REPUBLIC OF LEBANON
Council for Development and Reconstruction
CDR
Beirut

FEDERAL REPUBLIC OF GERMANY
Federal Institute for Geosciences and Natural Resources
BGR
Hannover

TECHNICAL COOPERATION

PROJECT NO.: 2008.2162.9

Protection of Jeita Spring

SPECIAL REPORT NO. 7

Mapping of Surface Karst Features in the Jeita Spring Catchment

Ballouneh
October 2011

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Mapping of Surface Karst Features in the Jeita Spring Catchment

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Commissioned by:	Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, BMZ)
Project:	Protection of Jeita Spring
BMZ-No.:	2008.2162.9
BGR-Archive No.:	xxxxxxxxx
Date of issuance:	October 2011
No. of pages:	59

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1	Site Selection for Wastewater Facilities in the Nahr el Kalb Catchment – General Recommendations from the Perspective of Groundwater Resources Protection	January 2011
2	Best Management Practice Guideline for Wastewater Facilities in Karstic Areas of Lebanon – with special respect to the protection of ground- and surface waters	March 2011
3	Guideline for Environmental Impact Assessments for Wastewater Facilities in Lebanon – Recommendations from the Perspective of Groundwater Resources Protection	November 2011
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7	Mapping of Surface Karst Features in the Jeita Spring Catchment	October 2011
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9	Soil Survey in the Jeita Catchment	November 2011
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List of Abbreviations

asl	Above mean sea level
BMZ	German Ministry of Economic Cooperation and Development
CDR	Council for Development and Reconstruction
COP	Method for groundwater vulnerability mapping developed by the European Union project COST 620
DEM	Digital elevation model
DST	Dead Sea Transform Fault
EPIK	Method for groundwater vulnerability mapping developed by SAEFL
FC	Financial cooperation
GW	groundwater
KfW	German Bank for Reconstruction and Development
LGM	Last Glacial Maximum
LRA	Litani River Authority
MAPAS	Company operating Jeita Grotto
MoEW	Ministry of Energy and Water
MY	Million years
SAEFL	Swiss Agency for the Environment, Forestry and Landscape
TC	Technical cooperation
UTM	Universal Transverse Mercator
WEBML	Water Establishment Beirut and Mount Lebanon
WP	waypoint

Acknowledgements

In its effort to protect the water resources in the Nahr el Kalb catchment, the project *Protection of Jeita Spring* experienced great support not only at the political and institutional level but also from many municipalities and people in the catchment area.

We are especially grateful for the backing and support of the Council for Development and Reconstruction (CDR), namely its president, Nabil El Jisr, Dr. Wafaa Charafeddine (Funding Division Director) and Eng. Ismail Makki (Manager Projects Division), the Ministry of Energy and Water (MoEW), namely H.E. Gebran Bassil and his staff, the Water Establishment Beirut and Mount Lebanon (WEBML), namely its president, Joseph Nseir, as well as George el Kadi (Projects Manager), and Maher Chrabieh (Director of the Dbaye treatment plant).

Some of the technical installations could not have been achieved without the help of Jeita Grotto (MAPAS). Our sincerest thanks are extended to Dr. Nabil Haddad, Ayman Ibraheem, Najeeb Najeeb and all other staff at Jeita Grotto.

Many mayors and staff of municipalities in the catchment saw the opportunities which the project hopes to provide in the near future as a chance for development. Among those which very actively assisted the project we would like to highlight the municipalities of Ballouneh (Dr. Pierre Mouzawak, Simon Daou, Tony Daou) and Jeita (Samir Baroud).

The hydrogeological investigations are conducted together with the University of Goettingen, Department of Applied Geology. Joanna Doummar, as a PhD student at University of Goettingen cooperates closely with the project. The project is very much indebted to her for her tireless support and significant input. Prof. Martin Sauter and Dr. Tobias Geyer, her supervisors, provided valuable advice for our work.

The project was made possible by grants of the German Government, allocated through the Ministry of Economic Cooperation and Development (BMZ). Our thanks therefore go to the staff of the BMZ, KfW Development Bank and German Embassy. We experienced that this assistance is very much appreciated not only among the involved institutions and stakeholders but also the population living in the area.

0 Executive Summary

This report presents the results of a surface karst feature survey, conducted by the Technical Cooperation (TC) Project Protection of Jeita Spring (implemented by BGR and CDR). This survey was needed for the preparation of groundwater vulnerability to be prepared by the University of Goettingen for the project. Together with the hydrogeological investigations of the project, the groundwater vulnerability will form the basis for the delineation of groundwater protection zones for the Jeita spring and other important springs and wells in the Jeita catchment.

75% of the land surface in the Jeita catchment is covered by limestones. 30 % represents limestone of Jurassic age, 45 % limestone of Cretaceous age. Due to the specific conditions prevailing in the Jeita catchment during the geological history, all limestone units are intensively karstified. Only 25 % of the outcrop area in the Jeita catchment is composed of non-karstic units.

The intensive karstification created pathways for infiltration of water into the aquifer system and allows a relatively fast movement of groundwater as was observed through numerous tracer tests. Based on spring discharge measurements in the catchment groundwater recharge rates are believed to reach around 80 % in the Upper Cretaceous limestone and around 50 % in the Jurassic limestone.

Evidence for extensive Quaternary glaciations in the Mount Lebanon mountain range has been found by the project. During these glaciations karstification processes were probably even more extensive than today.

Fracture porosity in the lower part of the Jurassic aquifer seems to be low because fractures are mostly filled. Here groundwater flow mainly follows large conduits.

Partly an extensive secondary dolomitization of the Kesrouane Formation (J4) of the Jurassic is noticed. Calcium magnesium carbonate (dolomite) is much less soluble than calcium carbonate (limestone). Therefore karstification in dolomite is significantly less compared to limestone. It is assumed that dolomitization is related to intrusions of basalt and related hydrothermal waters along fractures.

Understanding the development of the karst system is paramount for the interpretation of the hydrogeology in the Jeita catchment. Groundwater flow is governed to a large extent by the geological structure. The study of the palaeoclimate, geological structure and tectonic development is key to an understanding of karst development and groundwater flow.

1 Introduction

Jeita spring emerges from a karst aquifer and shows a fast response to rainfall events of commonly between 10 to 30 hours, depending on the amount and spatial distribution of rainfall over the Jeita catchment. The spring is located at the current entrance to the Jeita Grotto touristic site. The underground river of Jeita can be followed to approx. 6 km upstream of the spring. Upstream of this point, named siphon terminale, the underground river descends to more than 60 m. The conduit probably continues from there on towards east but has not yet been explored. Jeita spring is the main source of drinking water to the Capital Beirut.

Due to the karstic nature of the rock units the groundwater is highly vulnerable to pollution. Many villages and housing projects are located in highly karstic areas. In non of these villages there is a wastewater collection and treatment system in place yet. Fuel and oil is assumed to be leaking into groundwater from many gas stations, car repair workshops, fuel depots for generators, heating oil and quarries. Quarries and decoration stone factories release sludge directly into streams causing high turbidity in the water resources.

Because of the already high and increasing number of pollution sources in the catchment, contamination of virtually all springs and wells in the catchment has become widespread. However, the monitoring system for water quality (and quantity) is insufficient.

The above mentioned conditions in the catchment lead to a high pollution risk and finally to a poor water quality for the consumer.

The aim of the German-Lebanese Technical Cooperation project Protection of Jeita Spring is to reduce the pollution risks by introducing groundwater protection zones. Landuse restrictions will be defined for the individual protection zones. Moreover the project is giving advice to its main partner, the Council for Development and Reconstruction (CDR) and a German financial cooperation project implemented by KfW development bank, concerning geoscientific aspects related to the planning of wastewater facilities in the Jeita catchment.

Commonly in karst areas the delineation of groundwater protection zones is done using groundwater vulnerability maps. For the preparation of those groundwater vulnerability maps the karst features had to be mapped.

Tracer tests were conducted in some highly karstified areas, showing that at some places infiltration is very fast so that in those highly karstified areas natural attenuation of contaminants will not take place.

2 Scope of work

For preparation of groundwater vulnerability maps in karst areas, commonly the type of karst features together with the level and extent of karstification provide the most important input (MARGANE, 2003) and will give an indication about where and which amounts of water will infiltrate into groundwater during rainfall events or snow melt. Karst feature mapping will however no allow determining the travel time for percolation. This will have to be established using tracer tests.

The mapping of surface karstic features therefore is the central component of a groundwater vulnerability map for karst areas.

The scope of work for surface karstic feature mapping was:

- Identify surface karstic features types and genesis
- Delimit individual karstic areas (e.g. dolines)
- Differentiate the level of karstification and describe factors leading to extensive karstification
- Indicate zones of high infiltration

3 Overview and location of the study area

Jeita spring is located northeast of Beirut, in Nahr el Kalb Valley. Nahr el Kalb River is the dividing line between the Metn district (to the south of the river) and the Kesrwan district (to the north of the river). Jeita spring, located 4 km upstream from the outlet of the river to the Mediterranean Sea is at an elevation of 60 m asl.

The limits of the groundwater contribution zone of Jeita spring were determined using structural geological and hydrogeological information and tracer tests (Figure 1; MARGANE et al., in progr.). The southern part of Nahr el Kalb Valley is not part of the Jeita catchment. Here geological dip is mostly towards south and tracer tests in this area were negative, i.e. no tracer from injections in this part arrived at Jeita. The groundwater catchment covers an area of 312 km² and encompasses the northern part of Nahr el Kalb valley, the mountain plateau between Mount Sannine and Afqa, the upper part of Nahr Ibrahim Valley, and extended areas north and west of the Jeita surface water catchment (Figure 1). This area was studied for its karst features.

Study area (UTM 36N):

