



**Ministry of Energy  
Geological Survey of Israel**

# **The Dead Sea Transform western margin along the Kinneret-Kinarot Basin, northern Israel**

**Amit Segev**



## **Abstract**

This study investigates the Cenozoic evolution of the Kinneret-Kinarot Basin (KKB) in general, and the geology of its western margin in particular. The basin is part of the N-S Dead Sea Transform plate boundary and the SE-NW Harrat Ash Shaam (HAS) volcanic field, and its parallel Irbid Rift which is close by. Geological, topographical and magnetic evidence was incorporated from about 40 km long KKB western margin, in order to complete a coherent geological map that can solve several issues concerning the Miocene and the Pliocene magmatism and tectonic. One of the main issues is dealing with the surficial flowing of the Pliocene Cover Basalt Formation. The exposed extent of these basalts on the KKB western margins enable one to conclude that there are downward flows from volcanoes on top of the mountain ranges, as follows (from north to south): Karne Hittim (flowed toward NE), Tel Maon (Teverya), Poriyya, Alumot, Sirin, Kokhav and Issachar (flowed toward SE). These basalts, as well as those from the Golan Heights, filled the KKB by more than 700 m of basaltic pile. Field evidence and their meaning about the Cover Basalts have important implications for the solution of mapping problems in the study area, and for accepting the idea that the present KKB morphology is similar to that of the Pliocene times. Accordingly, the presence of Lower Basalt outcrops, which previously mapped west of Menahamya, are replaced here by Cover Basalt that flowed eastward and downward to the KKB, similar to the above mentioned volcanos.

The exposed volcanos from the Lower Basalt phase are: Poriyya, Yavneel, Tavor, Givat Gazit & Tamra. Furthermore, significant negative magnetic anomaly near Menahamya may indicate a subsurface body of Lower Basalt rocks.

The updated geological mapping emphasizes the NWN to NW Hagal Yavneel crescentic fault that branches out from the DST western marginal fault. It belongs to several such exceptional faults between the Gilboa and northern Lake Kinneret regions, or following the intersection between the DST and the HAS. This intersection is typified, since the Early Miocene, by high heat flux and approximately N-S extensional stress.

## תקציר

המחקר הנוכחי עוסק בהתפתחות של אגן כנרת-כנרות בכלל ובגיאולוגיה של שוליו המערביים בפרט. אגן זה הוא חלק מגבול בין לוחות טקטוניים (סיני וערב) לאורך טרנספורם ים המלח וכן חלק מהשדה הוולקני של הררת-אש שאאם והבקע של אירביד הסמוך ומקביל לו. כיוון הטרנספורם לצפון-דרום וכיוון השדה הוולקני מדרום-מזרח לצפון-מערב. המחקר עושה שימוש בנתונים גיאולוגיים, טופוגרפיים ומגנטים לאורך כ-40 ק"מ מהשוליים המערביים של האגן הנחקר במטרה לסיים הכנת מפה גיאולוגית כוללת ואמינה. מפה זו תציג פיתרון למספר בעיות אזוריות פתוחות הנוגעות למגמטיזם ולטקטוניקה בתקופות המיוקן והפליוקן. שאלה מרכזית אשר היוותה מפתח להבנת האזור היא השתרעות ומקור סלעי תצורת בזלת הכיסוי מגיל פליוקן. מסקנת עבודה זו לגבי השתרעות מחשופי בזלות אלה על גבי השוליים המערביים של אגן כנרת-כנרות היא שהבזלות התפרצו מהרי געש המצויים על רכס השוליים וזרמו במדרון מזרחה לכיוון מרכז האגן. הרי הגעש הם (מצפון לדרום): קרני חיטים (הזרימה ממנו הייתה לצפון-מזרח), תל מעון (טבריה), פוריה, אלומות, סירין, כוכב ויששכר (הזרימה ממנו הייתה לדרום-מזרח). בזלות אלה, וכן גם בזלות שהתפרצו וזרמו מרמת הגולן מערבה, מילאו את האגן בלמעלה מ-700 מ' עובי של בזלות. למסקנה מהעדויות שהוצגו ולמשמעות שלה יש השלכות חשובות על פיתרון בעיות המיפוי הגיאולוגי של אזור המחקר, כמו גם לקבלת ההצעה כי המורפולוגיה העכשווית של אגן כנרת-כנרות דומה ביותר לזו ששררה באזור בתקופת הפליוקן. על פי מסקנות אלה והנתונים הקיימים שונתה ההגדרה של מחשופי תצורת הבזלת התחתונה המיוקנית, ממערב למנחמיה, לבזלת הכיסוי. לאחר שינוי זה נראה שהרי הגעש המיוקנים באזור המחקר הם: פוריה, יבנאל, תבור, וגבעת גזית ותמרה הסמוכים זה לזה. אנומליה מגנטית שלילית, משמעותית, ליד מנחמיה עשויה להעיד על המצאותו של גוף בזלתי מיוקני, השייך לבזלת תחתונה, בתת-הקרקע של אזור זה.

עדכון המפה הגיאולוגית של השוליים המערביים של אגן כנרת-כנרות מדגיש את נוכחותה של מערכת העתקה קשתית של העתקי חגל-יבנאל בכיוון צפ'-מע'-צפ' לצפ'-מע' המתפצלת מהעתק המערבי של טרנספורם ים המלח. העתק זה משתייך לסדרה של ארבע מערכות העתקה קשתיות דומות, הנמצאות מאזור הגלבע בדרום ועד לצפון הכנרת, כלהלן: מערכת העתקי רוויה-גלבע; מערכת העתקי חגל-יבנאל; מערכת העתקי כנרת-חיטים ומערכת העתקי פוליה-ארבל. סדרה זו של ארבע מערכות העתקה קשתיות חופפת לאזור ההצטלבות שבין טרנספורם ים המלח לבין השדה הוולקני של הררת-אש-שאאם. הצטלבות זו מאופיינת בשפיעת חום גבוהה (הגבוהה ביותר במרחב) ובמאמצי מתיחה משמעותיים שכיוונם המקורב הוא צפון-דרום.

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## 1. Introduction

The Dead Sea Transform (DST) fault, is the plate boundary between the Arabian and Sinai plates, which constitutes the major continental structural element that shapes the Cenozoic tectonic evolution of the Levant (Fig. 1A). The study area, which is located along the northern part of the DST (Fig. 1B), includes a thick sedimentary succession that hosts both magmatic and volcanic rock units. Several major volcanic events have led to thick (up to ~1000 m) basalt and gabbro successions which filled more than 700 m in the Kinneret-Kinarot Basin (KKB) along the DST (Fig. 2; Marcus and Slager, 1985; Segev, 2017). This intensive volcanism coincides with the northwestern edge of the Late Oligocene (~26 Ma) to the Pleistocene Harrat Ash-Shaam (HAS), the largest volcanic field on the Arabian plate (Fig. 1B). The volcanism is alkali-basalts, similar to that of other intra-plate continental basalts (e.g. Wilson, 1993; Shaw et al., 2003; Weinstein et al., 2006). Weinstein and Garfunkel (2014) reviewed the relationships between the volcanism along the DST and its structure (Fig. 3), and concluded that: (a) the volcanism is clearly part of the HAS magmatism; and (b) this tectono-magmatism is mainly connected to magma migration toward the surface due to better magma channeling and less with magma generation by mantle partial melting along the DST. In general, continental transforms frequently lack magmatism (e.g. most of the San Andreas fault system in California). However, volcanism does occur along some transform faults (e.g. the North Anatolian Fault in Turkey), particularly in or next to pull-apart extensional basins (Aydin and Nur 1982; Aydin et al. 1990; Tatar et al. 2007).

Geological investigations, including mapping of the southernmost part of the Golan Heights, north of the Yarmouk River gorge (the eastern part of Afqim 1:50,000 sheet 4-IV; Figs. 4A) was recently carried out by Segev and Reznik (in prep.). Based on previous mapping of the Jordanian side (Moh'd, 2000) and the western slopes of the Golan Heights (Michelson, 1979; Marcus and Slager, 1983; Michelson and Mor, 1985; Mor, 1986; Sneh, 2017) Segev and Reznik (in prep.) show that the Pliocene Cover Basalt Formation lava flows in the Yarmouk region, which covered the western slopes of the Golan Heights and Mt Gilad erupted from the Yarmouk River gorge. In places of gradual slopes, the basalt outcrops extend continuously and at steep slopes only relicts of basalt outcrops remain. These authors concluded that Pliocene basalts flowed westward and downwards on Mt Gilad and the southern Golan Heights escarpments to fill the Kinneret-Kinarot Basin (KKB). The observations and conclusions of Segev and Reznik (in prep.) arouse the question about the expansion of the Cover Basalt Formation on the western margin of the KKB. It turns out that similar observations and disagreements occurred during the 1950's 1960's in Teverya geology. Schulman (1966) described the "fact that from the

elevation of -200 m at the southern corner of the town to the very top of Tel Maon hill (Teverya) in the west, at +250 m, there is a continuous exposure of the Cover Basalts". This led Bentor (1957) and Golani (1962) to suggest the presence of volcano on Tel Maon that its lavas flowed down eastward and northward over the steep slopes. Schulman (1966) suggests that two intersecting fault systems cause this occurrence in both Teverya and Kokhav HaYarden (Belvoir) regions.

