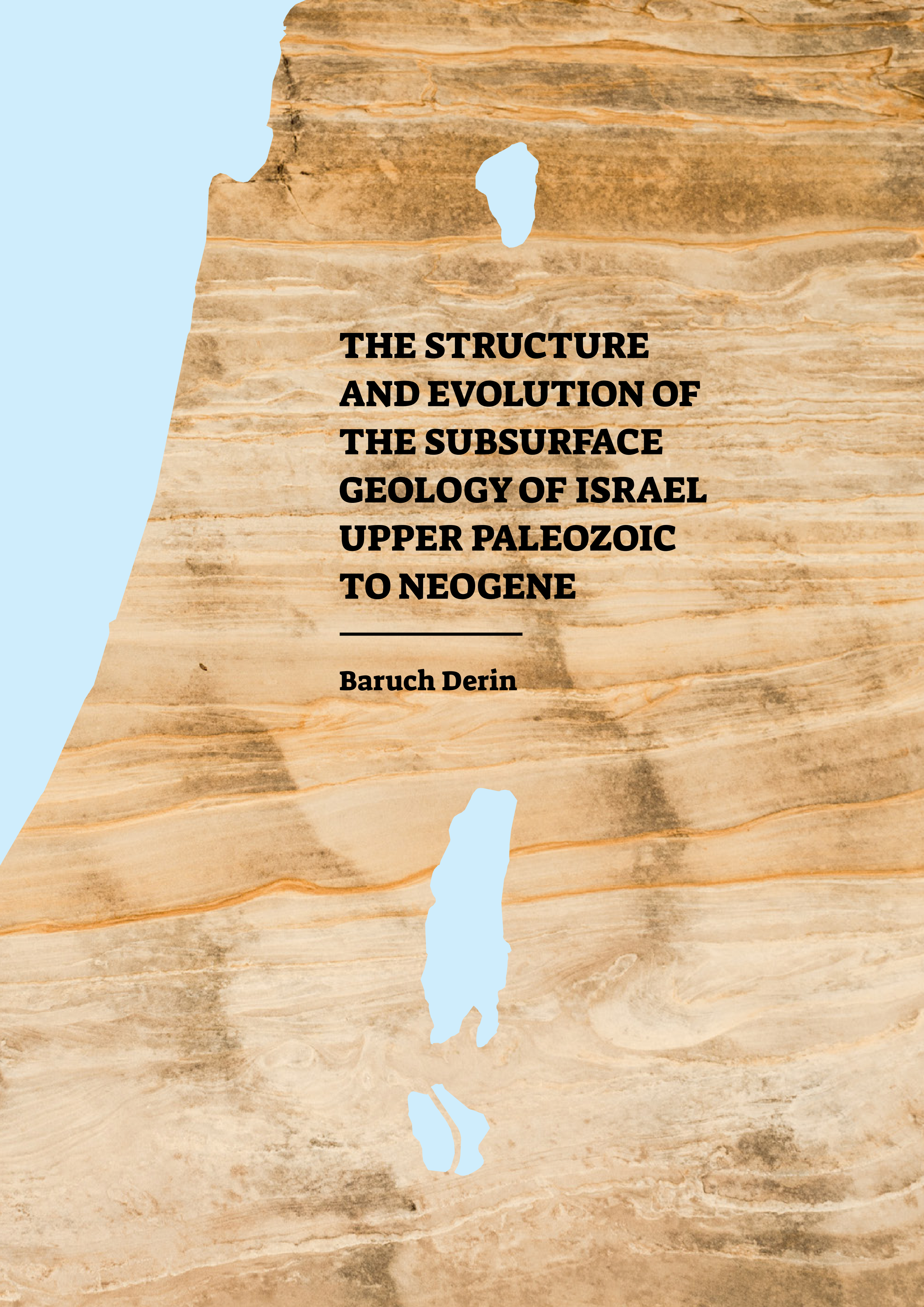

THE STRUCTURE AND EVOLUTION OF THE SUBSURFACE GEOLOGY OF ISRAEL UPPER PALEOZOIC TO NEOGENE

Baruch Derin

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BY

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PREFACE

More than 75 years have passed since Prof. L. Picard, the founder of geological research and education in Israel, published his monumental monograph "Structure and Evolution of Palestine, with Comparative Notes on Neighboring Countries". Picard's monograph (1943) was based on the exposed geology, data from water wells, and correlations with Alpine Europe. Since then, numerous studies have been carried out (e.g. Derin 2016, Garfunkel 1998, Garfunkel and Derin 1985, Segev et al. 2018), revealing disagreements among scholars as to onshore and offshore regional geological history. The present work is not a compilation, nor is it based on proposed theories; rather, it suggests a new approach to describing the geological evolution of Israel. It is closely related to Darin's (2016) monograph "The Subsurface Geology of Israel, Upper Paleozoic to Upper Cretaceous" which is essentially a stratigraphic analysis and summary of the geological sequence. It is our firm belief that after long years of data gathering and research, the time has come to present this new approach and re-evaluation of the accepted tectonic model.

Today, Israel's subsurface geology is fairly well-known, based on numerous seismic profiles and on more than 400 exploratory oil wells drilled onshore and offshore, extending beyond the continental shelf, and expanding from the sparsely penetrated Paleozoic up to the Quaternary. Most of the boreholes have been studied in detail by Derin and others, with findings published in numerous papers of the Micropaleontological Laboratory of the Israel Institute of Petroleum Research and Energy 300 km long, extending from northern Galilee to the Sinai border, and about 120 km wide, between the Jordan Rift Valley and the coast, altogether encompassing a surface area of approximately 42,500 km^2.

The stratigraphic interval studied and discussed herein ranges from the Upper Carboniferous to the Neogene. Beds older than the Upper Carboniferous have only been drilled in one well in Israel: Ma'anit-Josef 3 in the Samaria Province (Fig. 1). Thin, older Paleozoic sediments are found as outcrops in Sinai, reaching northward to the Eilat–Timna area (Weissbrod 2005), but are totally absent northward in the Negev, and in the southern Judea Province (Fig. 1).

It is suggested that two unconnected types of major events exist: tectonic and cosmic (extraterrestrial origin). At the Paleozoic–Mesozoic boundary (252 Ma), between the

Permian and Triassic periods, a high-energy cosmic event caused the global mass extinction of species (Dar et al. 1998). An asteroid impact caused partial mass extinction between the Maastrichtian stage and the Paleocene (66 Ma). In contrast, the Paleotethys–Neotethys boundary represents a tectonic event associated with faulting and volcanic activity, between the Carboniferous and Early Permian. All of the other events discussed are also tectonic events.

The new approach to the structure and evolution of the subsurface geology of Israel is presented here in outlines only. We hope that the concepts and ideas raised in this work will challenge future research and new thoughts on the subsurface geology of Israel.

מבוא

יותר מ 75 שנה חלפו מאז כתב פרופסור ל. פיקרד, אבי המחקר וההוראה הגיאולוגיים בישראל את המונוגרפיה המונומנטלית -

"STRUCTURE AND EVOLUTION OF PALESTINE, WITH COMPARATIVE NOTES ON NEIGHBORING COUNTRIES".

העבודה (1943) הייתה מבוססת על מחשופים גיאולוגיים, נתונים מקידוחי מים וקורלציה עם אירופה האלפינית. מאז נערכו בארץ מחקרים רבים בהם מציגים החוקרים מסקנות, לעיתים מנוגדות, לגבי ההיסטוריה הגיאולוגית של ישראל. המחקר הנוכחי איננו מהווה סיכום של מחקרים קודמים אלא מציג גישה חדשה בנושא ההתפתחות הטקטונית של ישראל. הוא קשור לספרו של ב. דרין –

"THE SUBSURFACE GEOLOGY OF ISRAEL, UPPER PALEOZOIC TO UPPER CRETACEOUS"

אנחנו חושבים שאחרי שנים רבות של איסוף נתונים ומחקר הגיע הזמן להציג גישה חדשה ולימוד מחדש של המודל הטקטוני המקובל. ידיעותינו על הגיאולוגיה של תת הקרקע כיום מבוססת על מספר רב של חתכים סיסמיים ועל יותר מ 400 קידוחים לחיפושי נפט המשתרעים מעבר למדף היבשת וכוללים את החתך הגיאולוגי מהפליאוזואיקון עד לקוורטר.

תקציר

המחקר הנוכחי משתרע על שטח שאורכו כ 300 ק"מ מצפון הגליל עד לגבול סיני ורוחבו כ 120 ק"מ בין בקע הירדן והחוף, שטח של כ 42,500 קמ"ר. האינטרוול הסטרטיגרפי שנחקר כאן הוא בין הקרבון העליון לניאוגן. מחשופים דקים של סדימנטים מפליאוזואיקון קדום יותר מוצאים בסיני וצפונה באזור אילת-תמנע (Weissbrod 2005). סדימנטים עתיקים מקרבון עליון בתת הקרקע נמצאו רק בקידוח אחד, מענית יוסף 3 באזור השומרון.

בישראל נמצאו שלוש קבוצות של קווים טקטוניים: קווים עתיקים, קווים טתיאליים וקווים צעירים מגיל אוליגוקן תיכון. הקווים מפרידים בין לוחות, פרובינציות ובלוקים הקשורים ל "משטרים טקטוניים" שונים ונוצרו במשך מרווחי זמן אחדים מהפליאוזואיקון להיום. הקווים העתיקים הפעילים החל מהפליאוזואיקון מסודרים מדרום לצפון הם: קו הנגב הצפוני, קו אשדוד, קו יפו, קו הכרמל וקו עכו. הקווים התטיאנים פעילים החל מאמצע הטריאס (אניזיאן מאוחר) וכוללים, ממזרח למערב את קו האניזיאן המאוחר, קו "פוסט נוריאן חלץ-עתלית וקו קצה המדף המערבי (איור 8).

הקבוצה השלישית של קווים הם הקווים הצעירים, פעילים מאז האוליגוקן האמצעי (מלפני 28 מ"ש) וקשורים לפעילות הטקטונית שהתקיימה על כל שטח הים התיכון, בדינרידים, יון, איטליה, סיציליה, סרדיניה וקורסיקה בתהליך הסגירה של הים התיכון. הקבוצה כוללת באזורנו את העתק התזוזה של ים המלח, הגרבן של הסואץ והגרבן של הנילוס.

בישראל זוהו שלוש הסדרות הסטרטיגרפיות העיקריות, הפליאותטיס, ניאותטיס והנאוגן של הים התיכון. על פי נתוני החזרה גיאופיזיים עמוקים (איור 5) אין סדימנטים עתיקים מדרום לקו אשדוד. אזור זה היה חלק מהלוח האפריקאי, אזור מורם חסר השקעה של סדימנטים במשך זמן הפליאוזואיקון. חתכי החזרה סיסמיים עמוקים מצפון לקו אשדוד, דומים לחתכים סיסמיים מהגליל, רמת הגולן, וסוריה, מראים חתך עבה במיוחד, מעל 5,000 מ' של סדימנטים פליאוזואים.

הניאותטיס (פרם עד טורון) הוא היחידה הסטרטיגרפית העיקרית בישראל, בעלת עובי של יותר מ 10 ק"מ של סדימנטים ימיים, אחת העבות בכדור הארץ עם מעט הפסקות סדימנטציה ועם גיוון בסביבות ההשקעה. במשך זמן זה ישראל נמצאה במרכז הניאותטיס עם חתכים סטרטיגרפיים ואירועים טקטוניים דומים גם למזרחו ובעיקר למערבו של אוקיאנוס הניאותטיס. יותר מ 70 תצורות ופרטים הוגדרו בשכבות הניאותטיס ע"י Derin (2016).

בסדרות הניאותטיס מכירים שלש פאזות טקטוניות: פאזת הפלטפורמה (פרם עד אמצע הטריאס), פאזת הביקוע (אניזיאן מאוחר עד אמצע יורה תחתון) ופזת התזוזה (אמצע יורה תחתון עד טורון) (איור 7). שתי הפאזות האחרונות דומות למזרח צפון אמריקה (נובה סקוטיה) ושולי היבשת בצפון מערב אפריקה (מרוקו) (Von Rad et all., 1981).

בזמן חתך הניאותטיס ישראל הייתה במרכז הים, אבל בזמן חתך הניאוגן ישראל הייתה בשוליים המזרחיים של הים התיכון ולכן החתך הסטרטיגרפי של הניאוגן איננו רציף ואיננו שלם, וכשליש מהחתך לא שקע או הוסר (איורים 22-23).

בארץ בניאוגן מוכרות ארבע פאזות טרנסגרסיביות של הים התיכון, הקשורות באירועים טקטוניים ואחריהן פאזות רגרסיביות ללא השקעה. הטרנסגרסיה הראשונה התרחשה בין השאטין (Chatian) לאקוויטן (Aquitanian) המוקדם (לפני 23-28 מיליון שנה), כהצפה שהגיעה עד לבקע של מפרץ סואץ שהתחיל להיווצר. לאחר הטרנסגרסיה הגיעה פאזה רגרסיבית ארוכה גם בישראל וגם בגרבן של הסואץ, פאזה שנמשכה כ- 6 מיליוני שנים, מאקוויטן המוקדם לבורדיגליין המאוחר (לפני 17-23 מיליוני שנים). הפזה הטרנסגרסיבית השנייה שנמשכה מבורדיגליין מאוחר ללנגיין (Langhian), לפני 14-17 מיליוני שנים קשורה לתהליך של שבירה גם בישראל וגם בגרבן של סואץ. בתקופה זו נוצר המילוי העבה בגרבן של הסואץ, כ- 2,000 מ', של אמצע המיוקן. הטרנסגרסיה השלישית התרחשה בין הסרבליאן (Serravalian) האמצעי לטורטוניאן (Tortonia) המאוחר ובעקבותיה הגיעה תקופה רגרסיבית שהתבטאה בהתייבשות הים התיכון ואיוד נרחב של גוף המים. הפזה הרגרסיבית המכונה "משבר המליחות המסיני" (Messinian Salinity Crisis) התחילה יותר מוקדם בישראל מאשר באמצע הים התיכון. בקידוחי מישור החוף בארץ, בתוך החתך האוופוריטי נמצאה פאונה פלנקטונית רק מגיל טורטוניאן ולא מסיניאן (Messinian).

לאחר "משבר המליחות" באה תקופה של שבירה רגיונלית. הטרנסגרסיה הרביעית שחדרה לתוך היבשת באמצע הפליאוקן המוקדם (Zanclian) הגיעה אל עמק יזרעאל צפונית לקו הכרמל ועד הכנרת, וצפון עמק הירדן.

קיימים שני סוגים של אירועים : טקטוניים וקוסמים (שמקורם מחוץ לכדור הארץ). האירוע שהתרחש במעבר פליאוזואיקון-מזוזואיקון (לפני כ250 מיליון שנה) הוא אירוע קוסמי שגרם להכחדה המונית של בעלי החיים בין פרם לטריאס. לעומת זאת, האירועים בגבול הפליאוטתיס והנאוטתיס הם אירועים טקטוניים הקשורים בשבירה ובוולקניזם שהתרחשו בין הקרבון לפרם המוקדם. בתקופה זו נשברה הפלטה האפריקאית לאורך קו צפון הנגב ונוצרה הפרובינציה של יהודה. אירוע ההכחדה החלקית בין המסטריכט והדניאן (לפני כ-66 מיליוני שנים) הוא אירוע קוסמי שנגרם כנראה ע"י פגיעה של אסטרואיד.

הגישה החדשה למבנה והתפתחות הגיאולוגיה של תת הקרקע בישראל מוצגת בעבודה זו בקווים מנחים בלבד. אנו מקווים שהתפיסות והרעיונות שמועלים כאן יאתגרו מחקרים עתידיים ורעיונות חדשים באשר לגיאולוגיה של תת הקרקע בישראל.

הבעות תודה

המחקר הנוכחי יוצא במידה רבה בזכות עזרתם של רבים מחברי.

אציין אחדים מהם ובראשם עמוס סלמון שקרא, העיר והביא את העבודה למצבה הנוכחי.

לחברי אליהו רוזנטל, אברהם סטרינסקי, אמוץ עגנון ועמית שגב שקראו, העירו או עזרו הן לגבי אינפורמציה, התוכן והן לגבי הסגנון. על סיוע באינטרפרטציה גיאופיזית של חתכים סיסמיים אני מודה ליובל בן גיא.

תודות לשי קירשנצויג על עיצוב חזית וגב כריכת המאמר.

לבסוף, אני מבקש להודות לנכדי אופק על האיורים הממוחשבים, הדיאגרמות, הטבלאות, המפות והחתכים שעשה.

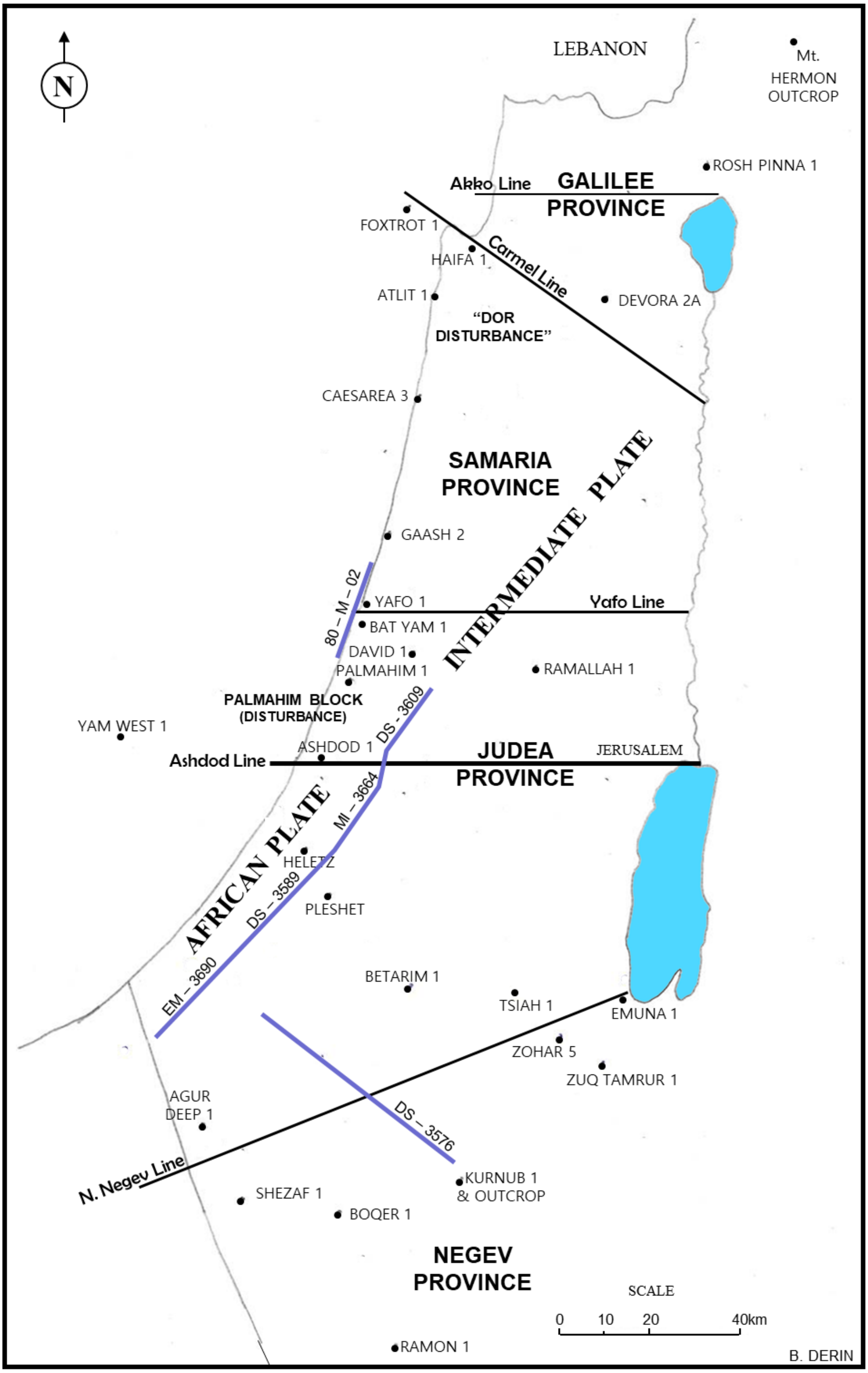

Figure 1: Location Map (Seismic and Tectonic lines, Plates, Provinces and Wells)

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CHAPTER 1 - INTRODUCTION

Three groups of tectonic lines or lineaments have been identified in Israel: the local old lines, the Tethyan–Mediterranean lines, and the younger (Middle Oligocene age) lines. The lines separate plates, provinces and blocks, related to different "tectonic regimes", and were formed and active during several time spans from the Paleozoic to Recent (Fig. 2).

The local old lines, which have been active since the Paleozoic and strike from south northward, are: the Northern Negev Line, the Ashdod Line, the Yafo Line, the Carmel Line and the Akko Fault Line (Fig. 3).

The Tethyan lines, active since the Middle Triassic (Late Anisian), include (from east to west) the Late Anisian Line, the "post-Norian Helez–Atlit Line" and the Western Deep Shelf Edge Line (Fig. 4).

The third group is the younger lines, active since the Middle Oligocene (~28 Ma) and is related to the intensive tectonic activity throughout the Mediterranean region, including Turkey, Greece, Dinarids, Italy, Sicily, Sardinia and Corsica, acting during the closing process of the Mediterranean Sea. In our area, the group includes the Dead Sea strike-slip fault, the Suez Graben and the Nile River Graben.

