

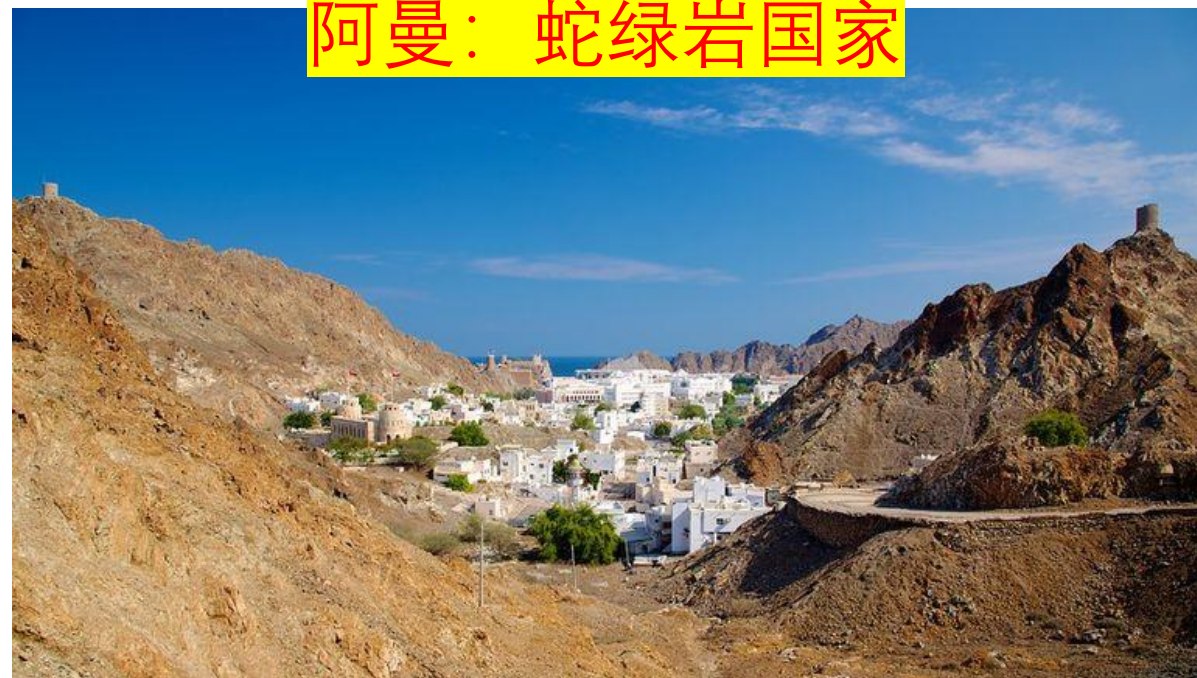
# 阿曼蛇绿岩仰冲 事件 Ophiolite obduction in Oman

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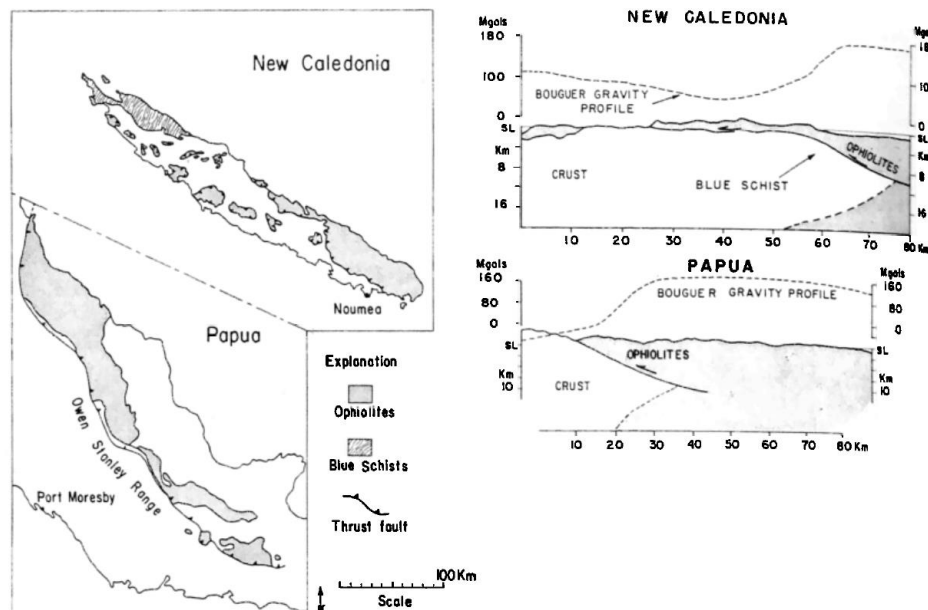
阿曼：蛇绿岩国家



# Plate Tectonic Emplacement of Upper Mantle Peridotites along Continental Edges

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U. S. Geological Survey, Menlo Park, California 94025



*Tectonophysics*, 31 (1976) 93-120

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## OPHIOLITE OBDUCTION

J.F. DEWEY

Department of Geological Sciences, State University of New York at Albany, Albany, N.Y. (U.S.A.)

(Submitted June 19, 1975; accepted for publication November 3, 1975)

蛇绿岩及其就位问题在板块构造诞生的初期就受到高度关注。

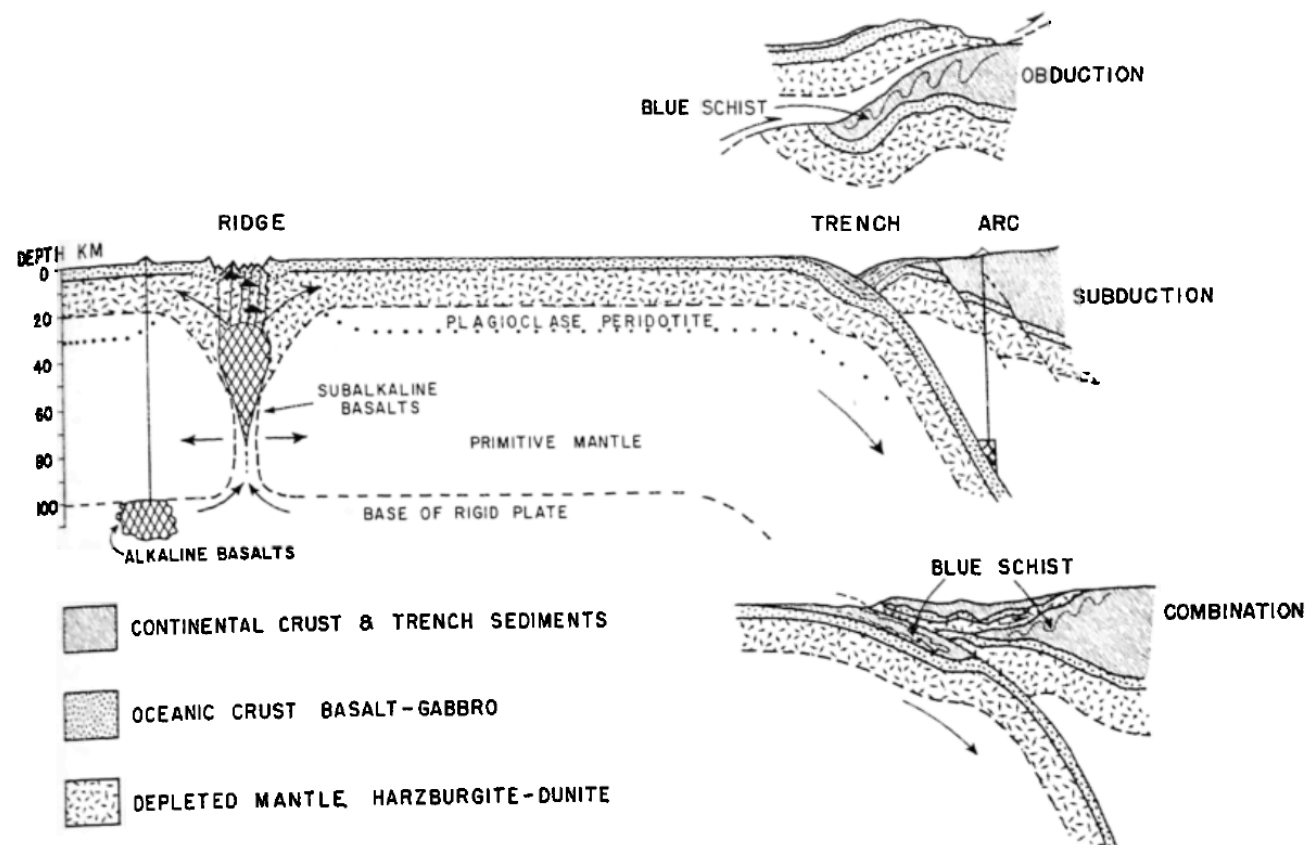


Fig. 6. Conceptual model illustrating the development of oceanic crust at active ridges and its subduction or obduction or both at consuming plate margins.

# Ophiolite obduction and geologic evolution of the Oman Mountains and adjacent areas

1977

W. K. GEALEY *Chevron Overseas Petroleum Inc., P.O. Box 7643, San Francisco, California 94120*

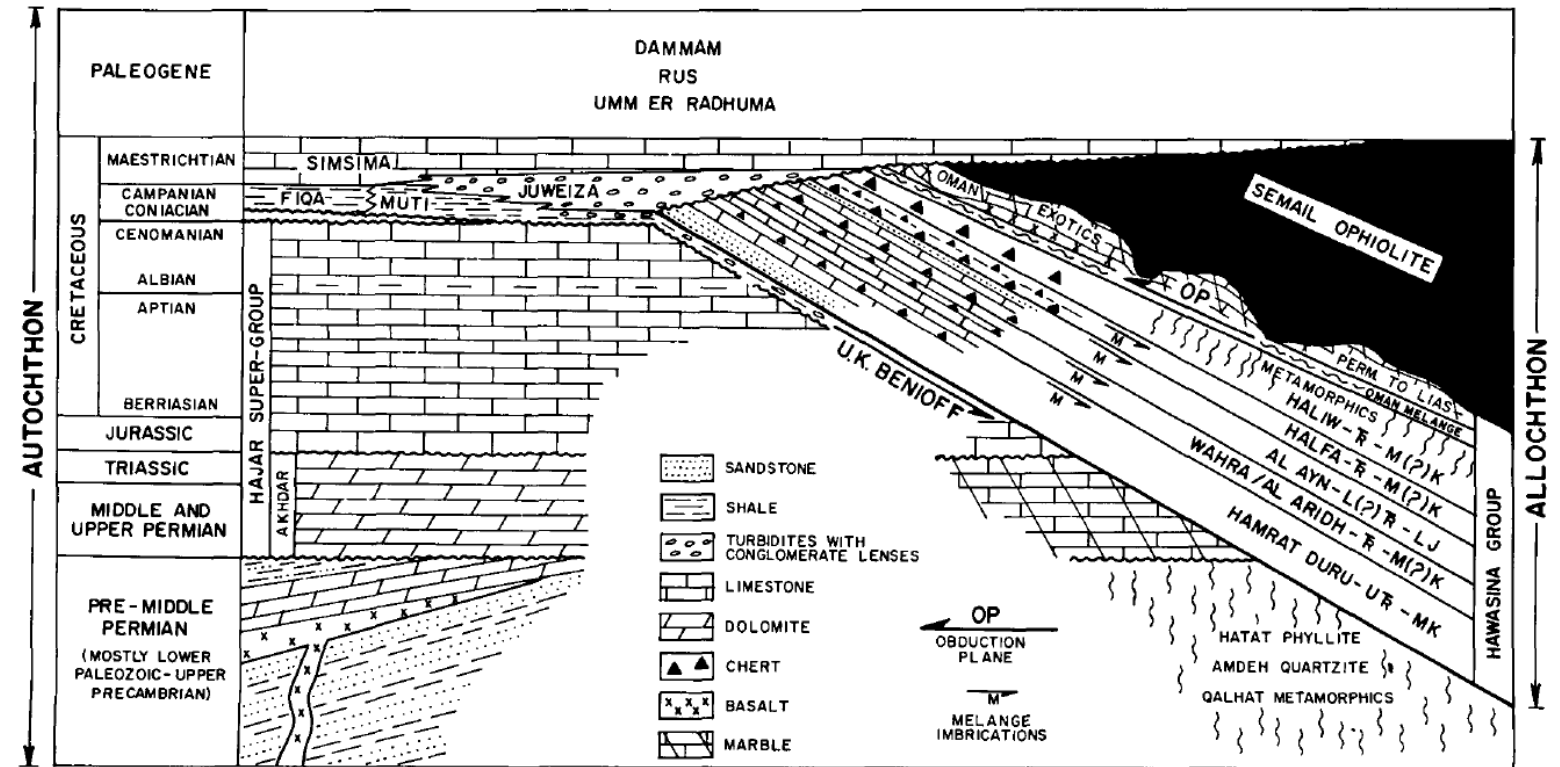
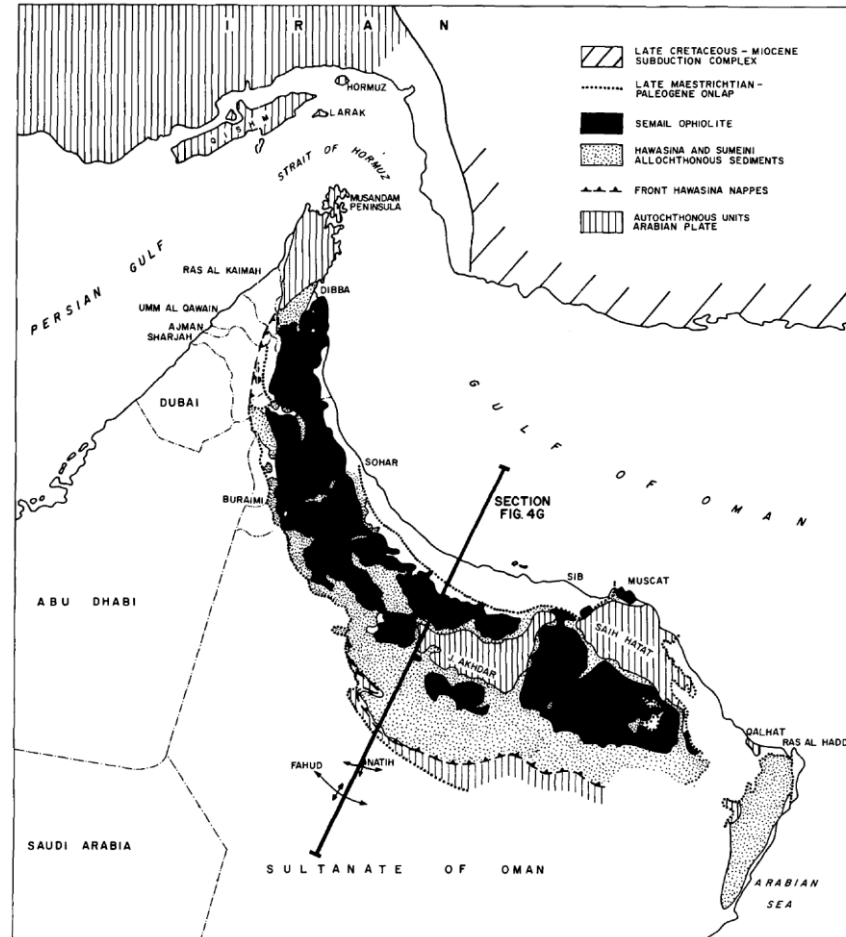
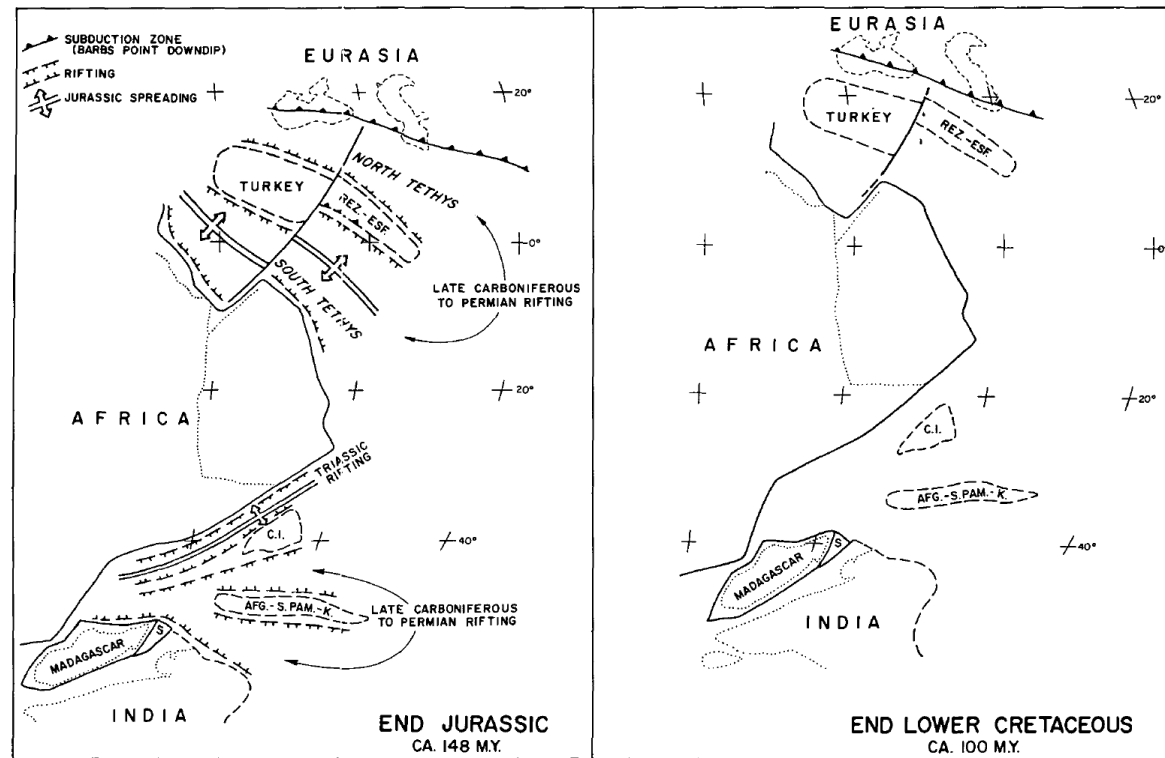