This controversy has some important implications for the relationships between the Miocene Lower Basalt Formation and Pliocene Cover Basalt Formation on this western margin and for the evolution of the KKB basin. In addition, the exposed rock units on the KKB basin margins have an important role on the interpretation of various geophysical studies dealing with the deep structure of the KKB (Ben-Avraham et al., 1979; Kashai and Kruker, 1987; Rotstein et al., 1992; Ben-Avraham et al., 1996; Hurwitz et al., 2002; Eppelbaum et al., 2004; Ben-Gai and Kashai, 2004; Ben-Gai, 2009; Ben-Avraham et al., 2014; Schattner et al., 2019; Rosenthal et al., 2019).

Large parts of the KKB western margin (Fig. 4B), were geologically mapped (1:50,000 scale) about 60 years ago (Schulman, 1959, 1962), whereas a small part on the south is included within Bet Shean Sheet (6-I, II; Hatzor, 2000) and a small part on the north within the Arbel (4-I, Bogoch and Sneh, 2008) and Teverya sheets (4-II, Sneh, 2017). The incomplete geological maps of Nazerat Illit (4-III) and Afiqim (4-IV) sheets are ongoing works at the Geological Survey of Israel.

The aim of the current investigation is to construct a composite geological map of the western KKB margin with emphasis on the Neogene-Quaternary rock units. These goals will be achieved by using the available geological maps of the study area using the findings and conclusions from Teverya region (Bentor, 1957; Golani, 1962) and from the southwestern Golan Heights of Segev and Reznik (in prep.).

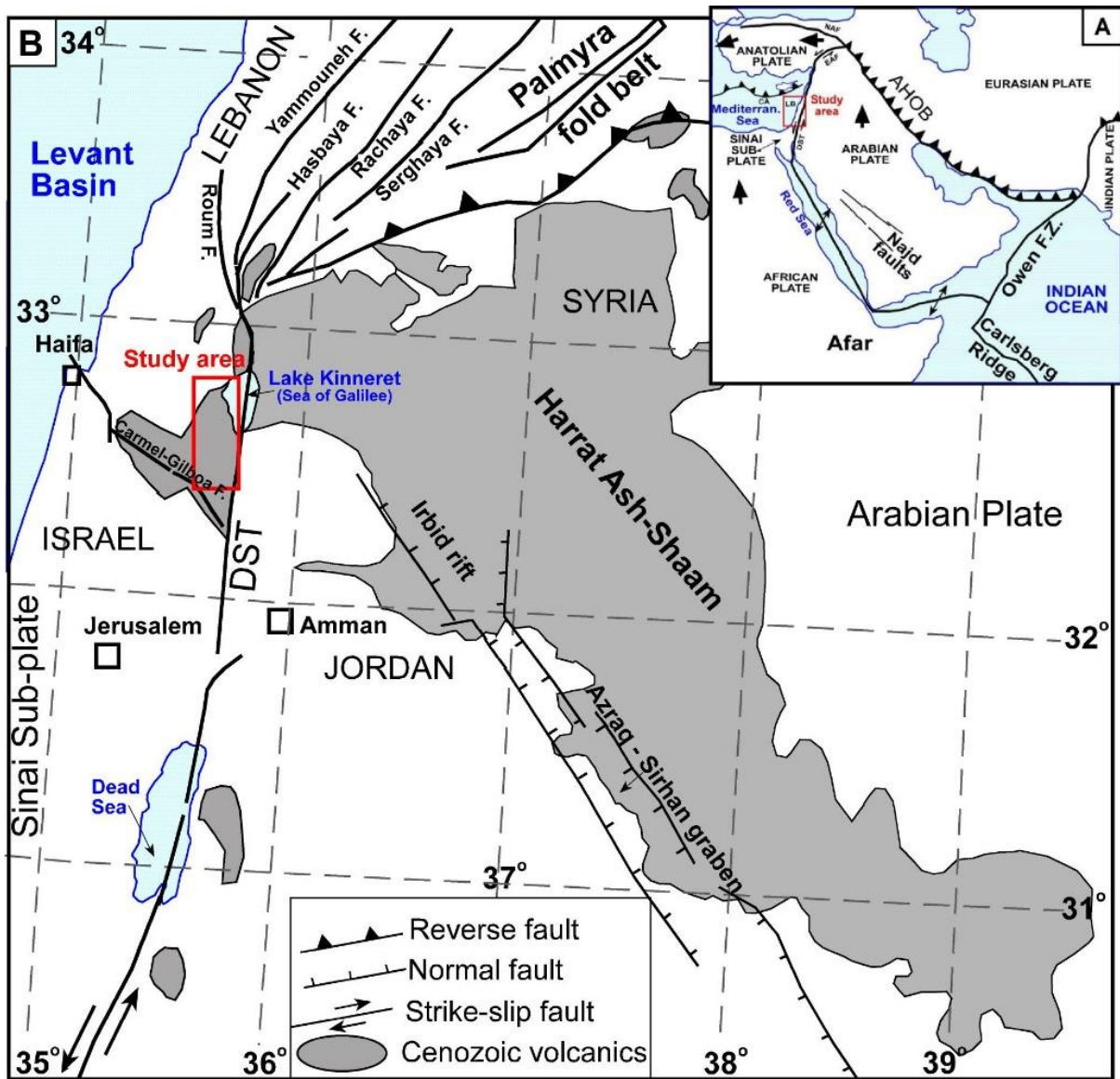


Figure 1. Tectonic settings of the Middle East and location of the study area.

## 2. Geological background

Late Eocene updoming of the Afar tectono-magmatic province, centered in Ethiopia and Yemen, (e.g., Cloos, 1953; White and McKenzie, 1989; Collet et al., 2000), resulted in regional uplift of the study area. This process revealed the initial Early Oligocene extensional phase and rifting of the Afro-Arabian plate between ~34 Ma and ~32 Ma, just before the Oligocene regional truncation surface (RTS), an angular unconformity with various magnitudes of angles typifying different tectonic blocks in the Levant area (Avni et al., 2012; Wald et al., 2019).

The Oligocene–Early Miocene Red Sea extensional regime reactivated the Senonian Azraq-Sirhan Graben (ASG) to form the Irbid rift in NW Jordan, the Golan Heights and the Lower Galilee (Segev et al., 2014). This rift terminated close to the present day Dead Sea transform (DST), where semi perpendicular wing-shaped deformation zones developed in the Golan Heights in the north, in the Jordan Valley and in the Dead Sea basin in the south. The deeper subsided basins (Irbid and Kinneret–Bet She'an) were covered by the shallow Oligocene marine ingression from SE Syria (Michelson, 1982; Michelson et al., 1987; Segev et al., 2017; Wald et al., 2019a). Two significant deep basins (>2000 m) on either side of the DST, Beteha in the east and Bet She'an in the west, are filled by twice as much Neogene sediments as in the surrounding regions. These basins were probably interrelated and formed coevally when the Irbid rift and the DST fault systems interacted during the Middle Miocene. At that stage the Arabian plate, which completed a relative ~35 km northward movement, and the initiation of volcanic activity, define a Lower Miocene age (~17 Ma) (Shaliv, 1991; Segev, 2000; Rozenbaum et al., 2016). This indicates an average motion rate of ~8.5 mm/year, which are strongly dependent on the age estimates (Segev et al., 2014). The latter authors suggest that after crossing the DST, the NW-trending active rifting opened the Lower Galilee valleys (Harod and Yisre'el) by the Carmel–Gilboa fault zone. The DST segments north of the Dead Sea basin form a right stepping pattern, and the complex structure of the DST–Irbid rift interaction resulted in a ~5 km deep basin extending from the Bet She'an region to the northern Kinneret, including the Zemah-1 deep well (Fig. 2). Parts of this Kinneret-Kinarot Basin (KKB) accumulated the initial Tertiary sedimentary cycle (Fiq and Susita formations) during the Oligocene time (Michelson, 1982; Michelson et al., 1987) (Fig. 5).