The three major stratigraphic sequences, i.e., the Paleotethys, the Neotethys and the Mediterranean Neogene sequences, have all been defined in Israel. Interpretation of deep seismic reflection data (Fig. 5) suggests the absence of sediments older than the Upper Carboniferous south of the Ashdod Line. This area was part of the African Plate, an uplifted area of no deposition during the Paleozoic time span. The deep seismic profiles which were recorded north of the Ashdod Line in central and northern Israel, are similar to the seismic profiles from the Galilee, Golan Heights, and Syria, indicating the presence of extremely thick over 5,000 m undefined older Paleozoic beds, which are known from the Levant Block (Weissbrod 2005).

The Neotethys (Permian to Turonian) is the main stratigraphic sequence in Israel and is one of world's thickest continuous sequences (up to 10,000 m) of marine sediments with minor time gaps reflecting great variability of depositional environments. During this time span, Israel was located in the central part of the Neotethys with stratigraphic sections and tectonic events similar to both eastern and mainly western sides of the

Neotethys Ocean (Fig. 6). Overall, 80 formations and members of the Neotethys sequences were discussed and defined in Derin (2016).

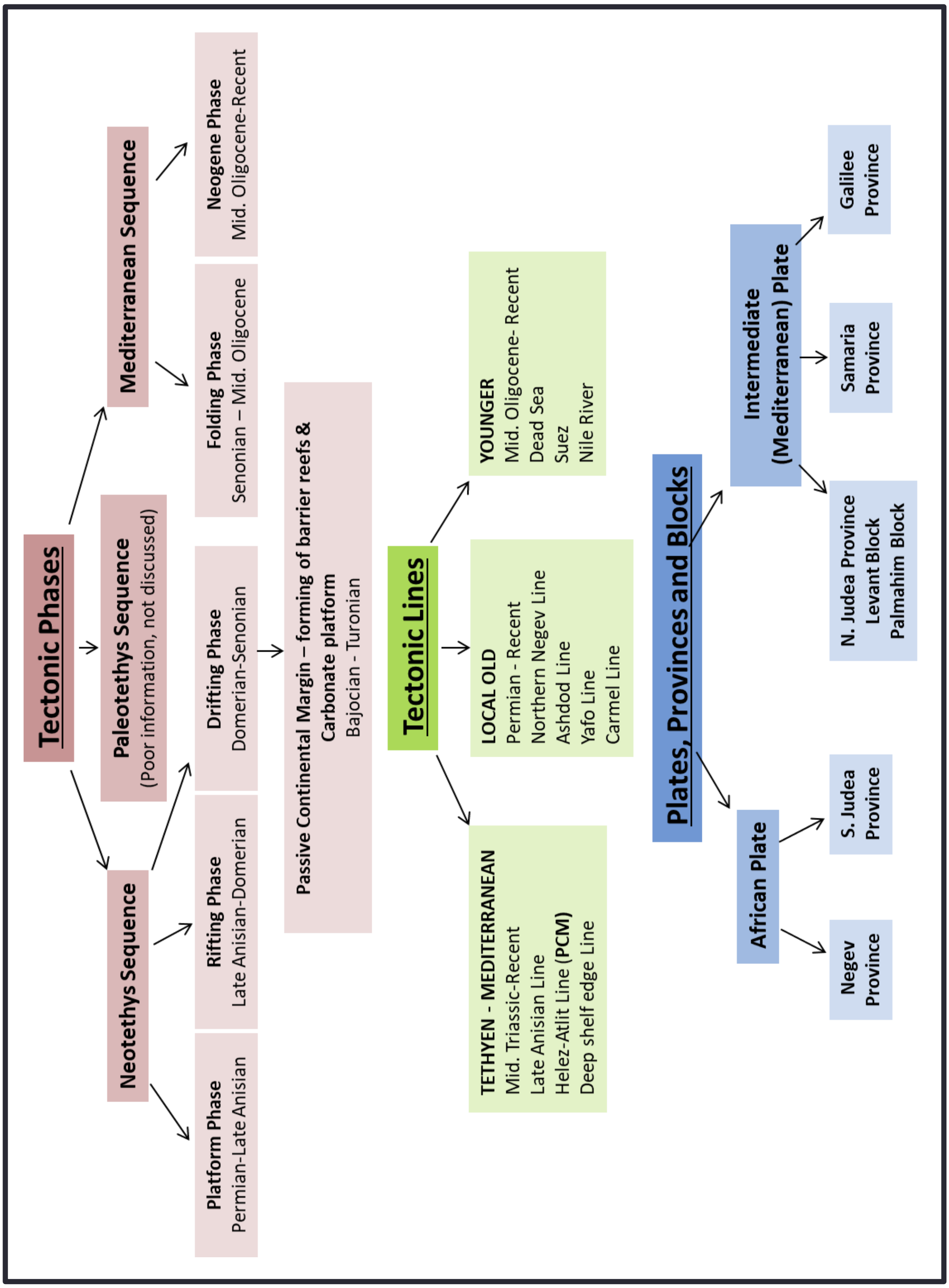

Figure 2: Tectonic Phases, Tectonic Lines, Plates, Provinces and Blocks

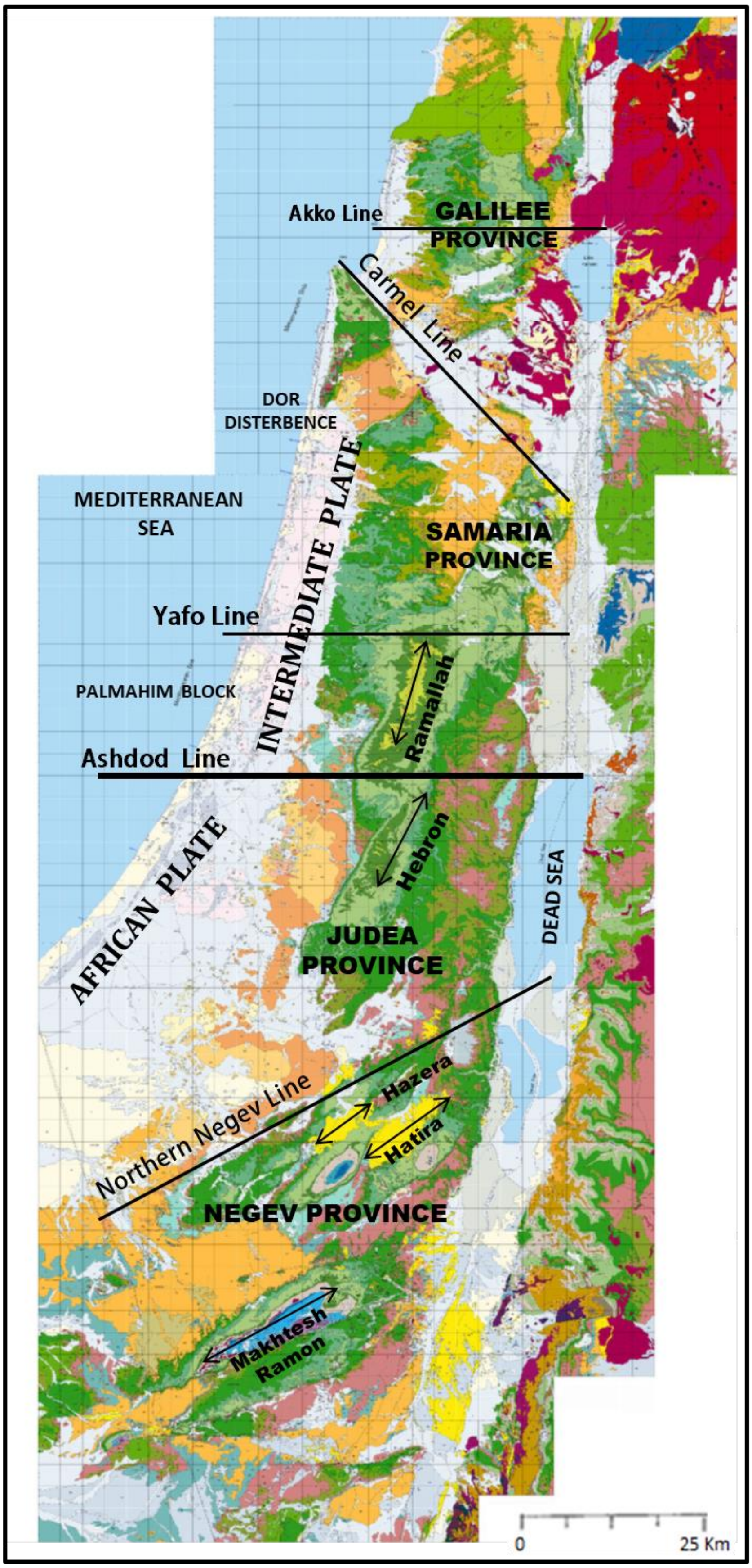

Figure 3: LOCAL OLD LINES - Active since Paleozoic to Recent

Northern Negev, Ashdod, Yafo, Carmel & Akko

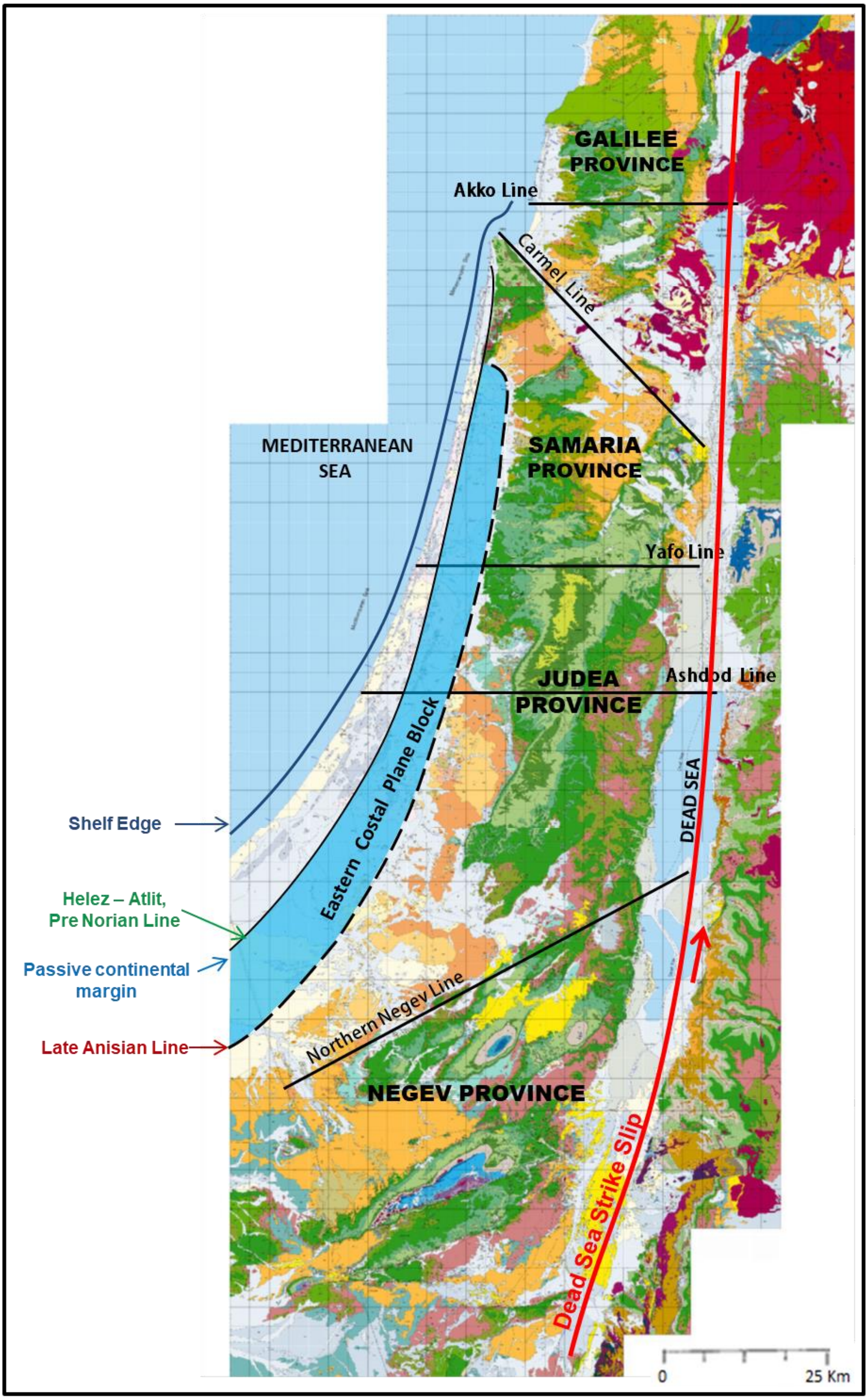

Figure 4: Tethyan-Mediterranean Lines- Active since Late Triassic
Young Dead Sea Line- Active since Oligocene to Recent

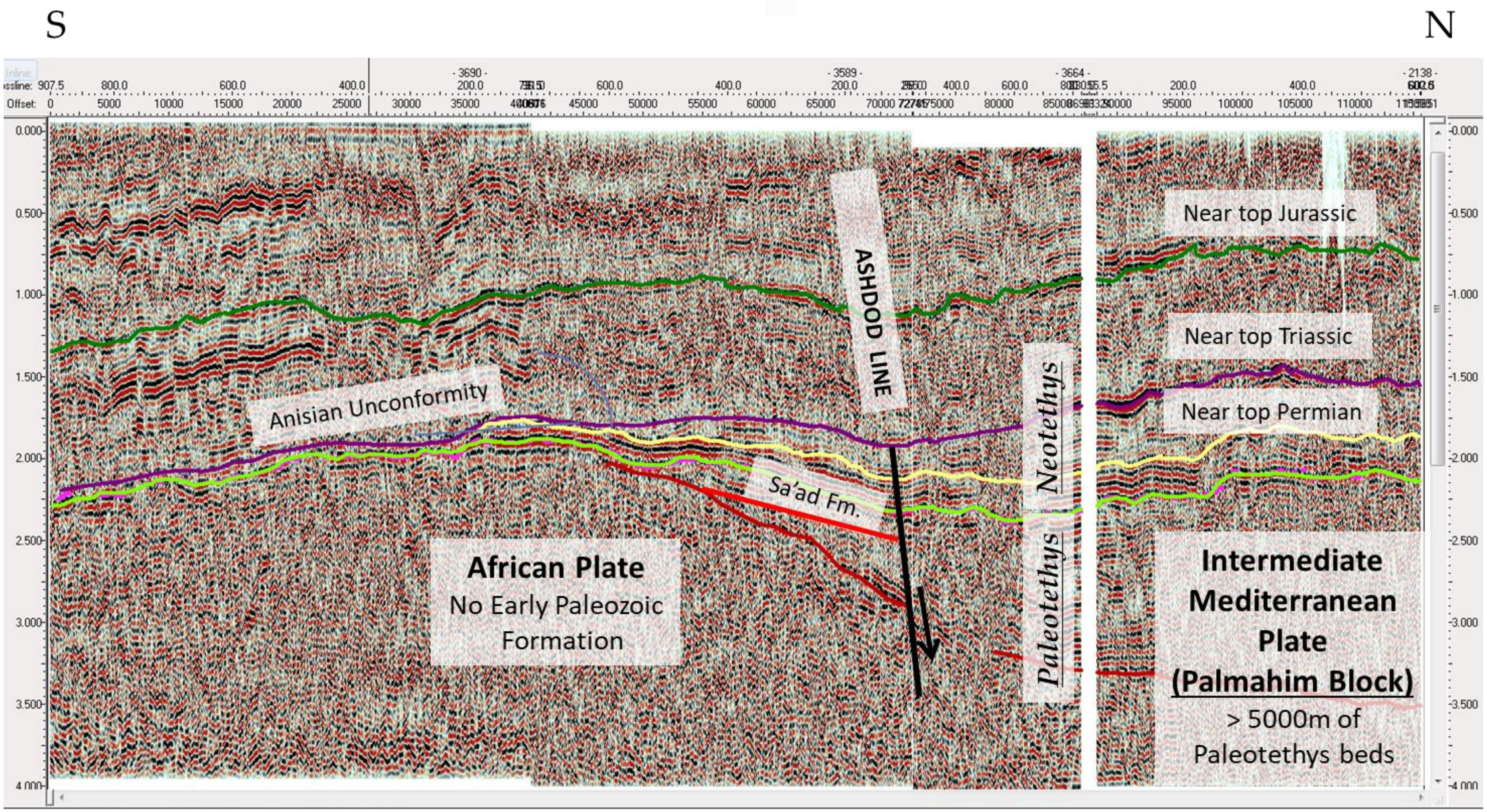

Figure 5: NE-SW seismic lines MI-3664, DS-3609

Over 5,000m of Paleozoic sequence was detected North of Ashdod Line (For location see Fig. 1)

Modified after Y. Ben-Gai, 2018

Figure 6: Neothethys

Israel is located in the "CENTER" of the Neotethys with similarities to both Eastern and Western Neotethys

After: D.J.J. van Hinsbergen, T.H. Torsvik, S.M. Schmidt, 2019, *Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic*, Gondwana Research (2019).

Three tectonic phases are recognized in the Neotethys sequences: the platform phase (Permian to Mid-Triassic), the rifting phase (Late Anisian to Domerian) and the drifting phase (Domerian to Turonian) (Figs. 7, 8). The rifting and drifting phases resemble those of the eastern North America (Nova Scotia) and northwestern Africa (Morocco) continental margins (Von Rad et al. 1982).

The Mediterranean sequence consists of two phases: the Alpine (Syrian Arc) folding phase (Senonian to Middle Oligocene) and the Neogene phase (Middle Oligocene to Recent). The onset of the Alpine folding phase, which obliterates all previous structures, left its stratigraphic evidence in all Cretaceous and later formations.

During the Neogene, Israel was located along the eastern margin of the Mediterranean Sea and therefore, the stratigraphic sequence is not complete or continuous (Figs. 9, 10). The ages given to the stratigraphic zones are based on the planktonic zonation by Blow (1969). Four transgressive phases connected to tectonic events and followed by regressive and non-deposition phases have been defined in the Neogene (Figs. 10, 11).

The first transgression, which lasted from the Chatian to Early Aquitanian (28–23 Ma), was the first sea flooding into the just-formed Gulf of Suez Rift. The transgression was followed by a long regressive phase in both Israel and Suez Graben which lasted about 6 Ma from the Early Aquitanian to Late Burdigalian (~2317-14Ma). The second transgression phase lasted from the Late Burdigalian to Late Langhian (17–14 Ma) and was connected to increased faulting in both Israel and the Suez Graben. It is the main Neogene transgression fill in the Suez Graben, with over 2,000 m of Middle Miocene sedimentation (Fig. 11). The third transgression, during the Middle Serravalian to Late Tortonian, was followed by the main regression phase and drying of the entire Mediterranean, the so-called "Messinian salinity crisis", with widespread evaporation starting in Israel in the Tortonian, earlier than in the middle Mediterranean. The Miocene "salinity crisis" was followed by regional faulting and later by the Pliocene transgression, which reached far inland during the Early–Middle Pliocene (Zanclian–Piacenzian) when seawater penetrated into the Yizrael Valley, north of the Carmel Line, reaching the Sea of Galilee and the northern Jordan Valley.

Two unconnected types of major events have been suggested to exist: tectonic events and cosmic (extraterrestrial origin) events. At the Paleozoic–Mesozoic boundary (between the Permian and Triassic, 252 Ma), a high-energy cosmic event caused the global mass extinction of organisms (Dar et al. 1998). In contrast, the Paleotethys and Neotethys boundary (300 Ma) was a tectonic event, associated with faulting and volcanic activity between the Carboniferous and Early Permian (Fig. 12). An asteroid (cosmic) impact caused partial mass extinction of species (mainly planktonic fauna) between the Maastrichtian stage and the Danian stage (66 Ma; Fig. 10).

Commercial hydrocarbons have been found in transgressive beds of the Neotethys sequence: gas in the Late Permian Arqov Formation, light oil and condensate in the Middle Triassic Saharonim Formation, gas in the Middle Jurassic Zohar Formation and oil in the Early Cretaceous Helez Formation. The Middle Jurassic gas in Zohar Formation seems to be derived from the Triassic beds, through the North Negev Line. Siliciclastic reservoirs with commercial gas were found in the Neogene regressive phase: Noa-Yam fields in the near-shore sand in the Early Pliocene, and gas in the deep-water turbidites sand in the Tamar–Leviathan field of Middle Miocene age (Figs. 10, 11).