N 3,754,000 – 3,778,000

E 742,000 – 777,000

Mapping of Surface Karst Features in the Jeita Spring Catchment

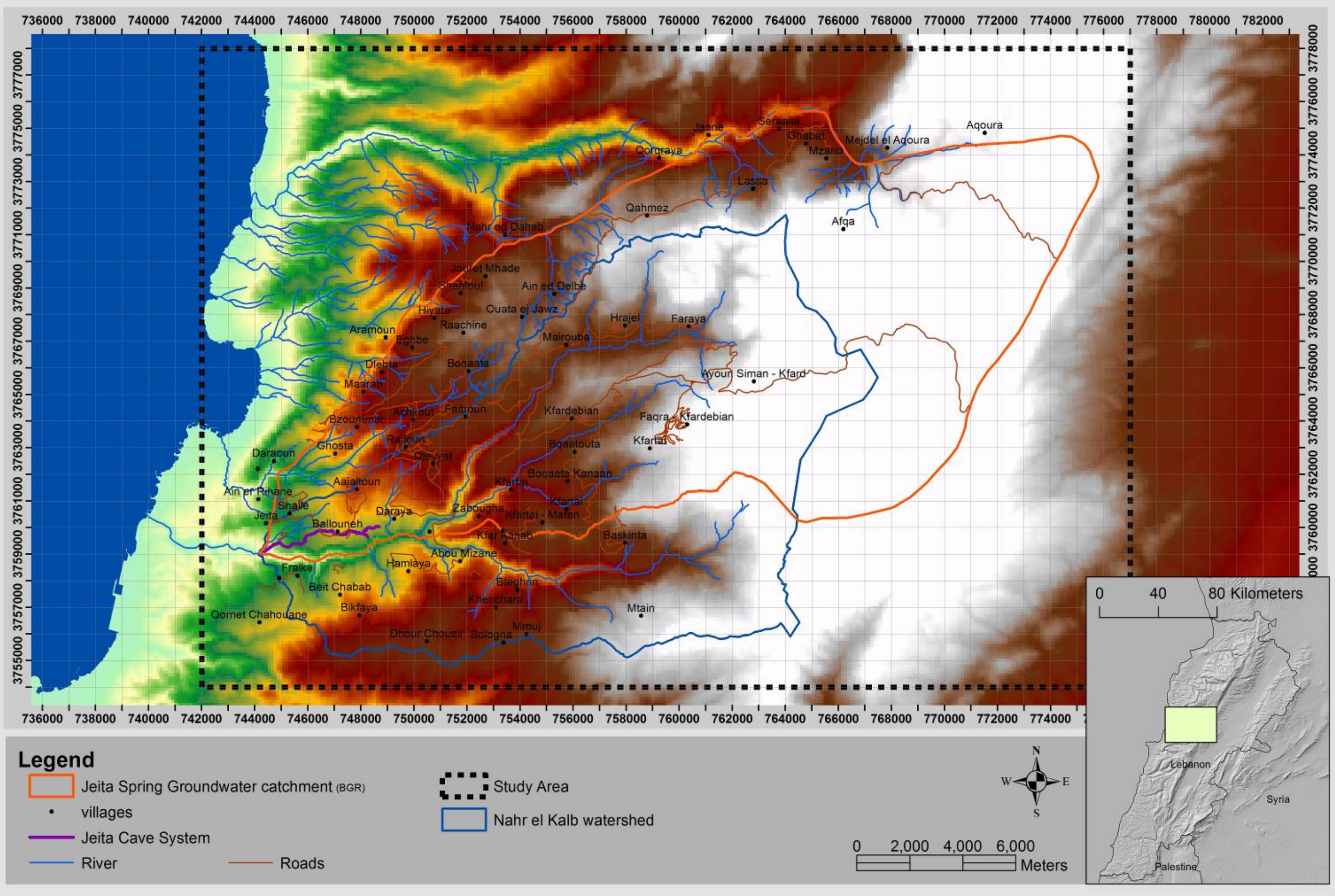

Figure 1: Study Area and Groundwater Catchment of Jeita Spring.

In terms of elevation, the study area ranges between 60 m asl (Jeita) and 2,628 m asl (Mount Sannine).

The topography of the study area can be divided into four main features:

- Narrow and deep valleys formed by extensive erosion over an extended time period in the massive and thick Jurassic limestone, generally following main faults; this feature mainly occurs in at lower to medium elevations (up to 1,000 m asl).
- Less inclined hilltops between those valleys; here villages have developed.
- At the top of J4, the massive Jurassic limestone, there are large areas where bare strongly karstified limestone rocks emerge, between soil filled depressions.
- In the area exceeding 1,800 m asl a high plateau was formed with generally light inclinations; no surface drainage pattern has developed here and the plateau is scattered with thousands of depressions (dolines).

4 Methodology

4.1 Data

The following resources were used:

- Geocoded satellite mosaic (ICONOS, 2005; provided by Department of Geographic Affairs);
- Geocoded raster data:
    - Geological maps 1: 50,000
      Map Sheet Beirut (Dubertret, M. L. 1945),
      Map Sheet Zahle (Dubertret, M. L. 1945),
    - Topographic maps 1: 20,000 (UTM 36N)
      Map Sheets M-7, M-6, M-5, L-7, L-6, L-5 (provided by Department of Geographic Affairs)
- Information from field work:
  Large scale karst features
  Detailed scale karst features
  Border of karst fields
  Field photos
  Waypoints (WP) from GPS measurements.

4.2 Mapping Procedure

The karst feature mapping was needed to prepare groundwater vulnerability maps using the EPIK (SAEFL, 2000) and COP (VIAS et al, 2002) methods. The groundwater vulnerability maps will be prepared with a grid size of 50 m * 50 m. The karst feature map had to provide the same accuracy.

First a ranking system differentiating between every component and rank in terms of infiltration capacity was developed. All surface karstic features were documented by photos (Pho) and their location recorded as waypoint (WP) by GPS (Annex 1). Field work took place during April to October 2011.

After the field work waypoints were entered into ArcGIS or Google Earth and the extent of each feature as observed in the field was digitized.

5 Geology of the Study Area

Topographical, geological and structural conditions are the main factors determining groundwater flow in the Mount Lebanon mountain range. The structural setup is quite complex and is mainly governed by elements resulting from the African/Arabian-European continental collision between the Upper Cretaceous and the Tertiary. The dominant element is the Beqa'a Graben with the left-lateral Yammouneh shear fault at its western boundary. The Beqa'a Graben is the northern extension of the Red Sea-Dead Sea-Jordan Rift Valley transform fault mostly referred to as the Dead Sea Transform Fault (DST). Along the DST a left-lateral displacement of 105-110 km took place between the African and the Arabian plates (http://woodshole.er.usgs.gov/project-pages/dead_sea/ tectonic.html).

The geological units occurring in the study area (Figure 3) are mainly composed of limestones/dolomites and to minor extent classic sediments. The timescale of the mapped formations ranges from the Lower Jurassic to Upper Cretaceous (Figure 2).

Due to the lack of a detailed geological map for the Jeita catchment, a new geological map was prepared by BGR (HAHNE et al., 2011).

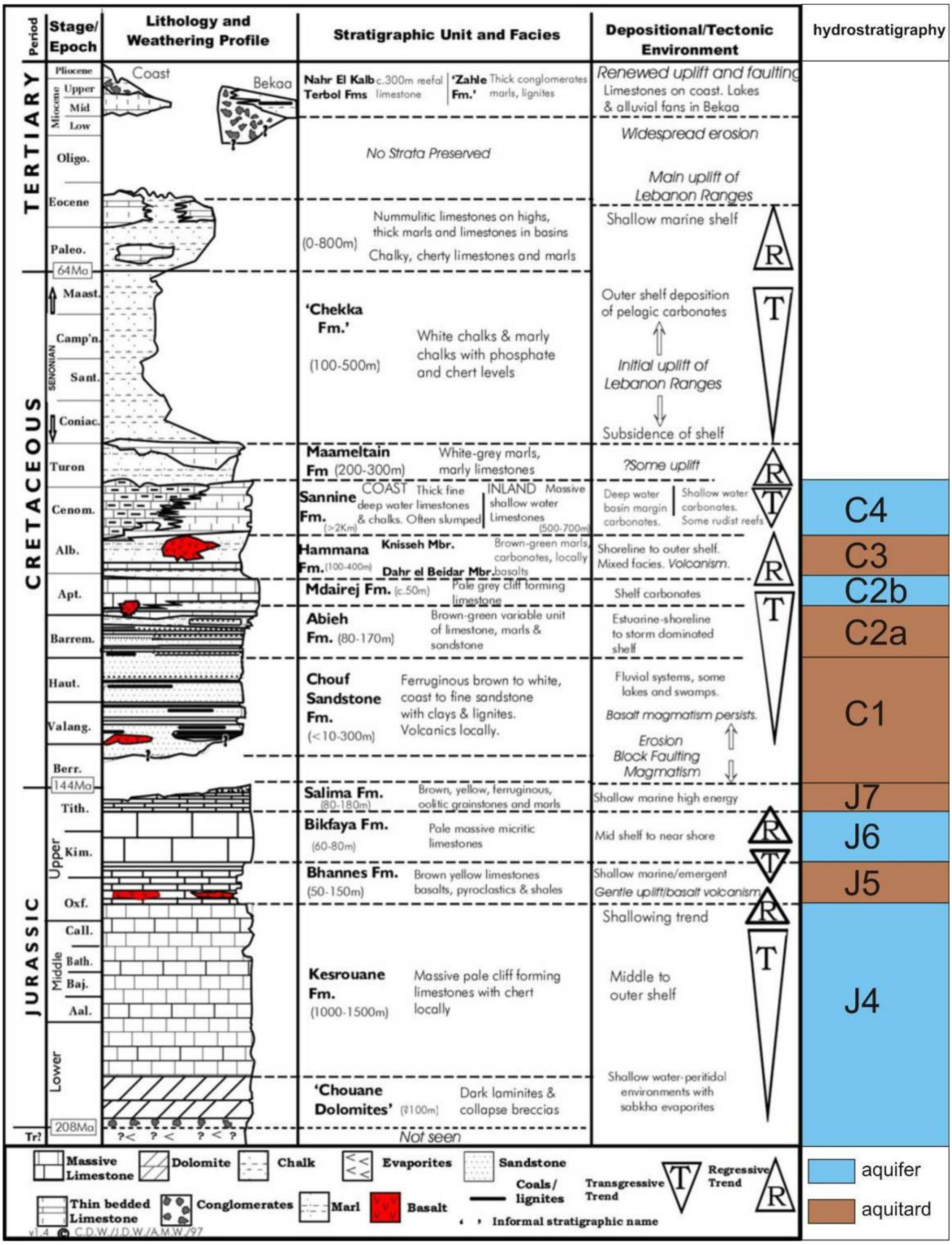

Figure 2: Hydro-lithostratigraphy in the Jeita Catchment (modified after WALLEY, 2001)

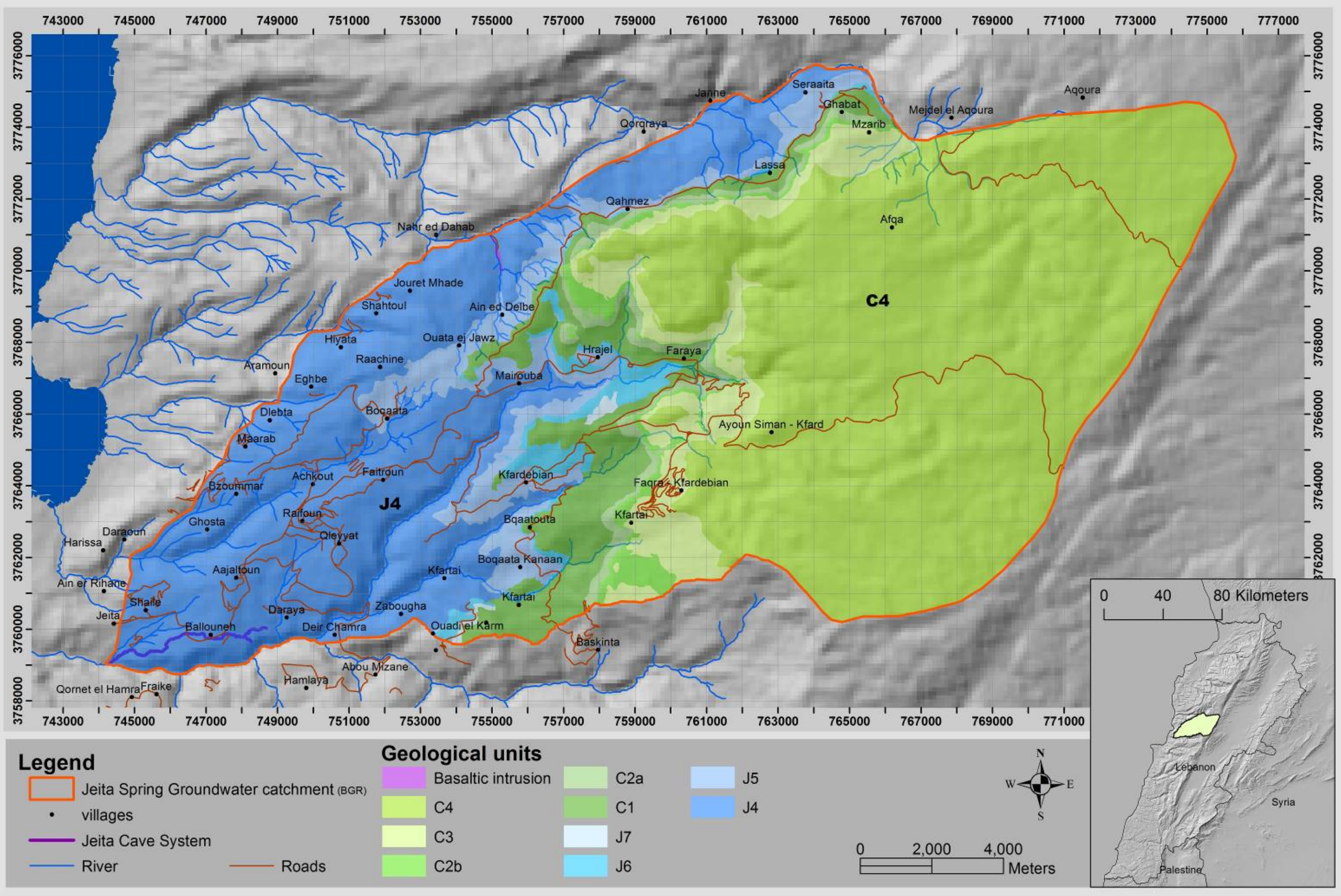

Figure 3: Geological Units occurring in the Jeita Groundwater Catchment (modified after HAHNE et al., 2011)