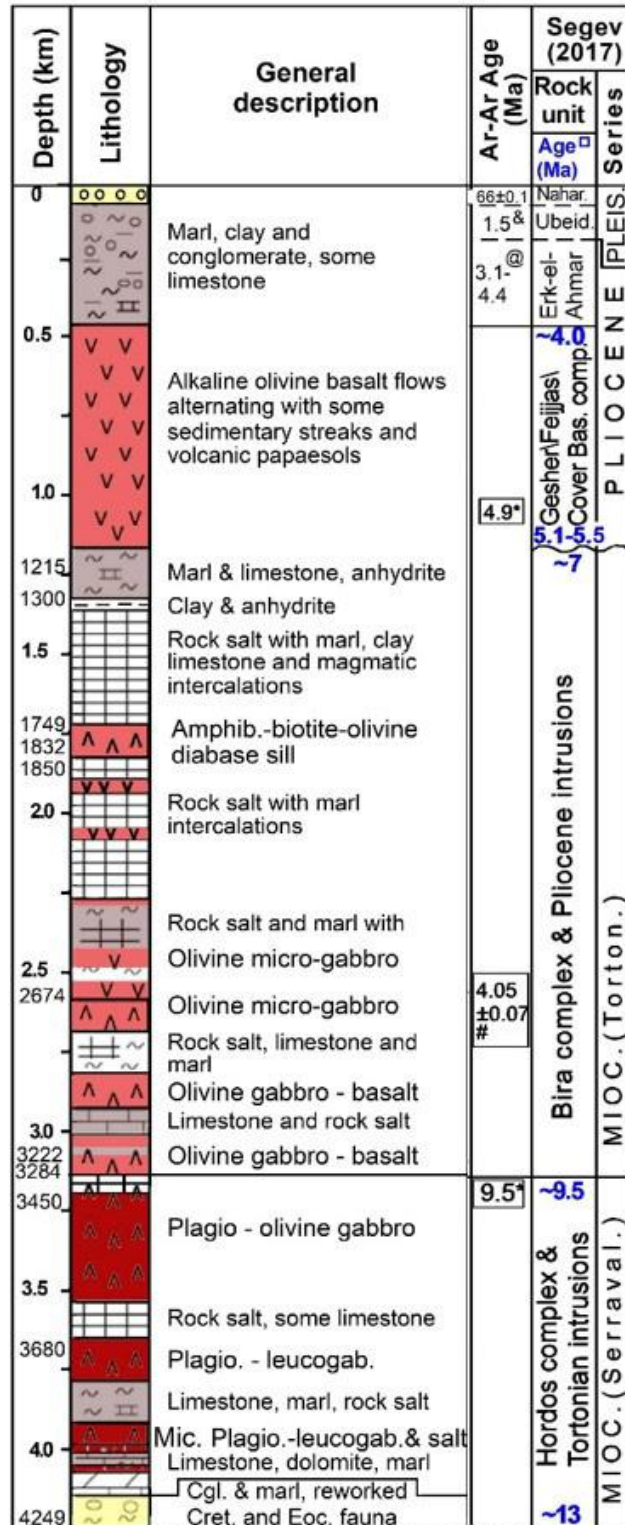


Figure 2. Zemah-1 well: simplified lithology (modified after Marcus & Slager,1985; Sandler et al., 2001). Mioc. =Miocene; Pleis. = Pleistocene.

### **3. Mapping units since the Miocene**

The formations since the Miocene time in the study area were studied and described by many researchers (e.g. Bentor, 1946, 1960; Schulman 1962; Michelson, 1979; Giveon, 1984; Michelson et al., 1987; Shaliv, 1991; Raab et al., 1997; Shaked-Gelband et al., 2014; Rozenbaum et al., 2016). A brief description will be displayed here.

#### **3.1. Hordos and Lower Basalt contemporaneous formation**

Early-Middle Miocene fluvial-lacustrine sediments of the Hordos Formation interfingers with lava flows and volcanic bodies of the Lower Basalt Formation (Fig. 5). Both formations build the volcano-sedimentary succession which started at ~17 Ma (Shaliv, 1991; Segev, 2000), after the development of the Regional Truncation surface (RTS) of the Oligocene time (Avni et al., 2012; Wald et al., 2019a).

Sneh (1993) reported that Middle Miocene oyster-bearing marine deposits in a red mudstone and conglomerate sequence belongs to the Hordos Formation, and is unconformably overlain by green marls of the Bira Formation. It is located south of Teverya in the "Swiss Forest". Segev (2017) suggests that Middle Miocene transgression of the Mediterranean might have filled the Kinneret-Kinarot basin and as a result deposited evaporite sediments at its bottom.

The Lower Basalt (Schulman, 1962) is a sequence of flows comprising largely alkali-olivine basalt and basanite (Weinstein, 2000; Weinstein et al., 2006). The formation has a wide distribution mainly west of the KKB. The basalts overlie an erosional unconformity incised in Eocene to Cretaceous sedimentary formations. Various younger Neogene units overlie the Lower Basalt with an erosional angular unconformity. The thickest exposure of the Lower Basalt Formation, in Kokhav HaYarden (Fig. 4B), reaches 450 m (Schulman, 1962). The nearby Belvoir-1 well penetrated 650 m of the formation near its proposed neck (Shaliv, 1991). The latter author has established a radiometric age range for this formation between ~17 Ma and 9 Ma, whereas the oldest ages were found in the base of the formation at Poriyya, Kokhav HaYarden, Giv'at Hamore, and Mt Gilboa regions. Ages between 14 and 12 Ma were determined for Kokhav HaYarden (Rozenbaum et al., 2016), Nahal Tavor (Baer et al., 2006), Shadmot Dvora and Bira-3 boreholes (Shaliv, 1991). This author as well as Schulman (1962) identified intrusive gabbro bodies of similar age range near Kokhav HaYarden, Giv'at Hamore, and Indur (east of Yizre'el Valley). They ascribed the intrusions to the feeding system of this volcanic phase. Ages between 12 and 10 Ma were determined for basalts at the upper section of Kokhav HaYarden (Rozenbaum et al.,

2016). The latter authors suggest that from ca. 12 to 10 Ma, lava erupted from Kokhav HaYarden volcanic center and marks the end of the Lower Basalt phase. It is probably associated with tectonic activity that broke up the SE Galilee basin by normal faulting into sub-basins which reflect the new relief.

### **3.2. Umm Sabune Formation**

This clastic unit named by Schulman (1962), is composed mainly of pyroclastic components. The base of the formation overlies the Lower Basalt with an erosional unconformity and the top grades into marls and shales of the overlying Bira Formation (Rozenbaum et al., 2016). Basaltic pebbles with polished surfaces, tuffs, and scoria bombs are found near the Nahal Tavor vent (Baer et al., 2006). Thickness of the formation varies from zero to about 215 m in Nahal Tzavon (Wadi Umm-Sabune) (Schulman, 1962; Aharon, 1997).

A thick flow in the Kokhav HaYarden section yielded a  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau age of  $10.07 \pm 0.05$  Ma and a thin flow within mixed- pyroclasts and basalt clasts, paleosols in the NB 1 borehole yielded a plateau age of  $10.73 \pm 0.09$  Ma (Rozenbaum et al., 2016). Considering the time gap from the 11.16 Ma age of the underlying basalt, the latter author suggests that from a lithostratigraphic point of view, erosion and conglomerate deposition started earlier at this location and the 10.73 Ma flow is part of the Umm Sabune Formation.

Shirav et al. (1995) suggest that the Umm-Sabune conglomerate is mostly a sequence of volcanic eruption-induced volcanoclastics which alternate with fluvial sediments.

### **3.3. Bira Formation**

The Bira formation conformably overlies the Umm-Sabune Formation and is unconformably overlain by the Gesher and the Cover Basalt formations. It consists of bedded or laminated soft dolostones, calcareous dolostones, dolomitic limestones and marls (Rozenbaum et al., 2017).

An oyster bed at the base and a layer of various marine macrofossils in the upper part of the formation ("lumachelle bed") is recognized in several locations (Shaked-Gelband et al., 2014). Gypsum beds occur in the upper part of the formation along the western escarpment of the Jordan Valley. Thick evaporites sequence, mainly halite, in the subsurface of the Kinarot basin (Segev, 2017) is tentatively correlated with the Bira Formation (Shaliv, 1991; Segev, 2017).