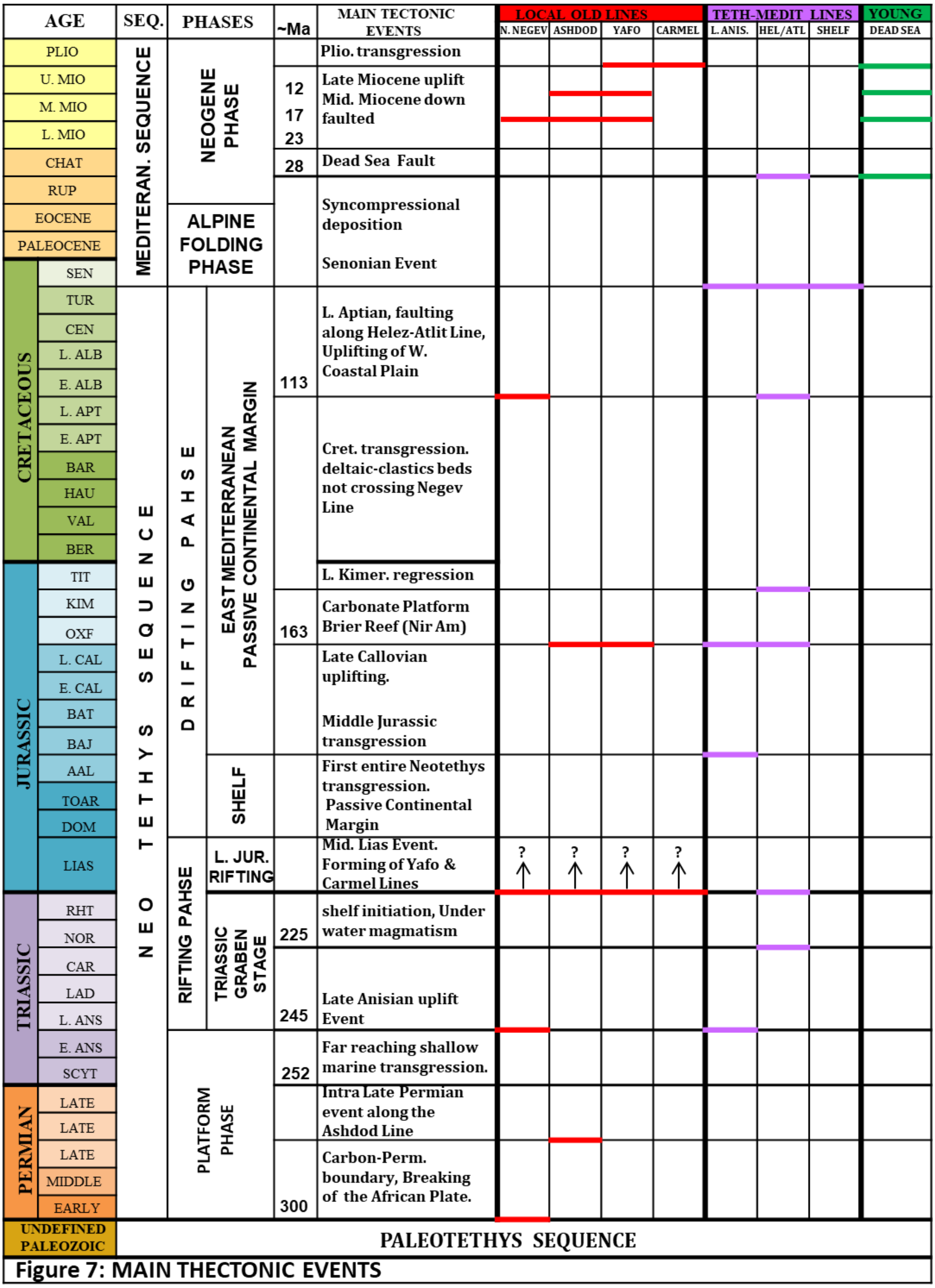

Figure 7: Main Tectonic Events

AGE		SEQ.	PHASES		MAIN EVENTS
	PLIO	MEDITERAN. SEQUENCE	NEOGENE PHASE		Pliocene transgression along Carmel fault reaching Lake Kinneret
	U. MIO				Late Miocene uplift of Palmahim Block (Ashdod & Yafo lines)
	M. MIO, L. MIO				Middle Miocene down faulting of Palmahim Block (Ashdod & Yafo lines)
	CHAT				Forming of Suez Graben, Nile River and the Dead Sea Strike Slip Fault.
	RUP				
	EOCENE, PALEOCENE		ALPINE FOLDING PHASE		Senonian / Paleocene, Extra terrestrial Event
CRETACEOUS	SEN				Senonian Event, Syncompressional sedimentation
	TUR, CEN, L. ALB	NEOTETHYS SEQUENCE	DRIFTING PHASE	EAST MEDITERRANEAN PASSIVE CONTINENTAL MARGIN	Largest Cretaceous regional transgression. Thick platform, carbonate-dominated, shallow water rocks. Cretaceous Passive Continental Margin.
	E. ALB				Albian shelf edge.
	L. APT, E. APT				L Aptian, faulting along Helez-Atlit Line, Uplifting of western Coastal, erosion of Gevar Am Fm. and conglomerate fill (Lior Fm.).
	BAR, HAU				Early Cretaceous marine transgression. Thick deltaic-clastics beds- Gevar Am Fm. In W. Coastal Plain, not reaching the Negev Province
	VAL, BER				Continental magmatism, Tayasir Volcanics in Samaria and Galilee Provinces.
JURASSIC	TIT				Regional uplifting and regression during Late Kimmeridgian-Tithonian
	KIM, OXF				Cal/Oxf. Unconformity. Entire Neotethys transgression during Oxfordian. Passive Continental Margin, carbonate platform- Brier Reef (Nir Am).
	L. CAL, E. CAL, BAT, BAJ				Unconformity, Late Callovian uplifting of Coastal Plain, tilting to the East and gradual erosion toward the West. Dolomitization and Karstification in Palmahim Block. Regional Mid. Jurassic transgression. Forming of Passive Continental Margin , Oolithic shoal & reef.
	AAL			SHELF	Late/Middle Jurassic Event. Regional regressive phase
	TOAR, DOM				First transgression in entire, East and West Neotethys with similar carbonatic shelf.
	LIAS		RIFTING PHASE	L. JUR. RIFTING	Mid. Liassic Event. Forming of Yafo, Carmel Lines, trough in Judea Province with evaporites. Continental magmatism (Asher Volcanics).
TRIASSIC	RHT, NOR, CAR			TRIASSIC GRABEN STAGE	Norian Helez-Atlite Line. Down to the West fault, shelf initiation of S-E Neotethys-Mediterranean coast line. Under water magmatism (Atlit Basalt). Limited transgression; shelf edge reef.
	LAD, L. ANS				L. Anisian Event, W. Coastal Plain uplifted, tilting to East, Syn rifting sedimentation. deep erosion, over 1000m of continental conglomerate & red beds fill. Graben in Judea-Samaria provinces with thick evaporites section.
	E. ANS, SCYT		PLATFORM PHASE		Far reaching Early Triassic shallow marine transgression. Permian / Triassic boundary, Cosmic Event
PERMIAN	LATE, LATE				Far reaching first Neotethys transgression. Down to the North faulting along the Ashdod Line. Northern edge of the African Plate,
	LATE, MIDDLE				Middle Permian Fluviatile beds, north to N. Negev Line. Southern shore line of Early Neotethys
	EARLY				Carb./Perm. Boundary. Fault along the Negev Line. Breaking of the African Plate
UNDEFINED PALEOZOIC		PALEO TETHYS			Early Paleozoic, down to the North fault along the Ashdod Line. Separating the African Plate from Levant Block .

Figure 8: Main Tectonic Phases and Events

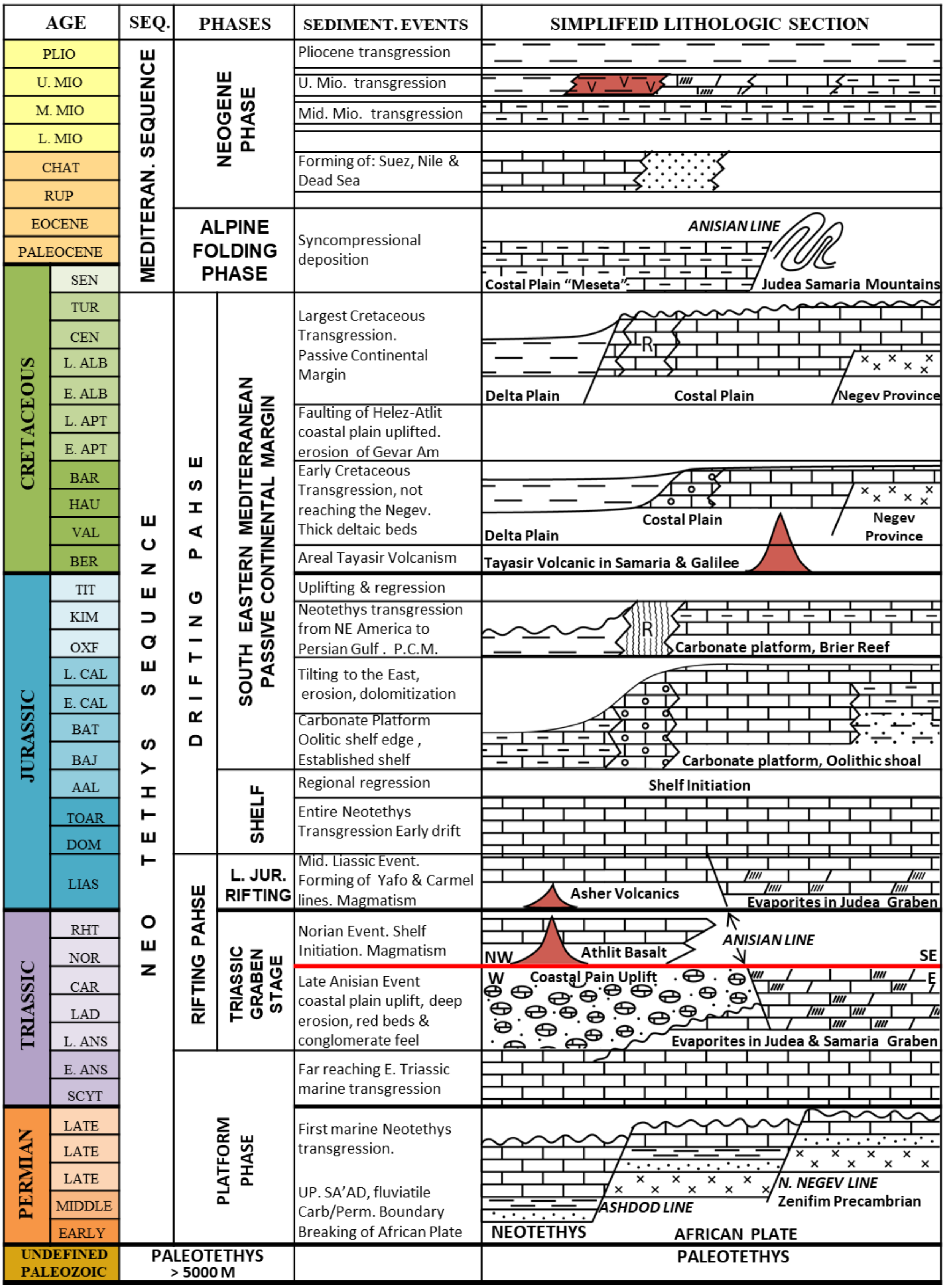

Figure 9: Evolution of Southeastern Mediterranean during Neothethys-Neogene Sequences

ERA	SEQ.	PERIOD		EPOCH/AGE	AGE (Ma)	EVENTS
CENOZOIC	NEOGENE	NEOGENE	PLIOCENE	PIACENZIAN		IV. TRANSGRESSION
				ZANCLIAN	4.5~	
				MESSINIAN	8~	REGRESSION- "Messinian Crisis" **Noa-Mari – gas in shallow, near shore sand**
			MIOCENE	TORTONIAN		III. LATE MIOCENE TRANSGRESSION - Faulting and volcanism
				SERRAVAL.	12.5~	
					14~	REGRESSION- No marine deposition
				LANGIAN	17~	II. MAIN EAST MEDITRRANEAN MIOCENE TRANSGRESSION (Suez Graben fill)
				BURDIGAL.		REGRESSION- No marine deposition **Tamar – gas in off shore deep water turbidites sand**
				AQUITAN.	23~	
		PALEOGENE	LATE OLIGO	CHATIAN	28~	I. MEDITERRENIAN SEA TRANSGRESSION- Breaking of Mediterranean Plate. Forming of Suez Graben, Nile River, Dead Sea Strike Slip Fault
	NEOTETHYS (Taqiye Fm.)		EARLY OLIGO.	RUPELIAN		? NO DEPOSITION
				EOCENE		**SENONIEN – OLIGOCENE Alpine Tectonic Phase**
				PALEOCENE		**Shallow marine Intra tectonic deposition**
				DANIAN	66~	COSMIC EVENT- Meteoric impact. No visible tectonic activity
MESOZOIC		CRETACEOUS		SENONIAN	90~	ALPINE TECTONIC EVENT- Forming of the Syrian Arc
				TURONIAN		

Figure 10: Mesozoic – Cenozoic Boundaries in South Eastern Mediterranean

EPOCH	STAGE	PLANKTONIC ZONE		TRAN. – REG. PHASE	ISRAEL	GULF OF SUEZ
PLEISTOCENE	Gelasian	N23	*Hy.baltica*	**IV. TRANSGRESSION** 4.5 MA	**YAFO-** marls & shale	**TRANSGRESSION FROM INDIAN OCEAN**
		N22				
PLIOCENE	Piacenzian	N21	*G.inflata*			**CLASTICS NO MARINE DEPOSITED**
		N20	*G.crassaformis*			
	Zanclian	N19	*G.puncticulata*			
		N18	*G.margaritae- .*			
MIOCENE (Late)	Messin.	N17	*G.conomiocea*	**NOT DEPOSITED** MAVQIIM EVAPORITES (Messinian Crisis) 8.0 MA; 3.5 MA	**NOA-** MARI, Shallow Near shore sand	
	Tortonian	N16	*G.acostaensis*			
		N15	*G.menardi*	**III- Late MIOCENE TRANSGRESSION** 12.5 MA	**Bat Yam** Volcanics **Mavqiim** Evaporites **Ziqim** Marls **Ziqlag** Limestone	
MIOCENE (Middle)	Serravalian	N14	*G.mayeri*			
		N13	*G.druryi*			
		N12	*G.ruber*	**MISSING OR REDUCED SECTION** 14 MA; 1.5 MA		
		N11	*G.fohsi*			
	Langhian	N10	*G.periferoacuta*			
		N9	G.peripheroronda	**II. "Mid. MIOCENE" TRANSGRESSION** 17 MA	**Bet Guvrin**	**Main Suez Fill (>2000m)** Zeit, South Gharib, Belayim. Kareem, Rudeis Formations
		N8	*G.glomerosa / sicanus*			
MIOCENE (Early)	Burdigalian	N7	*G.trilobus*	**NOT DEPOSITED** 23 MA; 6 MA	**TAMAR / LEVIATAN** Deep water turbidites sand **ZOHR** Off shore Egypt Carbonate build up	
		N6	*G.dissimilis*			
		N5	*G.dehiscens*			
	Aqultan.	N4	*G.primordius / kugleri*			
OLIGOCENE (Late)	Chatian	N3 P22	*G.angulisuturalis*	**I. TRANSGRESSION First Mediterranean Sea flooding** 28 MA	**LAKHISH** Reefoidal limestone, clastics	**Nukhul** Limestone & clastics **Forming Suez Graben**
		N2 P21	*G.opima*			
OLIGOCENE (Early)	Rupelian	N1 P20	*G.ampliapertura*			
		P19	*S.chipolesis / P.micra*			
		P18				

Figure 11: The Neogene Sequence

CHAPTER 2 - STRATIGRAPHIC SEQUENCES

Three major stratigraphic sequences have been defined in Israel: the Paleotethys (Early Paleozoic to Late Carboniferous), the Neotethys (Permian to Turonian) and the Mediterranean (Senonian to Recent), the latter sequence consisting of the Alpine (Syrian Arc) folding phase (Senonian to Lower Oligocene) and the Neogene phase (Middle Oligocene to Recent).

The boundary between the Paleotethys and the Neotethys should be placed between the Late Carboniferous continental Lower Sa'ad Formation and the Early Permian fluviatile Upper Sa'ad Formation, which is the earliest Neotethys transgression. The boundary is a tectonic event, connected with magmatic activity, as detected in boreholes Pleshet 1 and Gevim 1 (Derin 2016, Derin et al. 1985) on top of the Lower Sa'ad, and by the formation of the Northern Negev Line (Fig. 12).

The absence of sediments dating to before the Late Carboniferous south of the Ashdod Line indicates that it was an uplifted area of non-deposition during the Cambrian to Permian time span. Interpretations of deep seismic reflection data (Fig. 5) suggest the presence of thick older Paleozoic beds, north of the east–west trending Ashdod Line. The numerous tectonic events that occurred during the Permian to Recent (Figs. 5, 8–10) are discussed in Derin (2016).

Two unconnected types of major animal extinction events are suggested: tectonic and cosmic. The Permian–Triassic (P–T) extinction (252 Ma), which wiped out over 90 percent of terrestrial and marine animals, was due to high-energy cosmic ray jets (cosmic event) (Dar et al. 1998, and Fig. 12). The P–T extinction boundary is not related to lithological changes, and is defined in essential clastic beds by the extinction of the extremely rich "fusulinids" Permian fauna and the appearance of poor and "primitive" agglutinated Triassic foraminifera. On the other hand, the Paleotethys and Neotethys boundary between the Carboniferous and the Permian was a tectonic event followed by a flood basalt event (Derin 2016, Derin et al. 1985) as mentioned above, and faulting (Fig. 12).

Similarly, the Cretaceous–Paleogene (K–Pg.) extinction event, or K–T extinction, which occurred approximately 66 Ma, was the result of a meteoric (asteroid) impact that caused

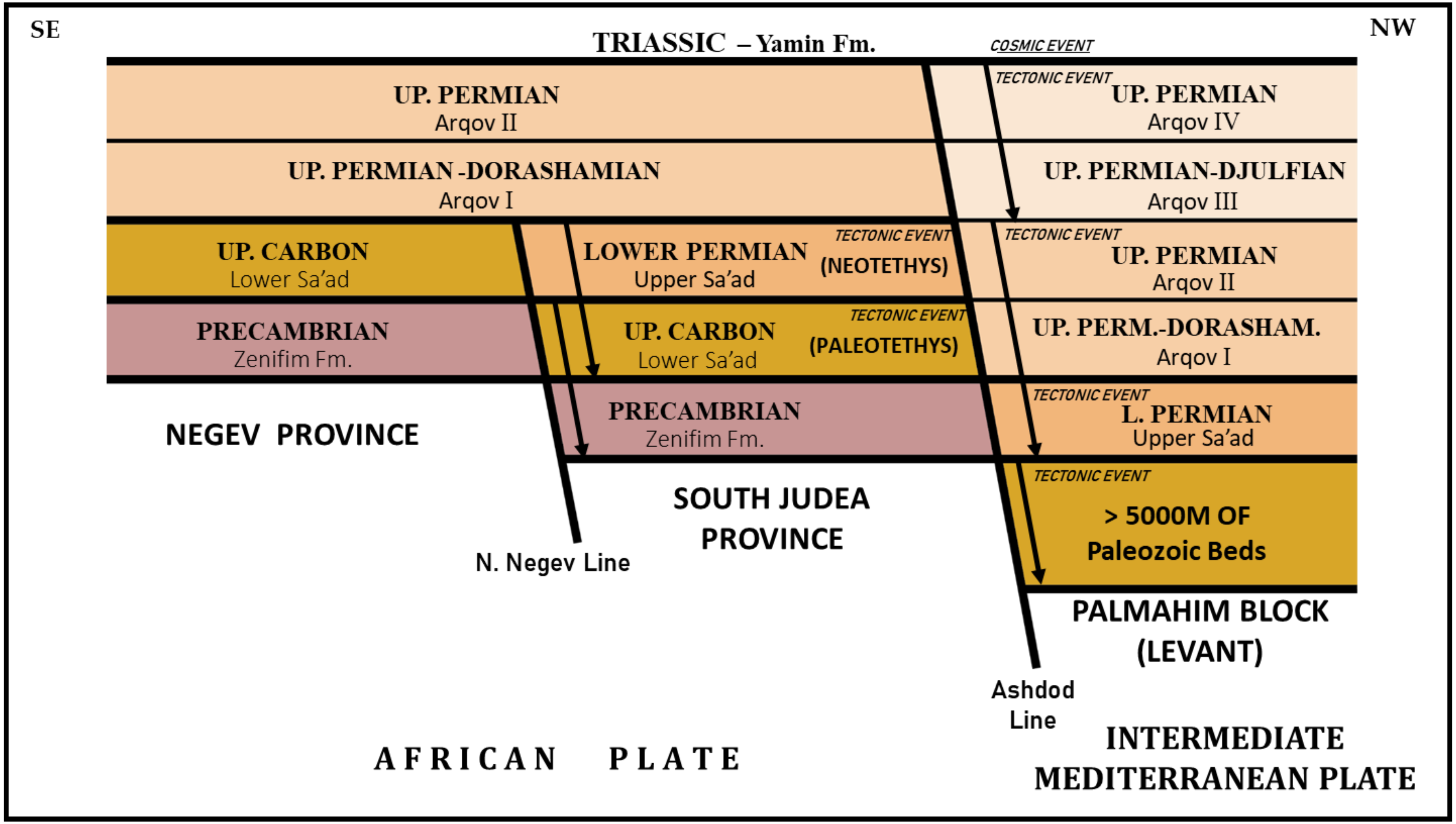

Figure 12: Simplified Cross Section of Upper Paleozoic Section in Southeastern Israel

N. Negev Line: Carbon-Perm: Paleotethys - Neotethys boundary, Intra Permian- Tectonic Event

Ashdod Line: Early Paleozoic, intra Permian Tectonic Events and Permian-Triassic Cosmic Event

(For location see Fig. 1)

the extinction of planktonic organisms such as nannoconids, planktonic foraminifera such as *Globotruncan* spp., non-avian dinosaurs, ammonoides, and plesiosaurs, and the appearance of new planktonic families such as *Globorotala* spp*.* of the Danian age. The benthonic organisms were less influenced and did not suffer total extinction. The extinction did not follow a lithologic change, and occurred in Israel within the lower part of the marly Taqiye Formation (Derin 1961, and Fig. 10).