5.1 Limestone Units

Four predominantly carbonatic units which act as karstic aquifers crop out in the study area (Figure 4). Those karstic geological units cover more than 75% of the catchment area.

5.1.1 J4 (Kesrouane e Formation)

Age: Lower (Liassic) to Upper (Oxfordian) Jurassic.

Thickness: 1,000 m to 1,070 m in the mapped area.

Lithology: it consists mainly of massive micritic limestone. Fossils shells are common in layers.

Secondary dolomitization has affected large parts of the J4 sequence. The genesis of dolomites has not yet been studied in Lebanon. However, it can be safely assumed that dolomitization is most likely related to the intrusion of basalt and related hydrothermal waters along fractures (SHARP et al., 2010; DAVIES & LANGHORNE, 2006).

This unit is a cliff-forming formation covering 88 km² of the total catchment area. Generally color changes between light grey to almost white. The entire formation is deeply karstified. This karstification started with the uplift of the Mount Lebanon mountain range in the Upper Cretaceous. In the Jurassic large conduits and caves have formed, among them Jeita cave with one of the most important springs in Lebanon, Jeita spring. In the lower and central part of the Jeita catchment, the uppermost part of the J4 has often been exposed for long time periods and is thus most extensively karstified.

5.1.2 J6 (Bikfaya Formation)

Age: Kimmeridgian to Thitonian.

Thickness: approx. 100 m in the mapped area.

Lithology: it consists mainly of massive micritic limestone. Layers of (partially large) chert nodules are common witch allow a clear differentiation to almost similar shaped J4.

Cliff-forming formation, covering only 5.3 km² of the total catchment area, the color is light grey to almost white, chert nodules are common in this formation. The sequence is karstified at a similar level as the J4 formation.

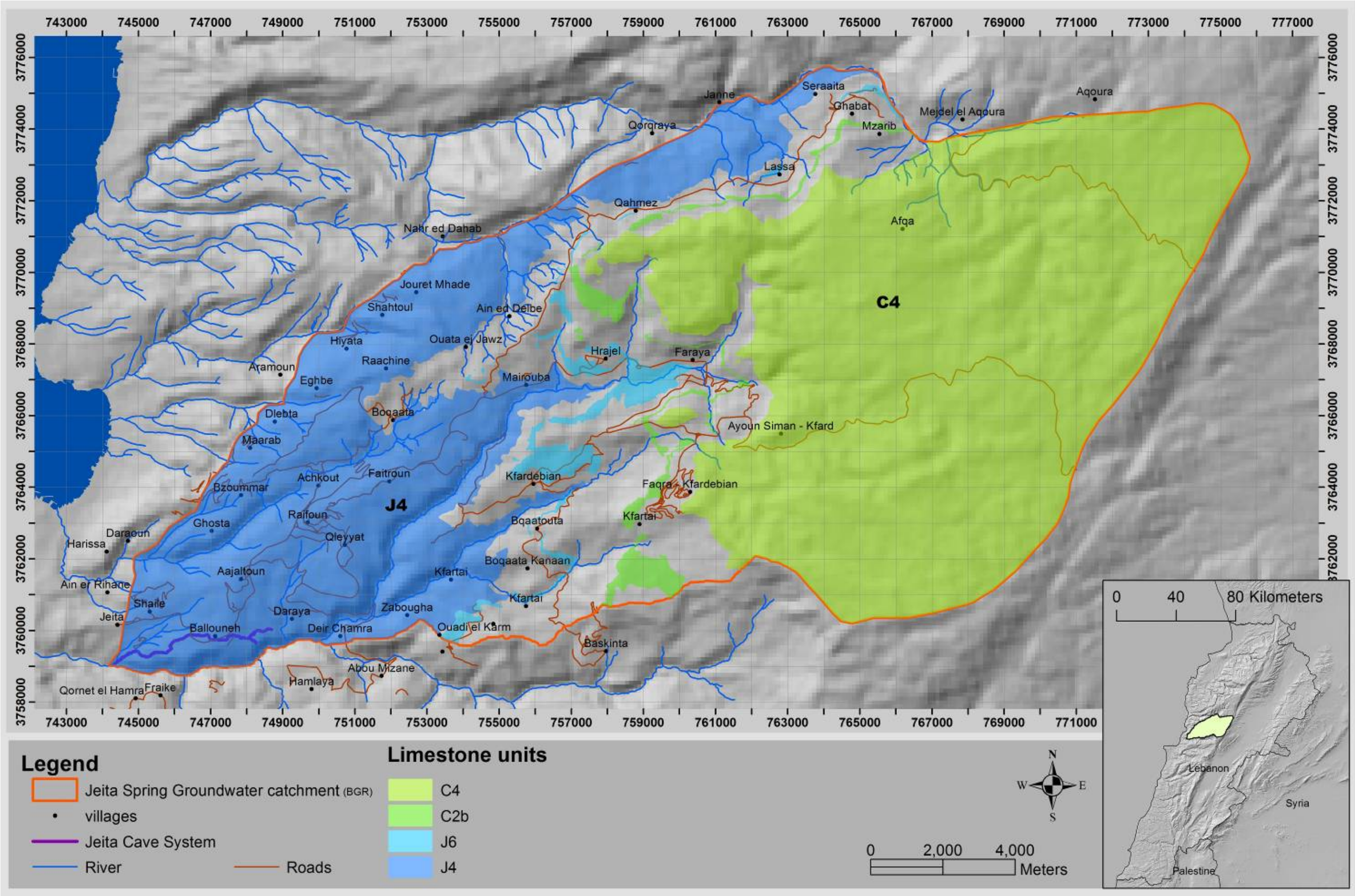

Figure 4: Limestone Geological Units.

5.1.3 C2b (Mdairej Formation)

Age: Early Cretaceous to Aptian

Thickness: approx. 50 m in the mapped area.

Lithology: it consists of massive light grey micritic limestone.

It is a Cliff-forming formation, covering only 4.2 km² of the total catchment area, a massive light grey limestone and strongly karstified.

5.1.4 C4 (Sannine Formation)

Age: Upper Albian to Cenomanian

Thickness: approx. 1,050 m in the mapped area

Lithology: It consists mainly of micritic light grey and beige limestone. At the base green and grey marl with bioturbation occurs.

This formation forms the gently north and east dipping high plateau of the Mount Lebanon mountain range, covering 148 km² of the Jeita catchment. The entire formation is highly karstified.

The largest aquifer in the Jeita catchment is the Upper Cretaceous C4 aquifer in the upper part, on the high plateau, the second largest is the Jurassic J4 covering the central and lower parts of the catchment.

5.2 Geological Units not subject to Karstification

Between the above mentioned predominantly carbonatic geological units, clastic and volcanic rocks of relatively low thickness are found. In some of these units marls and thin intercalations of limestones are observed (Figure 5). These units act mainly as aquitards and are not subject to karstification. In the geological sequence J5 to C3, the intercalated J6 and C2b aquifers play only a very minor role (there are no major springs emerging from these aquifers) and therefore for general considerations this entire sequence is regarded as an aquitard (MARGANE et al., in progr.).

5.2.1 J5 (Bhannes Formation)

Age: Late Oxfordian to Early, possibly Mid Kimmeridgian

Thickness: 200 m in the mapped area.

Lithology: composed from basalt, soft yellow marls and limestone, clay and silt stones all in thin layers. This formation acts as an aquitard.

5.2.2 C1 (Chouf Sandstone Formation)

Age: Berriasian to Hauterivian

Thickness: up to 380 m in the mapped area.

Lithology: At the base of C1 basalt intrusions are found at many locations. The sequence starts with ochre dolomites, followed by yellow limestone, grey marl and fine sandstone. Sandstone varies in color from grey and brown to yellow, orange, red and pink. It can be almost white. In the Mayrouba and Qahmez area, small springs emerge from this unit (discharge generally less than 5 l/s), however, in general it can be regarded as a low permeable sequence or even aquitard.

5.2.3 C2a (Abieh Formation)

Age: Barremian to Aptian

Thickness: 20 to 150 m in the mapped area.

Lithology: this unit consists of grey and ochre sandstones alternating with green, brown, reddish and beige claystones and marls as well as ochre and light grey fossiliferous limestones.

The Abieh Formation forms a very low permeable unit acting as an aquitard.

5.2.4 C3 (Hammana Formation)

Age: Upper Aptian to Middle Albian

Thickness: 110 to 350 m in the mapped area. Thickness is influenced by faults, probably formed during the deposition of the sequence.

Lithology: this formation consists of green, grey, ochre, red and beige claystone, and light grey marls. At the base of the unit basalt intrusions are often found, leading to the formation of red soils.

This unit is partly permeable and a number of small springs emerge from it but can be regarded as non-karstic.

The non-karstic geological units in the catchment cover less than 25% of the total groundwater contribution zone of Jeita spring.