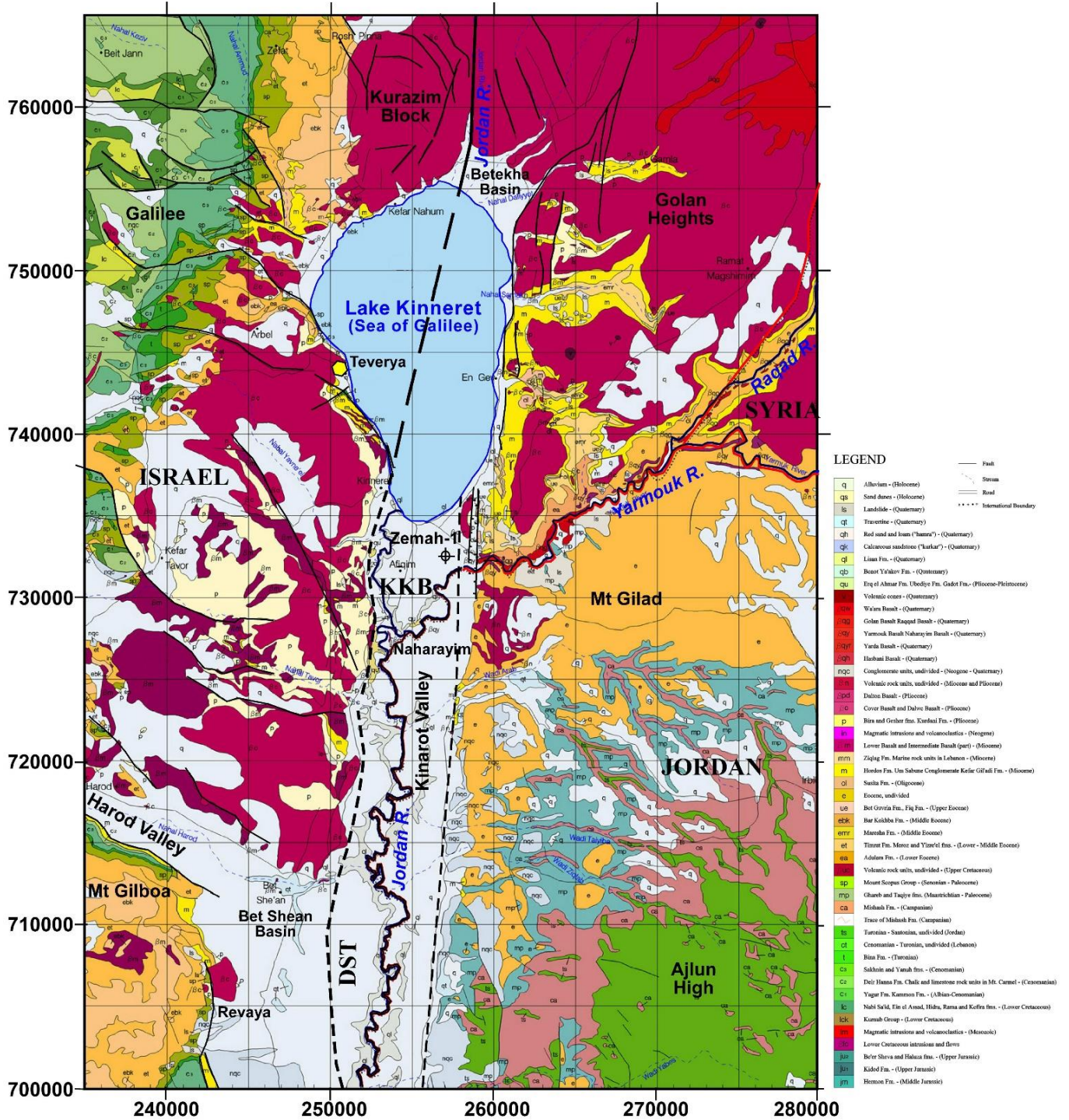


Figure 3. Location and geological map 1:200,000 of the Kinneret - Kinarot region (modified after Sneh et al., 1998) (DST faults after Schattner et al., 2019).

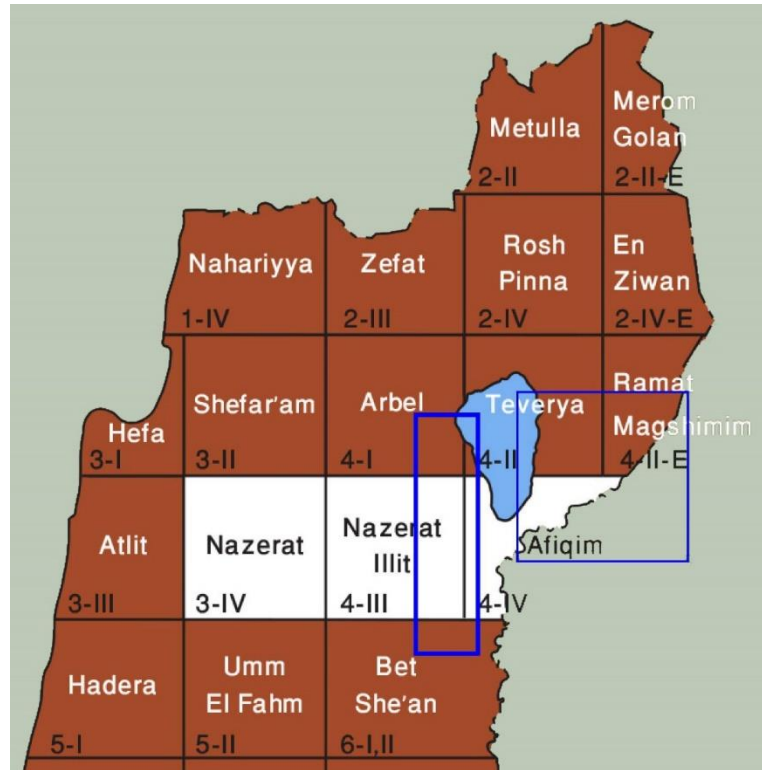


Figure 4 A. Index Maps.

The lower basalt flow from Kokhav HaYarden yielded a  $9.09 \pm 0.09$  Ma  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau age and the upper flow yielded nearly identical  $8.48 \pm 0.09$  Ma and  $8.51 \pm 0.06$  Ma  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau ages. Two samples from the flow in the NB 1 borehole did not yield plateau ages.

### 3.4. Gesher Formation and Fejjas Tuff

The fresh to brackish lacustrine sediments of the Gesher Formation interfingered with Fejjas Tuff and in places where both formations are absent, the Pliocene Cover Basalt Formation base was found to be ca. 5.1 Ma (Rosenbaum et al., 2017). Therefore, the Fejjas Tuff has been considered to be part of the Cover Basalt. The age of the Gesher Formation is also concurrent with the Cover Basalt Formation (Shaliv, 1991; Heimann et al., 1996) within an Ar-Ar age range of 5.1 Ma to 4.0 Ma for samples north of Bet She'an (Rosenbaum et al., 2017; Fig. -). South of Bet She'an, in Revaya and Marma-Feiyad, an Ar-Ar age range of 5.42 to 5.65 is defined by Dembo et al. (2015). A freshwater environment is suggested for the Gesher Formation based on several macrofauna species (Picard, 1943; Bentor, 1946; Schulman, 1962).

### **3.5. Cover Basalt Formation**

This Formation is exposed in northern Israel (Picard, 1936; Schulman, 1962), southern Golan Heights and northwestern Mt Gilad in Jordan. Heimann et al. (1996) compiled the published age data and bracketed the formation's age between 5.5–3.3 Ma. K–Ar and Ar/Ar dating of the Cover Basalt in the study area yields an age of 5.1–4.0 Ma, whereas the youngest age is from the top Kinneret quarry (Rozenbaum et al., 2016). The exposures of this formation are widely spread on the KKB western margin and a few sites near Ubeidiya and Newe Ur (Heimann and Braun, 2000; Fig. 4 A,B). Maximum exposed thickness of this formation in the study area is ~150 m. Basalts have chemical and mineralogical characteristics of alkali olivine basalt and the chemical analyses show relatively low silica, high total alkalis, high K, and high TiO<sub>2</sub> contents (Weinstein, 1998, and references therein).

### **3.6. Erk-el-Ahmar Formation**

The Erk-el-Ahmar Formation (Horowitz, 1974; Tchernov, 1975; Heiman and Braun, 2000) is exposed only within the Kinarot Valley. It consists of alternating layers of brown clay, marl, silt, sand, and conglomerate with few carbonate and organic rich layers. The lower part of the section is rich in mollusks, flora, and fish remains. Tchernov (1975) describes freshwater mollusk species and skulls of mammals and elephants from a site near Kibbutz Gesher. The upper part of the section contains a few phosphate layers (Heiman and Braun, 2000). Hominid chert tools were found in the sequence by Horowitz (1979), Verosub and Tchernov (1989). Horowitz (1979) suggested that this formation was deposited in fresh to brackish lacustrine conditions. Braun (1992) interpreted maximum thickness of the formation to be ~500 m, although only 75 m is exposed. The formation has many intra-formational unconformities and has been faulted and tilted, mainly eastward, from 15° to vertical (Heiman and Braun, 2000). On the surface, the conglomeratic or basaltic members of the Naharayim Formation or the Lisan Formation unconformably overlie the Erk-el-Ahmar Formation.

Cosmogenic burial ages, using <sup>26</sup>Al, <sup>10</sup>Be, and <sup>21</sup>Ne in quartz-chert sedimentary mixtures, of the exposed 2–36 m below the surface yielded a Pliocene age range of 3.15–4.5 Ma (corrected dates) for this lacustrine formation (Davis et al., 2011). This date is very close to the final Cover Basalt eruptions.