Five tectonic phases, separated by distinct tectonic events (uplifts or down warps), are recognized in Israel: three phases in the Neotethys sequence (Derin 2016, Garfunkel 1998) and two phases in the Mediterranean sequence (Figs. 7–9).

From the Permian to the Carnian, the orientation of the marine transgressions into Israel was from northeast to southwest. From the Late Triassic (Norian) onwards, the marine transgressions have been from northwest to southeast.

The Paleotethys sequence

Precambrian igneous and metamorphic basement rocks were found in several boreholes in southern Israel. Thin, old Paleozoic sediments were found as outcrops in Sinai reaching northward to the Eilat–Timna area (Fig. 1) but were totally absent northward, both on the surface and in all boreholes drilled south of the Ashdod Line in southern and central Israel. A stratigraphic gap exists in this area, between the Late Precambrian basement and Early Cambrian arkoses (the Zenifim Formation, Weissbrod 2005). In boreholes drilled south of the Ashdod Line (African Plate), the Precambrian igneous and metamorphic basement or arkoses are overlain by Late Carboniferous continental beds (Lower Sa'ad Formation), which represents either the uppermost section of the Paleotethys sequence or an intermediate continental phase between the Paleotethys and Neotethys sequences (Fig. 12).

The absence of sediments older than Upper Carboniferous in southern Israel indicates that the area south of the Ashdod Line was uplifted with non-deposition during the entire Paleozoic Era until the Permian, possibly (but not likely) followed by erosion which removed all sediments down to the Precambrian. Marine sediments appear in southern Israel only during the Late Permian, covering the area in pulses which persisted to the end of the Cretaceous.

Deep seismic reflection profiles, which were recorded north of the Ashdod Line (Fig. 5) in central and northern Israel, are similar to seismic profiles from the Galilee, Golan Heights and Syria. They reveal the presence of extremely thick (over 5,000 m) undefined older Paleozoic beds, which consist mostly of siliciclastic and fluvio-deltaic to mid-shelf settings that are known from the entire Levant Block and Arabian Plate (Segev et al. 2018, Weissbrod 2005). Similar old seismic reflections are entirely missing south of the Ashdod Line. It is suggested that the Ashdod Line represents the continuation of the northern edge of the African Plate, the southern coastline of the Paleotethys Sea in the eastern Mediterranean, and the southern boundary of the Intermediate Mediterranean Plate (Figs. 1, 3, 5, 6, and 13). Because the Paleozoic–Paleotethys sequence is practically unknown in Israel, and stratigraphic information is insufficient, this sequence is not detailed in the present study.

The upper part of the older Paleozoic was only penetrated in one borehole in central Israel: the Ma'anit-Josef 3 borehole (Figs. 1, 14). The section drilled in the well (5,700–5,900 m) consisted of finely laminated, barren, silicified algal limestone, deposited in shallow marine to lacustrine environments without any microfauna or pollen. Because of its stratigraphic position, we assume that it is of Devonian age, unknown elsewhere in Israel. The Devonian carbonates are unconformably overlain by a thick (5,045–5,700 m) non-marine silty-sandy sequence of the Lower Sa'ad Formation (Late Carboniferous), which is the thickest found in Israel. The Lower Sa'ad may be either an intermediate continental phase between the Paleotethys and the Neotethys sequences or the uppermost beds of the Paleotethys sequence. The Lower Sa'ad beds in the Ma'anit-Josef 3 borehole are unconformably overlain by conglomerate of the Late Anisian, Or Haner Formation (Fig. 14).

The pollen assemblage in the Lower Sa'ad Formation (Micro-Strat Report 2011 in Derin 2012) consists of: *Potoniesporites novicus, Laevigatosporites callosus, Protohaploxypinus microcorpus,* and *Pretricolpipollentis haradwaji*. According to Traverse (1988, p. 199), *Potonieisporites novicus*, when dominating the spectrum, is a typical uppermost Carboniferous marker spore, although it may still appear in the earliest Permian. The pollen assemblage found in the Upper Sa'ad Formation (base of the Neotethys) consists of: *Pretricolpipollentis haradawayi,* indicative of the Early Permian.

It is suggested that the boundary between the Paleotethys and Neotethys be placed between the continental Late Carboniferous (Lower Sa'ad Formation) and fluviatile Early Permian (Upper Sa'ad Formation). The boundary is a tectonic event, connected with a flood basalt event, as detected in the boreholes Pleshet 1 and Gevim 1 on the top of the Lower Sa'ad Formation (Derin 2016, Derin et al. 1985), and by the breaking of the African Plate and formation of the Northern Negev Line (Figs. 7–9). The Early Permian fluviatile beds were deposited only on the northwestern side of the Northern Negev Fault Line (Fig. 15). As such, the Northern Negev Line defines not only the boundary between the Negev Province and the Judea Province, but acts as the southern boundary of the earliest fluviatile Neotethys transgression in the southeastern Mediterranean during the Early Permian. The Ashdod Line marks the southern boundary of the Neotethys sequence in latest Permian and the boundary between the south Negev Block (African Plate) and Palmahim Block—which is part of the Levant Block (Figs. 3, 5, 6, 12, 13).

While the Paleotethys and Neotethys boundary is a tectonic event occurring between the Late Carboniferous and Early Permian, the Paleozoic and Mesozoic boundary between the Permian–Triassic is related to a cosmic ray jet event, which coincided with the global species mass extinction (Dar et al. 1998, and Fig. 12).

Figure 13: Intermediate Mediterranean Plate

1. The “Intermediate Mediterranean Plate”, extended between the African Plate in the south and the Euro-Asian Plate in the north and consists of Paleotethys and Neotethys beds. The plate fragmented to numerous “blocks“ (e.g. Greater Adria, Levant) during the Senonian–Eocene, Alpine tectonic phase.
2. The various blocks are drifting each other since Middle Oligocene, in the process of the closing of the Mediterranean Sea

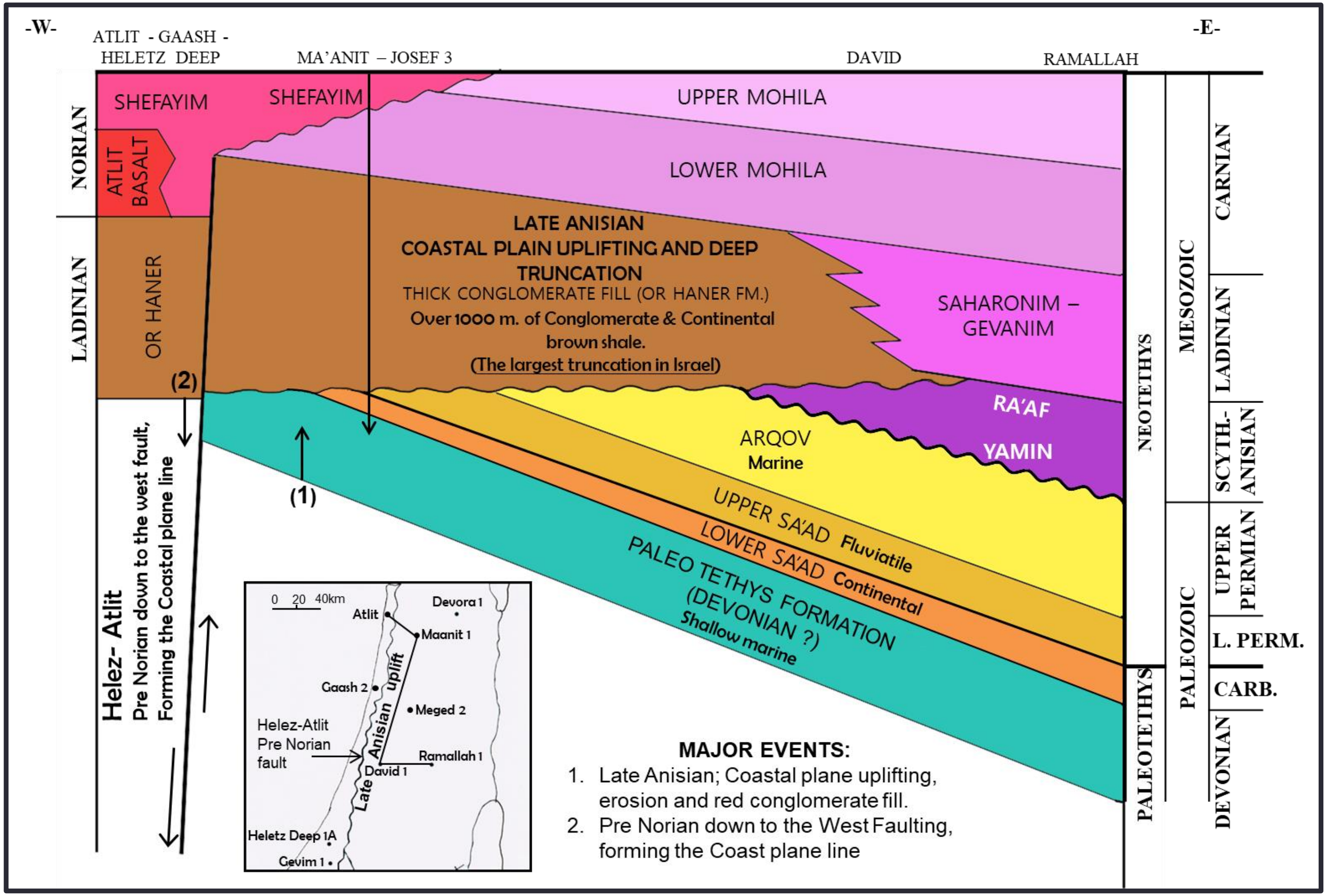

Figure 14: E-W Simplified cross section of Upper Paleozoic to Triassic in western Israel

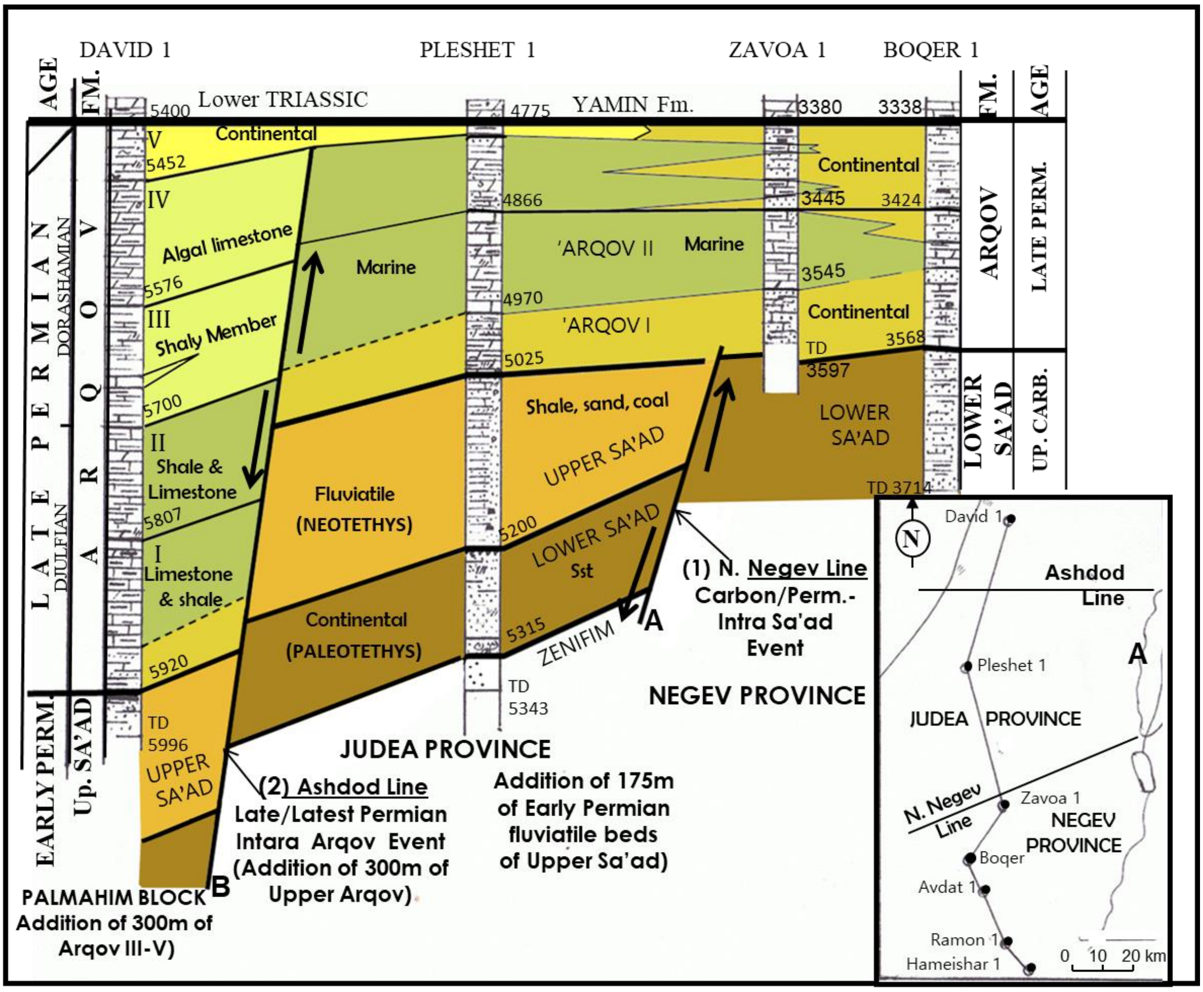

Figure 15: N-S cross section of the Upper Paleozoic in southern Israel

N. Negev Line: (1) Carboniferous-Permian boundary, Intra Sa'ad Tectonic Event

Ashdod Line: (2) Late-Latest Permian boundary, Tectonic Event

Datum line: Base Triassic - Yamin Formation (Cosmic Event)

The Neotethys sequence (Permian to Turonian)

The Neotethys sequence is the main stratigraphic sequence in Israel; attaining a thickness of almost 10,000 m, and one of the thickest sequences in the world. It is a nearly continuous section, with minor time gaps representing great variability in the depositional environments. Overall, 80 formations and members of the Neotethys sequences were discussed and defined in Derin (2016). The main tectonic phases and events are summarized in Figs. 7–9.

Three phases, separated by distinct tectonic events (uplifts, deep erosion or down warping), have been defined in the Neotethys sequence (Derin 2016, Garfunkel 1988, and Figs. 7–9): the platform phase, the rifting phase and the drifting phase. The rifting and drifting phases in Israel resemble the development and age of the eastern North American (Nova Scotia), and even more so the evolution of the northwestern African (Morocco) continental margins (Von Rad et al. 1982).

The platform phase (Early Permian to Mid-Triassic) consists of two parts separated by the boundary between the Paleozoic and Mesozoic eras, i.e., the Late Permian and the Early Triassic, which has already noted, was a cosmic event (Fig. 12).

The rifting phase (Late Anisian to Domerian) consists of two episodes: a Late Triassic rifting ("graben") in Judea and Samaria provinces and an Early Jurassic rifting phase identified only in the Samaria Province. The drifting phase (Domerian to Turonian), consists of a lower shelf phase during the Domerian to Aalenian, and upper **P**assive **C**ontinental **M**argin (PCM) phases (Fig. 9).

The PCMs, characterized by high-energy deposits, developed during the Middle Jurassic to Middle Cretaceous. The most distinct are the Middle Jurassic Sederot oolitic shoal, the Nir Am stromatolite barrier reef in the Upper Jurassic, and a coral and rudists reef in the Middle Cretaceous exposed in the western Carmel Mountain (Derin 2016, and Figs. 9, 16, 17). The location of the PCM line was more western during the Jurassic than during the Cretaceous. Both faunal assemblages and lithology's of the PCMs of Israel resemble those of the PCM in southern Europe.

During the Permian to Turonian, the Neotethys time span, Israel was located in the middle of the Neotethys, manifesting a similar stratigraphic section and tectonic events on both the eastern, but mainly western sides of the Neotethys. Over 80 formations and members were described from the Neotethys sequence in Derin (2016). During the Permian, Israel was located on the western margins of the Neotethys. This position changed in the Triassic when the Neotethys moved westward to what became the western Neotethys, with Israel located on its eastern side (Fig. 6). In the Early–Middle Jurassic, Israel was located in the central part of the Neotethys, with similarities to both its east and west sides. From the Late Jurassic to the Turonian, Israel was situated on the eastern side of the western Neotethys. All transgressions from the Early Permian to Carnian were from the northeast; from the Norian onward, during the Upper Neotethys and the Mediterranean sequences, all of the transgressions to Israel were from the northwest.

The cumulative Jurassic sequence in Israel, including offshore, reaches about 4,700 m in depositional environments, ranging from shallow clastic shelves to deep open marine zones, as fully discussed in Derin (2016, and Fig. 17). Similar depositional environments characterize the Cretaceous rocks, which are very common in Israel and in the Levant Basin (Derin 2016, Segev et al. 2018, and Weissbrod 2005). On land, Cretaceous rocks, usually overlying an erosional unconformity, point to a major regression at the end of the Jurassic. Westward, at the base of the continental slope and offshore, deposition was almost continuous and Berriasian rocks (Ashqelon Formation) overlie Tithonian beds (Yam Formation) (Derin 2016, and Fig. 18).

The thickness of the Cretaceous offshore sequence along the western edge of the central and southern Israel platform varies between 1.6 and 2.5 km. landward, the thickness decreases to 1.5–0.5 km. The thickness of the interval predating the Turonian beds varies only slightly on the platform and basin, but on the separating slope, it increases from 0.5 km to 2.5 km, reflecting deposition on a relief formed during intra-Cretaceous movements. During the Early Cretaceous, from Berriasian to Late Aptian, the Negev Province was uplifted, remaining without any Early Cretaceous marine deposits (Yo'av group) (Fig. 18).

During the Middle Cretaceous, three major events of uplifting and unconformity were observed mainly in the western coastal plain. The first is the Aptian–Albian boundary in the western Judea and Samaria provinces; the second unconformity is between the Early Albian and Late Albian, as indicated by the thick Late Albian beds offshore, the Talme Yafe Formation beds in the Judea Province, which unconformably overlie the

Gevar ‘Am or Heletz formations of Hauterivian–Barremian age; the third unconformity is observed offshore between the Albian–Cenomanian boundary, and is found only in the Samaria Province; there, the thick Early Cenomanian Item Formation unconformably overlies the Hauterivian–Barremian Gevar 'Am Formation (Figs. 16, 18).

The largest Cretaceous regional transgression occurred during the Early Albian, when marine deposits reached southern Israel as far as the Eilat area (Fig. 1). The onshore plane of the upper Early Albian unconformable boundary is recognized by the glauconitic beds known as the "Green Stage", which define the boundary between Uza and Hevion formations and the boundary between the Kurnub Group and Judea Group (Fig. 18).

Post-Turonian beds, on both the platform and the basin, display conspicuous thickness variations compared to older beds, apparently as a result of nontectonic deposition on the active Syrian Arch structures.

The top of the Cretaceous sequence when not truncated is a seemingly continuous marine chalky section evidenced in outcrops and in the subsurface. Its top is recognizable by a major faunal break, reflecting a worldwide extinction at the Cretaceous–Tertiary boundary (66 Ma). This was not a tectonic event, marked by a conspicuous lithologic change, or a magmatic eruption (at least in our area), but the result of a meteoric impact that caused the extinction between the Maastrichtian and Danian within the marly Taqiye Formation and not between the Senonian Gareb chalk and the Taqiye marl (Fig. 10).

