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Council for Development and Reconstruction
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Federal Institute for Geosciences
and Natural Resources
BGR
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TECHNICAL COOPERATION

PROJECT NO.: 2008.2162.9

Protection of Jeita Spring

TECHNICAL REPORT NO. 4

Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring supported by Remote Sensing

Hannover

September 2011

Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring supported by Remote Sensing

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Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
CDR	Council for Development and Reconstruction
DEM	Digital Elevation Model
DSFS	Dead Sea Fault System
ETM	Enhanced Thematic Mapper
GDEM	Global Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
m asl	Metres above sea level
MoEW	Ministry of Energy and Water
RGB	Red Green Blue (colour bands combination)
SRTM	Shuttle Radar Topography Mission
WE-BML	Water Establishment Beirut and Mount Lebanon
WP	Way Point (measured by GPS)

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Technical Reports		
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
4	Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring supported by Remote Sensing	September 2011
5	Hydrogeology of the Groundwater Contribution Zone of Jeita Spring	In progress
6	Water Balance for the Groundwater Contribution Zone of Jeita Spring using WEAP including Water Resources Management Options and Scenarios	In progress
7	Groundwater Vulnerability Mapping in the Jeita Spring Catchment	April 2012
Special Reports		
1	Artificial Tracer Tests 1 - April 2010 (prepared with University of Goettingen)	July 2010
2	Artificial Tracer Tests 2 - August 2010 (prepared with University of Goettingen)	November 2010
3	Practice Guide for Tracer Tests	Version 1 January 2011
4	Proposed National Standard for Treated Domestic Wastewater Reuse for Irrigation	July 2011

Report No.	Title	Date Completed
5	Artificial Tracer Tests 4B - May 2011 (prepared with University of Goettingen)	September 2011
6	Artificial Tracer Tests 5A - June 2011 (prepared with University of Goettingen)	September 2011
7	Mapping of Surface Karst Features in the Jeita Spring Catchment	October 2011
8	Monitoring of Spring Discharge and Surface Water Runoff in the Jeita Spring Catchment	In Progress
9	Soil Survey in the Jeita Spring Catchment	First Draft November 2011
10	Mapping of the Irrigation System in the Jeita Catchment	First Draft November 2011
11	Artificial Tracer Tests 5C - September 2011 (prepared with University of Goettingen)	February 2012
12	Stable Isotope Investigations in the Jeita Spring Catchment	In Progress
13	Micropollutant Investigations in the Jeita Spring Catchment	May 2012
14	Guideline for Gas Stations - Recommendations from the Perspective of Groundwater Resources Protection	May 2012
15	Tritium - Helium Investigations in the Jeita Spring Catchment	In Progress
16	Hazards to Groundwater and Assessment of Pollution Risk in the Jeita Spring Catchment	In Progress
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1	Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley	May 2012
1-1	Quantification of Infiltration into the Lower Aquifer (J4) in the Upper Nahr Ibrahim Valley, Addendum No. 1	June 2012
Reports with KfW Development Bank (jointly prepared and submitted to CDR)		
1	Jeita Spring Protection Project Phase I - Regional Sewage Plan	October 2011
2	Jeita Spring Protection Project -	May 2012

Report No.	Title	Date Completed
	Feasibility Study - Rehabilitation of Transmission Channel Jeita Spring Intake – Dbaye WTP	
3	Jeita Spring Protection Project - Environmental Impact Assessment for the Proposed CDR/KfW Wastewater Scheme in the Lower Nahr el Kalb Catchment	In Progress

Acknowledgements

In its effort to protect the water resources of Jeita Spring 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 Jisr, Eng. Ismail Makki and Wafa Charafeddine, the Ministry of Energy and Water (MoEW), namely H.E. Gebran Bassil and his advisors, the Water Establishment of Beirut and Mount Lebanon (WEBML), namely its president, Joseph Nseir, as well as Georges El Kadi (project manager), Maher Chrabieh (Director of the Dbaye treatment plant) and Dr. Paul Souaid (Director of the Water Laboratory at the Dbaye treatment plant).

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 and German Embassy in Lebanon. We experienced that this assistance is very much appreciated not only among the involved institutions and stakeholders but also by the population living in the study area.

I was accompanied by my Lebanese colleague Jean Abi Rizk most of the time during the last two campaigns. His excellent knowledge about the study area and his kind and gentle way to handle people was a great help for fast progress of the mapping works.

Executive Summary

The main reason for the geological mapping conducted in the framework of the technical cooperation project Protection of Jeita Spring was that the existing geological map, prepared in the early 1940s, was not accurate and detailed enough.

An in-depth understanding of the geology and tectonic setup, however, is the basis for an understanding of flow in the groundwater system. Also the natural protection of the aquifers system highly depends on the lithology, level of fracturation, karstification and the formation of a karst network. Therefore the detailed geological mapping conducted at the beginning of the BGR project was of utmost importance for all later groundwater investigations. The mapping work was supported by remote sensing.

The still ongoing groundwater investigations have shown that the boundaries of the surface water catchment are very different from the groundwater catchment. The area investigated in this report is thus referred to as “groundwater contribution zone” representing a part of the whole groundwater catchment.

1 Scope of Work

The bilateral German-Lebanese Technical Cooperation project "Protection of Jeita Spring" aims to reduce the risk of pollution for the main source of water supply of Beirut.

Basic demands for vulnerability estimation are up-to-date geological- as well as structural maps.

Existing geological maps (published in 1945) do not meet the project's requirements. Old maps are partially misinterpreted and geological formations are mapped too coarse, as they do not specify all of the calcareous units which represent hydro geologically important aquifers.

For this reason, the scope of the assignment in this report was

- detailed geological mapping of the Jeita Spring/Nahr el Kalb catchment supported by remote sensing,
- structural measurements,
- delimit karst features, major fault- and fracture zones by various remote sensing methods and to verify them in the field.

Special caution had to be taken in many areas due to scattered land mines.

The Jeita project provides support to the Lebanese institutions responsible for planning of wastewater facilities in the Nahr el Kalb catchment. Partners of this technical cooperation project are the Council for Development and Reconstruction (CDR), the Ministry of Energy and Water (MoEW) and the Water Establishment Beirut and Mount Lebanon (WE-BML) as well as the municipalities involved.

Field work was done during three campaigns: 13/04/2010 to 12/05/2010, 01/09/2010 to 28/09/2010 and 09/03/2011 to 31/03/2011.

2 Working Area

The working area comprises mainly the surface catchment of the Nahr el Kalb River, NE of Beirut, covering 302 square kilometres of mapped ground (figure 1). Its geographical corners are approximately 33°54'20''N / 35°38'20''E in the SW and 34°3'10''N / 35°54'8''E in the NE. The lowest point with 47 m above sea level (asl) is situated W of Jeita spring in the Nahr el Kalb River. The highest point, Mount Sannine, with 2,628 m asl, is situated on the high plateau of the Mount Lebanon mountain range, which represents the main groundwater recharge area.

The results presented in this report document the geological mapping conducted in the surface water catchment of Jeita spring. While in the beginning it was assumed that the extent of the groundwater catchment of Jeita spring is similar to the surface water catchment, this later turned out to be not the case (MARGANE et al., in progr.). Due to results of the ongoing groundwater investigations the project area had to be redefined several times in the course of the geological mapping. The geological mapping continued later, will be documented in another project report.

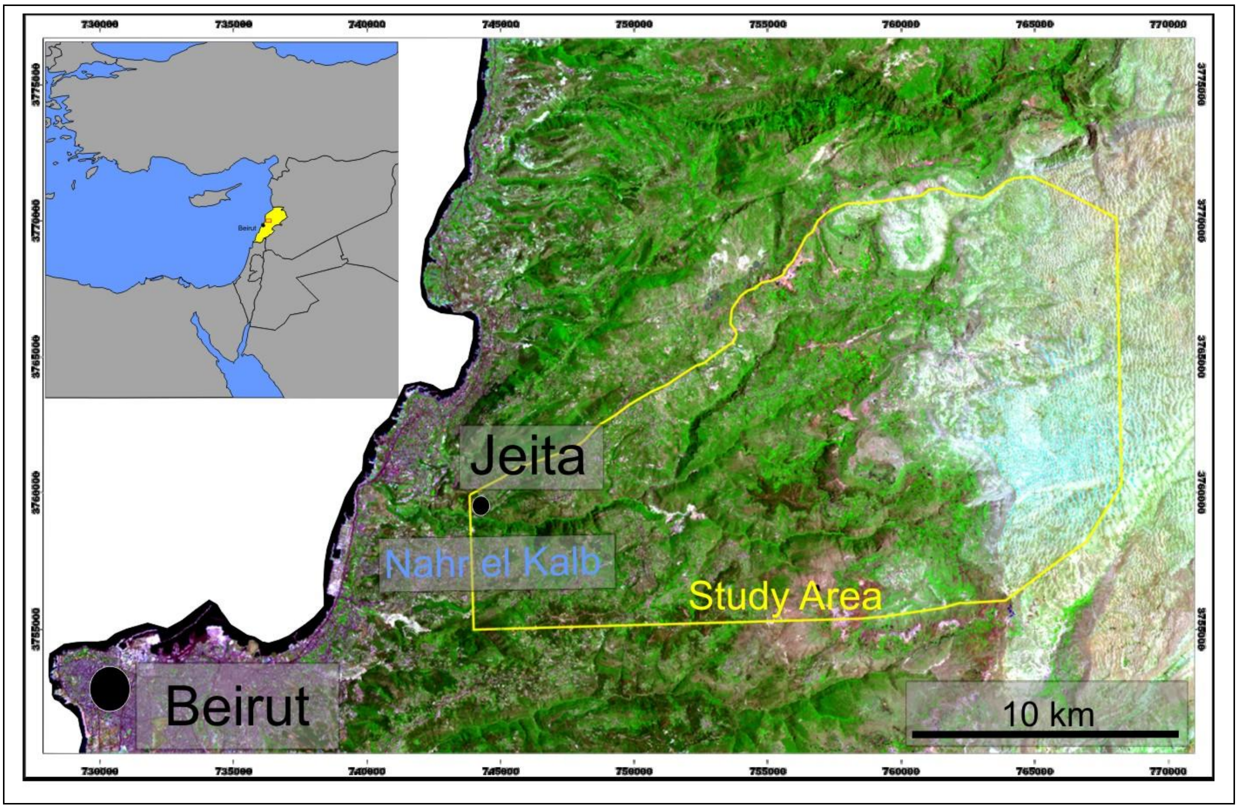

Figure 1: Location of the working area in Lebanon marked by yellow frame. Landsat ETM, 22/06/2000, bands 7,4,2 (RGB)

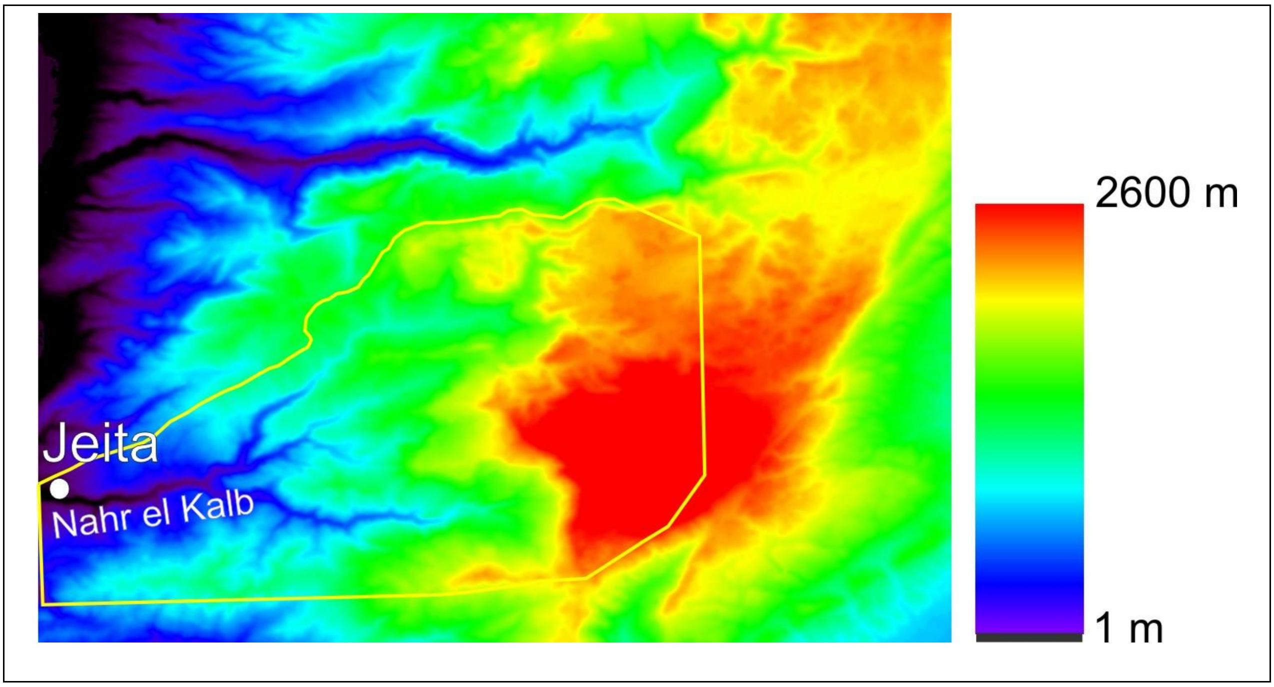

Figure 2: Location of the working area in Lebanon in ASTER GDEM with colour-coded altitudes

Snowfall is most important for groundwater recharge. In this catchment snow accumulates generally at elevations exceeding approximately 1,000 m asl. At elevations above 1,900 m, the mountain range consists of an extensive high plateau. This plateau is covered by dolinas of different sizes (average: 10 metres deep and up to 100 metres in diameter). Snow is particularly accumulated in these cavities while in the surrounding hills snow cover is less. Snow cover also depends on the prevailing wind direction (which in winter is from WSW).

3 Data

The following data were used within Arc View GIS (version 3.2) for geological / tectonical analysis and fault vectorization:

- Enhanced and geocoded satellite images:
  - Quick Bird, panchromatic and multispectral images with a ground resolution of 0.6 m and 2.5 m respectively. Acquisition dates: 01/12/2007, 12/08/2008, 07/09/2009 and 18/09/2009.
  - Landsat ETM with ground resolution of 30 m (panchromatic 15 m). Acquisition date: 22/06/2000.
  - ASTER GDEM digital elevation model (stereoscopic ASTER satellite DEM combined with SRTM-DEM) with ground resolution of 1 arc-second (approx. 25 m at latitude of study area).
- Geocoded raster data:
  - Geological maps
    - Map Sheet Beirut (Dubertret, M. L. 1945),
    - Map Sheet Zahle (Dubertret, M. L. 1945),
  - Topographic maps 1 : 20,000 (UTM)
    - Map Sheets M-7, M-6, L-7, L-6, L-5, K-7, K-6, K-5,
  - Land Mine Map 1 : 20,000, IMSMA, Mine Action Center Beirut, Lebanon, 19/04/2010
- Information from field work:
  - Detailed geology
  - Karst features
  - Layer dip/strike
  - Sense of movement at fault planes
  - Field photos
  - Waypoints (WP) from GPS measurements.

Coordinates of all locations surveyed in the field were taken with GPS (Garmin 60 CSx, average accuracy of +/- 5 m). This information was afterwards entered into GIS tables, referred to as "waypoints" (WP). The spatial reference system used for this study is UTM 36 N, WGS 84.

The following layers have been created as an ArcView-project:

- Geology
- Major lineaments
- Lineaments
- Thrust Faults
- Syncline
- Anticline
- Dip
- Dip estimated (from satellite images)
- Sense of movement (along faults where possible)
- Waypoints (with more information in correlated ArcView-data table about: coordinates of location, altitude asl, date of acquisition, layer dip, sense of fault movement, geological formation, general notes concerning geology and field observations, photo numbers of field photos and viewing direction)
- Contribution Zone of Jeita Spring
- Lines of cross sections

In figures, which show field photos, the location refers to coordinates of a waypoint (WP) listed in the data tables in the appendix.

4 Tectonic Setting

The working area is situated in the zone of influence of the Dead Sea Fault System (DSFS). It has been subjected to multiphase deformation:

1. Development of a coast-parallel (NNE-SSW-trending) mega-structure of a wide spanned asymmetric anticline with steep layer dip (25°-75°) towards the west and more gentle dip (05°-10°) towards the east. Deformation started in Late Mesozoic/Early Cenozoic (WALLEY 1988), and generated contemporaneously the syncline of Bekaa Valley and the anticline of Anti-Lebanon mountain range, both situated east of the working area (figure 4).
2. Development of the Dead Sea Fault System with left-lateral shear zones. According to WALLEY (1988) a total displacement of 47 km along the Yammouneh Fault, (situated directly east of the study area) can be observed, based on correlating Mesozoic geological structures between the Mount Lebanon and Anti-Lebanon ranges (GOMEZ, ET AL., 2007).
3. Synthetic fault-branches which are linked to the main fault (Yammouneh Fault striking NNE) at angles of approximately 45° affecting the mega-anticline by faulting and to a minor extent also by folding (second- and less-order folds).

The recent transpressional regime has generated a restraining bend, represented by the Mount Lebanon mountain chain (GOMEZ ET AL. 2007). Faults are still active with moving rates in the DSFS of 4.4 mm - 5.1 mm per year. The prominent Yammouneh Fault, adjacent to the study area, features slip rates of 5.0 ±1.1 mm/a. Recent coastal uplift is observed and displayed by notched shorelines especially in the northern part of Lebanon (GOMEZ ET AL. 2007; figures 3 and 4).

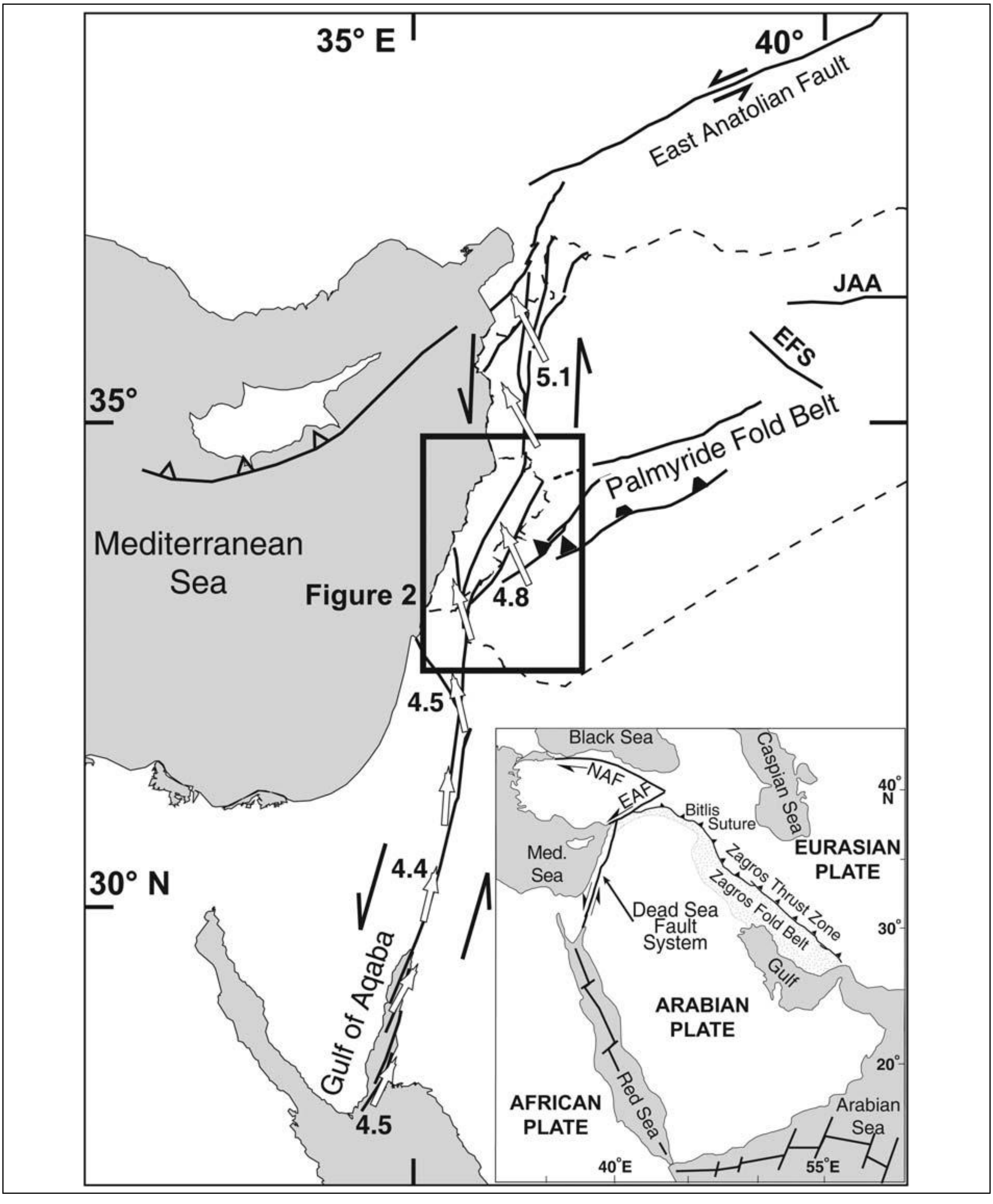

Figure 3: "Regional tectonic map of the Dead Sea fault system. Directions (white arrows) and rates (mm/a) of motion of the Arabian plate relative to the Sinai plate are based on the plate model of REILINGER ET AL. (2006). Abbreviations: JAA, Jebel Abdel Aziz; EFS, Euphrates fault system; NAF, North Anatolian fault; EAF, East Anatolian fault. Inset depicts the plate-tectonic setting of the Arabian–Eurasian collision" GOMEZ ET AL. (2007)

