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**Characterization of the Jurassic reservoir potential in
the Eastern Levant margin using reconstruction of the
depositional environment and the diagenetic history**

Final report

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Abstract

Exploration efforts for hydrocarbons reservoirs in the Levant Basin offshore Israel are of great interest, especially after the recent discoveries of large Oligo-Miocene gas reservoirs at the center of the Levant Basin. According to structural and seismic interpretation studies of the Levant Basin margins, there is a variety of potential structural and stratigraphic oil-traps offshore Israel. Several offshore and onshore boreholes showed oil marks and oil accumulation in the Jurassic section, especially in the Barnea, Sderot and Zohar formations, suggesting there is a potential of finding other hydrocarbons reservoirs in this section. The current study focuses on the diagenetic evolution of potential reservoir rocks within the Jurassic sedimentary section along the Levant margin in Israel in order to track evidence for the formation and accumulation of hydrocarbons within these rocks. Although many studies were done on those wells, none of them examined the diagenetic history of the cements in the Jurassic section. Guided by lithostratigraphic description and electric logs, sampling efforts target rock cuttings and drill cores from the richest clastic intervals recovered from boreholes in the coastal plain and offshore central Israel. A petrographic examination of the cement phases will determine their relative age and paragenetic sequence. Chemical and stable isotope analysis of cement phases will be done in order to reconstruct the burial history and the geothermal gradient of the potential reservoir rocks.

Twenty seven Jurassic samples had been studied of offshore and onshore wells. Massive cement is noticed in most of the samples and the porosity in most of the samples is very low, and no hydrocarbons have detected in them. Among the observed authigenic minerals, the current report focuses on the carbonate mineral system. Four authigenic carbonate mineral phases observed: calcite, siderite, ankerite and dolomite. Paragenetically, the calcite mineral is former to the three other phases, which replaced it.

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1. Introduction

Paragenetic sequence study is a useful tool for the reconstruction of depositional environments and burial history of sedimentary rocks. Diagenetic processes can be studied by petrographic observations aiming to determine the sequence of the cement mineral assemblages. For example, mineralogical, geochemical and isotopic study of sequential generations of cement in Lower Cretaceous sandstones of the Heletz Formation enabled the reconstruction of their thermal and burial history, and showed a connection between the diagenesis of the reservoir sandstones and hydrocarbon accumulation in the Heletz-Kokhav oil field in southern coastal Israel (Calvo, 1992; Calvo et al., 2011). The present study will try to characterize the reservoir potential of the Jurassic sections offshore and coastal central Israel using similar methods.

The study area (Figure 1) is located in the coastal plain and offshore central Israel, between Kefar Darom-1 and Til-1 boreholes to the south and Petah Tikva-2 and Delta-1/1A boreholes to the north. Across its center the research area is approximately 45 kilometer wide and 110 kilometer long.



Figure 1: The Levant Basin in the eastern Mediterranean Sea. The research area is shaded (map by U.S Energy Information Administration, 2013).

The Heletz-Kokhav oil field is located at the south-eastern edge of the study area. It can be assumed that the Jurassic rocks, which lie beneath the Lower Cretaceous rocks in the Heletz-Kokhav oil field and its surroundings, have experienced the same burial history as the overlying rocks, since the latter's lithification. Yet, the burial history and the geothermal gradients of the Jurassic rocks prior to the deposition of the Lower Cretaceous layers are not known. The current study will attempt to reconstruct the burial history and the geothermal gradients of the Jurassic period.

2. Research Goals

The major objective of this study is to perform a detailed research about the natural diagenesis of intervals of the Jurassic sandstones, shales and limestones in the Levant Basin eastern margin, at the shallow offshore marine and coastal plain of central Israel. A determination of the mineralogical and chemical compositions and stable isotope ratios of the cement diagenetic phases within the studied rocks will be done, and a characterization of their relative age, formation environments and diagenetic sequence. The diagenetic process study will help to form a comprehensive geological, geochemical, geo-hydrological and geothermal approach and reconstruction of the geothermal gradients and burial history, for the understanding of a possible hydrocarbon reservoir within the studied section.

3. Geological Background

The Levant Basin (Figure 1) and the continental margin next to it were formed by continental rifting of Permian to Middle Jurassic age (Bein and Gvirtzman, 1977; Garfunkel and Derin, 1984; Garfunkel, 1998; Brew et al., 2003). During the Jurassic, the Levant region formed a sector of Gondwana's continental platform-shelf, south of the Neo-Tethys Ocean. The Jurassic sequence of the Levant is composed of a thick sedimentary cover, recording Early-Middle and Late Jurassic tectonics, related to active rifting. Tectonism formed relative highs and lows delimited by normal faults, resulting in differential rates of subsidence (Freund et al., 1975; Hirsch, 2005). Consequently, the Jurassic strata in the Levant are characterized by thickness and facies changes

documenting variable paleotectonic and paleogeographic settings, and transgression and regression cycles, independent of the global eustatic sea-level (Brew et al., 2003; Hirsch, 2005). Thickness changes are also due to different amount of erosion during the Jurassic and at the Jurassic-Cretaceous boundary.

The contact of the overlying Jurassic rocks with the Triassic sequences is usually characterized by disconformity and a small angular unconformity, representing tectonic and volcanic activity (Asher volcanics), erosion and lack of sedimentation from Middle Norian to Early Jurassic times (Goldberg, 1970; Freund et al., 1975, Hirsch, 2005). After having been exposed to erosion, the Triassic rocks were covered by clay horizons, probably of pedogenetic origin (Garfunkel, 1978). A small Oxfordian volcanic event occurred in the Galilee and Lebanon, suggesting an unconformity, separating the Middle and Late Jurassic. An early Oxfordian truncation is present in the central Coastal Plain (Hirsch, 2005). Magmatism (Tayasir volcanics), uplift, erosion and deep truncation at the end of the Jurassic are recorded by a Jurassic-Lower Cretaceous unconformity throughout Israel (Eliezri, 1963; Nevo, 1963; Freund et al., 1975; Garfunkel, 1989; Gvirtzman, 1997; Hirsch, 2005).

Jurassic rocks in the Levant are exposed within the eroded cores of monoclines in southern Israel (mainly in the Ramon Crater and in the Large Crater) and northern Sinai (Egypt), in Wadi el Malih (eastern Samaria) and they also form the core of Mount Hermon anticline in northernmost Israel, Syria and Lebanon. Jurassic rocks have also been penetrated by a significant number of onshore and offshore boreholes along the coastal plains of Israel. Hirsch (2005) divides the Jurassic paleogeography of Israel into three provinces: (1) The Galilee platform, which extends to the north to Lebanon and Coastal Syria; (2) the Judean Embayment, which extends to the Anti-Lebanon (Mount Hermon) and Palmyra chain, separated from the Sinai Deep by (3) the Negev High, which includes most of North-Eastern Sinai facies.

The Jurassic sedimentary sequence throughout Israel records diverse depositional environments, from terrestrial to deep marine settings. The biostratigraphy often exhibits endemic character, related to the isolation of the

southern Tethys shelf (Hirsch, 2005). In the Early Jurassic the southern Levant region was covered by an epeiric sea forming a shallow marine platform (Derin, 1974), while wearing down of the Arabian Massif in the south and southeast contributed clastics to the deposited sediments (Hirsch, 2005). Shallow continental shelf carbonates are characteristic of the central coastal plains and offshore Israel during Early to Middle Jurassic times, while in the Late Jurassic times the depositional setting deepened to the shelf margin and continental slope (Derin, 1974; Gardosh et al., 2011), named offshore the “Delta trough” (Hirsch, 2005). Sedimentation along the continental slope, bounded above by occasional reefs and shoals, included the accumulation of a mostly shaly section of deep marine origin, interbedded with turbidity current and debris flow fragments (deposits of coarser affinity) that were derived from the shallow shelf (Garfunkel and Derin, 1984). The coarser clastic beds, both carbonate and siliciclastic material, were deposited within channels and along their rims. Hirsch et al. (1988; 1995; 2005) suggested the existence of an Eastern Mediterranean landmass offshore, western to the Delta trough, as an explanation for the offshore distribution of shales. Benjamini, C. (by personal com.) suggests that the fine clastic grains were suspended within the epicontinental structural basins, making their deposition at today’s offshore possible.

All the Jurassic sections in Israel were united as the Arad Group (Goldberg, 1970; Derin, 1974), except for the latest Tithonian Yam Formation (Fleischer, 2002), which occurs only offshore Israel and the latest Jurassic (?) – Early Cretaceous Gevar’am Formation (Hirsch, 2005), which occurs along the southern coastline and offshore. It was suggested that the Yam and the Gevar’am formations represent a continuous sedimentation, through the Jurassic-Cretaceous boundary (Druckman et al., 1995; Hirsch, 2005). The Arad Group thickens towards the west and north, from 1,300 meter at the Negev to approximately 3,000 meter at the coastline areas and the Judean Hills (Hirsch, 2005; Calvo and Gvirtzman, 2013; Calvo, 2014). The upper part of the Arad Group is missing in all of the Negev outcrops. The entire Jurassic section is missing in boreholes south of the Ramon Crater. In those areas the Cretaceous section directly overlies pre-Jurassic rocks (Garfunkel, 1978).

The current study focuses on the clastic intervals in the Arad Group, as these are regarded as most fit for the study of the cement diagenesis. Nevertheless, it is important to describe here the practically full Jurassic section, in order to understand the sequence stratigraphy throughout the region. The Jurassic Arad Group was divided into the following formations (Goldberg, 1970; Derin, 1974; Goldberg et al., 1978) (presented in Fig. 2):

Mish'hor Formation (Goldberg, 1970), of Early Jurassic age, is composed of laterite soil horizons that alternates with massive clay layers known as “flint like clay”, filling karstic cavities in the Late Triassic Mohilla Formation (Goldberg, 1979).

Ardon Formation (Nevo, 1963; Goldberg, 1970), of Early Jurassic age on top of the Mish'hor Formation, is made of limestone, shale and dolomite of marine origin. In places some evaporitic horizons occur. The Ardon Formation represents sedimentary sequence of marine penetration, a sequential regression and a transition to hyper-saline environments, subtidal zones and shallow shelf area.

Inmar Formation (Nevo, 1963; Goldberg, 1970), of Toarcian to early Bajocian ages (Early to Middle Jurassic), mostly consists of sandstone layers and represents the maximum marine regression. Fluvial and deltaic sedimentation environments have developed on the expense of the previous shallow shelf region. In the Ramon area the whole section is sandy, though to the north it contains limestones and dolomites of shallow lagoon environment, known as the **Nirim** Formation (Derin, 1974). The **Nirim** Formation is also correlative to Ardon Formation. A marine incursion of the Nirim facies towards south, called the **Qeren** Member, separates the **Lower Inmar** of the **Upper Inmar** Member (known also as the **Rosh-Pinna** marls and shales in central Israel). Further north the Upper Inmar wedges out and replaced by the carbonatic **Haifa** Formation regime (Derin, 1974; Hirsch, 2005), a sequence that persists to early Oxfordian times (Hirsch, 2005).

Daya Formation (known also as **Mahmal** Formation in the Southern Negev), of Bajocian age (Middle Jurassic), is characterized by fossiliferous limestone, sandy limestone, shales and some sandstone. The sedimentation

environment is mostly marine (Hirsch, 2005), and represent a vast flooding event above the terrestrial layers of the Inmar Formation. In the Negev the Daya Formation is followed by the mostly siliciclastic and marly Bathonian **Sherif** Formation, which is regarded as a regression, shallow neritic to coastal environment deposition (Hirsch, 2005).