Figure 2. Diagram illustrating stratigraphic and tectonic relationships in Oman Mountains.



Gealey 1977

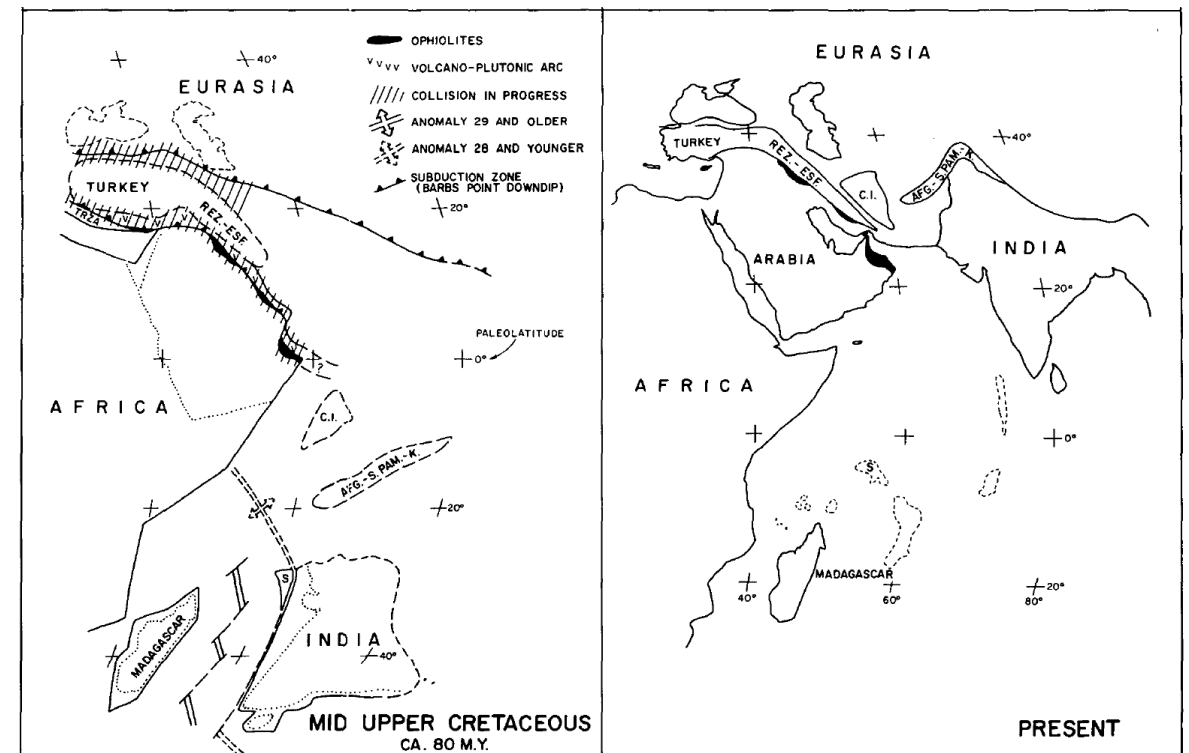
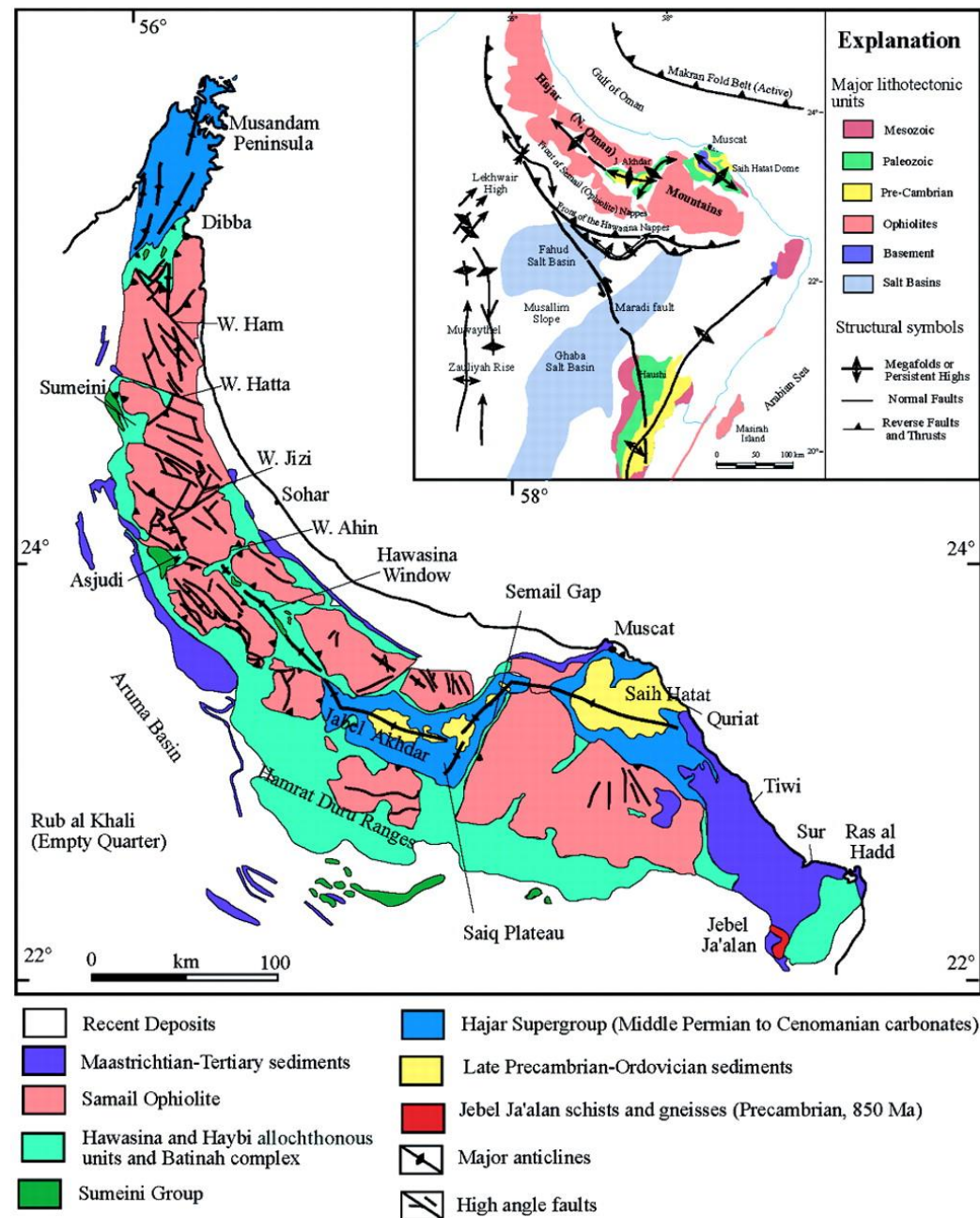


Figure 3. Interpreted post-Hercynian plate tectonic evolution of Middle East area. REZ.-ESF. = Rezaiych-Esfandagheh; C.I. = Central Iran; AFG.-S. PAM.-K. = Afghanistan-southern Pamir-Karakorum; S = Seychelles; TRZA = Tripolitza.



# 提纲

- 一、美国Coleman模型
- 二、英国Searle模型
- 三、2000s以来的争论
- 四、个人体会与思考



# 一、美国Coleman模型

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 86, NO. B4, PAGES 2495–2496, APRIL 10, 1981

Robert G. Coleman USGS, Menlo Park  
Clifford A. Hopson, UC, Santa Barbara

## Introduction to the Oman Ophiolite Special Issue

- late 1970's: one by a British group under the leadership of Ian Gass and John Smewing, working in the northwestern and central Oman Mountains, and another composed of an informal consortium of chiefly Americans, working primarily in the southeast.
- Principal objectives
  - (1) to document the composition, structure, and age relationships within this sample of Tethyan oceanic crust and upper mantle,
  - (2) to determine the petrogenetic and tectonic processes involved in its formation, and
  - (3) to use this information to improve the understanding of modern oceanic spreading centers.
- Also sought is a better grasp of the mechanisms and timing of tectonic detachment, transport, and emplacement (obduction) of this mass of oceanic lithosphere onto the Arabian continental margin.

15篇学术论文，地质学，地球物理，地球化学

# Coleman, 1981 JGR; USGS Menlo Park

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 86, NO. B4, PAGES 2497-2508, APRIL 10, 1981

## Tectonic Setting for Ophiolite Obduction in Oman

ROBERT G. COLEMAN

*U.S. Geological Survey, Menlo Park, California 94025*

The Samail ophiolite is part of an elongate belt in the Middle East that forms an integral part of the Alpine mountain chains that make up the northern boundary of the Arabian-African plate. The Samail ophiolite represents a portion of the Tethyan ocean crust formed at a spreading center of Middle Cretaceous age (Cenomanian). During the Cretaceous spreading of the Tethyan Sea, Gondwana Land continued its dispersal, and the Arabian-African plate drifted northward about 10°. These events combined with the opposite rotation of Eurasia and Africa initiated the closing of the Tethyan during the Late Cretaceous. At the early stages of closure, downwarping of the Arabian continental margin combined with the compressional forces of closure from the Eurasian plate initiated obduction of the Tethyan oceanic crust along preexisting transform faults, and still hot oceanic crust was detached along oblique northeast dipping thrust faults. Amphibolites developed at the base of the detached hot peridotite as it was thrust southward over oceanic volcanic and sedimentary rocks. Plate configurations combined with palinspastic reconstructions show that subduction and attendant large-scale island arc volcanism did not commence until after the Tethyan sea began to close and after the Samail ophiolite was emplaced southward across the Arabian continental margin. The Samail ophiolite nappe now rests upon a melange consisting mainly of pelagic sediments, volcanics, and detached fragments of the basal amphibolites which in turn rest on autochthonous shelf carbonates of the Arabian platform. Laterites and conglomerates with reworked laterites on the eroded upper surface of the ophiolite indicate a period of emergence prior to the deposition of shallow water Maastrichtian carbonates. Following emplacement (Eocene) of the Samail ophiolite, the Tethyan oceanic crust began northward subduction, and active arc volcanism started just north of the present Jaz Murian depression in Iran.