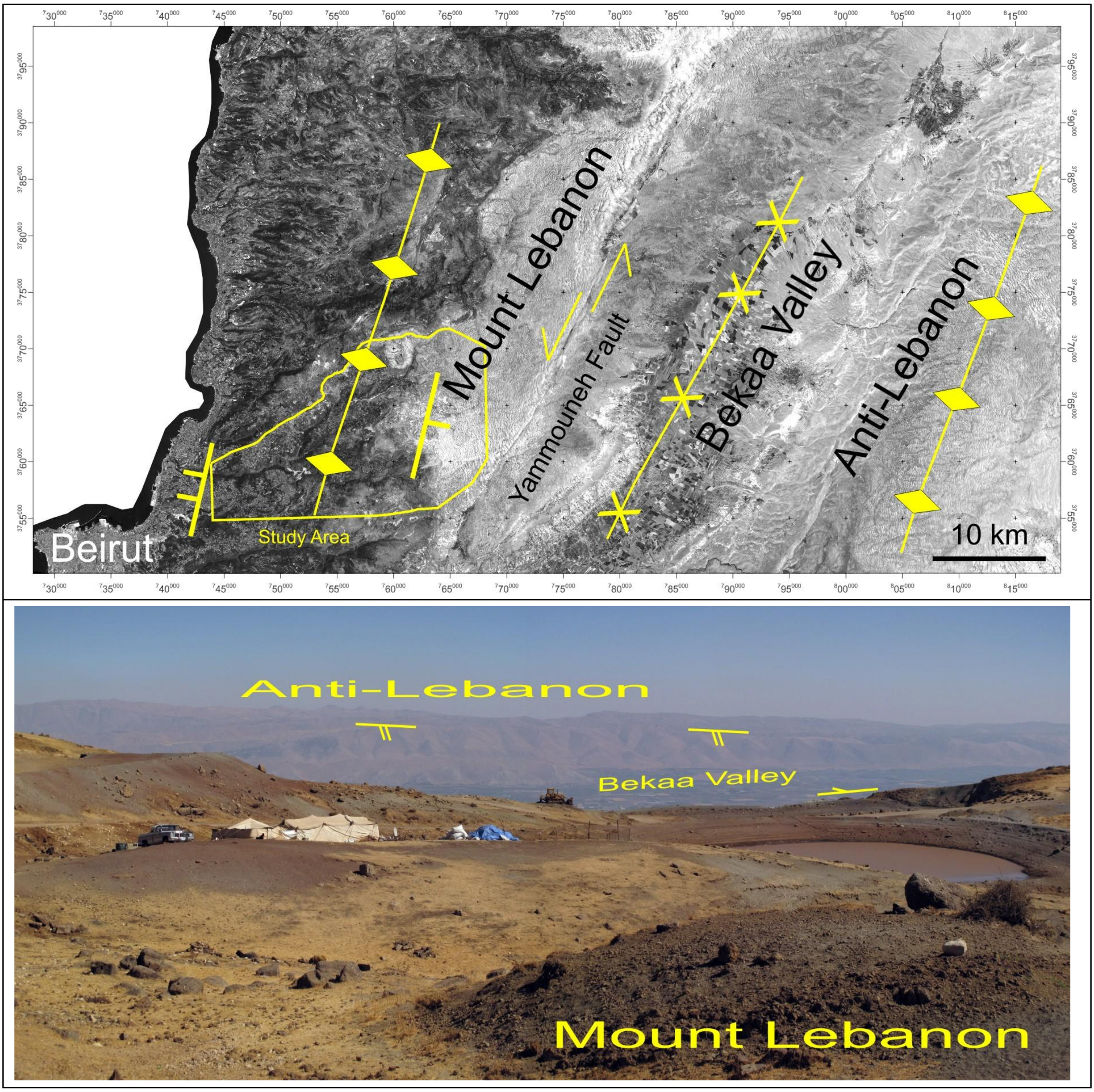

Figure 4: Above: Mega-structures of the study- and surrounding area. The mega-anticline of Mount Lebanon (first order-anticline) shows steep layer dips toward the west and gently dipping towards the east in the study area. The Yammouneh Fault represents one branch of the left-lateral Dead Sea Fault System (DSFS); projected into Landsat ETM band 3. Below: View to SE into Bekaa Valley and to Anti-Lebanon from WP 295

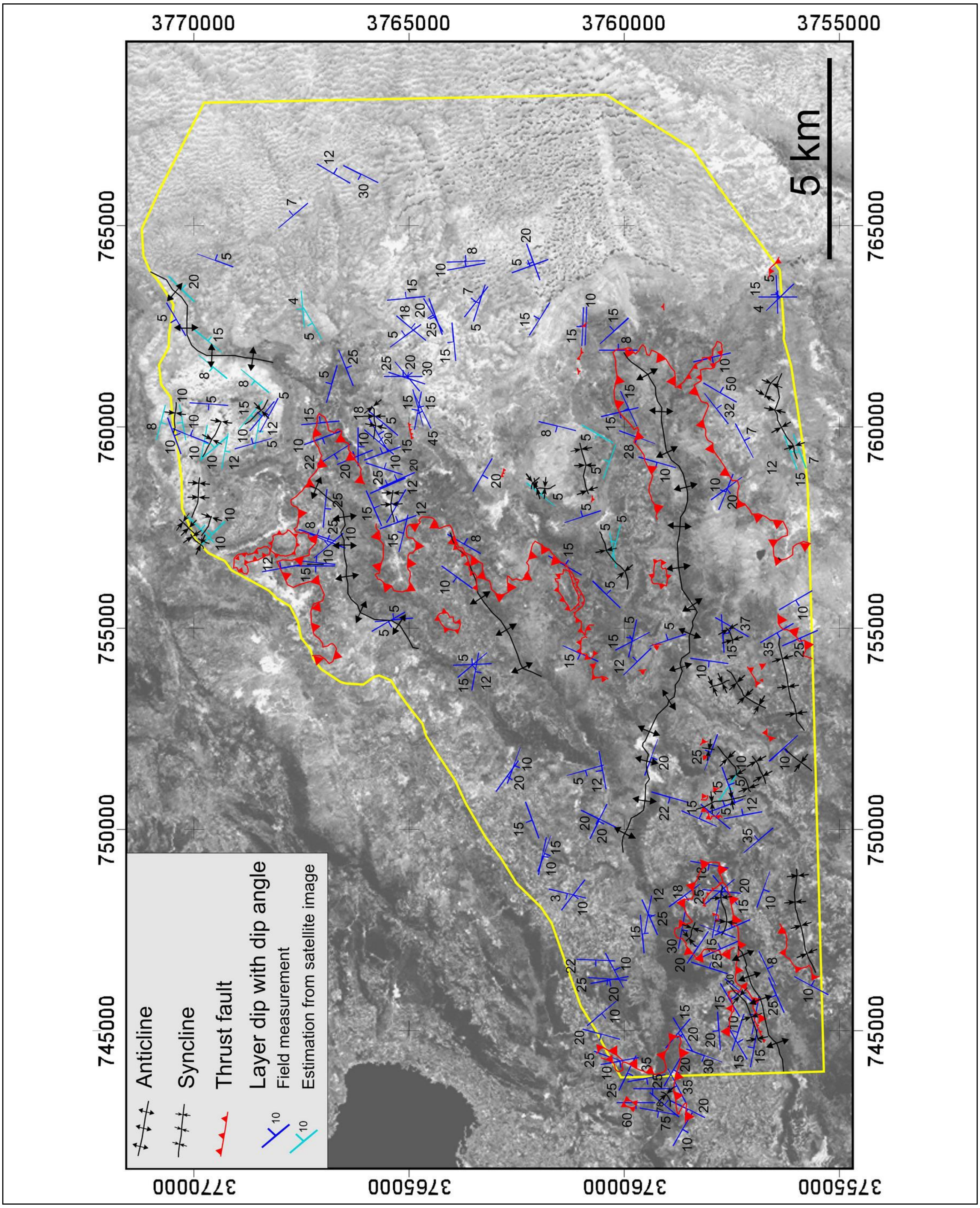

Figure 5: Examples of second order-anticlines, second order-synclines thrust faults and layer dips from field measurements and from estimations in satellite images projected into Landsat ETM band 3

4.1 Faults

Faults of any scale and many types can be observed in the working area. All main river valleys and most of other detectable lineaments are represented by faults. In most cases the major valleys show approximately vertical fault planes partially with well developed tear-off-edges and slicken sides which are implicating a left-lateral movement (figure 14). To a minor extent also right-lateral movement can be observed. Besides vertical faults and normal faulting (figure 15) also shallow layer-parallel and sub horizontal overthrusting occurs (figures 12 and 13). Due to the working area's transpressional regime, shear lenses (figure 11) and thrusts are well developed. Most faults are filled with fragmented material of the host rock (figure 6). In some faults of calcareous formations, a high iron content of pebbly fragmented host rock, iron concretions and highly ferruginous sandstone from other formations can be observed (figure 6), proving hydrothermal activity which is related to widespread multiphase basaltic intrusions. Locally iron contents can reach ore quality. At a location NE of Marjaba within Kesrouane Formation (J4) an abandoned iron ore mining site along a fault plane witnesses such place (figure 7). Major faults have been pathways for basaltic intrusions at several locations (refer to chapter 5.11).

Figure 6: Left: View along strike of a vertical fault trace in Kesrouane Formation (J4) filled with limestone breccia (WP 412). Right: Ferruginous sandstone and iron concretion of a fault with former hydrothermal activity due to widespread basaltic intrusions (WP 038)

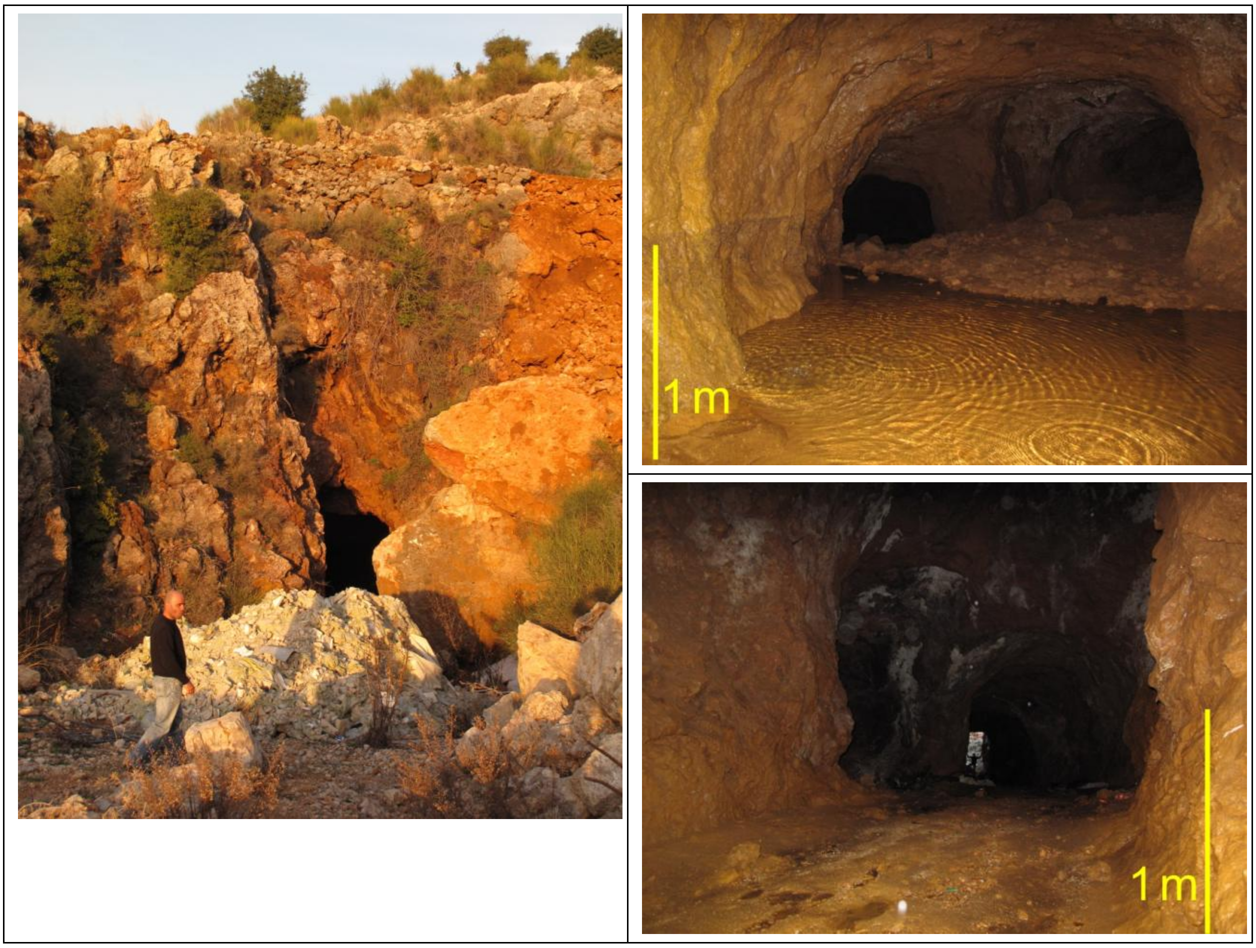

Figure 7: Abandoned iron ore mine at a fault plane in Kesrouane Formation (J4). Left: Entrance at excavated fault plane (WP 386). Right: View into the mine

Figure 8: Cavity along a fault plane in Hammana Formation (C3) at the border to Mdairej Formation (C2b). Left: View inside- and right: View outside the cavity (WP 089)

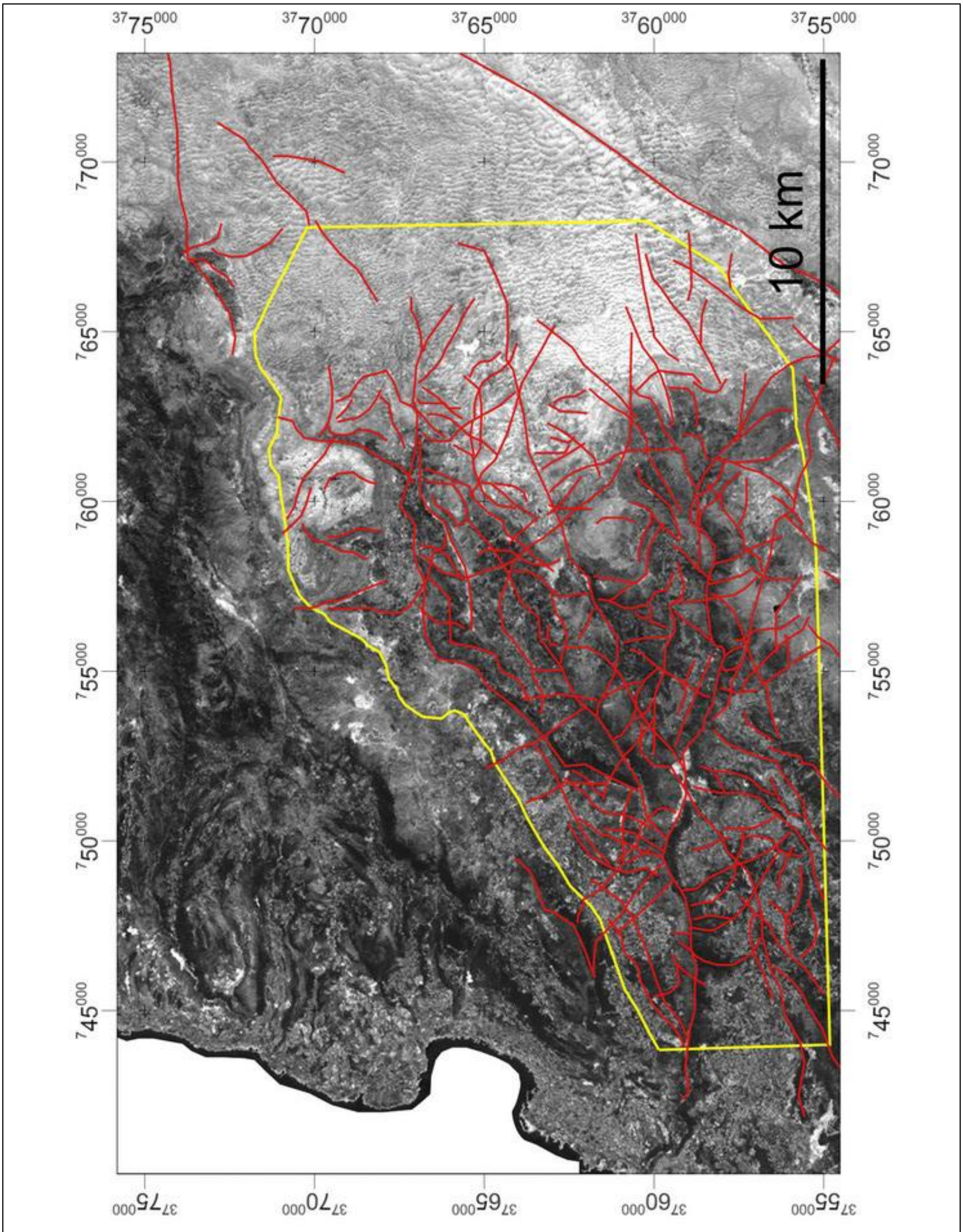

Figure 9: Examples of major faults derived from satellite images projected into Landsat ETM band 3

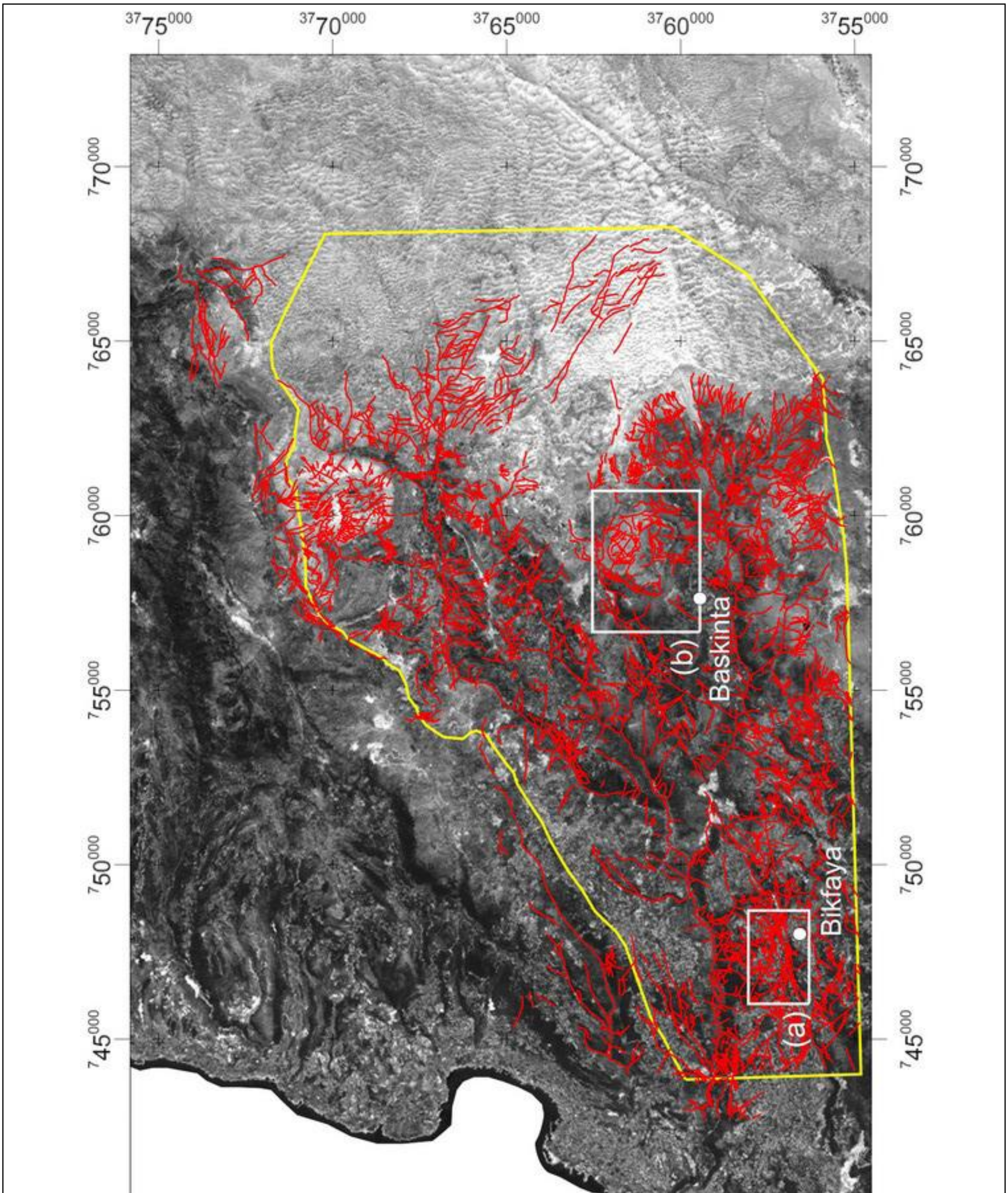

Figure 10: Examples of minor faults derived from satellite images projected into Landsat ETM band 3. White rectangles (a) and (b) mark areas shown in figures 11 and 12

