Samuel Neaman Institute
For Advanced Studies In Science And Technology

Oil Shale Occurrences in Israel

Geological Updated Information - 2013

Technion – Israel Institute of Technology

September 2013

אודות מוסד שמואל נאמן

מוסד שמואל נאמן הוקם בטכניון בשנת 1978 ביוזמת מר שמואל (סם) נאמן והוא פועל להטמעת חזונו לקידומה המדעי-טכנולוגי, כלכלי וחברתי של מדינת ישראל.

מוסד שמואל נאמן הוא מכון מחקר המתמקד בהתווית מדיניות לאומית בנושאי מדע וטכנולוגיה, תעשייה, חינוך והשכלה גבוהה, תשתיות פיסיות, סביבה ואנרגיה ובנושאים נוספים בעלי חשיבות לחוסנה הלאומי של ישראל בהם המוסד תורם תרומה ייחודית. במוסד מבוצעים מחקרי מדיניות וסקירות, שמסקנותיהם והמלצותיהם משמשים את מקבלי ההחלטות במשק על רבדיו השונים. מחקרי המדיניות נעשים בידי צוותים נבחרים מהאקדמיה, מהטכניון ומוסדות אחרים ומהתעשייה. לצוותים נבחרים האנשים המתאימים, בעלי כישורים והישגים מוכרים במקצועם. במקרים רבים העבודה נעשית תוך שיתוף פעולה עם משרדים ממשלתיים ובמקרים אחרים היוזמה באה ממוסד שמואל נאמן וללא שיתוף ישיר של משרד ממשלתי. בנושאי התוויית מדיניות לאומית שעניינה מדע, טכנולוגיה והשכלה גבוהה נחשב מוסד שמואל נאמן כמוסד למחקרי מדיניות המוביל בישראל.

עד כה ביצע מוסד שמואל נאמן מאות מחקרי מדיניות וסקירות המשמשים מקבלי החלטות ואנשי מקצוע במשק ובממשל. סקירת הפרויקטים השונים שבוצעו במוסד מוצגת באתר האינטרנט של המוסד. בנוסף מסייע מוסד שמואל נאמן בפרויקטים לאומיים דוגמת המאגדים של משרד התמ"ס - מגנ"ט בתחומים: ננוטכנולוגיות, תקשורת, אופטיקה, רפואה, כימיה, אנרגיה, איכות סביבה ופרויקטים אחרים בעלי חשיבות חברתית לאומית. מוסד שמואל נאמן מארגן גם ימי עיון מקיפים בתחומי העניין אותם הוא מוביל.

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Oil Shale Occurrences in Israel

Geological Updated Information - 2013

Tsevi Minster

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The following summary, that presents information and evaluation on the Oil Shale Deposits and Occurrences of Israel, is a modified version of a report in Hebrew by Dr Tsevi Minster.
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The original Hebrew report was published in the Geological Survey of Israel (GSI) as an open-file report number GSI/18/2009.

It appeared in Jerusalem on July 2009.

The current English version includes minor corrections and updates over the original 2009 Hebrew report.

It should be emphasize that the report reflects many years of research and studies in the GSI, part of which in association with several companies and institutions.

Considerable efforts and budgets were involved in obtaining the raw data and conducting its assessment.

Cover Picture: The Havarbar oil shale mine, Mishor Rotem, as observed from the west (September 2012).

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Introduction:

In most rocks in Israel that are termed oil shale, the main inorganic constituent is carbonate - namely chalks, marly chalks and chalky marls. Those domestic rocks are sometimes called 'bituminous' (e.g., bituminous chalks), though only small portion of the organic matter in the rock belongs to the organic group termed bitumen.

Sedimentary rocks that contain anomalous values of organic material are found in some intervals along the sedimentary sequence of Israel and adjacent countries. It is assumed that economical potential is limited only to the Upper Cretaceous sequence of the Mount Scopus Group, representing ages of Santonian to Paleocene, and especially the Mishash and the Ghareb formations (age: Campanian – Maastrichtian) within this sequence.

The sequence enriched in organic material of the Mount Scopus Group represents the global anoxic event that is dated to the Upper Cretaceous time. It is widely agreed that the primary source for the organic material (in oil shale rock) are micro-organisms. Bituminous sequences, which now reside in synclinal structures, represent an increase in tectonic activity, deepening of basins and probably relatively high productivity rates. Appropriate conditions (i.e., fast burial, depletion in oxygen levels in the water bodies) enabled the preservation of oil shale in many basins; it is plausible that their original distribution was wider than observed today due to oxidation and epigenetic activities.

Several large oil shale basins [e.g., Hatrurim hills (southeast of Arad), Ma'aleh-Adumim – Nabi-Musa (east of Jerusalem)] as well as some smaller ones, experienced epigenetic heating event in which the organic material was digested in parts of / all the basins and most inorganic constituents underwent substantial mineralogical changes.

Several researches suggest that the organic matter enriched sequence of the Mount Scopus Group was a major source rock for the hydrocarbons (oil, asphalt, gas) showings found in the Dead Sea Rift and on its margins.

Until today, tens of oil shale occurrences were revealed in Israel, almost all of them on the subsurface; in some of them (e.g., Nabi-Musa, En-Bokek, Oron, Nahash-Zameh) the oil shale are partially exposed. Almost 40 occurrences are presented herein (see table 3). The first domestic oil shale occurrences that were identified and studied were Nabi-Musa (where the rocks were used as heating material for centuries) and En-Bokek (in the 1950's). All other occurrences have been discovered by drilling activity (carried out especially for minerals, water and oil exploration).

The oil shale deposit of Mishor Rotem and many of the other occurrences in the Northern and Central Negev were discovered during prospecting for phosphates. During the late 1970's and the 1980's, a prospecting project, solely for oil shale, took place in various locations in the Northern Negev. In Mishor Rotem, the prospecting activity started in the 1970's and continues ever since for research and mining purposes. In the time-span of 2008-2012 a limited prospecting activity took place in the Ha'Shefela region. With the presently available data it is estimated that oil shale occurrences in Israel covers (in the subsurface) 15-20% of the country's total area.

In several localities, in central and southern Israel, sequences enriched in organic matter of Upper Cretaceous age are 200-400 m thick. In some of the boreholes that penetrated such thick sections the oil shale represent a major portion of the Mount Scopus Group. The defined Oil Shale Member of the Ghareb Fm, which is about 20 m thick at the type section locality (Giv'at Mador, southwest of Oron plant), reaches a record thickness of >130 m in Mishor Rotem.

The Oil Shale Member of the Ghareb Fm is characterized by a gradual decrease in the organic matter content from the base of the sequence upwards. The organic matter values (= EOM) in this rock unit are up to 26% [about 16% TOC (= Total Organic Carbon)] in the bottom of the Ghareb Fm, and they usually decrease upwards. In previous surveys and prospects a cut-off value of 10% EOM was used to calculate quantities and grades.

Generally, the host rocks for the enriched organic matter sequence are chalks and marly chalks. The sequence of the Oil Shale Member of the Ghareb Fm is also characterized by a relatively high moisture content (non-combined waters) averaging around 20%.

In some of the places where the Mishash Fm sequence was penetrated (below the Ghareb Fm sequence and the underlying economic phosphates beds), there is a sequence 5-12 m thick and more, with 10-15% EOM content in chalky and siliceous host rocks. Such sections were found in Mishor Rotem, Oron, Nahal Zin and Biq'at Zin and they may be of economical significant in case of a combined mining of phosphates and oil shale. In several places in the Northern Negev (e.g., Hatrurim, Biq'at Zin) chalky sections of the Menuha Fm, that underlies the Mishash Fm, were found to be enriched in organic material as well.

The following presentation includes oil shale occurrences that are (or part of them, are) under an overburden of less than 250 m and it is indicated that they cover an area that is above 3 km^2. It is quite probable that oil shale bodies under greater depth may reside within the Dead-Sea Rift Valley, in the Dead-Sea & the Arava regions.

In few cases the data about a presented occurrence is based on 1-2 boreholes, but it was included herein as there is enough evidence to support the existence of a relatively thick and rich sequence

with possible lateral extension. Nevertheless, in no case herein a sole borehole did count for defining an oil shale occurrence.

The density of domestic oil shale rocks, that were analyzed, is between 1.6 - 2.0 gr/cm^3; as could be expected, when the organic matter content is high, the density of the raw rock is expected to be lower. For making the calculations of the reserves, an average specific density value of 1.7 gr/cm^3 was implemented.

There is a great similarity between the oil shale of Israel and some of the oil shale occurrences in Jordan and this may form a basis for a bi-national cooperation.

Fig. 1 demonstrates a general geological section of the sequence in southern Israel that contains the oil shale units.

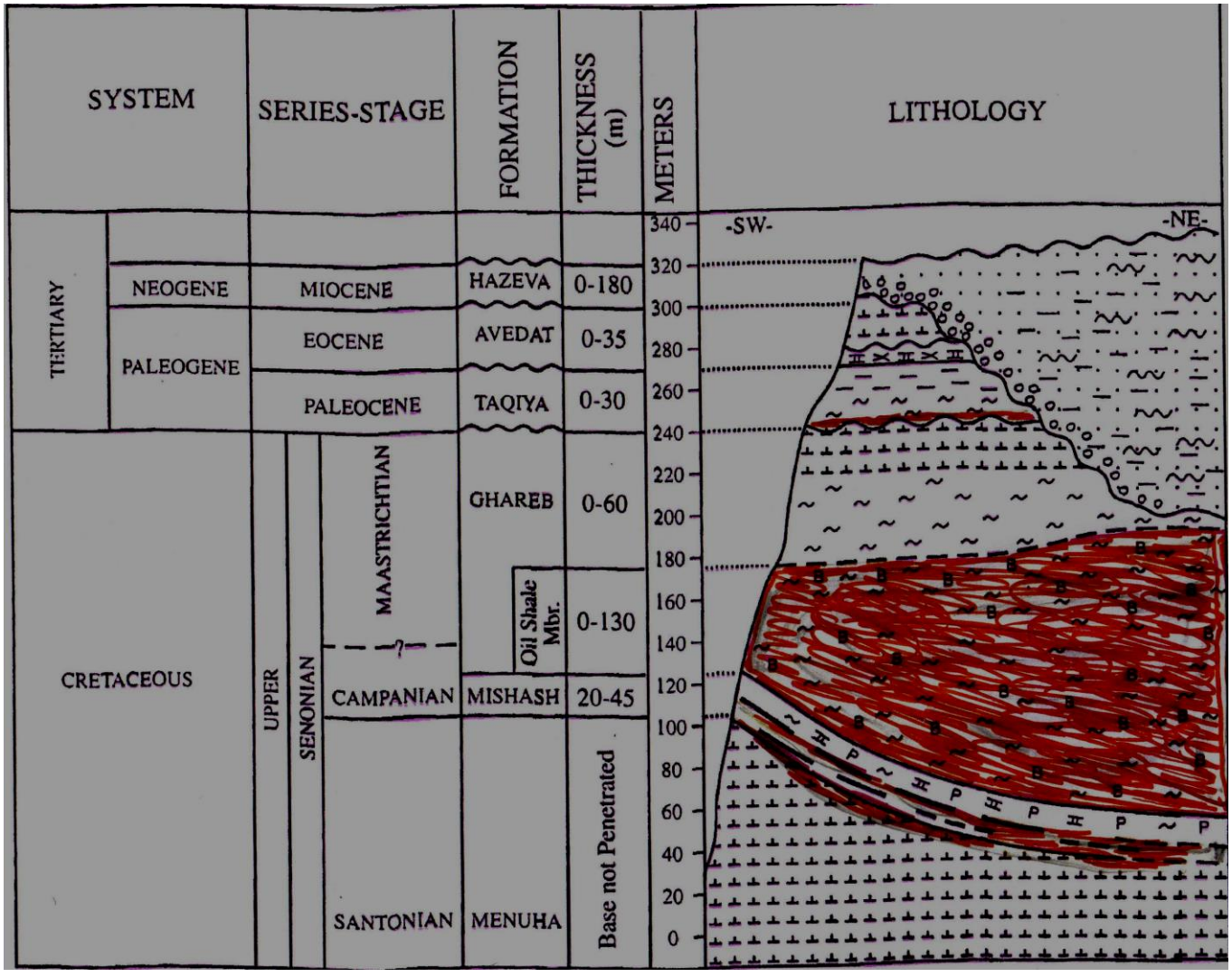

Figure 1. A general geological section of the geological sequence in southern Israel that contains the organic matter enriched sequences. (after Minster & Shirav, 1985).

In Fig. 2, a correlation chart demonstrates the Upper Cretaceous successions in various regions of Israel, and thus gives a more precise stratigraphic overview of the discussed geological units.

Table 1 summarizes average contents of major chemical constituents in Israeli oil shale samples.

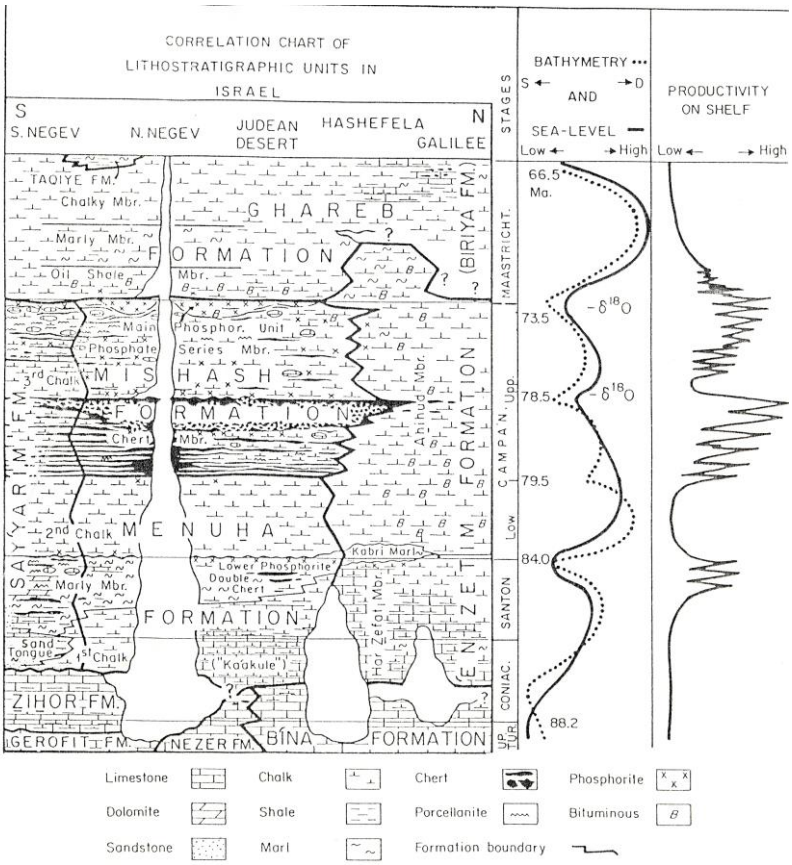

Figure 2. A correlation chart demonstrating the Upper Cretaceous successions in various regions of Israel, with emphasize on rock units that contain organic matter enriched sequences. (from Reiss, 1988).

Table 1. Average contents (%) of major chemical constituents in oil shale samples from Israel.

Sample *Type	EOM	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	SO_3	CO_2	TiO_2	Na_2O	K_2O
1	12.04	11.08	5.12	2.25	34.10	0.93	1.75	6.23	25.59	0.21	0.21	0.35
2	18.86	7.38	2.40	1.13	34.29	0.96	3.61	7.34	24.64	0.11	0.29	0.31
3	12.68	14.93	1.01	0.67	29.40	3.15	5.02	5.63	23.43		0.24	0.15

1. Samples from the upper part of the Oil Shale Member, Ghareb Fm. Averages for 100-200 samples. For Ti, Na & K the results represent averages of 50-90 samples.

2. Samples from the lower part of the Oil Shale Member, Ghareb Fm. Averages for 100-200 samples. For Ti, Na, K & CO2 the results represent averages of 30-85 samples.

3. Samples from the Mishash Fm., below the main Phosphate unit. Averages for 26-47 samples from 14 boreholes, representing successions of 5-28 m thick, in the Oron North Oil Shale Deposit.

Table 4, at the end of this report, summarizes the data about the oil shale fields and occurrences described herein. It is followed by a general map that shows locations and extensions of the described oil shale occurrences (Fig. 43).

A partial list of references (articles and technical reports), related to the described oil shale deposits and to the above introduction, is attached at the end of this summary.

Description of main oil shale deposits and occurrences in Israel:

1) Nabi-Musa (Fig. 3, 4; Table 2):

This oil shale occurrence is located to the south of Jericho (actually within the West Bank area), on the south-eastern edge of the Jordan Valley, in the Judean Desert. It is well known for centuries. Rocks from exposures there were mined for heating purposes and some hard oil shale varieties (probably from slightly metamorphosed locations) in nearby sites had a limited use in the building industry and in the far past – for the making of artifacts. The grayish-black stone attains on exposures a typical thin, white oxidation patina. These rocks were termed domestically as Moses Stone (or Hajar-Musa, in Arabic), probably because of the proximity of the exposures to the Nabi- (=prophet) Musa (=Moses) shrine.

The usage and study of this deposit started generations ago; analyses from the mid-19th century are given in Table 2.

Table 2. Results of "old" (mid-19th century) analyses of samples from the Nabi-Musa oil shale occurrence

Calcium carbonate	68.73	Calcium carbonate	82.10
Magnesium carbonate	0.27	Magnesium carbonate	0.00
Earthy residual		Silica	1.95
		Sesquioxides	1.95
Organic Matter	25.00	Organic Matter	13.55
Total	100.00	Total	100.00

During the 1970's the area was geologically re-examined and prospecting boreholes were drilled in the area, which for the first time supplied subsurface data on this oil shale occurrence. It was revealed that the Ghareb Fm sequence which is enriched in organic material is some 25-40 m thick with an average, EOM content of ~17%, a relatively high value, and a calorific value of about 1,240 cal/gr. It was also indicated that the occurrence is not laterally consecutive, as marly, non-

bituminous sections were penetrated in the heart of the deposit. As a result, a "lenses model" of the oil shale body was suggested (Fig. 3). The area of the overall occurrence is about 7 km^2, whereas the reserve figure is around 100 million tons (for oil shale rocks with cut-off of 10% EOM).

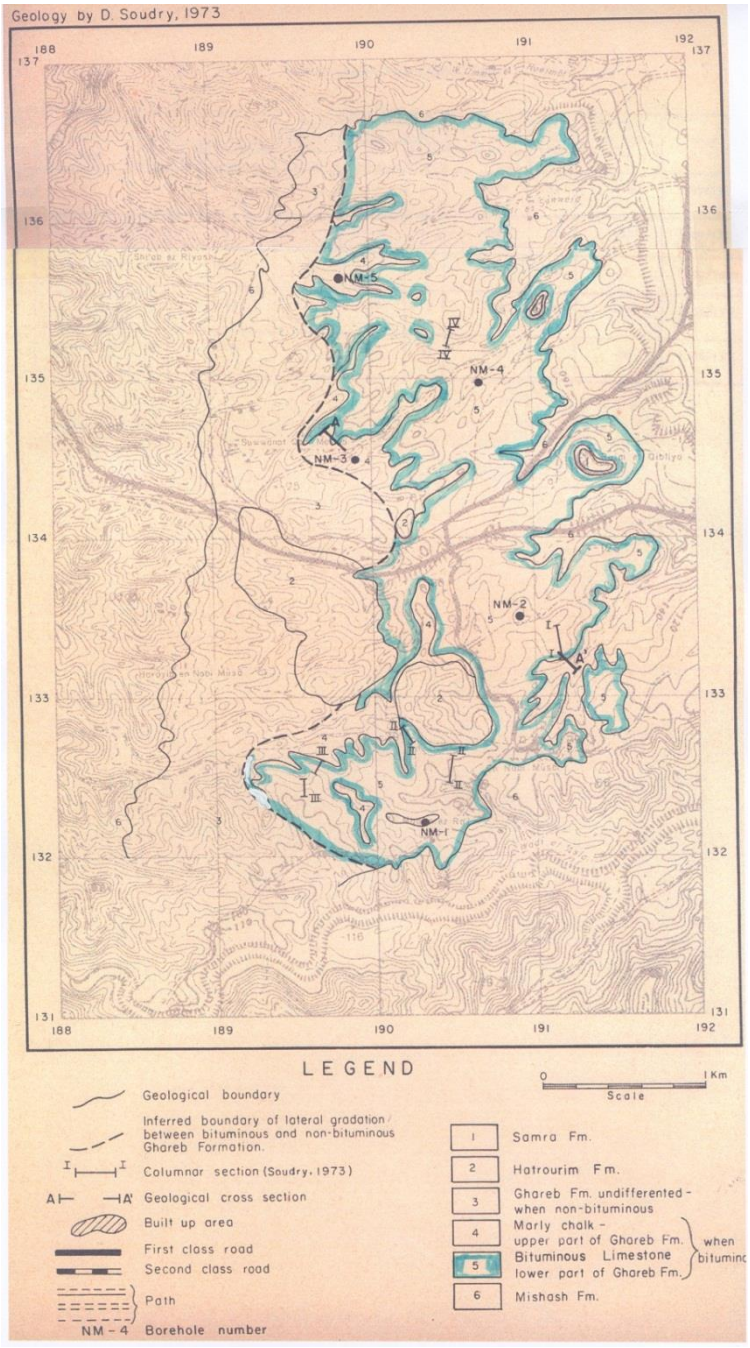

Figure 3. Geological map of the Nabi-Musa oil shale occurrence. Boundaries of the occurrence and locations of some of the 1972 prospecting boreholes are shown (from Shirav, 1976).

Chemical analyses indicate that the clay content of the Nabi-Musa Ghareb Fm's oil shale is lower than in the studied Negev oil shale occurrences.

All prospecting boreholes that were drilled in the Nabi-Musa oil shale field were targeted at the Ghareb Fm sequence. It is quite likely (see the attached section carried out by L. Picard in 1924, Fig. 4) that some beds in the underlying Mishash Fm are also enriched in organic material. But there is lack of information on the nature and grade (thickness, lateral distribution, EOM content) of these beds in the subsurface, hence their significance in the reserve picture. New data on this sequence might enlarge the reserve estimation about the entire Nabi-Musa oil shale occurrence.

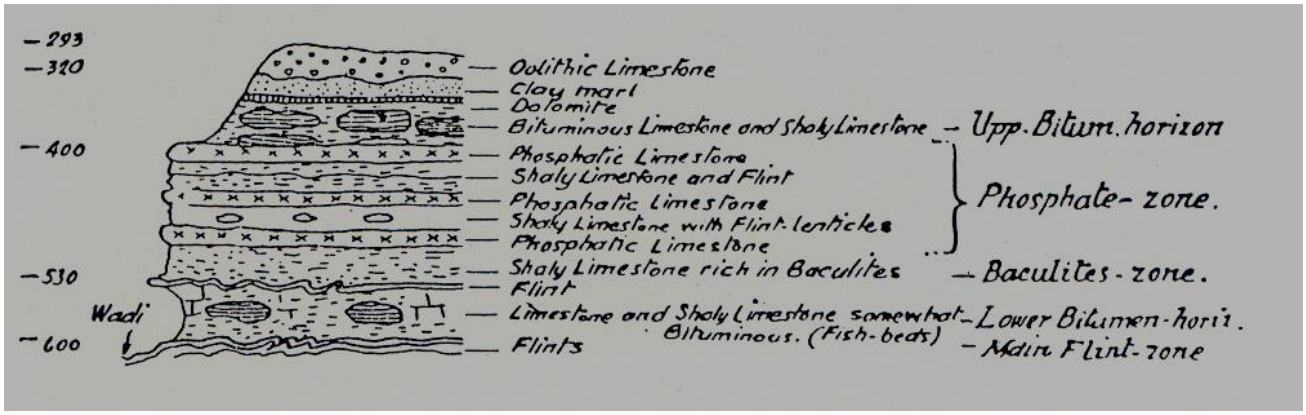

Figure 4. Columnar section carried out by L. Picard in 1924 (Picard, 1931), in El-Kiblieh hill (adjacent and north to road no 1), within the Nabi-Musa oil shale occurrence. Organic matter enriched beds are described well under the (Mishash) phosphorites.