The **Barnea** and **Sderot** formations (Derin, 1974) are considered local to the central and southern Coastal Plain. The Barnea Formation, of Aalenian to Bajocian ages (Middle Jurassic), is correlative to the Upper Inmar Member and Daya formations, and composed of micritic to biopelmicritic spiculitic limestones, alternating with greenish gray shales. The Barnea Formation represents deposition at beyond lagoonal shallow to open marine environment. The **Sderot** Formation, of late Bajocian to late Bathonian ages, is correlative to Daya and Sherif formations, and was defined as a complex section formed at variable sedimentary environments, and the main component is oolitic-detritic shoals (Hirsch, 2005), alternating with micritic limestones, intrabiomicritic limestones and shales layers. Sderot Formation represents deposition in a shallow platform environment, with medium to high energy conditions that change rapidly (Buchbinder, 1979).

The Barnea Formation is considered to be the source rock for hydrocarbons in the Heletz-Kokhav oil-fields (Bein and Sofer, 1987). Conway (2003) claims that the Barnea Formation is immature onshore and have no oil-generating potential. Offshore, at Yam-West-1 borehole, Conway (2002) defined Middle Jurassic units, of Bathonian and Callovian ages, as mature and well within the oil-window.

Karmon Formation (Derin, 1974; Druckman et al., 1994), of middle to late Bathonian age, is correlative to the upper part of the Sherif Formation, and is composed of variable shales and marls, alternating with shaly detritic gray limestone. The Karmon Formation represents regression and paralic depositional environment (Hirsch, 2005).

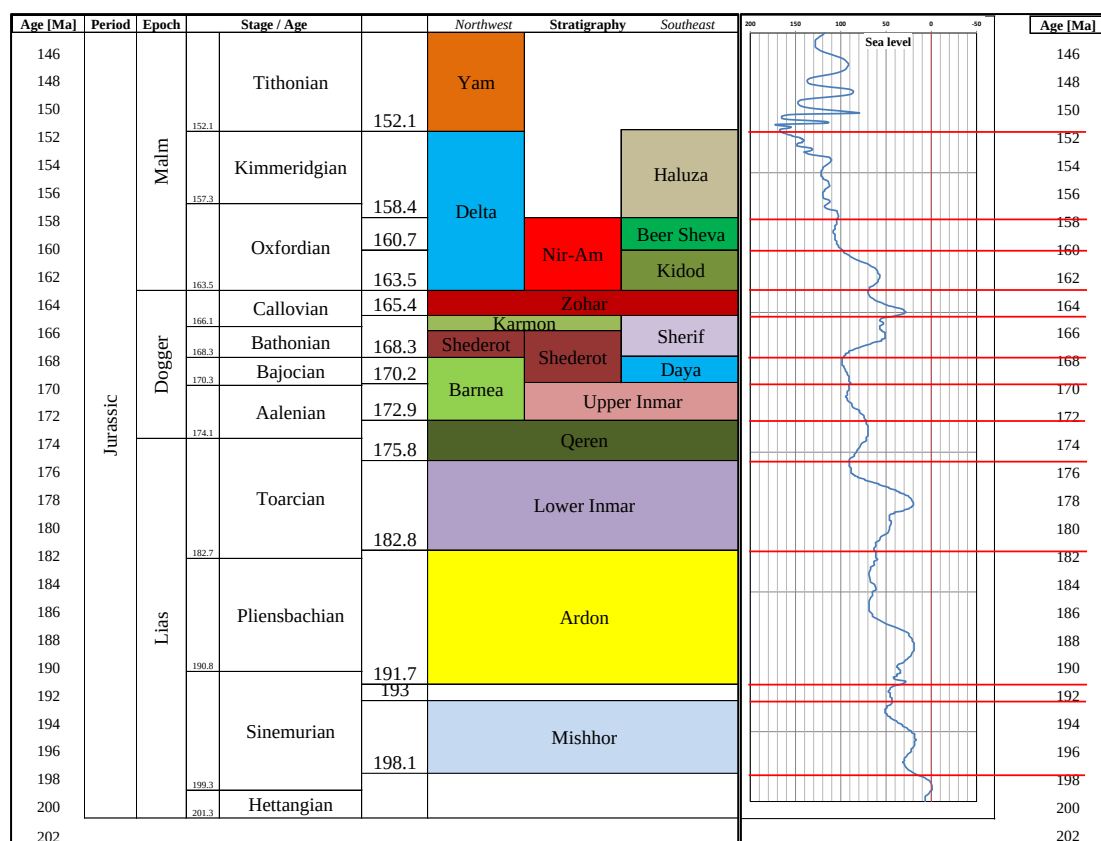


Figure 2: Chrono-stratigraphic scheme of the Jurassic formations in southern Israel (after Calvo, 2014).

Zohar Formation, of late Bathonian to Callovian ages (Middle Jurassic), is composed of layers of fossiliferous limestone, marl, shales and small quantities of silt and sand. In places faunal reefs appear within this formation. The Zohar Formation was deposited at low energy waves in a shallow shelf environment. The **Brur** calcarenite, a member of the Zohar Formation, of Callovian age (Middle Jurassic), represents a reappearance of shoals and reefoidal patches at the southern Coastal Plain (Hirsch, 2005).

The Daya, Sherif, Barnea, Sderot, Karmon and Zohar formations are equivalent to the massive carbonate Bathonian to Callovian facies of the **Hermon** Formation in central and northern Israel (Hirsch, 2005) and to the Aalenian to lower Oxfordian facies of the **Haifa** Formation in western-northern Israel (Derin, 1974; Hirsch, 2005).

Oil shows and oil accumulations were found in the Sderot and Zohar formations in several boreholes, onshore and offshore Israel: Yam-West-1, Yam-2 (Gardosh et al., 2011), Ashdod area boreholes (May and Shulman, 1981) and Yam-3. In places, where it is thick enough and not too faulted, the

Karmon Formation serves as a seal unit for the Sderot Formation oil accumulation.

Kidod Formation, of Callovian to early Oxfordian ages (Middle to Upper Jurassic), is composed of massive black shale layers that rarely alternate with limestone horizons. The contact with the Zohar Formation is sharp, and may indicate exposure and karst phenomena caused by epeirogenic movements, followed by a fast flooding to anoxic environments. The Kidod Formation is also known as **Majdal-Shams** Formation, of Early to Middle Oxfordian age. Hirsch (2005) notes that Picard and Hirsch (1987) emphasized separation between the two facies: Kidod is limited to specific areas in the Northern Negev and coastal plain, and Majdal-Shams Formation occurs elsewhere in the region. This requires differential water columns in the Judean Embayment and in the Negev, which deepens to the north. Nevertheless, the Kidod term is widely used, and will be used in this study.

Be'er-Sheva and **Haluza** formations, of Oxfordian to Kimmeridgian ages (Late Jurassic), are composed of alternating fossiliferous limestone, dolomite, shales and sand, representing progradational shallow shelf and intertidal zones. The Haluza Formation is the youngest Jurassic formation exposed on land. In northern Israel these formations are also known and united as the late Oxfordian-Kimmeridgian **Nahar Sa'ar** Formation. The reefoidal facies **Nir-Am** Formation (Derin, 1974), of the same age (Oxfordian), is local to today's northern-central and southern Coastal Plain (Caesarea and Kokhav oil field).

Delta Formation (Derin, 1974; Derin et al., 1988), of late Callovian to Kimmeridgian ages (Middle to Late Jurassic), is correlative to the Nir-Am, Kidod, Be'er-Sheva and Haluza formations, and composed of diverse types of rocks: marls, shales, a variety of limestones and volcanic material. The shales are interlayered with the limestones. The limestones are fossil poor and mostly composed of intraclasts, which occasionally contain allochthonous reef fragments. The Delta Formation represents deep marine to continental slope environment with reef fragments and shelf platform components. High energy debris flows carried fragments that accumulated together with marine, "starved basin", sediments. The bottom contact is sharp, probably indicating

exposure followed by fast flooding. The lower part of this formation might contain sandy intervals. The transition to the Early Cretaceous rocks is gradual in places; the transition to Yam Formation involves a faunal change.

Yam Formation (after Derin et al., 1990), of Tithonian age (Late Jurassic), is composed of grayish green shales with several limestone layers. The limestone contains allochthonous reef and skeletons components of sandy to clayey grain size. In places, few tens of meters' thick carbonate sandstone layers occur at the base of the formation. The depositional environment is similar to the Delta Formation. The Yam Formation may signify a continuous sedimentation, between the Late Jurassic and Early Cretaceous in the marine areas, contrary to the erosional unconformity, which prevailed in the terrestrial region of central Israel (Druckman et al., 1994).

Relative sea level fluctuations occurred throughout the Jurassic and are expressed by maximum surface flooding, maximum exposure high stand, and low stand system tracks (Hirsch, 2005). High stand system tracks occur especially at the Ardon Formation, the Daya Formation, the middle parts of the Sherif Formation, the Zohar Formation and the Kidod Formation. Low stand system tracks appear at the Lower Inmar Member, the lower and upper parts of the Sherif Formation, the Karmon Formation, just above the Kidod Formation and also above the Haluza Formation.

Gardosh et al. (2011) divided the Jurassic section into four sedimentary sequences. The first sequence (Jr1) is 1,000-1,500 meter thick and includes Mish'hor, Ardon, Lower Inmar and Qeren units. It records two flooding sequences (Mish'hor-Ardon and Lower Inmar-Qeren) above the top Triassic erosional plateau. The second sequence (Jr2) is also 1,000-1,500 meter thick, and includes the Upper Inmar, Daya, Barnea and Sderot units. The Jr2 sequence records three flooding sequences (Upper Inmar-lower Daya, upper Daya-middle Sderot and upper Sderot). The third sequence (Jr3) is 300-600 meter thick, and includes Karmon, Zohar, Kidod and Be'er Sheva units. The Jr3 sequence records two flooding sequences (Karmon-Zohar and Kidod-Be'er Sheva). In the present offshore area, several tens of kilometers west of the Middle to Late Jurassic shelf edge the Jr2 and Jr3 sequences are 600-700

meter thick all together. A fourth sequence (Jr4) is about 250-meter-thick, and includes only the Yam Formation and only one flooding sequence.

4. Methods

A first set of samples was collected from three offshore boreholes: Delta 1-1A, Yam Yafo-1 and Yam West-1 (Figure 3). Sampling was guided by drilling logs (Belpetco, 1970; Derin, 1970; Druckman et al., 1994; Gill et al., 1995), in order to choose the best intervals for a diagenetic study. Unfortunately, there are only three existing cores of the Jurassic section among the offshore boreholes; thus, mainly rock-cuttings were sampled. The rock-cuttings boxes of Yam-2 borehole reported fallen and mixed-up, therefore considered as unreliable and were not sampled. A total of 21 samples were collected (Table 1a). Occasionally, the standard boxes, each holding rock cuttings representing a three-meter-thick drill interval, did not contain sufficient amount of material for the planned analyses, and thus some of the samples represent material from two-three boxes. In those cases, the average depths were calculated (Table 1a).

Second sampling effort focusing on the coastal boreholes was done after examining lithostratigraphic and composite logs of more than 70 boreholes with more than 200 Jurassic strata cores. The boreholes, cores, their data and lithostratigraphy are assembled in Table 1, at the appendix, which is useful for future studies. The boreholes examined in favor for nearshore boreholes, and for proper intervals of interest (mostly of clastic rocks). Out of more than 200 cores examined, six cores, out of six boreholes, were chosen for sampling (Figure 3, Table 1b).