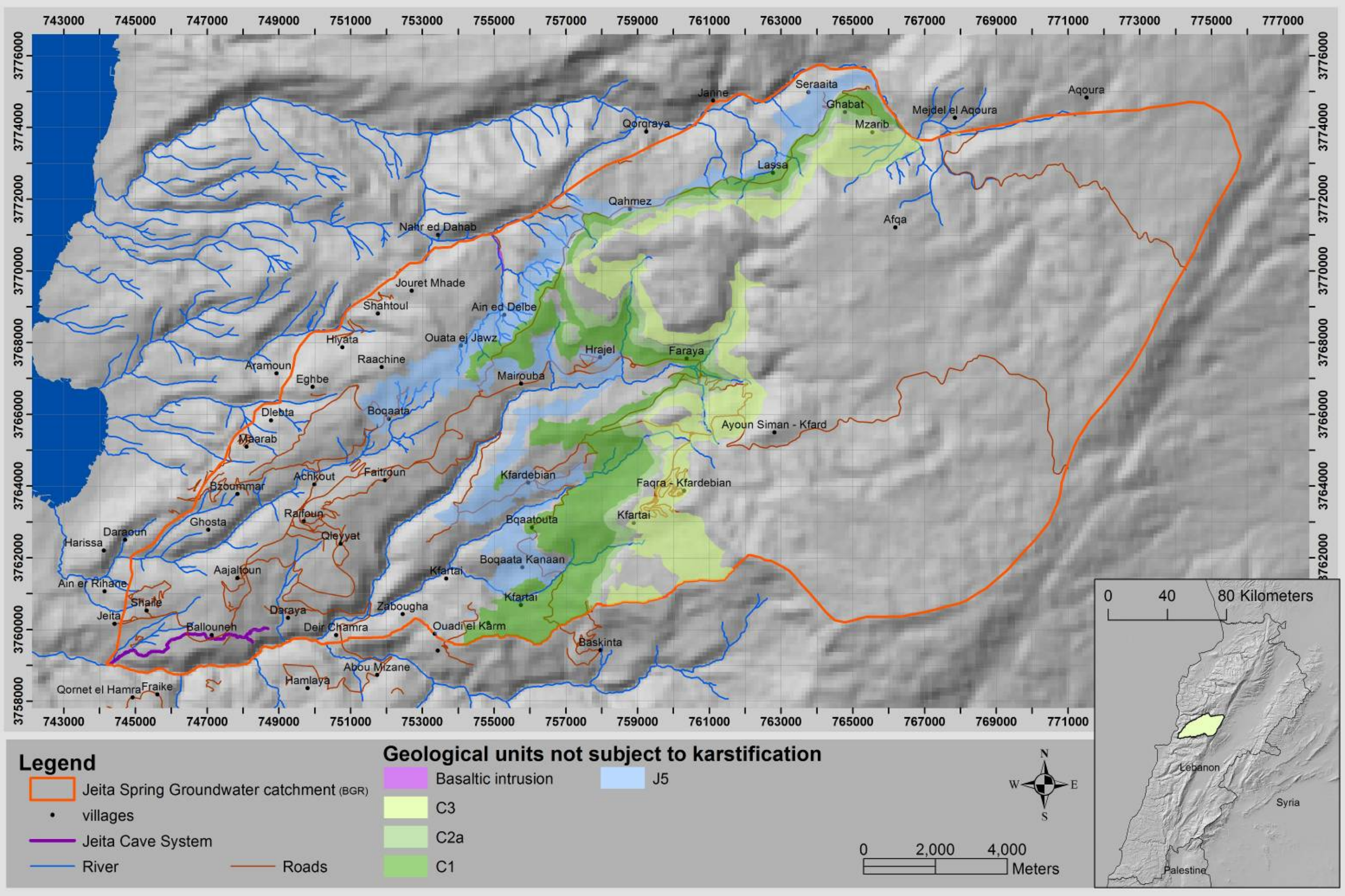

Figure 5: Geological Units not subject to Karstification

5.3 Karst Evolution

Karst formation is caused by biological and chemical dissolution and mechanical weathering processes in limestones. It depends on the composition, thickness and hardness of the limestone, on the intensity of fracturation (length, spacing, connectivity), on the fact whether fractures are filled and if so with what kind of material, on the climatic conditions (amount and intensity of rainfall, temperatures, extent and duration of snow cover, day/night temperature differences) as well as on the type and density of the vegetation cover.

The karst mapping revealed that the degree of karstification is quite different in the Jeita catchment and principally depends on the following factors:

- lithological composition;
- tectonics and structural development;
- climate (present-day and palaeoclimate) and
- exposure.

Although many geological units consist of limestone, its lithological composition varies considerably. Limestone dissolution often starts at bedding planes or fractures where the cohesion of rocks is disturbed. Dolines and poljes often follow zones of intensive fracturation. Karst conduits are often found bedding planes, i.e. lithological weak zones. Generally karstification is more intensive in areas with high rainfall.

However, the dissolution and weathering process is only one part of the karst formation process. The karst evolution is also closely linked to the general geological and structural development of an area. And in order to understand the groundwater flow mechanisms of a karst area, the geological and structural development has to be looked into.

The uplift of the Lebanon mountain ranges (Mount Lebanon and Anti-Lebanon) started in the Santonian of the Upper Cretaceous. However, until the Eocene a shallow marine environment prevailed and several hundred meters of predominantly marly sediments were deposited. The main uplift took place in the Eocene (56-34 MY ago) and thereafter (WALLEY, 2001). This is when the main erosion set in and karstification commenced. CO_2 levels were much higher than today (partly exceeding 2000 ppm (BEERLING et al., 2002), while today's CO_2 content of the atmosphere is only 390 ppm). Temperatures throughout the Tertiary were much higher compared to today. During the Paleocene-Eocene Thermal Maximum (PETM) sea-surface temperatures were more than 5°C higher than today (http://www.uta.edu/faculty/awinguth/PETM-Home.html; TRIPATI & ELDERFIELD, 2005). Both, higher concentration of atmospheric CO_2 and higher temperatures must have resulted in a higher rate of calcium carbonate dissolution and thus a very intensive karstification (Figure 6).

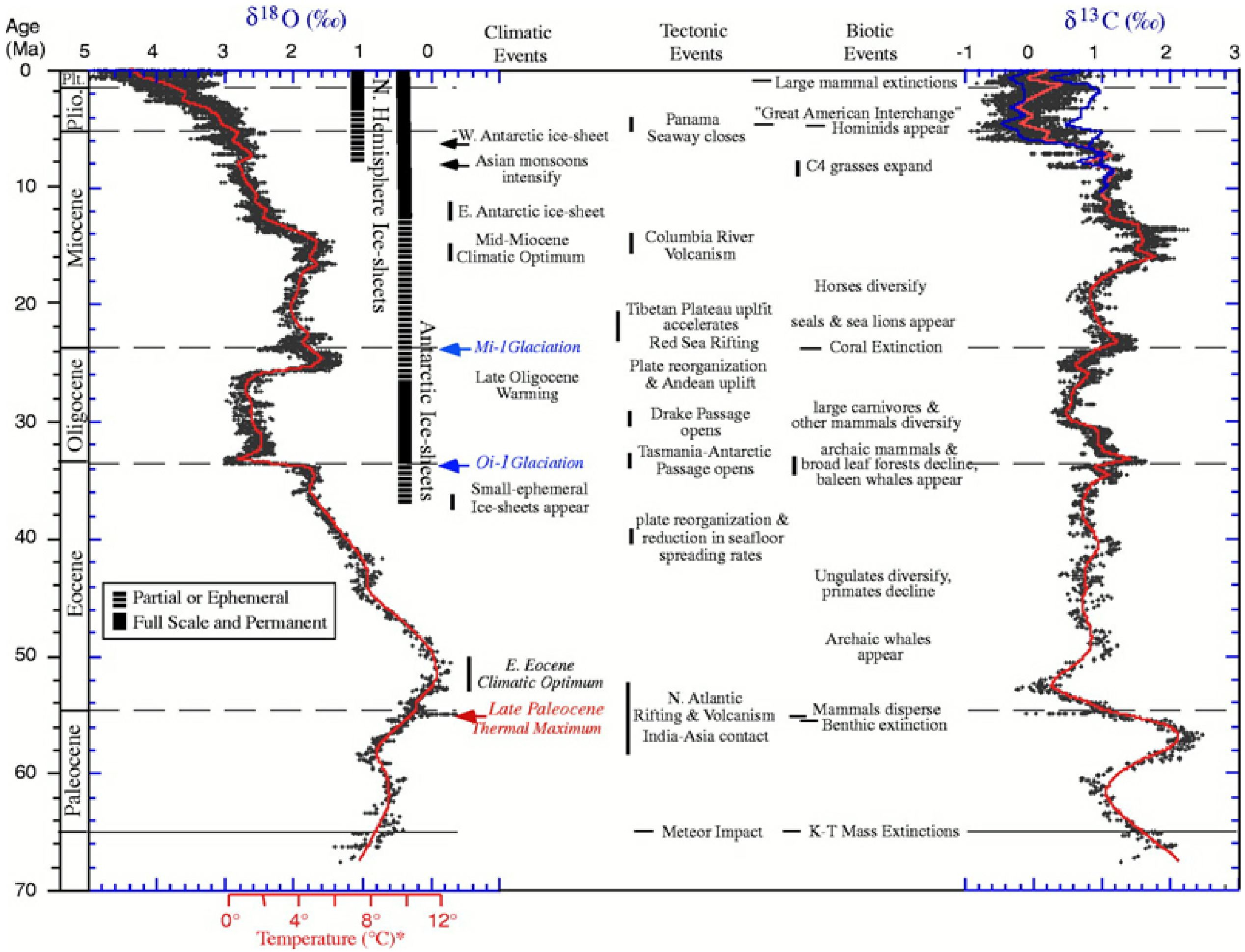

Figure 6: Changes in Earth's temperature and climate during the Tertiary and Quaternary (adopted from ZACHOS et al., 2001)

The Mediterranean Sea was formed in the process of continental collision between the African-Arabian with the Eurasian continent during the Tertiary, which led to the closure of the previous Tethys Ocean. In the Miocene, during the Messinian Salinity Crisis (6.0 - 5.3 MY ago; GAUTHIER et al., 1994), when the strait of Gibraltar was closed, the Mediterranean Sea dried up almost completely so that the drainage base level for the Mount Lebanon mountain range was several hundred meters lower than today. This might have caused an increased level of erosion.

During the Quaternary, large parts of the Lebanon mountain ranges (Mount Lebanon and Anti-Lebanon) were probably covered with glaciers. Esker-like structures were discovered by the project (MARGANE et al., in progr.) at very similar elevations of between 800 and 1,200 m asl, predominantly around 900 m asl (Figure 7), indicating that this must have been the lower limit of glaciation during the last glacial maximum (LGM). Similar glaciation limits at the LGM were reported from Turkey (SARIKAYA et al., 2011). Content in carbonic acid in water is temperature dependent, due to the fact that more CO_2 can be dissolved in water at lower temperatures (Henry's law). Cold rainfall thus contains more carbonic acid at a given partial pressure of CO_2 compared to rainfall warm rainfall. Therefore the carbonic acid content in rainfall and snow during the glacial periods must have been higher, resulting in a more intensive karstification.

Unfortunately comprehensive studies concerning Quaternary glaciations in this region (Syria and Lebanon) are still missing.

Karstification is most extensive where limestone had been exposed over a long period of time at elevations between 1,200 and 2,600 m asl and where actual rainfall is between 1,300 and 2,000 mm/a. The uppermost part of the Jurassic geological unit J4 exhibits large karrenfields, dolines and sinkholes at elevations between 1,000 and 1,400 m, The Upper Cretaceous Sannine Formation (C4) is exposed in the high plateau of the Mount Lebanon mountain range (> 1,800 m). There are practically no surface water runoff features developed on this plateau because rainfall and snow almost completely infiltrates into extended fields of dolines. The present day snow cover between December and May plays an important role for development of this extreme karstification of the Sannine Formation. But also Quaternary glaciations must have significantly increased karstification down to levels of around 900 m asl. Soils were most probably completely eroded during these glaciations.