美国科学院院士，1980；俄罗斯科学院院士 1994



1923-



2016年斯坦福大学杰出校友奖

- Samail蛇绿岩代表白垩纪中期洋中脊，是特提斯洋壳。
- 白垩纪阿拉伯-非洲板块向北漂移10°，晚白垩世特提斯洋开始关闭。
- 关闭早期阶段，两个板块的挤压，使得特提斯洋壳沿着之前存在的转换断层发生初始仰冲。热的洋壳拆离着斜向、倾向东北的逆冲断裂系。
- 拆离的热的橄榄岩向南逆冲到大洋火山和沉积岩过程中，在其底部发育辉石岩。
- 俯冲和大规模岛弧火山作用发生在特提斯海开始关闭之后，也发生在蛇绿岩侵位向南到阿拉伯大陆边缘之后。
- 现今的Samail蛇绿岩推覆体覆盖在一套混杂岩之上。混杂岩由远洋沉积、火山岩、拆离的底部辉石岩的碎块所组成。混杂岩逆冲在阿拉伯台地原地陆棚碳酸盐岩之上。
- 蛇绿岩表面被侵蚀，出现红土和砾岩，指示一段时间的暴露。之后沉积Maastrichtian浅水碳酸盐岩。
- Samail蛇绿岩（始新世）侵位之后，特提斯洋壳开始向北俯冲，在现今伊朗Jaz Murian凹陷之北出现活动弧火山作用。

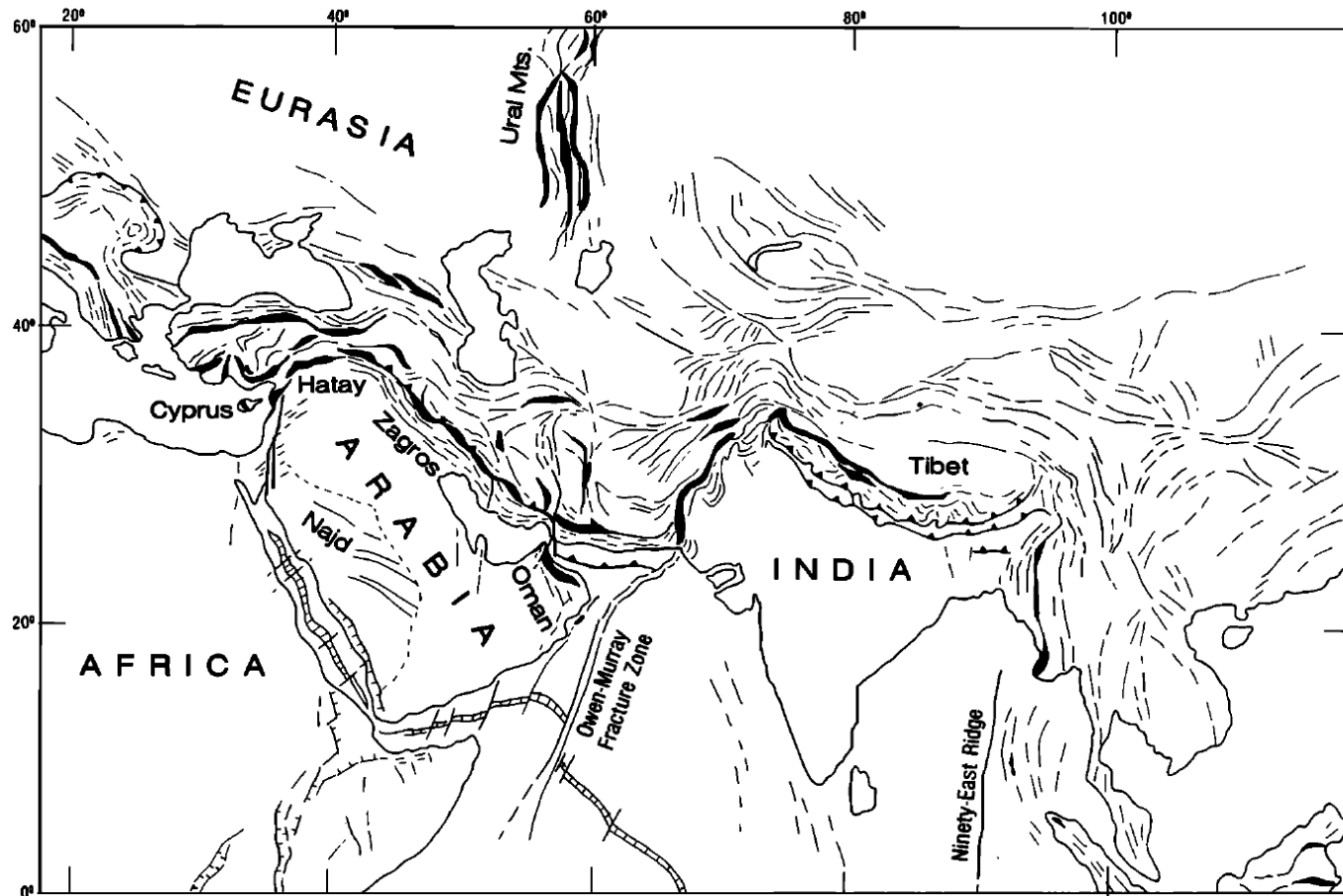
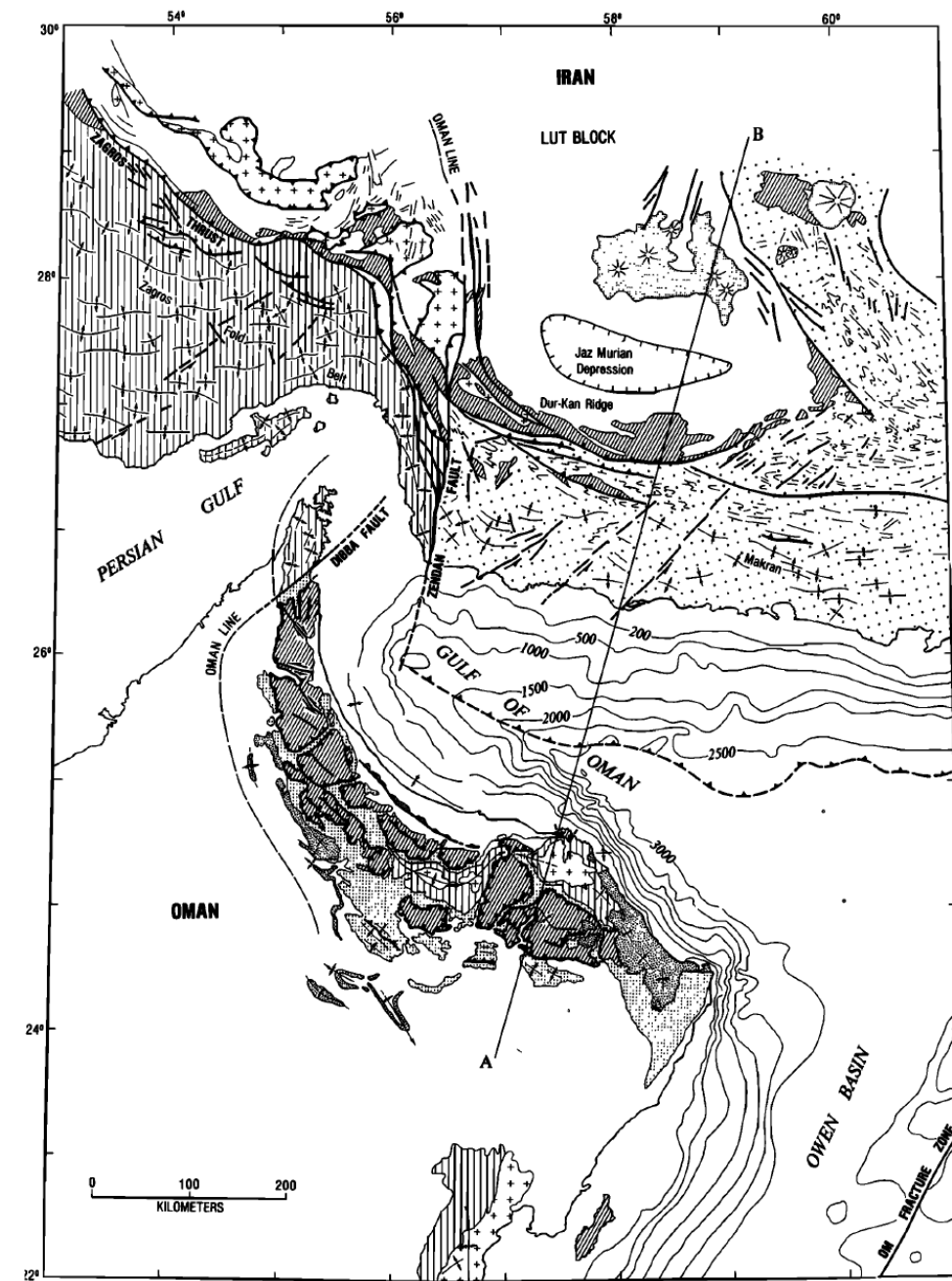


Fig. 1. Generalized tectonic map showing distribution of ophiolites along Tethys suture and modified after Gansser [1966]. Black areas include both ophiolite and colored melange zones.

Coleman, 1981 JGR



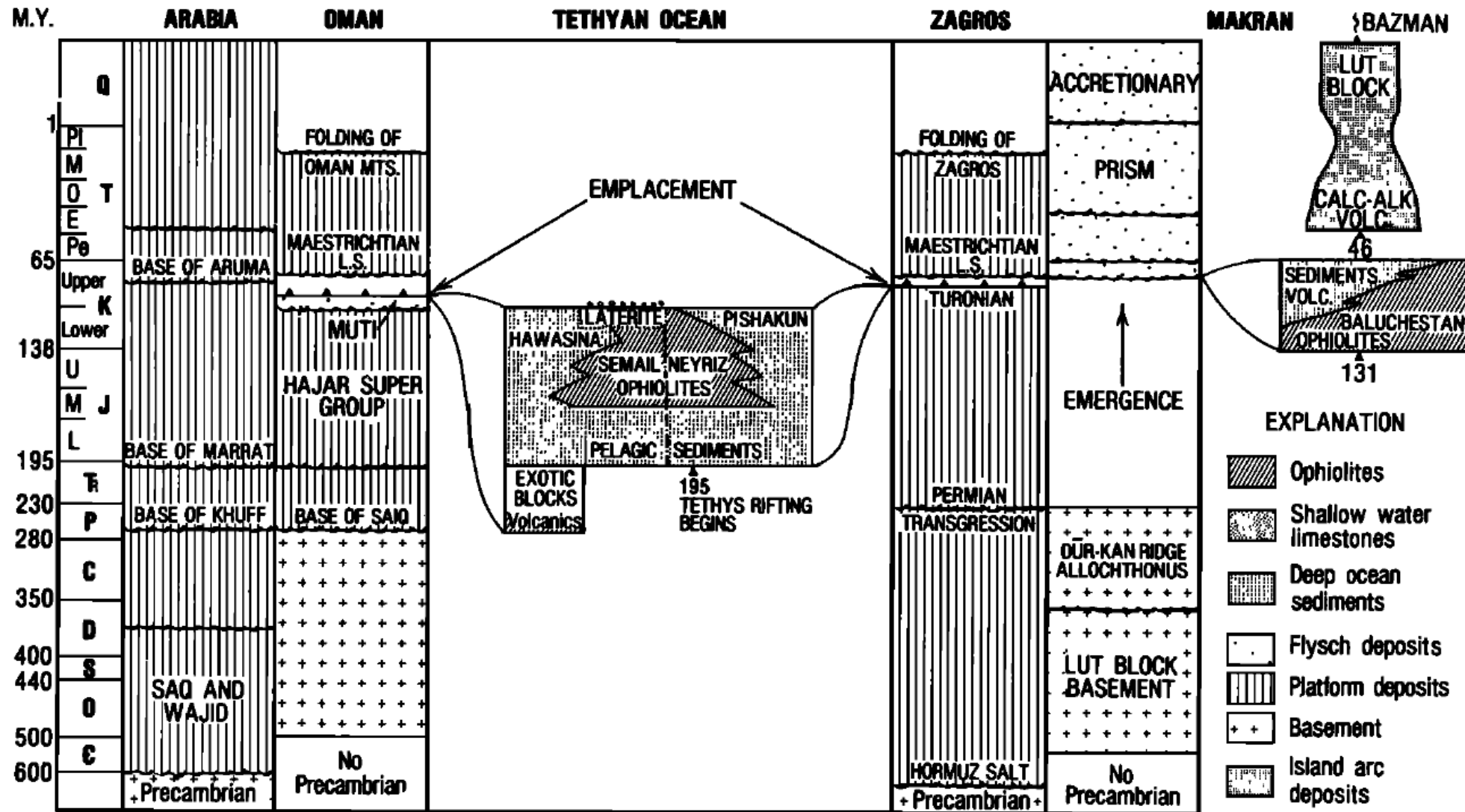


Fig. 3. Time-stratigraphic correlation chart for Oman and surrounding geographic segments. Patterns used in the explanation are the same as those used in Figures 4, 5, and 6.



早白垩世晚期和白垩纪中期碎屑岩的出现，标志着重要的沉积转变，代表着特提斯海的关闭

p2499

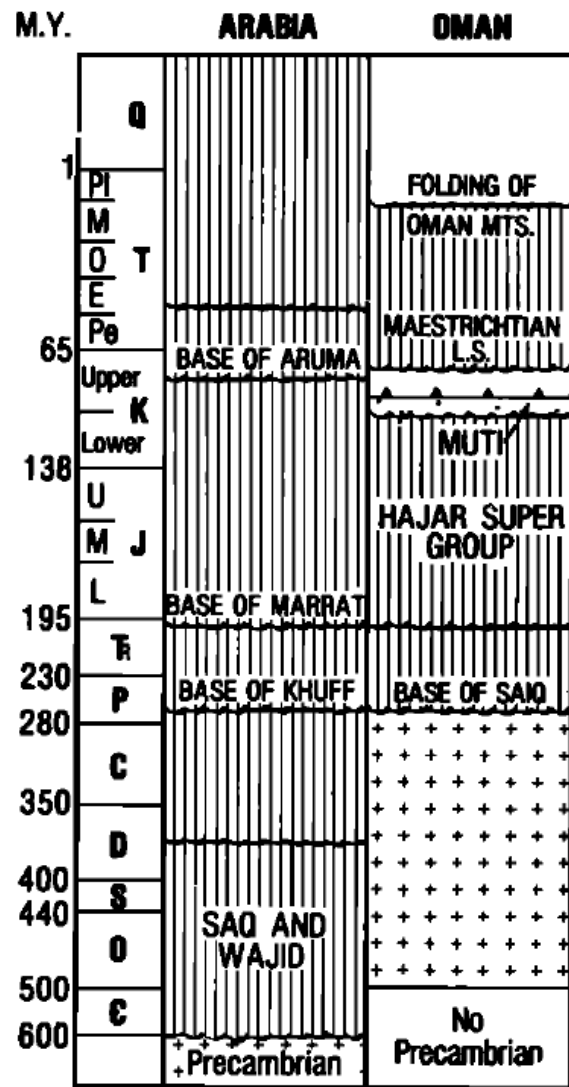


Fig. 3. Time-stratigraphic correlation

Muti组分布的西部，阿曼北部同时代出露 Fiqua组和Simsima组，Cam.-Maast.，在一些地方这些地层不整合在Smail和Hawasin单元之上。Maastrichtian时期的Juweiza组包含来自Smail和Hawasin单元的碎屑物质。这些沉积岩被解释为大陆边缘之上的前陆盆地的前缘沉积。这进一步指示，Smail蛇绿岩侵位时间为晚白垩世（Con-Maast.）(Glennie et al., 1974)

Muti组：Coniacian-Campanian，与下伏不整合接触。泥灰岩，页岩，灰岩砾岩透镜体，以及下伏地层来源的flysch沉积。

Hajar超群：3700m，不整合在变质基底之上。中二叠到晚白垩世；原地阿拉伯大陆边缘沉积。

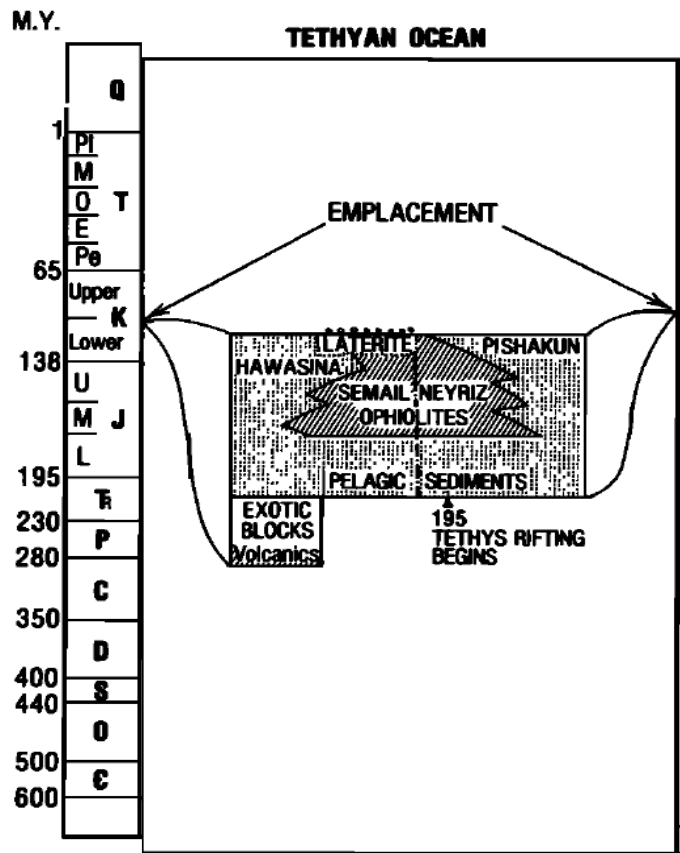


Fig. Correlation chart for Oman and surrounding regions. The correlation is the same as those used in Fig.