Two cross sections of the boreholes displayed and sampled are attached (Fig. 4 and 5), showing the formations penetrated by the boreholes.

A drilling log analysis and sampling of a recently available (2013) marine borehole, Yam-3, located within 1.5 kilometer north of Yam-2, will also take place.

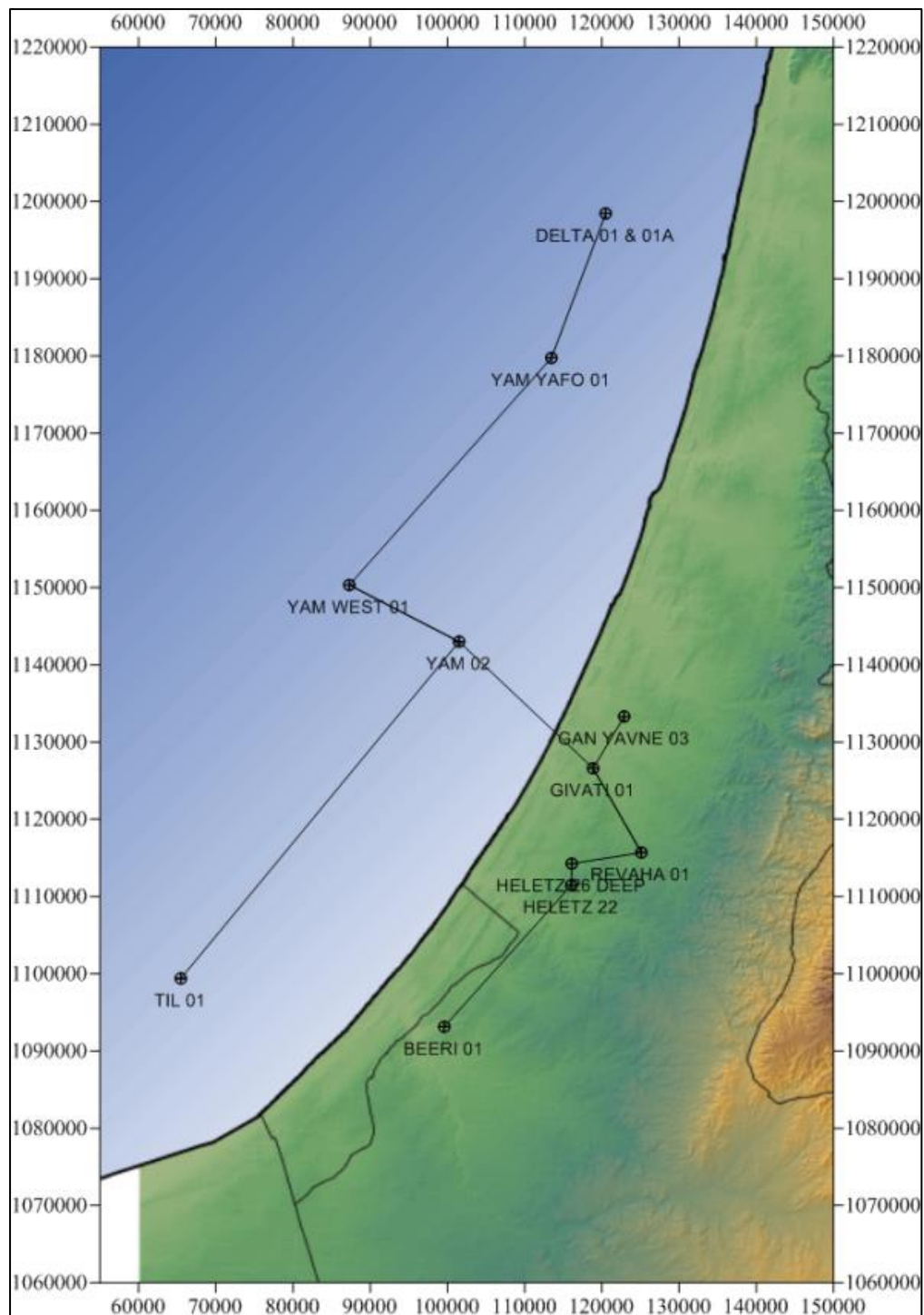


Figure 3: The research area, showing offshore boreholes and coastal boreholes that penetrated the Jurassic section.

Twenty thin sections were prepared for petrographic study under the optical polarizing microscope. Petrographic description is based on classifications and nomenclatures of Folk (1980), Dunham (expansion by Embry and Klovan, 1971, and revision by Wright, 1992), Boggs (2009), Flugel (2004), Nichols (2009) and Adams et al. (1984).

All samples examined by Scanning Electron Microscope (SEM), model FEI Quanta 450 equipped with Oxford Instruments EDS X-Max X-ray elemental system, in order to analyze the minerals texture, crystal shape and chemical composition. The SEM detectors, the secondary electrons detector (SE) and the backscattered electron detector (BSE), are useful tools to analyze the cement mineral phase's relations.

The diagenetic phases were studied for their mineralogical composition by X-Ray Diffraction (XRD). The thin sections were studied under specialized cathodoluminescence microscope for the cement minerals chemical and spatial patterns. All the drill cores and cuttings and most of the laboratories are located at the Geological Survey of Israel (GSI) in Jerusalem.

Table 1a: List of samples collected from offshore boreholes. Formation intervals are taken from the "Atlas Project" (Gill, 1972; Flexer et al., 1981; Fleischer and Varshavsky, 1998, 2002).

Borehole	Formation	Formation interval [m]	Sample no.	Avg. Depth [m]	Core/Cuttings
Delta 1-1A	Delta	4,235-4,423	D1a-1	4,333.2	Core No. 1
			D1a-2	4,336.7	
			D1a-3	4,337.7	
			D1a-4	4,339.2	Core No. 2
			D1a-5	4,339.5	
			D1a-6	4,341.4	
			D1a-7	4,342.4	
Yam West-1	Zohar	4,711-4,750	YW1-1	4,734	Cuttings
			YW1-2	4,745	
	Up. Inmar	5,080-5,195	YW1-3	5,167	
	Qeren	5,195-5,250	YW1-4	5,211	
			YW1-5	5,220	
Yam Yafo-1	Yam	4,190-4,410	YY1-1	4,236.75	Core No. 1
			YY1-8	4,357	Cuttings
			YY1-9	4,378	
	Zohar	4,895-4,963	YY1-2	4,915	
			YY1-3	4,926	
			YY1-4	4,943	
	Sderot	4,985-5,033	YY1-5	4,993	
			YY1-6	5,002	
			YY1-7	5,005	

Table 1b: List of samples collected from onshore boreholes. Formation intervals are taken from the “Atlas Project” (Gill, 1972; Flexer et al., 1981; Fleischer and Varshavsky, 1998, 2002).

Borehole	Formation	Formation interval [m]	Sample no.	Avg. Depth [m]	Core
Beeri-1	Up. Inmar	2,897-3,403	BE1-1	3,283.5	No. 20
Gan Yavne-3	Zohar	2,563-2,634	GY3-1	2,562.5	No. 4
Givati-1	Beer Sheva	2,232-2,354	GI1-1	2,234.3	No. 4
Heletz-22	Ardon	3,893-4,477	HE22-1	4,121	No. 24
Heletz-26 Deep	Nir Am	1,688-1,740	HE26-1	1,703.7	No. 8
Revaha-1	Beer Sheva	1,970.5-2,056	RE1-1	1,971	No. 12

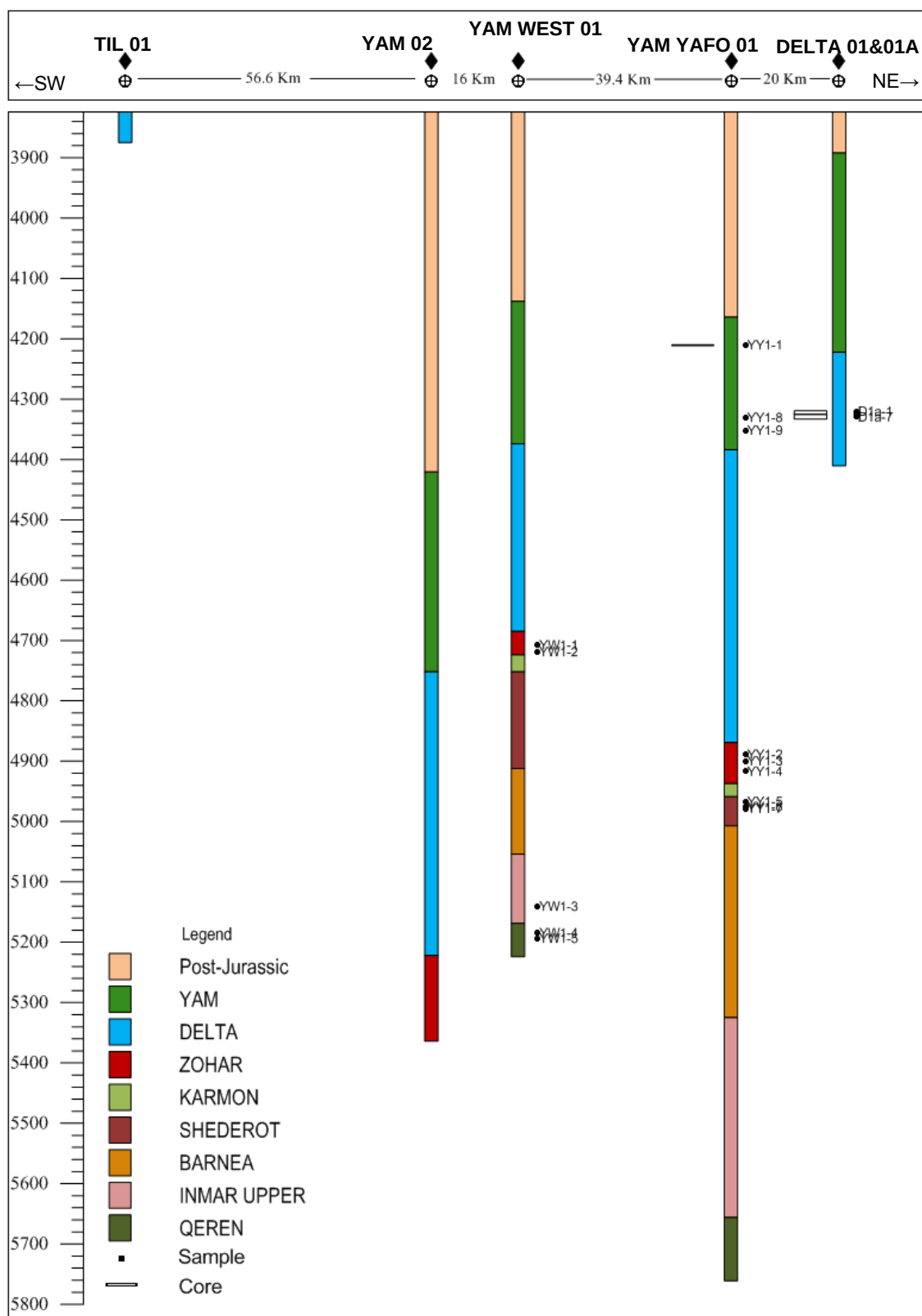


Figure 4: Cross section of the offshore boreholes, with stratigraphic subdivision core location, and samples taken.