2) En-Bokek (Fig. 5):

This is the first oil shale occurrence that was investigated in Israel, during the 1950's. Unfortunately, a great portion of the data (borehole data, various kinds of analyses, etc.) that was originally obtained about this site is not available today.

The oil shale occurrence is located along the shores of the Dead Sea, in a strip about 2.5 km long and up to 0.8 km wide, to the north and southern sides of the gorge of Nahal Bokek. The oil shale sequence is exposed in several locations along this strip; in the northernmost portion of the deposit a quarry was developed to supply oil shale raw material to adjacent infrastructure projects. The sequence enriched in organic material reach thickness of about 180 m, which include the Mishash and Ghareb formations and possibly part of the overlying Taqiye Fm. Reserves in the En-Bokek deposit were estimated to be around 100 million tones; they may be even greater. The organic matter content, that was indicated for these oil shale succession, is relatively high (average oil yield values of 8-9% were reported) but they may differ from other Negev oil shale deposits, having higher magnesium values (dolomite?) and possibly different organic properties that has to be restudied.

Parts of the En-Bokek oil shale deposit are located in immediate proximity to the En-Bokek resort area, which includes many hotels and tourist sites; it is plausible that its eastern edges may be also below the Dead Sea itself (which now is, in fact, operational pools of the Dead Sea Works). It should also be mentioned that additional sequences enriched in organic material were penetrated

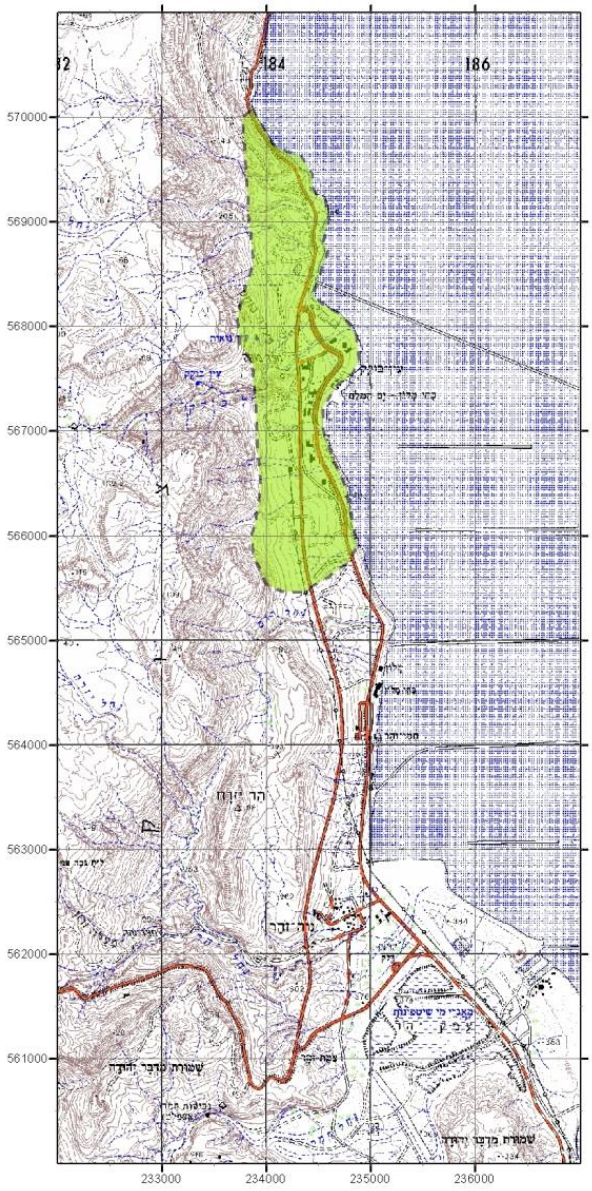

Figure 5. Approximate boundaries of En-Bokek oil shale occurrence, to the west of the Dead Sea.

west and close to Neve Zohar (to the southwest of En-Bokek), and this may be a southern continuation of the En-Bokek oil shale deposit.

3) Mishor Rotem (Fig. 6-11):

The oil shale deposit in Mishor Rotem (MROSD - Mishor Rotem Oil Shale Deposit) was intensively studied in the last 40 years. It is estimated that more than 300 boreholes were carried out within its area and hundreds of works been written on it, mainly technical and laboratory reports and scientific papers as well.

The Ghareb Fm reaches thicknesses of more than 160 m in the subsurface whilst it is up to 75 m only in (non-bituminous) exposures. The thickness of the Oil Shale Member (Ghareb Fm) reaches values of up to ~130 m, but usually it is around 30-75 m thick (average for about 200 boreholes - ~48 m).

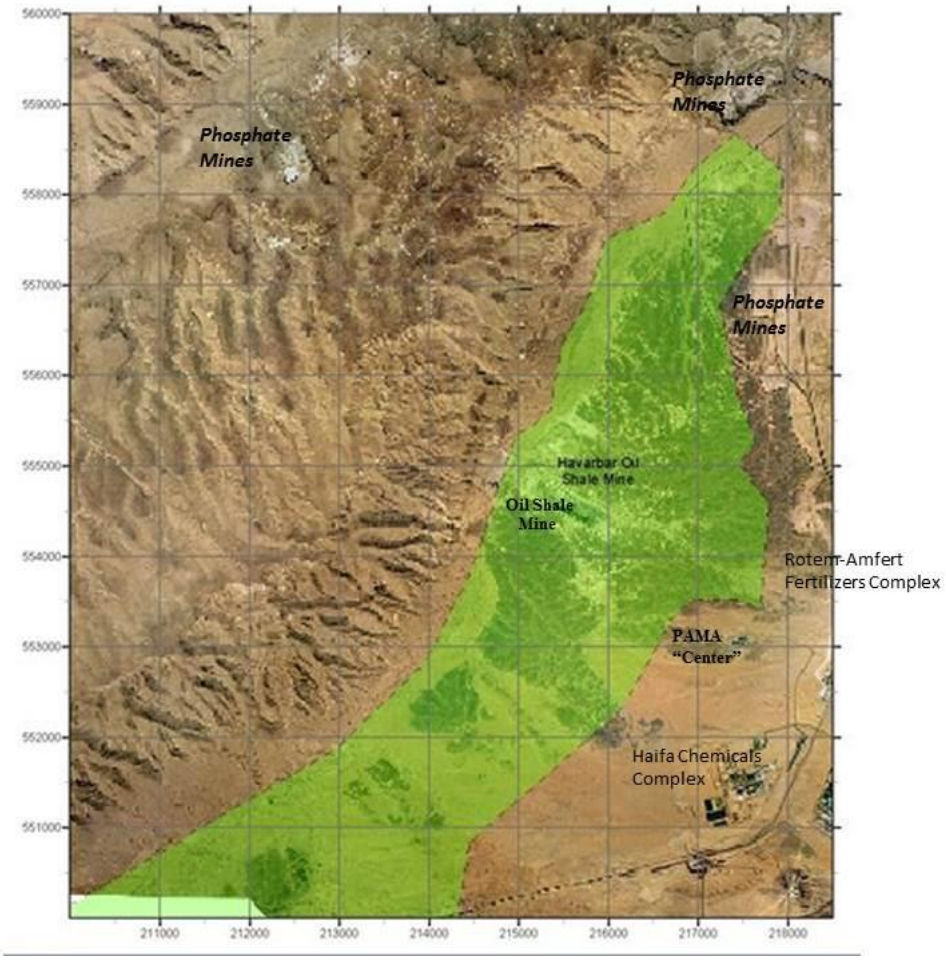

Figure 6. Approximate extension of the Mishor Rotem Oil Shale Deposit (in green) displayed on an ortho-photo background. Some additional sites in the area are shown.

The area of the MROSD (north of the Dimona - Sedom highway) is about 23 km^2. The reserves of oil shale having EOM values of above 10% (Ghareb Fm) are around 2.5 billion tons, with an average EOM value of ~14%. Vertical logs of the organic matter content in 2 representative boreholes are shown in Fig. 7.

The organic matter content has excellent correlation with the following technological parameters - calorific value (range of 1000-1800 cal/gr) and oil yield (range of 6-12%). The overburden thickness ranges, with the topography between 15 m to more than 100 m, with a clear thickening trend to the south. It is mainly composed of Neogene sandstones and conglomerates and non-bituminous and low-bituminous marls of the Ghareb Fm.

A rich phosphate sequence, which is usually bituminous, underlies the Ghareb Fm oil shale body. In previous economic studies, a preliminary figure of ~10 million tons of bituminous phosphates was calculated as a possible reserve for each sq. km, below the Ghareb Fm oil shale body. Under these phosphates, a carbonaceous - siliceous - phosphate sequence of ~10 m thick and more was penetrated in places and was found to be enriched in organic material. As this bed was not studied thoroughly, it has never been incorporated into the MROSD reserve picture. An example to the preliminary information about this sequence is shown on Figure 8.

Experimental mining of oil shale for research facilities started in 1979 in an underground mine. In the 1980's an open-pit mine was developed in Nahal Havarbar valley, near and to the east of Nahal Ef'e. This mine is still in operation and supplies the raw oil shale to the 12.5 MW power plant. This plant is functioning within the industrial complex of Rotem Amfert Negev Ltd. (RAN), producing electricity (for the net) and steam used in the nearby industries.

It is estimated that since the opening of the oil shale mine in Nahal Havarbar until the end of 2002, more than 9 million tons of oil shale were mined and the production goes on at an approximate annual rate of 450,000 tons. The actual state of the mine for 2008/9 is presented in Figure 9.

The facilities for the study and utilization in Mishor Rotem were planned, designed and built by PAMA (Energy Development Resources) Ltd. Since 2001 the power station and the oil shale mine are operated by RAN.

Due to technological complications in the burning process at the power station, present open pit mining of the MROSD does not include the lowermost part of the oil shale sequence, which contains the highest EOM values (18-25%). Thus, the richest oil shales of the Ghareb Fm are, in fact, not mined and during the mining activity they are covered with overburden from new parts of the mine. This fact has some disadvantages, and in particular may harm the future utilization of the underlying bituminous phosphates. It should also be mentioned that the poor oil shale rocks (having organic matter content of less than 10-12% EOM) are not used and referred to as part of the overburden.

Parallel to the studies and the energy generated from the combustion of oil shale rocks, PAMA developed and built retorting facilities that remained in a demonstration stages. Additional studies to find uses for the oil shale were carried out by PAMA, one of which was an advanced and

successful feasibility study on cement making out of the oil shale and other raw rocks from the surroundings.

A major byproduct of the oil shale utilization is the retained ash (OSA = oil shale ash), which reaches annual amounts of about 250,000 tons. The combustion stages improve some physical properties of the inorganic fraction, such as absorption. Sieved OSA is consumed as cat-lit product (most of it is exported), for padding of dairy barns and in sewage treatment. In the past other potential uses of the OSA were examined in advanced studies (e.g., manufacturing of light blocks).

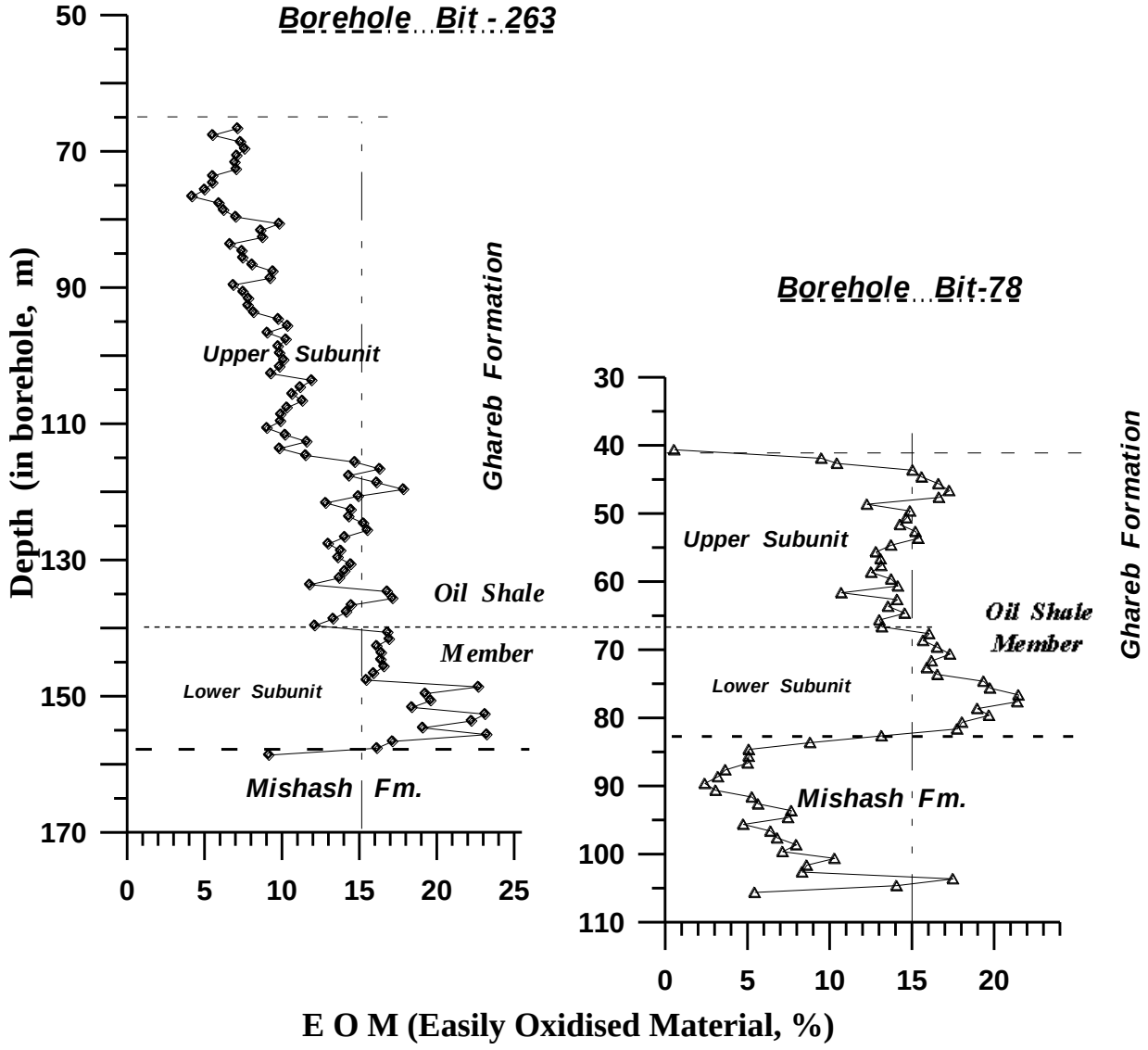

Figure 7. Vertical logs of the organic matter content in 2 representative boreholes in the MROSD. Locations (coord): Bit-78 - 216630/550125; Bit-263 - 215310/553717.

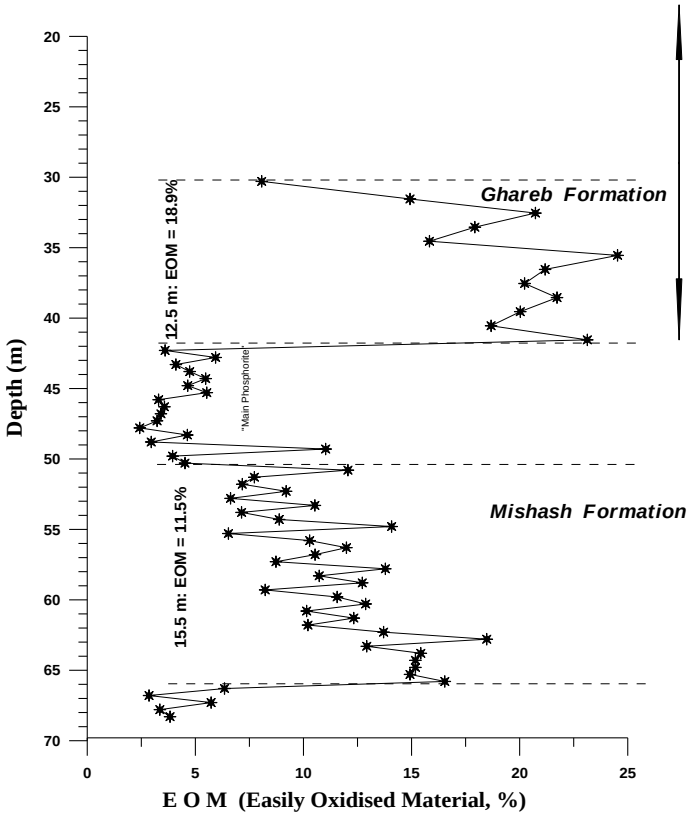

Figure 8. Vertical log [organic matter content] of borehole Bit-102 (coord. - 217750/558020, northern part of Mishor Rotem).

Figure 9. Configuration of the Havarbar oil shale mine (Mishor Rotem), as recorded in 2008/9.

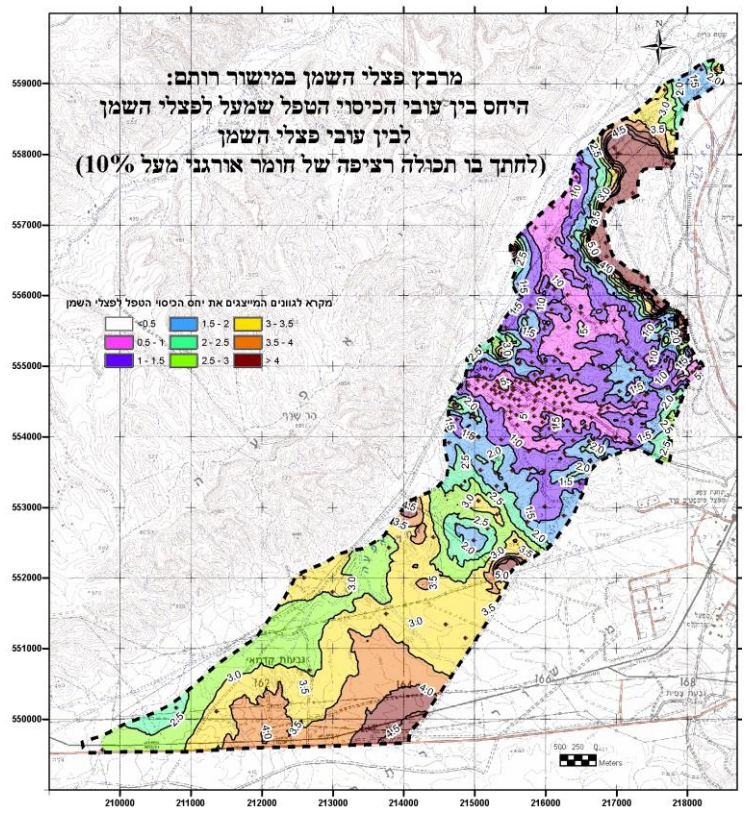

Figure 10. Map showing the Overburden to Oil Shale (Ghareb Fm) ratio (Stripping Ratio) in the MROSD. Prepared based on data from ~260 boreholes. Source: Minster (2007).

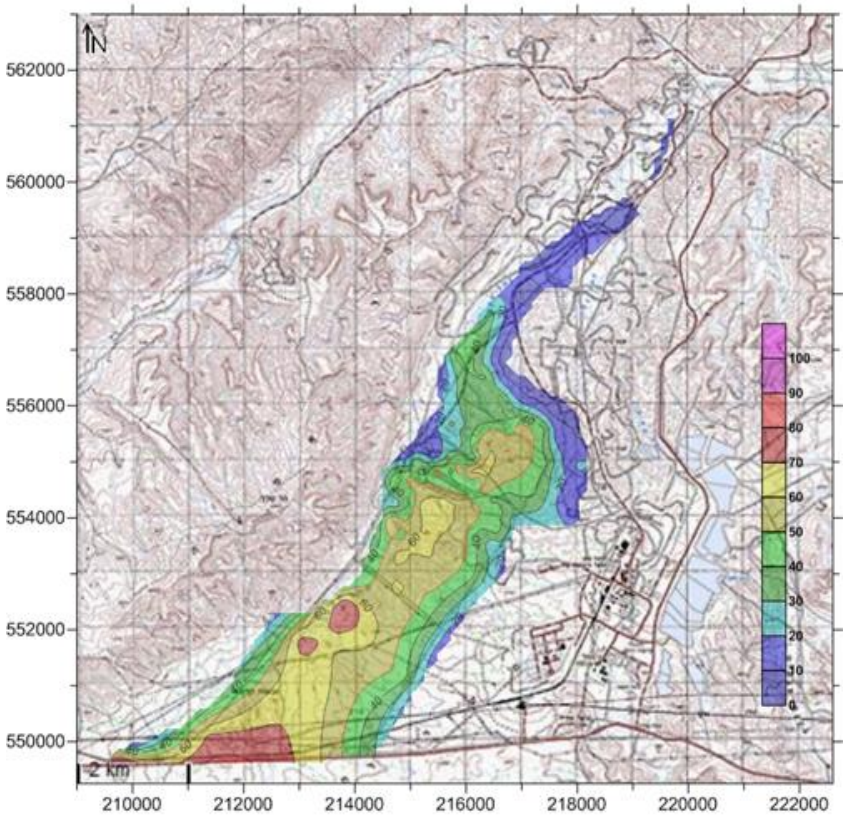

Figure 11. Isopach (thickness) map of the Oil Shale unit (Ghareb Fm) in the MROSD. Based on data from ~240 boreholes. Source: Minster & Sladek (2012).

With the ongoing oil shale mining activity in Mishor Rotem, considerable amounts of overburden rock material are removed and needs to be dumped. It is estimated that about 0.5 million tons of overburden needs to be remove annually, in average; this figure will probably be greater in the future as there is a gradual increase in the overburden to oil shale ratio around the open mining area. Figure 10 represents the overburden to oil shale (Ghareb Fm) ratio (=Stripping Ratio) in the MROSD area. Figure 11 demonstrates the thickness (isopach) of the oil shale sequence (Ghareb Fm) in the MROSD.

4) Mishor Yamin (Fig. 12, 13):

This oil shale deposit in Mishor Yamin is, in fact, the southern extension of the MROSD (Fig. 12). The artificial demarcation line between them is the Dimona - Dead Sea highway. The data from boreholes is rather limited when its relatively large area (about 50 km^2) is considered and also in comparison to the sizable amount of information regarding the neighboring Mishor Rotem deposit. The available data is mostly confined to the western and southwestern edges of the basin.

The geological section and the properties of the oil shale sequence of the Ghareb Fm are probably very similar to the descriptions from Mishor Rotem, but the overburden above the oil shales is thicker (up to ~150 m) and it includes, in the western and southwestern parts of the deposit, marls of the Taqiye Fm and also some limestone of Eocene age. A vertical log of the organic matter content, in one of the deepest borehole carried out for oil shale, is demonstrated in figure 13.

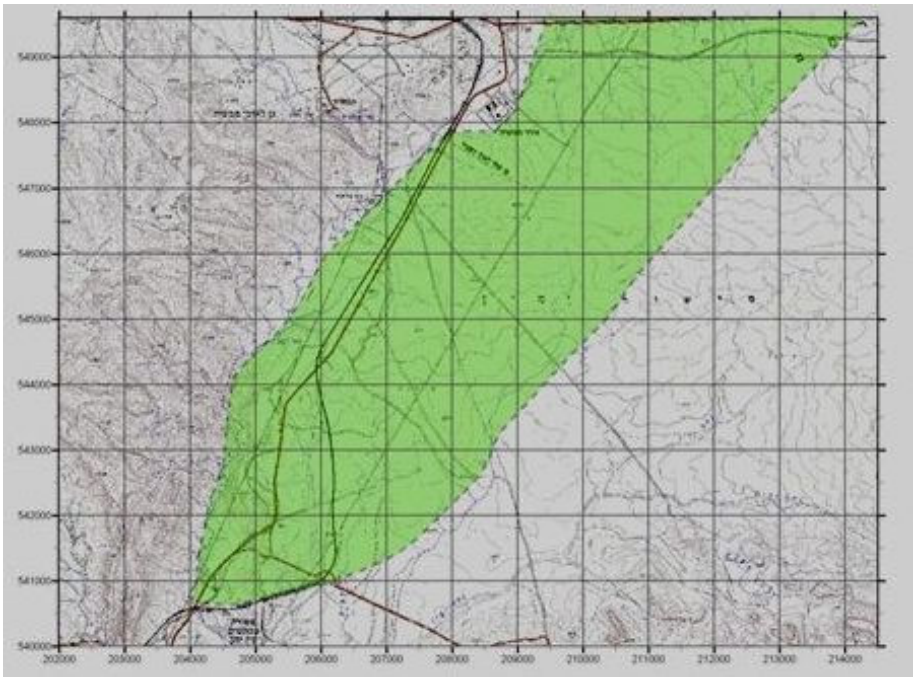

Figure 12. Approximate boundaries of the oil shale deposit in Mishor Yamin.