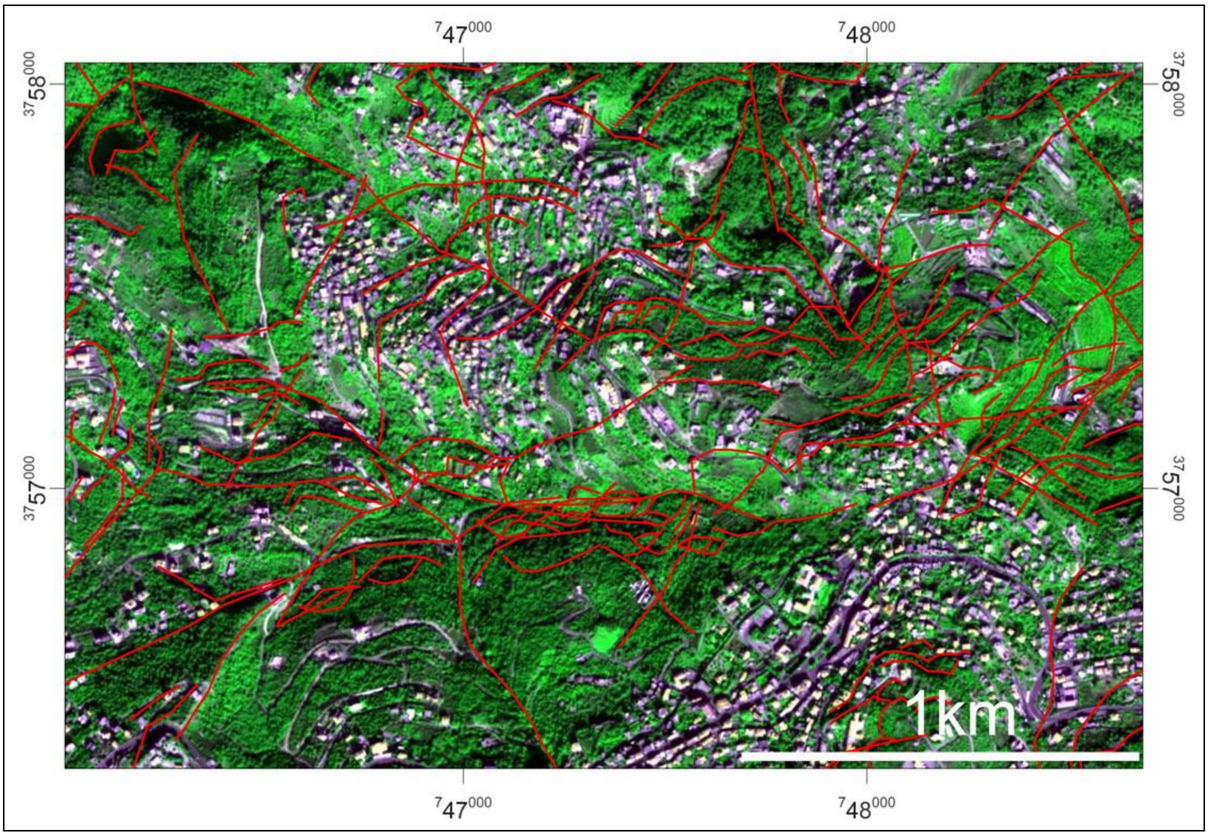

Figure 11: A fractal pattern of shear lenses bordered by faults (elliptical red lines). An example from Bikfaya. Faults defining shear lenses are commonly best visible in high resolution satellite images as their extension is not enhanced by incised valleys. Quickbird bands 3,4,2 (RGB). Location within the working area is marked in figure 10 by white rectangle (a)

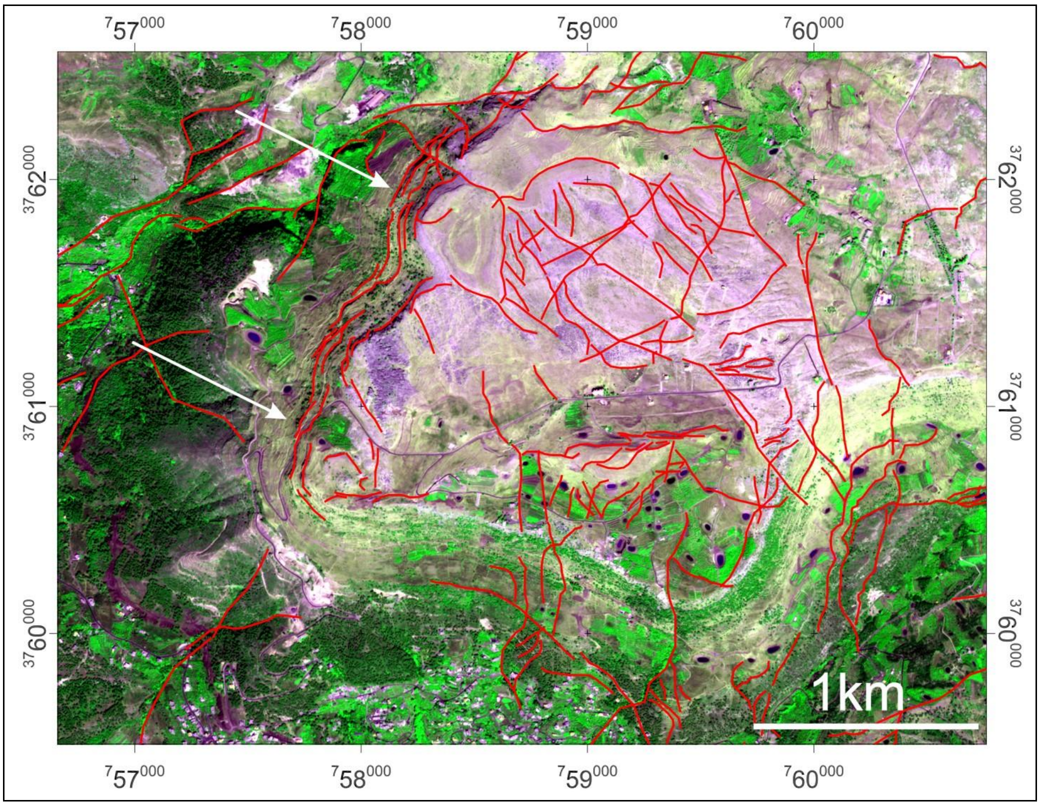

Figure 12: Faults concordant to sedimentary layers (white arrows). Example from small plateau north of Baskinta. Quickbird bands 3,4,2 (RGB). Location within the working area is marked in figure 10 by white rectangle (b)

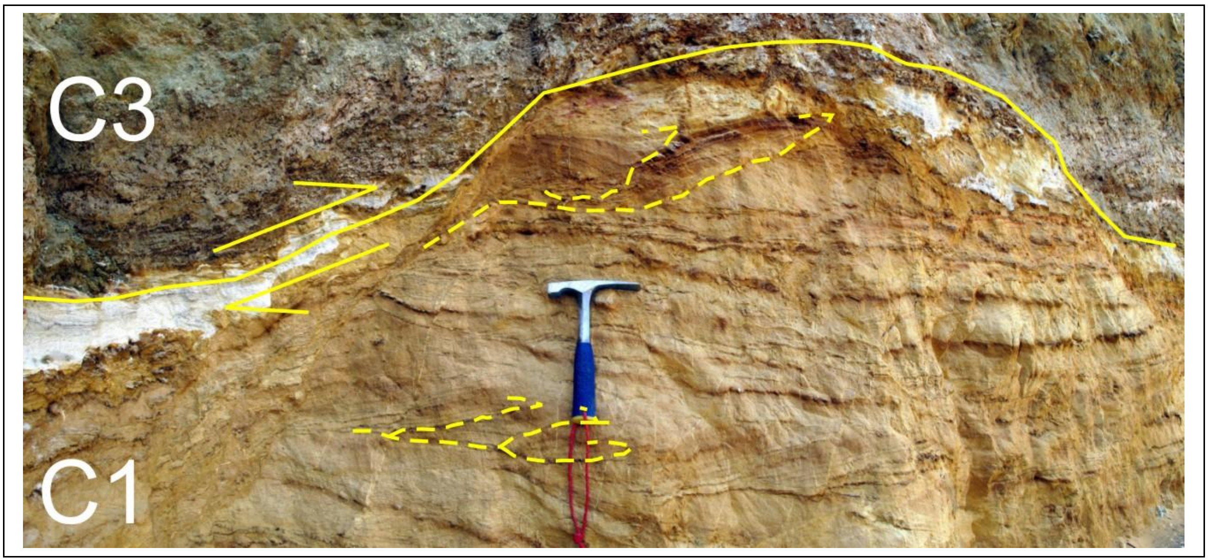

Figure 13: Shallow over thrusting of Hammana Formation (C3) over Chouf Sandstone Formation (C1). View towards 220° SW). Outcrop at a building pit, WP 169

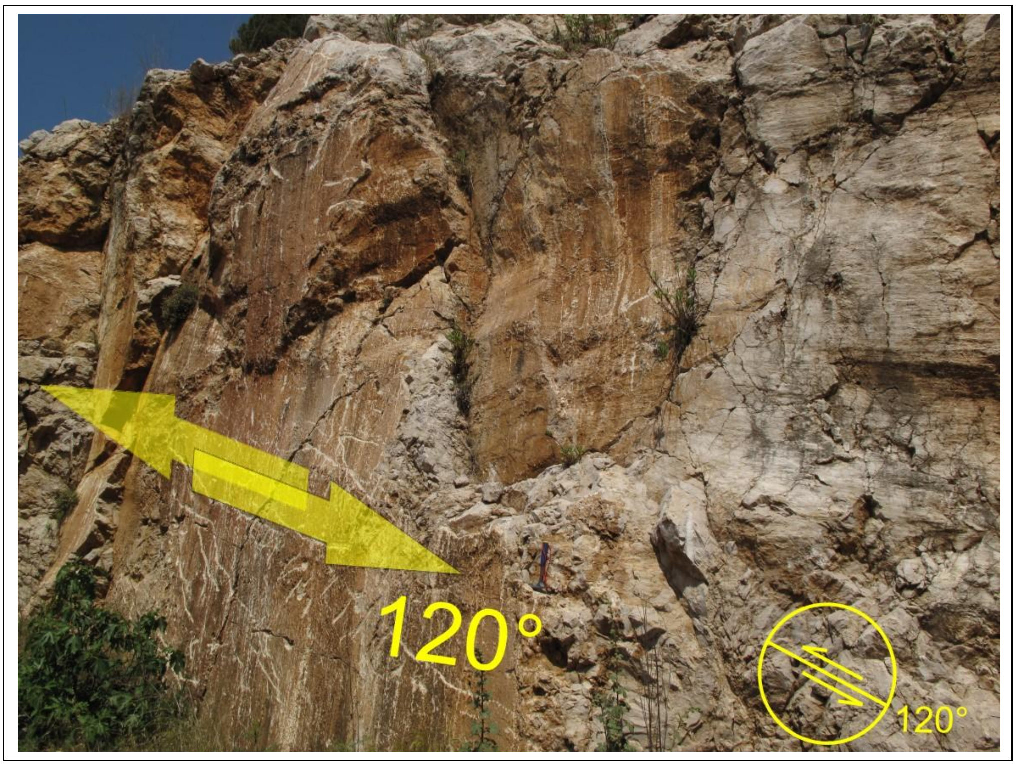

Figure 14: Vertical fault plane in Kesrouane Formation (J4) striking 120° SE with tear-off edges indicating a left-lateral movement. (Location east of Ain Aalaq, WP 024)

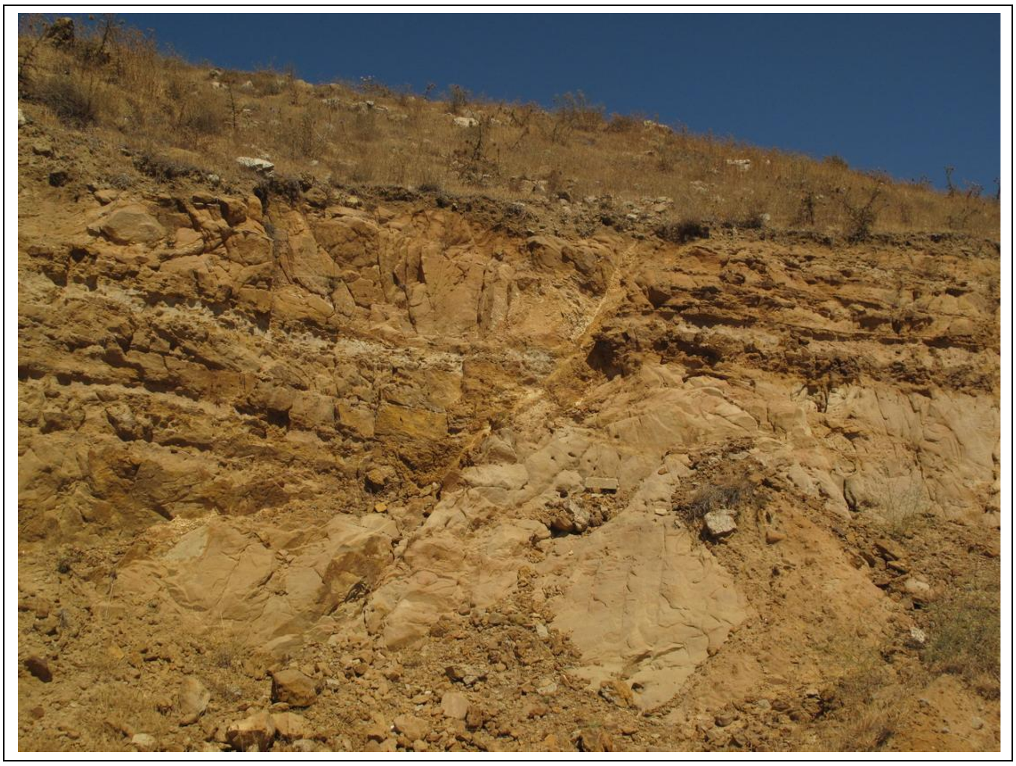

Figure 15: Normal fault in Chouf Sandstone Formation (C1) can pretend greater thickness at some locations e.g. west of Baskinta (WP 235)

5 Geology

The geological units of the working area are mainly composed of lime stones/dolomites and to minor extent clastic sediments, displaying alternating transgressional- and regressional palaeo-environments (figure 16). The time scale of the mapped formations ranges from Lower Jurassic (Liassic) to Late Cretaceous (Cenomanian).

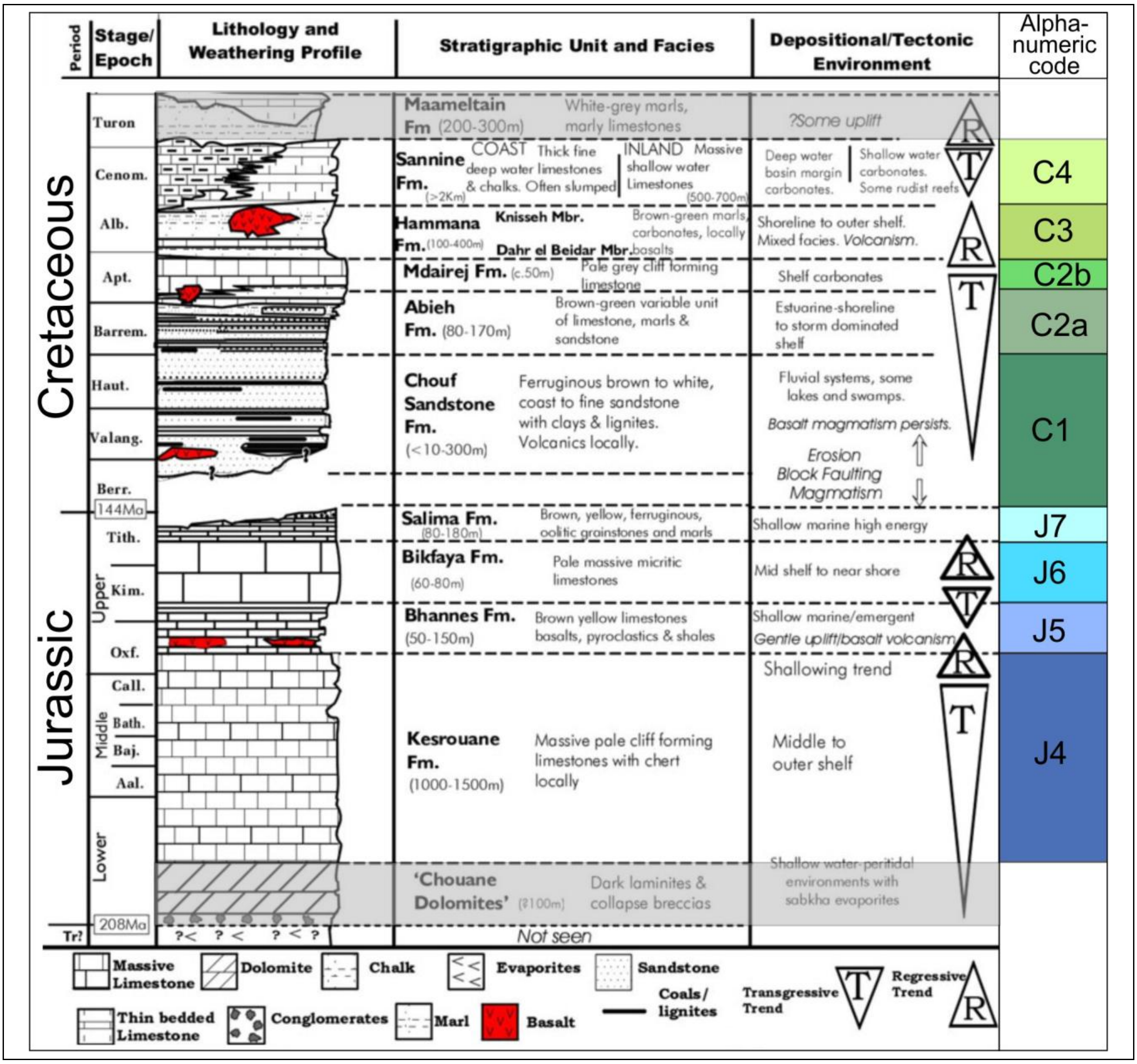

Figure 16: Stratigraphy and depositional environment of the working area modified after WALLEY (1997). Colours of alphanumerical code correspond with colours of geological map

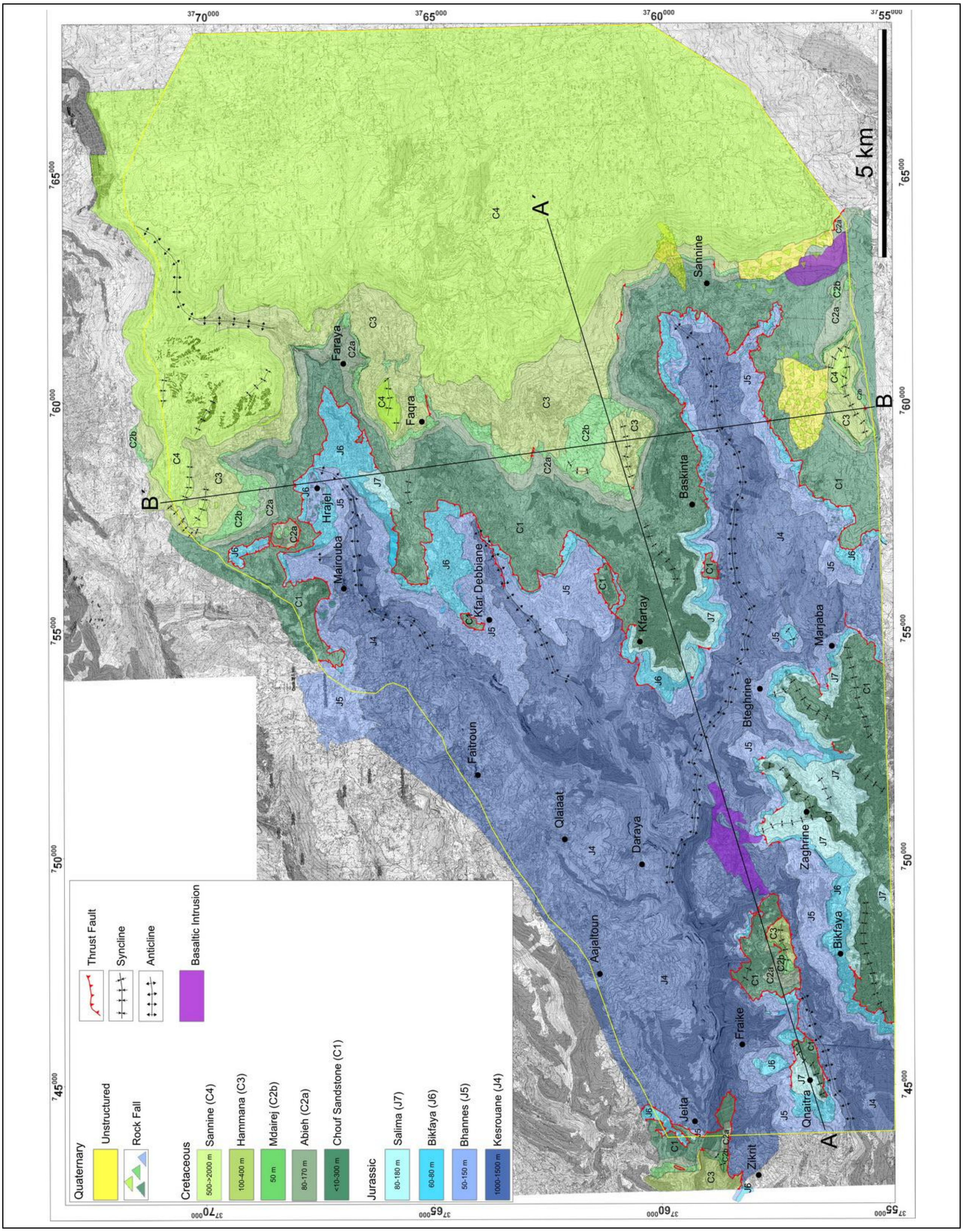

Figure 17: Geological map of the extended Jeita Spring Catchment projected into topographic map sheets M-7, M-6, L-7, L-6, L-5, K-7, K-6 and K-5

5.1 Cross Sections

Two cross sections were developed with vertical exaggeration by 2 (figure 18). Cross section A-A´ expands from SW to NE, cross section B-B´ expands from SSE to NNW in the higher eastern part of the working area (figure 17).