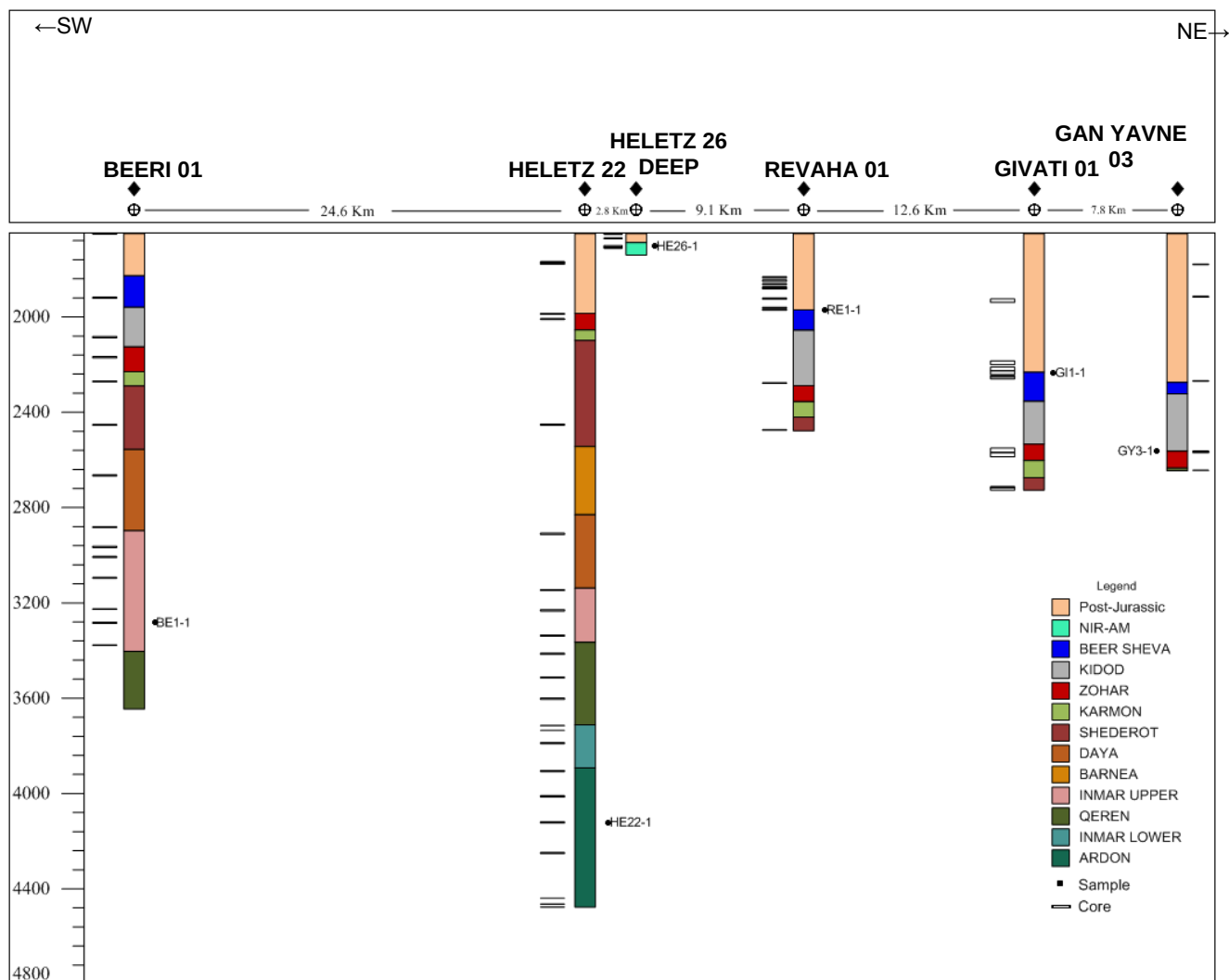


Figure 5: Cross section of the onshore boreholes, with stratigraphic subdivision core location, and samples taken.

5. Results

Lithology

The majority of rock fragments are made of calcite in most of the samples. Some samples contain mostly quartz grains (Be1-1, He26-1, Re1-1, YY1-8, YY1-9), and consider as sandstones, or limy sandstones, for their massive carbonate cement texture. For instance, YY1-9, a sample from the base of Yam Formation, at Yam Yafo-1 borehole, which includes mostly grains made of quartz, supported and cemented by carbonate (Plate 1, Figure a). Few samples are considered as sandy limestones, or limestones containing a different percent of quartz grains (He22-1, YW1-1, YY1-1). In some samples,

along the main lithology there are shales deposits (D1a-4, Gi1-1, YW1-3, YW1-4, YY1-1, YY1-6).

The porosity of the sampled rocks is poor, especially of the rocks containing distinguished grains (of quartz, peloids, lithoclasts or others). The porosity of samples of limestones composed of hard to distinguished grains, or limestones which not containing grains at all, is higher than the other sampled rocks.

Authigenic minerals

The sampled rocks are rich with authigenic minerals. Carbonate minerals cement is vast and almost total. Dissolution cavities are recognized in some of the grains, quartz and calcite, and in places filled by authigenic material, mainly calcite; inner cement tiny cavities are also recognized.

The authigenic minerals noticed are of the following groups: carbonates (calcite, siderite, ankerite and dolomite), tectosilicates (oligoclase and quartz), clay minerals (including micas), sulfides (pyrite), evaporites (gypsum, halite), and other minerals as iron and titanium oxides. The current report is focused on the carbonate authigenic mineral system only.

Carbonates

The atomic percentage of the authigenic minerals cations (Ca^{2+} , Mg^{2+} , Fe^{2+}) of the carbonate group, measured with the BSE, are projected on the carbonate ternary plot (Figure 6) in order to classify the carbonate into the mineral phases. As seen in the ternary plot it is easy to divide the measured samples into the calcite mineral phase (the top head of the ternary plot, with dominant Ca^{2+} cation) and the siderite mineral phase (the right head of the ternary plot, with mostly Fe^{2+} cation). The middle dots of the ternary plot are of the dolomite mineral group, divided by the Fe^{2+} atomic content, to dolomite (nonferrous) and ankerite (ferro-dolomite). In the current study the dolomites and ankerites are divided at 5% Fe^{2+} content: below 5% iron – dolomites, above 5% iron content – ankerites.

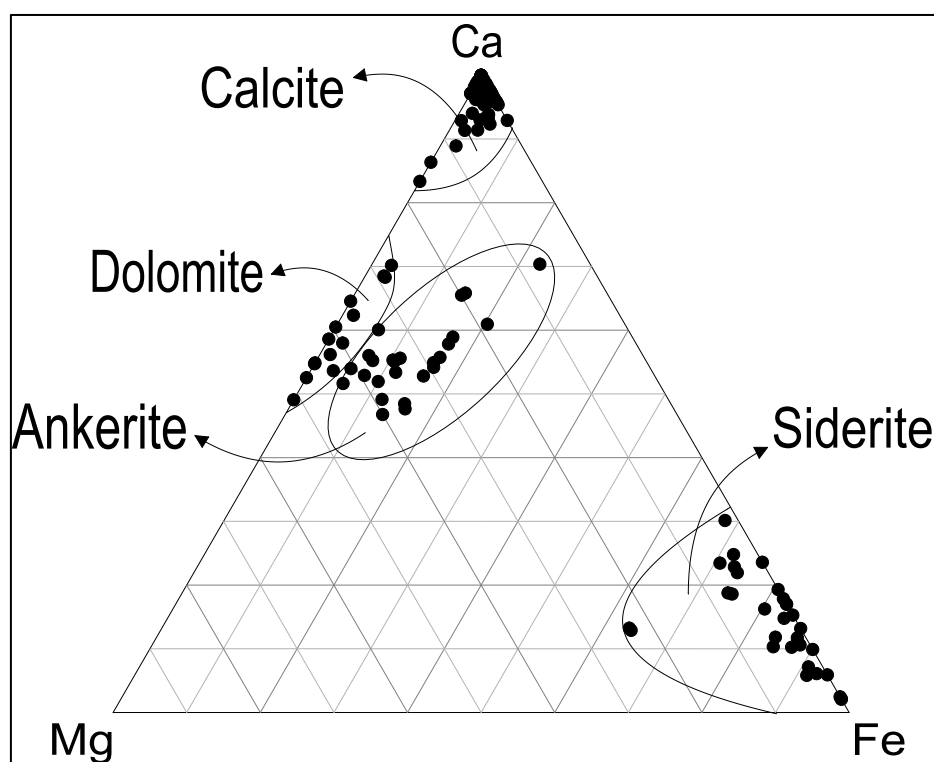


Figure 6: The distribution of the cation elements of the carbonate cement phases, shown with the ternary plot.

Calcite:

The calcite is the most common cement mineral in the samples, found almost in every sample, and fills most of the samples spaces. The calcite appears in the rock as (1) fossils calcite, as original component or as replace of aragonite; (2) cement fabric of the rocks and as (3) single cement crystals, both can be formed between grains, in matrix framework and in cavities within grains (Plate 1, Figure b).

The cement is of hypidiotopic drusy fabric (Plate 1, picture a and c), with crystal size from 10 μ m up to 150 μ m, pore filling, with up to 2 μ m inner vugs, as an outcome of dissolution, and of hypidiomorphic granular fabric (Plate 1, Figure d), with crystal size from less than 1 μ m up to 10 μ m. The single non-fabric calcite crystals are variable in size, some up to 15 μ m of hypidiomorphic crystals and some up to 65 μ m of idiomorphic crystals. Another appearance is syntaxial overgrowth, mostly on echinoderm skeletal grains (Plate 3, Figure a).

The calcite main phase was form before the siderite and ankerite, and seems also as previous to the dolomite authigenic crystals.

The median chemical formula of the authigenic calcite is $\text{Ca}_{0.97}\text{Fe}_{0.01}\text{Mg}_{0.02}\text{CO}_3$, the cations distribution of the calcite is presented in Figure 7a.

Siderite:

The siderite is mainly found in calcite rich cement fabrics of granular limestone rocks in samples from the marine boreholes.

Most of the siderites are idiomorphic cement crystals, replacing the calcite cement fabric (Plate 1, Figure e). The siderite can be seen as single crystals, separated crystals, aggregated crystals, as a full cement fabric replacer (Plate 1, Figure f), or as tabular crystals (Plate 2, Figure a). The siderite crystals are variable in size from less than 1 μm up to 50 μm crystal. The siderite in places may be replaced by clay minerals.

The median chemical formula of the siderite is $\text{Fe}_{0.82}\text{Ca}_{0.15}\text{Mg}_{0.03}\text{CO}_3$, the cations distribution of the calcite is presented in Figure 7b.

Ankerite:

The authigenic crystals of ankerite are found in samples of offshore boreholes. The ankerites can appear as idiomorphic single crystals (Plate 2, Figure b), of 30-50 μm , as hypidiomorphic bulk crystals replacing dissolved quartz grains and calcite cement, matrix or fossils grains (Plate 2, Figure c). The single idiomorphic crystals of ankerite formed in shaley matrix (Plate 2, Figure b), while the grain and cement replacing ankerites are present in limestones.

The ankerite seems as calcite replacement in places, indicating that ankerite is latter relatively to the calcite cement.

The median chemical formula of the ankerite is $\text{Ca}_{1.10}\text{Fe}_{0.26}\text{Mg}_{0.68}(\text{CO}_3)_2$, the cations distribution of the calcite is presented in Figure 7c.

Dolomite:

Nonferrous authigenic dolomites are not common, and present only in limestone samples, and mainly in samples taken from offshore boreholes.

