by sparite, and these specimens were classified as depositional breccias. Two samples classified as non-breccias are probably homogeneous fragments of the breccia. Two other samples were composed entirely of sparite. Based upon their homogeneous carbonate mineral composition, they were classified as non-breccias, but they are probably directly related to area breccia formation.

The analysis of these samples assisted in establishing a basic understand of the geology of the study area. Equipped with this knowledge, an assessment of the nature and source of the building stones used in the construction of Ix Chel was completed. The Ix Chel site is comprises three distinct groups, namely the main plaza (Group A), a possible palace complex (Group B), and the acropolis (Group C) (Fig. 8.12). These groups extend roughly along a north–south axis. In the periphery of Ix Chel, agricultural terraces, too numerous to be mapped, were observed. At present, only a relative chronology for Ix Chel exists, and absolute dating remains difficult. Collected surface ceramics suggest a Late Classic occupation, as do the many caves that have been investigated thus far. Because these caves lie relatively close to Ix Chel, they may have been used by Ix Chel's inhabitants as ritual places.

Thirty-two rock samples were collected with these samples coming from the surface of ruined buildings at the site, suspected quarry sites, and area outcrops. The purpose of this inquiry was to determine similarities and differences between stones used to face the buildings at Ix Chel (Fig. 8.13) and area rocks from outcrops and suspected quarry sites. The analysis of the samples was blind, in that they were collected in the field and thin sections were prepared from the collected samples, and sample id numbers were coded to thin section id numbers; however, this information was not made available to the researchers completing the analysis. Hence, it was unknown to these researchers which samples were from building stones, which were from quarry sites and which were from outcrops. In this way, any bias introduced because of prior knowledge was kept at a minimum.



**Fig. 8.12** A map of the Ix Chel Archaeological site on the Vaca Plateau in Belize



**Fig. 8.13** A quarried and shaped building stone from the Ix Chel Archaeological Site in Belize

Samples	Similarities
1, 2, 3, 6, 10, 19, 30	Classified as Fossiliferous Micrite, Pelletiferous Micrite, or contained fossils or pelletal remains
11, 27, 31, 32	Classified as Biosparites, and contained >40% Sparite/Microsparite;
11, 15, 27, 28, 29, 30, 31, 32	Conglomerates
1, 2, 7, 8, 9, 10, 13, 14, 19-21, 24-27, 29-32	Porous Samples
2, 7, 8, 10, 13, 14, 16, 17, 19, 21, 22, 23	Non-Conglomerates with >3% Sparite/Micrite
1, 3-7, 9, 12-14, 16-26	Building Stones

**Fig. 8.14** Determinations based upon the analysis of thin sections with respect to the relationship between know building stones and other rock samples collected in the study area

Analysis of the sample thin sections determined whether they were breccia or non-breccia (Pettijohn 1975), and non-breccias samples were further analyzed (Folk 1962), and breccia samples were described using criteria outlined by Blount and Moore (1969). The brecciated rocks in the area are not used as stones to face the exterior of buildings at Ix Chel. The buildings are faced with softer, more easily formed and shaped stones. The various samples (building stones versus suspected quarry versus area outcrops) were compared to determine if they were petrographically similar.

Samples were analyzed by clast and matrix, and the calcite crystals were determined based on their measurement and translucence. Using criteria outlined by Folk (1962), the samples were classified in terms of lithology for the clasts, and matrix for the breccia's cement. Examination of the thin sections revealed that of the 32 samples, 22 (68%) were micrites, although 21 of these samples contained some microsparite and sparite clasts. Two of the samples were classified as fossiliferous micrite (6.25%), while three were pelletiferous micrites (9.4%). In four samples all clasts were sparite (12.5%).