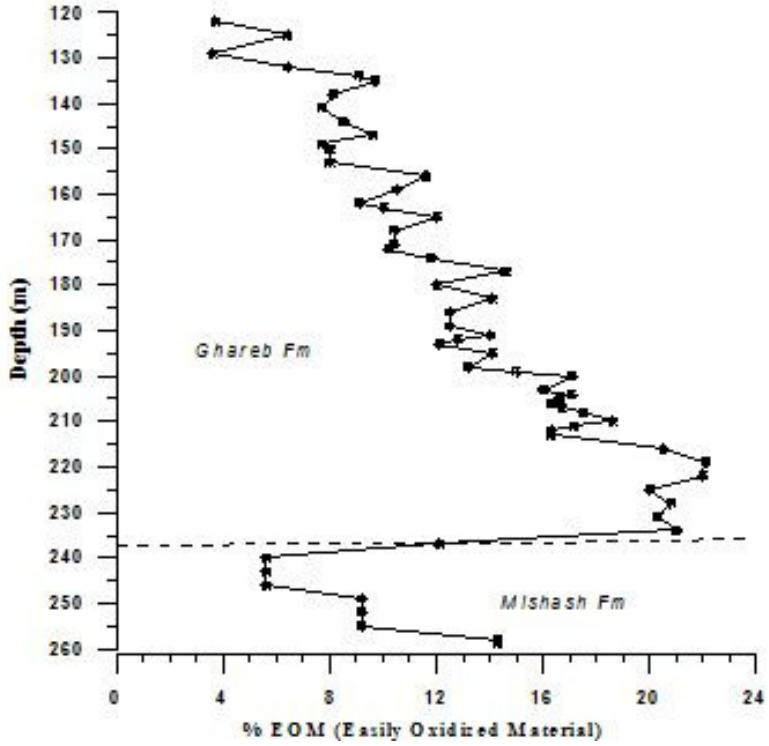

Figure 13. Vertical distribution of the organic material content in the Bit-57 borehole, Mishor Yamin.

The oil shale reserves in the Mishor Yamin deposit are estimated to be about 50% more than those of the MROSD. The reserves of oil shale, having EOM content of more than 10%, are probably above 3.5 billion tons. The average EOM value for this oil shale body is estimated to be 14-14.5%. It is indicated that in the western part of the Mishor Yamin oil shale deposit, the thickness of the Oil Shale Member is above 100 m and that the sequence with high organic matter content in the Mishash Fm is thicker than in Mishor Rotem. These oil shales were not incorporated into the above reserves figure, though they may have a very significant volume.

5) Oron North (Fig. 14, 15):

The Oron oil shale deposit is located southwest of the Oron plant (RAN) and is extended, in a shape of narrow strip, southwesterly to Giv'at Mador, the site of the type section of the Ghareb Fm. It is some 8 km long and 0.5-2 km wide (~10 km^2). It is adjacent to the Karbolet range, which builds the eastern edge of the Makhtesh Gadol anticline. The synclinal axis is close to this range and is approximately parallel to it. General location map of the deposit is presented in figure 14.

Most of the oil shale body of the Oron North deposit is a subsurface one, but it has some exposures in its southernmost edge, of both Ghareb and Mishash formations bituminous sequences.

The information on the Oron North oil shale deposit is based on about 30 research boreholes.

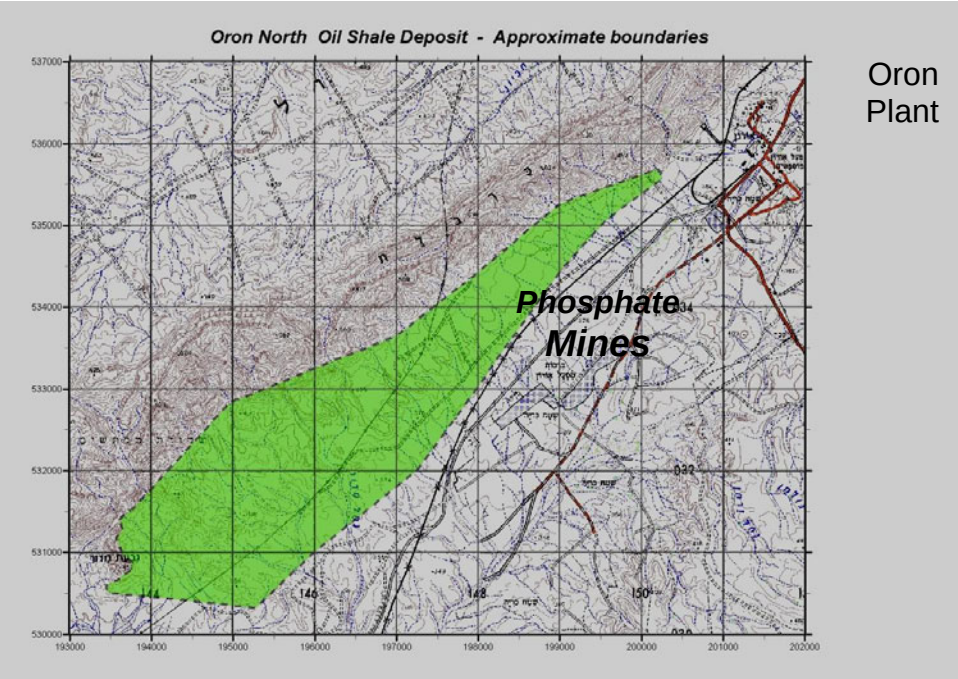

Figure 14. Approximate boundaries, the oil shale deposit of Oron North.

The Ghareb Fm sequence here has higher organic matter content than in Mishor Rotem - it contains in average above 15% EOM; the sequence of the Mishash Fm with relatively high organic matter content (EOM - 13-16%) is about 7-13 m thick.

The average thickness of the oil shale sequence (Ghareb Fm) is ~25 m, and thus the reserves are around 500 million tons. The total reserve figure is probably some 50% higher, and possibly more, when the sequence of the Mishash Fm sequence is also accounted.

An organic matter log of a borehole in the Oron North oil shale deposit is presented in Fig 15.

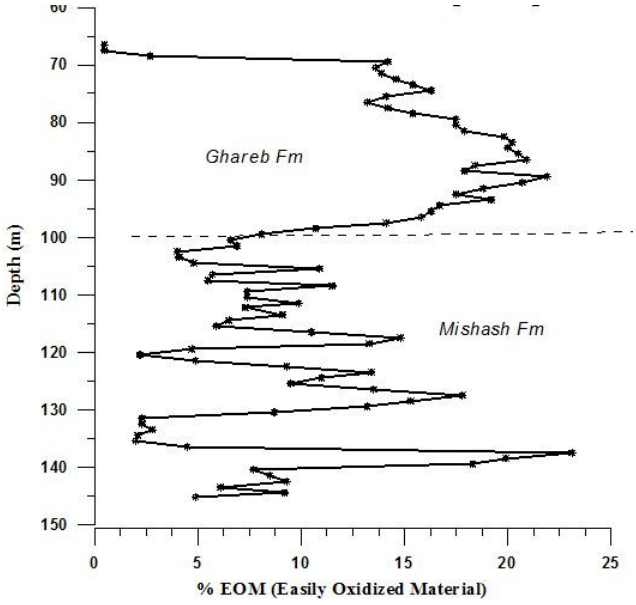

Figure 15. Organic matter content in the OM-15 borehole. The Oron North oil shale deposit.

6) Oron South (Fig. 16):

This oil shale occurrence is located along the eastern edge of the Makhtesh Gadol anticline, southwest of the Oron North oil shale deposit, to which it may be connected in the Giv'at Mador area. Its northeastern edge is adjacent to Giv'at Mador, and continues southwesterly to the Nahal Zin valley, thus covering the deeper structural portion of (what was previously named as) the Oron "7th" and "8th" phosphate fields.

In the defined area of the oil shale occurrence of Oron South, which is around 9 km^2, the available data is from some 10 boreholes drilled for oil shale finding and additional few prospecting boreholes for phosphates in which the oil shale sequence was recorded.

In the Giv'at Mador area the top of oil shale is near the surface, but in most of the area they are under overburden of 20-75 m. The sequence enriched in organic matter, Ghareb Fm, is 20-30 m thick; in some of the boreholes it possesses relatively high organic content (average - 16-20% EOM). In most of the boreholes a well-developed, organic matter enriched sequence, was penetrated in the Mishash Fm, below the phosphate beds; it is 10-20 m thick and the average organic matter values are relatively high as well - 13-15% EOM.

The oil shale reserves in the Oron South occurrence are estimated to be around 675 million tons, of which some 60% are in the Ghareb Fm sequence and about 40% are in the organic material rich Mishash Fm, which probably covers slightly greater area than the oil shale body of the Ghareb Fm.

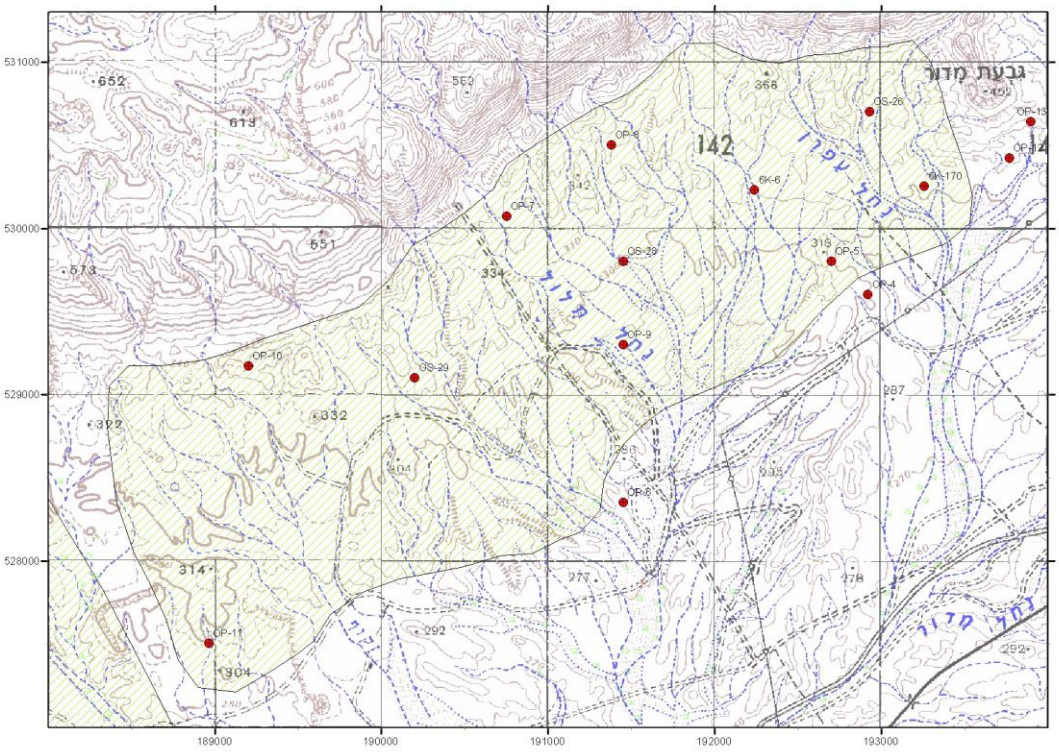

Figure 16. Approximate boundaries, the oil shale occurrence of Oron South.

7) Nahal Zin (Fig. 17, 18):

Along the Zin syncline, within a strip of more than 20 km long (which is extending from Nahal Hava in the southwest to Nahal Akrabbim in the northeast), many sections which contain oil shale rocks were penetrated, mostly during prospecting for phosphates; in addition to this, the oil shale sequence has many exposures around (in the foot of) Har Zin (Hor-Ha'Har). Based on data from about 120 boreholes, 6-7 separate oil shale occurrences can be defined, each ranging in area from ~0.5 km^2 to several square km. These occurrences are (from southwest to northeast, Fig. 17): Hagor (~1 km^2), Saraf, Hor-Ha'Har West (area of several km^2), Hor-Ha'Har, York'eam-South, York'eam-North and Akrabbim.

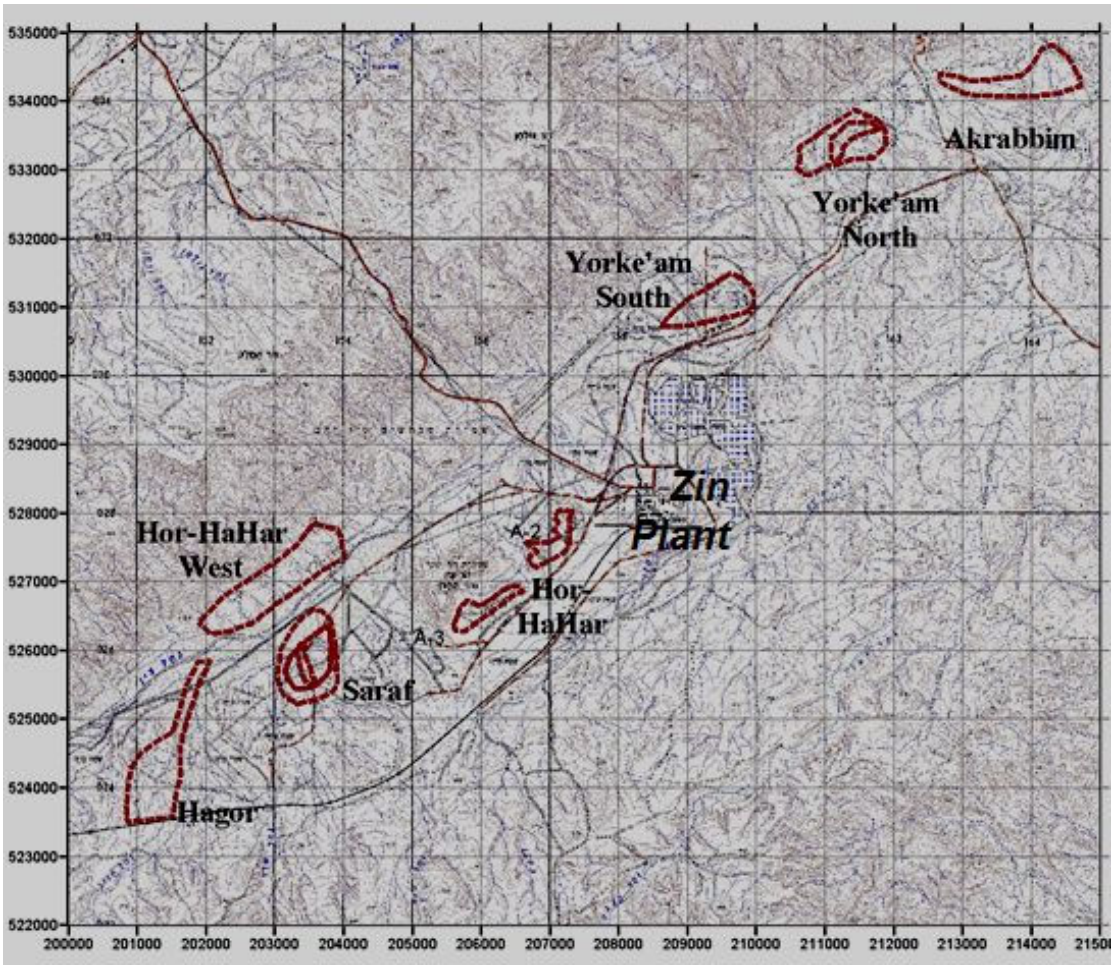

Figure 17. Oil shale occurrences along the Nahal Zin syncline.

The oil shale sequence of the Ghareb Fm is usually quite thin (6-9 m), apart from Hor-Ha'Har West field, where the oil shale sequence (>10% EOM) is 10-30 m thick. In most of the Nahal Zin oil shale occurrences the relatively thin oil shale section has an average organic matter values of 16-17% EOM; in the York'eam-North field the average EOM value is even higher - >22% EOM.

In the Mishash Fm, below the sequence of the Ghareb Fm, the phosphate beds and some other inter-bedded horizons are also enriched in organic material, having a wider lateral coverage than the bituminous Ghareb Fm. Lower beds in the Mishash Fm (known locally - the "chalky unit"), that are characterized by carbonaceous and siliceous composition, have an average thickness of almost 20 m with an average organic matter values of about 11% EOM. A vertical log of the organic matter content in a borehole which penetrated the whole sequence of the Mishash Fm is shown in Fig. 18.

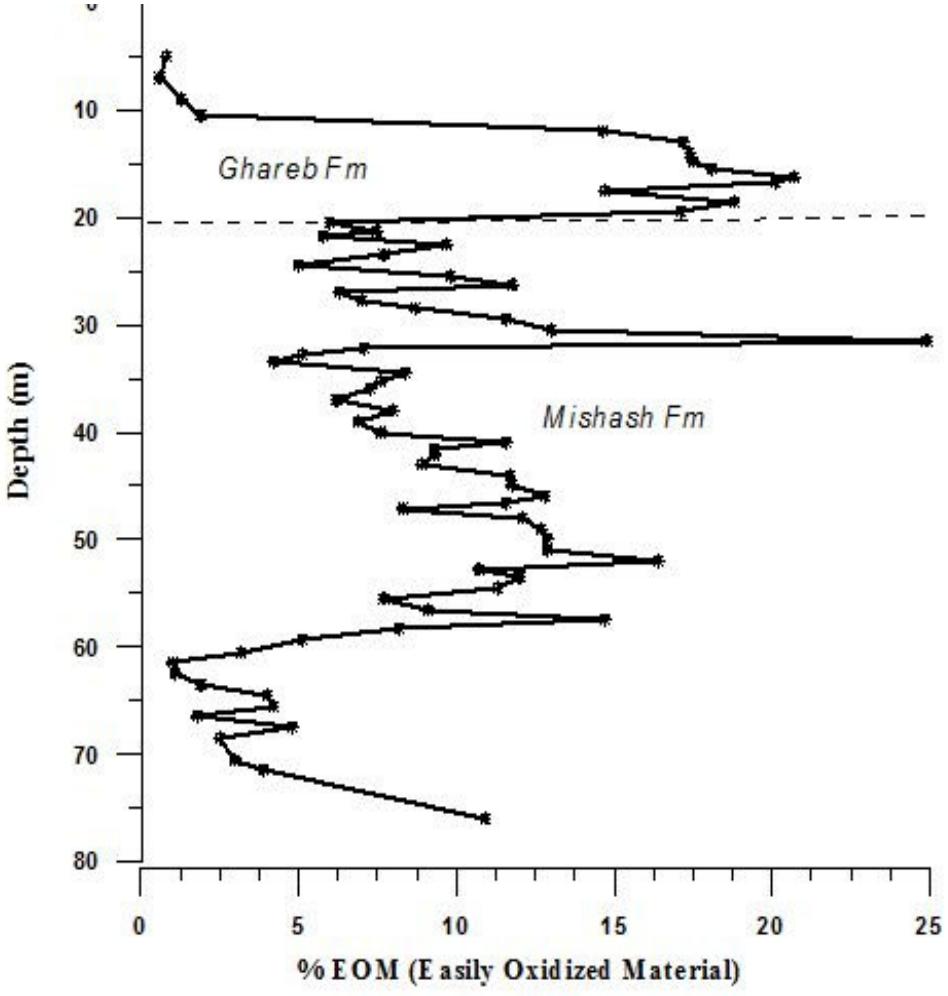

Figure 18. Vertical log of the organic matter content, the ZS-28 borehole (Saraf field, Nahal Zin).

The combined area of the oil shale fields in the Nahal Zin area was estimated to be 4-6 km^2 for the Ghareb Fm, and 9-13 km^2 for the "chalky unit", in the Mishash Fm (below the phosphate unit). The total oil shale reserves were estimated to be around billion tons, of which 25% belong to the Ghareb Fm; about 25% are confined to layers within the phosphate beds; and some 50% are attributed to the Mishash Fm "chalky unit". A different estimation, that did not include the Hor

Ha'Har West, York'eam-South and the Akrabbim fields, gave a much smaller figure of 50 million tons for the oil shale of the Ghareb Fm and the phosphate interlayers of the Mishash Fm.

It should be emphasized that although various Nahal Zin oil shale occurrences are quite close to each other, there are differences in some properties, such as the organic matter content, between the same beds in neighboring occurrences.

Nahal Zin area is a major mining and processing center of RAN.

8) Nahash-Zameh (Fig. 19):

The phosphate field of Nahash-Zameh is located in the eastern part of Biq'at Zin, about 15 km southwest of the Oron plant, between the valleys of Nahal Zin and Nahal Zinnim. Part of it is now within the Zinnim cliff natural reserve. In parts of this phosphate field, an organic-rich sequence of the Ghareb Fm, up to 30 m thick, was penetrated while prospecting for phosphates. Below most of that Ghareb Fm oil shale body (and in some areas where there are no indications to existence of bituminous Ghareb sequence), an organic matter enriched sequences of 5-20 m thick (in the Mishash Fm, below the phosphate beds) were penetrated; the data in hand indicate that the average organic matter content of this sequence is between 11-14% EOM.

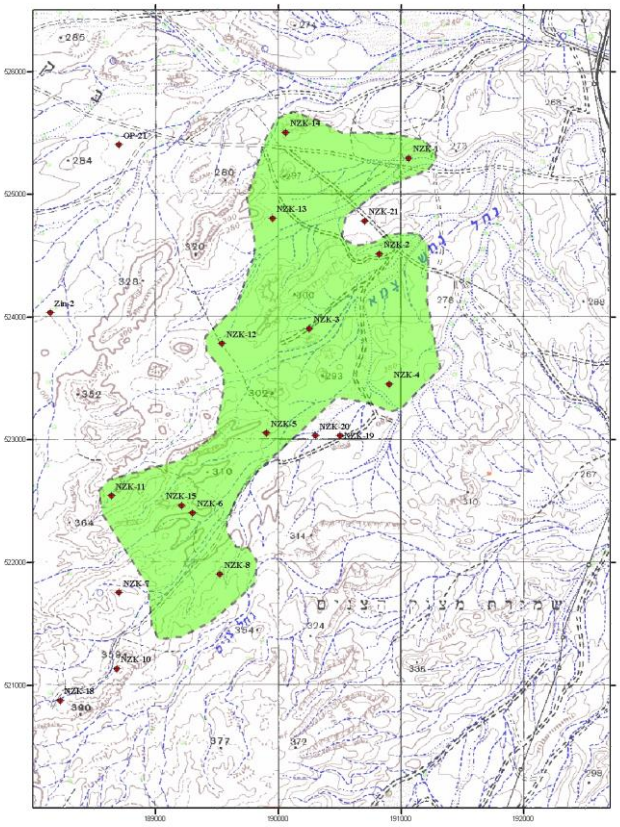

Figure 19. Approximate boundaries of oil shale occurrences of Nahash Zameh.

The consecutive area of the oil shale bodies (of both Ghareb and Mishash formations) in the Nahash-Zameh field is around 6 km^2 and an estimated, preliminary, reserve figure is about 200 million tons of oil shale.

9) Biq'at Zin (Fig. 20, 21):

This is a relatively large oil shale field located in a wide synclinal structure to the east of Sde Boker plateau and west of the Nahash Zameh and Oron South oil shale fields. Significant parts of it are now within the Zinnim Cliff natural reserve. General map of this field is presented in Fig. 20.