Dolomite crystals are idiomorphic to hypidiomorphic, and mostly seen as single crystals (Plate 2, Figure d), of 15-50 μm crystal size. The dolomite also appears as replaced skeletal calcite grains, some are weathered and/or shattered, of 100-250 μm grain size.

It is hard to determine the diagenetic stage of the dolomitic cement relatively to the other cement minerals, but it seems as latter to the calcite granular and drusy cement.

The median chemical formula of the dolomite is $\text{Ca}_{1.17}\text{Mg}_{0.81}\text{Fe}_{0.01}(\text{CO}_3)_2$, the cations distribution of the calcite is presented in Figure 7d.

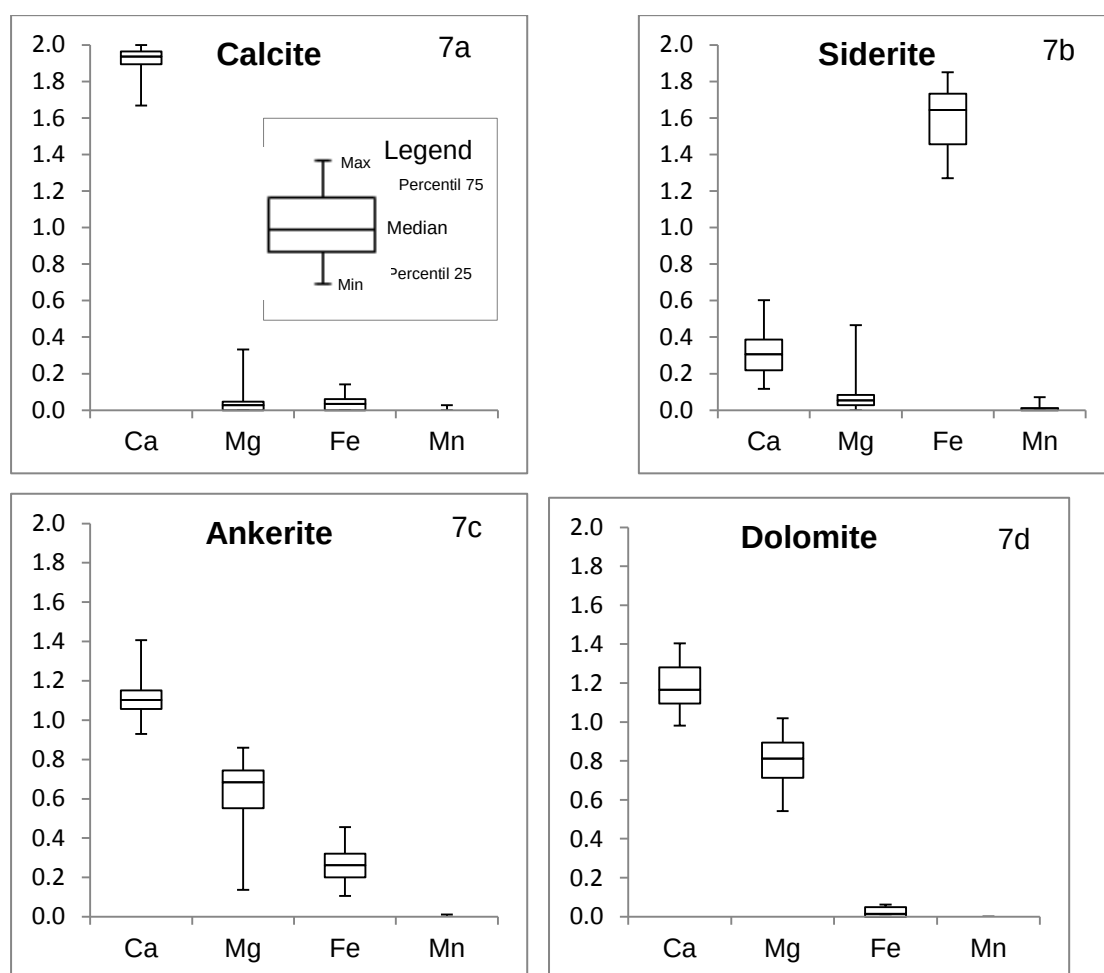


Figure 7: Box diagrams of the carbonate mineral phases, showing their cations median value out of two stoichiometric cations: a. Calcite. b. Siderite. c. Ankerite. d. Dolomite.

Plate 1:

Figure a: Fine grained limy sandstone with quartz grains inside a massive hypidiotopic drusy cement fabric of calcite crystals (SE photo, sample #YY1-9, Yam Formation, Yam Yafo-1 well, 4,378 meter depth).

Figure b: Medium grained sandy oosparite containing an inner dissolved quartz grain, with calcite cement (BSE photo, sample #Re1-1, Beer Sheva Formation, Revaha-1 well, 1,971 meter depth).

Figure c: Medium grained limy sandstone with quartz grains and hypidiotopic drusy cement fabric of calcite between them (BSE photo, sample #YY1-8, Yam Formation, Yam Yafo-1 well, 4,357 meter depth).

Figure d: Hypidiomorphic granular cement fabric of calcite in shales (BSE photo, sample #YW1-4, Qeren Member, Yam West-1 well, 5,211 meter depth).

Figure e: Two siderite crystals replacing calcite cement in intrapelsparite (SE photo, sample #D1a-1, Delta Formation, Delta-1-1a well, 4,333.2 meter depth).

Figure f: Intrapelsparite with hypidiotopic siderite cement fabric, replacer of calcite fabric, next to a calcite grain (SE photo, sample #D1A-6, Delta Formation, Delta-1-1a well, 4,341.4 meter depth).

Plate 1:

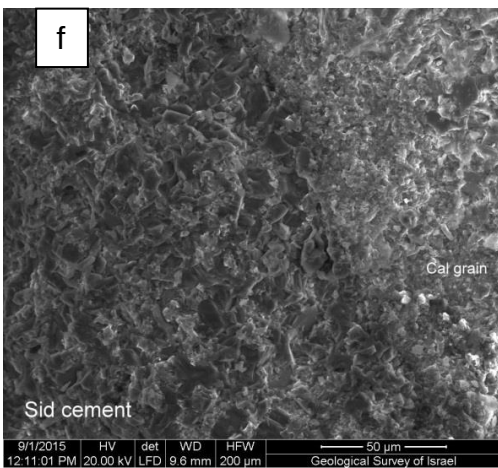
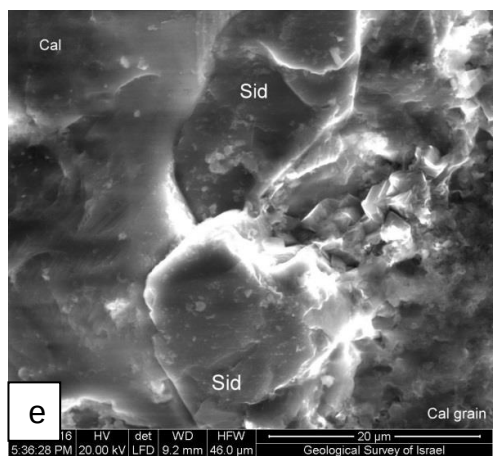
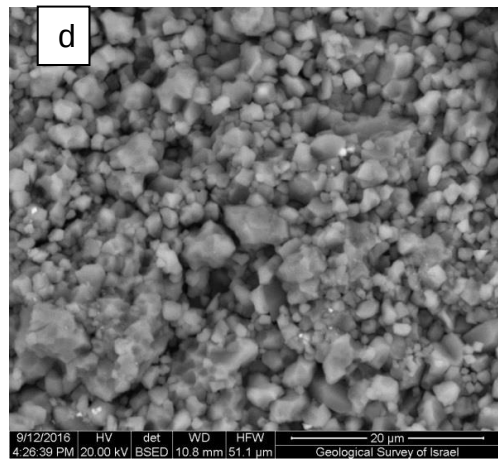
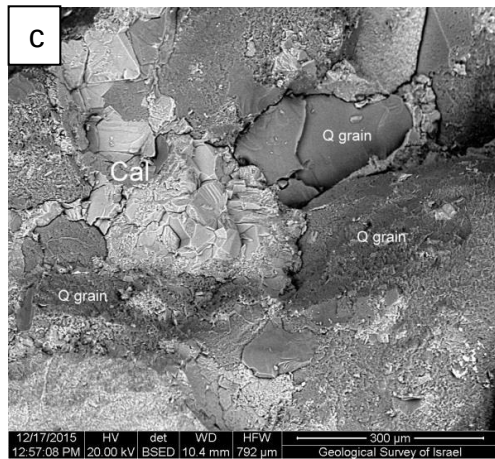
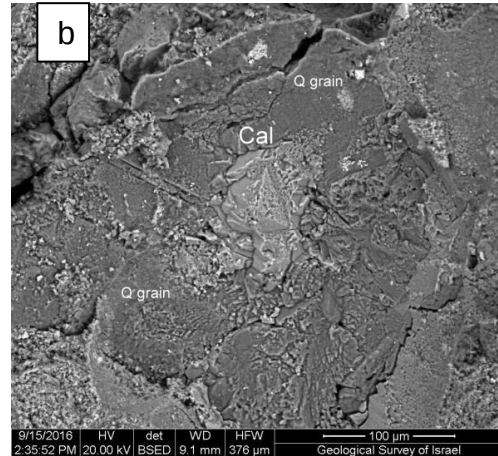
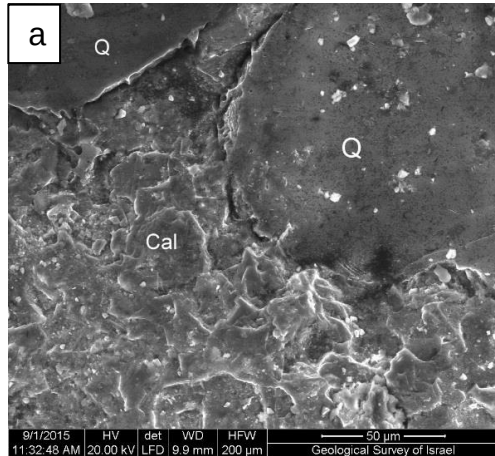


Plate 2:

Figure a: Tabular crystals of siderite in limestone (SE photo, sample #YW1-3, Upper Inmar Formation, Yam West-1 well, 5,167 meter depth).

Figure b: Shales with an idiomorphic ankerite crystal (SE photo, sample #YW1-3, Upper Inmar Formation, Yam West-1 well, 5,167 meter depth).

Figure c: Sandy limestone with two cement phases of ankerite, upper phase with medium magnesium content (39% of the cations), and the second with low magnesium content (19% of the cations), growing into a quartz grain cavity (SE photo, sample #YW1-1, Zohar Formation, 4,734 meter depth).

Figure d: Two dolomite crystals replacing calcite cement in limestone (BSE photo, sample #YW1-4, Qeren Mamber, Yam West-1 well, 5,211).

Plate 3:

Figure a: Syntaxial overgrowth cement on echinoderms pointed at with red arrows (XPL photo, sample #D1A-3, Delta Formation, Delta-01-01a well, 4,337.7 meter depth).

Figure b: Three different lithoclasts, composing a rudstone, with sutured contacts between them (PPL photo, Sample #D1A-3, Delta Formation, Delta-01-01a well, 4,337.7 meter depth).