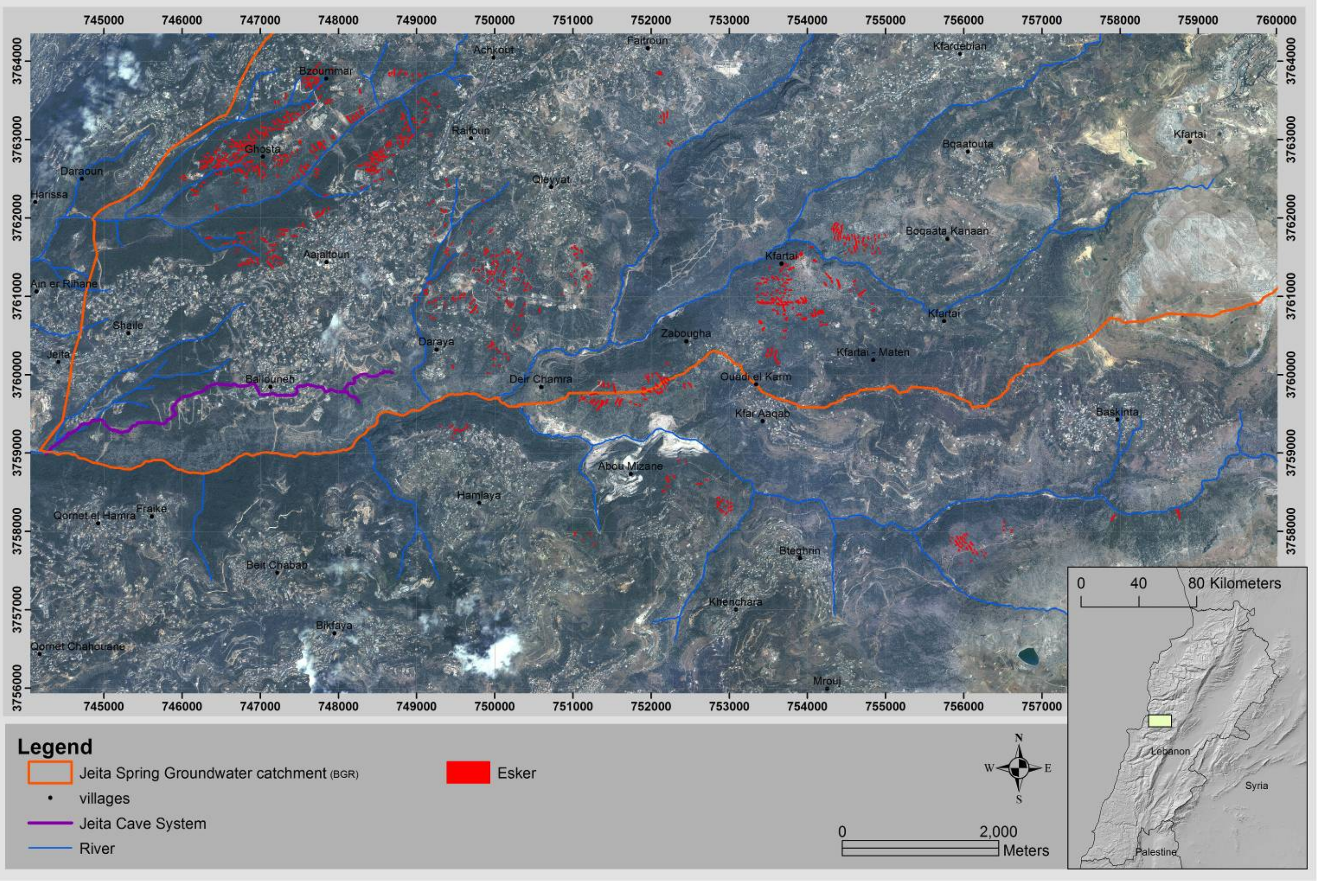

Figure 7: Spatial Distribution of Eskers in the Study Area.

6 Surface Karstic Features, Types and Scale

More than 80% of the study area is highly karstified geological units, many surface karstic features and forms can be found. Karst features can be divided in two main groups: large scale features (e.g. Figure 8), and small scale features (e.g. Figure 9).

Figure 8: Doline of 12m diameter (WP19)

Figure 9: Small Karren of 2 cm width and 20 cm length (WP67)

6.1 Large-Scale Karstic Features

Dolines

Figure 10: Doline excavated 3m of soil for agriculture (WP38)

Dolines are closed depressions in karst areas which are of circular shape. Dolines may be formed by dissolution of limestone rocks close to the surface or by collapse of the roof of a cave. Solution dolines tend to have a smooth funnel shape while collapse dolines often have cliff sides (Figure 10). Dolines often cause streams to sink underground.

Dolines in the high mountain range are mostly formed by frost weathering on fracture zones. Some are also formed by collapse of cavities following fault lines (Figure 11, 12). In the Jurassic J4 limestone dolines are formed mostly by collapsed cavities. At the bottom of these dolines an important amount of soil is accumulated.

Numerous dolines are found on the high plateau where the Upper Cretaceous C4 limestone crops out (Figure 12). A very large number was formed on the Qana plateau. But also in the uppermost part of the Jurassic J4 limestone, where it had been exposed over a long time period, such as in the Raashine, Boqaata, Achkout and Faitroun area, a large number of dolines is encountered. Doline in Lebanon is named "Joura".

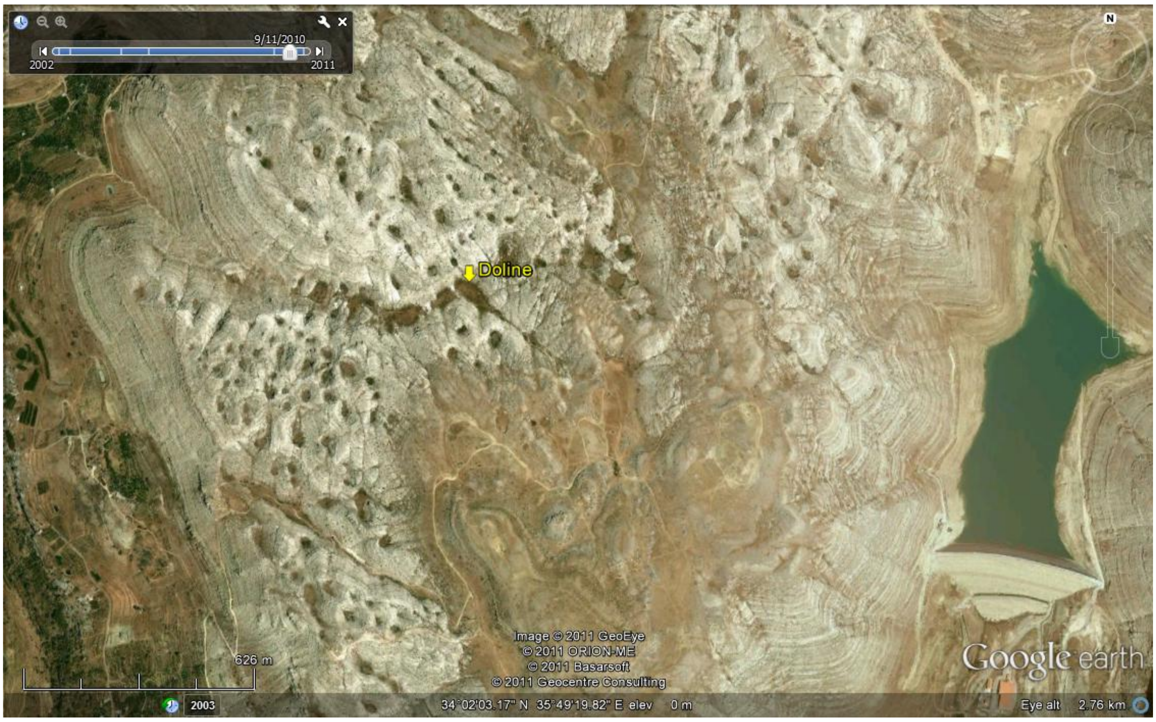

Figure 11: A Field of Dolines in the Qana Plateau of C4 Formation

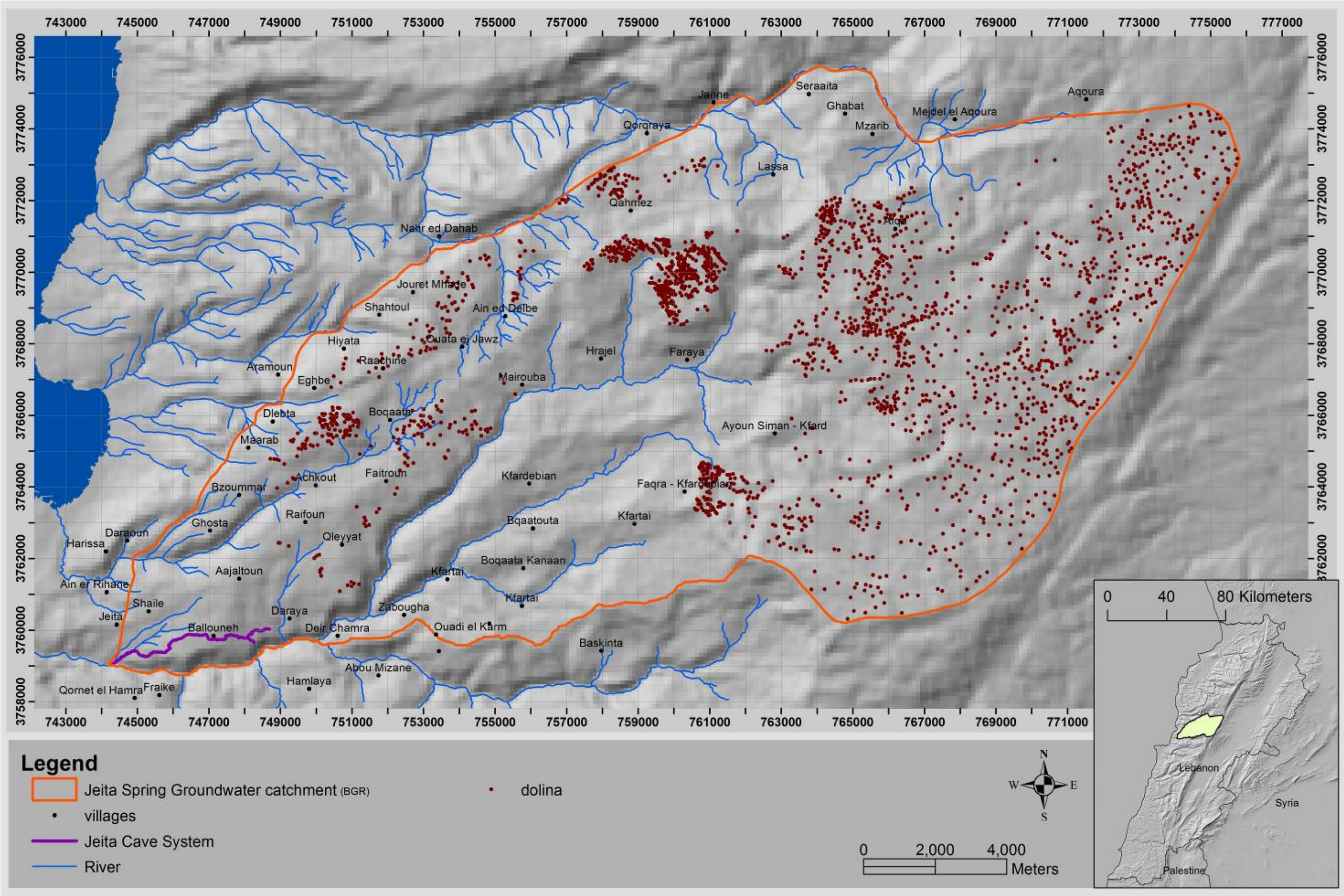

Figure 12: Distribution of Dolines in the Catchment Area.