Based on the modal percentages, and clast angularity, the samples were divided into three categories: Building stones, non-building stones, and conglomerates. Figure 8.14 provides the summation of which samples originate from what source. From a mineralogical standpoint, several of the non-conglomerates had >3% sparite/microsparite, which may be indicative of the same source, or may include samples near the transition zone in the rock outcrop between the conglomerate/breccias common in the area, and limestone (probably secondary depositional deposits) used for building stones. Of the non-conglomerates, samples 2, 8, and 10 were brecciated on a portion of the sample. Based on the brecciation in those samples and in the samples classified as conglomerates, the following were probably non-building stones: 2, 8, 10, 11, 15, 27, 28, 29, 30, 31, and 32. Of these, the following are conglomerates: 11, 15, and 27-32. Thus, samples 1, 3-7, 9, 12-14, and 16-26 are likely to be building stones (Fig. 8.14).

The building stones were collected directly from ruined structures in and around Ix Chel, and they were obviously shaped for their function. Quarry site 1 is located behind the B Group at Ix Chel and it is an outcropping of rock that is obviously different than most of the breccias/conglomerate rocks that outcrop in the area. The outcrop also appears to be extensively modified, possibly by quarrying. This rock is much softer, and more porous. Samples 29 and 30 were collected from this suspected quarried area, but at points where the softer, more porous rocks transition to the harder breccias. Samples 31 and 32 were collected from a site near Ix Chel that appeared to have been modified (excavated), but the rocks were brecciated. Below is the list of samples and where they were collected.

Building stones: 1, 3, 4, 5, 6, 7, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26,

Quarry Site 1 (Soft Rock): 8, 9, 10

Quarry Site 1 (near transition to Breccia): 11, 29, 30

Quarry Site 2: 31, 32

If the list above is compared to the determinations for sample source in Fig. 8.14, the determination for building stones, based on modal percentages and clast angularity, matches precisely with the list of collected building stone samples. One of the soft Quarry Site 1 samples (#9) was classified as a building stone, and samples 8 and 10 were classified as non-conglomerates with >3% sparite/micrite. The other suspected quarry samples were classified as conglomerates (although they were more porous than the normal conglomerates in the study area) and showed very little similarity to the building stones or other suspected quarry sites. Although not exactly similar to the building stones collected at Ix Chel, samples 8, 9, and 10 from the suspected quarry were similar enough to conclude that they could have been carved into building stones and they were similar enough to have been from the same source as the building stones at Ix Chel. Although the volume of material that appeared to have been removed from suspected quarry site # 1 was substantial, it was not near the volume that was required to construct the buildings at Ix Chel. Therefore, the suspected quarry site was a source for building materials for Ix Chel, but other sources must exist as well, and these sources have yet to be determined.

## 8.5 Conclusions

The multidisciplinary framework of geoarchaeology allows the full range of related disciplines such as geography, geology, archaeology, and religious studies (and when working in karst areas speleology) to be melded and applied to pursue new avenues of research and add to existing bases of knowledge. Understanding the cultural implications of physical data within a multidisciplinary framework were major components of the research discussed in this chapter. Such an approach enhances the understanding of the intrinsic relationships that exist between physical and cultural landscapes, and in some cases the utilization and exploitation of natural resources in these areas. It was the intent of this chapter to take previous studies conducted in Israel at Cave of Letters and Qumran, and in Belize at the Ix Chel

Archaeological Site on the Vaca Plateau, and stress the utility and importance of conducting karst-based, multidisciplinary research within the framework of the emerging discipline of Geoarchaeology.

The 1999 and 2000 John and Carol Merrill Cave of Letters Projects, and the 2001 and 2002 John and Carol Merrill Qumran Excavations Projects have added to the base of knowledge about both of these important locations, with the completion of detailed and accurate maps depicting multiple aspects of the site. These maps not only detail the spatial and temporal relationships at the sites, but the relationships between the physical landscape and the cultural landscape are highlighted. The use of geophysical applications also played a prominent role in this research. Ground penetrating radar at COL indicated the location and depth of the Bar Kokhba habitation surface, as did ERT, which aided in pinpointing the most advantageous locations for excavation. At Qumran, these technologies proved useful as well, indicating the possible locations of burials that have no surface expression and pinpointing a location where eight buried jars were discovered. GPR also indicated an area of disturbance that may be the location of the latrines for the city. ERT discovered new cavities beneath the Qumran site, and provided important information about the nature of the subsurface geologic materials in the area. Working within the multidisciplinary framework of geoarchaeology, we were able to apply various aspects of the geosciences to interpret past processes and events at the Cave of Letters and Qumran, providing new insights into the physical and cultural landscapes of these locations.