UTM coordinates:
A: 743,592.55/ 3,756,312.69. A’: 763,431.38/ 3,762,255.28
B: 759,8146.52/ 3,755,360.13. B’: 757,831.57/ 3,770,871.89
Topography ranges from 590 m asl to 2300 m asl.

Cross section A-A´

The vertical profile starts in the south west at an elevation of 620 m asl in J5 dipping roughly 15° to NNE. Passing hanging formations of J6 and J7 which are fault-affected by numerous shear lenses, the fault-affected hinge of a synclinal structure is met after 2 km. Here, C1 sandstone dips ca. 30° towards NW. C1 is thrusted over J6, suppressing J7. The J5-hinge of the following anticline is intersected after ca. 3 km. At 3.5 km, an isolated nappe of cretaceous formations from C1 to C3 is thrusted over J6. This nappe is also faulted and thrusted internally. It ends at 5.1 km. Following J6 formation is thrusted over J4, suppressing J5. A basaltic body is intruded discordantly into- and through J4. North of Zaghrine this intrusion migrates into J5 formation and thus can be considered as one source of J5 intrusion. The intrusion ends on the profile line at ca. 8 km at a major fault. The valley bottom of J4 formation at 9.2 km is the hinge of an anticline with limbs dipping ca. 20° to SW and 12° to NE. Proceeding to NE, the full Jurassic sequence is developed. Apparent C1-thickness of about 380 m east of Kfartay is fault-related by normal faulting and multiple shear lenses. 1.4 km North of Baskinta, a shallow syncline of cretaceous formations from C2a to C3 is developed. Its location originates from normal faulting and shearing. Following C2b- and C3 formations are fractured by faults until largely unaffected C3 and hanging C4 formations, gently dipping towards NE, terminate the cross section after 20 km.

Cross section B-B´

The cross section starts in the SSE at an elevation of 1760 m asl. An internal faulted and thrusted syncline of cretaceous formations ranging from C2a to C3 is intersected. After ca. 1 km a major rock fall area with blocks of mainly C3- and C4 formations is passed. C1 is thrusted over J6, suppressing J7. A small lens of C1 is sheared between J6 and J5. The valley bottom is build up by an anticline of J4 formation with limbs dipping gently 05° to SSE and steeper with 10° to 28° to NNW. 1 km east of Baskinta C1 sandstone is thrusted over J6 formation, suppressing J7. Thickness of C1 is thus increased by about 90 metres due to thrusting and shearing. The intersected plateau NE of Baskinta consists of cretaceous formations from C1 to C3. It forms a shallow syncline. The NNW part of this syncline is formed by a major slice of formations ranging from C2a to C3 which are internally thrusted and sheared, repeating sequences from C2a to C3 three times (except for one sequence where C2a is suppressed by overthrusting). Thickness of C2b is extremely oversized by multiple shear lenses in the first part after the syncline´s hinge. The valley bottom after 9.5 km is built up by a C1 anticline. Thickness of C1 is again increased, apparently by multiple shearing. The following C1-peak shows a relative vertical off set of at least 400 metres, considering the thicknesses of the following Jurassic formations. The valley bottom at ca. 11.8 km is built up by a J5-anticline. Intersecting the town of Hrajel, normal faulting of J6 formation can be observed. In between faulted J6-outcrops, rock fall of C1 formation occurs over J5 formation. Proceeding to NNW, C1 is thrusted over J6. After this part, the sequence from C1 to C3 is developed with moderately normal-faulted C2b formation. The C3-peak is folded, building a syncline-anticline-syncline-structure. The NNW peak is built up by a C4-syncline. Its hinge shows a vertical off set of approximately 25 metres. The cross section ends after ca. 15.7 km with C3 formation dipping 10° to SE.

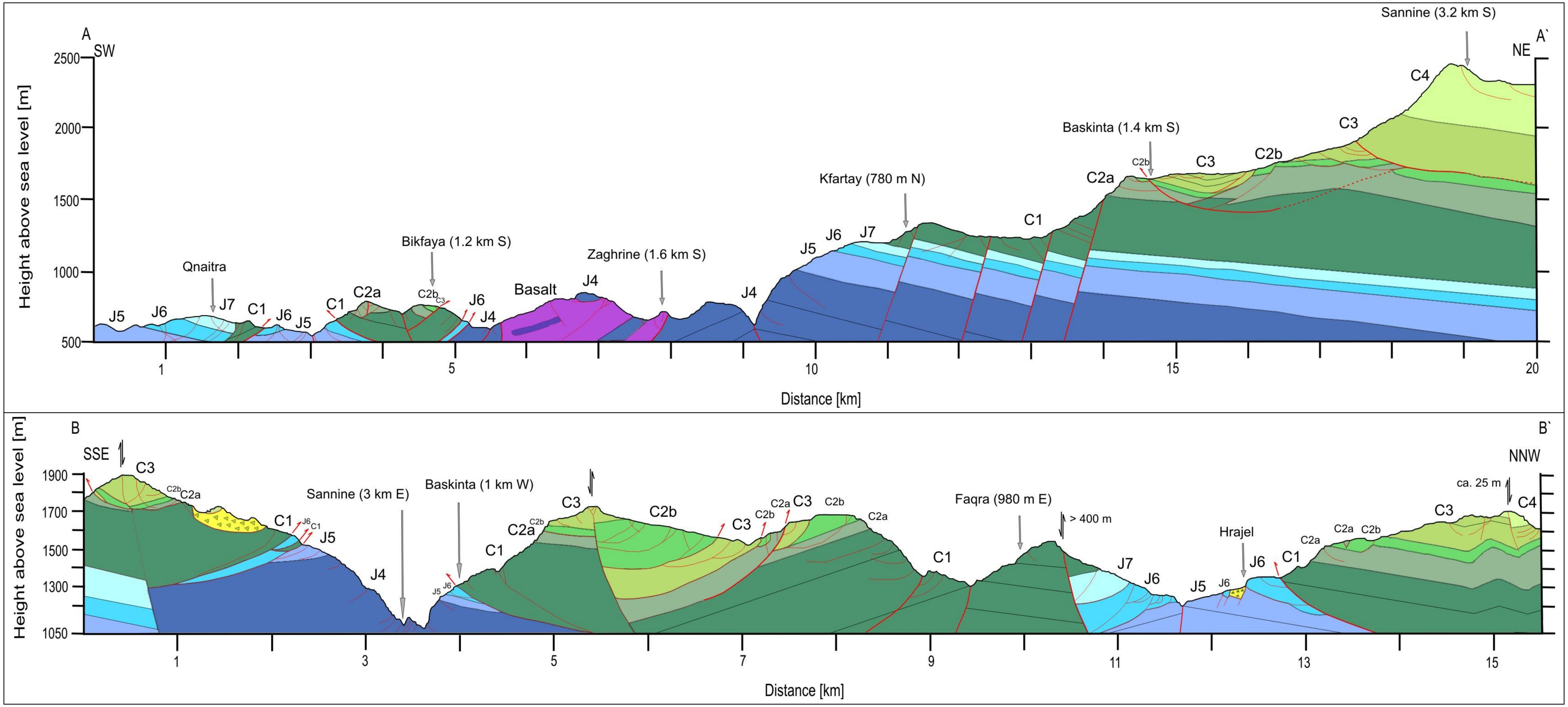

Figure 18: Above: Cross section A-A´ from SW to NE. Below: Cross section B-B´ from SSE to NNW. Both cross sections are vertical exaggerated by 2. For position of the section lines refer to figure 17

5.2 Kesrouane Formation (J4)

The age of Kesrouane Formation ranges from Lower- (Liassic) to Upper Jurassic (Oxfordian). The thickness varies from 1000 m to 1500 m (WALLEY, 1997). In the mapped area it reaches a thickness of 1070 m. J4 crops out in most main valleys from 170 m asl north of Zikrit to 1240 m asl east of Kfar Debbiane.

This cliff-forming formation consists mainly of massive micritic limestone and dolomite (figures 19 to 23). Locally micrite is developed splintery and white like porcelain. Generally the fresh colour changes between light grey to beige, the colour of the altered surface is light grey to almost white. Fossils shells are common in layers as well as distributed in a micritic matrix. Locally ooides occur in layers with shells. Iron nodules in combination with fossils were found sometimes. Fossil content consists mainly of bivalves (amongst others oysters), gastropods (amongst others *Nerinea*), corals and sponges. A very uncommon occurrence of a thick chert layer was found east of Daraya (WP 381). The whole formation is deeply karstified and host of the Jeita Spring (refer to chapter 6).

Figure 19: Above: View to the north over Nahr el Kalb valley towards Mrah El Mir, west of Daraya onto typical massive and faulted J4 (WP 405 from 300° to 020°). Below: Typical light grey and karstified Kesrouane Formation on a closer view

Figure 20: Light brown/beige dolomite of J4 (WP 092)

Figure 21: Left: Coral branches (WP 138). Right: Coral branches. Steinkern formed by white micritic matrix. The original coral material is dissolved (WP 371)

Figure 22: Left: Gastropodes in different cross sections (WP 150). Right: tall mushroom-like sponges, enhanced by yellow lines (WP 171)

Figure 23: Very uncommon for Kesrouane Formation is an occurrence of a thick chert layer (beige layer below bush) east of Daraya (WP 381)

5.3 Bhannes Formation (J5)

The age of Bhannes Formation is Upper Jurassic and ranges from late Oxfordian to early, possibly mid, Kimmeridgian. The thickness varies from 50 m to 150 m (WALLEY, 1997). In the mapped area east of Bikfaya J5 reaches a thickness of 200 m due to layer thickening by shallow overthrusting. SW of Kfar Debbiane a fault-related thickness of 340 m can be observed. J5 occurs according to stratigraphical order almost all over the working area. West of Kfartay and Sannine as well as east of Fraike and NW of Jeita it is suppressed tectonically by thrust faults.

The base of Bhannes Formation is often intruded by basalts, which show a spheroidal shape due to weathering (figure 24) and contain fragments of underlying J4 limestone. In some places fresh looking basalts and weathered layers of purple/red pyroclastics were found (figure 25). Locations of intrusions display typical reddish to purple soil. A major part of J5 consists of soft yellow marls and limestones, clay- and siltstones with colours from ochre to red, grey and green and shows a recessive weathering topography. At a few locations, banks of more than four metres thickness of light grey cliff forming limestone occur. The altered surface sometimes shows light grey reduction zones within light brown limestone as a secondary, ground water-related, feature (figure 26). The fine limestones occasionally contain ooides and can locally display ripple marks and bioturbation. The observed fossil content consists mainly of bivalve, gastropods and crinoids (figure 27). At the Top of this formation a one metre-thick bank of yellow and brown ferruginous cellular sandstone was found 1 km east of Mairouba (figure 28).

Figure 24: Left: Spheroidal altered basaltic intrusion (WP 042). Right: Fresh surface of a basalt in J5 (WP 028)

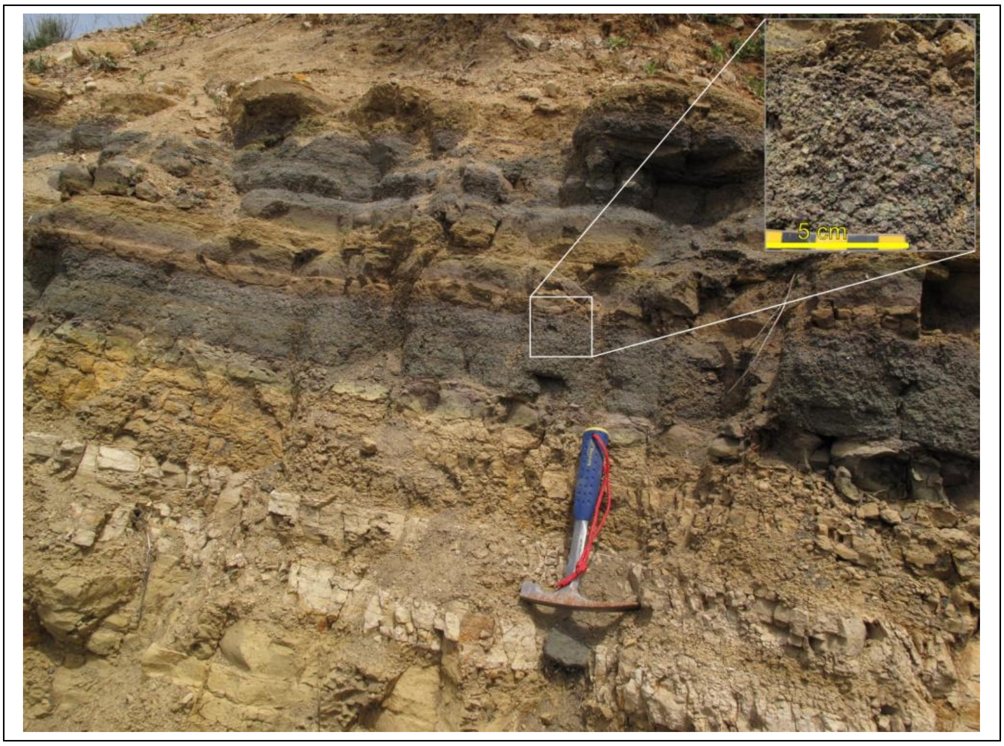

Figure 25: Succession of yellow and white marl, brown siltstone, green and purple claystone developed from former pyroclastics. Inset shows close up of area marked by white rectangle (WP 037)

Figure 26: Thick micritic limestone bank of J5 with light grey reduction zones due to former ground water influence (WP 332)

Figure 27: Left: Crinoid shells inclusive calyx (WP 395). Right: Limestone with shells and tall gastropods (WP 408)

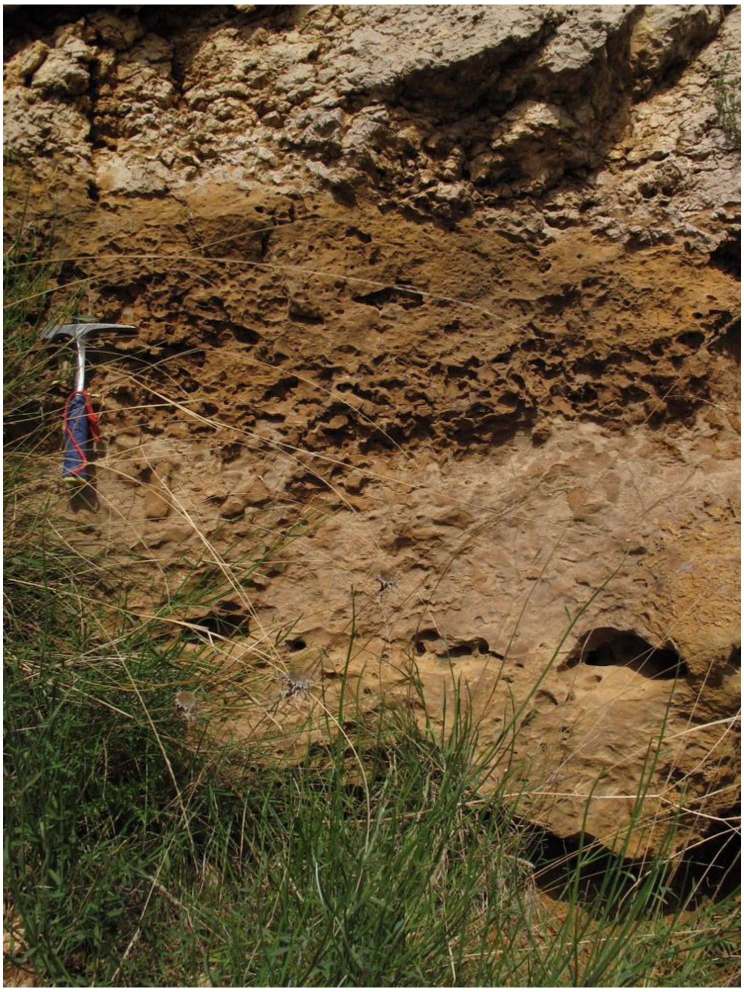

Figure 28: Cellular yellow and brown ferruginous sandstone on top of J5 formation east of Mairouba (WP 042)

5.4 Bikfaya Formation (J6)

The age of Bikfaya Formation is Upper Jurassic and ranges from Kimmeridgian to the middle part of Tithonian. According to WALLEY (1997) the thickness varies from 60 m to 80 m. In the mapped area south of Bikfaya J6 gains a thickness of 100 m. NE of Kfar Debbiane a fault-related thickness of 160 m can be observed. This formation is overthrusted by cretaceous C1 in most parts of the northern and eastern outcrops as well as in a small area west of Bikfaya. North of Mairouba, Zaghrine and Kfartay, east of Fraike and Kfar Debbiane, as well as W of Jeita and Sannine J6 is suppressed tectonically by thrust faults.

This cliff-forming, widely traceable, formation consists mainly of massive micritic limestone. Generally the micrite is porcelain-like and splintery. The colour of altered surface is light grey to almost white, the fresh colour light grey to beige. Layers of (partially large) chert nodules are common (figures 29 and 30) especially in the middle and upper level of the formation and generally allow a clear differentiation to almost similar shaped J4. Ooides are common in layers with fossil shells; iron nodules and ferritized fossils occur locally (figure 31) as well as bioturbation. Observed fossil content is bivalves (amongst others oysters), gastropods, corals and sponges (figure 32). Especially corals tend to silicify (figure 31), which appears to be a good criterion for differentiation against J4.

Possible tectonic activity during sedimentation is shown at a location west of Zikrit, where broken layers of fine limestone are cemented synsedimentarily with another type of coarse limestone, which display boreholes and can be interpreted as a hardground (figure 33).

Figure 29: Left: Typical chert nodules of Bikfaya Formation in light grey micritic limestone (4.5 km SW Sannine). Right: Layered chert in light grey limestone (WP 154)

Figure 30: Left: Chert nodule overgrown by yellow green lichen while limestone is covered by pink coloured lichen (WP 026). Right: Layered chert in light grey limestone (WP 153)

Figure 31: Silicified coral branch (left, WP 105) and ferritized fossils (right, WP 105) appear to be typical for J6

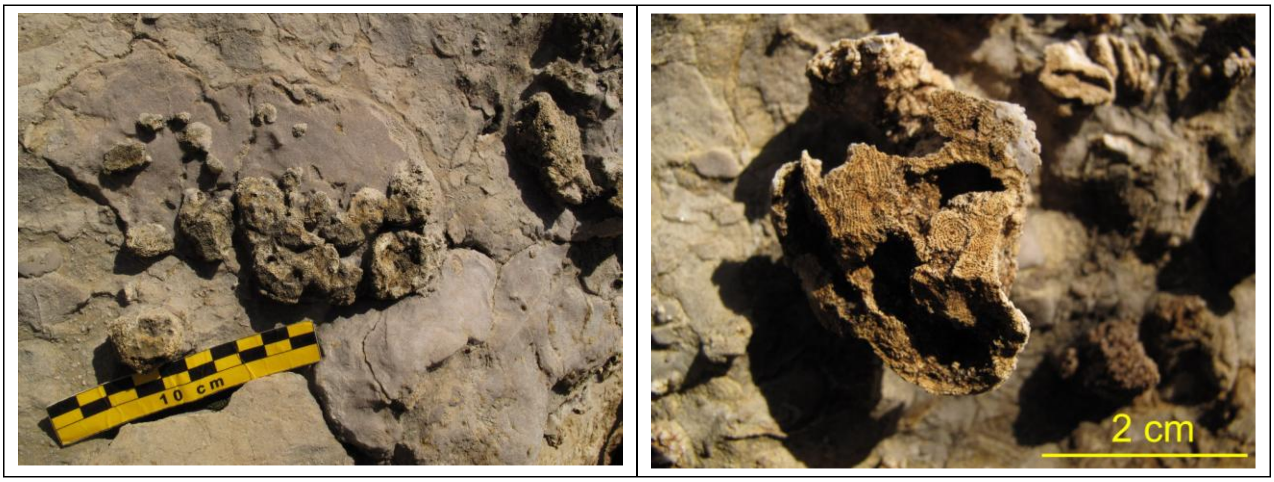

Figure 32: Left: Bottom side of a sponge with stems. Right: Close-up of sponge stem with internal structure (both WP 372)

Figure 33: Possible tectonic activity during sedimentation. Broken layers of fine limestone are cemented synsedimentarily with a yellow coarse limestone. Both display boreholes and can be interpreted as hardgrounds (WP 120)

5.5 Salima Formation (J7)

The age of Salima Formation is Upper Jurassic and comprises the upper part of Tithonian. According to WALLEY (1997) the thickness varies from 80 m to 180 m. This applies to measurements in the working area, whereas the highest thickness of 180 m SE of Zaghrine is fault related. This formation is almost fully suppressed tectonically by thrust faults in the northern and eastern parts of the working area. The only outcrop in the north is NW of Faqra as well as W and NW of Baskinta. In the south it is well developed and exposed except for a small part west of Bikfaya. An isolated occurrence as part of a small nappe is found around the village of Qnaitra.