Plate 2:

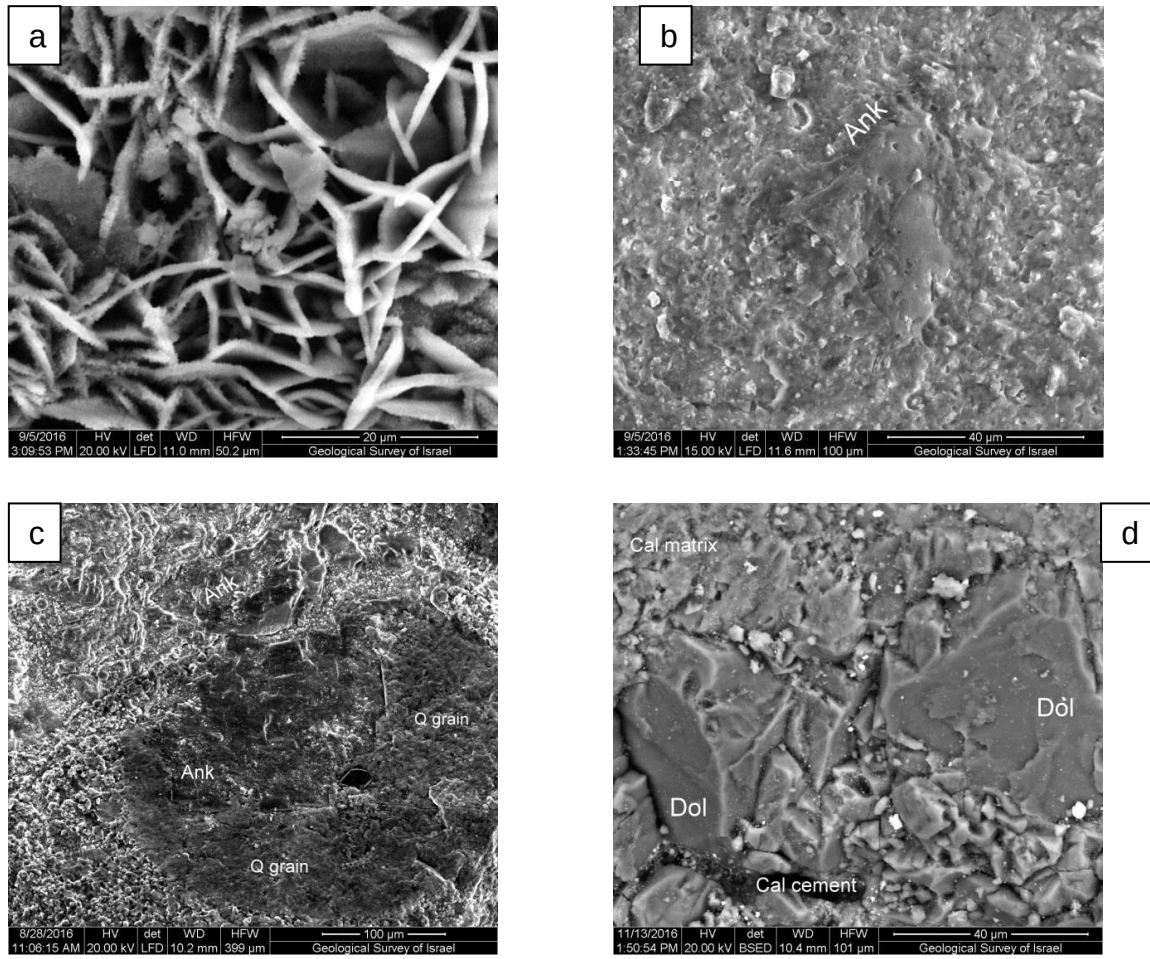
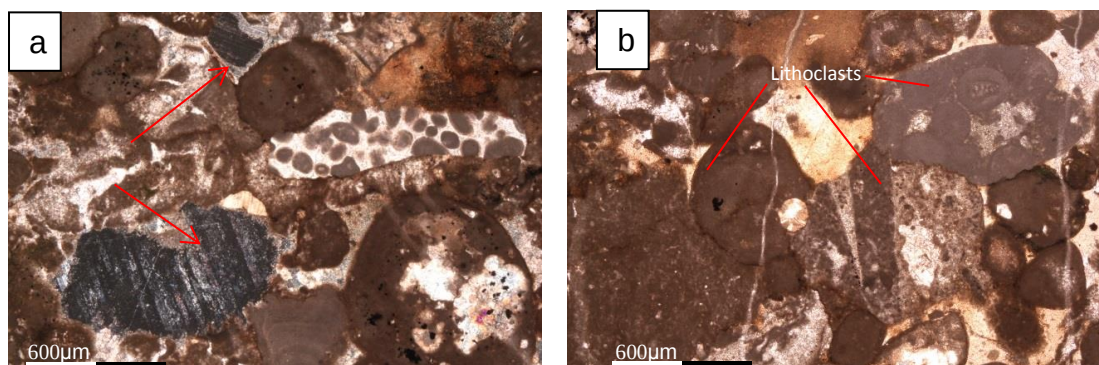


Plate 3:



6. Discussion

Massive void-filling calcite cement is present in most of the samples, and seems complete, suggesting burial phreatic environment. The granular fabric cement, even though not present in most samples, may indicate of more than one crystallization phase. The 150µm size of the cement fabric crystals and monocrystalline syntaxial overgrowth cement indicate of deep burial environment.

The authigenic carbonate mineral phases – siderite, ankerite and dolomite - are identified as replacers for the main cement mineral of calcite. Siderite is the most common of them, and documented as a possible replace for the whole cement fabric. The existence of siderite and ferro-dolomite (ankerite) indicating an iron-rich formation water, which penetrated the rocks' voids. Calcite and ankerite found as void-filling cement inside dissolved grains of quartz.

The voids inside quartz grains (some filled with cement) and the sutured contacts between grains (Plate 3, Figure b), indicating burial and pressure dissolution prior to cementation. Dissolution voids are also found in the cement itself, indicating for a dissolution following cementation.

Comparing the Jurassic cementation of the current study and the Lower Cretaceous rocks cementation of the Heletz Formation (Calvo, 1992; Calvo et al., 2011), it seems that the Jurassic rocks had experienced most of the cementation prior to the Middle Cretaceous burial cementation, found at the Heletz-Kokhav oil field. The Jurassic rocks diagenesis shows signs of ferro-dolomitization in places, though it is considerably less than the hydrocarbon-related ferro-dolomitization that the Heletz Formation diagenesis recorded.

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Appendix

Table 1: List of the cores of onshore boreholes in the research area, that have been reviewed in order to find ideal clastic core intervals. Information is taken from the “Atlas Project” (Gill, 1972; Flexer et al., 1981; Fleischer and Varshavsky, 1998, 2002), and the lithostratigraphic and composite logs.

Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
ASHDOD 01A SIDETRACKING	2	2591-2598.5	50	7.5	ZOHAR	Limy dolomite		26.5
ASHDOD 01A SIDETRACKING	3	2598.5-2602	70	3.5	ZOHAR			
ASHDOD 01A SIDETRACKING	4	2699-2713	90	14	KARMON	Shaley limestone		
ASHDOD 01A SIDETRACKING	5	2713-2718	85	5	KARMON-SDEROT			
ASHDOD 01A SIDETRACKING	6	2718-2735	20	17	SDEROT			
ASHDOD 02	3	2580-2584	25	4	ZOHAR	Dolomite	Oil in fractures	1.0
ASHDOD 03	1	2582.5-2586	86	3.5	ZOHAR			34.6
ASHDOD 03	2	2586-2587	95	1	ZOHAR	Dolomite		
ASHDOD 03	3	2587-2599	86	12	ZOHAR			
ASHDOD 03	4	2599-2608.6	100	9.6	ZOHAR			
ASHDOD 03	5	2690.4-2692.5	90	2.1	SDEROT			
ASHDOD 03	6	2692.5-2695.5	95	3	SDEROT	Dolomite		
ASHDOD 03	7	2725-2731	100	6	SDEROT			
ASHDOD 04	1	2546-2550.3	100	4.3	ZOHAR	Dolomite to limestone		14.7
ASHDOD 04	2	2648-2658.4	100	10.4	KARMON	Limy marl to Dolomite		
ASHDOD 05	1	2563-2565.5	80	2.5	ZOHAR	Limestone	Oil	10.4
ASHDOD 05	2	2692-2701	93	9	SDEROT	Dolomite		
ASHDOD 06	1	2561-2570	100	9	ZOHAR	Dolomite		9.0
ASHQELON 02	4	3921-3929	100	8	BARNEA			27.8
ASHQELON 02	5	3929-3946	100	17	BARNEA			
ASHQELON 02	6	3985-3986.5	95	1.5	BARNEA			
ASHQELON 02	7	4013-4013.3	33	0.3	BARNEA			
ASHQELON 02	8	4016-4019.3	40	3.3	BARNEA			
ASHQELON 03	2	3475-3493.3	100	18.3	BARNEA	Dolomitic limestone		18.3
BARNEA 01	1	3344-3348	100	4	BARNEA	Limestone		57.0
BARNEA 01	2	3416.5-3422	100	5.5	BARNEA	Limestone	Oil in fractures	
BARNEA 01	3	3422-3429	100	7	BARNEA	Limestone	Oil	
BARNEA 01	4	3429-3442	100	13	BARNEA	Limestone	Oil	
BARNEA 01	5	3442-3449	100	7	BARNEA	Limestone	Oil	
BARNEA 01	6	3451-3460	50	9	BARNEA	Limestone	Oil	
BARNEA 01	7	3659-3675	100	16	BARNEA	Limestone		
BEERI 01	9	1917.2-3922.1	31	4.9	BEER SHEVA	Limestone to dolomite		12.6
BEERI 01	10	2081.8-2087.9	40	6.1	KIDOD	Shales to limestone		
BEERI 01	11	2165.9-2172		6.1	ZOHAR	Shales to limestone with siliciclastics	Little organic matter	
BEERI 01	12	2268.9-2272.6	58	3.7	KARMON	Limestone to shales		
BEERI 01	13	2451.2-2455.2	25	4	SDEROT	Limestone to silicified dolomite		
BEERI 01	14	2662.7-2667	16	4.3	DAYA	Limestone		

Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
BEERI 01	15	2880.4-2884	17	3.6	DAYA	Limestone	H ₂ S	
BEERI 01	16	2962-2968		6	UP INMAR	Limestone		
BEERI 01	17	3005.3-3009.6	14	4.3	UP INMAR	Limestone	Asphalt in fractures	
BEERI 01	18	3093.4-3096.5	61	3.1	UP INMAR	Shales		
BEERI 01	19	3224.8-3227.8		3	UP INMAR	Limestone		
BEERI 01	20	3281-3286		5	UP INMAR	Limestone to sandstone		
BEERI 01	21	3376.6-3378.7	79	2.1	UP INMAR	Calcarous shales		
BEERI 02	1	1724-1739	100	15	BEER SHEVA	Limestone		33.0
BEERI 02	2	2049-2067	100	18	ZOHAR	Limestone		
BEERI WEST 01	1	1979-1994	100	15	BEER SHEVA			15.0
BRUR 06 DEEP	3	1873-1881.8	98	8.8	ZOHAR	Slightly cherty limestone		14.2
BRUR 06 DEEP	4	1919.9-1932.1	46	12.2	ZOHAR	Limestone		
BRUR 08	1	1855.6-1861.4	100	5.8	ZOHAR	Limestone		44.4
BRUR 08	2	1861.4-1878.5	100	17.1	ZOHAR	Limestone		
BRUR 08	3	1878.5-1892.2	100	13.7	ZOHAR	Limestone		
BRUR 08	4	1900.4-1913.8	58	13.4	ZOHAR	Limestone		
BRUR 09	2	1875.4-1891.5	10	16.1	ZOHAR	Chalky limestone		29.9
BRUR 09	3	1892.5-1910.5	47	18	ZOHAR	Chalky limestone to dolomite		
BRUR 09	4	1910.5-1916.3	100	5.8	ZOHAR	Limestone to calcarenite		
BRUR 09	5	1916.3-1930.3	100	14	ZOHAR	Limestone		
BRUR 09A	1	1867-1875.5	100	8.5	ZOHAR			12.5
BRUR 09A	2	1880-1898	50	18	ZOHAR			
BRUR 10	1	1963.8-1967	100	3.2	KARMON	Limestone		21.4
BRUR 10	2	1999.5-2017.7	100	18.2	SDEROT	Limestone		
DAVID 01/1A	1	2684-2702	19	18	DAYA	Dolomite	HC saturation	10.0
DAVID 01/1A	2	2874-2882.5	19	8.5	UP INMAR	Dolomitic limestone	HC saturation	
DAVID 01/1A	3	3185.3-3190	40	4.7	QEREN	Dolomitic breccia	HC saturation	
DAVID 01/1A	4	3500-3518	17	18	ARDON			
GAN YAVNE 03	4	2562-2567	3	5	KIDOD-ZOHAR	Slightly sandy limestone		1.0
GAN YAVNE 03	5	2567-2570	10	3	ZOHAR	Limestone		
GAN YAVNE 03	6	2643-2644.7	30	1.7	KARMON	Limestone		
GAN YAVNE 04	1	2643-2648	100	5	SDEROT	Limestone to dolomite		5.0
GAN YAVNE 05	1	2676-2682	100	6	SDEROT	Limestone to dolomite	Oil?	21.0
GAN YAVNE 05	2	2682-2697	100	15	SDEROT	Limestone to dolomite	Oil?	
GEVAR AM 01	5	2275.8-2293.8	100	18	SDEROT	Limy shales		18.0
GEVAR AM 02	1	2449-2451.1	100	2.1	BARNEA	Limestone		15.0
GEVAR AM 02	2	2451.1-2452.6	100	1.5	BARNEA	Limestone	Oil	
GEVAR AM 02	3	2452.6-2454	100	1.4	BARNEA	Limestone	Dead oil	
GEVAR AM 02	4	2454-2464	100	10	BARNEA	Limestone	Dead oil	
GIVATI 01	4	2226-2242	100	16	BEER SHEVA	Limestone to Sandy limestone		72.6
GIVATI 01	5	2245-2250	100	5	BEER SHEVA	Limestone		
GIVATI 01	6	2250-2260	66	10	BEER SHEVA	Limestone		

Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
GIVATI 01	7	2550-2568	100	18	ZOHAR	Limestone	Asphalt	
GIVATI 01	8	2569-2587	100	18	ZOHAR	Limestone	Asphalt	
GIVATI 01	9	2712-2716	100	4	SDEROT	Limestone	Dead oil	
GIVATI 01	10	2716-2727	100	11	SDEROT	Limestone	Dead oil	
HELETZ 02	30	1973.9-1976.9	50	3	ZOHAR	Limestone		0.5
HELETZ 22	6	1985-1989.2	60	4.2	ZOHAR	Limestone		29.1
HELETZ 22	7	2008-2008.6	25	0.6	ZOHAR	Limestone		
HELETZ 22	10	2449.5-2454.5	100	5	SDEROT	Limestone with siliciclastics		
HELETZ 22	11	2907.3-2913.3	60	6	DAYA	Limestone with grains		
HELETZ 22	12	3144-3148.3	25	4.3	UP INMAR	Limestone with grains		
HELETZ 22	13	3228.6-3234.2	45	5.6	UP INMAR	Limestone		
HELETZ 22	14	3334.8-3340.1	82	5.3	UP INMAR	Shaley limestone		
HELETZ 22	15	3411-3416.2	13	5.2	QEREN	Dolomite		
HELETZ 22	16	3511.3-3515.6	18	3.3	QEREN	Limestone with siliciclastics		
HELETZ 22	17	3599.7-3605.1	18	5.4	QEREN	Dolomite		
HELETZ 22	18	3714.6-3715.2	93	0.6	LO INMAR	Limestone		
HELETZ 22	20	3786.4-3790.6	17	4.2	LO INMAR	Limestone		
HELETZ 22	21	3903-3908	17	5	ARDON	Dolomite		
HELETZ 22	22	4009.1-4013.5	85	4.4	ARDON	Dolomite with siliciclastics		
HELETZ 22	23	4013.5-4013.6	0	0.1	ARDON	Dolomite		
HELETZ 22	24	4118.5-4124	11	5.5	ARDON	Sandstone to dolomite		
HELETZ 22	25	4247.4-4252	13	4.6	ARDON	Limestone		
HELETZ 22	26	4438.7-4439	90	0.3	ARDON	Dolomite		
HELETZ 22	27	4464.1-4464.4	0	0.3	ARDON	Dolomite		
HELETZ 22	28	4476.3-4476.6	100	0.3	ARDON	Dolomite		
HELETZ 26 DEEP	8	1700-1706	100	6	NIR AM	Limestone to carbonate sandstone		12.0
HELETZ 26 DEEP	9	1706-1709	100	3	NIR AM	Limestone		
HELETZ 26 DEEP	10	1709-1712	100	3	NIR AM	Limestone		
HELETZ 31	6	2486.4-2491	100	4.6	ZOHAR	Limestone	Dead Oil	4.6
HELETZ 34	6	1838.9-1852.6	22	13.7	ZOHAR	Shaley bioclastic limestone		22.0
HELETZ 34	7	1910.8-1917.8	49	7	ZOHAR	Chalky limestone		
HELETZ 34	8	1919-1934.6	100	15.6	ZOHAR	Limestone		
HELETZ 38 (SHLOMO 1)	1	1710-1728	100	18	NIR AM			32.4
HELETZ 38 (SHLOMO 1)	2	1728-1738	96	10	NIR AM			
HELETZ 38 (SHLOMO 1)	3	1738-1745	68	7	NIR AM			
HELETZ DEEP 01	1	2101-2109	35	8	SDEROT	Limestone		2.8
HODIYA 01	3	1786.4-1804.4	50	18	NIR AM	Limestone		9.0
HOGA 01	3	2372.7-2376.5	65	3.8	SDEROT	Dolomite		2.5
KARMON 03	1	2130-2136	78	6	KIDOD	Limestone		13.7
KARMON 03	3	2241-2256	23	15	ZOHAR	Limestone		
KARMON 03	4	2300-2308.5	65	8.5	ZOHAR-KARMON	Limestone	H ₂ S	
KEFAR DAROM 01	3	3275-3293	31	18	SDEROT	Limestone to mudstone		17.9

Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
KEFAR DAROM 01	4	3293-3309	77	16	SDEROT	Limestone to mudstone		
KISSUFIM 01	2	2315-2333	100	18	BEER SHEVA	Limestone to shales		26.4
KISSUFIM 01	3	2363-2381	30	18	BEER SHEVA	Limestone		
KISSUFIM 01	4	2647-2650	100	3	ZOHAR	Limestone		
KOKHAV 07	9	1915.5-1917	100	1.5	NIR AM	Limestone		1.5
KOKHAV 08	5	1828.5-1831.8	100	3.3	NIR AM	Limestone		3.3
KOKHAV 10	3	1626.1-1631.5	100	5.4	NIR AM	Calcarenite limestone		5.4
KOKHAV 12	2	1833.7-1848.8	100	15.1	NIR AM	Limestone		15.1
KOKHAV 13	4	1703.2-1715	100	11.8	NIR AM	Limestone		11.8
KOKHAV 16	1	1612.1-1619.6	100	7.5	NIR AM	Limestone	Dead oil	61.2
KOKHAV 16	2	1619.6-1629.2	100	9.6	NIR AM	Limestone	Oil & heavy oil in fractures	
KOKHAV 16	3	1629.2-1646.9	100	17.7	NIR AM	Limestone	Oil in fractures	
KOKHAV 16	4	1652.6-1668.8	100	16.2	NIR AM	Limestone		
KOKHAV 16	5	1668.8-1671.9	100	3.1	NIR AM	Limestone to shales		
KOKHAV 16	6	1671.9-1689.6	40	17.7	NIR AM	Limestone		
KOKHAV 17	5	1609.3-1624	100	14.7	NIR AM	Limestone		62.3
KOKHAV 17	6	1624-1635.3	100	11.3	NIR AM	Limestone		
KOKHAV 17	7	1635.3-1651	100	15.7	NIR AM	Limestone		
KOKHAV 17	8	1651-1667.8	100	16.8	NIR AM	Limestone	Oil in fractures & pores	
KOKHAV 17	9	1667.8-1685.3	100	17.5	NIR AM	Limestone	Oil in pores	
KOKHAV 18	4	1671-1681	95	10	NIR AM	Limestone to shales		52.0
KOKHAV 18	5	1681-1697	55	16	NIR AM	Limestone	Little oil	
KOKHAV 18	6	1697-1712	100	15	NIR AM	Limestone	Little oil	
KOKHAV 18	7	1712-1719	85	7	NIR AM	Limestone		
KOKHAV 18	8	1719-1736	20	17	NIR AM	Limestone to chalk		
KOKHAV 18	9	1736-1742	100	6	NIR AM	Limestone		
KOKHAV 18	10	1742-1752	90	10	NIR AM	Limestone to chalk & shales		
KOKHAV 19	1	1700-1718.3	100	18.3	NIR AM	Limestone to shales		43.4
KOKHAV 19	2	1718.3-1733	100	14.7	NIR AM	Limestone to shales		
KOKHAV 19	3	1750.2-1766.9	100	16.7	NIR AM	Limestone to shales & chalk		
KOKHAV 20	5	1671-1682.5	93	11.5	NIR AM	Limestone		30.9
KOKHAV 20	6	1698.7-1714.8	97	16.1	NIR AM	Limestone		
KOKHAV 20	7	1714.8-1719.4	100	4.6	NIR AM	Limestone		
KOKHAV 21	5	1731.2-1731.9	100	0.7	NIR AM	Limestone		16.5
KOKHAV 21	6	1731.9-1747.7	100	15.8	NIR AM	Limestone		
KOKHAV 22	6	1730.3-1748	89	17.7	NIR AM	Limestone		33.8
KOKHAV 22	7	1748-1766	100	18	NIR AM	Limestone		
KOKHAV 23	4	1740-1749	100	9	NIR AM	Limestone		9.0
KOKHAV 25	6	1702-1720	100	18	NIR AM			18.0
KOKHAV 27 (RONI 01)	1	1719-1728	30	9	NIR AM			2.7
LIOR 01	2	2476-2476.7	100	0.7	ZOHAR	Limestone		1.4
LIOR 01	3	2578-2578.7	100	0.7	SDEROT	Limestone		
NAHAL OZ 01	1	2480-2489	100	9	SDEROT	Limestone to chalky	Dead oil &	9.0