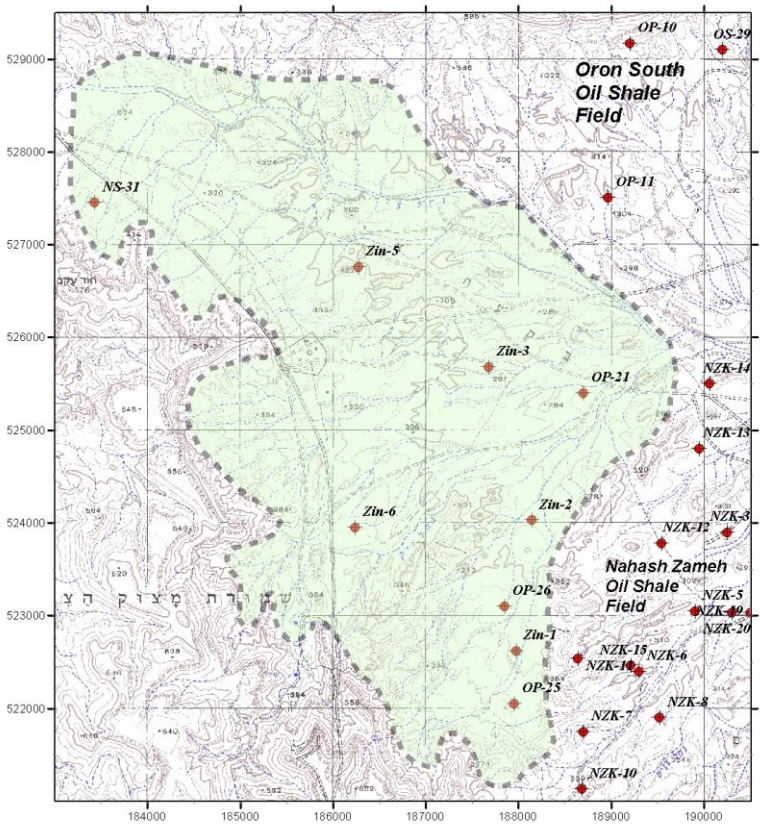

Figure 20. Location and approximate boundaries of the oil shale occurrence of Biq'at Zin.

In this area the sections of the Mount Scopus Group are well developed, and in great part of the succession are probably enriched in the organic material content. In the eastern edge of the field the overburden above the oil shale sequence of the Ghareb Fm is 20-40 m, but in most of the area it is considerably thicker - 100-120 m and in some places probably even more; the overburden includes sequence of the Paleocene Taqiye Fm. Reliable information on this field needs relatively deep boreholes, but in fact few were carried out and thus the available data is limited, especially when location of some boreholes is controversial. The oil shale sequence of the Ghareb Fm is probably 40-80 m thick, and there are indications that below this sequence there is an organic-rich

sequence several tens of meters thick in the Mishash Fm, below the phosphate beds. It is also indicated that in parts of this oil shale field, a portion of the chalky Menuha Fm, underlying the Mishash Fm, is also enriched in organic material. A vertical log demonstrating the organic matter content in two boreholes (in the Biq'at Zin oil shale occurrence) is shown in Fig. 21.

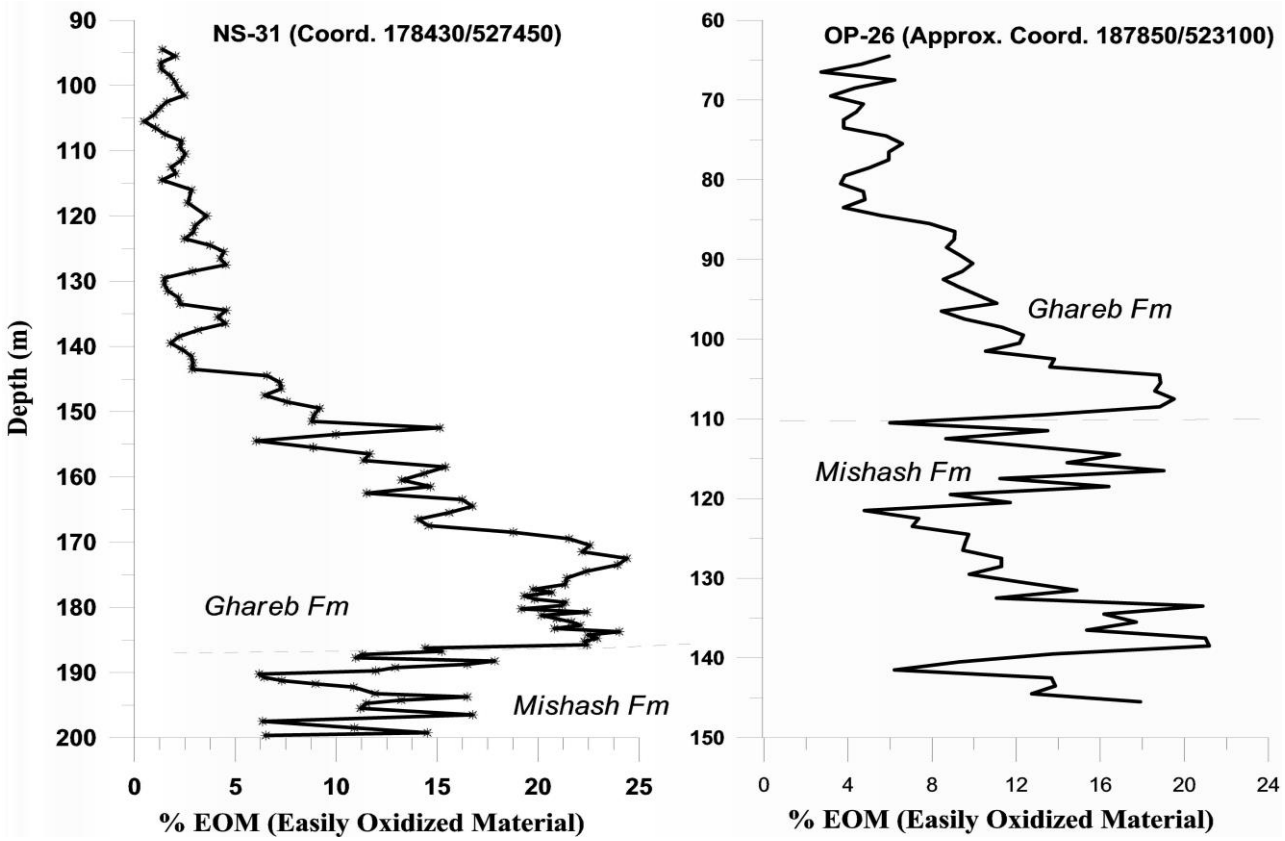

Figure 21. Vertical distribution of the organic matter content in two boreholes drilled in Biq'at Zin.

It is indicated that the area of the Biq'at Zin oil shale field is approximately 30 km^2; based on the modest assumption that the average thickness of the oil shale sequence (Ghareb and Mishash formations, combined) is 50 m, a preliminary estimate of the reserves in both formations is 2.7 billion tons.

It is likely that the Biq'at Zin oil shale field is extending to the west and northeast and thus it is connected with the defined oil shale fields of Sde-Boker – Avedat and Oron South, respectively. It is highly probable that the Biq'at Zin oil shale occurrence continues, in the subsurface, to the west and southwest directions, under the Avedat plateau, under thicker overburden. If this is the case, the actual reserves of oil shale in this deposit may be significantly higher than the preliminary figure given above.

10) Sde-Boker - Avedat (Fig. 22, 23):

South of Midreshet Sde-Boker locality, in the wide incised valleys of Nahal Zin and Nahal Havarim, well developed oil shale sequences were penetrated in 4 boreholes that are located along an east-west strip some 5 km long. They are probably representing an oil shale field that is extended to the west and south of their locations (Fig. 22). The roof of the oil shale section, Ghareb Fm, was penetrated at depths of 50-150 m, and they were found to be 20-80 m thick. This sequence is especially thicker in the eastern part of the area, south and southeast of Midreshet Sde-Boker and close to it.

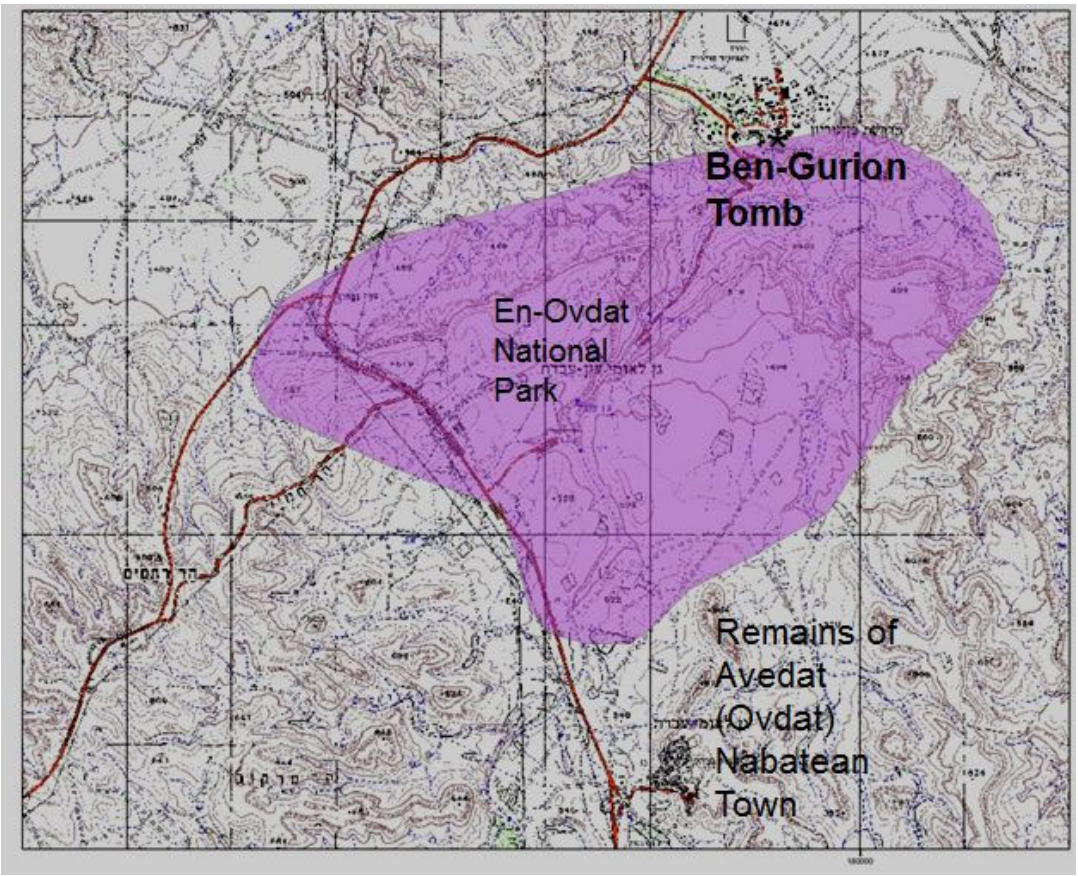

Figure 22. Location and approximate boundaries of the oil shale field of Sde-Boker - Avedat.

The oil shale sequence of the Ghareb Fm is relatively rich in organic matter content; in one of the boreholes, some 30 m of this sequence possess an average EOM value of 19.2%. In the 3 eastern boreholes an organic matter enriched sequence was penetrated in the Mishash Fm as well, and it is indicated that this phenomenon 'continues' downwards, in the Menuha Fm, until about 90 m below the Mishash – Ghareb contact (as was found in the oil borehole of Ben-Gurion 1). Logs of two of the above mentioned boreholes are presented in Fig. 23.

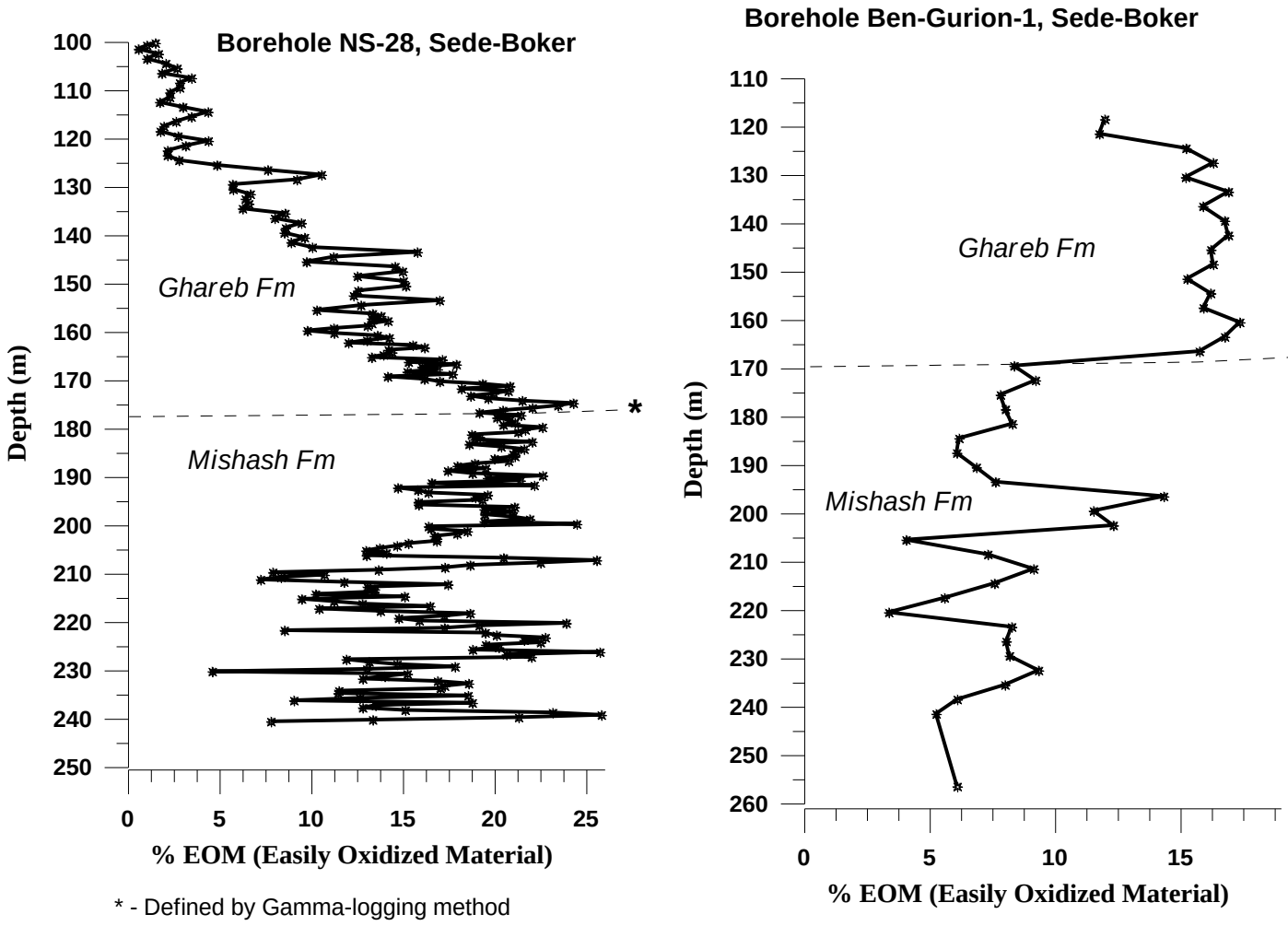

Figure 23. Vertical logs of the organic matter content in two boreholes, Sde-Boker – Avedat oil shale occurrence.

Based on the data from those 4 boreholes, the area of this Sde-Boker - Avedat oil shale deposit is more than 20 km^2 and a preliminary estimate of the oil shale reserves, in both Ghareb and Mishash formations, is about 1.8 billion tons.

About 6 km to the south of the described borehole area, on the Avedat plateau, is a site where the oil prospecting borehole of Avedat-1 (coord. 177650/520940) was carried out, in which an organic matter enriched sequence (Ghareb & Mishash formations) was penetrated at the interval of 370-490 m. It is geologically plausible that this succession is a continuation of the Sde-Boker occurrence, in a somewhat lower (deeper) structural position. If this is the case, the area of the field will be significantly larger and hence the reserve figure. It is also possible, as indicated above, that the Sde-Boker - Avedat oil shale field is connected with the Biq'at Zin field, in its eastern edge. It should be mentioned that parts of this oil shale occurrence are probably located below a national park (En Avedat) and a nature reserve (Zinnim Cliff).

11) Nevatim (Fig. 24, 25):

Southeast of Nevatim and west of Ar'ara in the Negev (=Aroer) locality, well developed oil shale sequences of the Ghareb and the Mishash formations were penetrated in two, relatively deep, research boreholes: an oil prospecting borehole [Nevatim-1 (coord. 192060/566170)] and the M-8 corehole (coord. 187480/563810). The proposed occurrence is located just about 10 km east-southeast of Be'er-Sheva (Fig. 24).

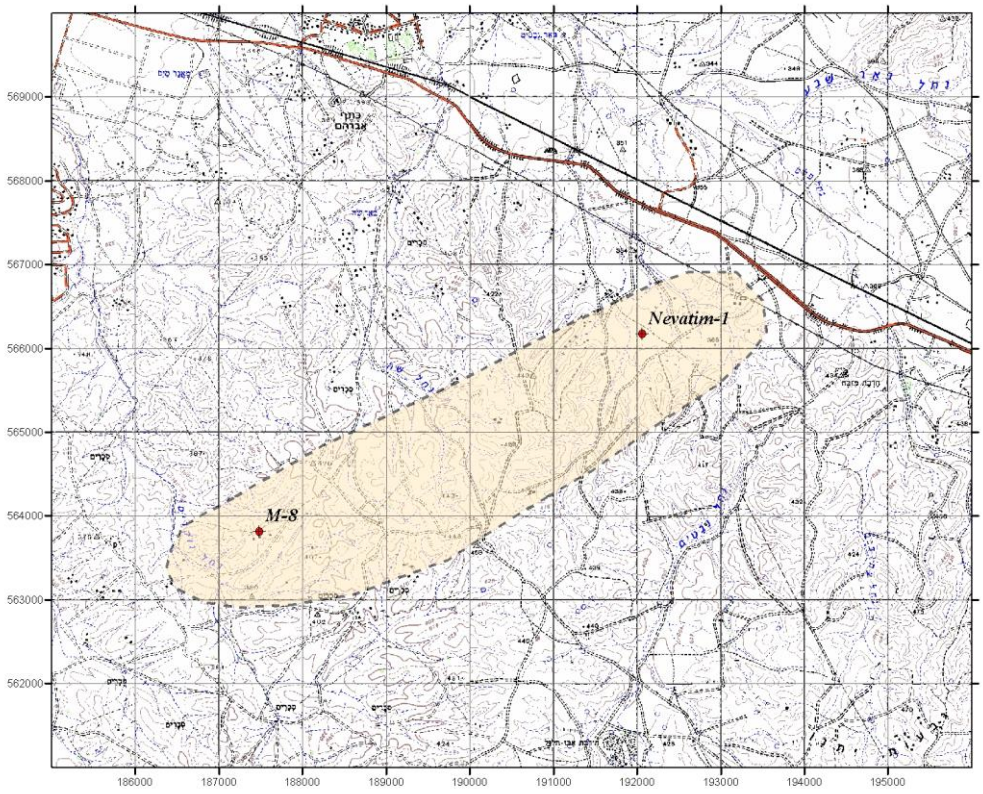

Figure 24. Location and approximate boundaries of the proposed oil shale occurrence of Nevatim.

In the Nevatim-1 borehole the organic matter enriched sequence is approximately between 140 to 200 m for the Ghareb Fm and there is an additional, organic matter enriched succession of about 40 m within the underlying Mishash Fm. In the M-8 borehole the corresponding depths are approximately 340 to 392 m for the Ghareb Fm and at least 35 m for the Mishash Fm (the bottom of the borehole is within this unit). The organic matter vertical distribution in these two boreholes is demonstrated in Fig. 25.

The synclinal structure in which those boreholes are located has N-NE – S-SW trend, along which additional oil shale occurrences are indicated (in the localities of Bir Mishash and Giv'ot Mari'it). The oil shale body deepens to the west, with the structure of this basin: in the M-8 borehole it is some 190 m deeper than in the Nevatim-1 borehole, which is about 5 km to the east-northeast.

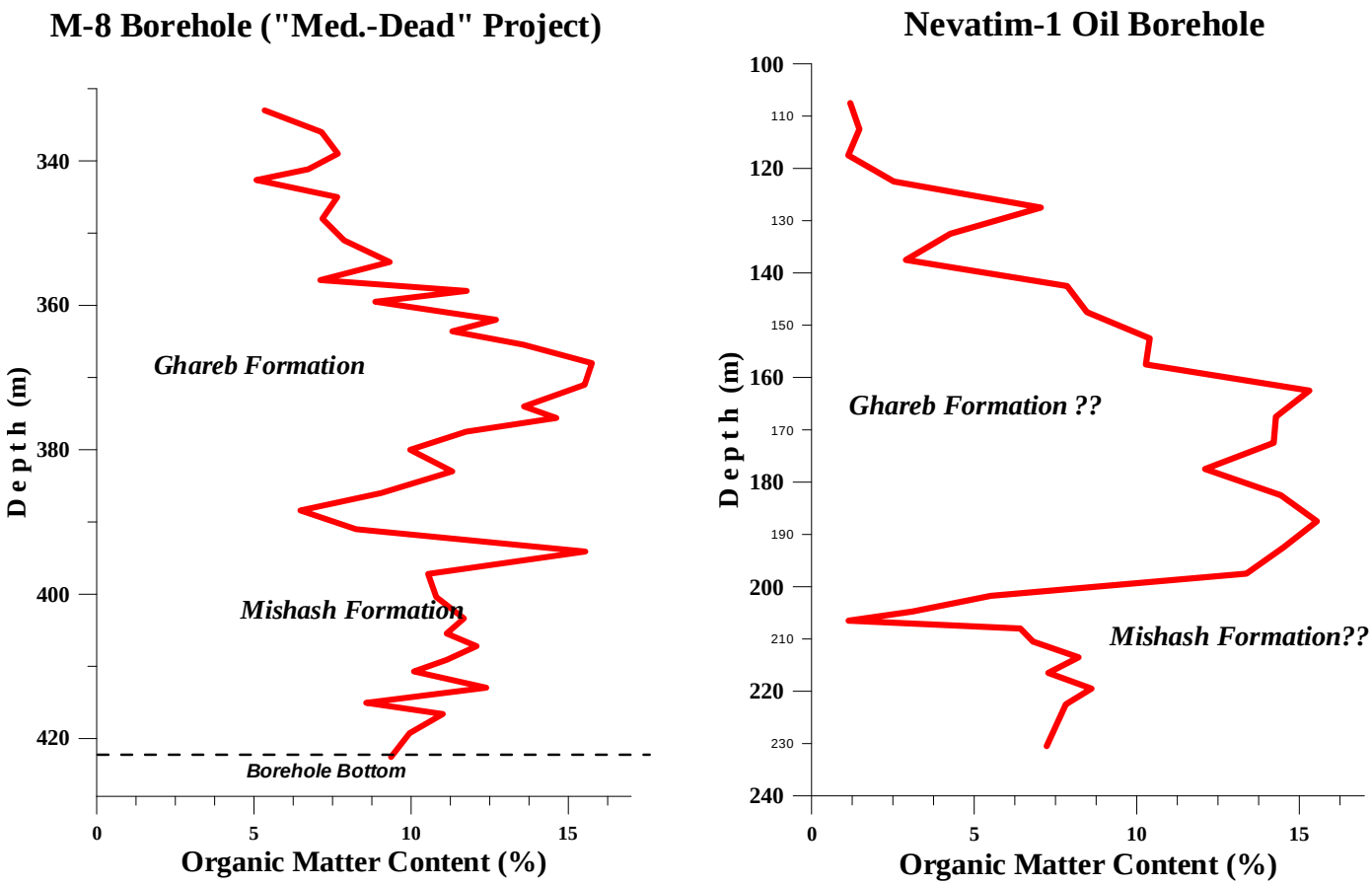

Figure 25. Vertical logs of the organic matter content in the two key boreholes located in the Nevatim oil shale occurrence.

The proposed oil shale occurrence may cover an area of about 12 km^2, and thus the reserves could be around 1 billion tons; it is possible that actual amounts are greater, depending on the real extension of the occurrence, yet to be defined.

12) Yeroham (Fig. 26):

This field is located in the Yeroham syncline, west and southwest of the town and very close to it. Four prospecting boreholes for oil shale were carried out in 1982. Oil shale sequences of the Ghareb and the Mishash formations were penetrated in three out of the four boreholes. In one of the boreholes a 50 m sequence of the Ghareb Fm was sampled having an average organic material of about 15% EOM. The thickness of the overburden is 90-130 m.