The lithology of J7 appears quite similar to that of J5. It is usually thin bedded and shows generally a recessive weathering topography except for cliff-forming parts of thick limestone banks (figure 34). The formation is variable with red to purple clay- and silt stone, soft brown, yellow, green and grey marls with bioturbation (figure 37) and ripple marks and fine ferruginous ochre sandstone with iron nodules. Limestone banks can attain thicknesses of more than 4 metres and show brown and yellow colours at the altered surface and light grey to beige at a fresh surface. They can be micritic and nodular from bioturbation and sometimes show light grey reduction zones as a secondary feature from former ground-water influence (figure 39). In most occurrences limestones contain ooides (figure 36), which can be cross-bedded (figure 35) and intraclasts from fine limestone. Fossil content is bivalves (amongst others oysters, figure 38), corals and echinites (figure 38). WALLEY (1997) mentions also ammonites.

Figure 34: Left: Succession of soft brown marls, resistant limestone and fine ochre sandstone on top. (WP 029) Right: Banks of beige oolitic limestone and reddish clay- and siltstone (WP 249)

Figure 35: Left: Thick banks of oolite at top of Salima Formation (WP 374). The area with pine trees is built up from hanging Chouf Sandstone Formation (C1). Right: Cross-bedded oolitic limestone (WP 373)

Figure 36: Left: Oolitic limestone consisting of approximately 1 mm ooides. Right: The same specimen in a close-up showing the spheroidal structure of ooides (both WP 375)

Figure 37: Left: Bottom side of a limestone layer showing strong branch-like bioturbation (WP176). Right: Closer view on branch-like bioturbation (WP 183)

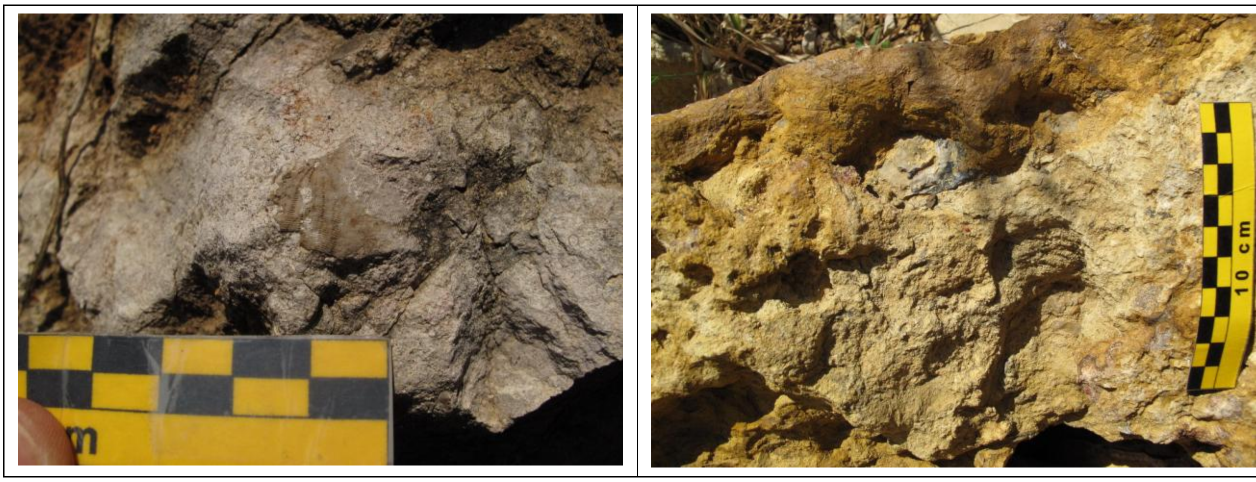

Figure 38: Left: Echinite in oolitic limestone (WP 056). Right: Grey oyster shell (centre top) in oolitic limestone (WP 176)

Figure 39: Thick micritic limestone bank of J7 with light grey reduction zones due to former ground water influence (WP 187)

5.6 Chouf Sandstone Formation (C1)

The age of Chouf Sandstone Formation is Early Cretaceous from Berriasian to Hauterivian. The thickness ranges from less than 10 metres to 300 m (WALLEY 1997). In the working area, a normal fault-related thickness of about 380 m can be observed between Kfartay and Baskinta. Two major slid blocks of C1 north and south of the "C1-peninsula" west of Baskinta and north of Kfar Debbiane document tectonic activity as well. As described before, C1 overthrusts lying formations in most parts of the northern and eastern outcrops as well as in a small area west of Bikfaya. North of Bikfaya and isolated nappe of cretaceous formations from C1 to C3 can be found. West of Jeita on the northern side of Nahr el Kalb River, C1 crops out as part of steep west-dipping flank of the anticlinal mega structure (figures 4). C1 is overthrusted by C3 formation west of Jeita on the southern side of Nahr el Kalb River, which was documented in a small outcrop at a building pit (figure 13). South of Jeita an outcrop of C1, fragmented by shear lenses, overthrusts J4 formation.

The base of C1 is intruded by basalt at many locations of the working area; especially the area between Baskinta and Kfar Debbiane is affected (figure 42). The formation starts at many locations with a sequence of ochre cellular dolomites (locally with bioturbation) followed by yellow limestone, grey marl and fine sandstone. The name-giving thick sandstone banks are separated by thin clay- and siltstone layers. Sandstone varies in colour from grey and brown to yellow, orange, red and pink depending on iron content (figure 40). Sandstone can be almost white as well, where iron is leached. At many locations sandstone is ferruginous and contends iron concretions. Sedimentary structures as cross-bedding (figure 41) and graded bedding (figure 46) from coarse- to fine sandstone are common. At contact zones with basaltic intrusions a thin thermal overprinting shown in glassy rims can be observed (figure 42). Where layers of lignite occur, natural bacterial sulphate reduction can be observed (figures 43 and 44). This reaction produces sulphur and sulphuric bacterial biomass and a typical “acid smell” is noticeable (figure 44). At a location south of Jeita, C1 is developed as a thick horizon of reworked material from lying formations of J4 and J6 starting with well rounded limestone conglomerates fining upwards to coarse and middle grained quartz sandstone (figure 46).

A very uncommon and so far not described occurrence of beige dolomite and white oolite both containing C1 sandstone intraclasts was found NE of Kfartay (figure 45).

Figure 40: Soft orange brown Chouf Sandstone is often vegetated by umbrella pine trees (N Baskinta)

Figure 41: Inclined layers of brown Sandstone. Inset shows cross-bedding of fine and coarse sandstone beds (WP 051)

Figure 42: Left: Basaltic intrusion in C1 sandstone. Right: The same basaltic intrusion 10 m south. Inset shows a glassy rim in sandstone due to thermal overprinting of intrusion (both WP 339. Inset: WP 327)

Figure 43: Left: Black lignite (WP 305). Right: Petrified and ferritized wood (WP 293)

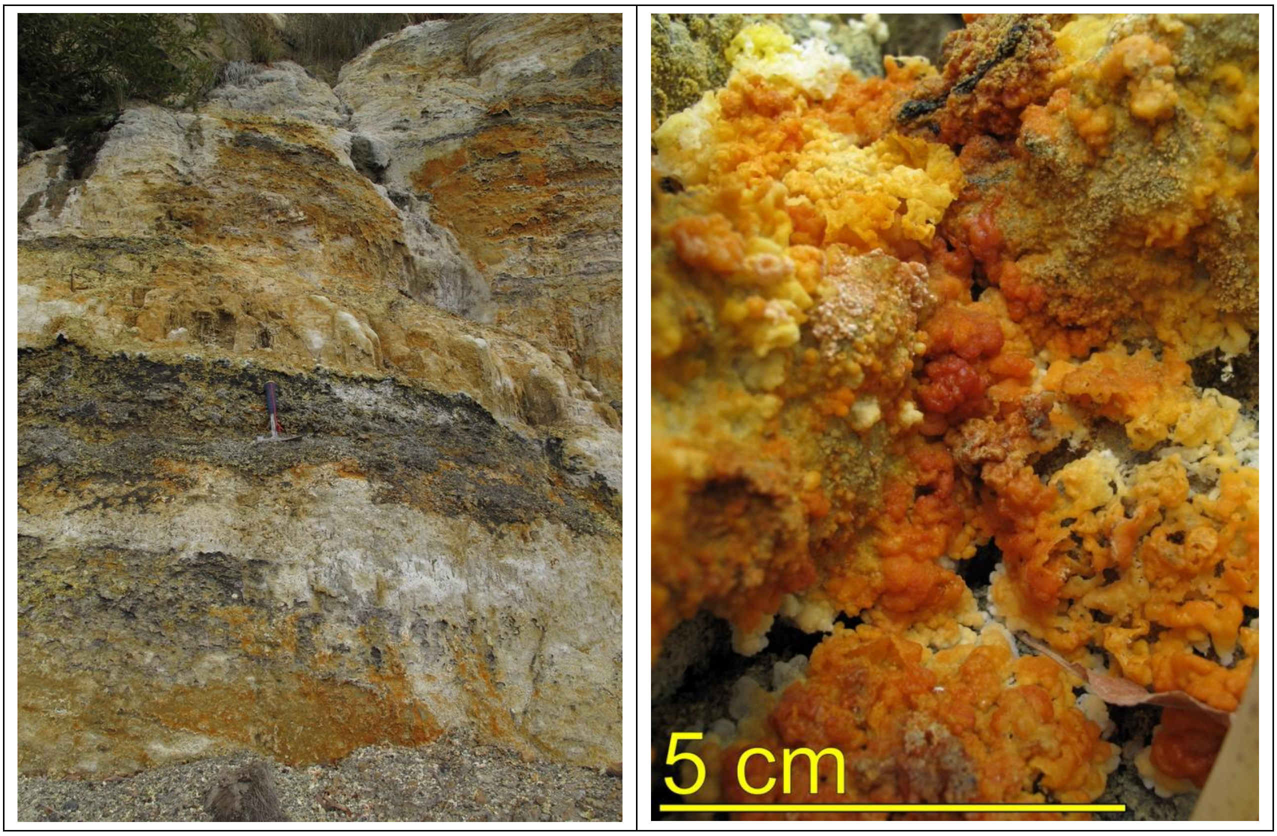

Figure 44: Left: Lignite horizon in soft sandstone covered with yellow sulphuric biomass from bacterial sulphate reduction. Right: Close-up of bacterial sulphuric biomass (both WP 305)

Figure 45: Left: Uncommon occurrence of intraclasts of C1 sandstone in white oolite. Right: Intraclasts of C1 sandstone in beige dolomite (both WP 358, NE of Kfartay)

Protection of Jeita Spring - Geological Map, Tectonics and Karstification in the Groundwater Contribution Zone of Jeita Spring supported by Remote Sensing

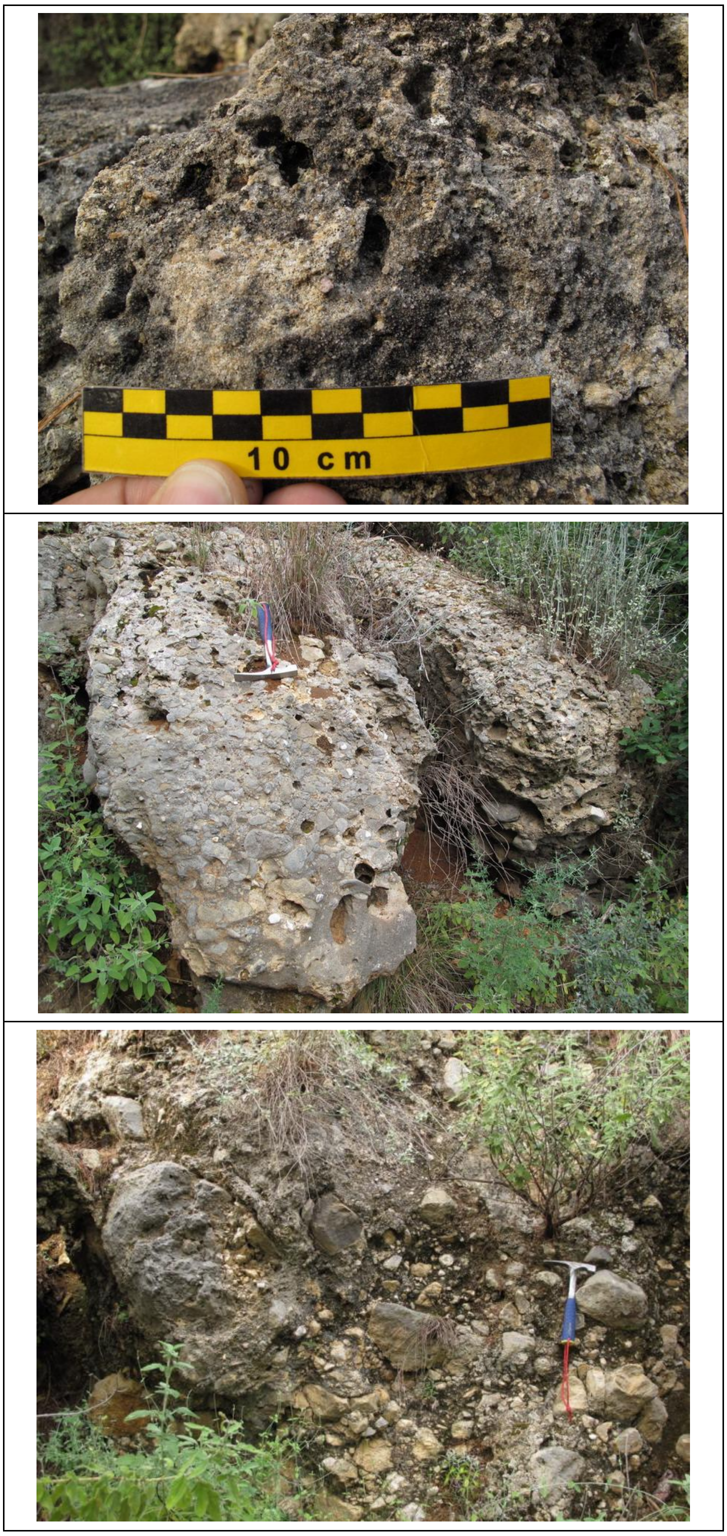

Figure 46: Fining upward sequence in C1 formation starting with very coarse well rounded conglomerate of components from lying J4 and J6 limestone formations (bottom), coarse conglomerate of the same components (middle) ending with coarse sandstone of quartz- and feldspar grains (top) all at locations of WP 146, south of Jeita, southern bank of Nahr el Kalb River

5.7 Abieh Formation (C2a)

The age of Abieh Formation is Early Cretaceous Barremian to earliest of Aptian. The thickness ranges from 80 m to 170 m (WALLEY 1997). In the working area thicknesses from 20 m east of Sannine to 150 m north of Faraya were found. C2a crops out mainly in the eastern part of the working area. North of Bikfaya it is part of an isolated nappe of cretaceous formations from C1 to C3. West of Jeita on the northern side of Nahr el Kalb River, C2a crops out as part of steep west-dipping flank of the anticlinal mega structure (figures 4 and 47). South of Jeita an outcrop of C2a overthrusts J4 formation. It shows a left stepping horizontal offset of 145 m and 300 m respectively towards the outcrop of the northern side of Nahr el Kalb River.

Abieh Formation is a very variable unit. It 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. Marls can contain reworked C1-sandstones and conglomerates of palaeo channels occur locally (figure 49). Limestone can be sandy and contains ooides sometimes. Fossil content of limestones is bivalves (amongst others oysters), sponges, gastropods (figure 48) and sometimes echinoderms. Locally basaltic intrusions occur at the top of C2a / base of C2b respectively.

Figure 47: Left: Coloured marls, claystone- and limestone banks of the steep dipping western limb of the mega-anticline of Mount Lebanon (WP 059). Right: Thick fossiliferous limestone bank (WP 131)

Figure 48: Left: Gastropods of C2a limestone (WP 059). Right: Sponge of C2a limestone (WP 131)

Figure 49: Left: Conglomerate of a palaeo stream channel Right: Close-up on conglomerate, consisting of basalt, limestone, sandstone and chert nodules (both WP 419)

5.8 Mdairej Formation (C2b)

The age of Mdairej Formation is Early Cretaceous and comprises approximately the whole Aptian. According to WALLEY (1997) the thickness is about 50 m. This is true for the mapped area except for faulted parts, which pretend a greater thickness up to 80 metres for example north of Mairuba. C2b crops out mainly in the eastern part of the working area. North of Bikfaya it is part of an isolated nappe of cretaceous formations from C1 to C3. West of Jeita on the northern side of Nahr el Kalb River, C2b crops out as part of steep west-dipping flank of the anticlinal mega structure (figure 4). South of Jeita an outcrop of C2b overthrusts J4 formation. It shows a left stepping horizontal offset of 330 metres towards C2b of the northern side of Nahr el Kalb River.

Mdairej Formation is cliff-forming and widely traceable (figure 50). It allows the mapping geologist a good orientation within the stratigraphic section. The lithology consists mainly of massive light grey micritic limestone. It contains bivalves locally. This unit is strongly karstified (refer to chapter 6).

Figure 50: C2b Rock Bridge east of Faqra (WP 020). This formation is widely traceable and allows good orientation within stratigraphic sequence

5.9 Hammana Formation (C3)

The age of Hammana Formation is Early Cretaceous from upper Aptian to middle Albian. The thickness ranges from 100 m to 400 m and is in most places around 140 m (WALLEY 1997). In the working area thicknesses from 110 m SE of Sannine to 350 m NW of Sannine were found. Both thicknesses are influenced by faults. C3 crops out mainly in the eastern part of the working area. North of Bikfaya it is part of an isolated nappe of cretaceous formations from C1 to C3. West of Jeita on both sides of Nahr el Kalb River, C3 crops out as part of steep west-dipping flank of the anticlinal mega structure (figure 4). SW of Jeita an outcrop of C3 overthrusts J4 formation as well as C1, which was only noticeable at a location of a building pit (figure 13).

Hammana Formation is a very variable mainly thin-bedded unit (figure 51). Its base is often intruded by basalts in the working area (figure 52), forming purple to red soils. This formation consists of green, grey, ochre, red and beige claystone and nodular, bioturbated marl alternating with brown, yellow and beige, often micritic, limestone. Marls sometimes show light grey reduction zones as a secondary, ground water-related, feature. Limestone contains bivalves (amongst others oysters and brachiopods, figure 53) and sometimes ooides. WALLEY (1997) describes additionally glauconitic marl with ammonites (*Knemiceras*). At the border to Sannine Formation (C4) cellular, possibly evaporitic / dolomitic, limestones and soft marls with calcite-filled geodes occur (figure 54).

Figure 51: Typical thin-bedded sequence of Hammana Formation with coloured claystone and marl and ochre to beige limestone (WP 019)

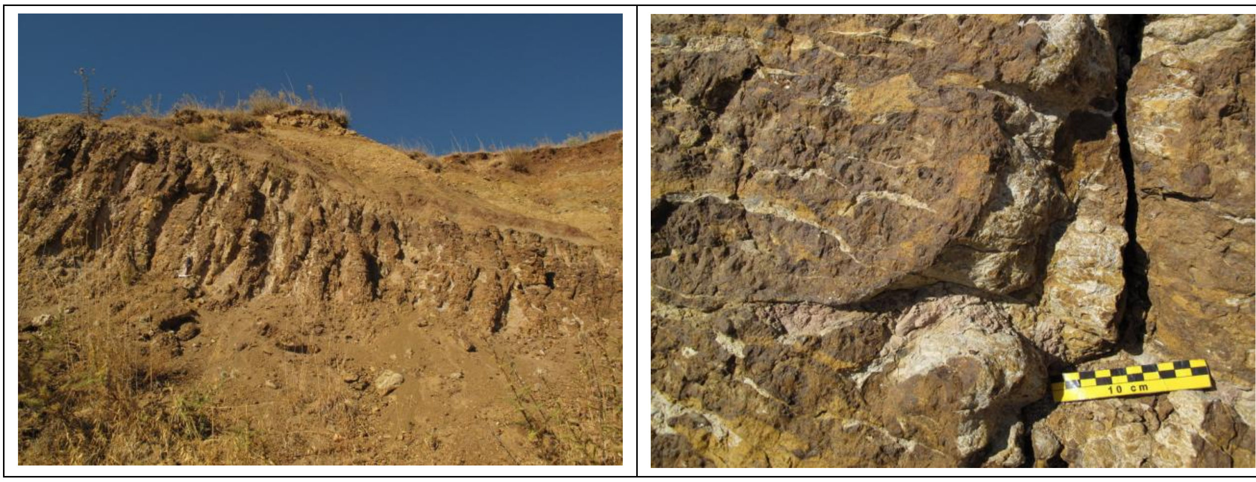

Figure 52: Left: Basaltic intrusion at the base of C3. Right: Close-up of altered and fragmented basalt (both WP 239)

Figure 53: Left: Brachiopods (WP 034). Right: Oysters (WP 021a)

Figure 54: Left: Border of C3 and C4 formations with green and grey claystone and marl. Marls often contain calcite-filled geodes in this part of the sequence (WP 227, inset: WP 258). Right: Cellular dolomitic limestone at the border of C3 and C4 formations (WP 257)

5.10 Sannine Formation (C4)

The age of Sannine Formation is Late Cretaceous from upper Albian to Cenomanian. The thickness is greater than 2000 m for the coastal type of this formation and 500 m to 700 m for the inland type (WALLEY 1997). In the working area only the coastal type occurs and represents the youngest unit with a thickness of approximately 1050 m at highest elevation of 2628 m at Jabal Sannine. C4 builds up the gently east-dipping high plateau of the mega-anticline's eastern limb of Mount Lebanon (figure 4). North of Faqra an outcrop of C4 isolated by normal faulting shows a vertical offset of 140 m at the base. Southeast of Sannine a similar outcrop shows a vertical offset of approximately 60 m.