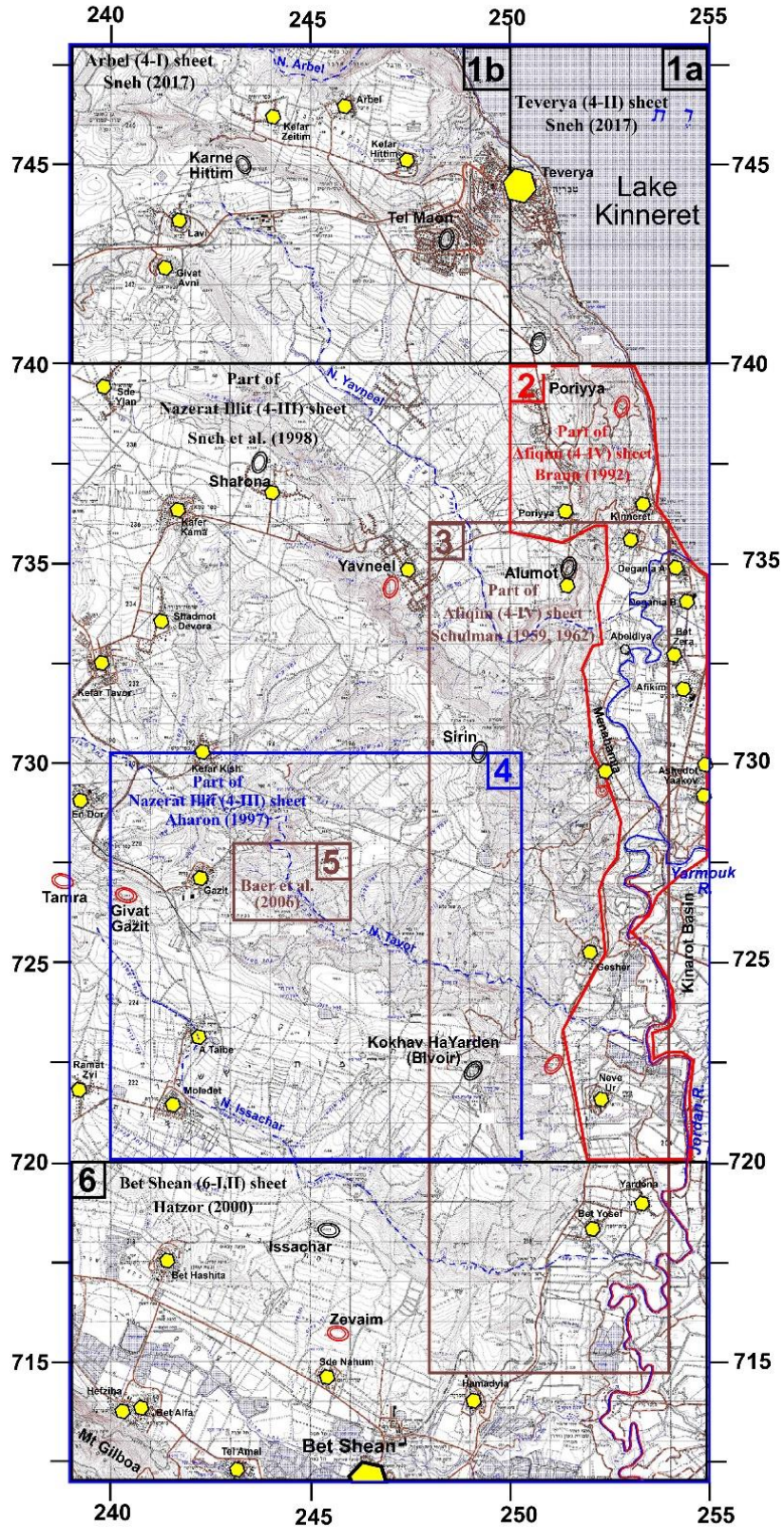


Figure 4 b. Study Area coverage of previous geological maps (sources).

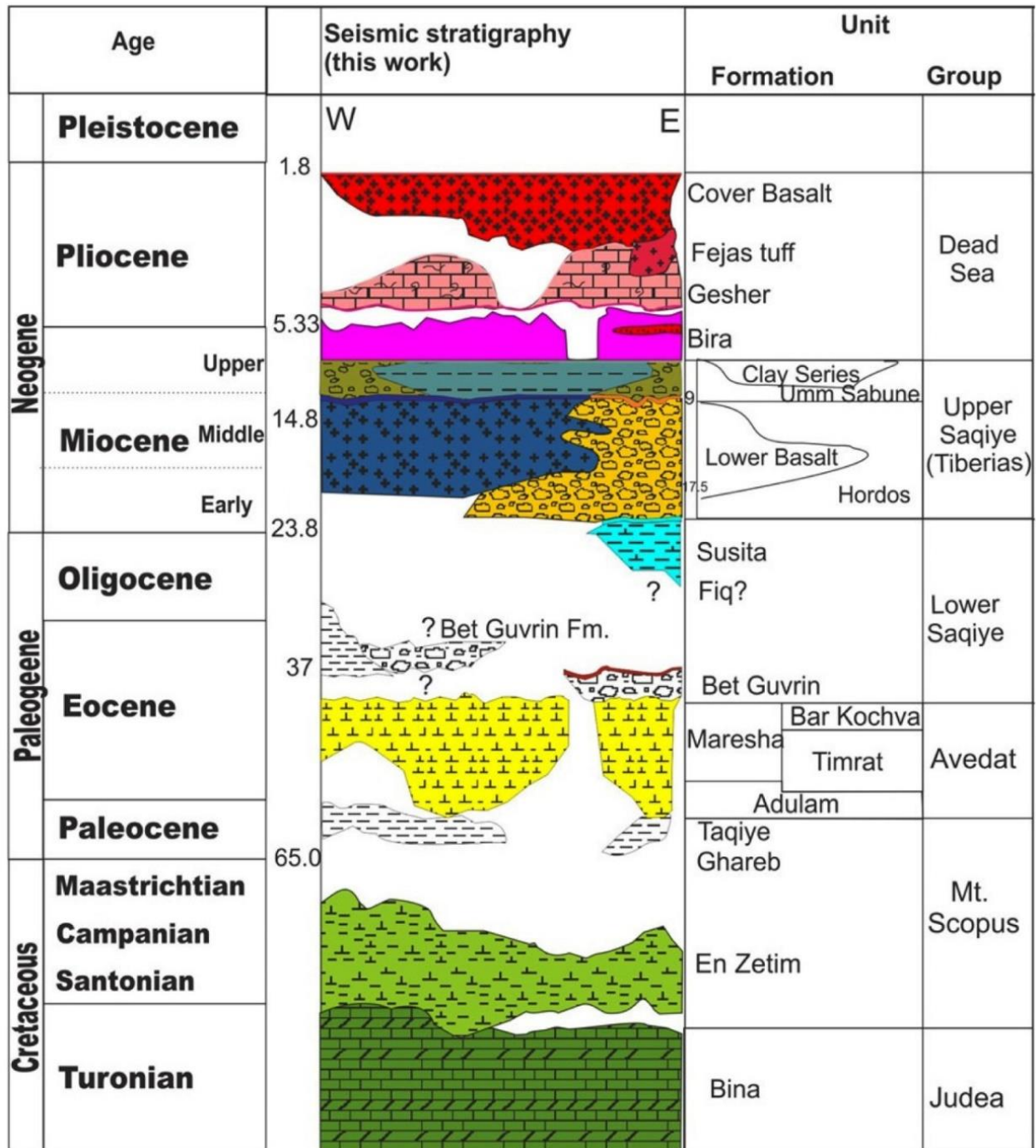


Figure 5. Composite chronostratigraphic section of the SE Galilee region (from Wald et al, 2019a). Ranges of radiometric ages of basalts and pyroclastic are those of Shaliv (1991), Heimann et al. (1996), Segev (2000), Rozenbaum et al. (2016).

### **3.7. Ubeidiya Formation**

The Ubeidiya Formation is exposed in a limited area, mainly west of Kibbutz Bet Zera (a known archeological site), and near Degania B (Fig. 4 B), as well as near Al-Adassiyah in Jordan and northwest of Tel Qatzir (Blankenhorn, 1897; Picard, 1932; Schulman, 1962; Picard and Baida, 1966 a,b). The formation consists of oolitic limestone, chalk, lacustrine clay, and fluvial conglomerate (Picard and Baida, 1966 a,b). The base of the unit is not exposed and the upper contact with the Naharayim or Lisan formations is unconformable. The exposed thickness in Ubeidiya is 154 m (Picard and Baida, 1966 a,b). The Ubeidiya Formation is folded and the strata are tilted in several places by up to 50° (Heimann and Braun, 2000). This formation is well known for its significant archaeological and faunistic assemblages (e.g., Stekelis, 1966; Goren, 1981; Bar-Yosef and Tchernov, 1986; Tchernov, 1986).

### **3.8. Naharayim Formation**

The Naharayim Formation (Picard, 1932), a lacustrine, fluvial, and volcanic unit, is exposed in the central part of the Kinarot Valley (e.g., Heimann and Braun, 2000). Its lower contact with the Erk-el-Ahmar and Ubeidiya formations is a significant angular unconformity. This horizontal formation is covered, in places, by the Lisan Formation. The lower Yarmouk Basalt within this formation, is K-Ar and Ar-Ar dated to  $0.79 \pm 0.05$  Ma, whereas the upper basalt unit is K-Ar and Ar-Ar dated to  $0.67 \pm 0.09$  Ma (Heimann and Braun, 2000). In Zemah-1 well thickness of Naharayim Formation is 42 m, according to the palynological considerations of Horowitz (1983).

### **3.9. Lisan Formation**

The Lisan Formation (Lartet, 1869) is exposed from the Sea of Galilee in the north to south of the Dead Sea in the south. Its age in the Dead Sea area is 70–17 Ka (e.g., Begin et al., 1974; Kaufman et al., 1992; Marco, 1996), however, according to Heimann and Braun (2000) the age of the Lisan Formation in the Kinarot Valley is ~30–17 Ka. The thickest outcrop in the Kinarot Valley is ~25 m near Menahamya. The Lisan Formation overlies unconformably the Erk-el-Ahmar, Ubeidiya and Naharayim formations and is covered by alluvium. In most of the area, the Lisan layers are horizontal, but in some, they dip 5° towards the east.

The Lisan Formation in the study area is mainly clastic and consists of local detrital material (mainly Turonian limestone, Eocene chalk and chert, and Neogene basalts) having a variable size

between clay and pebbles (up to 30 cm). Pure aragonite layers are rare and some diatomite layers were found in places, south of Kibbutz Gesher. According to Begin et al. (1974), the fauna and flora assemblages of the Lisan is poor (*Melanopsis*, *Melanoides*, *Theodoxus*).

## **4. Geological mapping**

### **4.1. Method**

The study area extends within several standards 1:50,000 sheet of the Survey of Israel, from north to south (Fig. 4 A): Arbel (4-I), Teverya (4-II), Nazerat Illit (4-III), Afiqim (4-IV) and Bet Shean (6-I, II). The northern Arbel and Teverya sheets (Bogoch and Sneh, 2008; Sneh, 2017), and southern Bet Shean sheet (Hatzor, 2000) were accomplished and used here almost as is, but generalized the Cretaceous and the Eocene formations.

Sources for the current map (Fig. 4 B) were as follows: (a) the western part of Afiqim sheet is mapped by Schulman (1959, 1962), Braun (1992) and Heimann and Braun (2000; mainly within the Kinarot Basin); (b) the southeastern part of Nazerat Illit sheet is mapped by Aharon (1997) and Baer et al. (2006); (c) several previous geological maps of different parts of the study area are compiled to 1:200,000 map by Sneh et al., (1998).