Based on the current information, an oil shale occurrence covering an area of about 5 km^2 can be defined. The indicated oil shale reserves are more than 350 million tons.

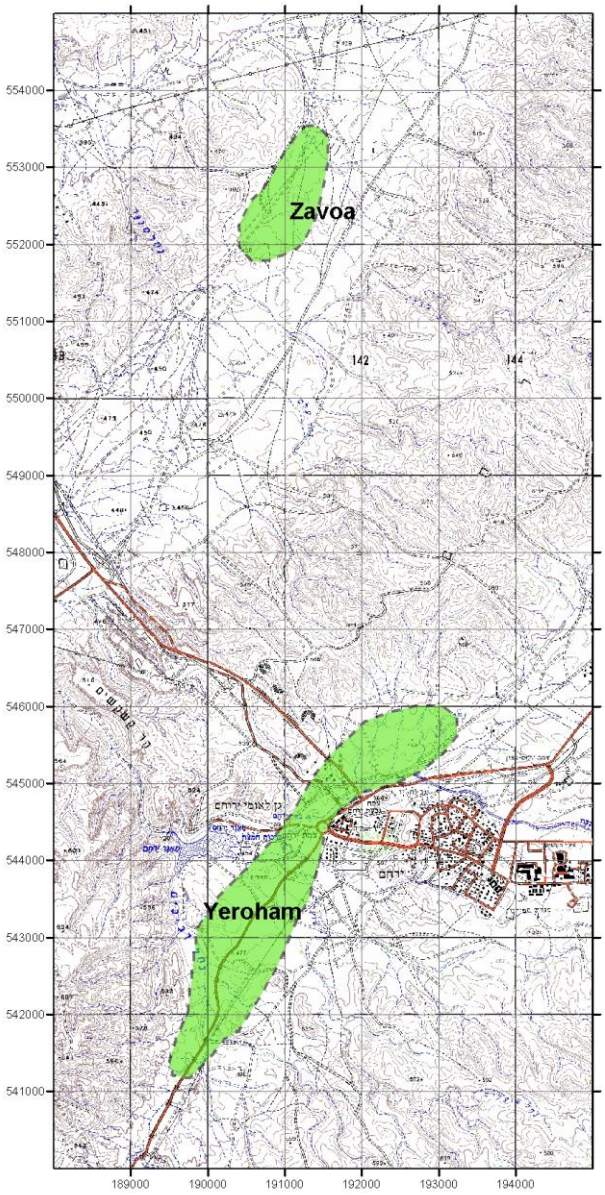

Figure 26. Location and approximate boundaries of the oil shale occurrences of Yeroham & Zavo'a.

13) Zavo'a (Fig. 26):

This relatively small occurrence is located in the Zavo'a syncline, between Har Zavo'a and Rekhes Yeroham. Six prospecting boreholes for oil shale were carried out in this area in 1982, 3 of which penetrated oil shale sequences of the Ghareb and Mishash formations. In two of the boreholes the overburden was found to be about 65 m and a sequence some 15 m was sampled having an average organic material of about 13% EOM.

Based on the available data, a small oil shale occurrence covering area of 1-2 km^2 can be defined. Preliminary reserve estimation is about 50 million tons.

14) Shivta (Fig. 27):

Oil shale sequences, probably associated with both Ghareb and Mishash formations, were penetrated in 3 boreholes carried out in 1982, under overburden of 55-70 m. The prospecting activity was targeted in a wide valley, whose area is about 15 km^2, situated within a bigger synclinal structure about 7 km to the south-southwest from the ruins of Nabataean Shivta (Fig. 27).

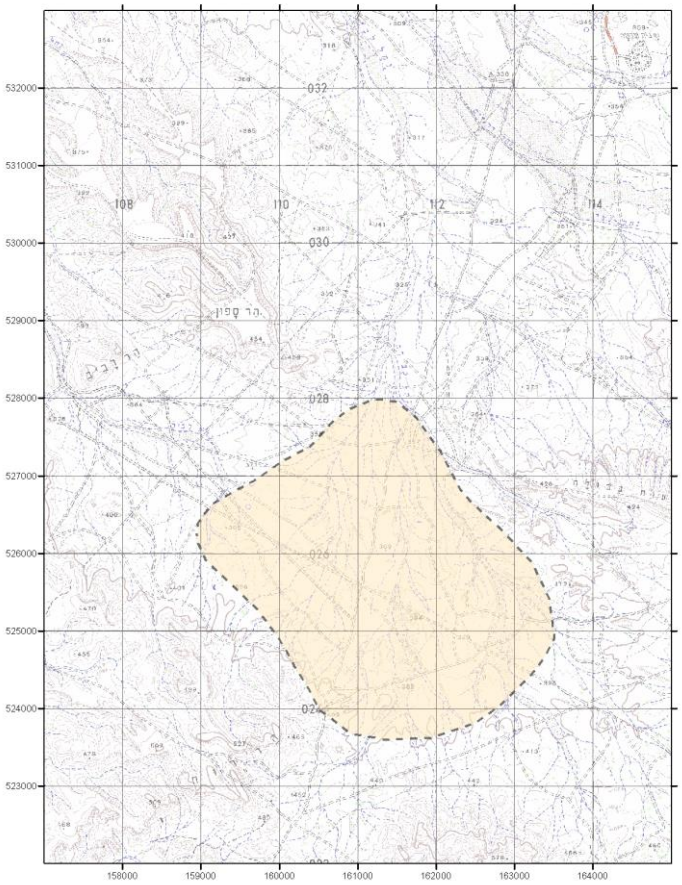

Figure 27. Location and approximate boundaries of the proposed oil shale occurrence of Shivta.

The bottom of this valley is located on altitudes of ~350-400 m, bordered by Giv'ot Kevuda (east), Har Rut (south), Ramat Rut in (south & southwest), and Har Raviv & Har Safun (north).

The drainage from this valley is to the north, through Nahal Raviv & Nahal Kevuda.

The penetrated oil shale sequence is 25-80 m thick. Higher organic matter values are indicated in the Ghareb Fm; relatively low organic matter values were found in the Mishash Fm. In one of the boreholes, a sequence of ~50 m thick was penetrated in which the average EOM content is almost 14%. Based on the existing data it is suggested that the area of oil shale occurrence is about 10 km^2, and if it is consecutive in the entire occurrence, the reserves may be about 750 million tons.

15) Mash'abim (Fig. 28):

Rock successions belonging to the Mount Scopus Group that are enriched in organic material, were penetrated in more than 15 boreholes (most of them carried out for finding of water), in the northwestern Negev. These localities include areas around the Negev junction, Mash'abim junction, Ashalim & Revivim villages, Ze'elim bases and also further to the southwest, around Nizzana.

It was revealed, in some of these water boreholes (i.e., Ze'elim, Retamim & Revivim villages, Mash'abim junction, Ashalim and Nizzana), that the thickness of oil shale (of both Ghareb and Mishash formations) penetrated is 150-250 m. The thickness of the overburden above the oil shale successions varies: from 30 to 80 m (in Mash'abei-Sadeh – Ashalim, Ze'elim, Negev junction areas) to 250-350 m deep (in Revivim and Nizzana areas).

With the preliminary data in hand (actually, rather old water borehole reports) in hand, it is likely to suppose that in places, parts of the Taqiye Fm sequence are also enriched with organic matter.

Borehole data indicate that oil shale occurrences cover relatively wide (subsurface) parts of the shallow valleys in this vicinity, that are mainly parts of synclinal structures; it is also reasonable that in some / parts of the structures the oil shale body/ies are extending to below Eocene sequences. As stated the information is preliminary, in aspects like the extension of the oil shale and its quality. In a borehole (NS-18) conducted near the Negev junction an organic matter average value of >15% was revealed in a succession ~15 m thick. At this stage there is no additional known information about oil shale quality in this entire area.

Based on the above summarized preliminary data, it is suggested to define at the current stage of knowledge, a consecutive oil shale occurrence that has the shape of a rainbow upon which some 10 consecutive neighboring boreholes penetrated oil shale succession, with no "negative" points in-between. The inferred occurrence covers an area of about 75 km^2, starting (in the northwest) north of Retamim, south to Revivim & Mash'abim junction, than to southwest, till a point west of Ashalim (Fig. 28).

Taking into account an average organic-matter-enriched sequence of 100 m thick (Ghareb & Mishash formation combined; existing data indicate that thicker sections do exist in some of the boreholes), a preliminary reserve estimation would probably be well above 10 billion tons of raw oil shale.

As indicated above, the overburden is rather thin at the vicinities of Mash'abim junction and Ashalim village, and comes to be considerably thicker in the Revivim & Retamim neighborhoods (to the north).

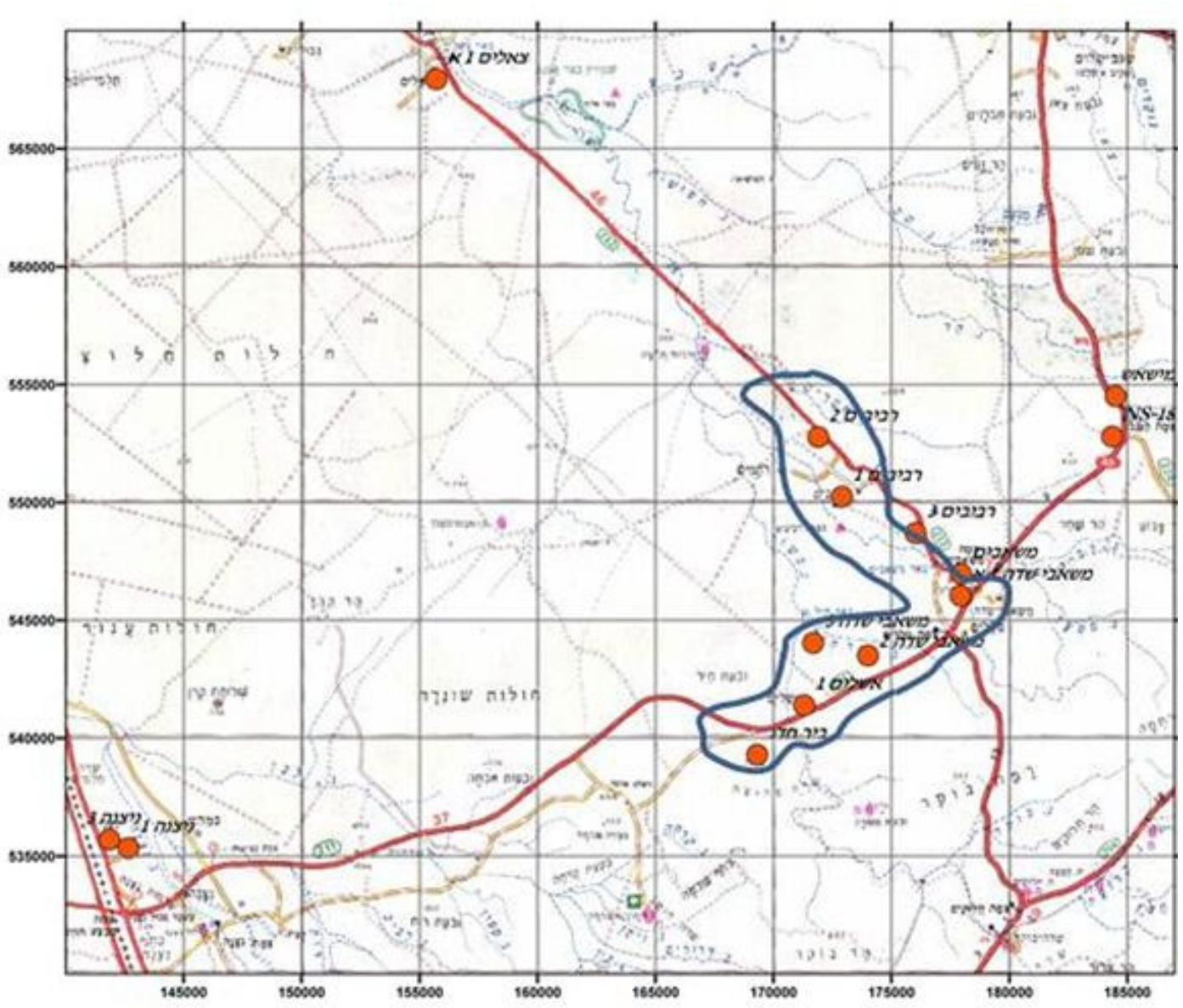

Figure 28. Location and approximate boundaries of the proposed oil shale field of Mash'abim. Boreholes that penetrated oil shale succession are shown in red. Grid dimension is 5X5 km.

From geological point of view, it is plausible that the oil shale occurrence is in fact greater, but to prove it a research boreholes in and around this occurrence are essential. There is also a need to provide reliable data on the organic matter content / oil yield of this sequence, from almost none knowledge at the present state.

The Arava Oil Shale Occurrences:

In the western margins of the Arava Rift Valley, many subsurface occurrences of organic matter enriched sequence within the Mount Scopus Group were penetrated, structurally influenced by Eastern Negev geological features. In most of those occurrences the oil shale beds are associated with phosphate strata. Some of those shows can be accumulated into consecutive fields and thus inferred boundaries were preliminarily drawn. In other areas (e.g., En-Ofarim, En-Tamid, Nekarot) the existing data from the subsurface seems to be limited as to define fields at this stage. The following oil shale occurrences in the area are presented herein:

16) Gidron (Fig. 29):

This oil shale occurrence is located some 6-7 km to the west and southwest of the Hazeva (Gidron) Field Center, between Nahal Gidron and Nahal Shahak, within the Makhteshim – En Yahav Natural Reserve (fig. 29).

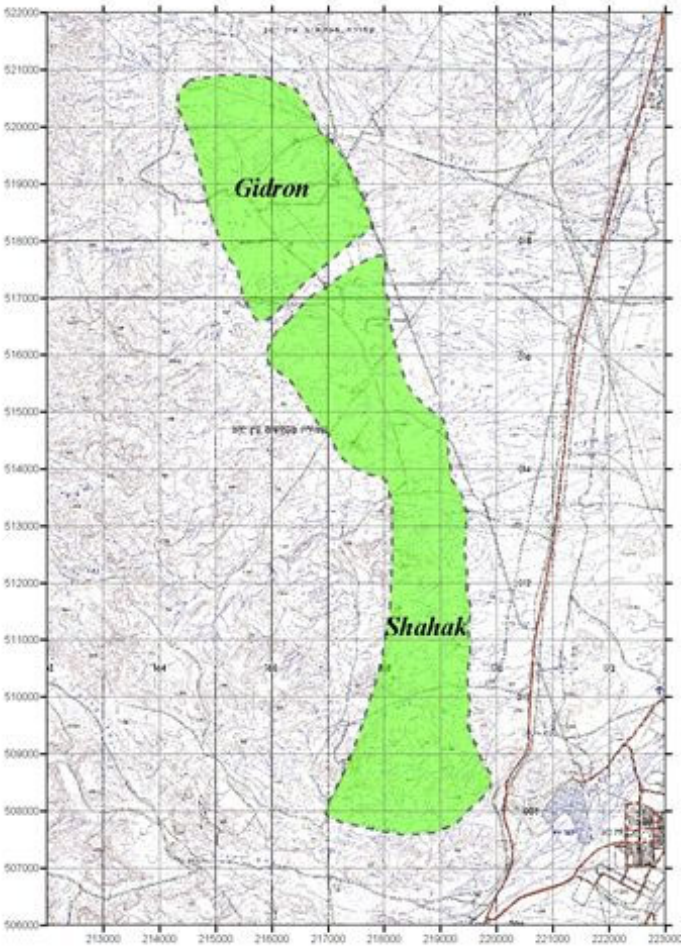

Figure 29. Location and approximate boundaries, the oil shale fields of Gidron & Shahak.

The organic matter enriched sequence of the Ghareb Fm is 5-18 m thick whereas the overburden is about 20-35 m thick. The oil shale succession thickness may be growing larger to the east of the defined area, under thicker overburden.

The area that was defined for this oil shale field is some 6 km^2, and preliminary reserves estimations are about 100 million tons. Few analyses indicate that the organic matter content in this field are relatively low (~10%). Additional reserves may be located to the east, in deeper structures, and possibly having higher grades.

17) Shahak (Fig. 29):

This oil shale occurrence forms a strip some 9 km long and 1.5-2.5 wide, located between Nahal ShahaK in the north and Nahal Nemiah in the south, east of Kippat Sheizaf; In its northern part it is 5-7 km to the east of the Arava highway, but in the south, opposite En Yahav, it is very adjascent to that main road. It may be a southern extension of the Gidron oil shale occurrence. Based on data from 18 boreholes, the organic matter enriched sequence of the Ghareb Fm is 10-25 m thick and the overburden thickness is 20-70 m. The area of this field is around 15 km^2, and preliminary reserves estimate is about 400 million tons. Additional possible reserves may reside to the east of the defined area, in deeper structurally settings.

18) Shilhav - Omer (Fig. 30):

This oil shale occurrence forms a narrow strip (of some 13 km long and about 0.5-1.5 wide), located in the Omer syncline, between the Omer anticline (west) and the Tsofar anticline (east); In the north it is about 2 km west of the Sapir industrial area and it extends to the south close to Nahal Tsofar, ~ 4 km southwest of the Bildad camp. Based on data from 8 boreholes, the organic matter enriched sequence of the Ghareb Formation is 20-65 m thick and the overburden thickness is 10-40 m. The area of this field is around 15 km^2, and a preliminary reserves estimate is about 550 million tons. Few analyses indicate that the organic matter content of this field may be higher than in the neighbouring oil shale occurrences.

19) Har Nishpe – Ha'Meshar (Fig. 31):

This field includes oil shale occurrences that are located to the west and southwest of the Shilhav - Omer occurrence and are extending westerly 10 km and more, as extended to Mitspe Ha'Meshar. Two fields were distinguished: 1) Har Nishpe - Nahal Re'im: south of Nahal Ashosh and Har Nishpe; 2) HaMeshar: which is bordered by Har HaMeshar and Mitspeh Ha'Meshar.

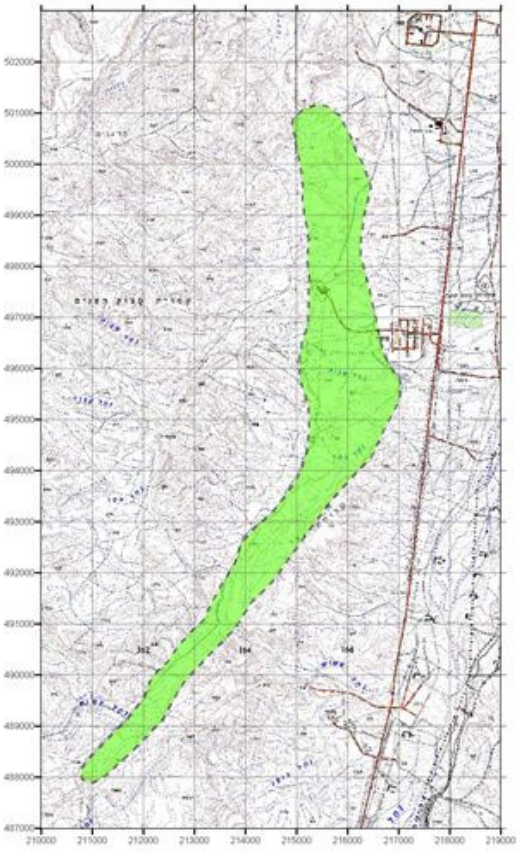

Figure 30. Location and approximate boundaries of the oil shale field of Shilhav - Omer.

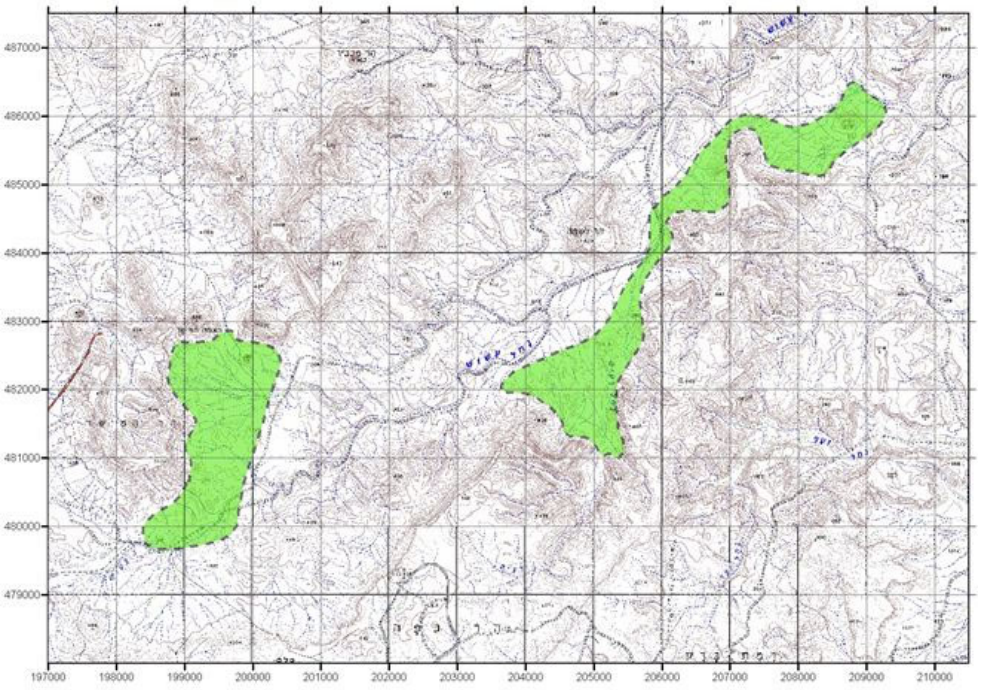

Figure 31. Location and approximate boundaries of the oil shale occurrences of Har Nishpe & Ha'Meshar.

Based on data from 7 boreholes, most of which were drilled for the purpose of oil shale prospecting, the organic matter enriched sequence of the Ghareb Fm is 20-55 m thick (~12-14% EOM, on average) and the overburden thickness is 5-65 m. The area of thess field is at least 8 km^2, and a preliminary reserves estimate is about 300 million tons. It is highly probable that these fields are extending to the south and west directions, below Ramat Baraq and Har Ha'Meshar (below overburden of 100-150 m). If this is true, the area of these oil shale occurrences, the reserves (and the grades as well) are expected to be significantly higher.

20) Paran (Zihor) (Fig. 32):

In the central part of the Arava, at the vicinity of lower Nahal Paran basin - Zihor Junction, several sections enriched in organic material (Mount Scopus Group sequence) were penetrated in some water boreholes. The oil shale thickness is up to 80 m. Based of those data points, and supported by later data of Rotem Amfert Ltd prospection, a consecutive oil shale occurrence of 4-5 km^2 is indicated in proximity to the Zihor Junction in which the reserves estimate is some 150 million tons with moderate EOM values. It is posible that this field is extended to the south , and the reseves figure may be higher, accordingly.