The same can be said for the research conducted in Belize. Analysis of lithologic and geomorphic features within the 25 km<sup>2</sup> study area revealed that the karst landscape is greatly influenced by the lithology and structure of the bedrock. The majority of limestone in the study area formed adjacent to a structurally emergent area, as a depositional breccia consisting mostly of lithoclasts of micrite with a sparry calcite cement. Variations in composition of the lithoclasts reflect local variations in the depositional environment. Geologic structures including faults, joints, and fractures formed during periods of uplift in and adjacent to the study area. These periods of uplift account for the existence of some tectonic breccias in the study area. By studying the petrology of the area and related features, it was possible to gain a limited understanding of the formation and evolution of the northern Vaca Plateau's karst landscape. It also aided in understanding the relationships that exist between the physical landscape and the cultural landscape developed by the ancient Maya. They were very much guided by the nature of the physical landscape in their daily lives, be it ritual activities in caves, extensive terracing of the poor quality, clay rich soils that exist on the karst landscape, or the source of the building materials used to built their cities. A study of the building stones at Ix Chel, and comparison to the rocks at a nearby suspected quarry site, indicated that some of the building materials did indeed come from very near Ix Chel. However, it also indicated that there was another, yet unknown source, which leaves yet another avenue for future research to be added to the already extensive list.

Karst research has drawn from the basic paradigms of many disciplines (e.g., geography, geology, biology, geochemistry, geomorphology, geophysics, hydrology),

which were often amalgamated under the zeitgeist of a “karst-based” research project. This is still the case, but the scope has been furthered broadened to include other disciplines and sub-disciplines such as history, anthropology, archaeology, human ecology, climate and paleoclimate, environment and paleoenvironment, and resource conservation and management. Karst-based research needs to continue this evolution, for it only makes it a more viable pursuit in the quest for new knowledge and understanding.

**Acknowledgements** The research associated with the projects discussed in this manuscript could not have been completed without the contributions of many people. With regard to the Israel research, I thank Richard Freund Director of the Maurice Greenberg Center for Judaic Studies at the University of Hartford, who served as Project Director on most of the projects, as well as fellow researchers Harry Jol (University of Wisconsin-Eau Claire) and Paul Bauman (Worley-Parsons). I also thank the Israel Antiquities Authority for all of their assistance, as well as all the students who have assisted with this work over the years. In Belize, I thank Dr. James Webster and Bill Reynolds who have worked with me on this research for over 20 years, as well as all of the other researchers and students who have come and gone on the project. Thank you to Melissa Milner for her tireless work on the Ix Chel building stone study. I also wish to thank the Belize Institute of Archaeology, its Director Jamie Awe, and the Research Director John Morris. Your support through our 20 plus years of work in Belize is greatly appreciated. I also thank my wife Keen, and my sons Will, Sam, and Joe for their love and support as I travel the world in my quest for new knowledge. Lastly, I dedicate this manuscript to and thank Pierre “Clint” Colas, for his knowledge of the Maya, his friendship, sense of humor, and his love of life. You may be gone, but you will never be forgotten. I really miss you man!