The Sannine Formation of coastal type consists mainly of micritic light grey and beige limestone. At the base green and grey marl with bioturbation occurs. Mainly at the basal section, calcite-filled geodes were found (figure 56). In marls and fine limestones chert nodules are common (figure 55). Locally they appear to originate from recrystallised round limestone concretions. Some limestones are dolomitic; some beds appear evaporitic and are very porous (figure 57) resulting from dissolved material. Limestones can be developed with fine lamination and often show slumping in those cases (figure 55); they contain dolomitic intraclasts and chert nodules. Fossil content is echinites (figure 60), bivalves, amongst others oysters, brachiopods and rudists of the type *Hippurites* (figure 60) and according to WALLEY (1997) ammonites. Oyster beds are 50 cm thick locally (figure 59). The whole formation is deeply karstified (refer to chapter 6).

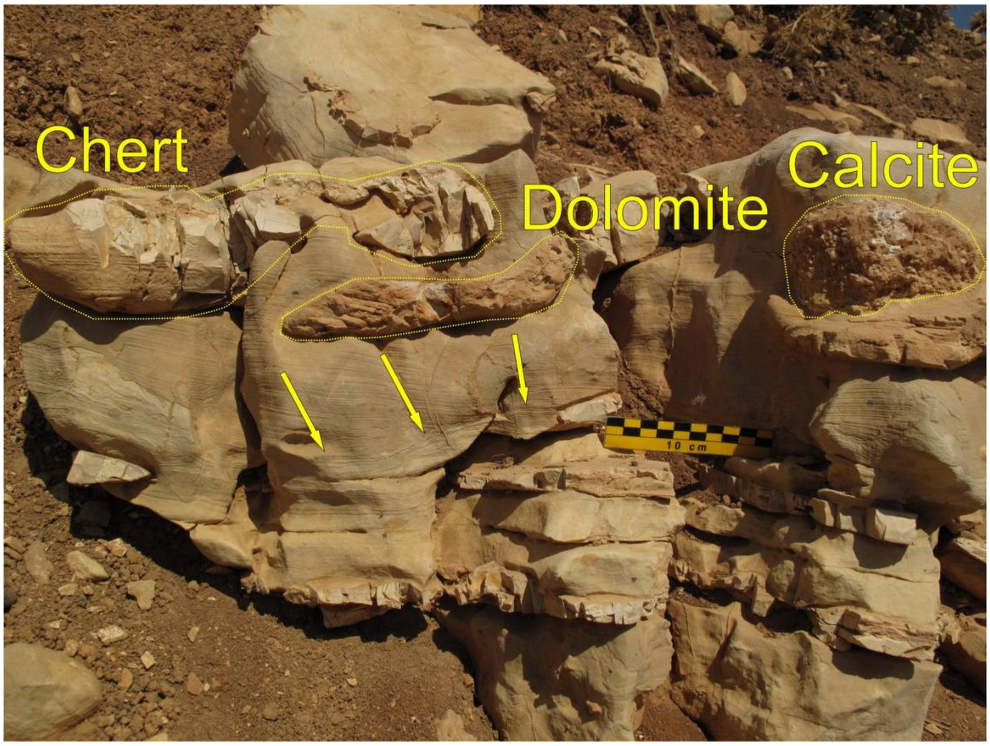

Figure 55: Laminated limestone showing slumping (arrows) and contains chert nodule, calcite-filled geode and dolomitic intraclast (WP 271)

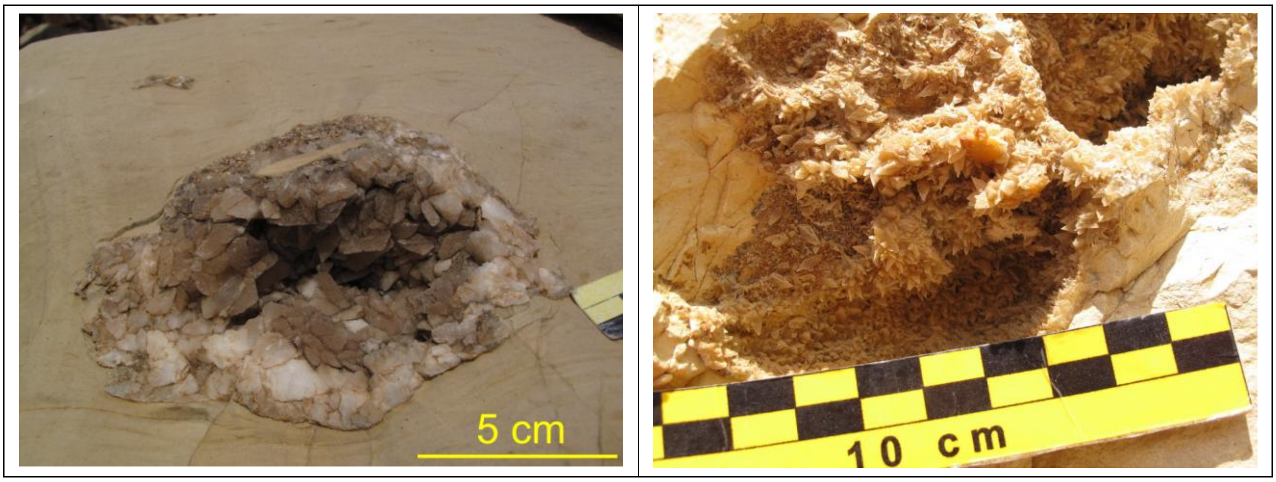

Figure 56: Geodes filled with calcite crystals. (Left: specimen from rock fall NE Sannine, right: WP 213)

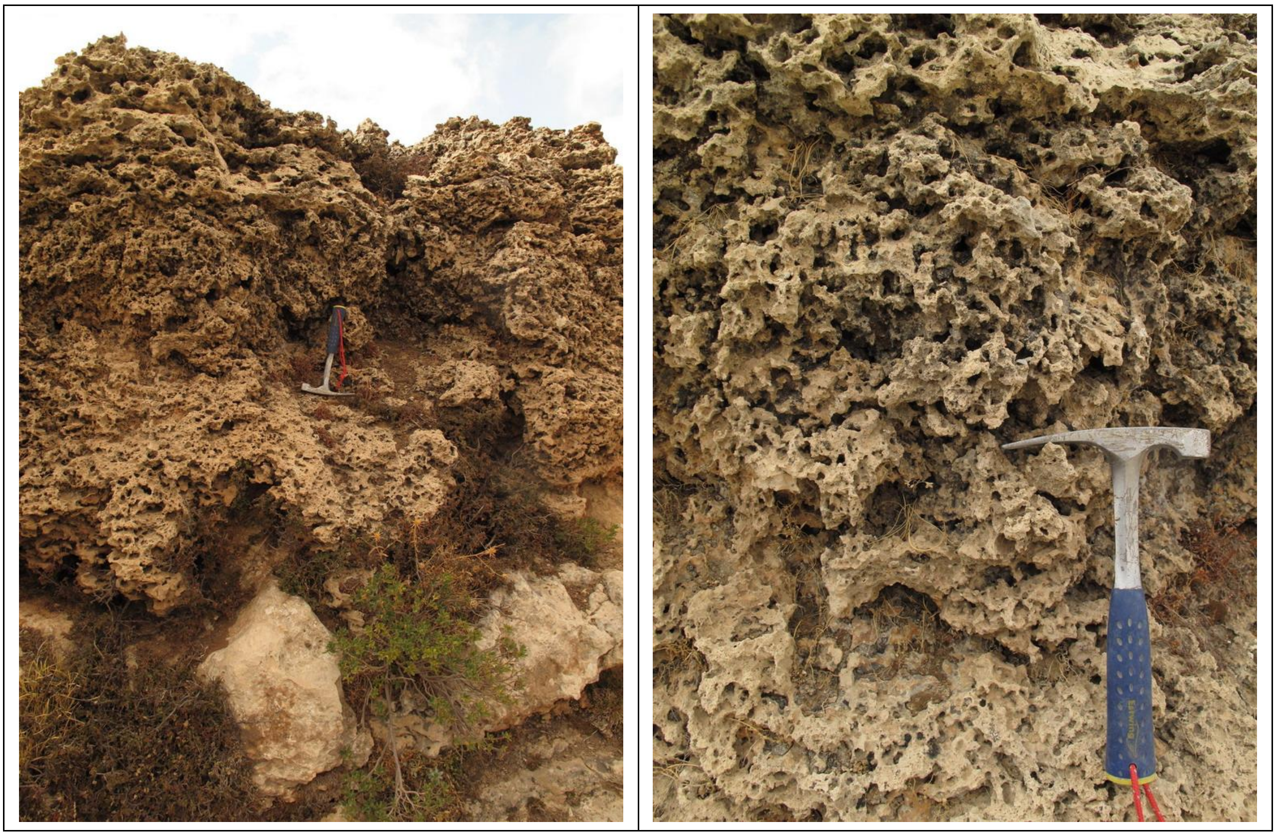

Figure 57: Left: Porous soft limestone, probably evaporitic environment. Cavities originate from dissolved material. Right: Close-up of the same limestone (both WP 273)

Figure 58: Probably evaporitic limestone (5.6 km SE WP 273)

Figure 59: Left: Bank of oyster shells. Right: Close-up of oysters (both WP 272)

Figure 60: Left: Rudist bivalve *Hippurites* (WP 220). Right: Echinite (WP 283)

5.11 Basaltic Intrusions

In the working area basaltic intrusions are common at the bases of J5, C1 and C3, as mentioned in the accordant chapters (figures 24, 42, 52). These intrusions are considered to be part of the accordant formation and thus are not extra-enhanced in the geological map, although they may be well traceable. Basalt thickness varies largely and depends on the pre-existing topography during deposition.

In two areas an exception was made. The first is situated between Daraya and Zaghrine, where basalt is intruded discordantly into and through J4 (figure 61). North of Zaghrine this intrusion migrates into J5 and thus can be considered as one source of J5-intrusion. The second area is at the south eastern edge of the working area along a major fault striking south east towards Bekaa Valley. This intrusion is most likely of Barremian / Aptian age as C2a formation is affected as well.

Basalt ages have not yet been determined as would be required. Basalt dykes passing through the J4 formation have been found in the Nahr Ibrahim and Nahr ed Dahab areas. It is believed that the occurrence and thickness of basalt is related to certain tectonic features. Basalt thickness seems to be high especially in the areas along Sannine fault, such as the two intrusive basalt area mentioned above, and the Qamezh fault, e.g. in the Qartaba area. These faults have a strike of around 80°.

Figure 61: Left: Basaltic intrusion into J4 showing ochre soil development (WP 009). Right: Basaltic intrusion into J4. Inset shows J4-limestone fragments in an altered basaltic matrix (both WP 007)

5.12 Quaternary

In the working area, quaternary features appear to be limited to river sediments, rock fall, soil development and karstification. The following figures (62 to 65) should give a short overview about selected issues. Evidence of Quaternary glaciations was found at several locations in and near the project area (ABI RIZK & MARGANE, 2011). This issue will be further exploited in the updated geological report (MARGANE & ABI RIZK, in progress).

Figure 62: Huge landslide north of Sannine mainly consisting of C4-limestone. Panoramic view from position of WP 291, looking from NW to NE (view angle from 330°-100°)

Figure 63: Rock fall consisting of huge blocks of mainly C4-limestone. Blocks are dipping with slope, endangering roads and new-built houses inside this area of a housing estate 1 km south east of Faqra (WP 263)

Figure 64: Left: Cemented mixture of conglomerate and rock fall consisting mainly of C4-limestone. Right: Close-up on cementing matrix, containing char coal (black pieces of different sizes, approximately 2 mm to 2 cm) and documenting quaternary forest burns (both WP 302, Afqa)

Figure 65: Left: Carbonate-cemented sand of C1 formation forming in- and along a small fissure in J6-limestone. Right: Close-up on a cemented “C1-sandstone-mound” (both WP 358)

6 Karstification

Karstification is a common feature of all calcareous units of the working area. All calcareous units generally show karst features as vertical and horizontal tubes and holes, karren, sinter coatings, stalagmites and stalactites of different sizes, caves and sinkholes.

Due to its thicknesses, Kesrouane- and Sannine Formations are karstified deepest and thus act as most important aquifers. Jeita Spring emerges from Jeita Grotto, a karst cave of approximately 9 km length developed along a NE-striking fault. That cave is accessible for tourists on the first hundred metres at two levels. The height from lower level with cave stream to the ceiling of the upper level is approximately 120 metres. J4 formation hosts many more known (and yet unknown) caves and is hosting 260 metres-deep Baatara Sinkhole (figure 68, outside the working area).

A similar situation can be found in C4 formation, hosting huge multi-level caves like Afqa- and Rouaiss Caves (figures 82 and 83, outside the working area), where Afqa is location of an abundant spring as well. The area of C4 high plateau is covered by dolinas where many of them are aligned along faults following a certain strike direction (figures 77 and 78).

Further details concerning the issue of karstification and its genesis are laid down in ABI RIZK & MARGANE (2011).

The following sections show figures of karst features (figures 66 to 83) within each karst-affected formation to document the grade of karstification.

6.1 J4

Figure 66: Typical surface of karstified J4 with karst tables (left) and sharp-edged karren (right, both WP 229)

Figure 67: Left: Entrance to sinkhole further pathway blocked by fallen rocks after approximately 10 m (WP 229). Right: Deeply (> 10 m) karstified J4, 1.5 km SE Marjaba (WP 032)

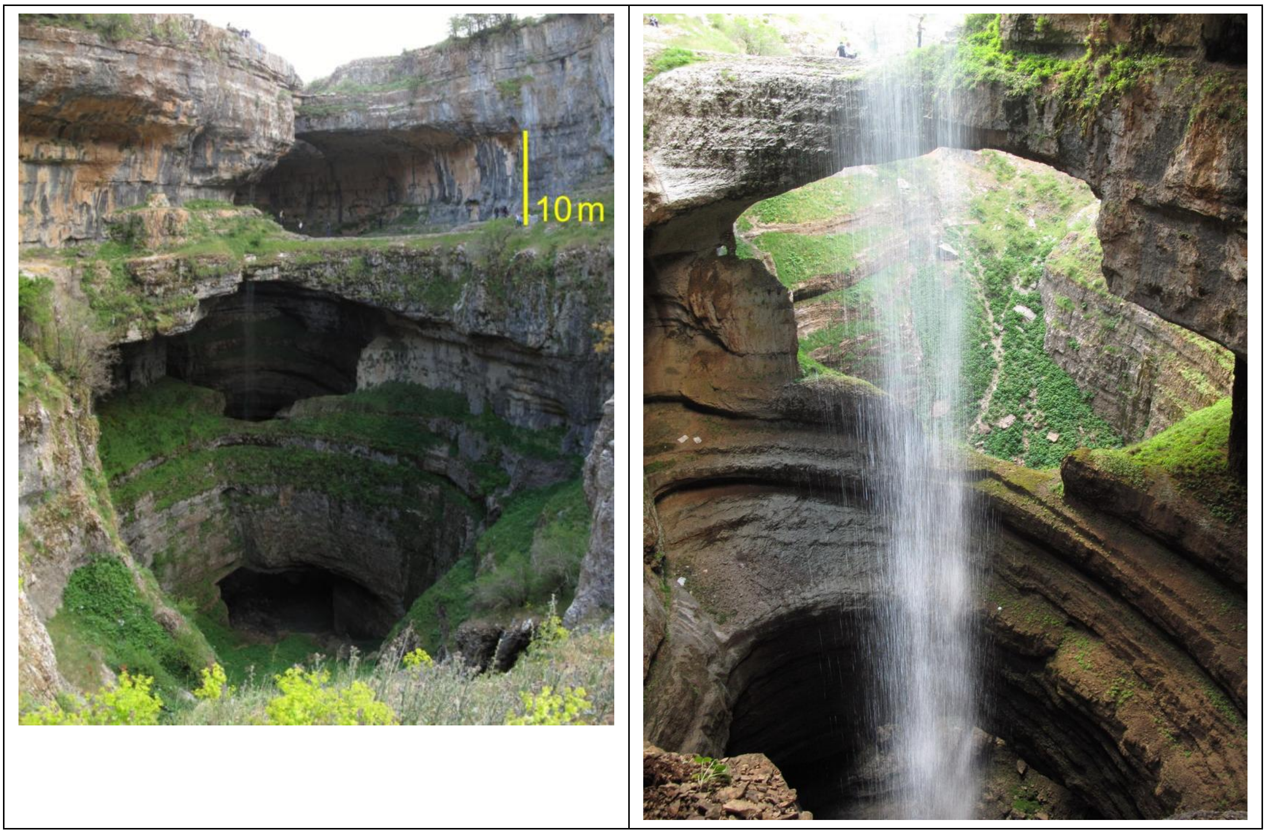

Figure 68: Baatara Sinkhole in J4 (outside the working area) with natural bridges and a depth of approximately 260 m

Figure 69: View onto stalactites inside Jeita Grotto, travelling the stream of the lower level of the cave by boat

Figure 70: Left: Sinter columns and stalactite curtains of Jeita Grotto. Right: stalactite curtain in Jeita Grotto on a closer view

Figure 71: Left: Sinter coating on a quarry wall, witnessing former cave (WP 434). Right: Huge calcite crystals of a thick sinter coating (WP 427)

Figure 72: Cemented sinter fragments and mammal bone of J4-cave from Qadisha Valley

6.2 J5

Figure 73: Travertine in J5 Formation (WP 365)

6.3 J6

Figure 74: Left: Multidirectional cavities (WP 095). Right above: Vertical and horizontal tubes (WP 109). Right below: Sinter coating in a cavity (WP 158)

6.4 C2a

Figure 75: Sinter coating, dripstones and small sinter terraces on a limestone wall of C2a (WP 082)

6.5 C2b

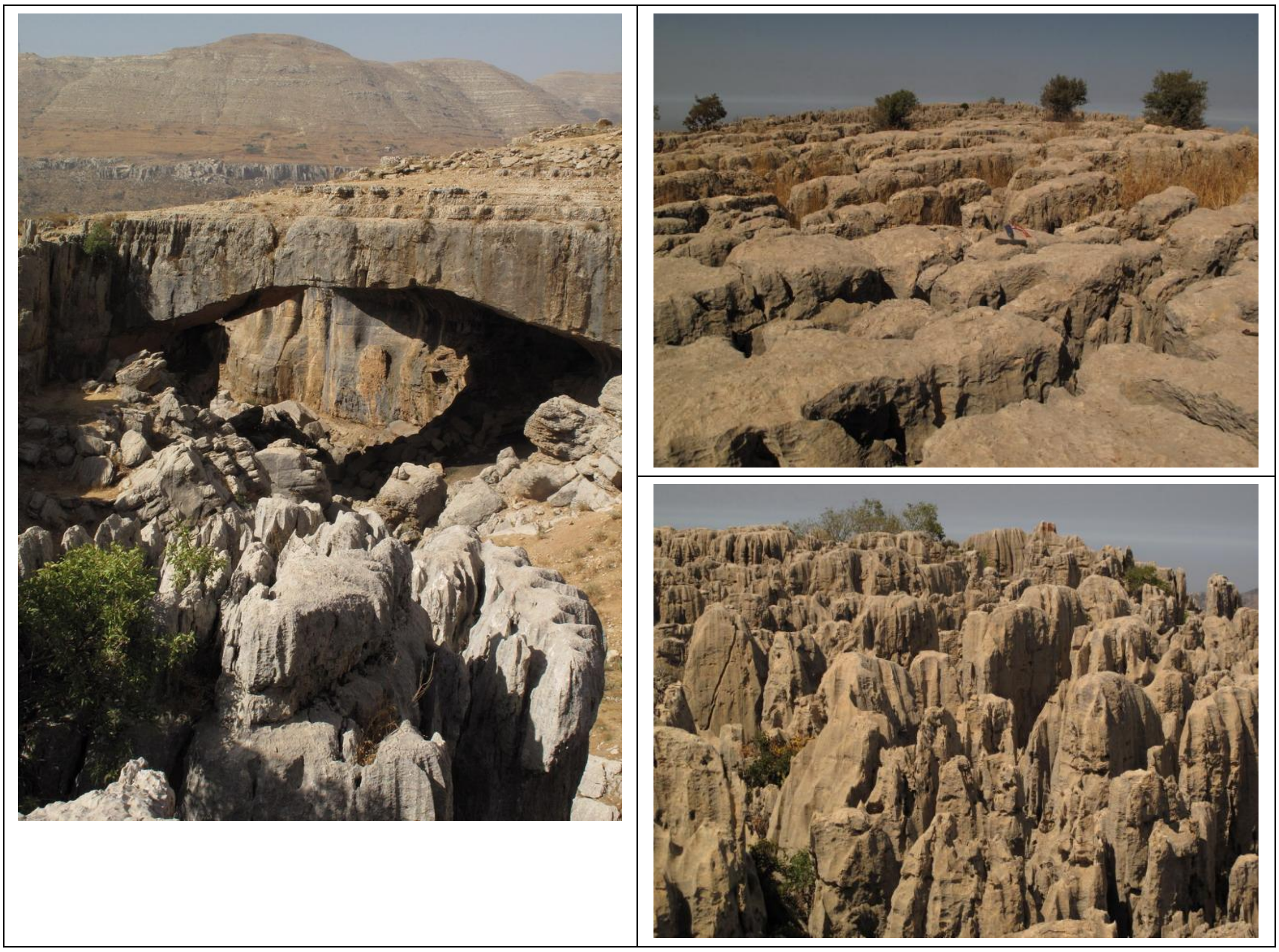

Figure 76: Left: Rock Bridge in C2b east of Faqra (WP 020). Right above and below: Deeply (> 3 m) karstified surface of C2b (both WP 334)