						limestone	asphalt	
Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
NEGBA 01	27	1798.3-1803.8	100	5.5	BEER SHEVA	Limestone		15.1
NEGBA 01	28	1854.7-1860.2	80	5.5	KIDOD	Marl		
NEGBA 01	29	1878.5-1883.7	100	5.2	KIDOD	Shales		
NEGBA 05	6	2107-2120	65	13	ZOHAR	Limestone		8.5
NEGBA 07	1	1714.5-1732.3	100	17.8	BEER SHEVA	Limestone		5.0
NIR AM 01	2	2317-2326.8	100	9.8	SDEROT	Limestone		9.8
NIR AM 02	2	1494.5-1498.1	92	3.6	NIR AM	Limestone		16.9
NIR AM 02	3	1531-1539.5	17	8.5	NIR AM	Limestone to siltstone		
NIR AM 02	4	1795.3-1807.4	100	12.1	NIR AM	Limestone		
NIR AM 03	4	1394.5-1405.7	80	11.2	NIR AM	Limestone		42.2
NIR AM 03	5	1405.7-1410.7	45	5	NIR AM	Limestone	Little dead heavy oil	
NIR AM 03	6	1480.4-1498.7	100	18.3	NIR AM	Limestone		
NIR AM 03	7	1977.2-1992.8	100	15.6	ZOHAR	Limestone		
NIR AM 03	8	2023.6-2028.1	100	4.5	KARMON	Shales		
NIR AM 04	2	1610-1613	100	3	BEER SHEVA	Limestone		32.7
NIR AM 04	3	1613.7-1622.7	95	9	BEER SHEVA	Limestone		
NIR AM 04	4	1936.7-1944	100	7.3	KIDOD	Limestone to marl & shales		
NIR AM 04	5	1945.5-1947	100	1.5	KIDOD	Shaley limestone		
NIR AM 04	6	1947-1947.7	100	0.7	ZOHAR	Marl to limestone & chert	Little oil	
NIR AM 04	7	1947.7-1948.3	100	0.6	ZOHAR	Limestone to cherty limestone		
NIR AM 04	8	1948.3-1948.9	100	0.6	ZOHAR	Limestone to chert		
NIR AM 04	9	1964.1-1981.5	60	17.4	ZOHAR	Limestone		
NIR AM 05	1	1587-1604.7	100	17.7	BEER SHEVA	Limestone		51.4
NIR AM 05	2	1887.9-1905.6	100	17.7	KIDOD	Limestone		
NIR AM 05	3	1905.6-1915	100	9.4	ZOHAR	Limestone		
NIR AM 05	4	1915-1922	95	7	ZOHAR	Limestone to cherty limestone		
NIR AM 06	1	1714-1733	100	19	BEER SHEVA	Limestone		55.0
NIR AM 06	2	1733-1751	100	18	BEER SHEVA	Limestone		
NIR AM 06	3	2063.8-2070.2	100	6.4	KIDOD-ZOHAR	Limestone to shales		
NIR AM 06	4	2070.2-2088	65	17.8	ZOHAR	Limestone		
NIR AM 08	3	1625-1637.2	100	12.2	BEER SHEVA	Limestone to dolomite	Little oil	40.9
NIR AM 08	4	1637.2-1646.7	100	9.5	BEER SHEVA	Limestone		
NIR AM 08	5	1646.7-1660.9	100	14.2	BEER SHEVA	Limestone to shales		
NIR AM 08	6	1981-1985.5	53	4.5	KIDOD	Limestone		
NIR AM 08	7	1985.5-1989	100	3.5	KIDOD	Limestone to little cherty limestone		
NIR AM 08	8	1989-1990.7	71	1.7	ZOHAR	Limestone		
NIR AM 08	9	2031-2047.7	41	16.7	ZOHAR	Slightly chalky limestone		
NIR AM 08	10	2155.5-2156.7	85	1.2	SDEROT	Limestone		
NIR AM 11	2	1872.5-1890.5	100	18	ZOHAR	Shaley to sandy limestone to shales		36.0
NIR AM 11	3	1890.5-1908.5	100	18	ZOHAR	Limestone	Little oil	
NIR AM 12	1	1898-1915	100	17	KIDOD			31.5

Name	Core No.	Core depth	% Core Recovered	Core length	Formation	Lithology (from log)	HC Indication	Jur. total rec. length per BH
NIR AM 12	2	1919.5-1934	100	14.5	KIDOD-ZOHAR			
NIRIM 01	7	2362.2-2368.3	100	6.1	ZOHAR	Limestone		6.1
NIRIM 02	11	2105.9-2117.4	100	11.5	BEER SHEVA	Limestone		15.4
NIRIM 02	12	2342.4-2344.5	70	2.1	ZOHAR	Limestone		
NIRIM 02	13	2344.5-2347	98	2.5	ZOHAR	Limestone		
PALMAHIM 01	1	2401-2412	100	11	KIDOD	Limestone to limy conglomerate & shales		11.0
PETAH TIQVA 02	1	2502-2513	100	11	SDEROT	Limestone	Little oil	11.0
REVAHA 01	12	1968.7-1971.7	73	3	BEER SHEVA	Slightly sandy limestone to slightly sandy shales		2.0
REVAHA 01	13	2276.3-2279	30	2.7	KIDOD	Shales		
REVAHA 01	14	2473.2-2475.5	13	2.3	SDEROT	Limestone to chalk		
SAAD 01	17	2030-2034	50	4	BEER SHEVA	Limestone to shales & marl		6.8
SAAD 01	18	2149.4-2150.7	31	1.3	KIDOD	Shales to marl		
SAAD 01	19	2297.3-2299	48	1.7	KIDOD	Shales		
SAAD 01	20	2299-2303	25	4	KIDOD	Shales		
SAAD 01	21	2337-2339	36	2	ZOHAR	Limestone		
SAAD 01	22	2370-2375.3	35	5.3	ZOHAR	Shales to limestone		
SHIMON 01	3	1989.4-2006.2	100	16.8	SDEROT	Limestone		16.8
SHUVA 01	5	1980.3-1990.3	82	10	BEER SHEVA	Limestone		20.7
SHUVA 01	6	2191.2-2203.7	100	12.5	ZOHAR	Limestone to marl		
TALME YAFE 04 DEEP	4	2717-2728	88	11	BARNEA	Limestone to dolomite	Little oil	45.0
TALME YAFE 04 DEEP	5	2728-2746	98	18	BARNEA	Limestone	Heavy oil	
TALME YAFE 04 DEEP	6	2903-2921	98	18	BARNEA	Limestone	Oil & heavy oil	
YAKHINI 01	1	2162-2172	100	10	ZOHAR	Limestone	Aphalt in stylolites	33.5
YAKHINI 01	2	2172.5-2185.5	100	13	ZOHAR	Limestone to chert	Aphalt in stylolites	
YAKHINI 01	3	2415.5-2426	100	10.5	SDEROT	Chalk to limestone & dolomite	Little asphalt	
YINNON 01	9	2488.4-2504.3	100	15.9	ZOHAR	Limestone	Little organic matter	15.9

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14. Supplementary Notes		
15. Abstract According to structural and seismic interpretation studies of the Levant Basin margins, there is a variety of potential structural and stratigraphic oil-traps offshore Israel. Several offshore and onshore boreholes showed oil marks and oil accumulation in the Jurassic section, especially in the Barnea, Sderot and Zohar formations, suggesting there is a potential of finding other hydrocarbons reservoirs in this section. The current study focuses on the diagenetic evolution of potential reservoir rocks within the Jurassic sedimentary section along the Levant margin in Israel in order to track evidence for the formation and accumulation of hydrocarbons within these rocks. Although many studies were done on those wells, none of them examined the diagenetic history of the cements in the Jurassic section. Guided by lithostratigraphic description and electric logs, sampling efforts target rock cuttings and drill cores from the richest clastic intervals recovered from boreholes in the coastal plain and offshore central Israel. A petrographic examination of the cement phases will determine their relative age and paragenetic sequence. Chemical and stable isotope analysis of cement phases will be done in order to reconstruct the burial history and the geothermal gradient of the potential reservoir rocks.		
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תקציר

בשנים האחרונות נתגלו מאגרי גז משמעותיים מגיל אוליגוקן ומיוקן במרכז אגן הלבנט, בעקבות זאת יש עניין רב במאמצי האקספלורציה ובאפשרויות הקיום של מאגרי הידרוקרבונים נוספים באגן הלבנט. על-פי מחקרים של פענוח סטרוקטורלי וסיסמי שנעשו בשנים האחרונות באזור אגן הלבנט, קיימות מגוון מלכודות נפט סטרוקטורליות וסטרטיגרפיות אפשריות מול חופי ישראל. מספר קידוחים ימיים ויבשתיים בשולי אגן הלבנט הראו סימנים להצטברות נפט בחתך היוראסי, במיוחד בתצורות ברנע, שדרות וזוהר, אלה רומזים על הפוטנציאל האפשרי למציאת הידרוקרבונים נוספים בחתך זה. מחקר זה מתמקד בהתפתחות הדיאגנזה בסלעי מאגר אפשריים בחתך היוראסי הסדימנטרי בשולי אגן הלבנט של ישראל, זאת על-מנת לאתר עדויות והוכחות ליצירה ולהצטברות של הידרוקרבונים בסלעים אלה. למרות שמחקרים רבים נעשו על קידוחים אלה, אף אחד מהם לא חקר את תהליך הדיאגנזה של משקעי הצמנט בחתך היוראסי. דיגום סלעי החתך נעשה, בעזרת ניתוח לוגים ליתוסטרטיגרפיים ולוגים חשמליים, תוך כדי התמקדות באינטרוולים הקלאסטיים ביותר של מטחן וגלעיני הסלעים שהוצאו מקידוחי הים והחוף במרכז ישראל. באמצעות בחינה פטרוגרפית של פאזות המינרלים בצמנט של דוגמאות הסלעים הנבחרות, ייקבע גילן היחסי של פאזות הצמנט, כדי ליצור רצף פאראגנטי של התרחשות האירועים בתהליך הדיאגנזה. תבוצענה אנליזות כימיות ואנליזות של הרכבי האיזוטופים היציבים בפאזות הצמנט, על-מנת לשחזר את היסטוריית הקבורה, את הגרדיינט הגיאותרמלי ואת פוטנציאל המאגר של סלעים אלה.

נדגמו ונלמדו 27 דוגמאות מהחתך היוראסי של קידוחים ימיים ויבשתיים. הובחן צמנט מאסיבי ברוב הדוגמאות. נוסף על כך הנקבוביות ברוב הדוגמאות נמוכה מאוד, לא התגלו הידרוקרבונים בדוגמאות אלה. מתוך המינרלים האותיגניים שנמצאו בצמנט, העבודה הנוכחית מתמקדת במינרלים האותיגניים הקרבונטיים. הובחנו ארבעה מינרלים אותיגניים קרבונטיים: קלציט, סידריט, אנקריט ודולומיט. מבחינה פאראגנטית, הצמנט הקלציטי הוא המוקדם מבין השלושה וקיים במופעים שונים. שלושת הקרבונטיים האחרים מחליפים את הצמנט הקלציטי.

מדינת ישראל
משרד התשתיות הלאומיות האנרגיה והמים
אגף מחקר ופיתוח

**אפיון פוטנציאל סלעי המאגר ביחידות היוראסיות באזור הים
הרדוד של ישראל באמצעות שחזור סביבות ההשקעה וההיסטוריה
התרמלית והדיאגנטית של השוליים המזרחיים של אגן הלבנט**

דו"ח מסכם לפרויקט

המחקר מהווה בסיס לעבודת גמר לתואר מוסמך באוניברסיטת בן-גוריון בנגב בהדרכה
משותפת עם פרופ' ירון קציר

אסף לוין ורן קלבו

המכון הגיאולוגי

המחקר מומן על-ידי משרד התשתיות האנרגיה והמים על-פי חוזה מספר 2013-17-033

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