在Hawasina沉积岩里出现少量的钙碱性火山岩，时代可以从三叠纪都有，并不是新特提斯洋南向俯冲的产物，是特提斯洋打开时 graben-horst-related火山作用。

局限分布在蛇绿岩之上发现一套红土laterite单元,厚可达30米(Bailey and Coleman, 1975)。在一些地方，红土再沉积形成层状的沉积。这个单元之上出现粗粒cobbly砾岩，砾石为石英岩和改造的Samail蛇绿岩碎屑。海侵在Hawasina和Samail推覆体（红土和砾岩）之上的不整合沉积Maastrichtian浅水灰岩。

Samail推覆体: harzburgite tectonite and includes igneous layered gabbro sheeted dikes, pillow lavas; 未见切割侵入岩。洋壳，厚度15-17公里。走向延伸450公里；每一个蛇绿岩推覆体50-100公里 in strike outcrop width. 世界洋壳出露最大之一。

Hawasina allochthonous unit: 放射虫硅质岩、灰岩浊积岩、浅海灰岩；薄的、叠瓦推覆体；时代：二叠纪到晚白垩世都有。

多数研究者认为，阿拉伯大陆边缘北侧的新特提斯海很可能是一个狭窄的海湾（Smith, 1974; Stocklin, 1974; Sonnenfeld, 1978）；然而，基于least square, continental fit, and paleomagnetic data的构造古地理重建却显示一个大的向东开口的特提斯海（Smith and Briden, 1977; Owen, 1976）

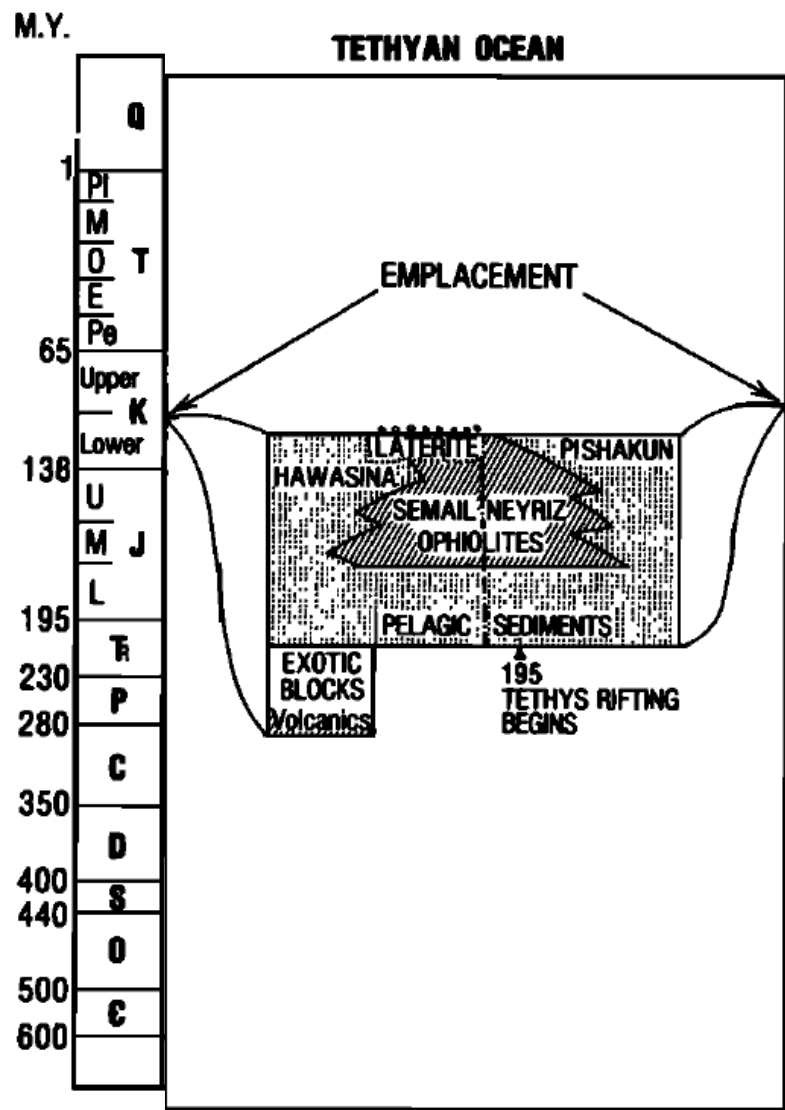


Fig. 1. Correlation chart for Oman and surrounding regions. The units and their correlation are the same as those used in Fig. 1.

Samail蛇绿岩: 亏损地幔9-12km, 5km堆晶辉长岩, 层状岩墙1.5km, 之后为枕状玄武岩。根据各单元厚度、火山历史、地震波速度与现今洋壳的对比, 这套蛇绿岩无可争辩地形成于古代特提斯扩张洋脊。

斜长花岗岩时代为95Ma (Tilton, 1981); 玄武岩枕间的硅质岩内放射虫化石指示时代Cenomanian-Turonian (100-86 Ma). 没有T-J洋壳的直接证据。

层状岩墙研究表明古扩张洋脊在N15-20°W, 宽度约275公里 (Pallister, 1981)

构造化的橄榄岩的底部是一个狭窄的变质岩带, 与橄榄石过渡的是不到1米厚的石榴子石角闪岩, 变为角闪岩、绿片岩, 最后过渡为未变质的Hawasina群沉积和火山岩。整个厚度不超过1公里。这种反序变质晕是形成于Samail蛇绿岩从特提斯洋壳拆离时, 并且发生在侵位到阿曼大陆边缘之前。Ar-Ar年龄90my (Alleman and Peters, 1972; Lanphere, 1981)

Zagros fold belt: 200-300公里宽。延长超过1300公里。东北边界主札格罗斯逆冲断裂与Sanandaj-Sirdjan带；与阿曼大陆边缘一样，属于阿拉伯北缘碳酸盐台地。没有出现前寒武纪结晶基底

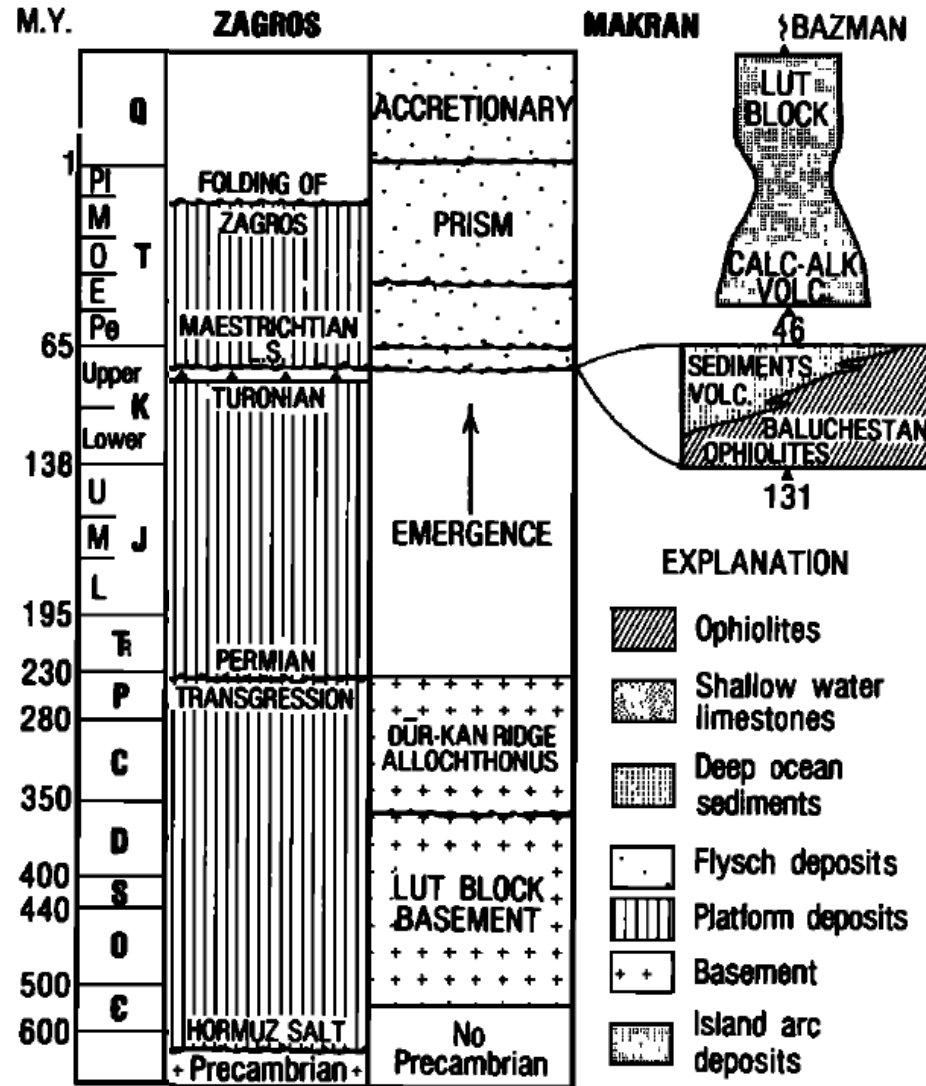


Fig. Geographic segments. Patterns used in the exposures 4, 5, and 6.

Makran大陆边缘和阿曼湾

白垩纪-古新世远洋沉积-火山岩，始新世-中新世复理石、始新世-早上新世陆棚沉积岩。与阿拉伯碳酸盐台地完全不同。

# Makran北部，白垩纪-古新世远洋沉积-火山岩推测沉积于新特提斯洋壳之上

- along the north boundary of the Makran, where a narrow zone of ophiolites consisting of peridotite, gabbro, calc-alkaline sheeted dikes and pillow lavas, and pelagic sedimentary deposits forms the boundary between the Lut block and a narrow continuation of the Sanandaj-Sirjanz one represented by the Bajgan complex of metamorphic rocks and the Dur-kan complex of shelf limestone [McCall, 1978] (Figure 4).
- In some areas, interbedded pelagic rocks within pillow lavas yield microfossils that indicate a range from Early Cretaceous to early Paleocene in the Dar Anar complex; from Late Cretaceous to early Paleocene in the Mokhtarabad complex and from Campanian to Maastrichtian in the Ganj complex.
- The pillow lavas and associated sedimentary rocks are unconformably overlain by Eocene shallow water deposits. These ophiolites are faulted southward against the Dur-kan Ridge, a structural unit that separates them from the Makran flysch [ Houshmand-Zadeh, 1977].



现今阿曼湾，大致380公里宽，之下很可能是侏罗纪-白垩纪的特提斯洋壳。  
Makran海岸的北向俯冲很可能开始于始新世，证据来自于Jaz Murian凹陷之北的钙碱性火山弧的年龄。  
(Jung et al., 1976)

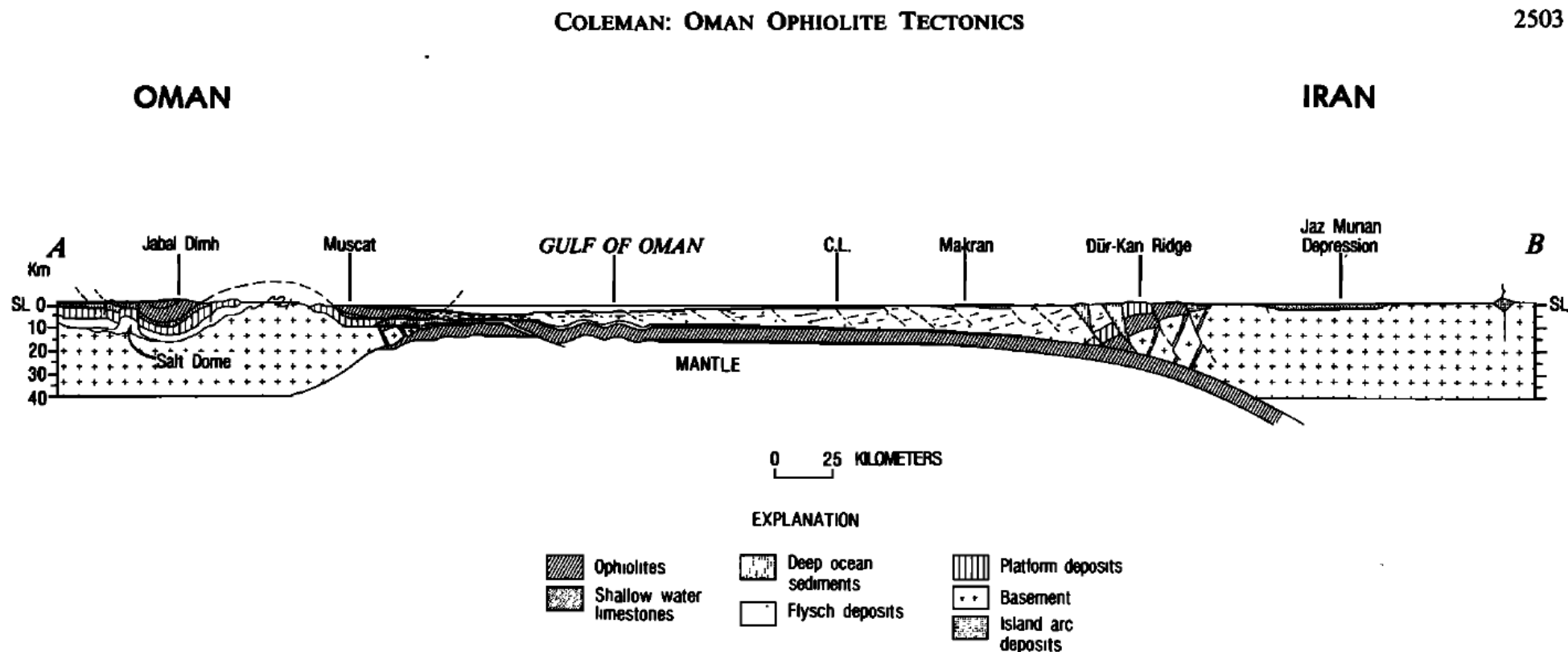


Fig. 5. Stylized cross section from Oman to Iran. Ocean crust (ophiolites) within the Gulf of Oman are considered to be part of the Tethyan ocean crust. Configuration of the flysch deposits taken from *White and Ross* [1979]. C.L. marks the coast line of the Makran area in Iran.