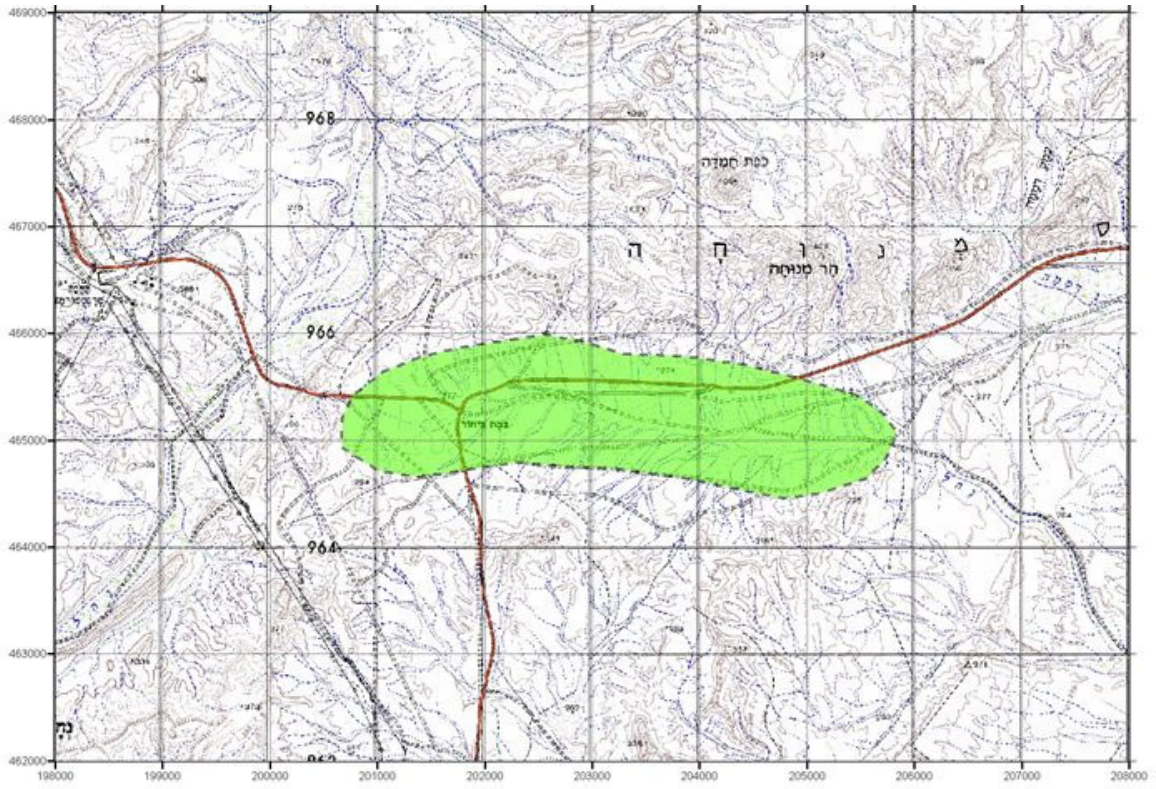

Figure 32. Location and approximate boundaries of the oil shale field of Paran (Zihor).

A relatively thick (above 150 m) and rich (in organic material) sequence was penetrated in the Paran-20 water borehole (drilled in the Nahal Barak valley, coord. 213176/480575, about 1.5 km to the west of the Arava highway). It is located some 8 km east of the Har Nishpe oil shale field and may represent a significant synclinal body. However, as it is a sole point of data in its area, at the present no oil shale body (and field) could be defined around it,.

21) Zenifim (Nahal Hiyyon) (Fig. 33):

This large oil shale occurrence is supposed to cover an area of about 300 km^2 in the Hiyyon syncline, to the west of the Mitzpe-Ramon - Eilat highway, some 90 km to the north of Eilat. It is located between the Zenifim monocline to the west and the Mishor Hiyyon to the east, between Giv'ot Tsehiha to the north and Tsukei Uvda to its south.

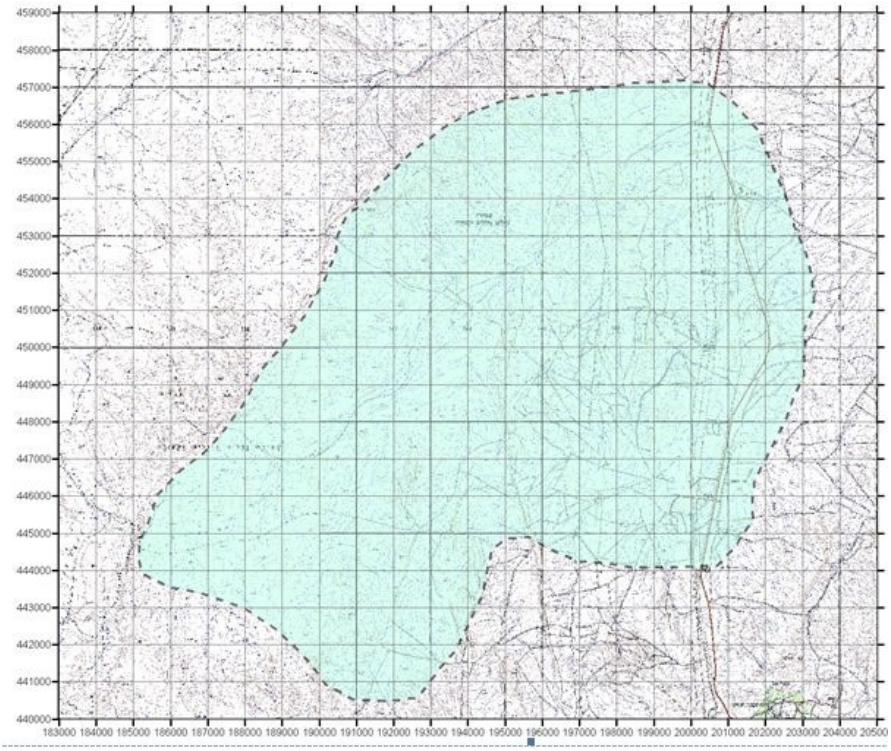

Figure 33. Location and approximate boundaries of the oil shale occurrence of Nahal Hiyyon (Zenifim).

The Ghareb Fm sequence is well developed, especially in the west part of the area, having thicknesses of 110 m and more. At that area the lower part of this formation (20-60 m) is bituminous, but with relatively low values of organic matter (approximate average value of 8% EOM). Based on the results that came from the prospecting boreholes, the inferred reserves estimate is about 2,000 million tons, but as the data for such a large area is relatively limited, it is possible that the quantity of the reserves of this deposit is even higher.

The Foothills - Coastal Plain Oil Shale Occurrences:

Rock sequences enriched in organic material, that belong to the Mount Scopus Group, were penetrated in numerous (>100) water boreholes which are located in the eastern edges of the central and the northern coastal plain of Israel (Mishor HaHof) and in the western foothills of the Judea and Samaria Mountains, from the North-western Negev in the south, through the Sharon Plain and to the north in the western Galilee foothills. Although the existing data about the extension and the grades of these occurrences is limited and in some areas is actually very much a preliminary one, it indicates about the plausible existence of at least three**,** relatively shalow, large oil shale occurrences that might be proven to be very significant oil shale deposits. Great portion of those occurrences is located below man-made infrastructures that include rural – agricultural areas, build-up localities and various other land uses..

22) Ha'Shefela (Fig. 34-36; Table 3):

This is most probably the largest oil shale occurrence that is known to exist in Israel. Based on the available data (from some 53 boreholes, most of them drilled for water, table 3), it is estimated to cover an area of between 1,000 to 1,400 km^2 and possibly more. This occurrence is located in central Israel and has a shape of a N-S directed strip some 70 km long (from Mevo Modi'im in the north to Eshel HaNasi College in the south) and 5-20 km wide, close to and west of the Judea Mountains foothills (Fig. 34).

The organic matter enriched sequence of the Mount Scopus Group has a wide range of thicknesses on this occurrence area - from several tens of meters up to 550 m. The thickest sections were penetrated in the vicinities of Hartuv - Eshta'ol, Agur and Amazia. The thickness of the overburden varies as well; it ranges from several tens of meters up to 300 m and in limited areas possibly more. Localities where it is relatively thin (around 50 m and less) are Mevo Horon - Sha'ar HaGay, Hartuv - Eshta'ol, Kefar Uriyya, Gezer, Agur and Amazia. The data on the organic matter content is very limited, but there are indications (from boreholes in the Hartuv - Eshta'ol and the Sheqef areas) that relatively thick sequences (120-200 m) possess rich EOM values averaging 15-16%. This preliminary data is confirmed and enlarged by recent IEI prospecting activity.

The deposit extension is demonstrated in the attached map (Fig. 34), where areas in which oil shale sections that are above 150 m thick were incorporated. The calculated total area having such thickness and more is almost 1000 km^2, which means that the inferred volume of oil shale rocks in this occurrence is at least on a magnitude of 200,000 millions m^3; this means that the reserves

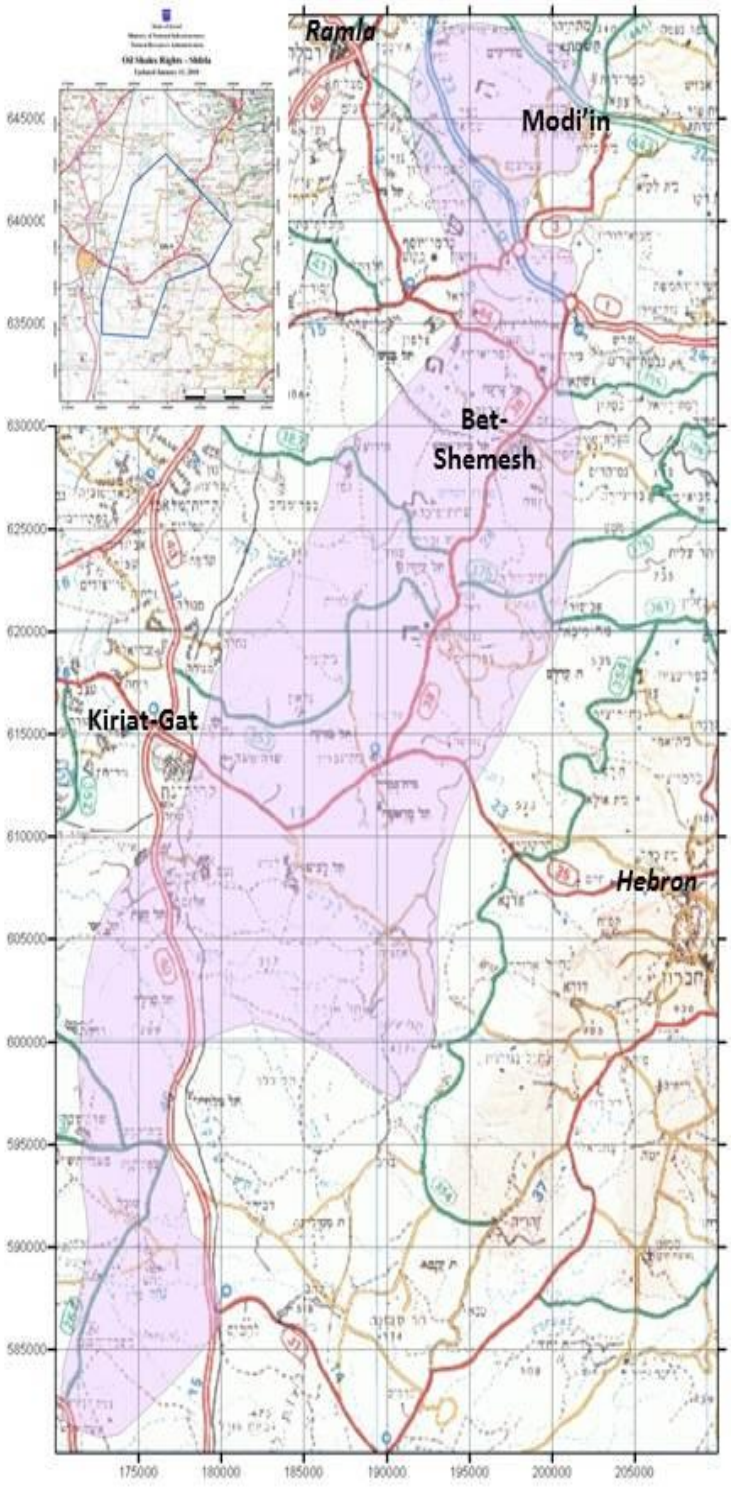

Figure 34. Location and approximate boundaries of the oil shale occurrence of Ha'Shefela. IEI\Genie's permit area is shown in the top left.

preliminary estimate are 300-350 billion tons and probably more than that. With the available data in hand it is also indicated that within the entire occurrence, a consecutive area of at least some 450 km^2 contain oil shale sequences having thicknesses of above 250 m.

Table 3: Data on boreholes that penetrated oil shale succession in the Ha'Shefela Basin

BOR_ID	X	Y	ASL (m)	Depth (m)	OS Thick (m)	OS (from)	OS (to)	BOR_Type *	Archive(GSI)
Gezer(S)	192220	642500	119	210	57	47	104	W	430
Modiin-1	203300	640900	220	543	88	110	198	W	
Qubeb	194990	641980	140	267	+207	60	267	W	1616
Nana(Y)	187630	641980	73	235	85	70	155	W	L2852
Nana-5	187640	643680	90	220	45	123	168	W	2661
Nana-6	187610	642890	84	310	57	102	159	W	2663
Nana	187128	641650	71	203	59	102	161	W	L1199
Hulda-2	187750	638190	90	223	69	82	151	W	2659
Kfar_Menahem-1	182200	627500	80	784	140	200	340	W	977
Um_Halhal	186380	635100	76	177	+89	87	176	W	L1514
Uzza	175530	606500	120	575	160	330	490	W	1455
Galon-3	185800	615250	175	404	+130	274	404	W	411
Galon-4	185530	615150	178	677	180	248	428	W	399
Komemiut	174300	617200	82	610	60	310	370	W	1593
Lakhish-SH1	173202	607326	102	582				O	
Lakhish-SH11	177290	608141	162	587				O	
Lakhish-SH16	175156	607294	136	567				O	
Nehusha-1A	187473	615464	207	966	265	347	612	W,O	4771
Zavdiel-SH15	174130	614740	105	446				O	
Zavdiel-SH16	174640	614150	104	428				O	
Agur-1	192200	625400	198	615	+78	219	297	W,O	1437
Agur-2	191980	625800	210	485	+345	140	485	W	1414
Agur-3	193800	623900	229	731	403	140	543	W	2727
Agur-4	198234	621389	276	782	509	15	524	W,O	3272
Agur-5	199097	620851	286	799	335	15	350	W	3965
Eshtaol-2	201350	631650	250	266	218	17	235	W	35
Eshtaol-2A	201350	631650	250	566	240	20	260	W	2585
Eshtaol-3	202340	635940	291	462	52	55	107	W	2830
Eshtaol-6	201591	635275	292	605	240	39	279	W	
Eshtaol-7	201307	630662	267	1226	323	30	353	W	4769
Hartuv-1	199700	630300	225	300	241	9	250	W	2706
Hartuv-1A	199100	629740	205	438	370	40	410	W,O	533
Hartuv-2	200120	629180	230	556	236	20	255	W,O	518
Hartuv-3	200963	629813	225	520	363	12	375	W	517
Hartuv-3A(1)	199700	630300	201	300	+291	9	300	W	2717
Hartuv-3B	199500	630100	220	328	+318	10	328	W	524
Hartuv-4	200160	628710	225	630	360	19	379	W	519
Hartuv-B	200650	629700	230	231	+202	26	228	B	
Horon-1	203300	637900	330	190	+140	52	190	W	
Kfar_Uriya-2	195370	633750	174	150	+120	30	150	W	995
Kfar_Uriya-3	196100	634200	170	331	80	40	120	W	1033
Kfar_Uriya-5	193250	635750	133	150	36	25	61	W	946
Kfar_Uriya-6	195304	634391	165	260	110	30	140	W	956
Kfar_Uriya-7	196730	630010	196	508	231	7	238	W	922
Kfar_Uriya-9A	197900	633600	200	452	192	20	212	W	870
Latrun	198440	637860	335	210	+175	35	210	W	
Modiin-2	204286	639791	248	1029	30	42	72	W	4960
Modiin-3	203070	637146	300	1127	117	36	153	W	4828
Modiin-4	203588	638651	244	1156	270	18	288	W	4569
Netiv_HaLH	198023	621679	274	761	284	205	489	W	1249
Zora-B	196750	629850	190	203	154	43	197	B	
Amazia	193686	604825	336	925	549	12	561	W	3937
Sheqef-1	193000	602500	365	1005	209	266	475	W	4770
Mishmar_HaNegev-1	171800	580800	190	555	180	200	380	W	1182
Mishmar_HaNegev-2	174200	584800	220	575	110	160	270	W	1180
Mishmar_HaNegev-3	171966	582964	193	563	215	270	485	W	2834
Ziklag-1	187727	592590	347	556	36	168	204	W	3974
Aderet-IEI	199263	617971	399	600	~295	255	550	B	
Gal'on-IEI	185400	615140	175	523	?120	?330	?450	B	
Nahal Guvrin-IEI	189008	614360	231	598	~190	330	520	B	
Zoharim-IEI	194510	613495	307	631	~160	340	500	B	
Lakhish-IEI	187527	607608	246	665	~240	370	610	B	

* **W** - Water borehole; **O** - Oil prospecting borehole; **B** - Oil Shale prospecting borehole.

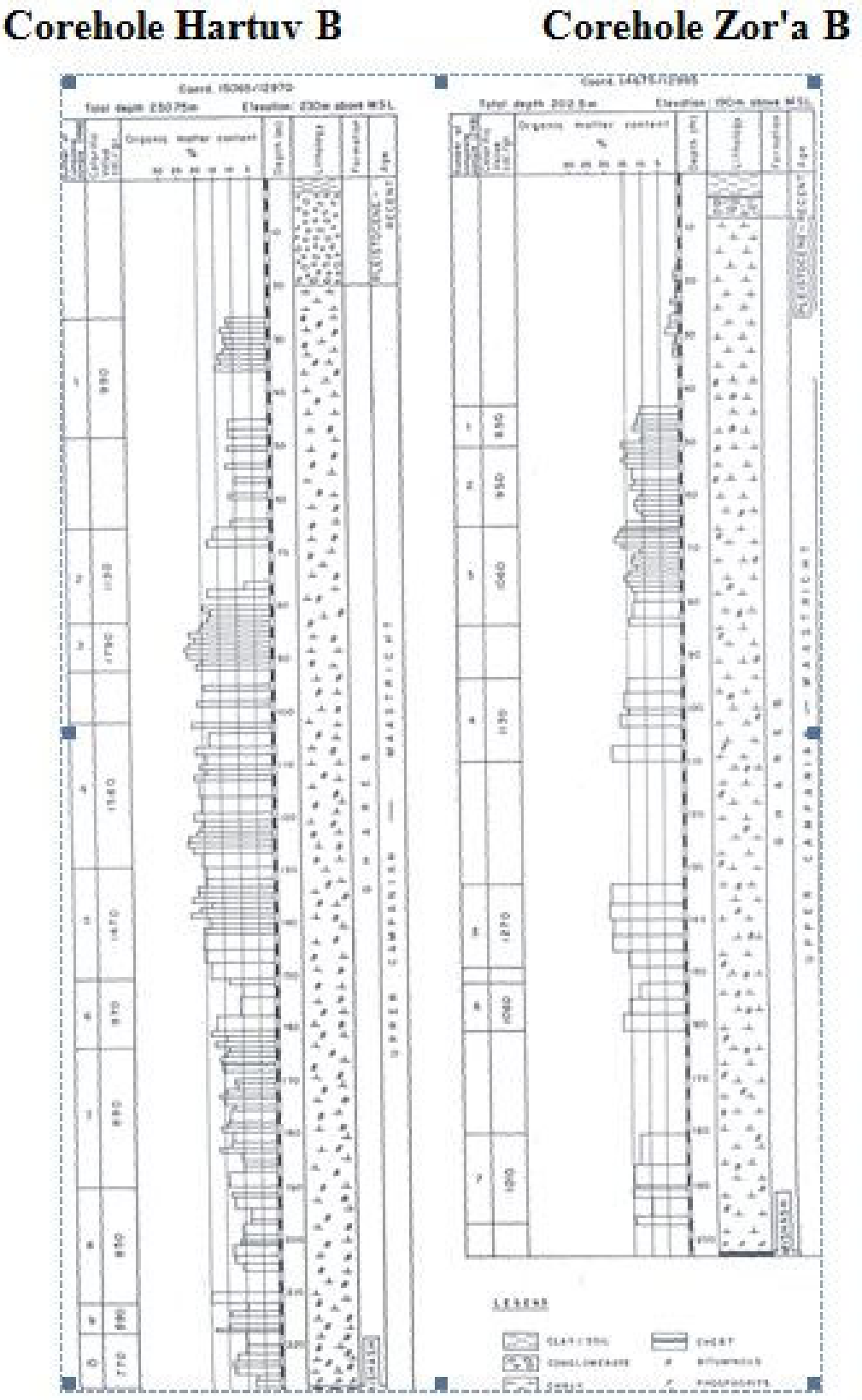

Figure 35. Lithology and organic matter content logs in two boreholes in Bet-Shemesh area, the oil shale deposit of Ha'Shefela (from Shirav & Ginzburg, 1980).

The data about this significant oil shale deposit is relatively limited, when its dimensions and analyses are considered. Additional important information was contributed by the IEI prospecting and research activity that started in 2008, and included drilling of 5 boreholes [located at the Zoharim, Bet-Guvrin, Aderet, Lachish & Gal'on sites (**http://iei-energy.com/downloads**)]. In these boreholes, carried out during the last 4 years, many analyses of different types were excuted. Several reports and articles have already published based on studies carried out by IEI. However, most of the obtained data is still not yet released. Thus, parameters of importance like the boundaries of the deposit, lateral changes, chemical compositions, grades and other properties needs to be further studied.

A lithological and organic material logs of 2 boreholes carried out in the Bet-Shemesh area in the early 1980's are presented in Figure 35. Some results from IEI's prospecting activity are demonstrated in Fig. 36.

Being aware of the great potential of the Ha'Shephela oil shale deposit, it is highly recommended to continue the research on other parts of the deposit and thus to have more reliable information on this significant resource.

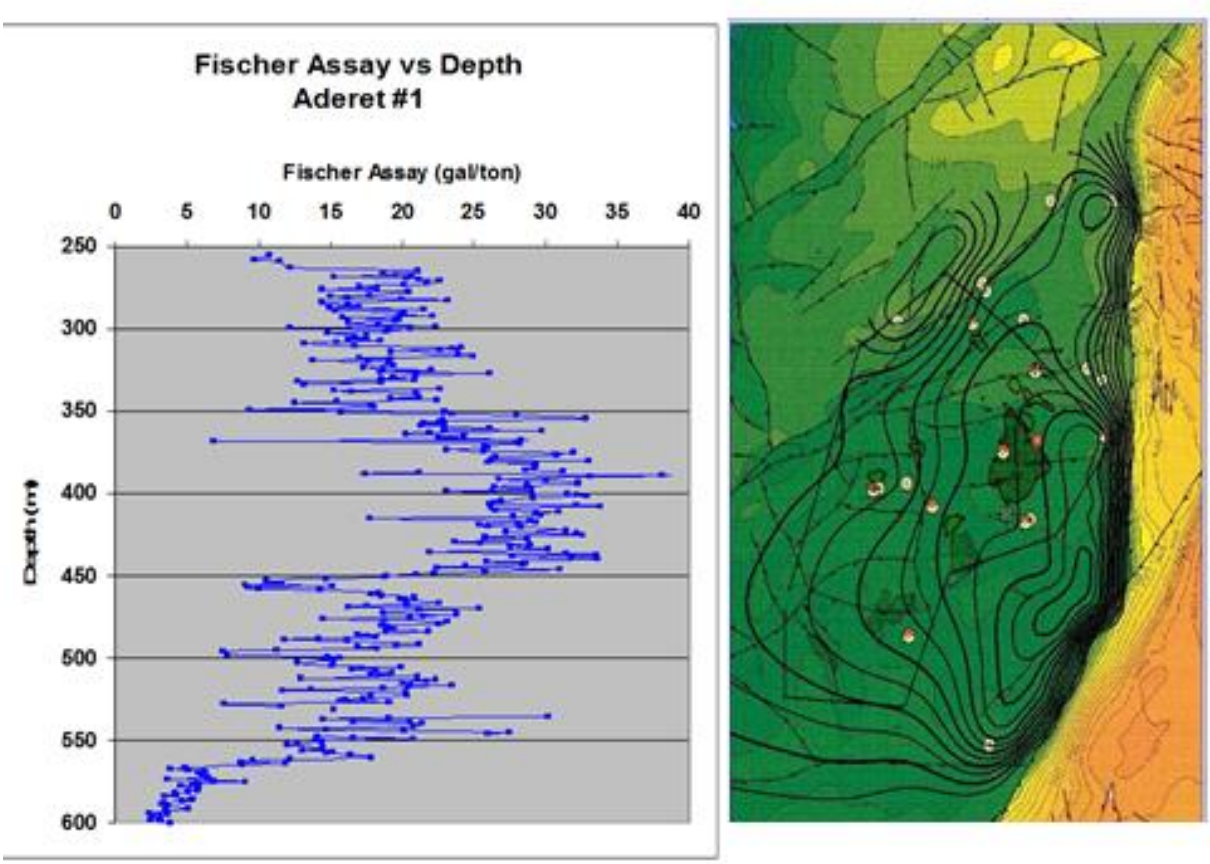

Figure 36. Right: Thickness of the oil shale sequence in part of the Ha'Shefela oil shale deposit. Left: Oil Yield (in Gal/Ton units) values in the Aderet borehole. Data provided by Y. Bartov, IEI.