Polje

Poljes are closed elongated depressions with flat bottoms, which are often adjacent to steep enclosing walls. They require extremely thick and geographically extensive carbonate bedrock to form. This is due to their size. Poljes have their own internal drainage systems and often have complex hydrogeological characteristics, including swallow holes and disappearing streams. They are frequently used for farmland and tend to flood at least once a season.

In the study area we found only one polje, in Wata el Jaouz village (Figure 13), “Wata” in Lebanon means a plane area, flat depressions with some water inside are named in Lebanon “Ramye” or “Ram”. This polje is 1.4 km long, 0.3 km wide and filled with basaltic soil from nearby basalt intrusions. The swallow hole, where the stream used to disappear in the North East side of the polje, collapses and becomes a small canyon.

Figure 13: Cultivated Polje in Wata el Jaouz (WP110)

Dry Valley

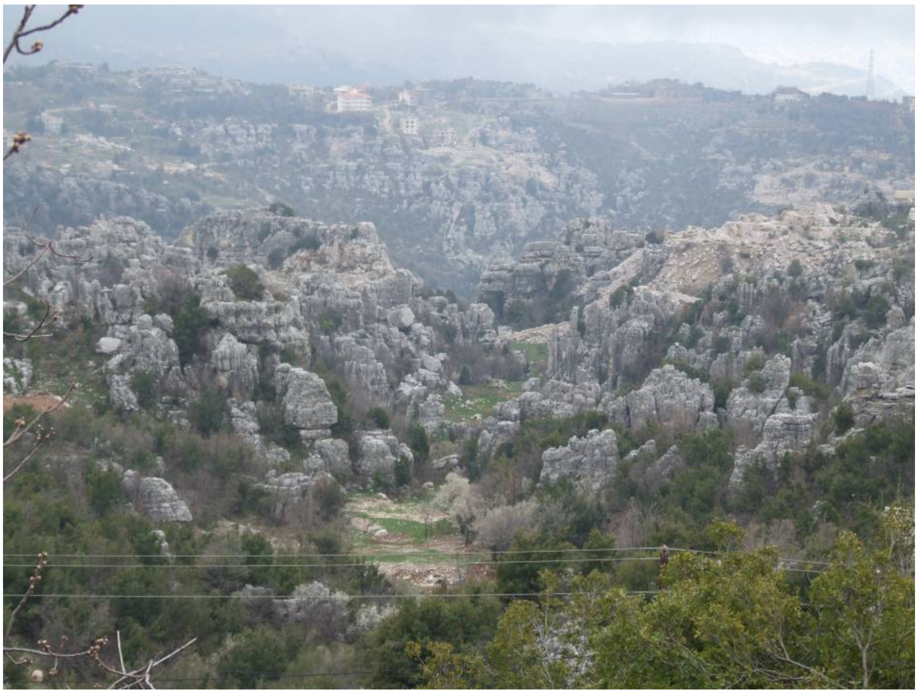

Figure 14: Dry Valley in Faitroun (WP45)

In karst areas most of the drainage occurs in the underground. Streams flowing over limestone sink into the underground and flow through conduits. The surface streams in dry valleys only flow at times of heavy rain when the underground drainage is unable to swallow all flow. Dry valleys often contain large boulders (Figure 15) but little fine sediment as their streams only flow during floods when there is too much energy to deposit mud and silt (Figure 14, 16).

Figure 15: Dry Valley with Boulders (WP109)

Figure 16: Trees growing in Dry Valley (WP108)

Blind Valley

Figure 17: Blind Valley in Qahmez (WP111)

This is a valley that is closed abruptly at its lower end by a cliff or slope blocking the valley. There may be a perennial or intermittent stream which sinks at its lower end (sinkhole) or it may be a dry valley (Figure 17).

Sinkholes

A sinkhole, named in Lebanon “Houwe” and “Baloua”, is a vertical cavity or opening that can be following a large fracture usually enlarged by dissolution, often becoming narrow at a bedding boundary where it can continue horizontally or vertically with thinner conduits (Figure 20). Usually sinkholes form a link between the land surface and the saturated zone (Figures 18, 19). They are found in large quantity in the Jurassic J4 area with different depths as well as in the upper Cretaceous C4, usually at the bottom of dolines.

Figure 18: Sinkhole following a Fault (WP67)

Figure 19: Sinkhole showing that Chemical Dissolution follows Weak Zones in the Rock (WP67)

Caves

Caves or caverns, named in Lebanon "Mghara", are large natural openings in the earth. Not all caves are formed by dissolution (Figure 20) but can be formed also by mechanical erosion and weathering. The size and length of caves varies largely. However, the fact that a cavern narrows to the point where humans can no longer explore it, does not mean that the karst drainage system ends there as well. Water draining through caves will continue through often narrow conduits, sometimes forming siphons. The bottom of caves can be holding some soil (Figure 21).

Figure 20: Cave in widened Fissure (WP105)

Figure 21: Bottom of a Cave covered with Soil and Grass (WP105)

Tower Karst

Figure 22: Tower Karst with marks of past Soil Levels during the Erosional History (WP85)

After extensive karstification most of the original rocks are eroded and only some cones emerge from a plane surface filled with soil (Figure 22). Tower karst is typically interpreted as a karst area in a very late stage of development (www.showcaves.com). It can be observed especially in the area between Faitroun and Wata el Jaouz.

Rinnenkarren, Tsingies, etc. often occur in tower karst areas (Figures 23, 24).

Figure 23: Spitzkarren, Rinnenkarren and Bedding Planes (Grikes) on a Tower Karst (WP83)

Figure 24: Rinnenkarren, Tsingies and Cavities on a Tower karst (WP81)

Rock Arch

Figure 25: Natural Bridge Faqra – Kfardebiane (WP106)
(length 52m, height 58m, width 62m, arch opening 38m)

In some very developed karst the river can disappear underground for a short distance in some conduits, which may be subject of collapse and erosion, the remaining solid rock sealing of these conduits looks like a bridge. A typical example of a rock arch can be observed at Faqra (Figure 25).

6.2 Detailed and Small Karstic Features

Karren Fields and Lapies

Figure 26: Karren Field with Tsingies

Dissolution by rainwater containing carbonic acid sculptures limestone to forms named karren. Shapes of parallel vertical grooves are named rinnenkarren (Figure 26). Other types of karren are spitzkarren, rundkarren, and trittkarren (names of German origin). When dissolution of the rock surface forms a shallow furrow in the downgradient direction, water is flowing into the furrow and through it, deepening it more and more over time. Finally the whole rock surface is drained through karren (Figures 27, 28, 29; www.showcaves.com).

Good examples of karren can be found at Faqra, near the archaeological site. Karrens are named in Lebanon “Chakhroub” and plural “Chakharib”.

Figure 27: Spitzkarren draining the Rock Surface

Figure 28: Rinnenkarren and Tsingies (WP67)

Figure 29: Draining Systems on Karren

Grikes

Grikes (crevasses, diaclases) are vertical joints (Figure 30) and bedding planes (Figures 31, 32) in limestone, which are widened by dissolution to deep elongated slots. These slots are called Grikes. Canyons are developed when a river passes by similar grikes. Large bedding planes are named in Lebanon “Kattin”.

Figure 30: Grike or Diaclase (WP67)

Figure 31: Erosion Progressing along Soft Rock Layer at Bedding Plane (WP67)

Figure 32: Bedding plane (WP67)

Kamenitzas

Kamenitza is one of the surface karst features existing in the Upper Jurassic J4 limestone (Kesrouane Formation) in Achkout, Boqaata, Raachin and Faitroun, named in Lebanon “Eld” or “Old”.

They are developed on any horizontal flat surface or inside a karren, where rain water doesn’t drain totally, the carbonic acid in the rainwater causes the surface of the rock to develop a depression. The clayey residue covers the bottom of the depression (Figure 33). Over time, during every rain event, the acid will attack the depression and erode the bottom slightly due to the clay protection, but the lateral parts of the depression will be attacked easily and eroded much faster, and stays for longer time than the rain event (one week or more) which enlarges the depression and creates overhanging edges of the depression (Figures 34, 35).

The size of a kamenitza varies between 4 cm to 100 cm or more sometimes.

Figure 33: Slightly developed Kamenitza on a horizontal Platform (WP107)

Figure 34: Large Size Kamenitza (80 cm diameter)

Figure 35: Kamenitza inside a Karren (WP107)

Overhanging Cavities

The highly karstified area of the Jurassic J4 limestone shows many of the surface karst features well known in the world. One of the karst features rarely found is this type of cavities, excavated on a cliff side, progressing towards uphill. This side of the rock remains more humid than exposed parts, which causes the beige taint due to clay sticking on it (Figure 36).

Figure 36: Overhanging Cavity in Karst Tower (WP67)

The hollowed parts of the original rock were less compact with high porosity which permits to retain infiltrating water.

This part of the rock stays more humid than the exposed parts which increase the frost weathering (mechanical erosion due to temperature variation between day and night causing dilatation and shrinking of the original rock). The original rock materials are cracked and eroded to create these overhanging cavities (Figure 37).

Figure 37: Detail showing the Cavity from Figure 36 (WP67)

Karst Pavement

Rainwater containing carbonic acid dissolves limestone and sculptures it along cracks or fissures. The water enters the crack and does not stay on the surface. The dissolution continues inside the crack, which gets wider and wider over time.

When limestone is affected by tectonic movements, fissures are created, usually parallel to each other with a more or less regular spacing. Sometimes also secondary fissures are formed at a certain angle to the primary fissures (www.showcaves.com).

The resulting karst pavements can be found at large scale covering 5 or 10 thousand square meters (Figure 38) or at small scale of a few square meters.

Figure 38: Large-Scale Karst Pavement (WP86)

6.4 Infiltrating and Non-infiltrating Karstic Features

Directly infiltrating karstic features are open and linked to the underground, without any natural filtering system, like sinkholes and diaclases or grikes and dolines (funnel shape) all with no soil filling at the bottom, these direct conduits permit infiltrating rainfall to reach groundwater with 70 to 80% infiltration rate, and with very high velocity.

Although in the epikarst sometimes pathways for infiltrating water may not be visible, usually areas with a high level of karstification have a high infiltration rate. Whether these pathways are open or blocked depends on the existence, type and thickness of the soil cover.

Even if in an area with karstified geological units there are no significant surface karstic features visible, there may be large cavities in the underground which only come to light during excavation work (Figures 39, 40, 41).

Figure 39: Infiltrating Conduits after Excavation in Antelias Quarries.