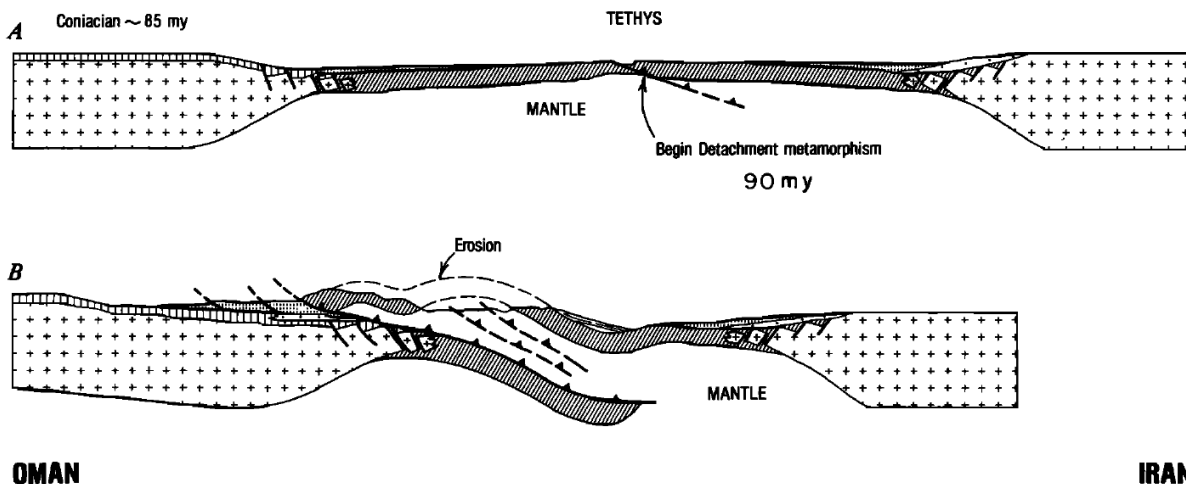


Fig. 6. Schematic diagrams depicting detachment and initial emplacement of the Samail ophiolite. (a) Beginning of detachment in Cenomanian time where crust is thin and upper mantle is still hot near active spreading along a Tethyan ridge crest. Detachment is initiated by closure of Tethyan ocean as Africa (Arabia) moves northward. (b) continued closure of the Tethyan ocean exposes oceanic crust to extensive erosion above sea level. Continental margin along Oman is depressed, and some oceanic and continental material is underthrust. Some gravity sliding of the pelagic sediments accompanies the emplacement of the Samail ophiolite nappe. Final configuration of the Samail ophiolite in relationship to the Gulf of Oman and present-day northward subduction under the Makran coastline is shown in Figure 5. Patterns used in the diagrams are the same as those explained in Figures 3 and 5.

## 两阶段侵位模式：

early detachment of a hot slab along weak zones of a still-cooling spreading center, combined with formation of a metamorphic aureole at the base of the ophiolite. Continued plate convergence and upwarping of the Tethyan oceanic floor along an Arabian margin as well as onset of erosion and later formation of laterite on the exhumed and eroded ophiolite mark the early stages of emplacement.

Finally, a combination of gravity sliding (as suggested by the Hawasina melange) southward into the foredeep along the Arabian margin and progressive convergence of the now-sinking continental edge under the oceanic crust has moved the Samail ophiolite to its final resting place (Figure 6).

Glennie et al. [1974] 估计总汇聚量几百公里，至少 165 km（蛇绿岩最大出露宽度）



## The Ophiolites of Oman

18篇论文

**Tectonophysics, 151, pp.401 (September 1988)**



- **Mapping** in the Oman ophiolite using enhanced Landsat Thematic Mapper images.
- The **Hawasina Basin**: A fragment of a starved passive continental margin
- **Mantle—crust transition zone** and origin of wehrlitic magmas
- Shear zones, thrusts and related **magmatism** in the Oman ophiolite
- **Mantle flow** patterns at an oceanic spreading centre
- The death of an **accretion zone** as evidenced by the magmatic history of the Sumail ophiolite
- obduction-related **metamorphism** in upper crustal nappes, Arabian continental margin, Oman
- **Segmentation** at a fossil spreading axis
- Duality of **magmatism** in the plutonic sequence of the Sumail Nappe, Oman.
- **Metalliferous** sediments within lava sequences of the Sumail ophiolite (Oman)
- **Fe-Ni-Cu sulfides** in tectonite peridotites from the Maqsad district, Sumail ophiolite
- K-Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  study of **metamorphic rocks** associated with the Oman ophiolite
- fluid inclusions and fossil **thermal** gradients in the crustal sequence of the Sumail ophiolite (Oman)
- **Structural mapping** in the Oman ophiolites
- A new **magma chamber** model based on structural studies in the Oman ophiolite.
- Complexity of the **crustal sequence** in the northern Oman ophiolite
- **Paleomagnetic** results from Oman ophiolites related to their emplacement.

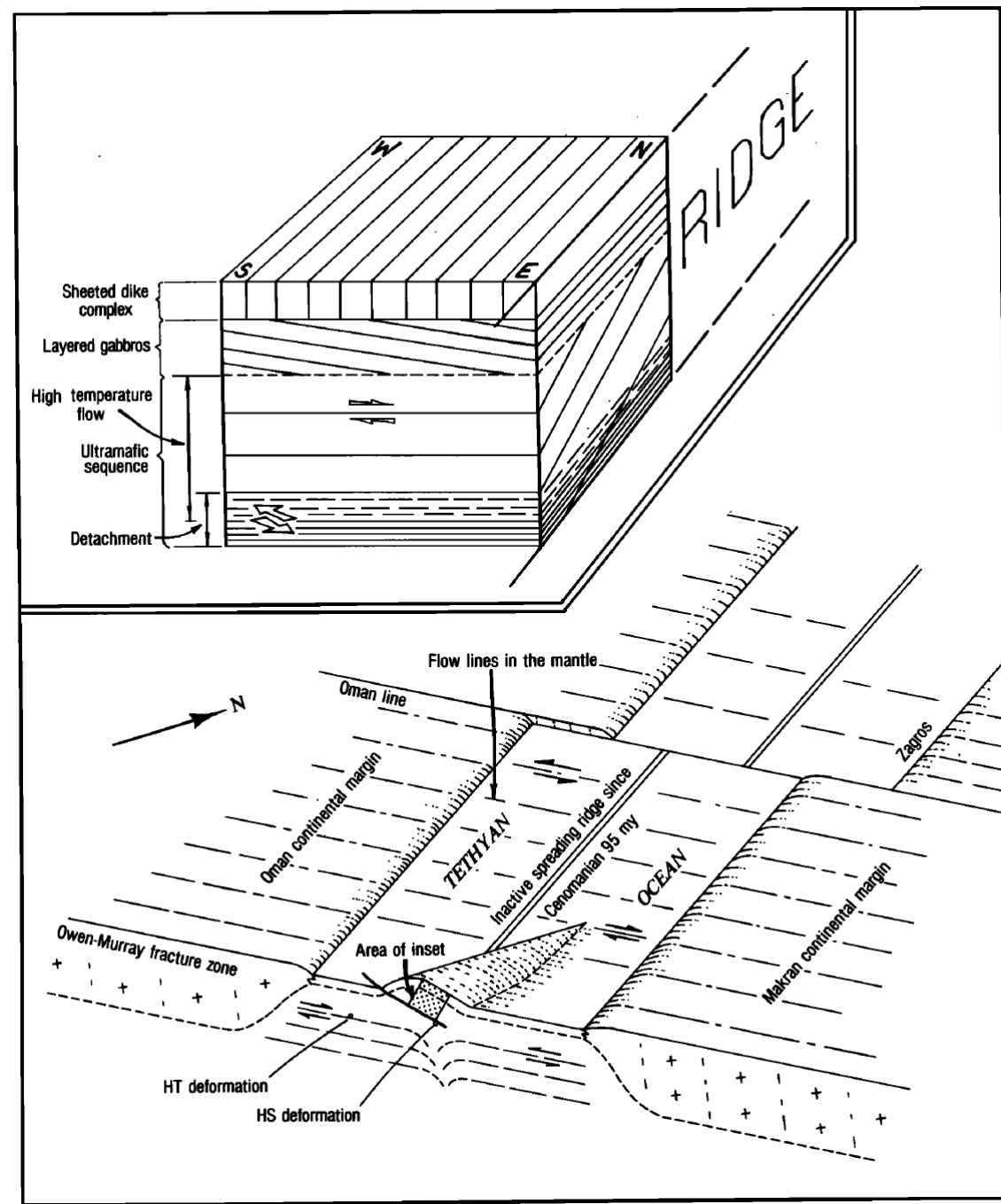
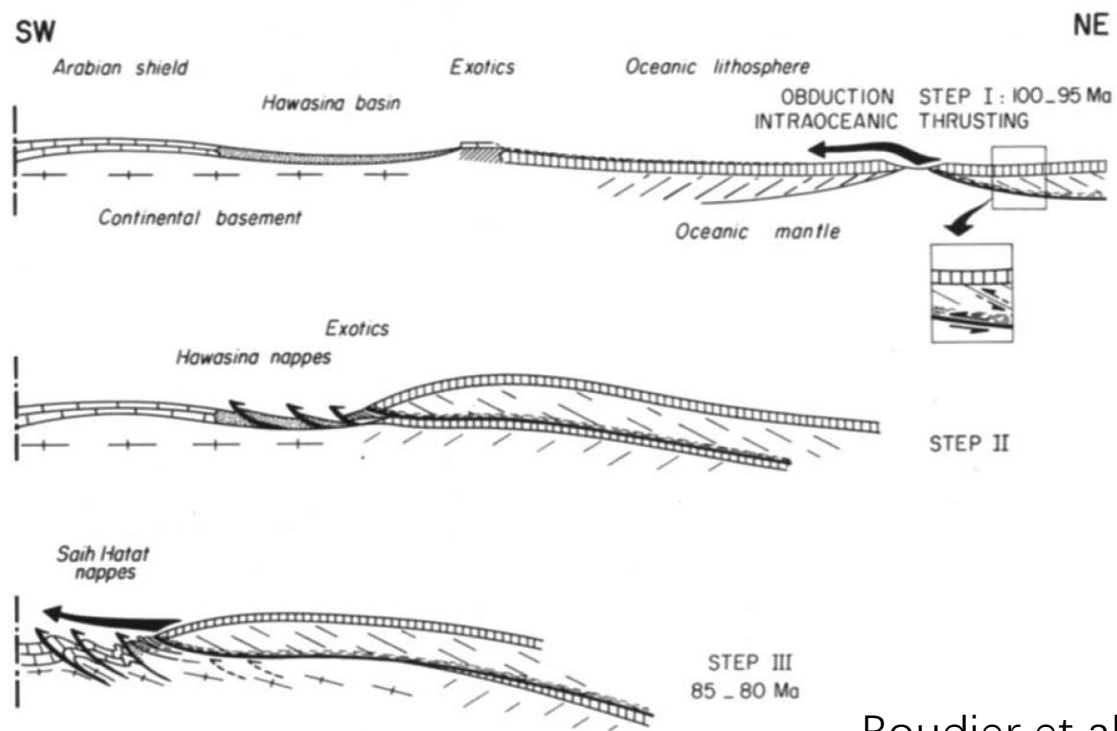
# Cross Section Through the Peridotite in the Samail Ophiolite, Southeastern Oman Mountains

F. BOUDIER

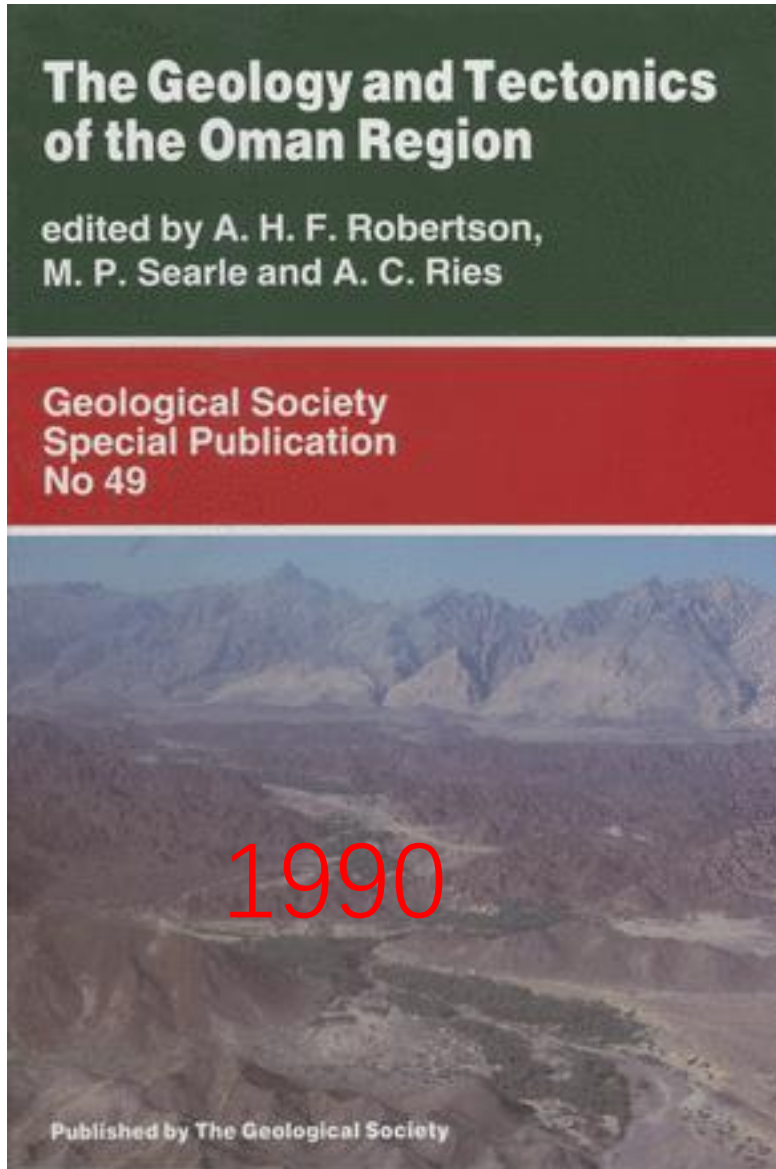
*Laboratoire de Tectonophysique, Universite de Nantes, 44072 Nantes, France*

R. G. COLEMAN

*U.S. Geological Survey, Menlo Park, California 94025*



## 二、英国Searle模型



48篇论文



Alastair Robertson



Mike Searle

**Evolution of the Oman Tethyan Continental Margin**  
**33 papers**

**Geology and Tectonics of South Oman 12 papers**

**Regional Tectonic Setting, 3 papers**

Geological Society, London, Special Publications

**The northern Oman Tethyan continental margin: stratigraphy, structure, concepts and controversies**

A. H. F. Robertson and M. P. Searle

*Geological Society, London, Special Publications* 1990; v. 49; p. 3-25  
doi:10.1144/GSL.SP.1992.049.01.02