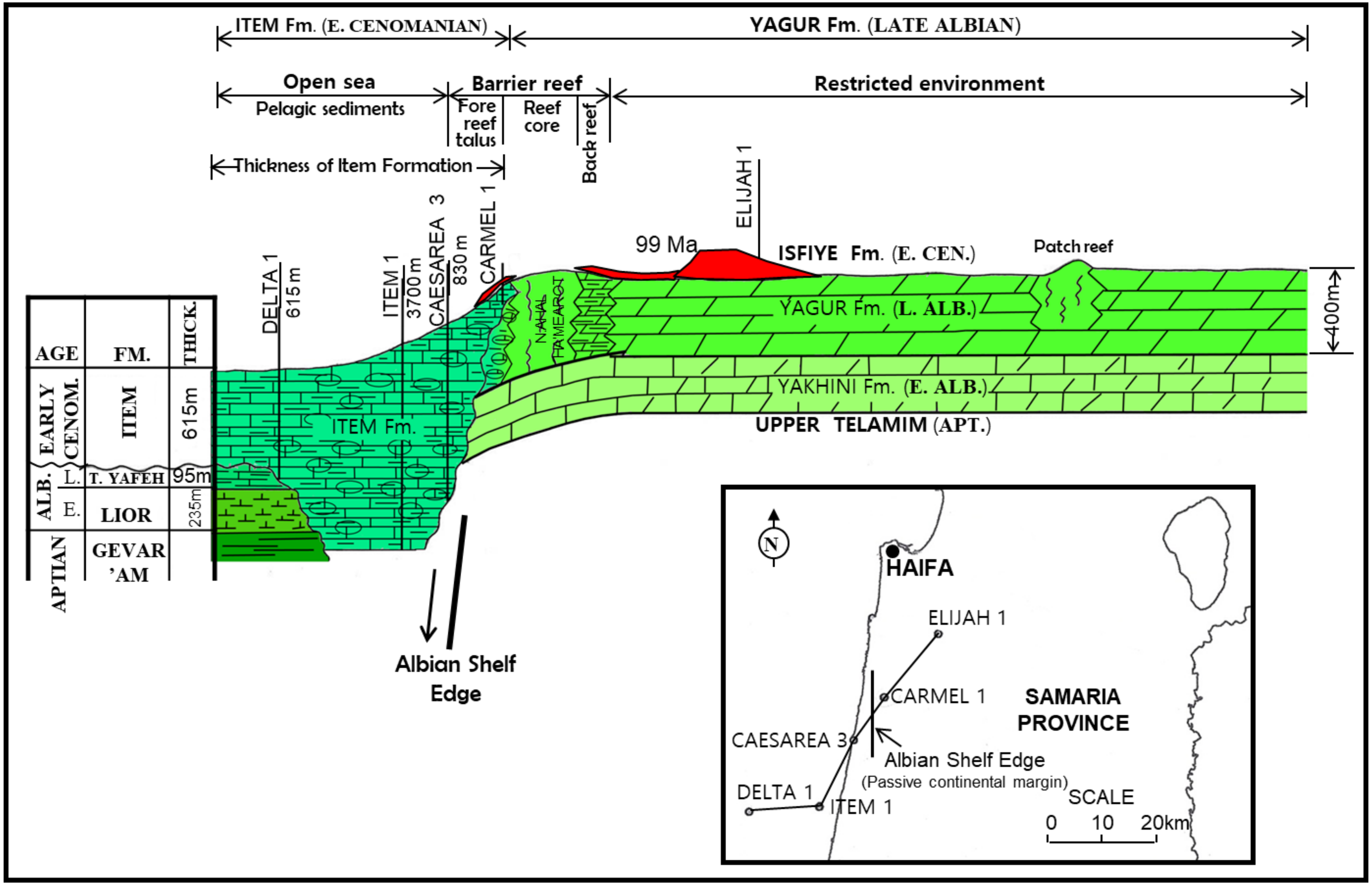

Figure 16: Albian-Cenomanian environments of deposition in Mount Carmel area (Samaria Province)

After: Segev and Sass, 2009

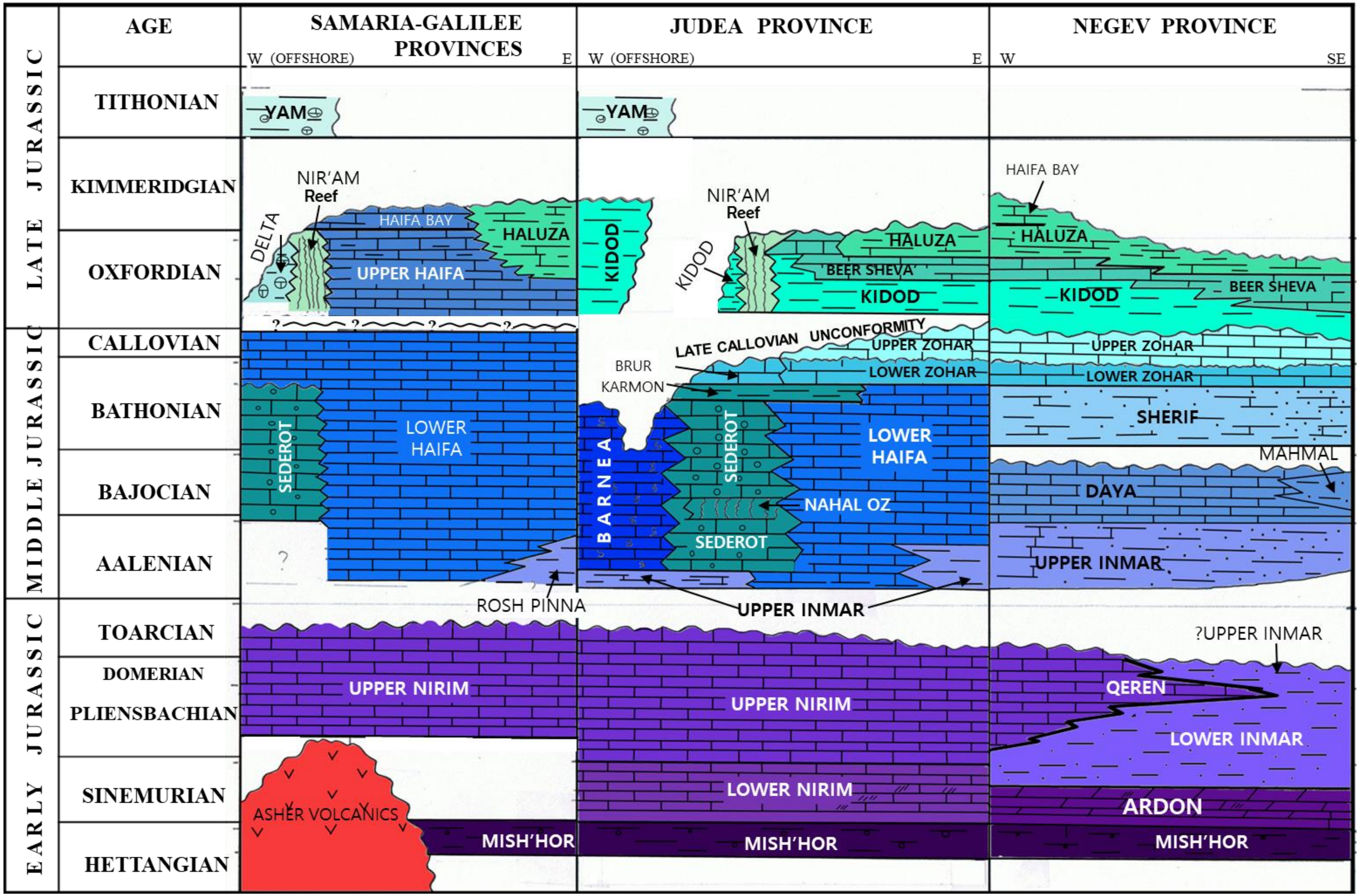

Figure 17: Distribution of the Jurassic formations in Israel

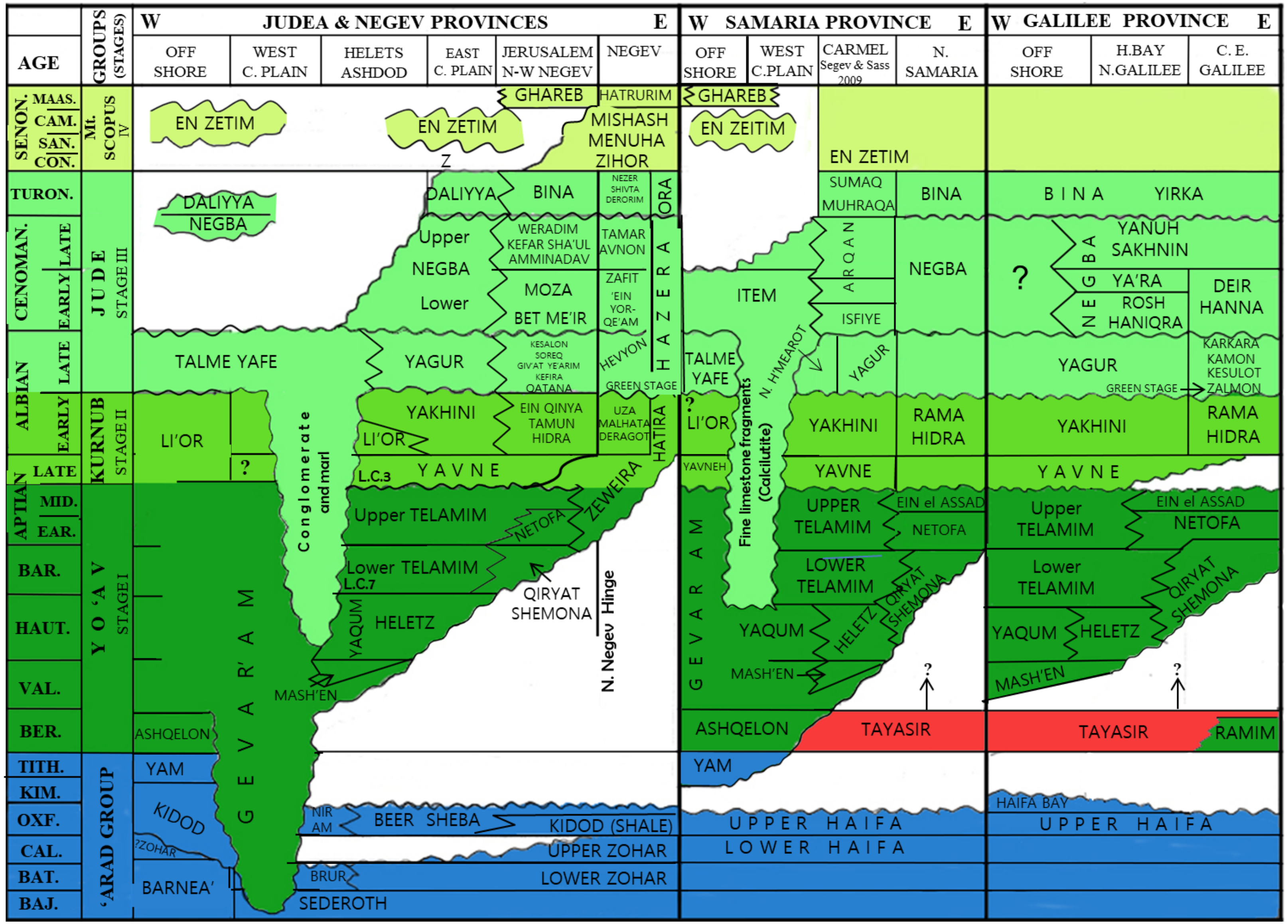

Figure 18: Areal and Vertical Distribution of Cretaceous formations in Israel

The Mediterranean Neogene sequence (Senonian to Recent)

The Mediterranean Neogene sequence consists of two phases: the Alpine–Syrian Arc folding phase (Senonian to Middle Oligocene) which is a transition phase between the Neotethys sequence and the Neogene phase, which lasted from the Middle Oligocene (~28 Ma) to Recent; the Senonian convergent phase, which caused intraplate shortening manifested by the Alpine-Syrian Arc folding (Krenkel 1925,and Fig. 19) which obliterated all previous structures and left its stratigraphic evidence in all Cretaceous and later formations.

The Neogene phase is one of the most discussed, disputed and controversial stratigraphic intervals (Segev et al. 2017, 2018). The present work is based on over 100 unpublished well reports prepared over more than 50 years by the author and his colleagues in the laboratory of "The Israel Petroleum Institute" for various oil companies working in Israel, Sinai and the Gulf of Suez. The ages and divisions given to the Neogene stratigraphic units (Figs. 9–11) are based on lithological and faunistical examination of well samples that were defined according to Blow's (1969) planktonic zonation (Fig. 11), and personal discussion with Blow and other leading international experts.

The "Intermediate Mediterranean Plate" consists of a broken mosaic of different lithospheric pieces that have been reactively in motion relative to each other since the Middle Oligocene (Chatian, ~28 Ma), with different orientations not related to the Alpine tectonic movement, or the African–Eurasian subduction. The Middle Oligocene tectonic phase, which is connected to volcanic activity and earthquakes, is known in the entire Mediterranean, from Turkey in the east, through Greece, the Dinarids, Italy, Sicily, Sardinia and Corsica in the west (Balia et al. 1991, Critelli and La Perlo 1998, De Zanche et al. 1992, Doglioni et al. 1994, Papanikolau 2009, Robertson et al. 2012, Şengör and Yilmaz 1981, and Fig. 21).

The Oligocene event is one of the more impressive tectonic movements of the region and includes the formation of the Dead Sea strike-slip fault, the Suez Graben, the Nile River Graben, the rejuvenation of the Akko Fault Line and in the subsurface, the uplifting of the Palmahim Block.

Unlike during the Neotethys period when Israel was located at the center of the Neotethys Sea, during the Neogene period, Israel was located on the eastern margin of the Mediterranean Sea. The stratigraphic sequence is not continuous and not complete, and about a third of the stratigraphic section was not deposited or is much reduced.

Four transgressive phases connected to tectonic events and followed by regressive and non-depositional phases have been defined (Figs. 9–11). The first transgression, which lasted from the Chatian to Early Aquitanian (28–23 Ma) was a shallow marine sea ingression which deposited clastic and reefoidal beds on the eastern coastal plain of Israel (Lakhish Formation) and northwestern Sinai (Lipson 1973). This was the first sea flooding into the just-formed Gulf of Suez rift (Nukhul Formation). The transgression was followed by a long regressive phase in both Israel and the Suez Graben which lasted about 6Ma, from the Early Aquitanian to Late Burdigalian (~23 to ~17 Ma). Huge gas fields (Tamar, Leviathan) were found in offshore Israel, in the deep-water turbidites sands that were deposited during this time span (Figs. 10, 11).

The second transgressive phase is the Middle Miocene transgression (Langhian) which lasted from the Late Burdigalian to Late Langhian (~17 to ~14 Ma). It was connected to increase faulting in both Israel and the Gulf of Suez. During this tectonic event, the Gaza–Be'er Sheva Canyon was formed (Buchbinder and Zilberman 1997) and major subsurface faulting (250 m) occurred along the Yafo Line, extending between the uplifted Palmahim Block (Bat Yam 1 borehole) in the south and the up thrown Samaria Province (Jaffa 1 borehole) in the north (Fig. 20).

The Middle Miocene phase is the main Neogene transgression which penetrated into the Gulf of Suez Graben with over 2,000 m of Middle Miocene section (Fig. 11), and which was examined by the author (e.g., Abu Zneime, B.M. 1 and Ras Garra wells). The formations from bottom-up are: Rudeis (marls and clastics), Kareem (marls and evaporites), Belayim, South Gharib and Zeit (various evaporites). During the Late Langhian (~ 14 Ma), the northern connection to the Mediterranean Sea was sealed, and the evaporites beds of the Middle Miocene age in the Suez Graben were overlain by Pliocene clastics. Since the Pliocene Gulf of Suez and Gulf of Eilat–Aqaba tectonic basins have been flooded from the south by the Indian Ocean seaway through the Gulf of Aden and the Red Sea. The Middle Miocene transgression was followed by a regressive phase with a reduced section that lasted about 1.4 Ma (Figs. 10, 11) from the Late Langhian to Middle Serravalian.

The third, Late Miocene transgression occurred from the Middle Serravalian to Late Tortonian (~13 to ~8 Ma), accompanied by basalt flow along the southern side of the Yafo Line (Fig. 20) in the Judea Province only, from Bat Yam 1 (500 m, submarine basalt) in the west and National Park 1 (200 m, subaerial basalt) in the east.

The main regression and the drying of the entire Mediterranean with widespread evaporation, i.e., the Messinian salinity crisis (Husu et al. 1973), started in Israel (Mavqiim Formation) earlier than in the middle parts of the Mediterranean. Tortonian, but not Messinian age planktonic microfauna were found in marls interbedded with the evaporites beds encountered in several boreholes only along the western coastal plain, but not in the eastern boreholes. Hence, there is no reason to relate evaporites beds drilled in the northern Jordan Rift Valley (Zemah 1 well) to the Messinian regressive phase. The thickness of the Messinian evaporites is variable; they overlie or are interbedded with the Bat Yam volcanic rocks, with marls of the Ziqim Formation, reefoidal limestone of the Ziqlag Formation and undefined clastics.

The Miocene salinity crisis was followed by a regional regressive phase with onshore clastics (Afiq Formation) and shallow-water sand (of Zanclean age) with commercial gas (Noa-Mari sand) in the southern offshore area of Israel and the Gaza Strip (Figs. 10, 11). The Pliocene faulting is clearly visible in the subsurface, along the Yafo Line, but now in the direction opposite that during the Middle Miocene (Fig. 20). A 300 m addition to the Pliocene beds was deposited in the downthrown Samaria Province (Jaffa 1 borehole) on the northern side of the Yafo Line in comparing to the uplifted Palmahim Block (Bat Yam 1 borehole) in the south. The regional Pliocene transgression into the Gaza–Be'er Sheva Canyon was rejuvenated and filled by clastics, and Yizrael Valley, north of the Carmel Line, was formed. Almost 800 m of Pliocene–Pleistocene beds were deposited in the Qishon Yam 1 borehole, drilled offshore in Haifa bay (Derin 2002); eastward, the Pliocene penetrated the Yizrael Valley north of the Carmel Line, reaching Lake Kinneret and the northern Jordan Valley in the Zemah 1 well. Marine marly beds found in the well between 1,750 and 1,780 m are intercalated with basalt flows and thick evaporites beds containing indicative planktonic and benthonic foraminifera of Zanclean–Piacenzian age such as: *Globigerinoides trilobus, G. obliquus extremes, Orbulina* *universa, O. suturalis, Globoquadrina altispira* and *Asterigerinata mamilae* (Gerry and Derin 1983).

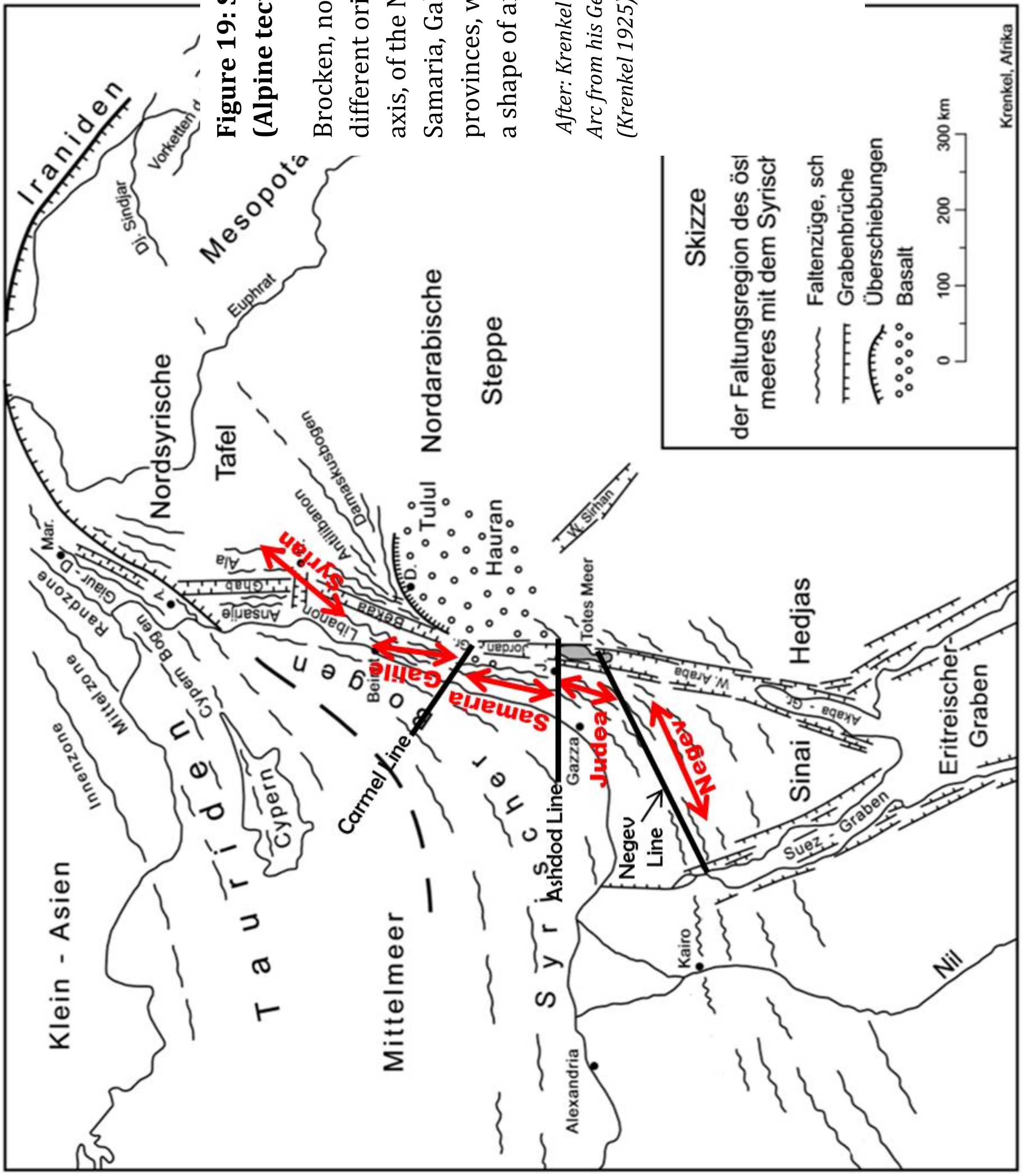

Figure 19: Syrian Arc (Alpine tectonic phase)

Brocken, not continuous and different orientation tectonic axis, of the Negev, Judea, Samaria, Galilee and Syrian provinces, which together give a shape of an arc.