Figure 40: Epikarst Cracks are filled with Soil with no significant Surface Karst Features (WP52)

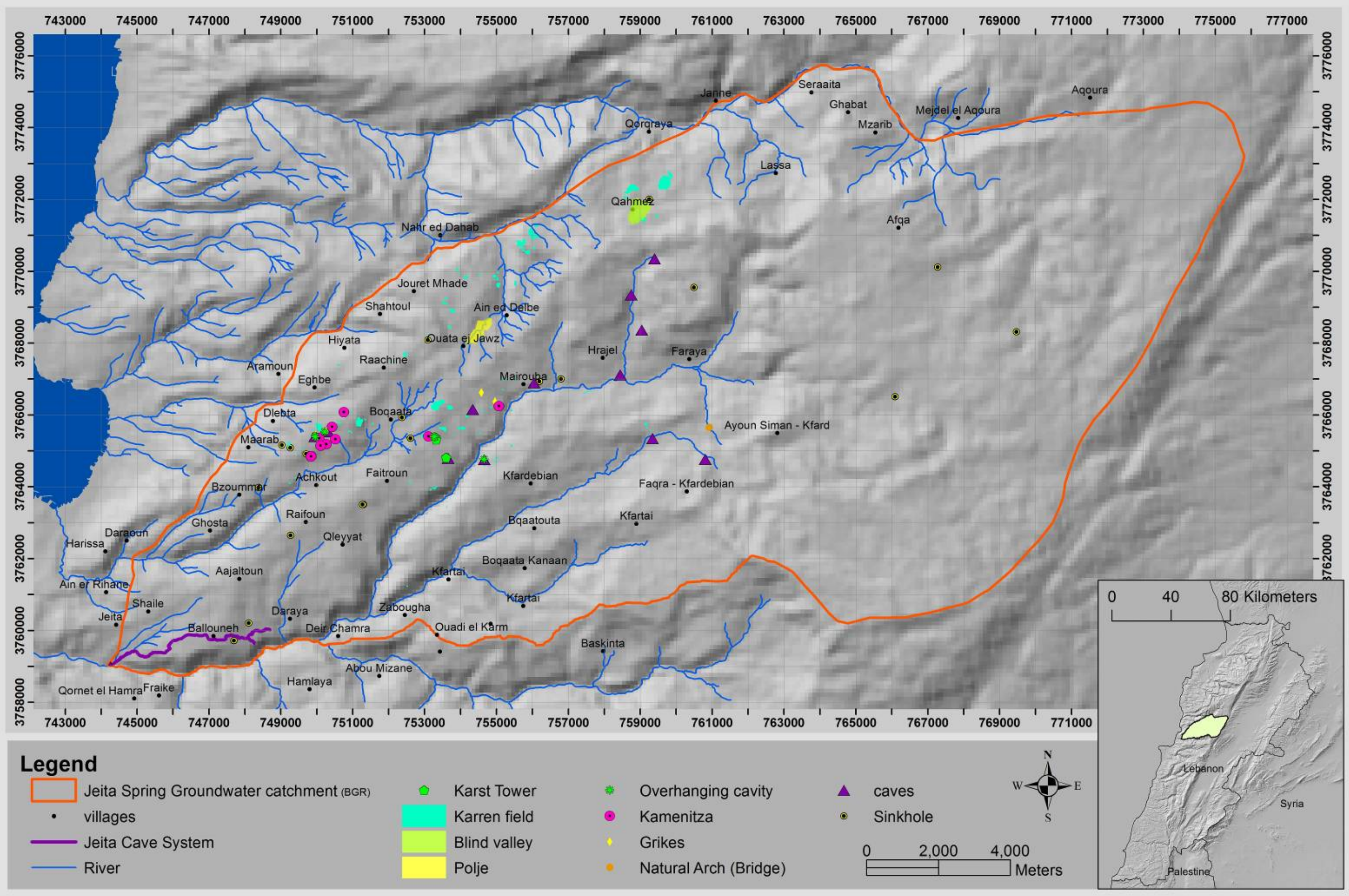

Figure 41: Spatial Distribution of Surface Karst Features

7 Results

A detailed karstic features mapping was conducted to find out occurrence of types, extent, spatial distribution, level of karstification and the evolution of the karst system (Figure 41).

Karst mapping will be used for two methods of groundwater vulnerability mapping, EPIK (SAEFL, 2000) and COP (VIAS et al., 2002). Both were specifically developed for groundwater protection in karst areas and are widely used for groundwater vulnerability mapping in karstic areas.

7.1 E-Factor Map for EPIK Groundwater Vulnerability Method

The EPIK method was elaborated in the framework of the COST 620 activities of the European Commission and later developed by the Swiss Agency for the Environment, Forest and Landscape (SAEFL, 2000). The parameters used are:

- development of the **E**pikarst,
- effectiveness of the **P**rotective cover,
- conditions of **I**nfiltration and
- development of the **K**arst network.

For the EPIK method the mapping of surface karst features is providing the parameter **E,** the **E**pikarst development (observed karstic morphology) and represented in a map. The E factor is subdivided into three categories:

- **E1** (caves, swallow holes, dolines, Karren fields, ruin-like relief, cuestas) representing the most infiltrating open karst.
- **E2** (intermediate zones situated along doline alignments, uvalas, dry valleys, canyons, poljes) representing an intermediate infiltration.
- **E3** (the rest of the catchment, absence of karst morphology) representing a low or no infiltration.

Based on the karst feature mapping conducted by the project, a map, grouping the entire area where geological units subject to karst formation are present into those three classes, wwa prepared (Figure 42).

The category mapped as low infiltration is where no karstic feature appears at the land surface and might be covered with soil.

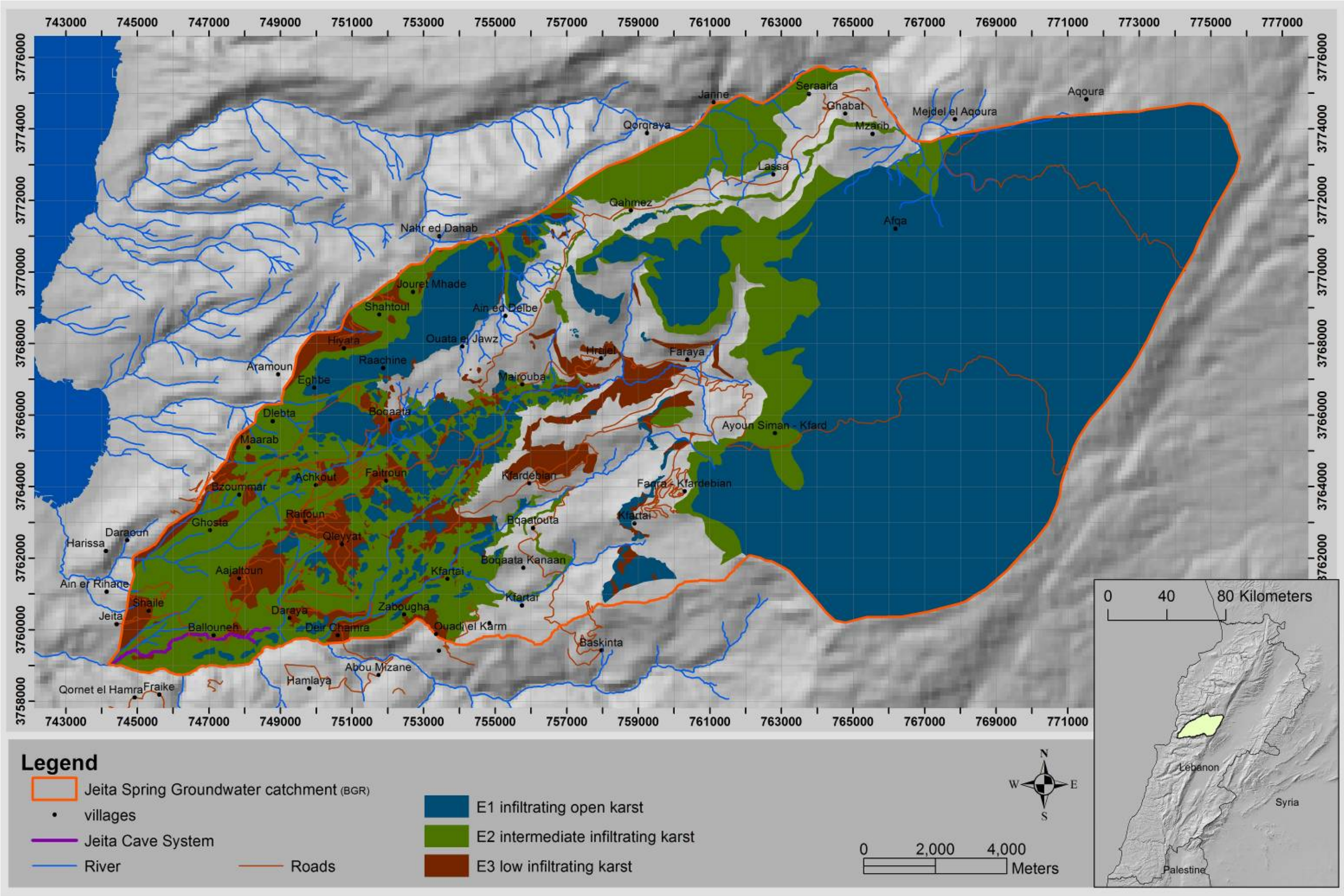

Figure 42: Spatial Distribution of E Factor for the EPIK Groundwater Vulnerability Map

7.2 Map for COP Groundwater Vulnerability Method

This COP method was introduced by the Group of Hydrogeology in the University of Malaga/Spain (GHUMA) in the framework of the COST 620 program as a standard method for groundwater vulnerability mapping in karst aquifers. It uses the parameters:

- C – concentration of flow
- O – overlying layers
- P – precipitation

For the COP method the karstic features mapping is providing the sf-subfactor of the C factor (concentration of flow of water towards karstic conduits that are directly connected with the saturated zone and thus indicate how the protection capacity is reduced) (Figure 43).

Concerning the C-factor, it is differentiated between two distinct geological settings: the catchment area of a swallow hole (scenario 1) and the rest of the area (scenario 2). In the first case, all water is considered to ultimately flow towards the swallow hole, whereas in the second case the amount of infiltration depends on the characteristics of the land surface.

C FACTOR (Concentration of flow)

SCENARIO 1 — Swallow hole recharge area

Distance to swallow hole (dh)

VII

Distance to swallow hole in meters	Value	Distance to swallow hole in meters	Value
≤ 500	0	(3000 - 3500]	0.6
(500 - 1000]	0.1	(3500 - 4000]	0.7
(1000 - 1500]	0.2	(4000 - 4500]	0.8
(1500 - 2000]	0.3	(4500 - 5000]	0.9
(2000 - 2500]	0.4	> 5000	1.0
(2500 - 3000]	0.5		

Slope and Vegetation (sv)

IX

Slope	Vegetation	Value
≤ 8 %	-	1
(8 – 31]	Yes	0.95
	No	0.9
(31 – 76]	Yes	0.85
	No	0.8
> 76 %	-	0.75

Distance to sinking stream (ds)

VIII

Distance to sinking stream	Value
< 10 m	0
10 - 100 m	0.5
> 100 m	1*

*: Also 1 when no sinking stream is present

Score $c = dh \cdot ds \cdot sv$

SCENARIO 2 — Rest of the area

Surface features (sf)

X

Karstic features	Surface layers: Absence	Permeable	Impermeable
Developed karst	0.25	0.5	0.75
Scarcely developed or disolution features	0.5	0.75	1
Fissured karst	0.75	0.75	1
Absence of karstic features	1	1	1

Slope and Vegetation (sv)

XI

Slope	Vegetation	Value
≤ 8 %	-	0.75
(8 – 31]	Yes	0.8
	No	0.85
(31 – 76]	Yes	0.9
	No	0.95
> 76 %	-	1

Score $c = (sf) \cdot (sv)$

XII

C SCORE	Reduction of protection
[0 – 0.2]	Very high
(0.2 – 0.4]	High
(0.4 – 0.6]	Moderate
(0.6 – 0.8]	Low
(0.8 - 1.0]	Very low

→ **C MAP**

Figure 43: Calculation of C-Factor for COP Groundwater Vulnerability Map

SCENARIO 1: swallow holes and its recharge areas

There is only one known large enough swallow hole, which has a rather small surface catchment

SCENARIO 2: the rest of the area

The surface features sub factor (sf), can be divided into 12 different classes based on the type of karst features and permeability.