1) 系统重建了阿拉伯板块边缘地层-沉积-构造演化历史

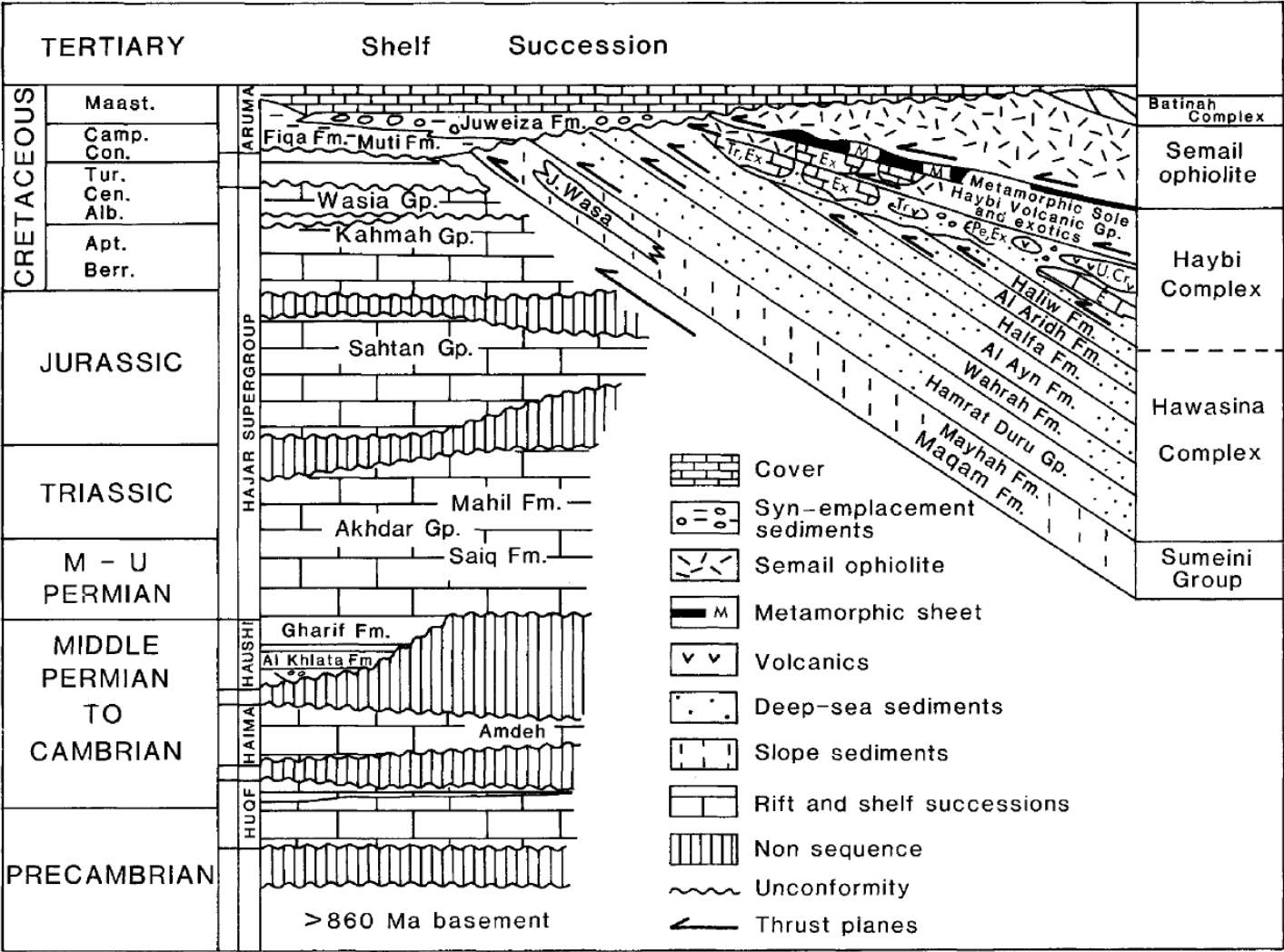


Fig. 2. Generalized tectonostratigraphy of the Oman Mountains, slightly modified and simplified after Glennie et al. (1974). The stratigraphy of the Hawasina has since been extensively redefined (see Figs 3 & 4).

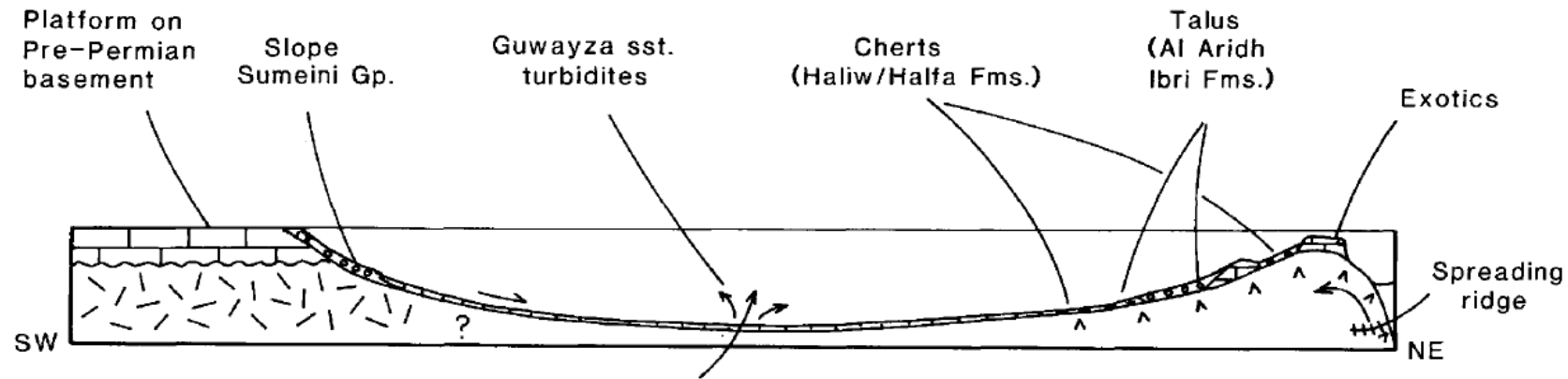
System	Stage	Age	SHELF SUCCESSION	CARBONATE PLATFORM SLOPE
CRETACEOUS	MAASTRICHTIAN	73	Localised erosion, fluvialite deposition, then marine transgression.	Steepening and collapse of slope, lithoclastics, mega-breccias, (Qumayrah Mbr); megabreccias until Coniacian (J. Fayad). Radiolarian chert, tectonic flexure of shelf.
	CAMPANIAN	83	Ophiolite-derived sediment, shale.	
	SANTONIAN		Collapse of platform to form foreland basin; siliciclastic turbidites, debris flows.	
	CONIACIAN	88.5	Wasia-Aruma break: unstable shelf, slope; subsidence.	
	TURONIAN	91	Hemipelagic carbonates (J. Salakh).	
	CENOMANIAN	97.5	Rudistic carbonate shelf, local basins.	
	ALBIAN	113	Regressive mega-sequence, NW prograding carbonate ramp.	
	APTIAN	119	Slope to bathyal in Musandam; also hemipelagic sediments.	
	BARREMIAN	125	Local tectonic instability until Barremian	
	HAUTERIVIAN	131	Maiolica in stable areas (J. Akhdar); calcareous and siliciclastic turbidites in unstable basinal areas (S. Hatat).	
JURASSIC	VALANGINIAN	138	250km of slope retreat; regional extension and deepening.	Contrasting slope morphologies; J. Sumeini-gullied slope margin and/or erosional escarpment; Hatta Zone-basement exposed on transform rift scarps; Dibba Zone-steep bypass slope marked by fine periplatform ooze; slumping. W. Qumayrah-steep escarpment margin with fault-generated megabreccias (W. thrust sheet has gullied slope). Later became a sloping ramp with periplatform ooze. J. Sham-redeposited facies on slope apron; Saih Hatat-subsidised platform and gentle slope.
	BERRIASIAN	144	Proximal subtidal massive bioclastic 1st.	
	TITHONIAN	150	Lithotia, oolitic limestones, lagoonal to restricted shelf (J. Akhdar).	
	KIMMERIDGIAN	156	Inner shelf carbonate (Musandam).	
	OXFORDIAN	163	Mixed carbonate-clastic sequence in broad shallow carbonate shelf (J. Akhdar); cf. submerged plateau (S. Hatat), with calciturbidites, pelagic micrite and carbonate debris flows.	
	CALLOVIAN	169	Unconformity on Triassic in J. Akhdar.	
	BATHONIAN	175	Unconformity of Rhaetic/Norian; basal siliciclastics; massive and algal limestone with Lithotia.	
	BAJOCIAN	181	Shallow marine platform in Musandam.	
	AALENIAN	188	Differential subsidence; normal faulting; escarpment margin suddenly developed; bypass margin with base of slope debris apron. Coeval J. Wasa Fm.-high energy reef margin and debris.	
	TOARCIAN	194	Very restricted shallow marine to locally continental accumulation on evaporitic (dolomitic) subsiding shelf.	
TRIASSIC	PLIENSCHACHIAN	200	Shoaling-upwards cycles similar to modern Abu Dhabi area.	Subsidence (Dienorian), small carbonate fans along faulted margin, growth faults, down-to-N displacements (J. Sumeini).
	SINEMURIAN	206	Stable shelf (J. Akhdar), fluvial clastics, restricted; marine transgression with Fe, shelf carbonates and bioherms.	
	HETTANGIAN	213	Unstable shelf (S. Hatat); clastics and carbonates; condensed sequences; intraplate volcanism; horsts and grabens; cherty limestones; local evaporites (Late Permian).	
	RHAETIAN	219	Shelf, hardgrounds, dolomites (Musandam).	
	NORIAN	225	Continental clastics prograde against basement high; local unconformity.	
	CARNIAN	231		
	LADINIAN	238		
	ANISIAN	243		
	SPATHIAN			
	SMITHIAN			
PERMIAN	GRIESBACHIAN	248		Relatively deep marine, wide outer shelf, thin-bedded, clayey, spicular limestone, local (J. Sumeini).
	TATARIAN	253		
	KAZANIAN	258		
	UFINIAN	263		
	KUNGURIAN	268		
	ARTINSKIAN	268		
	SAKMARIAN	268		
	ASSELIAN	286		

Fig. 13. Summary of the major controls on deposition on the Oman Late Palaeozoic–Mesozoic rift and passive margin.

STAGE		AGE	SHELF		SLOPE	BASIN	OMAN	OFF-MARGIN BUILD-UPS	DISTAL UNITS
			OMAN	U.A.E.	OMAN & U.A.E.	HAWASINA COMPLEX CENTRAL MTNS	EXOTIC MARGINAL FACIES CENTRAL MTNS	OMAN EXOTICS HAYBI COMPLEX CENTRAL MTNS	
CRETACEOUS	U	PALAEOCENE							
		MAASTRICHTIAN							
		85							
		73							
		CAMPANIAN							
		83							
		SANTONIAN							
		87.5							
		CONIACIAN							
		88.5							
		TURONIAN							
		91							
		CENOMANIAN							
		97.5							
JURASSIC	M	ALBIAN							
		113							
		APTIAN							
		119							
		BARREMIAN							
		125							
		HAUTERIVIAN							
		131							
		VALANGINIAN							
		138							
		BERRIASIAN							
		144							
		TITHONIAN							
		150							
TRIASSIC	U	KIMMERIDGIAN							
		156							
		OXFORDIAN							
		163							
		CALLOVIAN							
		169							
		BATHONIAN							
		175							
		BAJOCIAN							
		181							
		ALENIAN							
		188							
		TOARCIC							
		194							
		PLIENSCHACHIAN							
PERMIAN	U	SINEMURIAN							
		200							
		HETTANGIAN							
		206							
		RHAETIAN							
		213							
		NORIAN							
		219							
		CARNIAN							
		225							
		LADINIAN							
		231							
		ANISIAN							
		238							
		SPATHIAN							
PERMIAN	U	SMITHIAN							
		243							
		DIENERIAN							
		GRIESBACHIAN							
		248							
		TATARIAN							
		253							
		KAKANIAN							
		UFIMIAN							
		263							
		KUNGURIAN							
		268							
		ARTINSKIAN							
		SAKMARIAN							
		ASSELIAN							

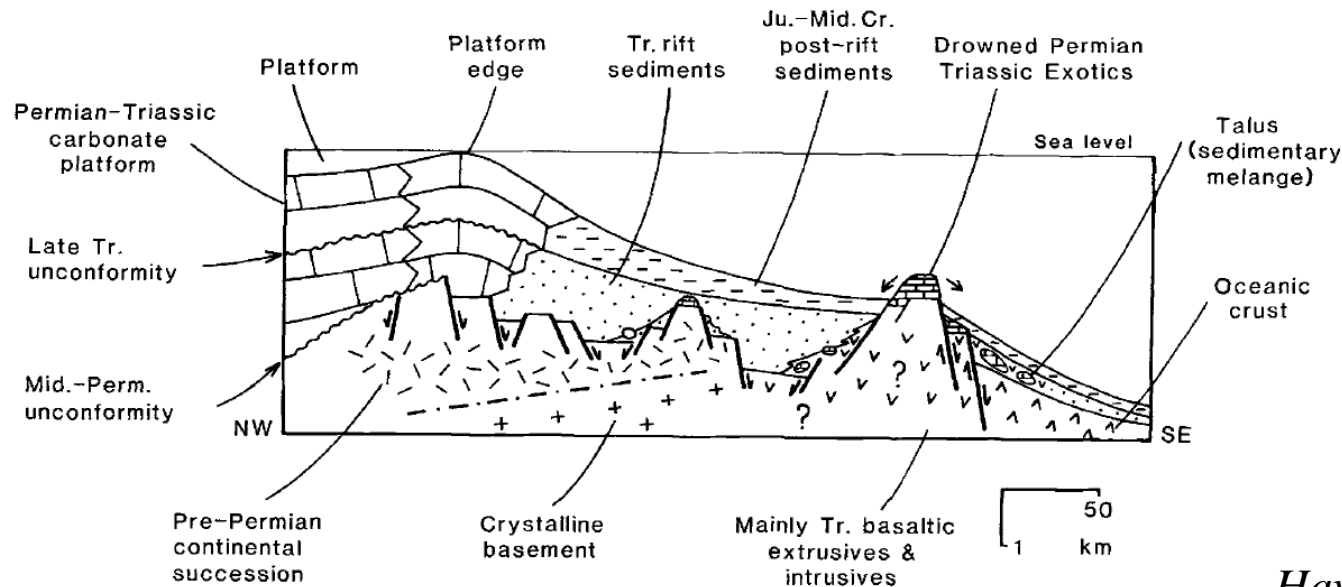
Fig. 4. Unified, proposed stratigraphy of the Late Palaeozoic–Mesozoic platform, slope and basinal units in the Oman Mountains.

Robertson and Searle 1990



## LATE TRIASSIC

**Fig. 5.** Glennie *et al.*'s (1974) first reconstruction. This assumes Permian to Late Triassic–Early Jurassic rifting and simple in-sequence thrusting.