After: Krenkel's map of the Syrian Arc from his Geologie Afrikas (Krenkel 1925)

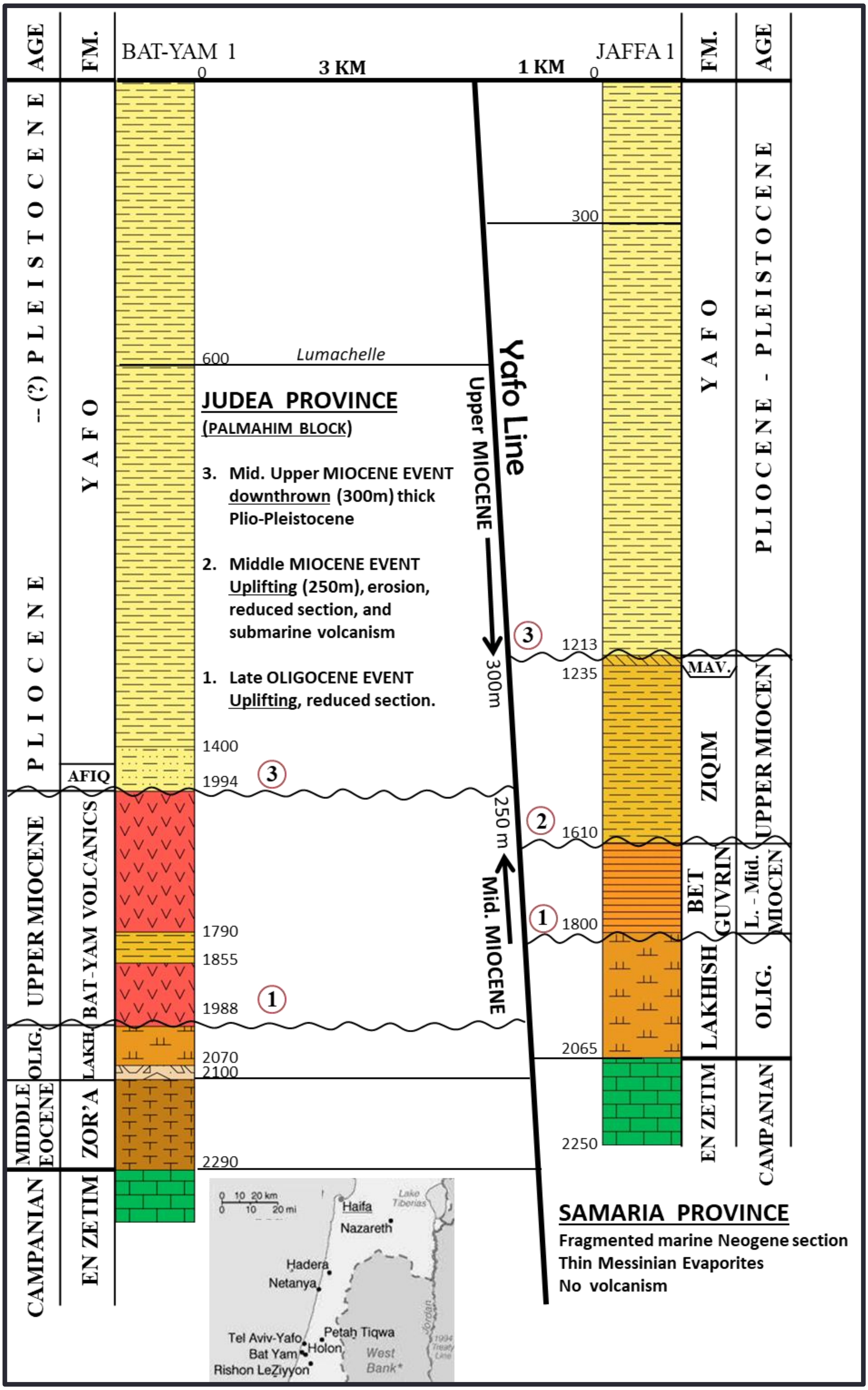

Figure 20: Tectonic movements along the Yafo (Hinge) Line

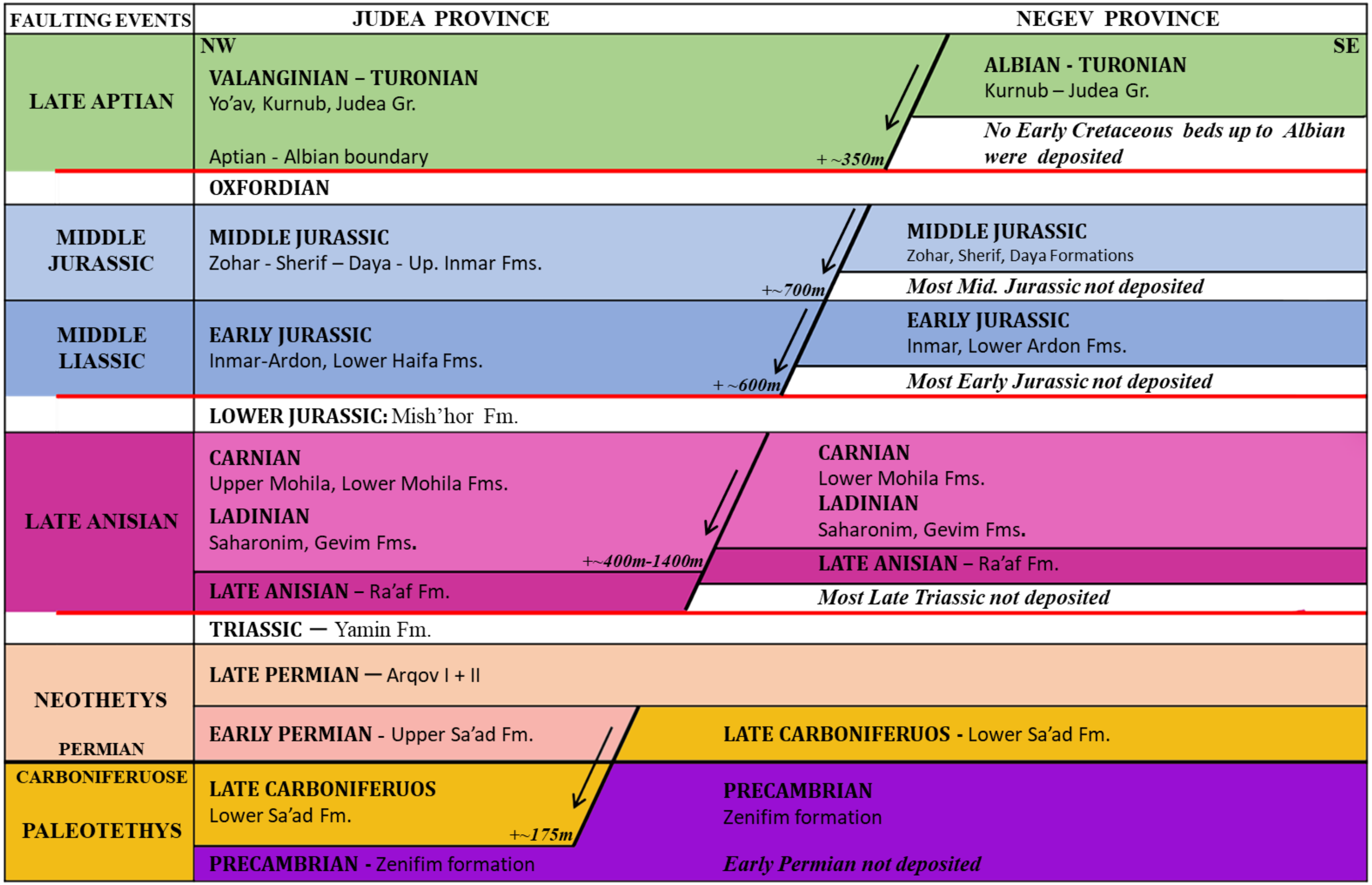

Figure 21: Main Tectonic events along the N. Negev line
(For location see Fig. 1)

CHAPTER 3 - TECTONIC LINES AND EVENTS

The stratigraphic analysis of the geological sequence of Israel suggests the recognition of three groups of tectonic lineaments, which have been intermittently active since the Early Paleozoic (Ashdod Line) and mainly from the Permian to Recent during several tectonic events (Figs. 7, 8). The accumulated subsurface data and the country-wide cross-sections, isopach maps and seismic profiles that transverse the tectonic lines show these lineaments as the location of rather abrupt faulting, distinct lithological changes and different thicknesses, defining them as tectonic features, and dividing the study area into plates, provinces and blocks, as discussed below (Figs. 5, 18, 19).

The three groups of tectonic lines are: local old lines, active since the Early Paleozoic and dividing the area into plates, provinces and blocks; Tethyan–Mediterranean lines, active since the Late Anisian and forming the southeastern Mediterranean coastline; and the younger lines, active since the Middle Oligocene, encountered throughout the entire Mediterranean region, and related to the closing of the Mediterranean Sea.

The major tectonic lines noticed in the time span from Late Paleozoic to Recent (Fig. 7) may not be connected or related to each other, and were formed in different times, as demonstrated in Fig. 7. The most pronounced lines are: the Early Paleozoic Ashdod Line, the Northern Negev Line (breaking the African Plate), the intra Late Permian rejuvenation of the Ashdod Line, forming the Palmahim Block, the Late Anisian Line, forming the precursor Coastal Plain Block, the pre-Norian Line, forming the shelf edge. The Yafo and Carmel, and probably Akko lines were formed later, after the drifting phase, in the Middle Liassic (Fig. 7), when the older lines were still active. The younger Middle Oligocene lines formed the Dead Sea, the Suez Graben and the Nile tectonic feature (Figs. 2, 4, 7).

Local old lines

Four major old tectonic lines related to the evolution of the Paleo- and Neotethys have been defined in Israel (Derin 2016). The lines from south to north are the Northern Negev Line, Ashdod Line, Yafo Line, Carmel Line, and probably the Akko (Amihud fault) Line (Fig. 3). These lineaments strike east to west or southwest to northeast and have been active from the Early Paleozoic to Recent, coinciding with the locations of rather abrupt lithological and thickness changes marking them as distinct tectonic features.

The Northern Negev Line

The Northern Negev Line is a southwest to northeast-directed, regionally tilted vertical fault, which is milder and less pronounced in its northern part. It is the most active line, acting at least five times since its formation (Figs. 12, 15, 21) at the boundary between the continental Late Carboniferous Lower Sa'ad Formation (Paleotethys) and the fluviatile Early Permian Upper Sa'ad Formation (Neotethys). The motion along this line is always in the same orientation, down faulting to the northwest. The Northern Negev Line separates the Negev and Judea provinces which were, until the Permian, both parts of the African Plate (Figs. 1, 12). The line was the southern coastal line of the Early Neotethys transgressions, consisting of Early Permian fluviatile beds of the Upper Sa'ad Formation, which do not cross the Northern Negev Line (Fig. 15).

Over a short distance of less than 20 km (Fig. 1), between boreholes Shezaf 1 (Negev Province) and Agur Deep 1A (Judea Province), a notable difference of more than 200 m in the thickness of the Permian was recorded along the Northern Negev Line. The line was active again during the Late Triassic as shown by the isopach map of the Upper Triassic formations, with a 400–1,400 m difference (Derin 2016). It was still there during the Early Jurassic when the Negev Province was uplifted (~600 m), and during the Middle Liassic (~350 m, Fig. 24), and it is therefore without marine deposits. The line again played a role during the Early Cretaceous, from Berriasian to Late Aptian, when the Negev Province was again uplifted and devoid of any marine deposits of the Yo'av Group (Fig. 18). It is possible that during the Middle Oligocene, the line formed the deeper southern coastline of the Dead Sea (Fig. 3). The Northern Negev Line was active during the increase in faulting in the Middle Miocene (Burdigalian to Late Langhian, ~17 to ~14 Ma) when the Negev Province was uplifted, and the Northern Negev Line acted as the southern barrier to the advance of the Gaza–Be'er Sheva Canyon (Buchbinder and Zilberman 1997).

The major changes along the Northern Negev Line can be detected in all the west-to-east-directed seismic profiles that cross it, such as in the interpreted seismic line DS-3576 (Fig. 22).

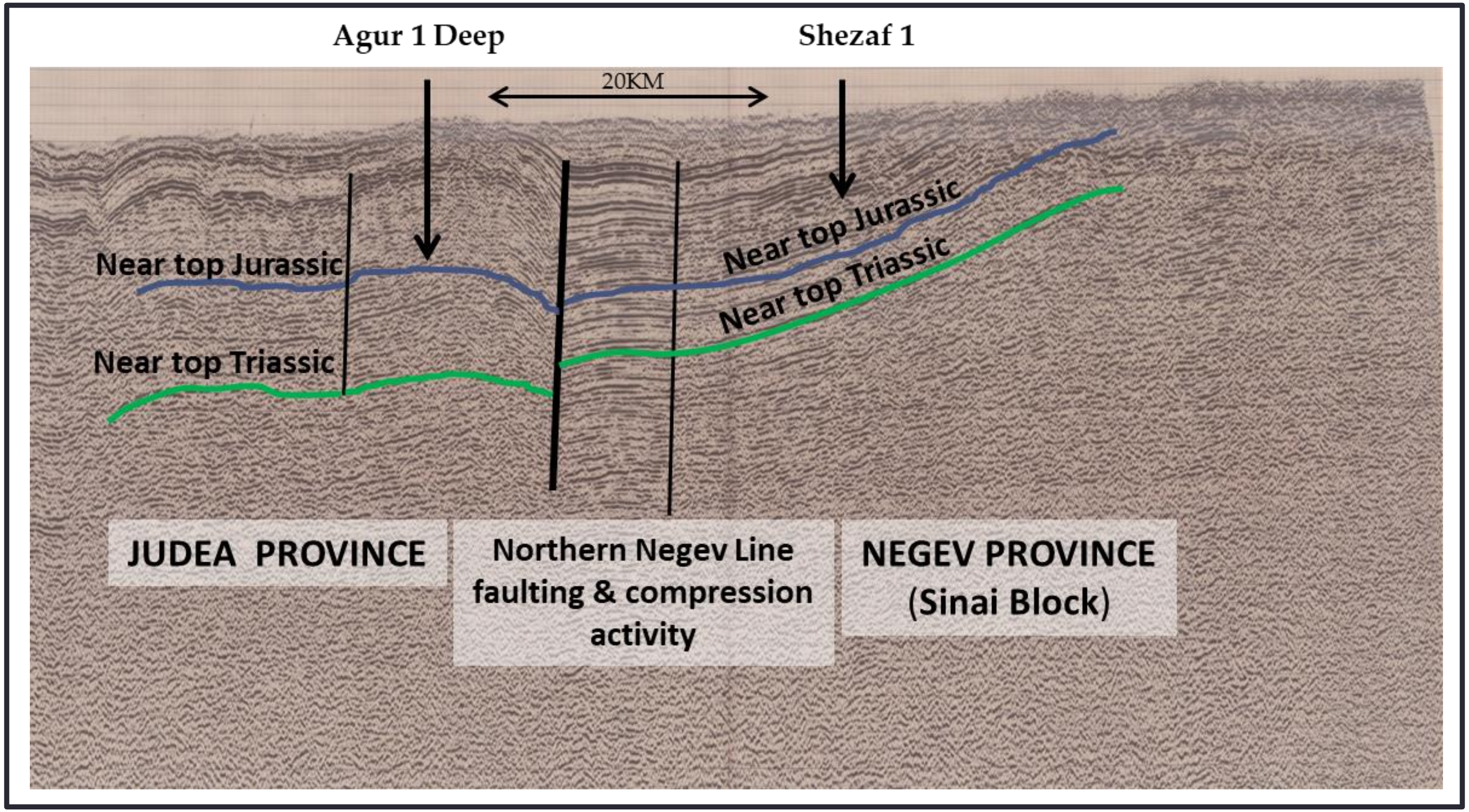

Figure 22: NW-SE, northern Negev seismic line (DS-3576)

Divide between the Negev and Judea Provinces (For location see Fig. 1)

Modified after U. Frieslender (Derin, 2016

The Yafo Line

The Yafo Line is a distinct tectonic lineament that crosses the country east to west, from the Dead Sea fault to offshore under the Mediterranean Sea bottom, parallel to the Ashdod Line (Figs. 1, 3, 19, 23). The Yafo Line was formed much later than the Ashdod Line, in the Middle Liassic tectonic event, and it is still active. The line marks the boundary between the Judea and Samaria provinces, and delineates the northern boundary of the Palmahim Block (Figs. 1, 3). The Judea and Samaria provinces differ sharply by their lithology, thickness and sequence. The differences are most prominent in the subsurface stratigraphic cross-sections and are even clearer in the offshore seismic profiles, as is visible on the nearshore seismic line 80-M-02 (Fig. 23). This profile suggests that the Yafo Line has, besides the vertical offset, a horizontal component that may have shifted the Judea Province (Palmahim Block) westward.

Lithological differences between the Judea and Samaria provinces are not discernible in the Triassic sequences. The differences begin during the Lower Jurassic, possibly in connection with the middle Liassic (pre-Domerian) tectonic event (Figs. 7–9) and the first Neotethys regional transgression, from northwestern Africa in the west, through southern Europe to the Oman Mountains in the east (Arkel 1956, Crescenti et al. 1969). The Yafo Line was, and still is occasionally active and, unlike the North Negev Line, in opposite directions. As such it may be regarded as a "hinge line".

Between the Judea and Samaria provinces, differences in lithology and thickness north and south of the line are clearly manifested, especially in the western coastal plain and in the offshore area. The Lower Jurassic deposits attain maximal thickness in the Judea Province, and display a complete and continuous stratigraphic sequence, whereas in the Samaria Province and like in the Negev Province, the Lower Jurassic beds were not deposited (Derin 2016, and Fig. 24). The shales of the Oxfordian Kidod Formation, which occur both on- and offshore in the Judea Province, are entirely missing in the Samaria Province and onshore of the Samaria Province, were replaced by limestones of the Upper Haifa Member; offshore of this province, the Kidod Shale was replaced by clastics of the Delta Formation (Derin 2016, and Fig. 16).

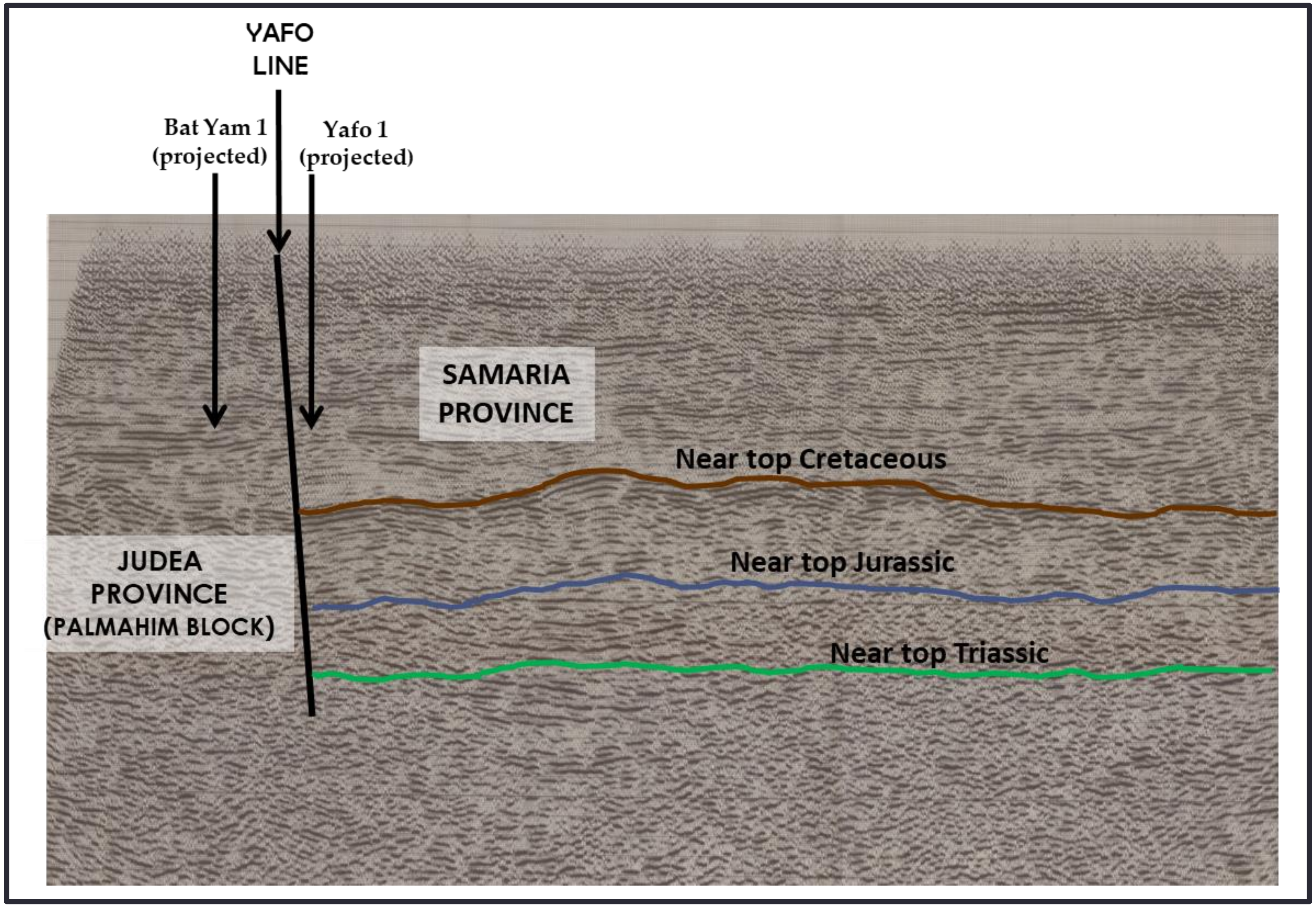

Figure 23: N-S near shore seismic line (80 – M – 02)