6.6 C4

Figure 77: Section of a “dolina chain” oriented along a lineament on deeply karstified C4 high plateau of Mount Lebanon (WP 224, view from 080°-115°)

Figure 78: Section of C4 high plateau north of Faraya. Dolinas aligned along lineaments and filled with vegetated soil. Three examples enhanced by yellow dashed lines. False colour Quickbird image; bands 3,4,2 (RGB), displays limestone as purple and pink, vegetation as green

Figure 79: Left: Karstified surface of C4 on high plateau (WP 286). Right: Karstified fissures often broaden and develop towards caves (3.5 km NE WP 270, 1.4 km SSW WP “cave”)

Figure 80: Left: Sinkhole and small cave developed along a small fault, view to the north. Right: View to the south into sinkhole and entrance of small cave (both WP "cave", 4.4 km SW WP 270)

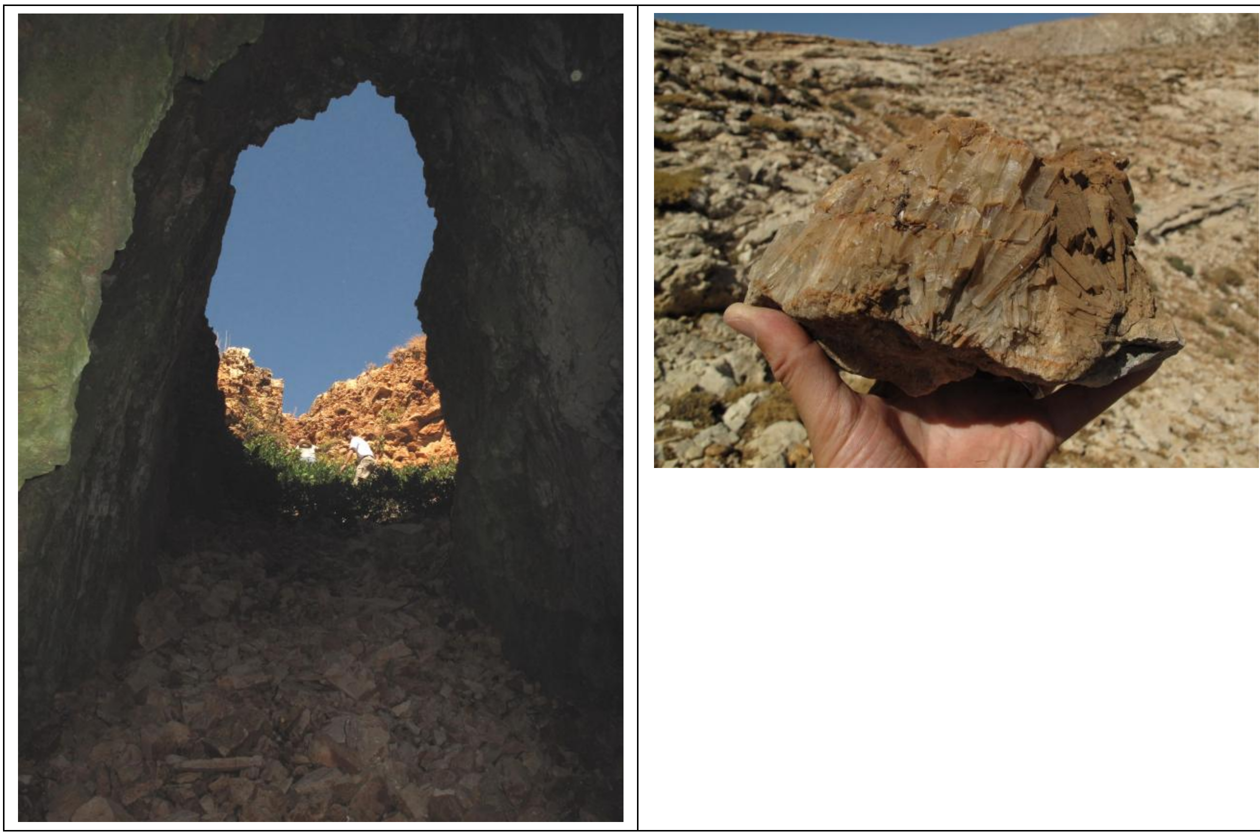

Figure 81: Left: View out of small cave (WP “cave”, 4.4 km SW WP 270). Right: Typical tall calcite crystals developed in a fissure (650 m SSE of WP “cave”)

Figure 82: Left: Small waterfall from spring emerging out of Afqa Cave (WP 302). Right above: Entrance of multi-level Afqa Cave. Height from bottom to ceiling is approximately 15 m (WP 302). Right below: Quarry in C4 close to Chabrouch Dam discovering caves; view to 260° (WP 275)

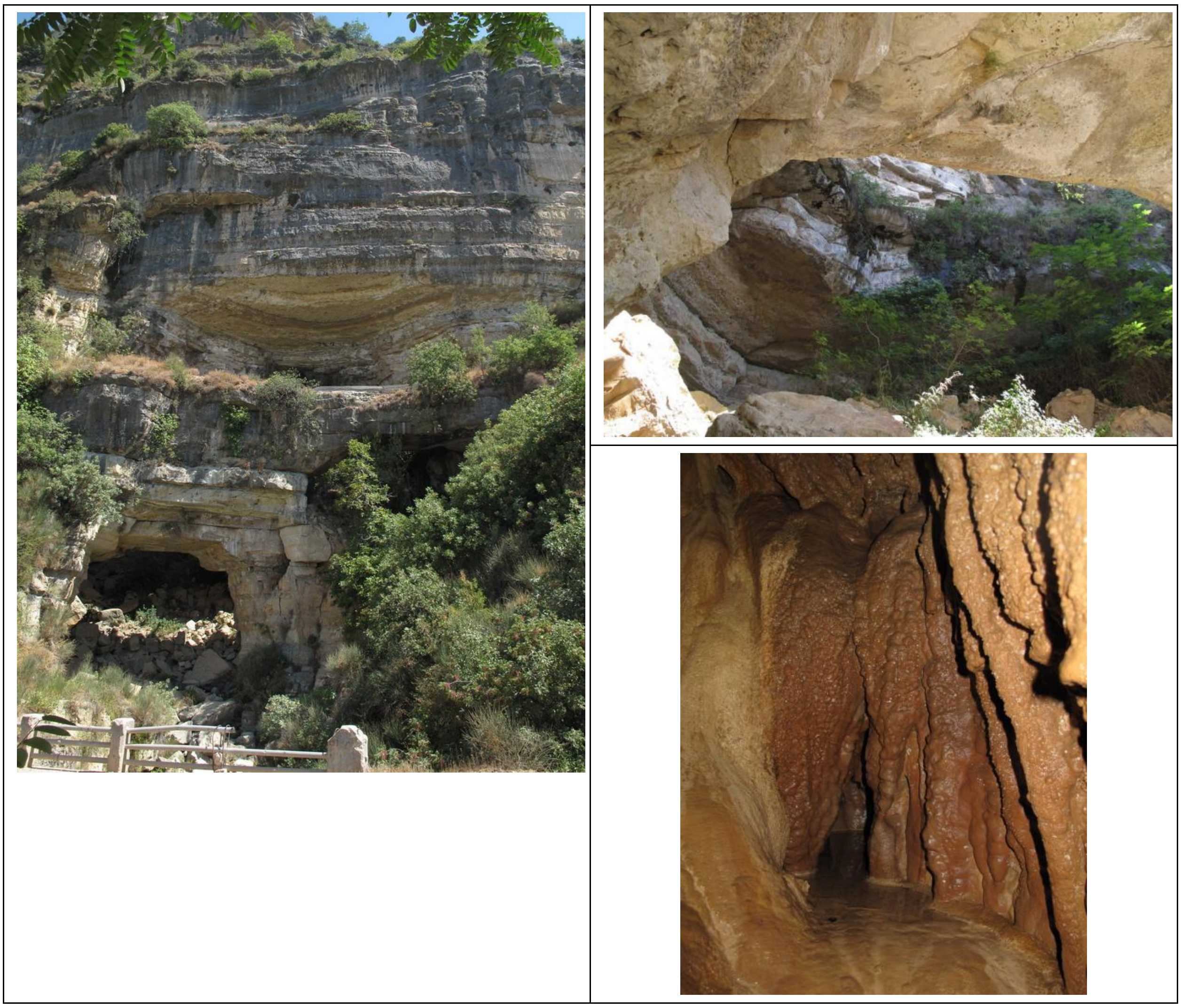

Figure 83: Left: Multi-level Rouaiss Cave. Right above: Rock bridges at entrance of Rouaiss Cave. Right below: Sinter formations in small corridor inside Rouaiss Cave (all WP "Rouaiss Cave")

6.7 Aquifers

Abundant springs can be found at the borders of C4/C3 formations (figure 85) e.g. Naber al Labbane (figure 84) and others. Many villages in the vicinity of geological borders between aquifers and aquitards start their names with "Naber" ("Nabaa" respectively) or "Ain" which means "spring". To a minor extent this is true also for borders of J5/J6, J7/C1 and C2a/C2b.

Figure 84: Naber al Labbane emerging at stratigraphical border of C3 with C4 (WP 021)

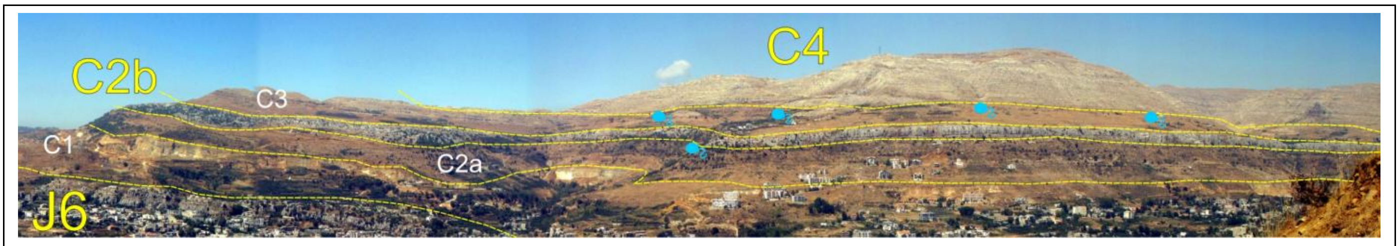

Figure 85: Important limestone aquifers of the working area marked in yellow letters (J4 is not visible from this position). Blue points are examples of springs, emerging at stratigraphical borders of aquifers and aquitards. View from WP 236 towards the towns of Mairouba (left) and Hrajel (right, view angle from 310° to 040°, NW-NE)

7 Remote Sensing

Mapping was supported by Landsat ETM satellite images with ground resolution of 30 m for multispectral – and 15 m for panchromatic data, as well as by Quickbird satellite images with ground resolution of 2.5 m for multispectral – and 0.6 m for panchromatic data.

Due to the synoptical perspective of satellite images it is possible to trace geological units and lineaments - beside any other features - over a large area.

Image enhancements as filtering allow an optimal interpretation.

By using multispectral data, which includes information from the infrared spectrum, it is possible to enhance especially formations, containing carbonates and display them in typical false colours (figure 86). Once a geologic marker e.g. C2b limestone bank was discovered, it is possible to define borders of lying and hanging formations particularly if they are consisting of different components than limestone. Areas of J5, J7 and C3 formations for example, often show small ponds, as their marl- and claystone layers are applicable for this use.

For structural analysis it is furthermore possible to estimate layer dip by considering geological features like “flat iron structures”. This is helpful especially in inaccessible areas due to scattered land mines or just rough and steep terrain.

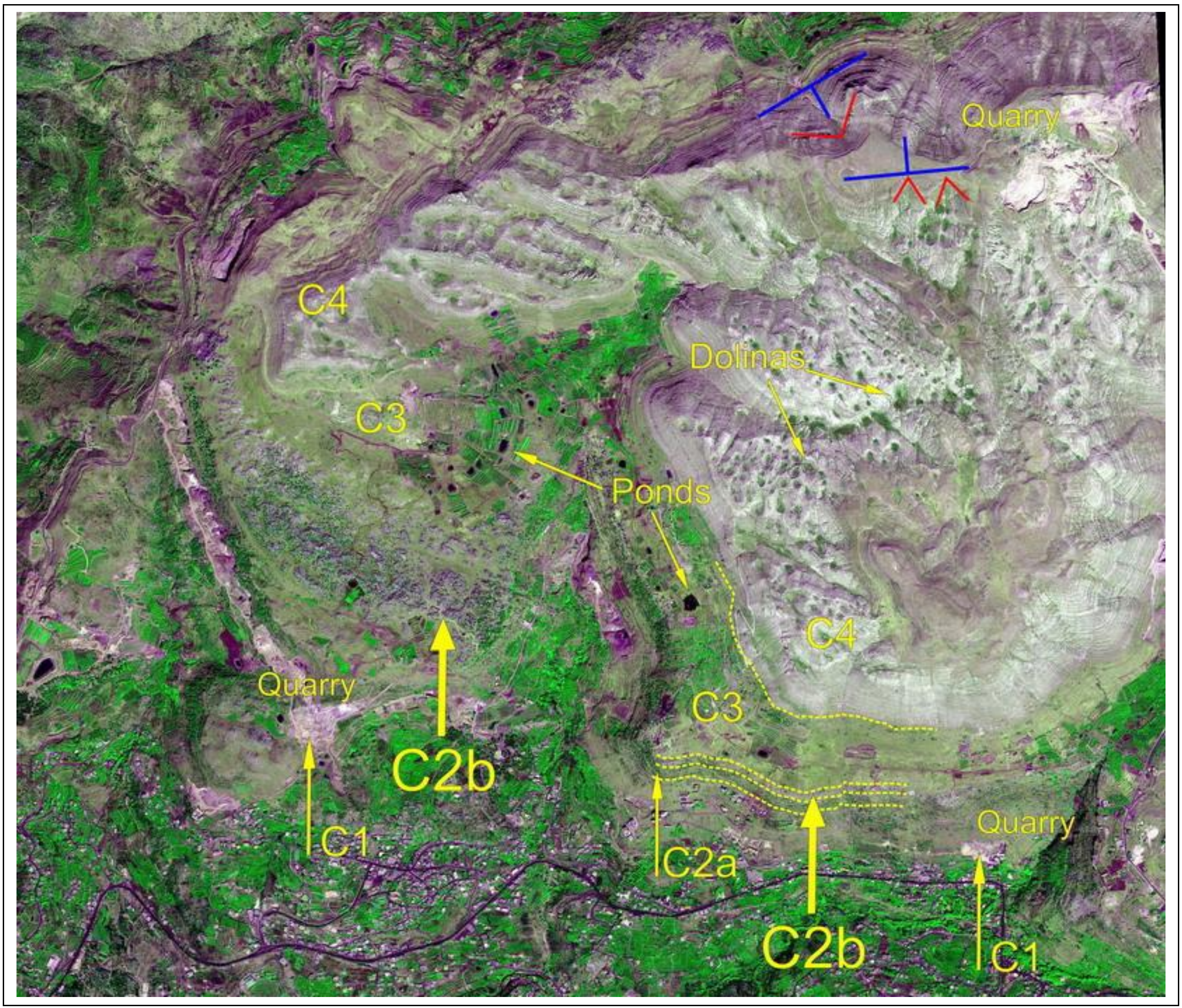

Figure 86: C1 to C4 formations NE Faraya. C2b is widely traceable and acts as geologic marker allowing definition of geological borders to lying- and hanging formations. Formations consisting of claystone and marl e.g. C3 often show ponds. Huge aligned dolinas are typical for C4 formation. Layer dip (blue symbols) can be defined, examining V-shaped “flat iron structures” (red symbols). Multispectral Quickbird image bands 3,4,2 (RGB)

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Appendix

Waypoints of measurements and field photos as mentioned in figures. Geodetic datum of coordinates (UTM) is WGS84

WP name	x UTM 36N	y UTM 36N	Height asl [m]	Date [ddmmyyyy hhmm]
1	743372.9	3758617.06	259.4	13.04.2010 10:11
2	747615.51	3757683.68	688.9	13.04.2010 10:39
3	747566.65	3757733.46	696.6	13.04.2010 10:53
4	747952.51	3757555.18	733.8	13.04.2010 10:59
5	747923.01	3757749.32	735	13.04.2010 11:02
6	748223.01	3758291.85	709.6	13.04.2010 11:11
7	749212.11	3757649.14	636	13.04.2010 11:30
8	749182.63	3757619.5	633.4	13.04.2010 11:40
9	750989.73	3758296.11	764.4	13.04.2010 12:00
10	751443.49	3758640.47	704.8	13.04.2010 12:05
11	752155.73	3759237.61	612.7	13.04.2010 12:12
12	750599.13	3759474.38	595.9	13.04.2010 12:45
13	750770.93	3759243.15	526.7	13.04.2010 13:08
14	751520.41	3760353.51	582.2	13.04.2010 13:51
15	750659.83	3759924.76	607.9	13.04.2010 14:07
16	750944.55	3759894	832.1	13.04.2010 17:24
17	754925.91	3760836.73	1096	13.04.2010 17:46
18	759011.32	3765781.43	1541.1	13.04.2010 18:15
19	759856.11	3765673.84	1559.1	13.04.2010 18:17
20	761000.84	3765530.74	1612.2	13.04.2010 18:25
21	761227.13	3765201.51	1635.3	13.04.2010 18:38
021a	761229.46	3765201.02	1637	07.09.2010 12:04
22	759181.24	3767343.14	1310.4	13.04.2010 19:05
23	756696.69	3767965.92	1331.3	13.04.2010 19:16
24	746065.4	3756163.29	781.4	14.04.2010 12:18
25	749798.76	3756453.34	972.3	14.04.2010 13:02
26	749817.21	3756448.72	977.8	14.04.2010 13:12
27	749733.07	3756446.06	963.6	14.04.2010 14:12

28	749718.52	3756453.67	960.5	14.04.2010 14:34
29	750582.97	3757285.78	1033.8	14.04.2010 15:12
30	750452.33	3757253.8	1023.9	14.04.2010 15:37
31	752408	3756934.13	936.9	14.04.2010 15:50
32	755952.69	3755877.99	1419.5	14.04.2010 16:31
33	755901.34	3755884.49	1416.9	14.04.2010 16:50
34	743011.18	3758920.45	81.8	15.04.2010 11:32
35	743072.79	3758963.87	93.4	15.04.2010 11:57
36	747563.71	3757101.69	828.3	15.04.2010 12:53
37	756641.24	3767444.66	1215.5	16.04.2010 12:14
38	756674.2	3767449.44	1234.9	16.04.2010 12:55
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40	756580.84	3767439.03	1222.2	16.04.2010 13:20
41	756558.07	3767440.41	1215.5	16.04.2010 13:39
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43	757047.11	3767133.1	1257.8	16.04.2010 14:26
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47	750487.65	3760898.36	892.9	18.04.2010 17:15
48	751478.44	3760310.88	577.9	19.04.2010 11:42
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50	743804.52	3759064.58	54.9	
51	743867.29	3759278.31	107.6	23.04.2010 09:57
52	744015.25	3759291	154.2	23.04.2010 10:41
53	744014.18	3759458.13	178	23.04.2010 10:58
54	743984.47	3759394.21	171	23.04.2010 11:40
55	743840.09	3759353.87	123.9	23.04.2010 12:10
56	743863.77	3759343.26	133.5	23.04.2010 13:02
57	743905.09	3759337	138.8	23.04.2010 13:25
58	743227.46	3759472.09	154.2	23.04.2010 13:55
59	743201.48	3759460.77	162.1	23.04.2010 15:01

60	743169.27	3759468.71	174.6	23.04.2010 15:15
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62	743058.85	3759669.22	178.4	23.04.2010 15:55
63	743007.45	3759668.23	181.8	23.04.2010 16:07
64	743147.11	3759474.36	159.7	23.04.2010 16:34
65	743136.4	3759513.15	159.2	23.04.2010 16:40
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75	742916.1	3759107.26	161.4	24.04.2010 12:20
76	743006.38	3759053.63	145.5	24.04.2010 12:45
77	743199.83	3759002.43	126.5	24.04.2010 13:04
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79	743504.24	3759075.4	144.1	24.04.2010 14:19
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95	744338.89	3760081.53	367.3	26.04.2010 12:12
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97	744207.47	3760026.86	359.2	26.04.2010 13:03
98	744219.07	3760104.3	357.3	26.04.2010 13:11
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107	744122.15	3759859.5	294	27.04.2010 11:49
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110	743970.97	3759717.41	251	27.04.2010 12:43
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113	743095.6	3758590.19	206.6	29.04.2010 11:07
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115	743077.56	3758460.3	216.2	29.04.2010 11:28
116	743057.75	3758193.85	228	29.04.2010 11:45
117	742954.56	3758133.71		
118	743154.2	3758256.93	233.2	29.04.2010 12:29
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120	742685.39	3758117.39	261.4	29.04.2010 13:11
121	742795.72	3758256.51	192.9	29.04.2010 13:43
122	742569.77	3758322.54	190.9	29.04.2010 14:04
123	742620.54	3758319.84	177	29.04.2010 14:21