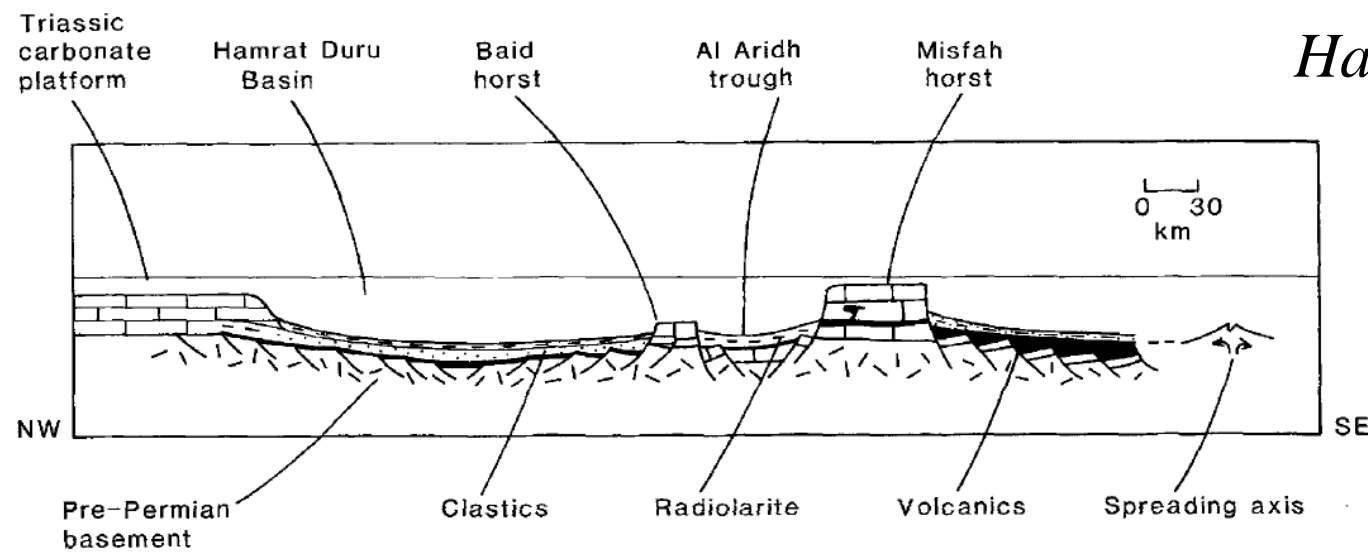


## EARLY CRETACEOUS

*Hawasina as a passive continental margin*

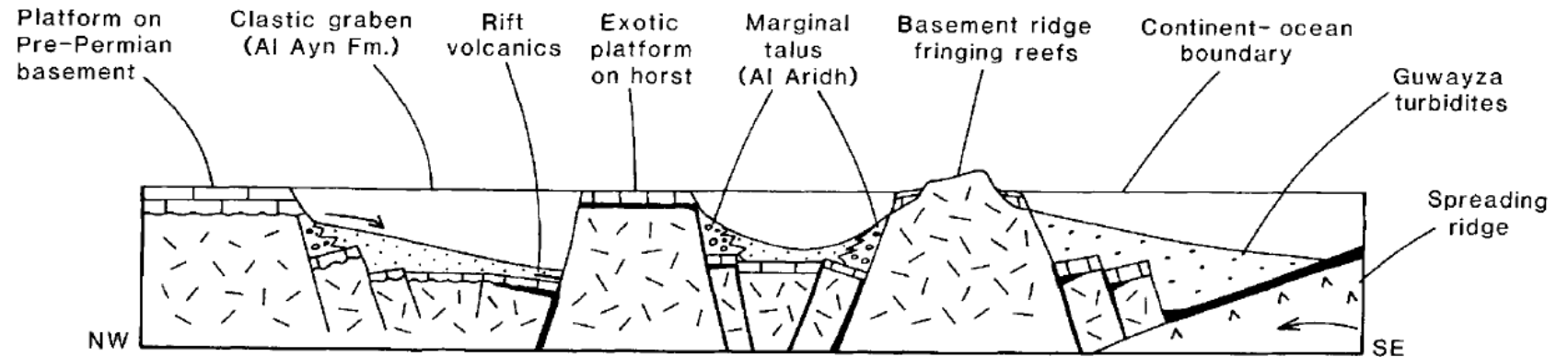
**Fig. 6.** Graham's (1980a,b) reconstruction. He drew a close comparison with the Mesozoic rift history of the North Atlantic. The Oman exotics were seen as seamounts along the continent–ocean boundary.

## *Hawasina as an intracontinental basin*



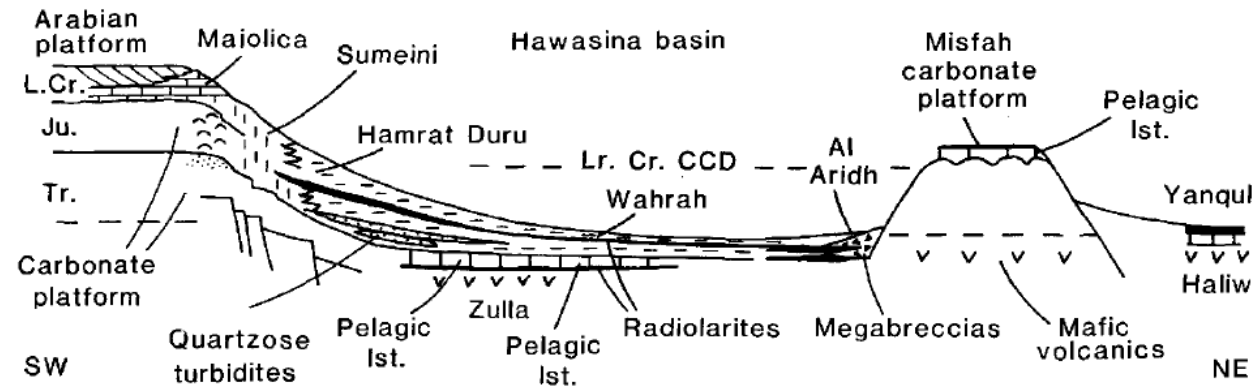
### LATE TRIASSIC

**Fig. 7.** Béchenec *et al.*'s (1988, 1990) reconstruction. This also assumes straightforward in-sequence thrusting, with the Hamrat Duru basin being underlain by stretched continental crust.

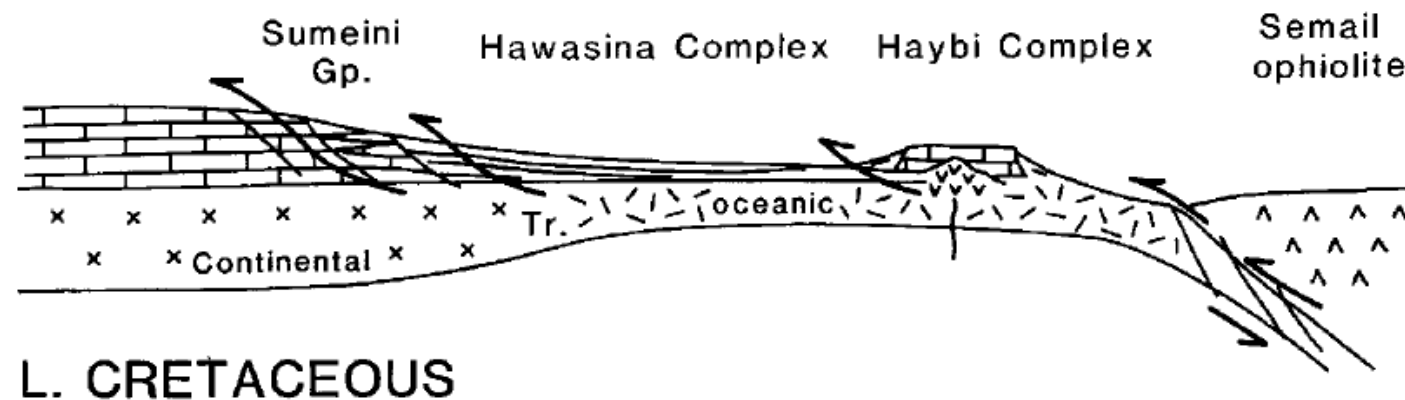


### LATE TRIASSIC

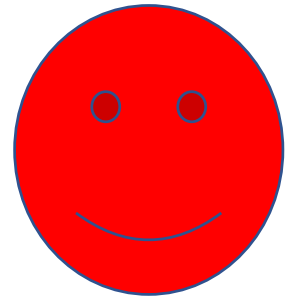
**Fig. 8.** Glennie *et al.*'s (1974) alternative reconstruction. In this, rifting is assumed to have taken place in the Late Triassic followed by subsidence and transgression of the continental margin by deep-water sediments. The present stacking geometry was achieved by major out-of-sequence thrusting in the Late Cretaceous.



**Fig. 9.** Bernoulli & Weissert's (1987) reconstruction. This assumes that some of Glennie *et al.*'s poorly dated 'distal units' instead formed the stratigraphically lower, more proximal part of the Hawasina basin. These units were later emplaced to their present high structural position by out-of-sequence thrusting during the Late Cretaceous. The model is based on data from the central Mountains.



**Fig. 11.** Searle *et al.*'s (1980) reconstruction (during initial Late Cretaceous deformation). In this the Oman exotics are seen as oceanic seamounts, while the Hawasina and Haybi Complexes are interpreted as oceanic units that were incorporated into a subduction–accretion complex.





# Volcanic rocks beneath the Semail Ophiolite nappe in the northern Oman mountains and their significance in the Mesozoic evolution of Tethys

M. P. Searle, S. J. Lippard, J. D. Smewing & D. C. Rex

## Haybi Complex

TABLE 4. *K-Ar age determinations of biotite micas*

Sample no.	Rock type and description	Location	Lat.	Long.	%K	Vol <sup>40</sup> Ar (rad)	% <sup>40</sup> Ar (rad)	Age (Ma)
OM 4909	Phenocrysts in ankaramite dyke	Wadi Ahin	24°02'	56°34'	6.80	6.582	92.4	233±9
OM 1818	Phenocrysts in ankaramite dyke	Asjudi	23°59'	56°18'	7.09	6.3771	95.1	218±9
AB 1	Phenocrysts in ankaramite block in mélange	Wadi Jizi	24°20'	56°23'	6.61	5.3279	94.2	200±8
OM 1790-1	Late interstitial poikilitic phase in jacupirangite	Jebel Ghawil	24°34'	56°01'	6.49	2.4683	83.2	92.5±4

All determinations carried out in duplicate and averages given.

Constants:  $\lambda_e = 0.584 \times 10^{-10} \text{ yr}^{-1}$ ,  $\lambda_B = 4.72 \times 10^{-10} \text{ yr}^{-1}$ ,  $K^{40}/K = 1.19 \times 10^{-2}$ .

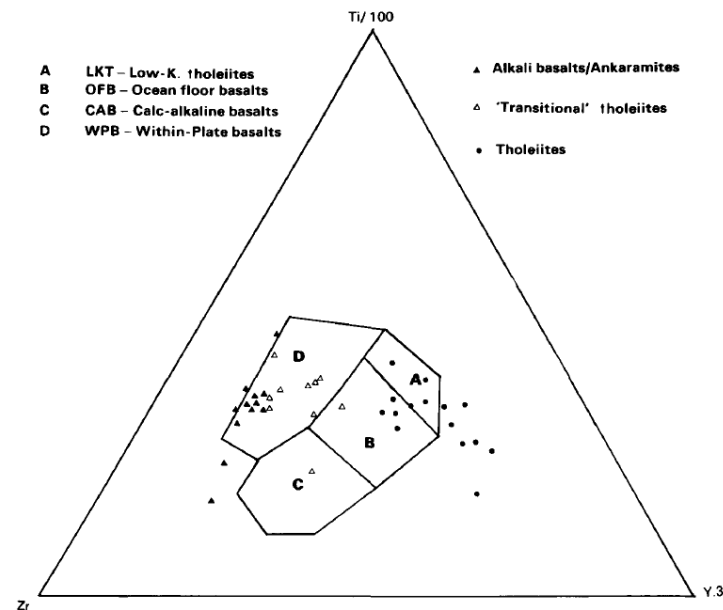
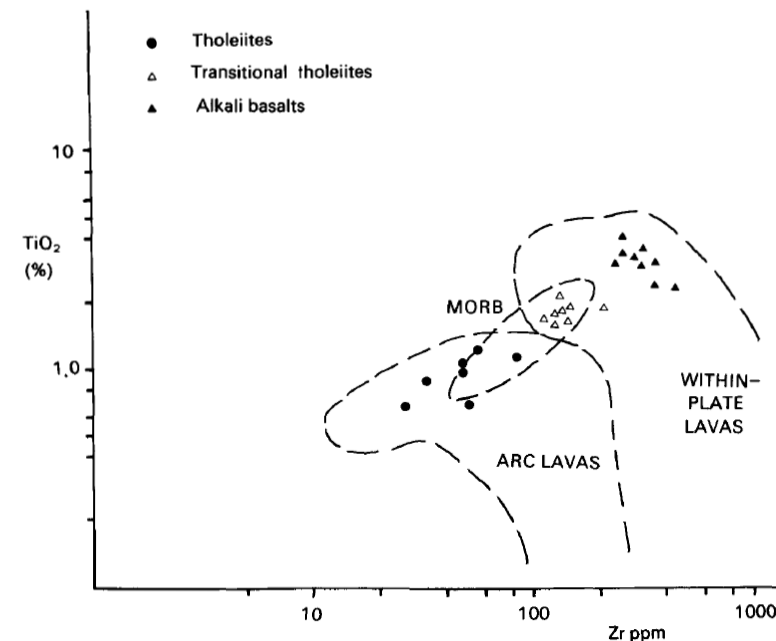


FIG. 7. Ti/100-Zr-Y.3 plot for the Haybi basalts (after Pearce & Cann 1973).