Transvers the Yafo Line and dividing between the Judea and Samaria Provinces (For location see Fig. 1)

Seismic interpretation by U. Frieslender

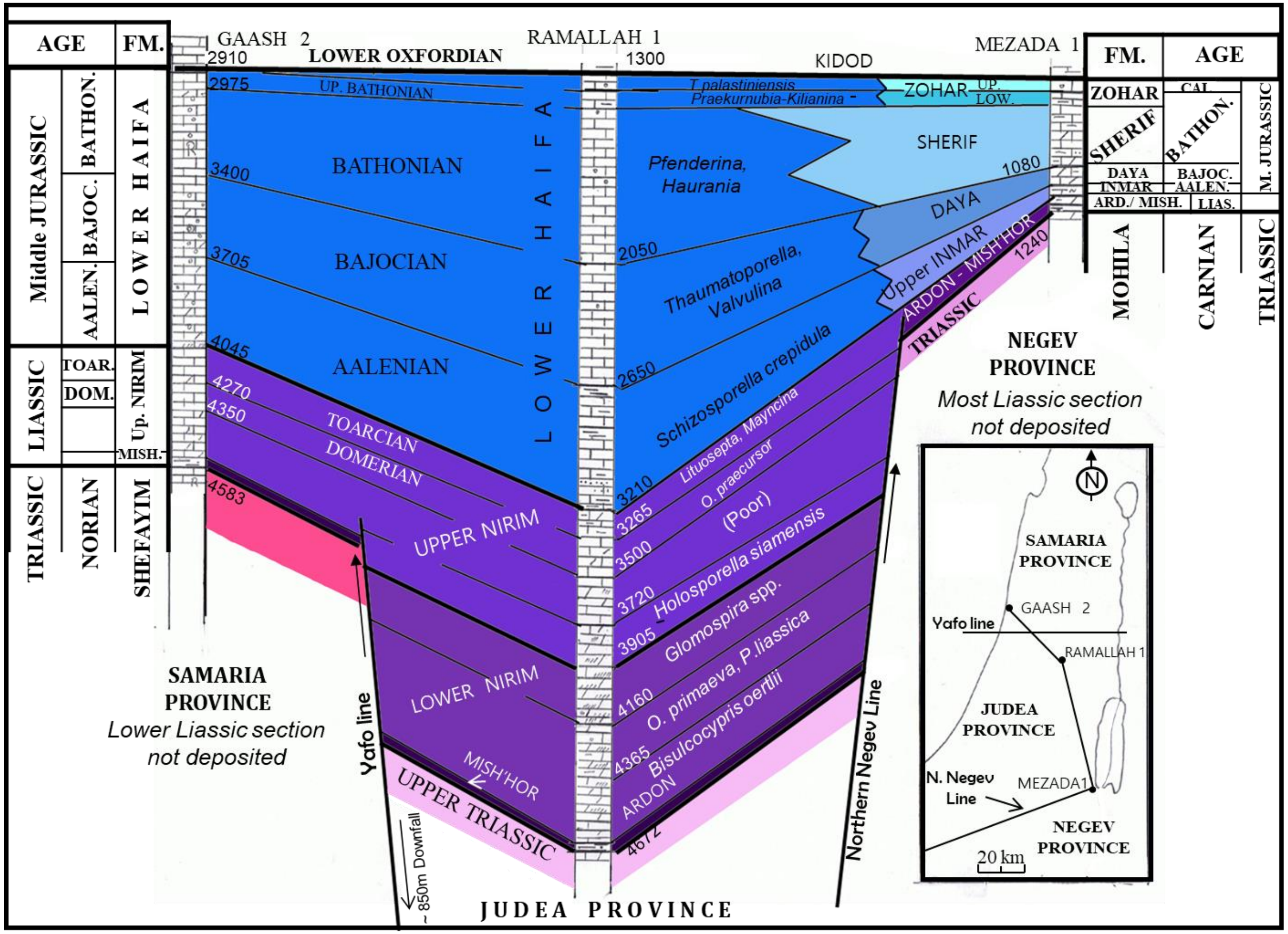

Figure 24: NW-SE cross section of Lower and Middle Jurassic in central Israel
(Note the different thicknesses in the Liassic section in the Negev, Judea and Samaria provinces)
Datum: Upper Jurassic

The Yafo Line continued to be active during younger ages. The Samaria Province was uplifted in pre-Eocene times, as evidenced by Eocene beds which were deposited in the western Judea Province (Bat Yam 1 borehole) but not north of the Yafo Line in the western Samaria Province (Jaffa 1 borehole) (Fig. 20). Upper Miocene basalt flows (Bat Yam volcanics) were observed along the southern part of the Yafo Line, within the northern side of the Judea Province, in borehole Bat Yam 1 (500 m) and in the eastern borehole National Park 1 (200 m), whereas in the Samaria Province (e.g., Jaffa 1), no signs of volcanics were found (Fig. 20). The last vertical movement along the eastern part of the Yafo Line was during the Pleistocene. It was manifested by a ca. 300 m uplift of the Samaria Province in relation to the Judea Province extending immediately to the south (Fig. 20).

Moreover, there are indications that the Yafo Line was still active during the Quaternary. At present, the line is demonstrated by the distinct cliff of old Yafo along the coastline, defining the "boundary" between Tel Aviv and Yafo (old Jaffa). The line runs along the old road from Yafo eastward, dividing the hilly dune area in the south (today the towns of Givatayim, Ramat Gan, and Bnei Brak) and the "plain area" north-west of the old road.

The Ashdod Line

The Ashdod Line is the most prominent old tectonic lineament in Israel; it crosses the country east to west, from the northern Dead Sea shoreline in the east, through Jerusalem and the way to Jerusalem, and westward, divides the southern Judea Province from the Palmahim Block, continuing far offshore under the Mediterranean Sea bottom in the west (Figs. 1, 3, 5, 6, 13, 23).

The line has been intermittently active from the Paleozoic to Recent, during the Early Paleozoic, Late Permian, Jurassic, Cretaceous and Neogene (but not during the Triassic), always with downward displacements to the north, and possibly northeast. Deep seismic reflections (Fig. 5) suggest the existence of undefined, more than 5,000 m thick Paleozoic sequences trending northeast from the Ashdod Line.

During the Paleozoic, the Ashdod Line was the eastern continuation of the northern margins of the African Plate, the southern coastal line of the Paleotethys Sea and the boundary between the African Plate and the Levant Block (Figs. 1, 3, 5, 6, 13, 25).

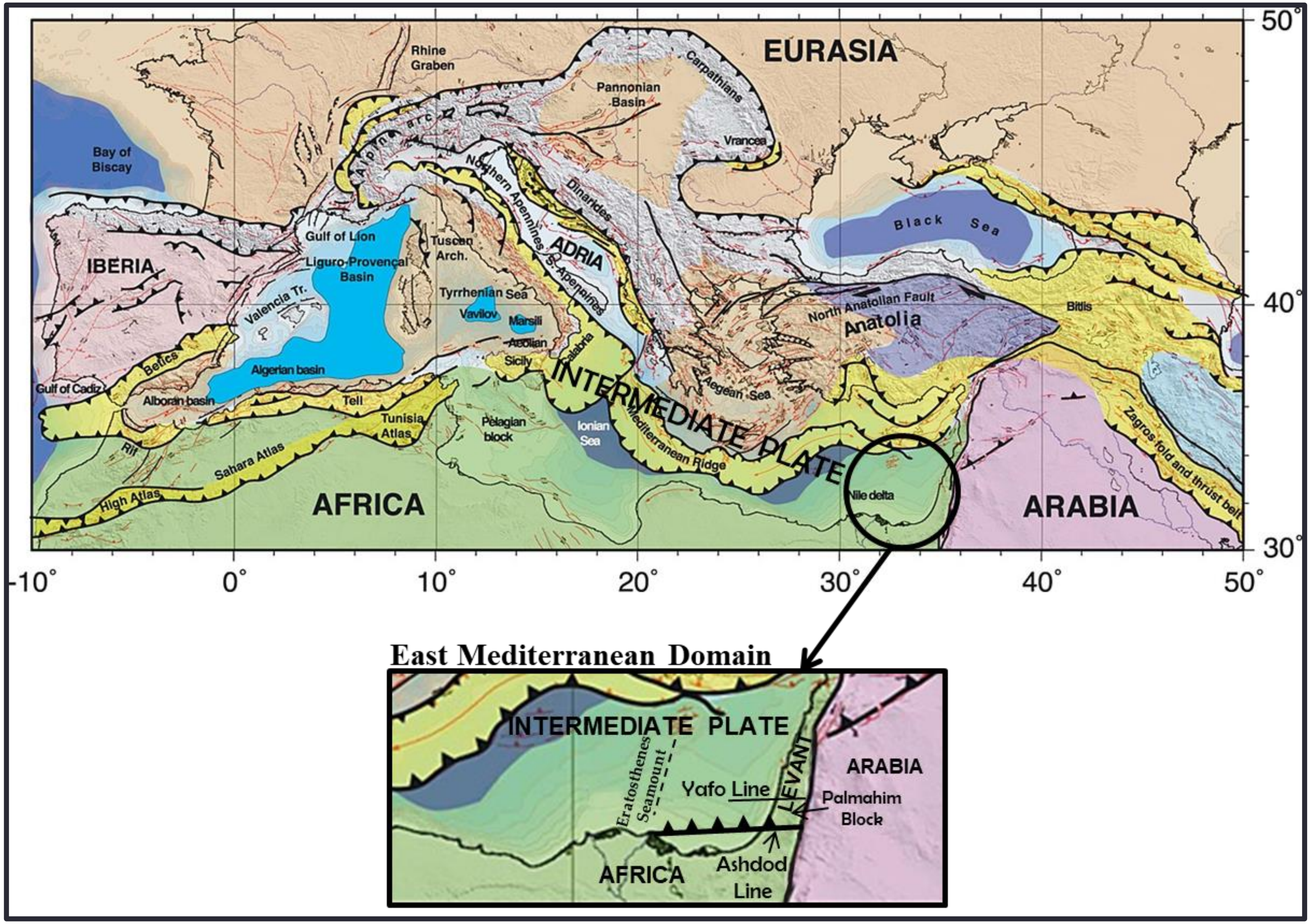

Figure 25: Plate Tectonic Setting of the “Intermediate Mediterranean Plate”

Modified after: Faccenna et al., 2014

The Ashdod Line transects the Judea Province into two parts; : the southern one (south Judea) stretches from the Northern Negev Line to the Ashdod Line, which was part of the African Plate, where no Paleotethys sediments are deposited, and the northern one, defined in this work as the Palmahim Block ("disturbance"), which is part of the Levant Block that extends from the Ashdod Line to the Yafo Line (Segev et al. 2018, Weissbrod 2005, and Figs. 3, 5, 6, 13, 25). The Levant Block, included in the present work in a newly proposed "Intermediate Mediterranean Plate", extends between the African Plate in the South and the Eurasian Plate in the North (Figs. 3, 5, 13, 25). The Levant Block resembles the recently defined "Greater Adria Block" (Van Hinsbergen et al. 2020), and numerous other blocks in the Intermediate Mediterranean Plate (Fig. 25).

There are no signs of major activity along the Ashdod Line during the Early to Middle Jurassic. At the end of the Callovian, the western part of the Palmahim Block was uplifted, resembling the uplifting during the Late Anisian Event. The Palmahim Block was exposed, and gradually truncated from east to west, with extensive dolomitization and karstic phenomena in its Middle Jurassic section (Derin 1995).

During the Alpine tectonic phase, the Ashdod Line formed an "en echelon" structure in the Judea mountains (Fig. 3), the Ramallah anticline in the northeast (Palmahim Block) plunging southwest from Ramallah to the Yad Kennedy memorial, and Hebron anticline (south Judea Block) in the southwest, plunging northeast from the village of Beit Jalla to Gilo (Fig. 3). It appears that during the Middle Oligocene, the Ashdod Line formed the northern deep-shore coast of the Dead Sea, similar to the Northern Negev Line which formed its southern deep-shore coast.

The Carmel and Akko lines

The Carmel Line separates Samaria Province in the south and Galilee Province in the north (Fig. 3). Achmon and Ben-Avraham (1997) proposed that it results from the “complex tectonic processes which were active during the mid-Paleozoic-Mesozoic evolution of this area.” Ben-Avraham and Hall (1977) suggested that the Carmel structure is old and probably started to evolve during the Upper Paleozoic, while Achmon and Ben-Avraham (1997) proposed that it “was created as a continental failed rift at the Triassic-Jurassic rifting event of the Neotethys.” Here we suspect that it was formed, like the Yafo Line, during the Middle Liassic (pre-Domerian) tectonic event and is still active today (e.g., Salamon et al. 2013). The Galilee Province is transected by the east–west Akko Line (Amihud fault) into Lower Galilee in the south and Upper Galilee in the north (Figs. 1, 6), which extends into the Lebanese territory (not studied here). It is not clear when the Akko Line was formed, whether it started to develop together with the Carmel structure during the Upper Paleozoic as suggested by Ben-Avraham and Hall (1977), or only during the Pliocene (Matmon et al. 2003). We assume that it may have formed, like the Carmel Line, during the Middle Jurassic. Unfortunately, only a few boreholes have been drilled in the Galilee Province and thus, subsurface information is scarce and any conclusions are equivocal.

Tethyan–Mediterranean-related lines

While the local old lines are oriented east–west, southwest–northeast or southeast–northwest and have been active since the Early Paleozoic, the Tethyan–Mediterranean lines are oriented north–south, parallel to the present coastline (Fig. 4). The lines were active in serial pulses since the Middle Triassic (Late Anisian event) to at least the Senonian and younger, and are related to the formation of the Judea–Samaria Mountain Chain and the present coastal plain (Fig. 4).

Two lines are discussed:

- the Late Anisian Line which is the most distinct and oldest line
- the pre-Norian Helez–Atlit Line

The Late Anisian Line and event (~245 Ma)

The Late Anisian Line is one of the most distinct and major tectonic lines, which shaped the morphology of Israel; it formed the precursor of the East Mediterranean Coastal Line and at present, defines the boundary between the coastal plain area in the west and the uplifted Judea and Samaria Mountain Chain in the east, close to the original position of the line.

The Late Anisian was a major event in all of Europe (De Zanche 1990, De Zanche et al. 1992, Doglioni et al. 1994, Garfunkel 1988, 1998, Garfunkel and Derin 1985, Doglioni and Neri 1988, Robertson et al. 2012). It is connected to the spread of eastern North America and northwest Africa and the evolution of their continental margins (Von Rad et al. 1982).

During the Late Anisian–Ladinian time span, the southwestern coastal plain area was an uplift tilted to the east and exposed to deep truncation. The truncation increased westward, where the entire Lower Triassic to Precambrian was eroded and later filled by a thick sequence of "African Plate" Paleozoic conglomerates (Figs. 9, 14). The Late Anisian event marks the deepest truncation and the thickest conglomerate fills (over 650 m in Ga'ash 2) known in Israel (Derin 2016, Fig. 14). The conglomerate beds consist of red-black shales ("choco shales"), marls and hard limestone fragments originating from the Early Paleozoic Precambrian fragments derived from the Helez area in the southwest (African Plate), where the Permian to Early Triassic is missing and the Or Haner Formation conglomerate overlies the Precambrian Erez Porphyry (Derin 2016, and Figs. 8, 9, 14).

In the eastern borehole (e.g., David 1 well, Derin 1995), the conglomerates are intermingled or interbedded with limestone of Ladinian age (Saharonim Formation). Therefore, this age is attributed to the Or Haner conglomerate. While the western side of the Late Anisian Line was an uplifted and eroded block, during the Ladinian-Carnian, the eastern side of the line was a deep trough the "Judea Samaria trough" (Derin 2016) filled with a more than 1,000m sequence of evaporites of the Mohila Formation as in Ramallah 1 and Devora 2a, the thickest known evaporate sequence in Israel (Derin 2016, Derin et al. 1980, and Fig. 14).

During the Alpine Orogeny Phase, the area east to of the Anisian Line, the original "Judea–Samaria trough", was uplifted, in a direction almost opposite to that of the original Anisian movement, forming the Judea–Samaria Mountain Chain (Fig. 4).

Helez – Atlit Line

The Helez–Atlit Line is a north–south, down faulted to the west strike fault running parallel to the present coastline. It was formed during the pre-Norian event (~225 Ma) and is the precursor of the present-day southeastern Mediterranean coastal plain shelf edge (Figs. 4, 14, 26). The area between the Helez Atlit Fault Line in the west and the Late Anisian Line in the east became the uplifted Coastal Plain Block, as discussed further on (Fig. 4).

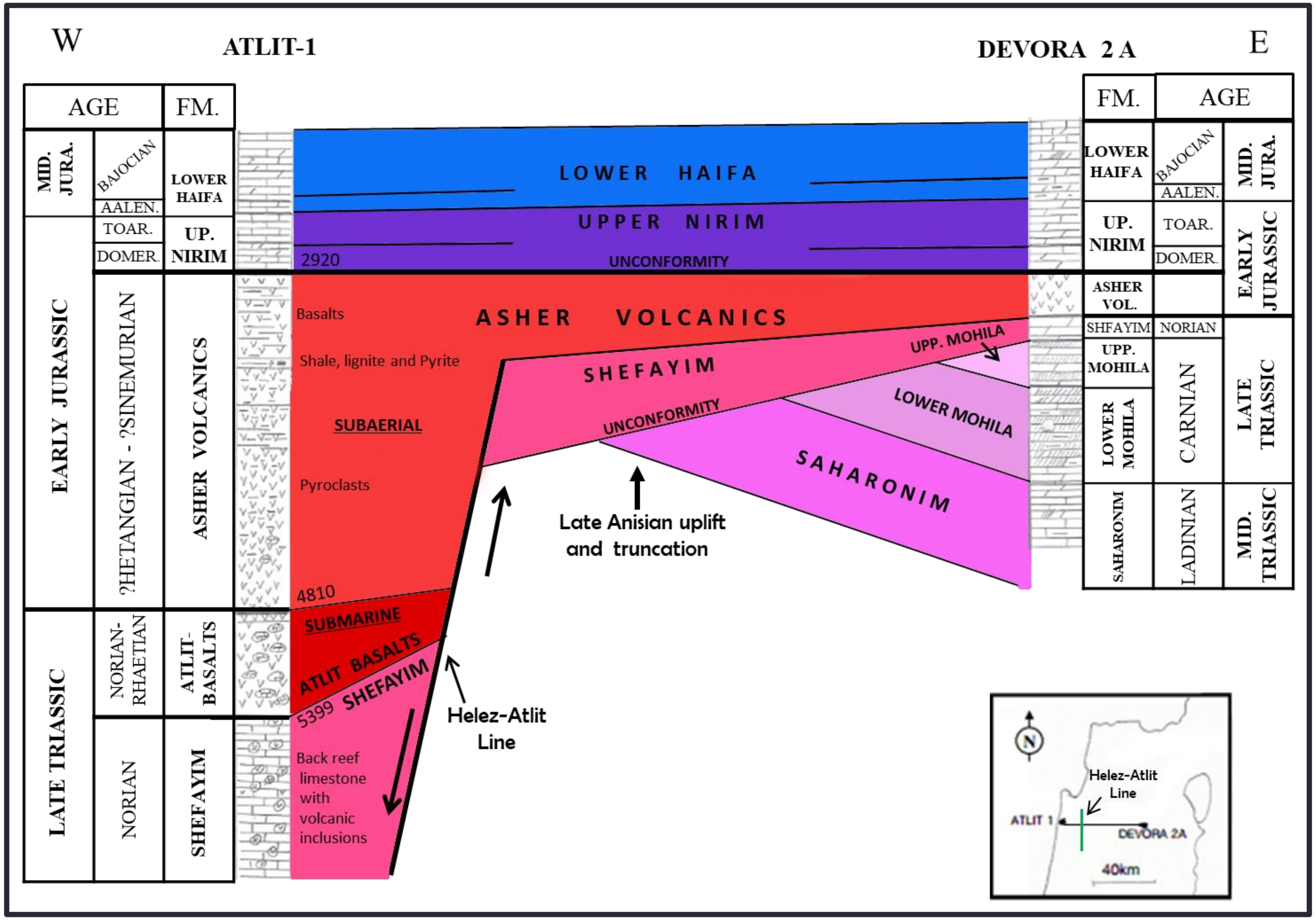

Figure 26: Volcanics atop Shefayim Formation

Showing: (1) Submarine Atlit Basalts (Norian)

(2) Subaerial Asher Volcanics (E. Jurassic)

The age of the Helez-Atlit line is defined by its stratigraphic position. In the southern coastal plain (Helez Deep 1A, Fig. 14), the Or Haner conglomerate (Ladinian) which overlies the Erez Porphyry (of undefined age), was down faulted to the west by the Helez–Atlit Line and is overlain by the transgressive Norian age Shefayim Formation (Derin 1979, 2016). In the northern coastal plain (Asher-Atlit 1), the base of the Shefayim Formation was not penetrated and we assume that no conglomerates were deposited there. The Norian Helez–Atlit Line became the shelf edge of the eastern Neotethys carbonate platform, where high-energy beds of PCM were deposited as discussed in the Neotethys chapter. The formation of the Helez-Atlit line is most likely connected to the spreading event of the eastern North America and Northwest Africa, and the evolution of their continental margins during the Triassic–Jurassic time span (Von Rad et al. 1982).