## References

- Aharoni Y, Rothenberg TB (1960) In the footsteps of kings and rebels in the Judean desert (in Hebrew). Massada, Tel Aviv
- Beres M Jr, Haeni FP (1991) Application of ground-penetrating-radar methods in hydrogeologic studies. *Groundwater* 29:375–386
- Blount DN, Moore CH (1969) Depositional and non-depositional carbonate breccias, Chiantla Quadrangle, Guatemala. *Geol Soc Am Bull* 80:429–442
- Butzer KW (1982) *Archaeology as human ecology*. Cambridge University Press, Cambridge
- Colas PR, Reeder P, Webster J (2000) The Ritual Use of a Cave on the Northern Vaca Plateau, Belize, Central America. *J Cave Karst Stud* 62(1):3–10
- Colas PR, Wölfel U, Reeder PR, Stengert KC et al (2008) Sites and sinkholes: archaeological investigations of Terminal Classic Maya Society on the Northern Vaca Plateau, Belize. *Mexicon* 30(6):126–135
- Colas PR, Stengert KC, Wölfel U (2006) The mapping of Ix Chel: a terminal classic secondary maya site on the Northern Vaca Plateau, Belize, Central America. In: Reeder PR (ed) *Annual report on multidisciplinary research activities on the Northern Vaca Plateau for 2006*. Institute of Archaeology, Belmopan
- Colas PR, Reeder PR, Webster J (2003) Vessel with a primary standard sequence in archaeological context in a cave on the Northern Vaca Plateau, Belize. In: *Wayeb Notes*, No. 7 (ISSN: 1379–8286)
- Colas PR (2001) Mapping of looters trenches at the site of Ix Chel, Northern Vaca Plateau, Belize, Central America. In: Reeder PR (ed) *Annual report on multidisciplinary research activities on the Northern Vaca Plateau*. Department of Archaeology, Belmopan
- Colas PR, Reeder PR, Webster J (1999) The ritual use of a cave on the Northern Vaca Plateau, Belize. *Cent Am J Cave Karst Stud* 61(1):3–10

- de Vaux R (1973) *Archaeology and the Dead Sea Scrolls*. Oxford University Press, London
- Eshel H, Broshi M, Freund R et al (2002) New data on the cemetery East of Khirbet Qumran. *Dead Sea Discoveries* 9:135–165
- Folk RL (1962) Spectral subdivision of limestone types: In W.E. Ham (ed) *Classification of carbonate rocks: a symposium*, American Association of Petroleum Geologist Memoirs 1, pp 62–84
- Fouache E (2007) What is geoarchaeology? *Geodin Acta* 20(4):I–II
- Gautam P, Raj S, Ando P (2000) Mapping of subsurface karst structure with gamma ray and electrical resistivity profiles: a case study from Pokhara Valley, Central Nepal. *J Appl Geophys* 45:97–110
- Jacobson C (2002) Resurrected: John the Baptist. [www.theage.com/articles/2002/08/02/1028157836462.html](http://www.theage.com/articles/2002/08/02/1028157836462.html)
- Jol HM, Reeder PR, Broshi M et al (2002) GPR investigations at Qumran, Israel: site of the Dead Sea Scrolls Discovery. In: Koppenjan SK, Lee H (eds) *Ninth international conference on ground penetrating radar*, April 29–May 2, Santa Barbara, CA, *Proceedings of SPIE (The international society for optical engineering)*, 4758, pp 91–95
- Jol HM, Reeder PR, Schroder JF et al (2000) Return to the cave of letters (Israel): a ground penetrating radar archaeological expedition. In: Noon DA, Stickley GF, Longstaff D (eds) *Proceedings of the 8th international conference on Ground Penetrating Radar (GPR 2000)*, May 23–26, Gold Coast, Australia, SPIE, 4084, pp 882–886
- Jol HM, Smith DG (1991) Ground penetrating radar of Northern Lacustrine deltas. *Can J Earth Sci* 28:1939–1947
- Jerma JL, Navvarro S, Cabrelles M et al (2010) Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study. *J Archaeol Sci* 37:499–507
- Lyu-Ayee P, Viles H, Tucker G (2006) The use of GIS-based digital morphometric techniques in the study of cockpit karst. *Earth Surf Process Landf* 32:165–179
- Pettijohn FJ (1975) *Sedimentary rocks*. Harper and Row, New York
- Polk JS, van Beynen PE, Reeder P (2006) Environmental reconstruction since 2,500 years ago using cave sediments from Belize. In: Onac BP, Tamas T, Constantin S et al (eds) *The Karst Record: Archives of Climate Change in Karst*. *Proceedings of the Symposium Climate Change, Karst Waters Institute: Special Publication 10*, Băile Herculane
- Polk JS, van Beynen PE, Reeder PR (2007) Late holocene environmental reconstruction using cave sediments from Belize. *Quat Res* 68:53–63
- Rapp H Jr, Hill C (1998) *Geoarchaeology: the earth-science approach to archaeological interpretation*. Yale University Press, New Haven
- Reeder P, Brinkmann R, Alt E (1996) Karstification on the Northern Vaca Plateau, Belize. *J Cave Karst Stud* 58(2):121–130
- Reeder P, Brady J, Webster J (1998) Geoarchaeological investigations on the Northern Vaca Plateau, Belize. *Mexicon* 20(2):37–41
- Reeder P (2009) Cave and karst geoarchaeology: new avenues for inquiry. In: *Proceedings of the 2009 international ubiquitous cave conference*, Danyang, South Korea, 6–8 November 2009, pp 59–90
- Reeder P (2003) Physical and cultural landscapes on the Northern Vaca Plateau, Belize. *J Belizean Aff* 5(1):5–30
- Reeder P, Jol H (2006) Water resource utilization at the Qumran Archaeological Site. *Isr Pap Appl Geogr Conf* 29:224–234
- Reeder P, Jol H, Freund R et al (2004a) Geoarchaeology of the Qumran Archaeological Site, Israel. *Focus Geogr* 48(1):12–19
- Reeder P, Jol H, Bauman P, et al (2004b) Multidisciplinary research at the Cave of Letters, Israel: a melding of physical and social sciences. *Transkarst 2004 conference proceedings*, Hanoi, Vietnam, 13–18 Sept 2004
- Reynolds JM (1997) *An introduction to applied and environmental geophysics*. Wiley, New York
- Roth M, Mackey J, Mackey C et al (2002) A case study of the reliability of multielectrode earth resistivity testing for geotechnical investigations in karst terrains. *Eng Geol* 65:225–232