23) Hadera-East (Sharon, Fig. 37, 38):

This oil shale occurrence is located in the northern Sharon Plain**,** in the region between Zemer villages (Nahal Haviva drainage area) in the southeast and to the town of Pardes-Hana - Karkur in the northwest. It is located in adjacency to the Green Line (in its southeastern side) in the south and forms a N-S strip of more than 10 km long and approximately 3-4 km wide (Fig. 37). The data used for determining the Hadera-East oil shale occurrence was based on general lithological logs (and their verbal descriptions) of some 15 water boreholes. This preliminary information indicates that a possible, consecutive oil shale body, do exist, at least within the proposed boundaries. But, it should be emphasized that there is no specific data about the organic matter grades and the chemical composition. Based on this initial information, it was estimated that the organic matter enriched sequence is up to 180 m thick and the overburden is ranging between 20 and 140 m, though it is probably ~50 m and less in about half of the data points. The inferred area of this occurrence is at least 35 km^2 and if an average thickness of 120 m is taken into account, the possible reserve estimate is around 7 billion tons. As clearly stated above, the values given are very preliminary and based only on indicative information and some structural hints.

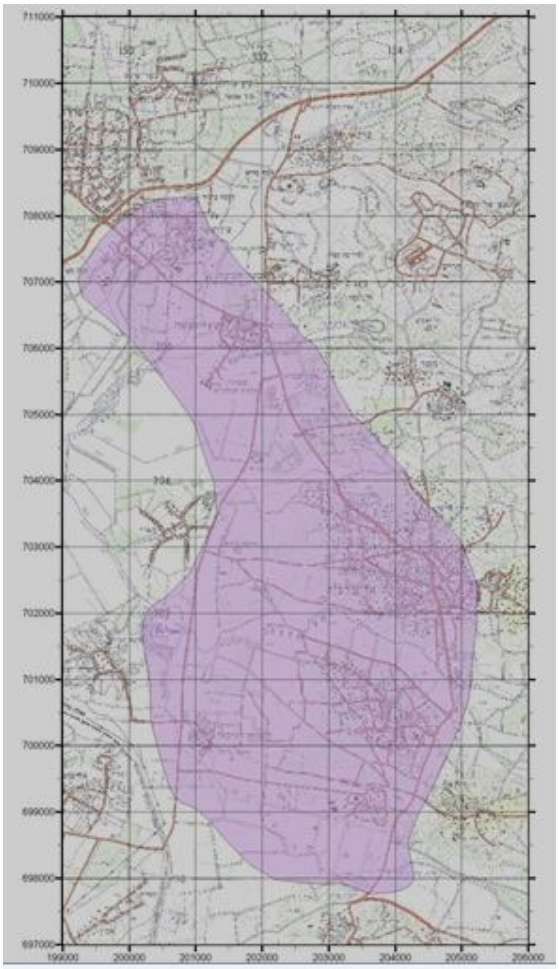

Figure 37. Location and approximate boundaries of the oil shale occurrence of Hadera-East.

Based on structural information, it was suggested in 2009 that this proposed oil shale occurrence is actually extending beyond the presented, assumed, boundaries (shown in Fig. 37). Thus, it was speculated that these possible extensions of this occurrence are primarily to the south and lo less extent, to the north. Having a possible thicker oil shale sequence (having some similarities with the Ha'shefela oil shale basin) than what is shown above, it was claimed that this occurrence may have the potential of being second in the reserves amount in the list of oil shale occurrences of Israel.

Recently, the above assumption was strengthened, as a more detailed study dealing with this oil shale occurrence (Goren, 2011, 2012), point out to a much larger consecutive oil shale occurrence that might possess an area of about 680 km^2 (Fig. 38). The recent examination did not include data obtained from new boreholes, but summarizes information revealed from existing boreholes and from analyses carried out on non-fresh cuttings samples, most of them generated from water drillings, few of oil prospecting activity. The nature of the samples may explain the rather low and medium level values obtained for the organic material. The organic material anomaly is within the Campanian to Paleocene sequence, and in particular in the Campanian – lower Maastrichtian window. Looking into this newly released information, it is suggested to substitute the Hadera East oil shale occurrence with the following two occurrences, that although being probably connected to each other, should be dealt with separately:

A) Reevaluation of the Hadera (which may be termed now - the **Sharon** basin, as it covers most of the central and northern parts of the Sharon plane) oil shale occurrence, indicates that it is about 25 km long (from an assumed locality about 15 km SE of Netanya to a WSW-ENE line extended between Nahal Hadera and Nahal I'ron), being ~7-15 km wide and thus covering an approximate area of ~250 km^2. Analyzed samples from 11 boreholes define an average oil shale sequence of about 70 m under an overburden of 30-750 m thick. The fact that most of the available results represent relatively low EOM values probably reflects their non-fresh nature.

   As the available data is still very preliminary, if an average thickness of some 50 m is considered, may indicate oil shale reserves that are in the order of 22 billion tons.

B) **Ramot Menashe** – this proposed oil shale occurrence covers most of the area of the Menashe syncline (which has a SW-NE directed axis) in the Carmel ridge; might be spread over an area of ~220 km^2 (having maximal dimensions of about 25x12 km). The newly obtained data is composed of only 2 analyzed boreholes, and thus it is considered premature to come out, on the base of it, with reliable preliminary estimates for the oil shale sequence thickness, its grades and reserves. However, it is indicated that the eastern flank of the basin (and in particular, the Meggido area) may possess thicker sequences and richer EOM grades.

Possible extensions of these proposed oil shale occurrences are superimposed on in Fig. 38.

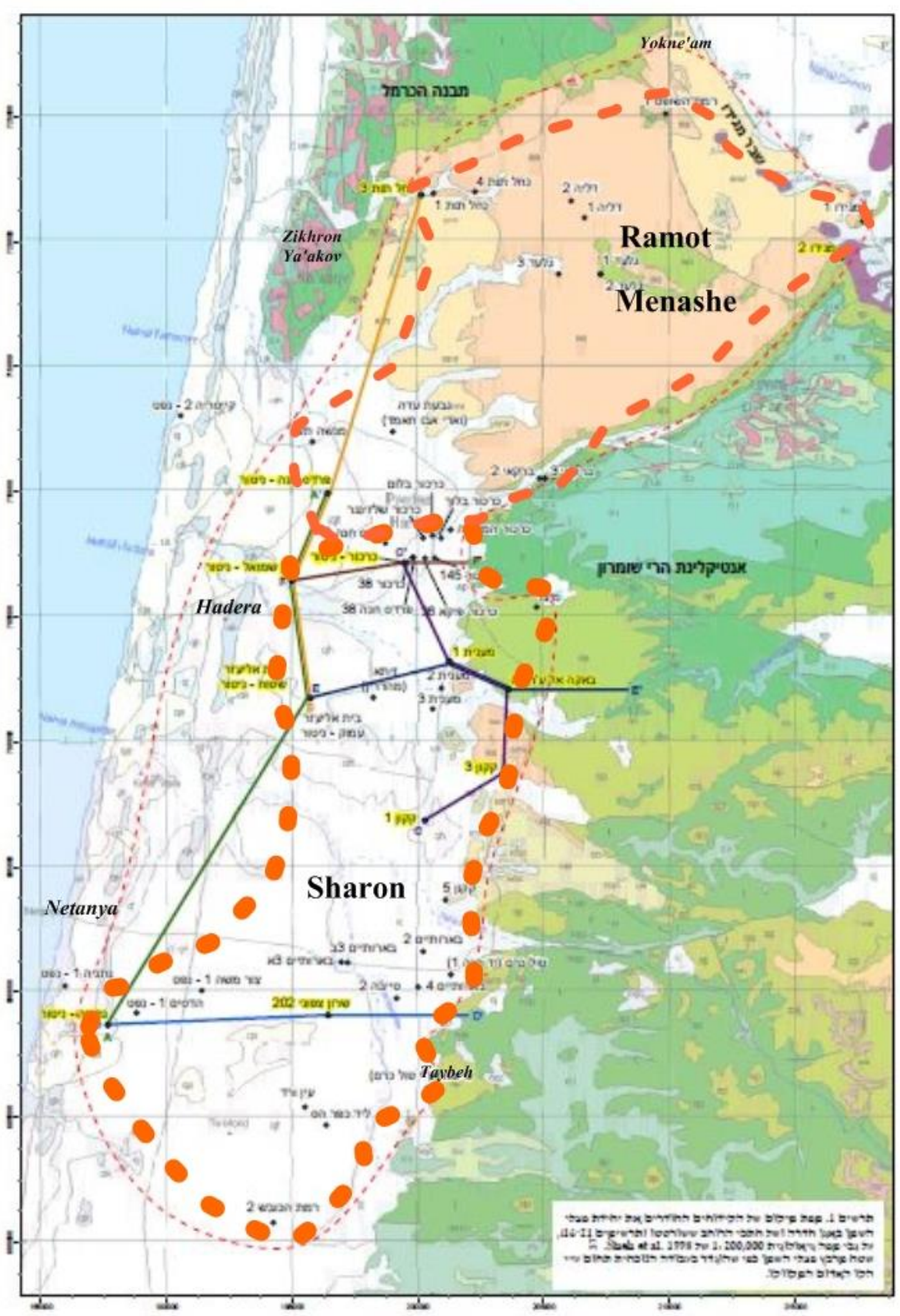

Figure 38. The oil shale occurrence in Hadera-East, as presented by Goren (2012). Proposed boundaries of this oil shale body (Sharon & Ramot Menashe occurrences) are shown in brown color.

Oil Shale Occurrences in Northern Israel:

Several oil shale occurrences are indicated in the Galilee, in surface and in the subsurface. The oil shales are confined mainly to the Mount Scopus Group sequence, especially the En Zeitim Fm, which is correlated with the Negev Mishash and (part of) Ghareb formations.

24) Emek Zevulun (Fig. 39):

This oil shale occurrence is located in the eastern part of the Zevulun Plain, in the area that roughly lies between (east of) Akko (Acre) and Shefar'am (southwestern edge of the Lower Galilee Region). Its approximate NS extension is parallel to the coastal shore, 5-10 km to the west. In fact, its southwestern suggested corner is only about 5 km northeast of the Haifa oil refineries (Fig. 39).

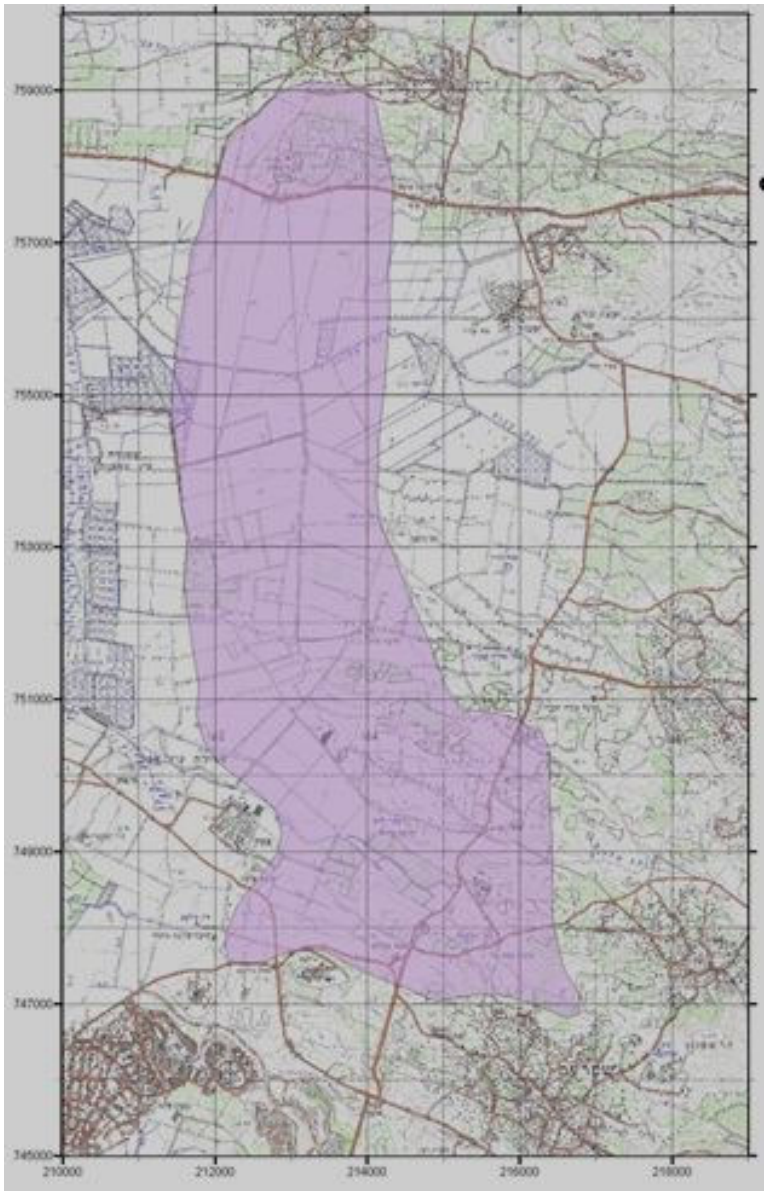

Figure 39. Location and approximate boundaries, the oil shale occurrence of Emek-Zevulun.

The available data is based on descriptions of some 15 water boreholes that indicate the possible existence of one consecutive oil shale body or two adjacent ones. Preliminary information might indicate an oil shale body of some 12 km long and around 2-4 km wide, covering an area of about 30 km^2 (and possibly more than that). In one borehole the thickness of the described organic matter enriched sequence is more than 300 m, but in about half of the rest of the boreholes it is only 50-100 m thick. The overburden thickness range is between 40 to 100 m, in most of the available boreholes. Taking a modest average value of 70 m for the oil shale sequence, the possible reserve estimation is about 3.5 billion tons. As stated above, it should be emphasized that the values given are indicative, based only on preliminary, very limited, information.

25) Arbel (Fig. 40, 41):

Of the oil shale indications of central and eastern Galilee, the field of Biq'at Arbel - Biq'at Kinrot (or simply – Arbel) seems to be of most significance. It is located below Biq'at Arbel and in several blocks between Mount Arbel and the Sea of Galilee, some of which are possibly below the western part of the lake, in that area (Figure 40).

Figure 40. Location and approximate boundaries of the oil shale occurrence of Arbel.

This oil shale occurrence is rather close to several historical sites, like Magdala, Ganassaret, Tiberias, Arbel, Horns of Hittim and Nabi-Shueib.

Research boreholes executed by IEC (Israel Electric Corporation) and some water drillholes in the area indicated that the organic matter enriched sequence is within the En Zeitim and Ghareb formations sequence and to a less extent, in the Taqiye Fm sequence.

Based on relatively few analyses, the organic matter content of the upper part of the sequence (which is around 90 m thick, and is assumed to be equivalent to the Ghareb Fm) is about 10-15% EOM and the underlying ~60 m thick sequence (probably equivalent to the Mishash Fm) possess lower organic matter values of about 6-10% EOM. The vertical variations in the organic matter content, in Arbel-1 borehole, are presented in Fig. 41.

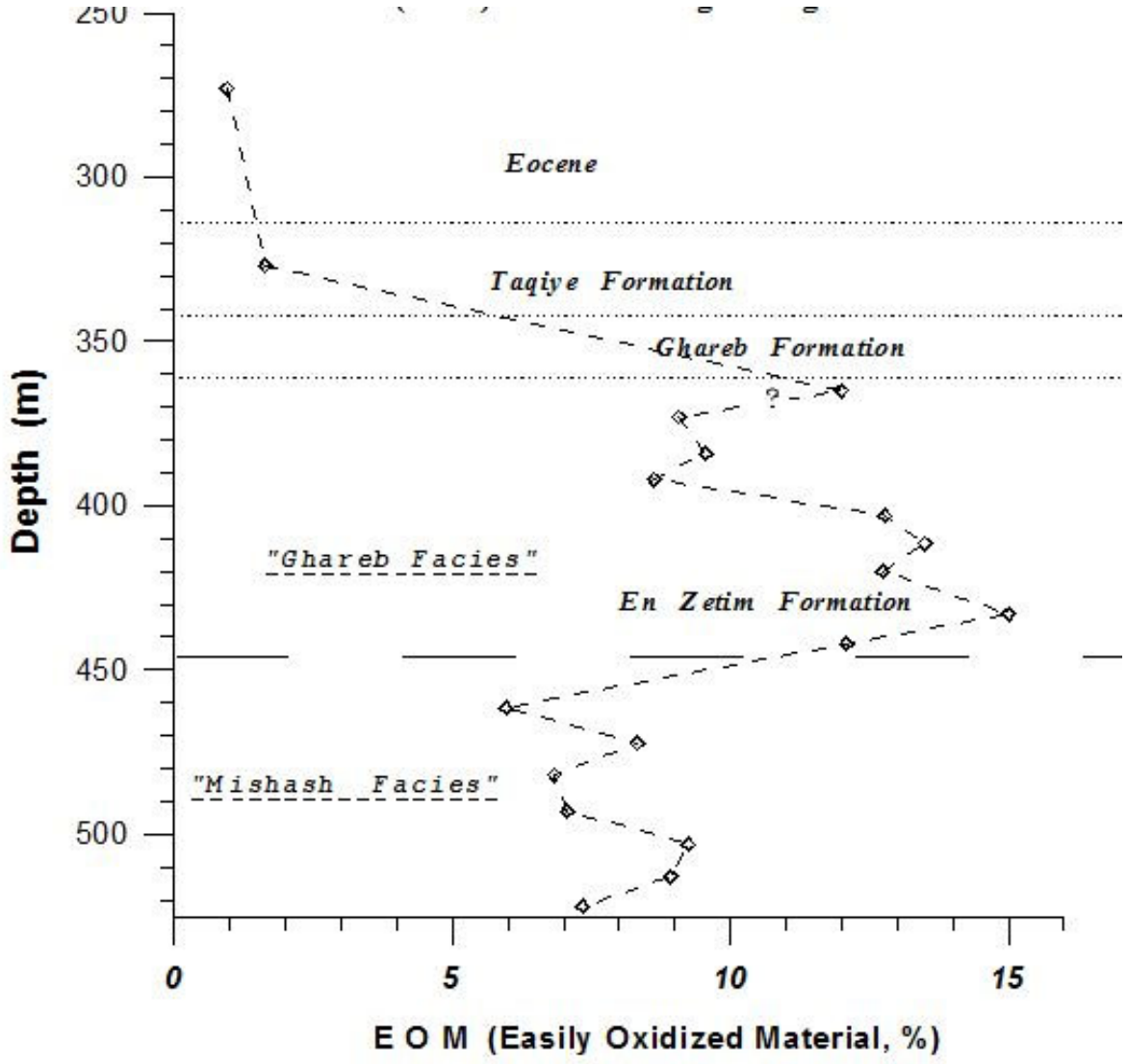

Fig. 41. Organic matter content log of the Arbel-1 (AB-1) borehole - oil shale occurrence of Arbel.

Preliminary estimations indicate that the oil shale body is extended upon an area of at least 10 km^2, under overburden of 50 to 350 m thick. Thus, an initial reserves estimation for the Biq'at Arbel - Biq'at Kinarot oil shale occurrence is about 1.2 billion tons. It should be emphasize that this oil shale body is located within several blocks that are separated by fault zones.

26) Southern Ramat HaGolan (Fig. 42):

Two deep water boreholes that were drilled in this area penetrated thick, well-developed (400 m thick and more) sequences of the Mount Scopus Group, that are enriched in organic material. These boreholes are En Said (coord. 265553/738826) and Meitsar-2 (coord. 265590/735694); oil shales are also exposed nearby on the southern edge of the Yarmouk gorge (Israel-Jordan boundary area), close to Hamat-Gader. Relatively high organic matter values were revealed on few samples from these sequences. As the data is very preliminary, it is impossible to speculate rerliable figures on the area and the volume of this occurrence but it is indicated that it may be very substantial, from the thickness, area and probably quality aspects.

It is also worth mentioning that to the south and southeast of the lower Yarmouk gorge, in Northern Jordan, and below the Irbid plateau, a very large oil shale deposit is reported, which may be a structural continuation of the Southern Ramat HaGolan oil shale occurrence. Oil shale exposures were described from this area, particularly from the gorge of Wadi El-Shalale (site name sometimes being used for this entire oil shale basin). This deposit mmight be, theoretically, one of the largest of the known Jordanian oil shale occurrences.

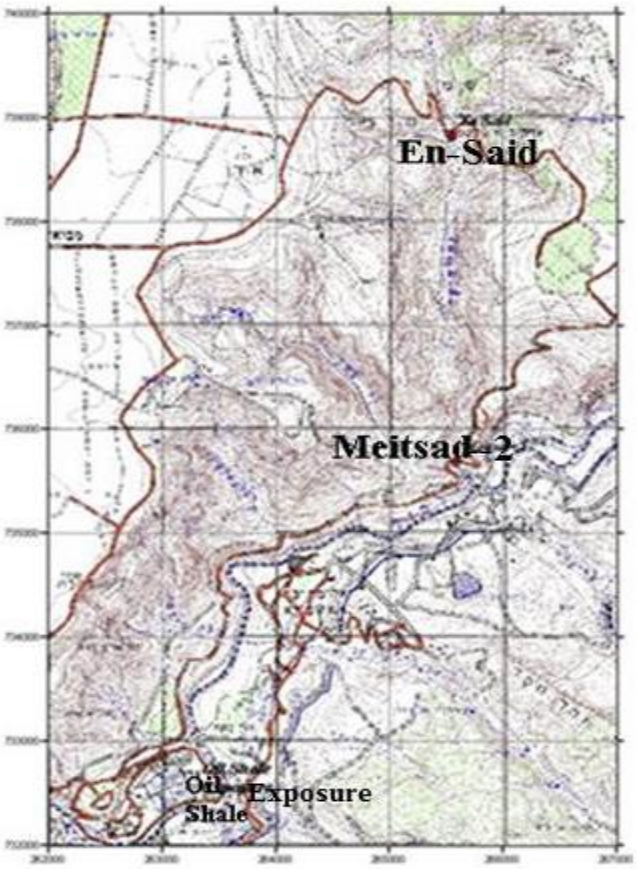

Figure 42. Southern Ramat Ha'Golan oil shale basin - locations of outcrop and water boreholes.

Table 4. Oil Shale in Israel – Summary of the described Data

Table 4 attempts to summarize the existing data on Israeli oil shale deposits and occurrences, as described on the information provided in the current report. Remarks on some of the presented parameters are as follows:

Number in Report: same numbers that are given to each occurrence in the complete description.

General location / Region: general description of the location, enabling to define groups of occurrences.

Area: Values (in sq km) measured by the GIS or taken from previous sources.

Thickness of oil shale (Ghareb Fm): based on available data. When data is scarce, it is a close estimation. In some of the occurrences these values refer to total organic matter enriched sequence, including the Mishash Fm.

Thickness of overburden: based on available data. When data is scarce, it is a close estimation.

Thickness of oil shale (Mishash Fm): based on available data. In many of the occurrences the data is not providing enough clues as to give numbers.

Borehole initiator: **P** – PAMA; **R** – Rotem Amfert (or the Phosphate Company); **S** – SAPASH & / or SAPA (national oil-shale prospecting project; national phosphate prospecting project); **O** - drilling for oil; **W** - drilling for water; **E** – other initiatives (NRC, Israel Electricity Co., Med-Dead project, etc.).

Approximate Technical Parameters: When enough EOM data is available; in some cases an estimated values are given. TOC and Oil Yield figures are based on the relations with EOM values, as quoted in the text.

Approximate Estimations of Reserves: Numbers in million metric tons, based on available numbers of areas and averaged considered thicknesses. In some cases the reserves includes estimations on reserves within the Mishash Fm sequence. It is most adviceable to refer to many of the given numbers as geological, possible reserves.