An important assumption for the current mapping comes from previous mapping of the southwestern Golan Heights or the eastern margin of the DST (Segev and Reznik, in prep.) and the accomplished Teverya (Sneh, 2017) and Bet Shean (Hatzor, 2000) geological maps. All these maps clearly show the spreading of the Cover Basalt Formation from the high mountain ranges (Mt Gilad, Golan Heights, Kokhav HaYarden, Sirin and Poryya Heights), ~200-300 m above sea level, down to the KKB foothills ~ -200 m above sea level. Therefore, the current investigation adopted these evidence and conclusions from the eastern DST margin by which the Pliocene Cover Basalt lavas flowed from the mountain ranges down to the KKB. Combining this concept together with most of the previous sources, rock definitions enabled solving the field relations in the study area. The main amendment to this approach was done for the Lower Basalt Formation outcrops between Nahal Yavneel and Kibbutz Gesher (Fig. 6). The basalts from these outcrops were not dated by radiometric methods, and their occurrence on the slope and between SSE-NNW faults is complicated.

The inferred location of the main DST fault is adopted from Schattner et al. (2019). The topographic contour lines were constructed by SURFER program from the DTM of Hall and Cleaver (1986).

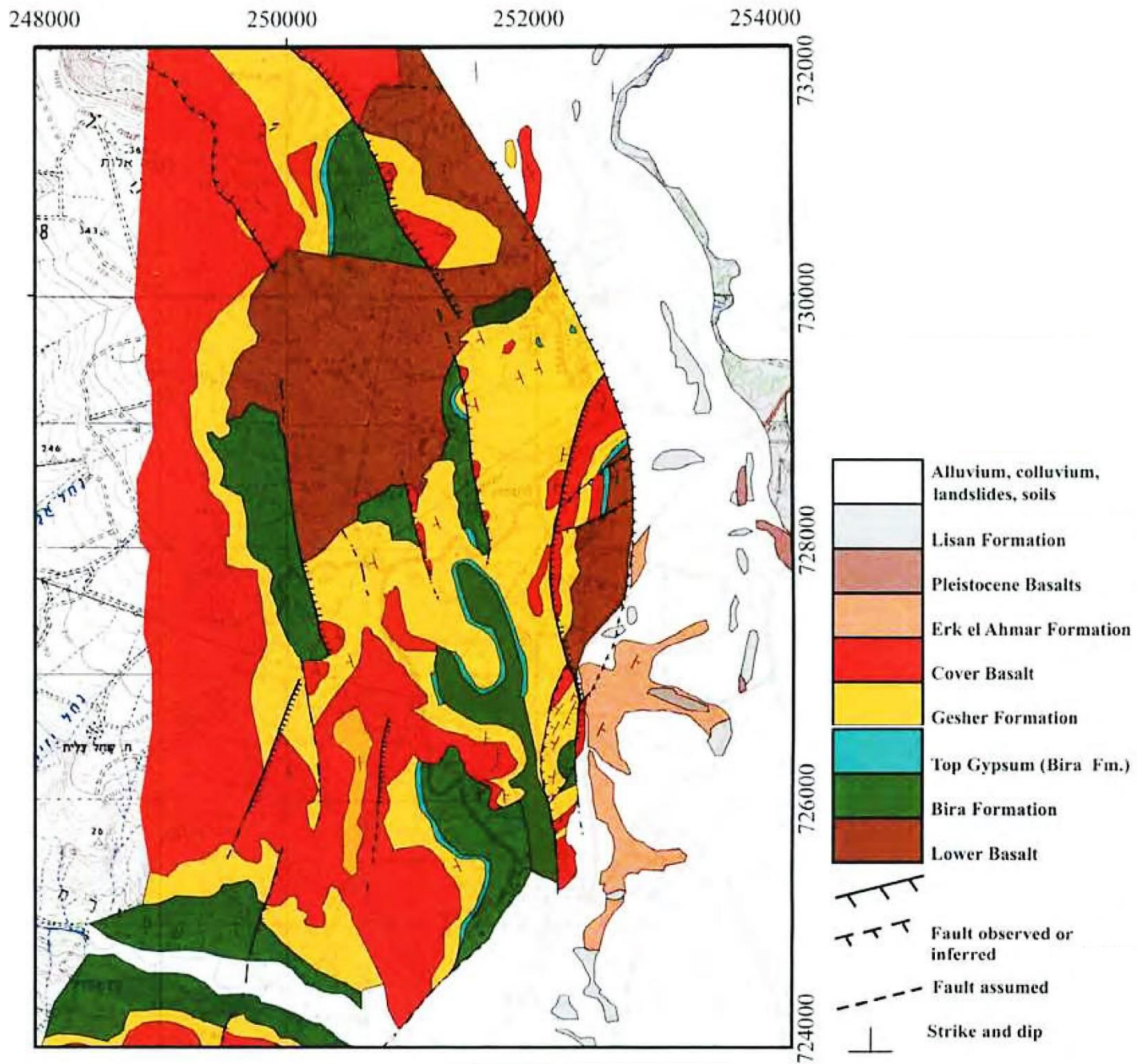
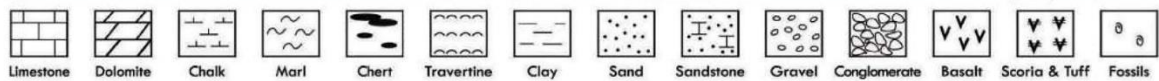


Figure 6. Geological map of Geshher-Menahemya region (after Rozenbaum et al., 2015, used Schulman, 1959 and Braun, 1992 as sources). This map exhibits the difficulties in understanding the geology of this region (for more explanation see text).

SYSTEM	SERIES - STAGE	THICKNESS (m)	AGE (Ma)	LITHOLOGY	LITHOSTRATIGRAPHY			
					SYMBOL	MAPPING UNITS	GROUP	
QUATERNARY	HOLOCENE	2+			Al	Alluvium, colluvium, soil	DEAD SEA	
		2+			Qt	Travertine		
	PLEISTOCENE	25			Qli	Lisan & Naharayim Fms.		
		154			Qu	Ubeidiye Formation		
	PLIOCENE	75+			Qe	Erk-el-Ahmar Formation		
			4.0		Pbc	Cover basalt		
		80			Ptf	Feljas Tuff		Gesher Formation
			5.6		Pg			Bira & Gesher fms.
		UPPER	70		Mb	Intermed. basalt		Bira Formation
			9.1		Mci			
NEOGENE	MIOCENE	MIDDLE	450+	Mh	Lower Basalt	Hordos Formation		
				Mβ1				
	Eocene	MIDDLE	180	Ea	Maresha Fm.	Bar Kokhba Formation		
		LOWER	50			Adulam Formation		
CRETACEOUS	UPPER CRET.	SANTONIAN	20			Menuha Fm., Har Zefat Mbr.		
		TURONIAN	70		Kjm	Bina Formation		
		CENOMANIAN	80+			Sakhnin Formation		



GEOLOGICAL LEGEND	
Contact between mapping units	—————
Contact, inferred	- - - - -
Fault	—————
Fault, throwdirection unknown	—————
Fault, inferred	——— ———
Fault, concealed	..... .....
Reverse fault	——— ———
River, Wadi (Nahal)	——— ———
Geographical border	—————
Volcano Normal\Reverse magnetic polarity	○ ○
Center of RTP magnetic anomaly	● ●
Normal\Reverse polarity	6 2
Schematic basaltic flow direction	→
Quarry	⊖
Settlement	⊙
Sampling site & radiometric age (Ma)	4.9 ▲

Figure 7. Stratigraphy and Geological legend for the geological map, figures 8, 9.