- Schiffman L (1995) *Reclaiming the Dead Sea Scrolls*. Doubleday, New York
- Schultz S (1960) *Zeitschrift des Deutschen Palastina-Vereins*. LXXVI, pp 53–58
- Sukenik EL (1955) *The Dead Sea Scrolls of the Hebrew University*. Hebrew University, Jerusalem
- Szukalski B (2002) Introduction to cave and karst GIS. *J Cave Karst Stud* 64:3
- van Schoor M (2002) Detection of sinkholes using 2D electrical resistivity imaging. *J Appl Geophys* 50:393–399
- VanderKam J (1994) *The Dead Sea Scrolls today*. William B. Eerdmans Publishing Company, Grand Rapids
- VanderKam J, Flint P (2002) *The meaning of the Dead Sea Scrolls*. Harper Collins, San Francisco
- Webster JW (2000) Speleothem evidence of late holocene climate variation in the Maya Lowlands of Belize, Central America, and Archaeological implications. Ph.D. Dissertation, University of Georgia
- Webster J, Brook G, Railsback L et al (2007) Stalagmite evidence from Belize indicating significant droughts at the time of Preclassic Abandonment, the Maya Hiatus, and the Classic Maya Collapse. *Palaeogeogr Palaeoclimatol Palaeoecol* 250(1–4):1–17
- Yadin Y (1963) The finds from the Bar Kokhba period in the Cave of Letters. The Israel Exploration Society, Jerusalem
- Zhou W, Beck B, Stephenson J (2000) Reliability of dipole-dipole electrical resistivity tomography for defining depth to bedrock in covered karst terranes. *Environ Geol* 39:760–766
- Zias JA (2000) The cemeteries of Qumran and celibacy: confusion laid to rest. *Dead Sea Discov* 7:220–253