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131	744047.11	3758556.59	252.7	29.04.2010 16:45
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140	744229.38	3758437.08	303.9	30.04.2010 16:47
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143	744427.56	3758583.82	375.3	30.04.2010 17:53
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151	744349.97	3757477.08	528.6	03.05.2010 10:48
152	745993.7	3757179.38	609.1	03.05.2010 11:34
153	746041.06	3757229.67	611.8	03.05.2010 11:42
154	745992.47	3756902.19	633.1	03.05.2010 11:57
155	745893.32	3756907.83	652.1	03.05.2010 12:13

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157	745632.18	3756976.54	633.1	03.05.2010 12:43
158	746166.53	3757186.97	611	03.05.2010 13:52
159	746155.22	3757127.18	605	03.05.2010 13:48
160	746302.6	3757088.83	605.8	03.05.2010 15:29
161	747041.62	3757394.65	681.5	03.05.2010 15:48
162	747070.26	3757183.28	687.5	03.05.2010 16:11
163	747074.4	3757954.49	681.7	03.05.2010 16:31
164	746909.67	3758073.52	638.2	03.05.2010 16:49
165	746675.2	3757893.15	571.6	03.05.2010 17:25
165A	746833.59	3757882.62	-10000000	03.05.2010 17:49
166	746688.37	3758065.98	560.8	03.05.2010 17:58
167	747148.19	3758293.07	643.5	03.05.2010 18:03
168	743629.36	3758465.15	281.8	05.05.2010 09:59
169	743176.33	3758803.92	175.3	05.05.2010 10:43
169a	743163.45	3758793.93	175.3	
170	743474.4	3758231.3	294.5	05.05.2010 11:39
171	743657.35	3758153.75	330.8	05.05.2010 11:42
172	744184.16	3757872.84	435.6	05.05.2010 12:12
173	745787.92	3757168.71	597.3	05.05.2010 12:28
174	745464.06	3757215.71	631	05.05.2010 13:02
175	745350.54	3757093.68	636.8	05.05.2010 13:13
176	745216.74	3756807.51	681.9	05.05.2010 13:28
177	745038.86	3756651.4	699.5	05.05.2010 13:47
178	745140.8	3756634.72	716.3	05.05.2010 13:54
179	745083.45	3756526.68	731	05.05.2010 13:59
180	745291.36	3756641.61	716.3	05.05.2010 14:35
181	745213.2	3756686.65	712.7	05.05.2010 14:43
182	745217.22	3756742.37	704.3	05.05.2010 14:49
183	745382.62	3756515.33	723.5	05.05.2010 15:39
184	745334.45	3756496.1	719.9	05.05.2010 15:52
185	745920.44	3756621.72	706.7	05.05.2010 16:25

186	745506.77	3756863.18	648.5	05.05.2010 16:49
187	744954.83	3756959.8	636.3	05.05.2010 17:04
188	744586.44	3756638.5	640.6	05.05.2010 17:28
189	762699.76	3762080.26	2340.9	07.05.2010 11:47
190	762406.07	3762110.42	2390.4	07.05.2010 11:49
191	762654.86	3761894.95	2464.4	07.05.2010 12:46
192	744717.55	3756975.76	602.9	11.05.2010 10:46
193	744523.81	3757136.81	574.5	11.05.2010 11:22
194	744531.53	3756481.8	642.5	11.05.2010 11:32
195	744571.84	3756483.51	644	11.05.2010 11:50
196	744592.02	3756497.46	652.9	11.05.2010 12:05
197	744568.99	3756554.36	646.6	11.05.2010 12:14
198	744578.45	3756617.98	652.1	11.05.2010 12:30
199	745772.02	3756775.26	697.3	11.05.2010 12:51
200	747473.68	3757470.63	780	11.05.2010 13:43
201	747513.76	3757434.38	778.1	11.05.2010 13:59
202	747210.86	3758050.51	671.8	11.05.2010 14:28
203	747410.97	3758267.18	645.2	11.05.2010 14:30
204	747524.8	3758255.61	632.2	11.05.2010 14:40
205	747525.23	3758356.08	627.6	11.05.2010 14:57
206	746945.04	3757344.07	670.2	11.05.2010 15:32
207	747067.2	3757751.4	650.2	11.05.2010 15:36
208	758138.61	3767704.47	1292.6	02.09.2010 09:32
209	758288.04	3767993.3	1317.6	02.09.2010 09:45
210	758637.29	3769109.75	1452.7	02.09.2010 10:00
211	758684.6	3769488.15	1534.1	02.09.2010 10:24
212	758936.54	3769660.24	1553.1	02.09.2010 10:36
213	759601.22	3768587.9	1631.2	02.09.2010 11:05
214	759621.07	3768860.87	1692	02.09.2010 11:24
215	759583.73	3769008.94	1709.3	02.09.2010 11:46
216	759577.62	3769039.63	1719.7	02.09.2010 11:53
217	760083.78	3768770.03	1820.6	02.09.2010 12:28

218	759903.85	3768745.2	1824.5	02.09.2010 13:07
219	760267.88	3768787.42	1824.5	02.09.2010 13:19
220	760365.66	3768653.68	1831.4	02.09.2010 13:29
221	760296.33	3768617.13	1818.4	02.09.2010 13:36
222	760684.27	3769233.3	1790.3	02.09.2010 14:01
223	760591.43	3770085.43	1814.4	02.09.2010 14:18
224	760812.17	3770512.16	1839.1	02.09.2010 14:39
225	759794.72	3770968.01	1783.8	02.09.2010 15:07
226	759788.79	3770569.09	1709.8	02.09.2010 15:25
227	759161.75	3770933.29	1668.5	02.09.2010 15:56
228	758676.94	3771140.46	1616.6	02.09.2010 16:12
229	752598.78	3760080.72	953.7	04.09.2010 15:55
230	755182.93	3765643.37	1114.5	05.09.2010 11:22
231	755206.49	3765517.01	1129.7	05.09.2010 11:40
232	757427.43	3765227.98	1439	05.09.2010 12:42
233	757353.66	3765268.04	1443.8	05.09.2010 12:56
234	757635.23	3765416.69	1467.3	05.09.2010 13:26
235	758041.27	3765445.3	1495	05.09.2010 14:01
236	758250.96	3765584.57	1528.4	05.09.2010 14:11
237	758970.82	3765757.9	1546.6	05.09.2010 15:35
238	759211.37	3765849.97	1550	05.09.2010 15:52
239	759342.18	3765800.16	1557.7	05.09.2010 16:16
240	759600.33	3765759.4	1594.5	05.09.2010 16:39
241	759824.46	3765903.65	1640.1	05.09.2010 17:12
242	759634.82	3765887.12	1611.8	05.09.2010 17:32
243	759598.09	3765847.7	1609.8	05.09.2010 17:38
244	758684.07	3765431.34	1505.1	06.09.2010 14:05
245	758633.03	3765431.38	1499.5	06.09.2010 14:21
246	758546.9	3765659.71	1536.1	06.09.2010 15:06
247	759254.63	3766477.26	1382.5	06.09.2010 15:17
248	758086.53	3765999.15	1402.4	06.09.2010 15:43
249	758000.69	3766014.34	1400	06.09.2010 15:52

250	758267.59	3766411.06	1346	06.09.2010 16:08
251	758346.22	3766433.08	1329.1	06.09.2010 16:11
252	759482.02	3766381.26	1381	07.09.2010 10:53
253	759511.91	3766407.17	1396.7	07.09.2010 11:03
254	759535.63	3766391.72	1418.3	07.09.2010 11:14
255	760107.75	3765762.57	1582.2	07.09.2010 11:45
256	761269.36	3765182.36	1638.9	07.09.2010 12:08
257	761289.83	3765325.13	1658.1	07.09.2010 13:26
258	761262.48	3765287.52	1653.6	07.09.2010 13:42
259	760419.89	3764909.82	1688.4	07.09.2010 14:38
260	760498.31	3764912.97	1690.8	07.09.2010 14:46
261	760496.5	3764878.07	1699	07.09.2010 14:54
262	760403.51	3764779.26	1729.8	07.09.2010 15:42
263	760451.48	3764803.78	1726.6	07.09.2010 16:00
264	762468.3	3765088.77	1850.9	08.09.2010 12:06
265	762405.25	3765111.67	1853.3	08.09.2010 12:19
266	762317.22	3765154.97	1850.2	08.09.2010 12:29
267	762273.65	3765228.92	1861.5	08.09.2010 12:43
268	763206.97	3765204.22	1962.4	08.09.2010 12:59
269	766299.08	3766310.93	2027.3	08.09.2010 13:39
270	766311.5	3767008.93	2014.1	08.09.2010 13:47
271	766195.61	3767197.39	2040.7	08.09.2010 14:01
272	765260.6	3768015.73	2014.6	08.09.2010 14:21
273	764151.54	3769953.44	1906.4	08.09.2010 15:15
274	762676.79	3770908.78	1877.3	08.09.2010 15:58
275	761552.39	3770993.13	1867.2	08.09.2010 16:31
276	762790.68	3764518.34	1904.2	09.09.2010 10:19
277	762747.53	3764467.29	1917.2	09.09.2010 10:35
278	762403.87	3761946.17	2433.4	09.09.2010 11:24
279	762684.58	3761894	2461.1	09.09.2010 11:51
280	763967.97	3762207.68	2317.1	09.09.2010 12:56
281	763996.37	3762131.31	2327	09.09.2010 13:10

282	764109.7	3762034.45	2358.5	09.09.2010 13:16
283	763101.79	3763459.91	2246	09.09.2010 14:18
284	763080.89	3763376.84	2237.6	09.09.2010 14:28
285	763989.55	3763715.77	2310.9	09.09.2010 15:01
286	764118.5	3763734.46	2320	09.09.2010 15:15
287	762115.74	3764013.26	2037.4	09.09.2010 16:38
288	762498.95	3760808.58	1822.1	10.09.2010 12:00
289	762504.57	3760729.24	1839.4	10.09.2010 12:15
290	762392.57	3760033.3	1720.2	10.09.2010 12:39
291	762618.43	3758396.45	1705.3	10.09.2010 13:26
292	762856.01	3756475.17	1813.2	10.09.2010 14:37
293	763232.77	3755945.86	1892.2	10.09.2010 14:52
294	763272.55	3756100.06	1924.4	10.09.2010 15:05
295	763944.09	3755789.22	1913.4	10.09.2010 15:10
296	761923.16	3759945.49	1588.5	10.09.2010 15:51
297	761920.97	3759847.3	1577.4	10.09.2010 15:59
298	760387.43	3759893.06	1482.2	10.09.2010 16:34
299	756608.06	3761294.66	1108.5	10.09.2010 17:42
300	756574.15	3761265.99	1111.2	10.09.2010 17:54
301	756586.77	3761250.68	1119.8	10.09.2010 18:02
302	766823.95	3773511.19	1139	12.09.2010 15:12
303	753589.13	3765432.21	1254.4	15.09.2010 10:24
304	756492.03	3768316.92	1365.4	15.09.2010 11:31
305	756710.38	3768584.5	1378.6	15.09.2010 11:52
306	756850.83	3768694.67	1371.7	15.09.2010 12:50
307	756794.87	3768624.87	1384.4	15.09.2010 13:03
308	757173.89	3767175.63	1261.1	15.09.2010 15:09
309	757319.23	3767419.47	1302	15.09.2010 15:25
310	757687.01	3767492.22	1324.6	15.09.2010 15:53
311	757154.17	3767642.44	1331.5	15.09.2010 16:25
312	758206.76	3767662.93	1305.3	15.09.2010 17:20
313	757997.61	3767221.17	1258.2	15.09.2010 17:30

314	761966.71	3767062.47	1551.9	16.09.2010 10:54
315	761067.28	3767055.57	1349.3	16.09.2010 11:41
316	760106.99	3767339.15	1284	16.09.2010 14:17
317	760272.74	3767305.86	1281.1	16.09.2010 14:34
318	759343.47	3766989.8	1243.3	16.09.2010 15:31
319	759748.55	3767273.12	1259.9	16.09.2010 15:52
320	759794.4	3766893.39	1314.5	16.09.2010 16:38
321	759238.63	3766790.98	1288.5	16.09.2010 17:09
322	758310.46	3766510.03	1323.6	16.09.2010 17:29
323	763186.88	3773076.39	1265.7	19.09.2010 11:28
324	758609.56	3767029.63	1215	21.09.2010 10:31
325	757603.83	3764888.98	1371.2	21.09.2010 12:21
326	756137.94	3764996.92	1420.9	21.09.2010 13:44
327	756022.93	3765156.88	1470.7	21.09.2010 14:07
328	756084.96	3765164	1474.5	21.09.2010 14:59
329	756173.12	3765131.64	1464.2	21.09.2010 15:11
330	755441.76	3764806.26	1352.9	23.09.2010 09:51
331	755212.01	3764188.74	1372.9	23.09.2010 11:05
332	756279.01	3763932.85	1295.5	23.09.2010 12:48
333	757102.32	3763772.24	1266.4	23.09.2010 13:59
334	758832.04	3763297.76	1698.5	24.09.2010 11:05
335	760045.22	3761442.48	1773.3	24.09.2010 12:28
336	757944.71	3761039.13	1612	24.09.2010 12:58
337	757777.28	3760824.65	1592.5	24.09.2010 13:11
338	757643.03	3760577.67	1545.4	24.09.2010 13:19
339	757412.5	3759644.59	1302	24.09.2010 13:39
340	759694.16	3759469.06	1337.3	24.09.2010 16:29
341	759756.74	3759454.46	1333	24.09.2010 16:31
342	759816.64	3759466.43	1333.9	24.09.2010 16:41
343	759285.59	3759296.91	1316.2	24.09.2010 17:43
344	756752.54	3761618.72	1147	27.09.2010 12:11
345	760469.34	3759659.41	1467.3	27.09.2010 13:09

346	761042.68	3757932.85	1454.1	27.09.2010 16:25
347	760463.95	3757495.09	1522.6	27.09.2010 17:31
348	758390.49	3757248.21	1501.9	27.09.2010 18:23
349	758499.08	3757236.74	1505.1	27.09.2010 18:38
350	755132.73	3761778.19	1092.4	09.03.2011 13:51
351	756004.15	3761413.85	1148.7	09.03.2011 14:11
352	755852.85	3760238.42	1187.3	12.03.2011 10:32
353	754812.07	3760712	1140.7	12.03.2011 11:15
354	754378.38	3760861.53	1107.6	12.03.2011 13:06
355	754907.61	3760829.24	1085.4	12.03.2011 13:25
356	754943.52	3760725.64	1083.3	12.03.2011 14:02
357	756161.39	3760942.11	1072.5	12.03.2011 15:06
358	756116.1	3760947.65	1061.9	12.03.2011 15:18
359	756106.17	3760941.95	1057.8	12.03.2011 15:36
360	754469.48	3760520.96	1114.5	12.03.2011 16:32
361	753417.01	3759779.66	1161.1	14.03.2011 10:16
362	754171.81	3759455.42	1196.7	14.03.2011 12:34
363	754744.33	3759574.26	1206.1	14.03.2011 14:18
364	754682.95	3759582.93	1215.9	14.03.2011 14:49
365	754700.66	3758706.79	1044.6	15.03.2011 10:16
366	755507.74	3758634.83	1053	15.03.2011 11:40
367	756204.31	3758735.44	1036.4	15.03.2011 12:52
368	759128.12	3758954.91	1187.8	15.03.2011 17:37
369	751474.36	3758798.58	684.8	16.03.2011 10:08
370	750810.63	3758637.91	794.6	16.03.2011 10:50
371	750276.92	3757932.38	898.5	16.03.2011 12:00
372	750498.7	3758062.22	945.1	16.03.2011 13:51
373	751921.32	3757621.39	1023.4	16.03.2011 17:22
374	751119.94	3757190.87	1022.2	17.03.2011 09:39
375	752035.46	3755822.41	1063.3	17.03.2011 13:32
376	750355.01	3756835.75	1014.5	17.03.2011 16:56
377	751810.88	3759117.66	580.5	17.03.2011 17:18

378	751493.09	3760738.18	595.9	17.03.2011 17:30
379	750230.18	3760420.79	710.3	17.03.2011 17:44
380	750281.69	3760414.27	706.2	17.03.2011 17:47
381	750425.71	3760484.35	734.6	18.03.2011 08:58
382	754200.79	3757667.24	966.7	18.03.2011 14:05
383	754896.97	3757338.04	1096.5	18.03.2011 16:19
384	755039.19	3757100.87	1129.9	18.03.2011 16:49
385	755076.64	3757095.22	1130.4	18.03.2011 17:01
386	755019.27	3756816.05	1151.5	18.03.2011 17:15
387	749426.6	3761770.24	854.7	19.03.2011 12:41
388	749353.35	3761823.14	855	19.03.2011 12:56
389	750239.71	3762068.98	992	19.03.2011 13:11
390	751337.59	3762685.93	1030.9	19.03.2011 13:35
391	751616.55	3762527.95	1028	19.03.2011 13:47
392	766828.94	3773560.29	1140.5	19.03.2011 15:56
393	754907.17	3755977.06	1195.3	21.03.2011 09:23
394	754767.84	3755410.07	1255.6	21.03.2011 10:33
395	754851.69	3755424.09	1263.3	21.03.2011 10:50
396	755722.45	3755513.23	1366.6	21.03.2011 13:47
397	748533.01	3756323.41	994.6	22.03.2011 09:50
398	746128.68	3755143.76	996.5	23.03.2011 10:26
399	748481.01	3757358	794.6	23.03.2011 11:23
400	748475.35	3757404.36	793	23.03.2011 11:37
401	748503.03	3757266.12	787.9	23.03.2011 11:46
402	749056.46	3757325.7	756.7	23.03.2011 12:26
403	747801.07	3757519.03	737.5	23.03.2011 13:44
404	748800.11	3757672.84	650	23.03.2011 15:21
405	748237.32	3758275.58	708.9	23.03.2011 15:53
406	749706.03	3757072.28	899	24.03.2011 10:51
407	749137.4	3757664.6	639.6	24.03.2011 12:52
408	748385.44	3758272.13	674.5	24.03.2011 14:31
409	746566.28	3757673.42	561.8	24.03.2011 16:46

410	746544.18	3757341.97	550	24.03.2011 17:11
411	744972.23	3757436.31	540.4	25.03.2011 10:43
412	744995.37	3757418.04	536.8	25.03.2011 11:01
413	744506.86	3756301.02	686.3	25.03.2011 14:46
414	745889.74	3756000.12	766.3	25.03.2011 15:25
415	746553.69	3756232.24	855.9	25.03.2011 16:13
416	754109.42	3763558.18	1252.5	28.03.2011 09:28
417	754098.68	3763575.88	1252	28.03.2011 09:29
418	753948.83	3763491.15	1230.1	28.03.2011 09:45
419	763064	3756043.76	1873.2	28.03.2011 13:08
420	763260.26	3755815.63	1911.5	28.03.2011 13:29
421	763227.27	3755910.52	1901.6	28.03.2011 13:36
422	763239.33	3755982.79	1893.2	28.03.2011 13:46
423	763295.68	3755980.25	1905.9	28.03.2011 13:52
424	761742.94	3757593.03	1492.1	28.03.2011 16:03
425	760862.3	3757405.91	1546.6	28.03.2011 16:35
426	759682.04	3756814.13	1716.8	28.03.2011 17:31
427	747417.9	3759341.49	557	30.03.2011 10:55
428	747470.61	3759157.95	436.3	30.03.2011 11:24
429	747535.87	3759163.65	444.3	30.03.2011 11:40
430	747837.41	3759150.88	418.5	30.03.2011 11:49
431	747904.27	3759190.82	417.6	30.03.2011 12:05
432	746514.08	3760038.98	598.3	30.03.2011 13:13
433	746273.7	3760148.5	573.5	30.03.2011 13:28
434	746298.49	3760183.89	576.2	30.03.2011 13:33
435	745447.18	3760342.71	478.4	30.03.2011 13:47
436	744930.21	3760343.43	431.5	30.03.2011 13:57
437	746768.19	3760475.6	667.5	30.03.2011 14:24
438	748425.26	3761177.81	803.5	30.03.2011 15:18
439	748400.8	3761052.63	791	30.03.2011 15:35
Baatara sink	764595.08	3785222.27	1525.2	01.05.2010 17:31
Cave	770133.84	3769181.88	1913.1	28.09.2010 12:46

Cracked House	758213.4	3759411.06	1239.7	10.09.2010 16:50
Faqra arch	759281.86	3765777.74	1544	06.06.2008 12:50
Jeita	744343.7	3759059.05	47	15.04.2010 09:19
Rock bridge	760928.11	3765650.07	1597.1	08.06.2008 10:34
Rouaiss Cave	768303.85	3778077.92		
Water distribution	760603.18	3757715.5	1460.6	27.09.2010 17:11