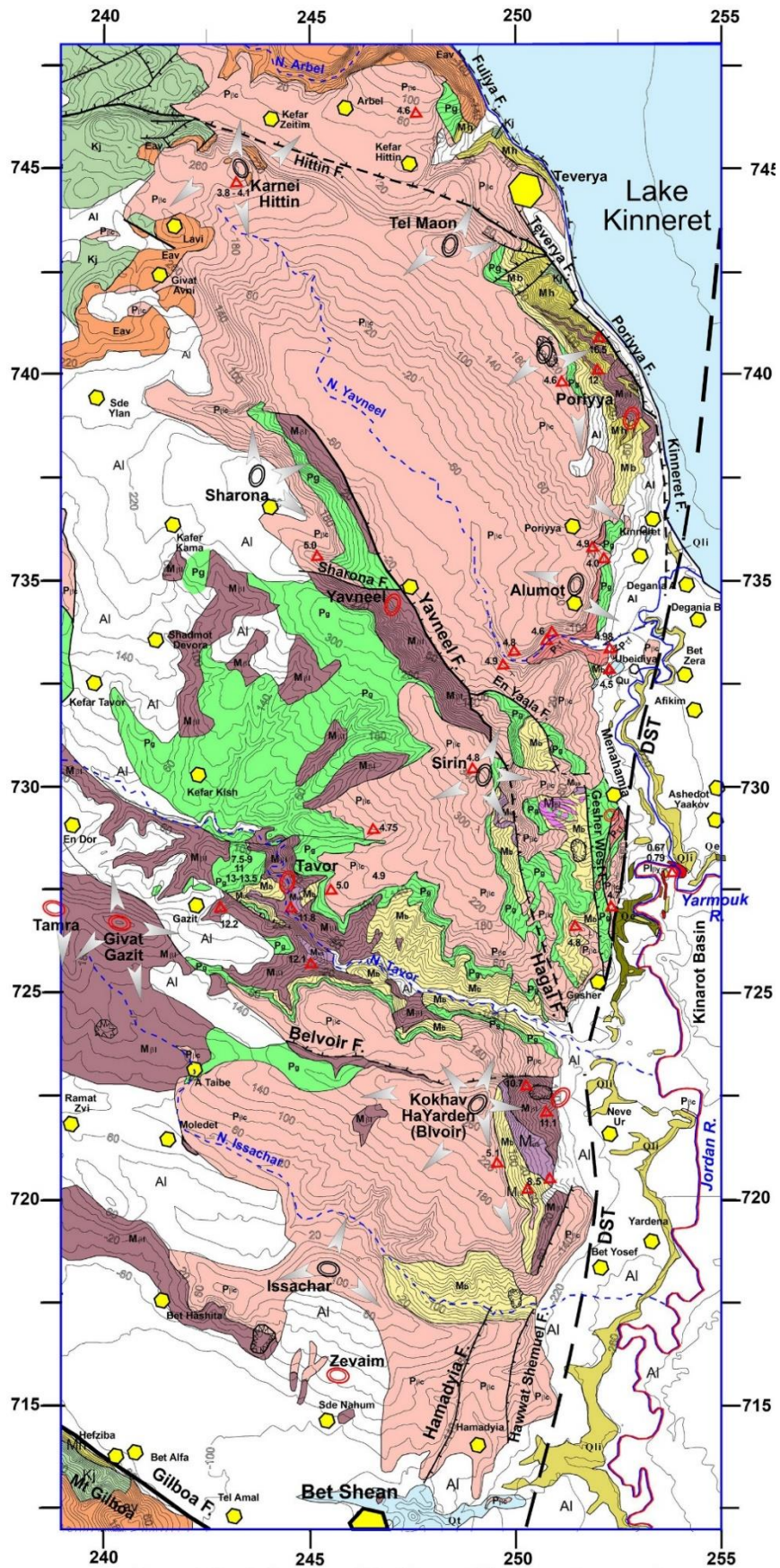


Figure 8. Geological map of the Kinneret-Kinarot western margin (for stratigraphy and geological legend see Fig. 7).

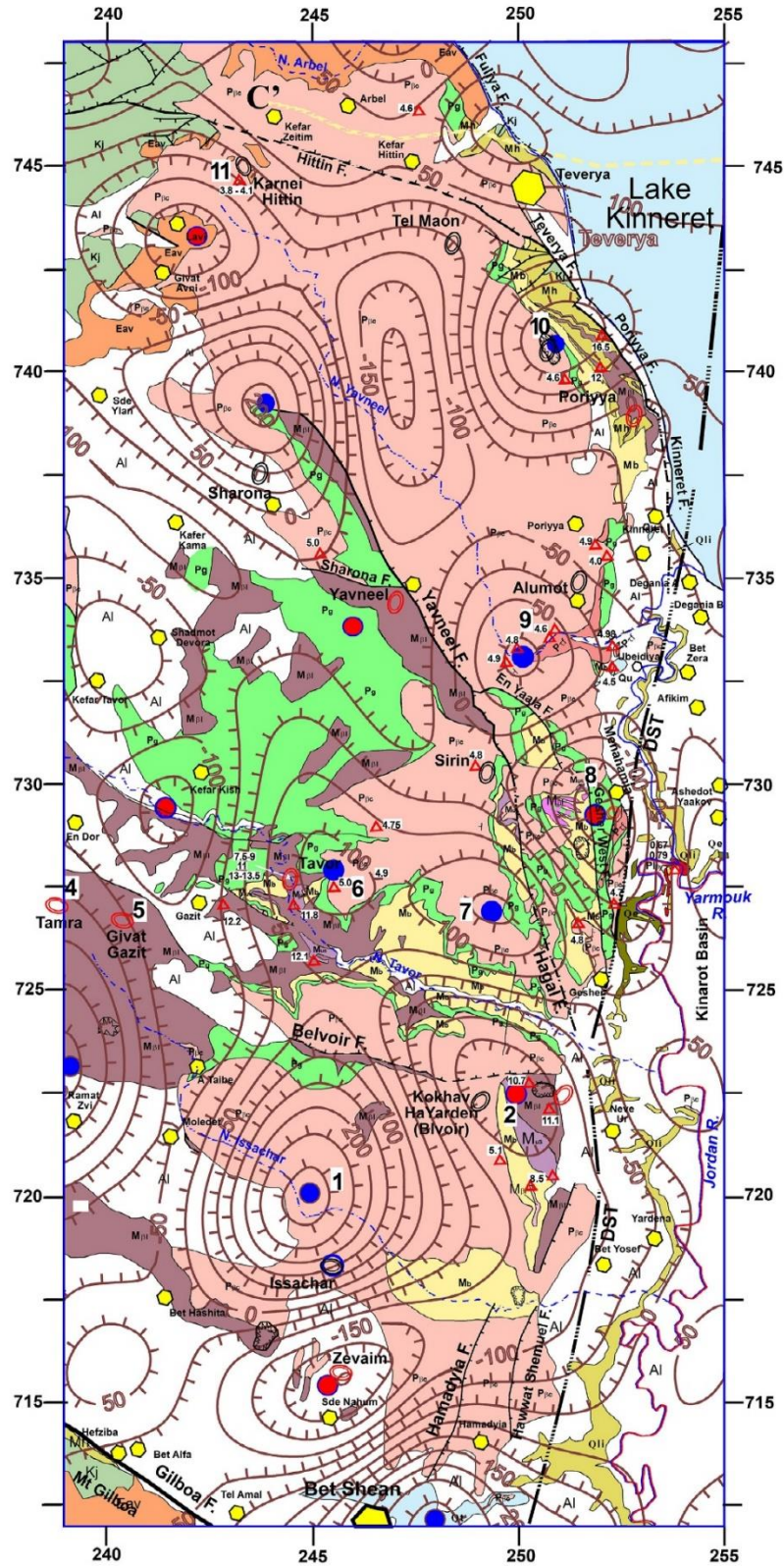


Figure 9. Geological map of the Kinneret-Kinarot western margin with Reduced-to-pole magnetic anomaly map (brown contour lines; after Schattner et al., 2019; for stratigraphy and geological legend see Fig. 7).

## **4.2. 1:50,000 Geological map of the KKB western margin**

The newly constructed geological map (Figs. 7, 8) enables a broad and coherent view along ~40 km of the KKB western margin. This map shows the dominant distribution of the Pliocene Cover Basalt Formation (CB) over the N-S DST western margin.

At the northern (Teverya region) and the southern (Bet Shean region) parts of the study area, the relatively gentle slopes are clearly covered by the CB that differentially covered the underlying rock units. Close to the central part of the map, in places with steep slopes and/or intensive faulting, like the Gesher Menahama region (previous mapping in Fig. 6), large parts of the CB were eroded and thus left a complex and puzzling geological situation.

The intensive faulting of Gesher Menahama region is probably due to the northwestward branching of the Yavneel Fault from the main DST fault zone close to its northeastward turn and oblique crossing of the Lake Kinneret Basin. Obscurity and perhaps controversy came up in the basaltic slopes west of Menahama. In Schulman's (1959) map, he defined these slopes as Lower Basalt (Fig. 8), however in Schulman's (1962) map the same basalts were not defined clearly. Rozenbaum et al. (2015, Fig. 8) adopted most of Schulman's version (1959), which emphasizes several logical problems that Schulman (1962) tried to change. Until now there are no available radiometric ages for these basalts, thus it is defined in the current map as Cover Basalt downslope flows, similar to the simpler regions of Teverya on the north and Nahal Tavor on the south. While the new map helps in understanding the wide geological complications, it does not deal with detailed sites that can enlighten important geological problems (stratigraphy, volcanology or structural). The completion of the new geological map actually accomplishes the aim of the current investigation.

In addition to the current regular geological mapping, published radiometric ages of various basalt rock units have been depicted on the map (red triangles) (Fig. 8). Moreover, to understand the subsurface of the study area, results of the Reduced-to-pole magnetic anomaly map (Schattner et al., 2019) are superimposed on the new geological map with the same numbering of the anomalies (Fig. 9).

## **5. Summary and conclusions**

### **5.1. Mapping and geomorphology**

Complications during the previous geological mapping of the Gesher – Nahal Yavneel region were due to (1) similarities between the rocks of the Lower and the Cover Basalt formations and the absence of radiometric measurements that could have been solved in this issue; (2) differential erosion

of the steep slopes covered by relatively thin Cover Basalt flows reveal non-sequential puzzling basalt outcrops; (3) the northwestward branching of the Hagal-Yavneel faults (Fig. 8) from the DST western fault caused complicate SE-NW sub-parallel step-faults; (4) erroneous assumptions and interpretations of Schulman (1959, 1962, 1966) about the age of the lithostratigraphical units and the faulting, as well as the mode the "Jordan Graben" formation (He didn't accept the presence of the DST). According to him, the site of the town of Teverya and its lakeshore in the Upper Pliocene, (~ -200 m a.s.l at present) were structurally higher than Tel Maon in the west (~+250 m a.s.l at present).