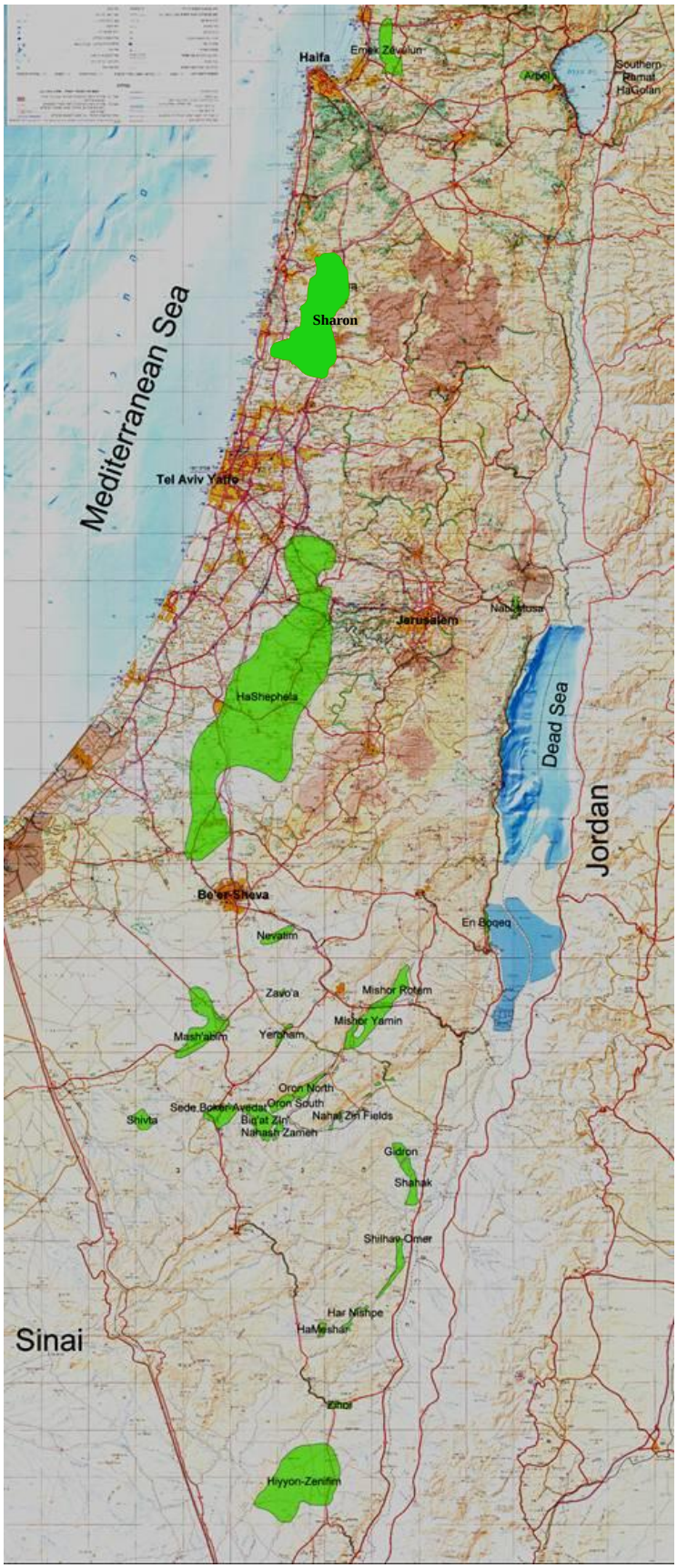

Figure 43. Schematic map of Oil Shale deposits and occurrences in Israel.

Oil Shale in Israel – Selected References

The following list reperesents a small part of the existing literature and data on the oil shale deposits and occurrences of Israel. A great portion of the information is restricted to reports and databases of very limited distribution, not listed below.

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Appendix – Data on some Technological Parameters characterizing Oil Shale rocks in Israel

Starting in the mid -1950's (En-Bokek studies) and till today, thousands of rock samples, having organic matter anomalies, were analyzed in domestic laboratories. Traditionally, the preliminary (and in most cases the only) analysis conducted to evaluate the organic material content was using a method of oxidizing a grinded rock sample with K-dichromate (based on analytical method presented by Allison, 1953); this method was adopted by major domestic labs (in some cases, with minor adjustments). Most rocks analyzed were oil shale and bituminous phosphorites, and the major labs were those of the Hebrew University, Geological Survey of Israel, PAMA, Rotem Amfert (and formerly – the Phosphate company) and the Israeli Institute of Measurement and Control.

Although being not satisfactory in its precision, clear advantage sides of this method were considered for years to be its simplicity, the short timing and the low expenses which made it quite popular. The values obtained in this routine method are termed the "Organic Material" (OM) or EOM (Easily Oxidized Material). It is estimated that some 15,000-20,000 analyses of this kind have been conducted during the whole prospecting period. But it became evident that these results could be compatible with other technological parameters used in other parts of the world. Thus, other methods of analysis were used, in various labs. The following summary is an attempt to examine the results of the traditional parameter of EOM, in comparison to analyses of organic carbon, oil yield and calorific value.

Organic Carbon (TOC), (Fig. 44, 45):

The parameter of the total organic carbon (TOC) is widely used to assess and represent the organic matter content in fossil fuels, as well as in soils, natural and industrial materials.

It was considered for years in Israel that the TOC parameter represents more accurately the organic material content, as the Easily Oxidized Material (EOM) procedure results may reflect also other constituents that tend to be oxidized easily. In a research conducted in 1982 (in the Geological Survey of Israel), the correlation between EOM and TOC was studied on various samples, in particular oil shale and bituminous phosphate. The obtained correlation equation (85 samples; correlation coefficient of 0.99; Fig. 44) was **TOC = 0.726 x EOM - 0.438**. In later unpublished studies, similar correlations were found, but with somewhat lower correlation coefficients (Fig.

45). Minor differences in this correlation chart can be seen when samples from the Ghareb and the Mishash formations are compared. Following the existing, available information, an average value of **TOC = 0.68 x EOM** was adopted for presentation and calculation usage, and in the summarizing table (Table 4). It is valid, in particular, for samples from the Ghareb Fm in Mishor Rotem, but may be used for preliminary assessment to other domestic deposits.

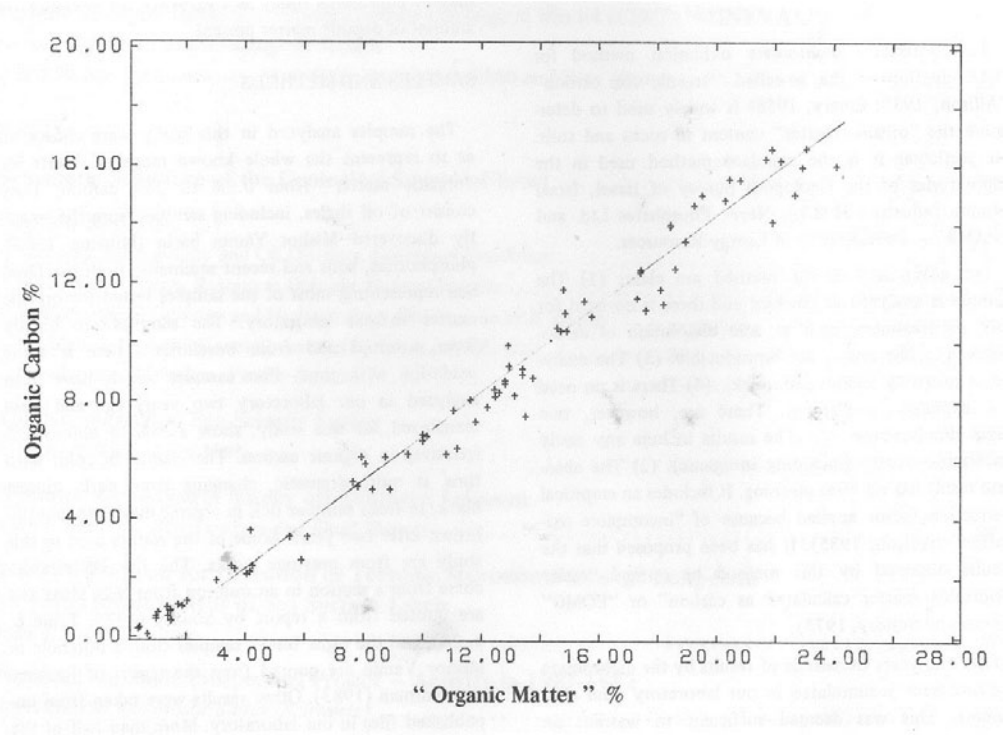

Figure 44. Correlation chart between Organic Carbon and "Organic Matter" results obtained from 85 samples (most of them – oil shale) in the GSI lab [from Nathan et al. (1983)].
The correlation equation was: **TOC = 0.726 x EOM - 0.438**

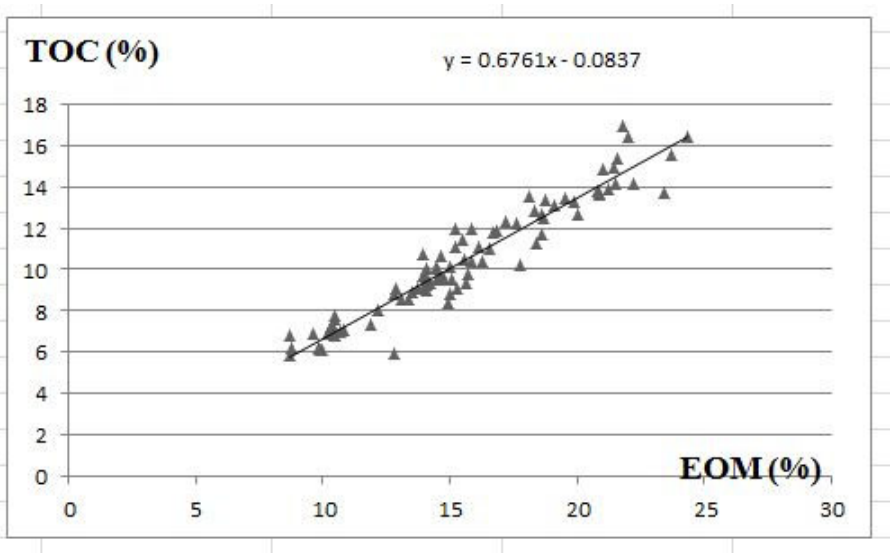

Figure 45. Correlation between Total Organic Carbon (TOC) and EOM values obtained from 91 oil shale samples, Ghareb Fm, Mishor Rotem. Cor. Coef. = ~ **0.9**. Source: this study.

Based on unpublished internal data of PAMA (analyses carried out by PAMA's laboratory). Recently, the geochemical laboratory of the Geological Survey of Israel choose to use the $\mathbf{OC^{WB}}$ parameter as a working method to present the Organic Carbon content of oil shale rocks (Gelman et al., 2012). It was determined in a variety of 43 domestic oil shale samples on which the Organic Carbon content was analyzed by the dry combustion method.

It may be argued that such a fundamental transformation in a method that was widely used to define a parameter of economically significance needs a much greater (than the 43 reference samples presented) studied population of samples, and a more diverse one. This is essential for continuation of economical research as great amount of Israeli oil shale samples were analyzed for their organic matter content by using the EOM procedure.

Technological parameters:

When economical-technological applications of oil shale rocks are considered there is a need to define some properties that evaluate most related parameters. The two most useful approaches are closely associated with the major exploitation directions – retorting and combustion; the corresponding technological parameters are the oil yield and the calorific value. Thousands of these parameters were analyzed, mostly in PAMA's lab. As can be deducted from the population of boreholes, most analyses were performed on samples from Mishor Rotem and to less extent on samples from Oron North, Nahal Zin and Mishor Yamin occurrences. Generally, the correlations between these parameters and the organic matter content (EOM) are very good. Minor differences do exist between sample groups from different deposits and the two studied beds (Ghareb and Mishash formations). The data given herein is mostly referring to the Mishor Rotem (Ghareb Fm) oil shale deposit.

Oil Yield (Fischer Essay), (Fig. 46, 47):

The analytical procedure in which this parameter is obtained is in fact a pyrolysis approach. After approved grinding scheme is being used, a weighted sample is mound into standard cylinder and heated until complete retorting (no oxygen). The resulted oil is weighted and its ratio to the original sample mass, in %, is the Oil Yield value. Water and gas amounts, formed during this process can also be measured.

This parameter has universal importance, having wide application for retort applications, and for comparison between various raw materials.

Figure 46 present a population of 846 samples from the Ghareb Fm obtained in Mishor Rotem, Mishor Yamin and Oron North oil shale deposits. The average EOM value for this population is 14.13% which correspond to Oil Yield value of ~6.2%.

Taking into account this relatively large population of samples given and a R-squared very good value of ~0.84, an average value ratio of **OY = 0.495 x EOM** was adopted for presentation and calculation usage, and was used in the summarized quality table of various oil shale occurrences in Israel (Table 4).

On the same Oil Yield to EOM presentation (Fig. 46), the US measurement mostly used units of Gallons (shale oil) per Ton (raw oil shale) were added, using the EOM content of 10% as a cut-off value. Thus, it can be deducted from this population of samples that in the Ghareb Fm oil shale in the most thoroughly studied oil shale deposit, the grade is equal to 12-27 Gallons per Ton (GTP), and an average value of 20 GLP may be used to represent the grade of the known (and mostly studied) Israeli oil shale deposits. From Fig. 47 it may be indicated that in the Mishash Fm, the oil yield for a given EOM value is somewhat higher compared to the Ghareb Fm oil shale samples. This indication may be of significance in retort-planned activities, but needs further research.

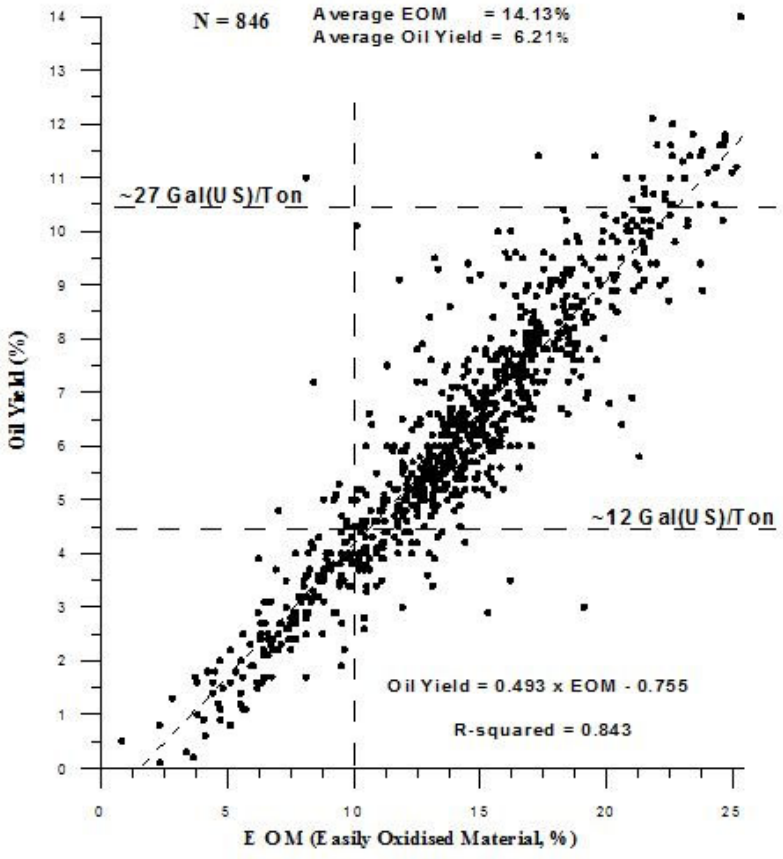

Figure 46. Correlation chart between Oil Yield (OY) and EOM results obtained from 846 oil shale samples of the Ghareb Fm in Mishor Rotem and additional occurrences. For comparison, Gallons per Ton (G/T) units widely used in the US and elsewhere were added.

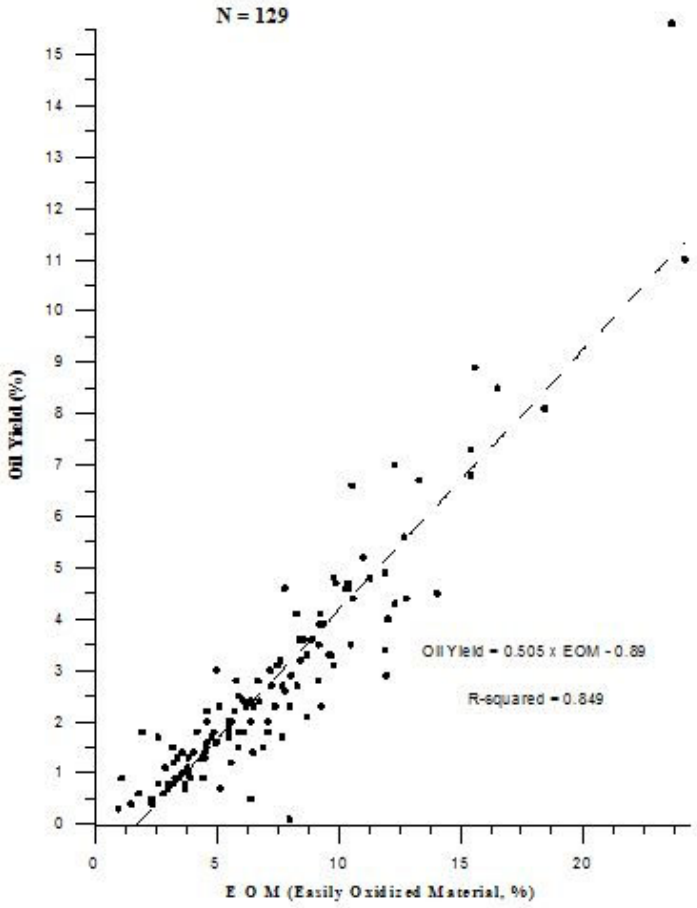

Figure 47. Correlation between Oil Yield and EOM results obtained from 129 samples, Mishash Fm., in Mishor Rotem & Mishor Yamin.

Calorific Value (CV), (Fig. 48):

The standard procedure of obtaining the Calorific Value (CV) in rock samples is applied by the lab apparatus known as 'Bomb Calorimeter'. The stages of the analysis on that facility are simple: weighing the original grind rock sample, and then firing it, in oxidized environment. The device measures the amount of the evolved heat which is presented in units of Kcal/Kg (or Cal/Gr).

Calorific value analyses were carried out not in the recent years of prospecting in Israel.

Fig. 48 presents a correlation between the Calorific Value (CV) results and the organic matter content (EOM) determined in a large population of 1052 samples of the Ghareb Fm, from boreholes in Mishor Rotem and Mishor Yamin oil shale deposits. On average, each 1% of EOM "contributes" ~74 calories. In this population, the CV values range between 650 and 1450 cal/gr (EOM ~10-20%). Few samples gave values of 2,000-2,100 cal/gr. When using a cut-off value of 10% (EOM), average CV is around 1125 cal/gr for the Ghareb Fm oil shale sequence.

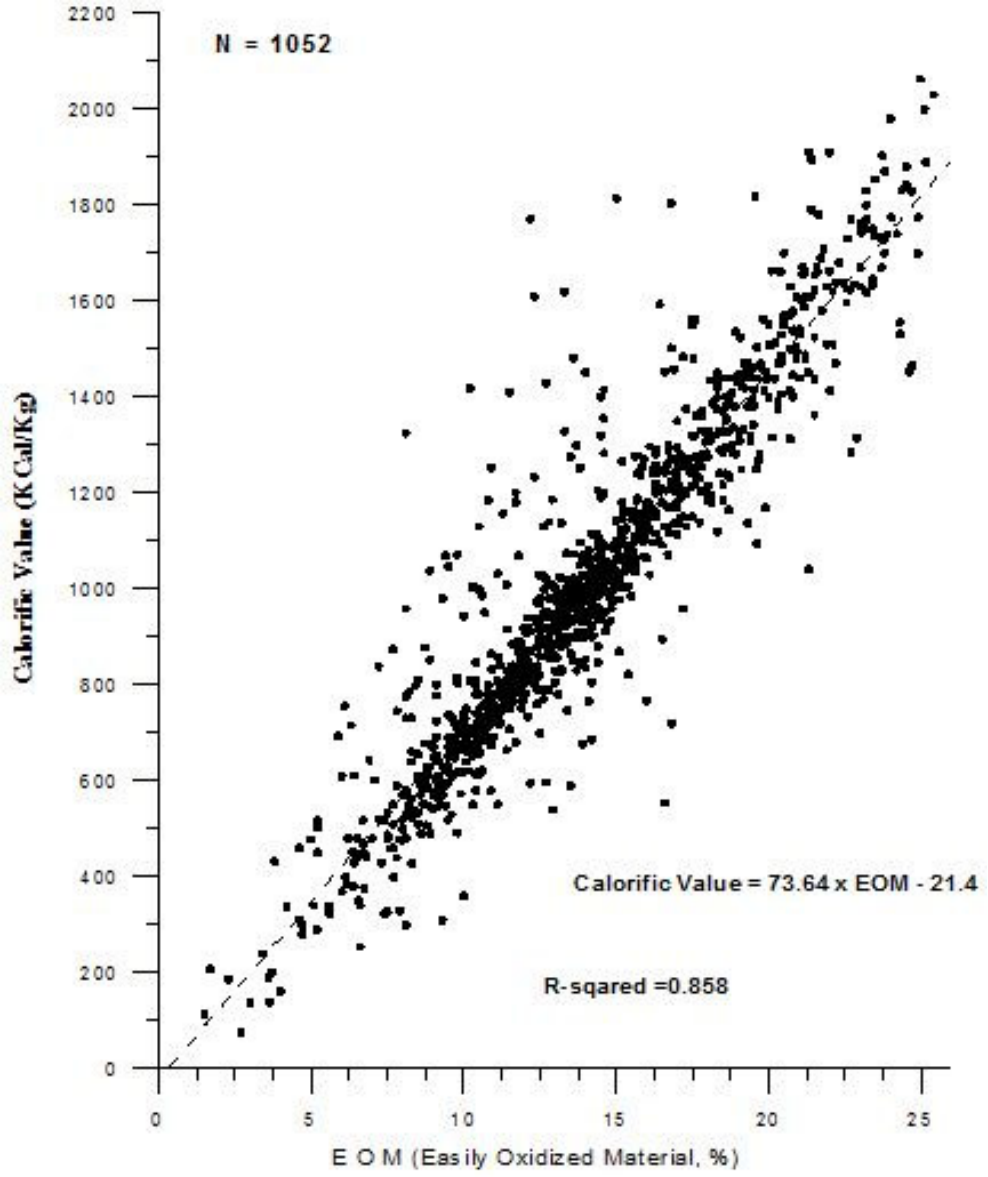

Figure 48. Correlation chart between Calorific Value (CV) and EOM results obtained from 1052 samples (Ghareb Fm) in Mishor Rotem & Mishor Yamin.

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List of Photographs

1. A quarry, north of En-Bokek and close to the Dead Sea shore, in which oil shale rocks were mined for use in infra-structure projects conducted by DSW (Dead Sea Works). Picture taken in autumn of 2007.

2. Outcrops of the lower part of the Oil Shale Member, Ghareb Fm. Oron North oil shale deposit, northeasterly of Giv'at Mador. The type section of the Ghareb Fm was executed in a nearby location.

3. Outcrops of the lower part of the Oil Shale Member, Ghareb Fm in the Southern cliffs of Har Zin (Hor HaHar). Black colors – products of natural, partial degradation of the organic matter.

4. The oil shale open-pit mine in Nahal Havarbar, Mishor Rotem. Picture taken in the early 2000's.

5. The oil shale open-pit mine in Nahal Havarbar, Mishor Rotem. Look to the east. Picture was taken in autumn of 2007.

6. Mining of oil shale in the open-pit mine, Nahal Havarbar, Mishor Rotem. The picture was taken in summer of 2007.

7. Recent (2012) phosphate mine, Nahal Ef'e, in Mishor Rotem, west of the oil shale open-pit mine The western edge of the oil shale body was exposed during the development of the phosphate mine.

(1)

(2)

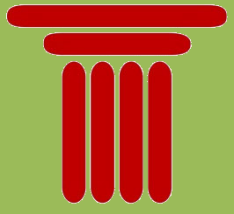
(3)

(4)

(5)

(6)

(7)



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