From the Permian to the Norian, all sea transgressions into Israel were from northeast to southwest, whereas from the Norian on, all Neotethys–Mediterranean transgressions were from northwest to southeast. From field observations and micropaleontological examinations, I found great similarity between the Norian reefoidal limestones (Shefayim Formation), which are associated with and embedded in marine lava flows (Atlit basalt), and the "Petra tou Romiou" Formation in southwestern Cyprus, which similarly consists of reefoidal limestone, embedded with Phasoula pillow lava (Derin et al. 1984).

The Deep Shelf Edge Line

The Deep Shelf Edge Line is a western offshore line, running parallel to the present coastline and clearly visible in seismic profiles. Its age of formation is unknown, but it most likely occurred during the young Miocene events (Figs. 4, 7).

Younger lines

The Middle Oligocene younger tectonic lines (~28 Ma) are among the more impressive seismically active tectonic movements that are still active to Recent. The most distinct feature in our region are the formation of the Sinai sub plate, the Dead Sea strike-slip fault system the Nile River system, and the Gulf of Suez Rift Graben (e.g., Salamon et al. 2003). The most pronounced subsurface feature is the uplifting of the Palmahim Block along the Yafo Line, which is visible only in seismic lines and the stratigraphic cross-section (Fig. 20). The Oligocene tectonic phase was a major event in the entire Mediterranean, related to the closing process of the Mediterranean Sea, with different movement's orientations of the various blocks (Critelli 1999, Critelli and La Perlo 1998, Doglioni et al. 1994, Faccenna et al. 2014, Papanikolau 2009, Robertson et al. 2012, Royden and Faccenna 2018, Van Hinsbergen et al. 2020).

The repeating earthquakes in Israel are strongly related to the activity of the younger lines, particularly the Dead Sea strike-slip and the Suez Rift (e.g., Salamon et al. 2003), as well as to noticeable activity associated with the Carmel Line (e.g., Hofstetter et al. 1996).

The Syrian Arch Lines

The term “Syrian Arch” defines the mountain chains which were formed during the Alpine orogenic phase. The term was introduced almost 100 years ago by Krenkel (1925) and is still widely employed. The Syrian Arch consists of four discontinuous mountain chains with different axis orientations, which together give the "shape of an arch" (Fig. 19). They include the Negev anticlines: Makhtesh Ramon, Makhtesh Hahira and Makhtesh Hazera striking southwest–northeast, parallel to the Northern Negev Line axis and related to its compression activity (Fig. 3); the Judea–Samaria mountains, striking "parallel" to the Late Anisian Line and connected to its compressive activity; the north–south striking Galilee mountains, and the southwest–northeast-directed Syria–Palmira axis, which is most likely connected to the northern movement of the east side of the Dead Sea strike-slip fault.

CHAPTER 4 - PLATES, PROVINCES AND BLOCKS

The study area covers a surface area of approximately 42,500 km^2. It is about 300 km long, from northern Galilee to the Sinai border, and about 120 km wide between the Jordan Rift Valley and the coast parallel to the nearshore area beneath the eastern Mediterranean Sea. The geological sequences of the area suggest the recognition of several lithological units: plates, provinces and blocks separated by regional tectonic lineaments characterized by abrupt changes in lithology and thickness. The lines have been intermittently active since the Early Paleozoic (Ashdod Line) and mainly from the Permian to Recent (Figs. 1, 5–7).

Plates

Two major plates, divided by the Ashdod Line, are defined in this work. The African Plate to the south of the Ashdod Line, and the newly proposed "Intermediate Mediterranean Plate" to the north of the line. The Intermediate Mediterranean Plate is located between the African Plate in the south and the Eurasian Plate in the north (Figs. 1, 3, 5, 6, 13, 25).

The Intermediate Mediterranean Plate hosts a diffuse mosaic of numerous microplates that move and deform independently from the overall plate convergence (Faccenna et al. 2014, Robertson et al. 2012, Royden and Faccenna 2018, Şengör and Yilmaz 1981, Van Hinsbergen et al. 2020). The intermediate microplates are not "detected blocks" of the African or Eurasian plates, and are independent blocks of the Paleotethys and Neotethys sequences. No Paleotethys sediments were deposited in the African Plate, while both thick Paleotethys and Neotethys sequences were deposited in the Intermediate Plate. The boundary between the African Plate and the Intermediate Plate is easily observed in seismic profiles which transverse the Ashdod Line (Fig. 5).

The African Plate

Over 5,000 m of the Paleotethys sequence are clearly identified in seismic profiles in central and northern Israel, north of the Ashdod Line (Fig. 5), but it is entirely missing in southern Israel, south of the Ashdod Line, an area which was part of the African Plate. As such, the Ashdod Line is the eastern continuation of the northern edge of the African

Plate, and the southern coastline of the Paleotethys (Figs. 3, 5, 6, 13, 25). All sediments older than Late Carboniferous are missing on the African Plate, and continental quartzose sandstones of the Lower Sa'ad (Late Carboniferous) unconformably overlie the Late Precambrian to Early Cambrian arkoses of the Zenifim Formation (Weissbrod 2005). The lack of sedimentation in the area south of the Ashdod Line (the African Plate) indicates that during most of the Paleozoic Era, it was an uplifted plate with no deposition, followed most likely by erosion which removed sediments down to the deeper Precambrian. Fluviatile and marine sediments of the Neotethys sequence appear only in the Permian, covering the Late Carboniferous sandstone in pulses which persist to the end of the Cretaceous (Figs. 5, 9, 12). During the Late Anisian event, the southwestern coastal plain was uplifted and the entire sedimentary section up to the Middle Triassic was eroded, with Or Haner conglomerate (Ladinian) overlying the Precambrian Erez Porphyry (Fig. 14, 26).

The Intermediate Mediterranean Plate

The proposed Intermediate Mediterranean Plate stretches between the African Plate in the south and the Eurasian Plate in the north (Figs. 13, 25). Its southern boundary is the Ashdod Line, which is the eastern continuation of the northern edge of the African Plate (Fig. 25). As already noted, the Intermediate Plate hosts a diffuse mosaic of numerous microplates that since the Oligocene, have moved and deformed independently from the overall plate convergence (Faccenna et al. 2014, Robertson et al. 2012, Royden and Faccena 2018, Şengör and Yilmaz 1981, Van Hinsbergen et al. 2020). The local microplate is the Arabian Block, from which the small Palmahim Block ("disturbance") and the Levant Block were fragmented. The Levant Block resembles the recently defined Greater Adria Block (Van Hinsbergen et al. 2020, and Figs. 1, 6, 13, 25).

Interpretation of deep seismic reflection data (Fig. 5) suggests the presence of over 5,000-m thick Paleozoic beds in the Intermediate Plate north of the east–west Ashdod Line which are missing in the southern African Plate. The Intermediate Plate was partially drilled into in Israel by only one borehole—Ma'anit-Josef 3 (Derin 2012, and Fig. 14).

Provinces

The Negev Province

The Negev Province formed as the result of the activity of the Northern Negev Line, a southwest–northeast regional vertical fault line, tilted to the northwest at the boundary between the Late Carboniferous (Lower Sa'ad Formation) and the Early Permian (Upper Sa'ad Formation, ~300 Ma). It is the boundary between the Paleotethys and the Early Neotethys (Figs. 9, 13, 25). The line separates the Negev Province to the south and the Judea Province to the north, both the Negev and south Judea provinces were part of the African Plate. During large parts of the Permian to Cretaceous time span, the Negev Province was an uplifted block, generally uncovered by sediments (Derin 2016). The stratigraphic sequence of the Negev Province was laid down in shallow water environments, characterized by low rates of deposition, incomplete sedimentary sequences and considerably thinner sections than their counterparts in central and northern Israel (Figs. 17, 18, 21, 22, 24).

The Upper Paleozoic sequence in the Negev Province consists of only two members: the Lower Sa'ad Member (Late Carboniferous) and the Lower Arqov Member (Late Permian), whereas wells drilled in the Judea Province are more completely penetrated most of the Permian section (Figs. 17, 18, 21, 22, 24).

A notable change in thickness of the Sa'ad Formation occurs over a short distance (less than 20 km, Fig. 1) between Shezaf 1 in the Negev Province, where only the Lower Sa'ad Member is present (115 m), and Agur Deep 1A in the Judea Province, where the Lower and Upper Sa'ad members together reach 335 m (Derin 2016). This sudden difference in thickness is related to "intra-Sa'ad" (Carboniferous–Permian boundary) vertical movement along the Northern Negev Line (Derin 2016, and Figs. 9, 12, 15, 21).

The Negev Province was reactive again during (1) the Late Triassic as shown by the isopach map of the Upper Triassic formations (Derin 2016). It still was there (2) in the Jurassic whenever the Negev Province was periodically uplifted hence without marine deposits. It played a role again (3) during the Early Cretaceous, from Berriasian to Late Aptian when the Negev Province was uplifted, remaining without any Early Cretaceous marine deposits of the Yo'av Group (Figs. 9, 12, 15, 17, 18, 21, 24). The major thickness changes along the Northern Negev Line between the Negev and Judea provinces can be detected in all west–east seismic profiles that cross it. One such interpreted seismic line (DS-3576) is included (Figs. 1, 22).

The Judea Province

The Judea Province is limited on the southeast by the Northern Negev Line and to the north by the Yafo Line. The province is transected by the east–west Ashdod Line which divides it into a southern "African segment" and a northern "Levantine segment". The Palmahim Block ("Palmahim disturbance") is the southern detached block of the Levant Block, and is limited to the north by the Yafo Line (Figs. 3, 21).

The Judea Province evolved as a discrete feature sometime later than the Negev Province. It is a complex, faulted block, with a thick volume of mainly Jurassic sediments. The stratigraphic sections (Figs. 15, 17, 24, 26) show downward vertical movement to the north of the Ashdod Line, and "an intra-Arqov" event of the Late Permian (Djulfian/Dorashamian) age along the line. Whereas in the uplifted area, south of the Ashdod Line, only the Lower Arqov members 1 and 2 are found, additional Upper Arqov members 3 and 4 occur on the downthrown northern side (Figs. 12, 15).

During the Late Anisian event, the southwestern coastal plain (Helez area) was uplifted and the entire sedimentary section below the Middle Triassic was eroded and filled with Or Haner conglomerates (Ladinian) which overlie the Precambrian Erez Porphyry (Figs. 9, 15). The Lower Jurassic deposits are at their thickest in the Judea Province, displaying a more complete sequence than those of the Negev, Samaria or Galilee provinces, where parts of the Lower Jurassic were not deposited (Fig. 24).

The differences in lithologic sequences between Judea and Samaria provinces are clearly manifested during Late Jurassic times (Fig. 17). The shales of the Upper Jurassic Kidod Formation in the Judea Province, which occur both on- and offshore, are entirely missing in the Samaria Province, where they were replaced onshore by limestone of the Upper Haifa Member, and offshore by clastics of the Delta Formation (Derin 2016). The shales of the Kidod Formation are deeply incised by multiple east–west-striking valleys (the most well-known being the Gevar 'Am Channel) under the western coastal plain of the Judea Province, filled by younger Cretaceous shales and clastics of the Gevar 'Am Formation. No such Jurassic canyons are known in the Samaria Province (Derin 2016, and Figs. 17,).

The Palmahim Block ("disturbance")

As mentioned above, the Ashdod Line transects the Judea Province into two segments: the southern segment stretching from the Northern Negev Line to the Ashdod Line which was part of the African Plate (the "African segment"), and the northern segment ("Tethyan segment") known as the "Palmahim Disturbance" and defined here as the Palmahim Block which in turn, is part of the Levant Block (Figs. 2, 6, 12, 13).

The Palmahim Block has been, since its establishment, an unstable east–west-trending block extending far offshore, located in the northern part of Judea Province, between the Ashdod Line in the south (which is the northern edge of the African Plate) and the Yafo Line in the north. The Palmahim Block represents a peculiar sedimentary-tectonic block that is part of the Levant Block (part of the Intermediate Mediterranean Plate) and covered by thick Paleotethys beds, bordered in the south by the "southern Judea segment" which was part of the African Plate, and where no Paleotethys beds were deposited (Fig. 5). As a result, the Palmahim Block was mainly influenced by the compressional activity of two tectono-stratigraphic systems, the African Plate in the south and the Intermediate Mediterranean Plate in the north (Figs. 3, 5, 12, 13). It is not certain when the block was formed or started to become active; we assume that it was formed in the Late Permian, connected to the activity of the Ashdod Line (Figs. 5, 12). No tectonic activity was discernible along the Ashdod Line in the Triassic or Early Jurassic, and we assume that the Palmahim Block was re-activated during the Middle Liassic event (pre-Domerian), connected to the formation of the Yafo Line. The Palmahim Block was active, since it was formed at least along the Yafo Line, not in the same direction, and most of the time it was an uplifted and eroded block, mainly offshore.

At the end of the Callovian, the western part of the Palmahim Block was uplifted, with gradually increasing truncation from west to east, involving extensive dolomitization and karstic phenomena of the Middle Jurassic section (e.g., David 1, Ashdod 1–4 and Hof Ashdod wells, Derin 2016). Neither truncation nor dolomitization was observed in rock of similar age in the southern Judea Province ("African segment), or in the Samaria Province. The Lower Cretaceous interval from the Barremian to Middle Cenomanian is entirely missing, either not deposited or eroded, as indicated by the Late Albian Talme

Yafe Formation beds which unconformably overlie the Gevar 'Am or Heletz formations of Hauterivian–Barremian age in deeply incised canyons (Derin 2016). Upper Cenomanian rudist's limestone and dolomite also overlie the Barremian Upper Gevar 'Am Formation (Derin 2016).

During the Middle Oligocene, the Palmahim Block was uplifted; the thickness of the Lower to Middle Miocene sequence is reduced or not deposited (Fig. 20). During the Upper Miocene, volcanic activity (Bat Yam and National Park volcanics) is noticed along the southern side of the Yafo Line, on the northern edge of the Palmahim Block (Judea Province), but not on the northern side of the Yafo Line in Samaria Province. The tectonic activity movement of the Palmahim Block changed to the opposite direction during the Early Pliocene. The Palmahim Block is down faulted to the south, a situation which continues to the Recent, with about 2,000 m of Plio–Pleistocene stratigraphic sections (Fig. 20).

The Samaria Province

The Samaria Province stretches from the Yafo Line in the south to the Carmel Line in the north (Fig. 3). Originally, Samaria was part of the Judea Province, and separated from it during the Middle Liassic. It is possible that both the Yafo and Carmel lines, which define the Samaria Province, were formed at the same time during the Middle Liassic. Both lines are still active today.

Only a few deep exploratory wells have been drilled in the western Samaria Province: Ga'ash 2, Atlit-Asher 1 and Meged. The entire interval from the Middle Triassic to the Permian, and deeper, was eroded and truncated in those wells during the Late Anisian uplifting (Figs. 14, 26). The Ga'ash and Meged wells were later filled by the Ladinian Or Haner conglomerate. Reefoidal beds of the Shefayim Formation of Norian age were deposited in Ga'ash 2 and in Helez Deep 1A (Derin 2016), overlying the Or Haner conglomerate. In the Asher-Atlit 1 borehole, the reefoidal limestone is intermingled with submarine Atlit basalt (Figs. 14, 26). We assume that no Or Haner conglomerate was deposited there. Lithological differences between the Judea and Samaria provinces begin in the Lower Jurassic, possibly in connection with the formation of the southern Levant continental margin. From that time onward, up to the Pleistocene, there are differences in lithology, thickness and sequence of events between the Judea and Samaria provinces, which are clearly manifested throughout Jurassic times and especially in the western coastal plain and offshore area. The Lower Jurassic deposits are at their thickest in the Judea Province, displaying a complete sequence, whereas in the Samaria and Negev provinces, the Lower Jurassic is missing, with no deposits at all. Both the Negev and Samaria provinces were uplifted blocks during the Early Jurassic, whereas the Judea Province between them was a gulf of the Early Liassic Sea (Fig. 24).

The first marine Jurassic beds in the Samaria Province are carbonate beds of Middle Liassic (Domerian) age which overlie either the base Jurassic lateritic paleosol of the Mish'hor Formation, or the Asher volcanics (Figs. 17, 26, 26). The Middle Liassic transgression was a major regional marine event extending over the entire Neotethys, from northwestern Africa in the west to the Oman Mountains in the east (Arkel 1956).

The shales of the Upper Jurassic Kidod Formation, which occur both onshore and offshore in the Judea Province, are entirely missing, offshore and onshore, in the Samaria Province. The Kidod shales were replaced onshore by limestones of the Upper Haifa Member and offshore, by thick clastic beds of the Delta Formation (Derin 2016, and Fig. 17). The Middle and Late Jurassic boundary in the adjacent Judea Province is easy to define, as the Late Callovian unconformity exposed the area to extensive erosion with thick Oxfordian shale of the Kidod Formation overlying the unconformity plane. In the Samaria Province where no Kidod shale was deposited, this boundary is not clear. Middle and Late Jurassic boundaries are within a seemingly continuous carbonate sequence and hence, can be distinguished only by micropaleontological examination, i.e., the extinction of Middle Jurassic microfauna and the appearance of Late Jurassic microfauna. The Jurassic sequences of the northern Samaria and Galilee provinces are overlain by the Cretaceous Tayasir volcanics (dated as Berriasian). These volcanics are missing in the Judea Province.

The established Late Jurassic trend in the western coastal plain and offshore continued during the Middle Cretaceous: deep truncations with young fill, associated with several intra–Cretaceous unconformities, e.g., thick marls and conglomerates of Late Albian age, and the Talme Yafe Formation in the Judea Province, versus a similar, but not identical, thick Cenomanian age Item Formation in the Samaria Province (Derin 2016, and Fig. 17). On land, the Cretaceous sequence of the Judea Province, in the subsurface and on the surface, is similar to that of the southern Samaria Province. The Berriasian age Tayasir volcanics present at the base of the Cretaceous in the northern Samaria and

Galilee provinces is missing in the southern Samaria and Judea provinces, where the Cretaceous sequence begins with younger sediments, usually of Valanginian age.

The Samaria Province was uplifted in pre-Eocene times, and this movement is reflected in the Eocene beds which were deposited in the western Judea Province in Bat Yam 1 but not in the western Samaria Province in Jaffa 1 (Fig. 20). Upper Miocene basalt flow is observed along the southern side of the Yafo Line, within the Judea Province, in borehole Bat Yam 1 (500 m) and in the eastern borehole National Park 1 (200 m) where, on the northern side of the Yafo Line in Samaria Province (e.g., Jaffa 1, Petah Tiqva 1 boreholes) no sign of volcanics was found. The last vertical movement along the eastern side of the Yafo Line is of Pleistocene age, indicated by a ca. 300-m uplift of the Samaria Province in Jaffa 1, in comparison to the Judea Province immediately to the south in Bat Yam 1 (Fig. 20).

The Galilee Province

The Galilee Province is separated from the Samaria Province in the south by the Carmel Line (Figs. 1, 3). The province is divided by the Akko Line (Amihud fault) into Lower Galilee in the south and Upper Galilee, which extends northward into Lebanon; as no subsurface data are available from Lebanon, the latter is not discussed here. Unlike the Judea and Samaria provinces which are more stable, moderately deformed and faulted, the Galilee Province was heavily deformed by intense tectonic activity and faulted during the Neogene (e.g., Ben-Avraham and Ginzburg 1990, Folkman 1976).

Six deep exploratory wells were drilled in the Galilee Province, the westernmost Asher Yam 1 situated offshore. Five of the six penetrated deeply into the Middle Jurassic, but only Devora 2a, located in the eastern Galilee, penetrated the thickest Triassic section in Israel without, however, reaching the Permian (Derin 2016, Derin and Gerry 1979, and Fig. 1).

Because there are no deep wells and the quality of the deeper seismic data is poor and insufficient, it is not certain that the Middle Triassic angular unconformity (Late Anisian event) and the thick clastics of the Or Haner Formation which are so dominant in the Judea and Samaria provinces exist in the Galilee Province. The Jurassic and Cretaceous sequences in the Galilee Province are similar to those of the Samaria Province, gradually thickening westward and northeastward (Derin 2016).

The Coastal Plain Block

The Coastal Plain Block is a north–south tectonic block extending between the Late Anisian Fault Line in the east and the pre Norian Helez–Atlit Line in the west, parallel to the present coastline (Fig. 4), which was formed during the pre-Norian. During the Jurassic and Cretaceous periods, the Coastal Plain Block was an intermediate area, located between the deep open sea environment with pelagic sediments in the west and northwest, and the shallow water-restricted environment in the east and southeast (Judea–Samaria Mountain Chain). By this and by the time at which it was formed, it resembles the Moroccan "Meseta" (Von Rad et al. 1982).

The western part of the coastal plain was, during the Jurassic and Cretaceous periods, the shelf edge of the southeastern Neotethys carbonate platform where PCMs developed. The western Coastal Plain Block is characterized by high-energy deposits such as oolithic shoals in the Middle Jurassic (Sederot Formation), Stromatoporoids barrier reefs in the Upper Jurassic (Nir Am Formation), and a rudists barrier reef in the Middle Cretaceous (Nahal Hamearot Formation) (Figs. 4, 9, 16, 17). At present, the eastern boundary (the original Late Anisian Line) is the western boundary of the Samaria and Judea Mountain Chain (Fig. 4).

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המבנה
וההתפתחות הגיאולוגית
של תת הקרקע בישראל
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