The modern approach for the DST plate boundary and further investigations, led to new insights into the current study. The Pliocene Cover Basalt expansion over the underneath formations along the entire KKB western margin is clearly indicate its downward flow into the KKB. These are exactly the same observations and conclusions of Segev and Reznik (in prep.) from the KKB eastern margin and of Bendor (1957) and Golani (1962) from the Teverya region. This conclusion contradicts the proposed explanation of Schulman (1966) by which two intersecting fault systems caused this occurrence in both Teverya and Kokhav HaYarden (Belvoir) regions. The existence of deep morphological depression within the KKB during Pliocene times is an expected consequence of the long lasting evolution of this DST segment. Segev et al., (2014) suggested initiation during the Oligocene northwestward propagation of the Irbid Rift that followed by the localization of the N-S DST during the Early Miocene ~20 Myr ago. Along this time table the Cover Basalt volcanism took place ~15 Myr after the beginning of the DST.

## **5.2. Volcanic eruption centers**

About eight volcanic eruption centers of the Lower Basalt Formation are suggested in the study area, as follows (red marks on Fig. 8; reviewed by Wald et al., 2019a, fig. 10a there): Zevaim (?), Kokhav, Givat Gazit & Tamra, Tavor, Menahamya (?), Yavneel and Poriyya. Most of these sites are close to negative magnetic anomalies (Schattner et al., 2019). In general, strong magnetic anomaly indicates significant subsurface basaltic body. Part of the Lower Basalt volcanos are close to younger, Cover Basalt volcanoes that typify by positive magnetic anomalies (black marks on Fig. 8). Therefore, the interpretation of the magnetic anomalies gives us only indications. According to this line of evidence, the Menahamya negative magnetic anomaly indicates possible large subsurface Miocene basaltic body. This site is close to the suggested volcanic center of the Intermediate Basalt (Schulman, 1962) that probably affected (metasomatism) the gypsum body at the upper part of the Bira Formation (Nissenbaum

et al., 1977; Segev and Wachs, 1979). The Menahamya intensive negative magnetic anomaly may indicate subsurface Lower Basalt basaltic body.

The suggested Cover Basalt eruption centers are based on the morphotectonic configuration and the location of mainly positive magnetic anomalies. The summit of the Cover Basalt volcanoes is located at least 100 m above its close surroundings. Eight volcanoes of the Cover Basalt phase are suggested in the study area, from south northward: Issachar and Kokhav (both close to anomaly 1), Sirin (close to anomalies 6, 7), Alumot (close to anomaly 9), Poriyya and Tel Maon (both close to anomaly 10), Sharona and Karneii Hittin. Excluding the last volcano all six lasted between ca. 5.1-4.5 Ma and actually acquired normal magnetic polarity. The Karnei Hittin volcano is younger (4.1-3.8 Ma) and acquired mainly reverse magnetic polarity.

### **5.3. Dominant fault systems**

The northwestward propagating Irbid Rift since the Oligocene (Fig. 10) caused a series of SE-NW to E-W sub parallel faults at eastern Samaria and the Lower Galilee area (Segev et al., 2014; Wald et al., 2019a). The Faria, El Buqeita, Tayasir and Gilboa faults belongs to the early stages of this rifting event. Excluding the Gilboa Fault, their limited NW extension indicates minimal propagating since the Early Miocene. However, this is at present still an intensive seismogenic region (Wetzler and Kurzon, 2016). Hashita and Belvoir faults, in the study area, belongs to this early faulting. In general, this fault system settled mainly between the Late Oligocene and the Early Miocene when the Irbid Rift reached the DST zone. From ~17 Ma the Irbid rift center, or the Betekha low, opposed the Bet Shean low.

The second NWN to NW fault system (crescent-shaped faults after Picard, 1954; Vroman, 1958; De Sitter, 1962.) is developed from the Bet Shean region on the south up to Lake Kinneret on the north, as follows (Fig. 10): (a) the Rewaya and Gefet faults that join together with the Gilboa Fault; (b) Hagal-Yavneel Fault; (c) Kinneret-Hittin Fault; and (d) Fullya-Arbel Fault. These four faults gradually branch out from the DST western marginal Fault and propagated toward the west. This fault system terminates close to the Central Galilee Escarpment (CGE, Matmon et al., 2003) which marks the northern end of the eastern Galilee Cenozoic magmatic belt (Fig. 3). The Kurazim high basaltic block is located north of the Kinneret Basin and northeast from the Galilee belt. It has similar characteristics to the KKB subsurface where several hundred meters of basalts flowed from the Golan Heights to fill this basin (Segev and Reznik, in prep.).

Both the SE-NW to E-W and the NWN to NW fault systems are exceptional all along the ~1,000 km of the DST. They occur exactly at the intersection between the SE-NW Harrat Ash-Shaam volcanic

field and the DST. This intersection is typified by two main characteristics: high heat flux and approximately N-S extensional stress, which have been active since the Early Miocene.

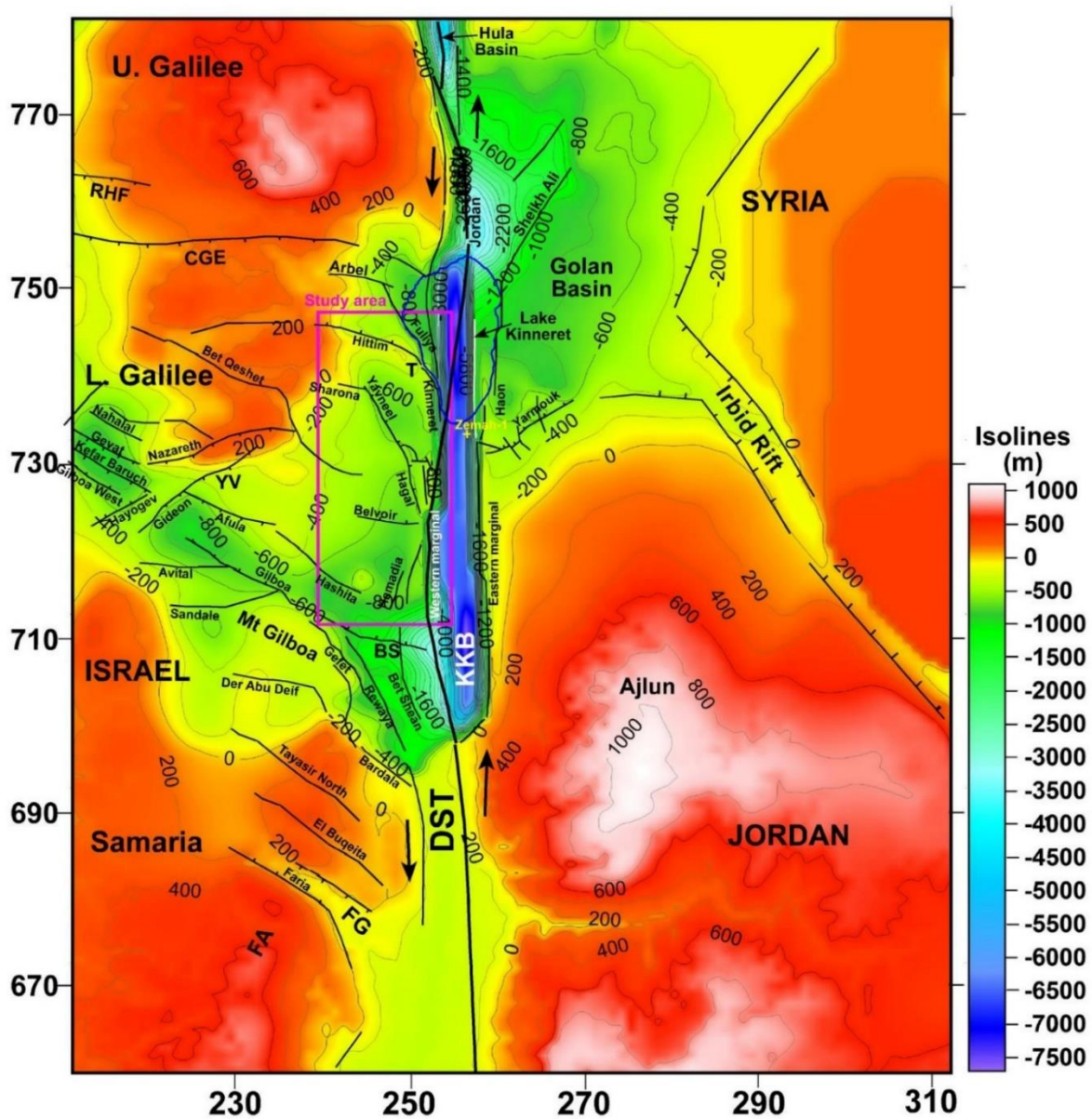


Figure 10. Structural color map of the Late Cretaceous top Judea Group interface in N Israel, NW Jordan and SW Syria (in meters, datum: present day MSL). The data is compiled after Segev et al. (2014), Rosenthal et al. (2015) and references therein. Faults in the Dead Sea–Kinneret-Kinarot-Hula basins are after Schattner et al. (2019) and references therein. The Carmel-Gilboa fault system is after Wald et al. (2019 a) and the Yarmouk Fault after Segev and Reznik (in prep.). KKB, Kinneret-Kinarot Basin; DST, Dead Sea transform; FG Faria graben; FA, Faria anticline; CGE, Central Galilee escarpment; RHF, Rosh HaNikra fault.

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