For the mapped area all karst geological units are highly developed karst so that during mapping the following values were differentiated:

- Absence: value 0.25
- Permeable: value 0.5
- Impermeable: value 0.75

The spatial distribution of the sf-factor used for the COP map is shown in (Figure 44).

The non-karstic geological units are mapped as covering surface layer; this is why the whole study area is mapped and has a value on the map.

In case of the absence of a covering surface layer a value of 0.25 was attributed for the geological units J4, J6, C2b and C4.

For the non-karstic geological units it was differentiated between:

For permeable units (geological units C3 and J7) as covering surface layers for underlying karstic units a value of 0.5 was assigned.

For the non-karstic geological units J5, C1 and C2a as covering surface layers a value of 0.75.was assigned.

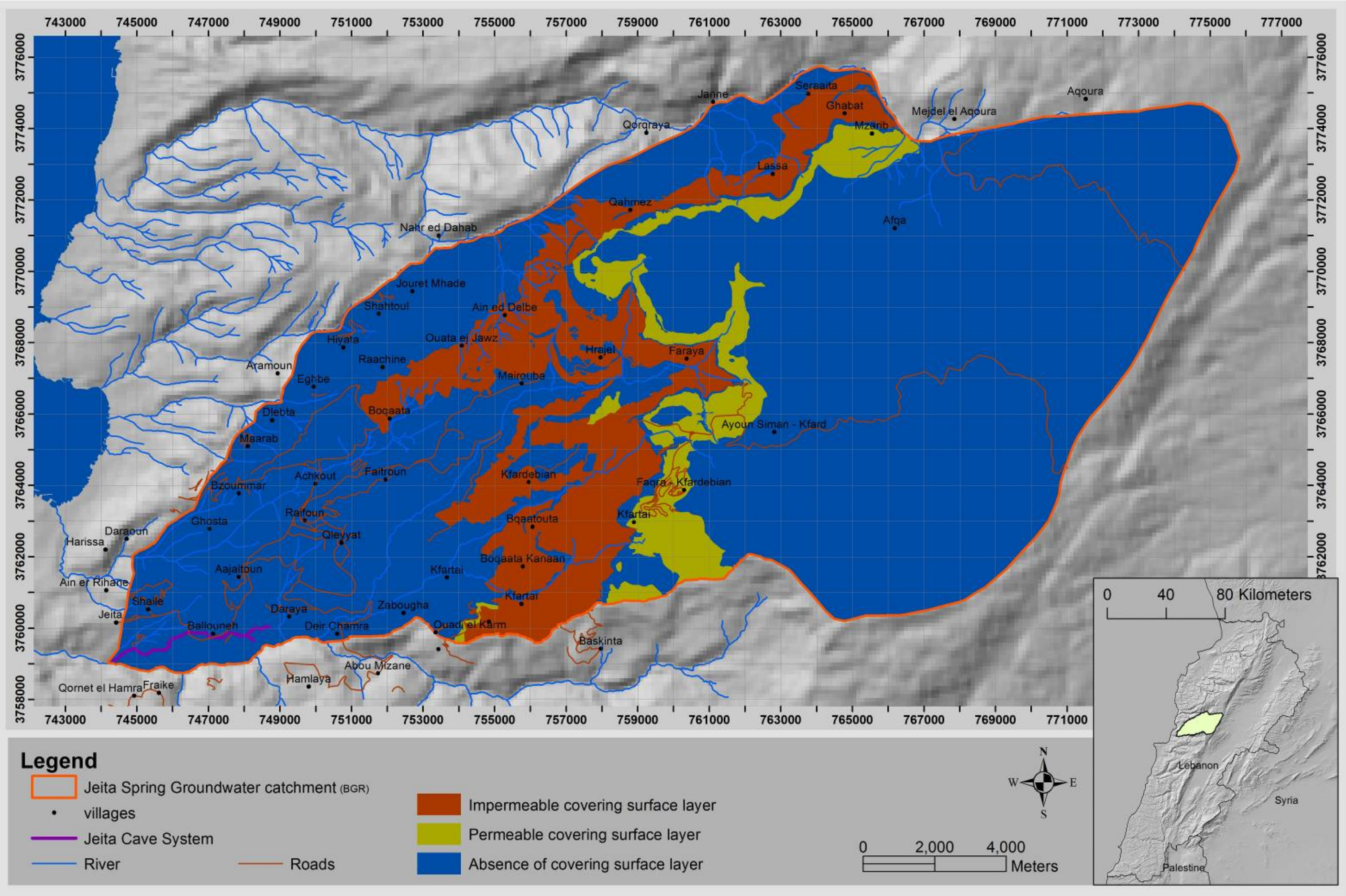

Figure 44: Spatial Distribution of SF-Factor of the C component for COP Groundwater Vulnerability Method

8 Discussion

In the EPIK method the E-factor, representing the epikarst, is mapped usually on the basis of geomorphologic karst features. Surface karst features are only one expression of epikarst, however, most features cannot be seen or only partly be seen at the surface. Epikarst can be highly developed without showing visible karst features at the land surface (Figure 45). Therefore EPIK groundwater vulnerability maps highly depend on the visibility of karst features and the quality of mapping of karst features.

Figure 45: Fissures filled with Soil without Indication at the Land Surface (WP53)

The surface karstification of the J4 Jurassic geological unit is caused by biological, chemical and mechanical weathering processes. It depends on the composition, thickness and hardness of the limestone, on the level of fracturation, on the fact whether fractures are filled and with what kind of material and on the type and density of the vegetation cover.

Karst conduits often follow bedding planes. A thin marl layer, 10 to 30 cm thick (Figure 46), was often observed separating thick limestone layers. Along this weak zone erosion starts enlarging cavities. Most surface karstic features in the J4 unit appear at elevations between 900 and 1,400 m asl.

On other hand karstification on the high plateau is highly developed due to glaciations during the Quaternary, covering large parts of the Mount Lebanon mountain range, down to elevations of approximately 900 m. This extensive ice cover which remained in place over thousands of years probably increased karstification processes due to permanent water availability, infiltration and frost weathering. Limestone blocks found in eskers at the lower limit of glaciations show a very high level of karstification. During the glaciations soils were abraded and transported downgradient with the ice so that at the end of the last glaciation probably no soil cover remained. The soil we see today must have formed only during the relatively short period after the last glaciation.

Figure 46: Layer of Marl in Massive Limestone of J4 (WP67)

Figure 47: Alignment of Dolines following Fault Lines in the C4 Formation

It is worthwhile mentioning that on Qana plateau alone (in C4 Sannine Formation) 402 dolines exist and that in the entire C4 outcrop in the Jeita catchment close to 1,850 dolines are present, while in the J4 unit (Kesrouane e Formation) there are only close to 360 dolines. These dolines (more than 2,200) are certainly features which allow for most of the infiltration and are therefore the main points of groundwater recharge (Figure 12, 47).

Concerning the COP method three aspects of karst are covered: a) direct infiltration through sinkholes (swallow holes), b) direct infiltration through disperse karst features (differentiation of level of karstification) and c) layers of low permeability covering the karst and hindering infiltration.

9 Conclusion

Between 2010-2011 a detailed geological map had been prepared by the project (HAHNE et al., 2011). During this mapping it was recognized that for the delineation of groundwater protection zones surface karst features would have to be mapped in detail. This mapping was accomplished during the second half of 2011.

The detailed mapping of karst features in the Jeita groundwater catchment proved to be invaluable for preparation of the groundwater vulnerability maps, which will be the basis for the delineation of groundwater protection zones. The availability and thickness of soil as a residue of karstification processes plays a major role concerning infiltration. The infiltration rate is high in extremely karstified areas, where there is little soil. Such areas are mostly found towards the top of the J4 formation, where it has been exposed over a long time period, such as e.g. in the area between Raashine and Wata el Jaouz or the Faitroun area. The low availability and thickness of soils in these areas may be related to the fact that soils were probably completely eroded in all areas higher than 900 m during the Quaternary glaciations. Only after the last glaciation soil started forming again. Despite this fact, soil of sometimes considerable thickness has accumulated in the meantime in valleys and depressions, hindering infiltration.

The palaeoclimate seems to have played a major role for the evolution of the karst. The level of karstification is extreme in the Upper Cretaceous C4 limestone, where fields of dolines are found and where virtually no surface drainage system has developed. Hundreds of eskers which have been identified by the project at elevations predominantly around 900 m asl (between 800 and 1200 m asl), it is inferred that the Lebanon and possibly also the Anti-Lebanon mountain ranges were covered by extensive ice sheets during the Quaternary. It is believed that these Quaternary glaciations increased karstification processes and are the main reason for the very intensive karstification in the Upper Cretaceous C4 limestone and the exposed uppermost Jurassic J4 limestone. This is related to the fact that solubility of CO_2 in water is higher at lower temperatures. At low temperatures also more carbonic acid is found in water, leading to a higher dissolution rate of carbonate rocks. In the high plateaus where the C4 limestone is exposed, there is practically no vegetation and rain and melting snow infiltrate directly into dolines and sinkholes in those areas. Because of the high elevation actual evapotranspiration is relatively low and it is estimated that about 80 % of precipitation contribute to groundwater recharge in the C4 aquifer (MARGANE et al., in progr.).

Doline fields, sinkholes, grikes and karrenfields are high infiltrating areas. Due to the extensive vegetation and soil cover it was sometimes difficult to map surface karst features in the epikarst. Below the epikarst it becomes even more difficult to assess the infiltration capacity. Here numerous conduits of various sizes have developed draining the water infiltrating in the epikarst towards the groundwater. With increasing depth of the unsaturated zone the fractures seem to have been filled with clayey material. This can be observed for instance in Nahr el Kalb in the lower part of the Jurassic J4 limestone. In Jeita grotto there are only few places where infiltrating rain reaches the grotto through open fractures after heavy rainfall events. During tracer tests in Nahr es Salib at the end of the rainy season infiltration in the river bed into the J4 aquifer was negligible (MARGANE et al., in progr.). This leads to the assumption that fracture porosity in the lower part of the J4 aquifer is low and groundwater is mainly channeled through conduits.

Partly an extensive secondary dolomitization of the Kesrouane Formation (J4) of the Jurassic is noticed. Calcium magnesium carbonate (dolomite) is much less soluble than calcium carbonate (limestone). Therefore karstification in dolomite is significantly less compared to limestone. It is assumed that dolomitization is related to intrusions of basalt and related hydrothermal waters along fractures.

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Annex 1

Waypoints for field photos as mentioned in figures.

WP name	Longitude	Latitude	Height asl [m]
19	35.776991	34.013381	1224
38	35.738452	34.000961	1306
45	35.739821	33.992654	1258
52	35.70684	33.983824	1059
53	35.720439	33.98946	1148
67	35.706498	33.999426	1201
81	35.736659	33.987575	1197
83	35.740462	33.992066	1243
85	35.743172	33.997033	1273
86	35.742911	33.998541	1284
101	35.669416	33.978893	700
102	35.666846	33.975908	665
105	35.753975	34.005226	1305
106	35.824915	33.999062	1595
107	35.704922	33.994419	1089
108	35.754835	33.996491	1134
109	35.762214	33.997481	1149
110	35.758377°	34.026189°	1284
111	35.805441°	34.055401°	1447