# “Oman Exotics”—Oceanic carbonate build-ups associated with the early stages of continental rifting

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G. M. Graham\*

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GEOLOGY, v. 10, p. 43–49, JANUARY 1982

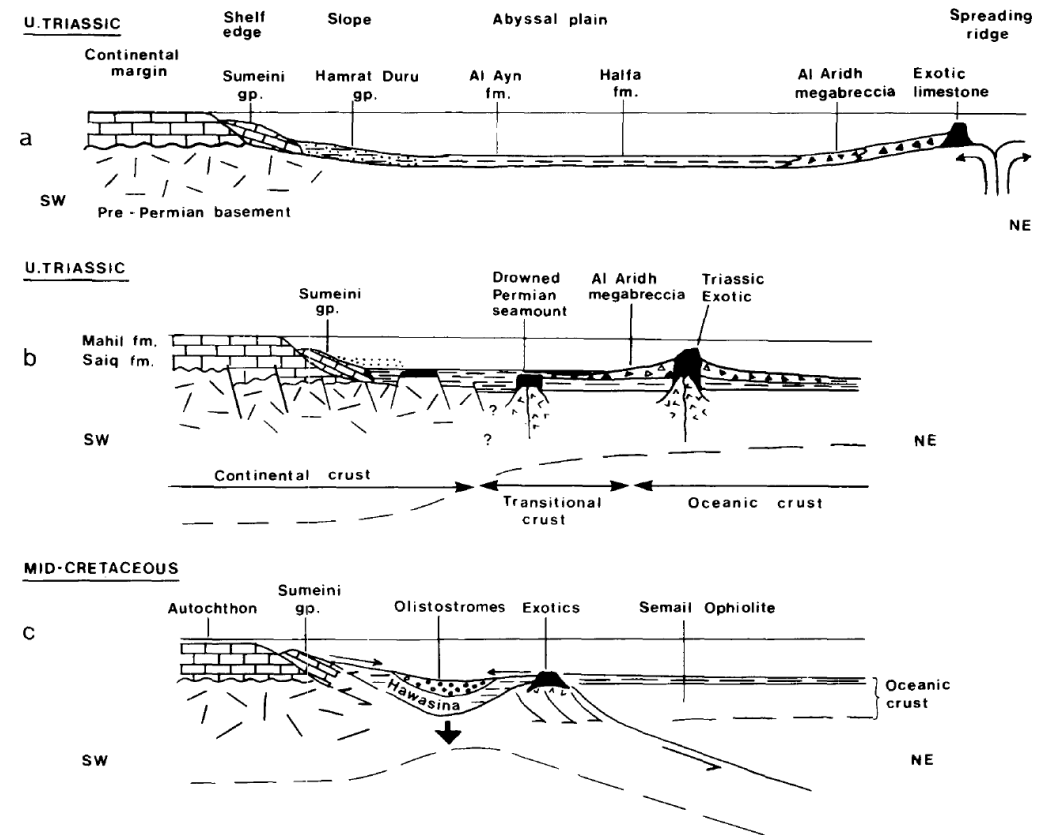
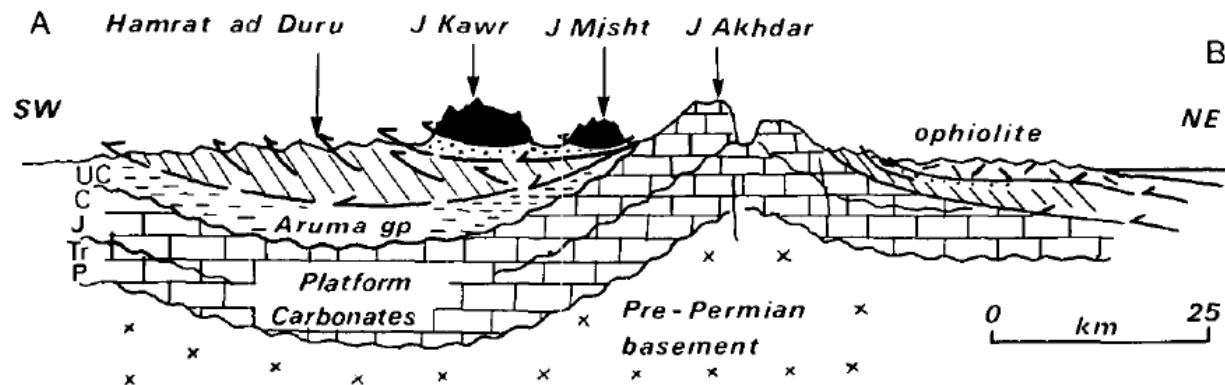


Figure 5. Reconstruction of Oman continental margin at end of Triassic time. a: After Glennie and others (1973); b: model proposed in this paper; see text for discussion; c: Oman continental margin during middle-Late Cretaceous, when olistostrome deposits accumulated in rapidly deepening trough, before and during emplacement of all allochthonous units.

## 2) 蛇绿岩仰冲之下发现高压-超高压岩石（榴辉岩），为大陆边缘深俯冲的结果，时代为80 Ma

*J. geol. Soc. London, Vol. 140, 1983, pp. 97–104, 6 figs., 2 tables. Printed in Northern Ireland.*

### Cretaceous high pressure metamorphism in NE Oman and its relationship to subduction and ophiolite nappe emplacement

Stephen J. Lippard

**SUMMARY:** An occurrence of glaucophane-bearing schists is reported from near Muscat in NE Oman in rocks which underlie the Upper Cretaceous Semail ophiolite nappe. These blueschists formed by the metamorphism of quartz sandstones, shales and basic igneous rocks belong to a pre-Permian basement in the area. Metamorphic micas (phengites) from these rocks have been dated at between 101 and 80 Ma (K-Ar ages) indicating a mid- to late-Cretaceous age for the high pressure event. A syn- to late- $F_1$  assemblage of almandine + glaucophane + phengite in the pelites shows that the peak of metamorphism reached about 400–450°C and 4–8 kbars pressure. This was followed by a greenschist facies overprint with the formation of epidote and albite porphyroblasts in the meta-igneous rocks and a widespread retrogression to chlorite. The high pressure metamorphism is ascribed to the effects of partial subduction of the NE Oman continental margin during the initial stages of ophiolite obduction and the subsequent greenschist facies event to uplift of the area during the later stages of emplacement of the nappes.

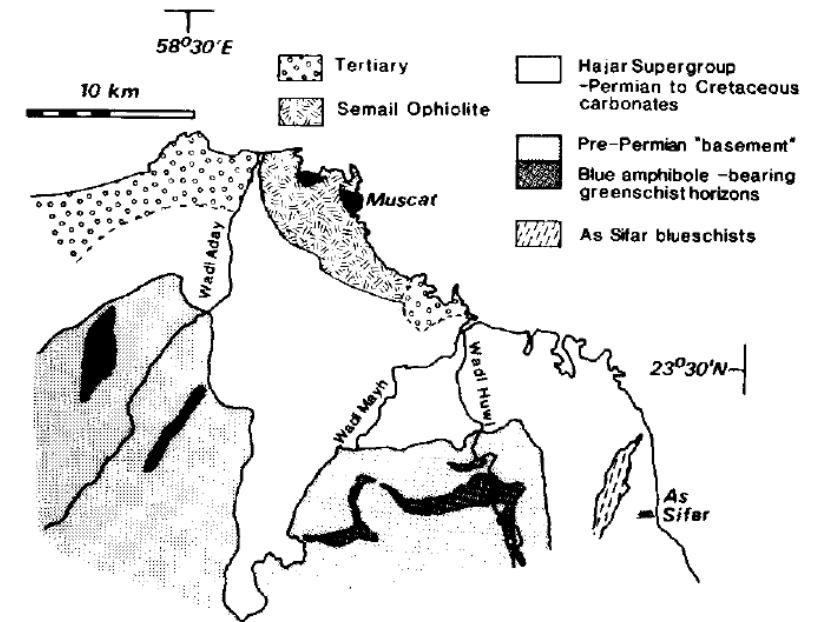


FIG. 2. Sketch geological map of the NE part of the Saih Hatat area.

## Structure and metamorphism of blueschist–eclogite facies rocks from the northeastern Oman Mountains

M. P. SEARLE<sup>1</sup>, D. J. WATERS<sup>1</sup>, H. N. MARTIN<sup>1\*</sup> & D. C. REX<sup>2</sup>

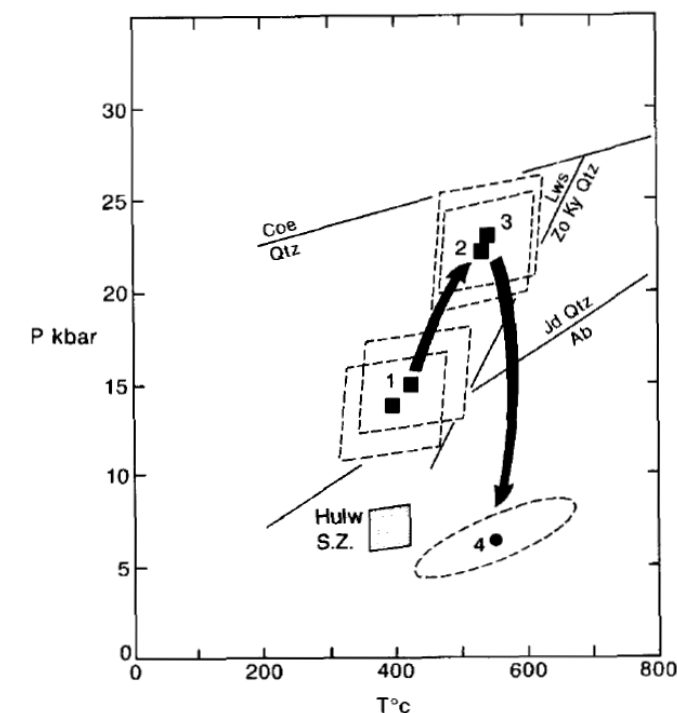
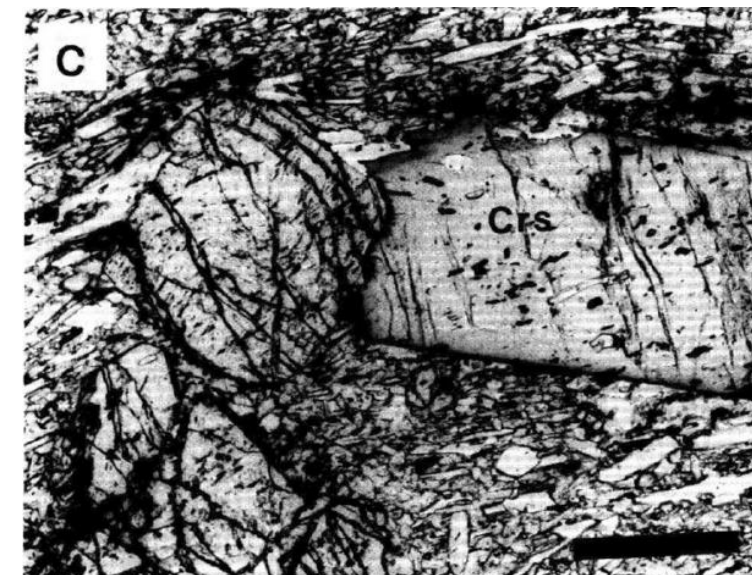
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*\*Née Wills*

**Abstract:** The northern part of the Saih Hatat window, Oman, shows high-pressure metamorphic rocks derived from shelf sediments and pre-Premian continental basement, and is atypical of sub-ophiolite metamorphism elsewhere. The high-pressure rocks are divided into structural units originally bounded by foreland-propagating thrusts formed during ophiolite obduction, although now many contacts are backthrusts, normal faults or extensional shear zones. Metamorphic breaks exist across many unit boundaries. The deepest unit (As Sifah) has eclogite-facies assemblages in metabasites and metapelites which record evolution of  $P$ – $T$  conditions along a clockwise path culminating at  $23 \pm 2.5$  kbar,  $540 \pm 75$  °C, contrasting markedly with overlying units (5–10 kbar, 200–500 °C), although separated by <10 km on the ground. The dominant penetrative structures in the eclogites predate exhumation, but broad zones in the enveloping and overlying schists show a later, greenschist-facies extensional fabric. Phengites from eclogite-facies schist show discordant  $^{40}\text{Ar}/^{39}\text{Ar}$  apparent ages. Our tectonic model relates all the high- $P$  units to a single convergent event in the Late Cretaceous. The As Sifah eclogites were exhumed in two stages: (i) tectonic emplacement against other units at *c.* 20–25 km depth, and (ii) exhumation of the entire high- $P$  zone by culmination collapse after obduction.

Metabasic eclogite





# Dating the subduction of the Arabian continental margin beneath the Semail ophiolite, Oman

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NG12 5GG, UK, and Department of Geology, Leicester University, Leicester LE1 7RH, UK

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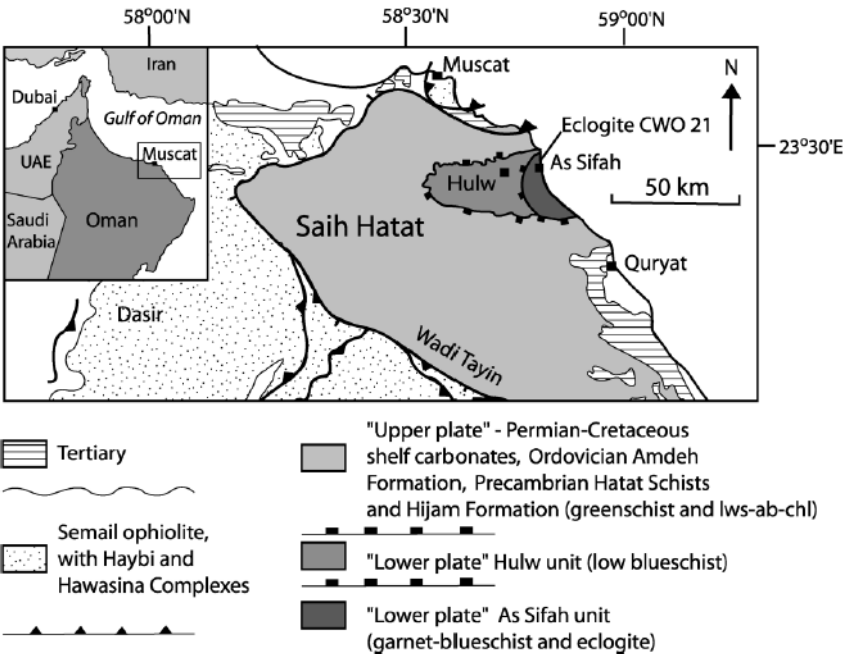


Figure 1. Geologic map of Saih Hatat, Oman. Inset shows position of Oman in Arabia; box indicates location of Saih Hatat. Location of sample CWO 21 is shown. Lws-Ab-Chl—lawsonite-albite-chlorite facies; UAE—United Arab Emirates.

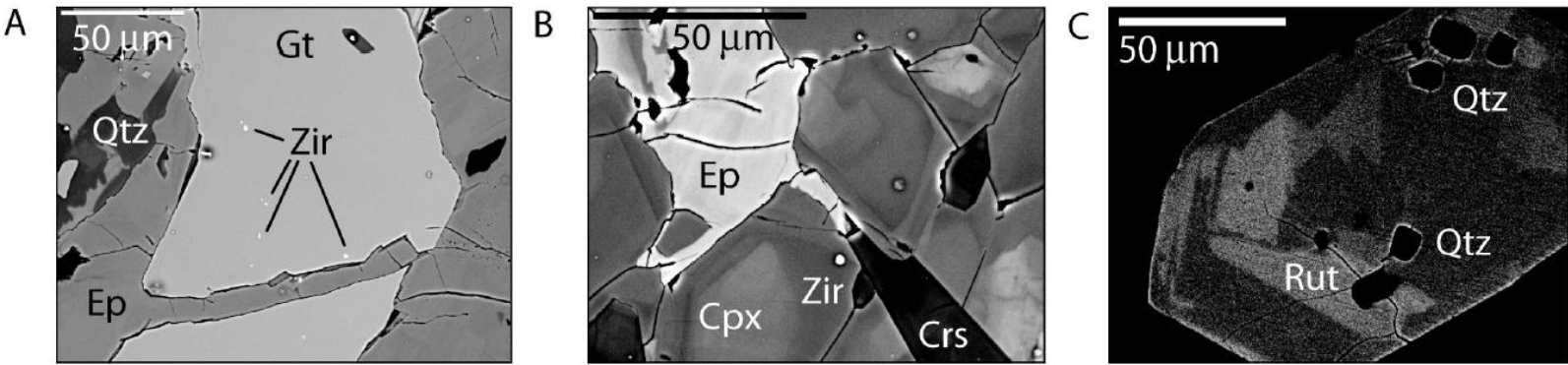
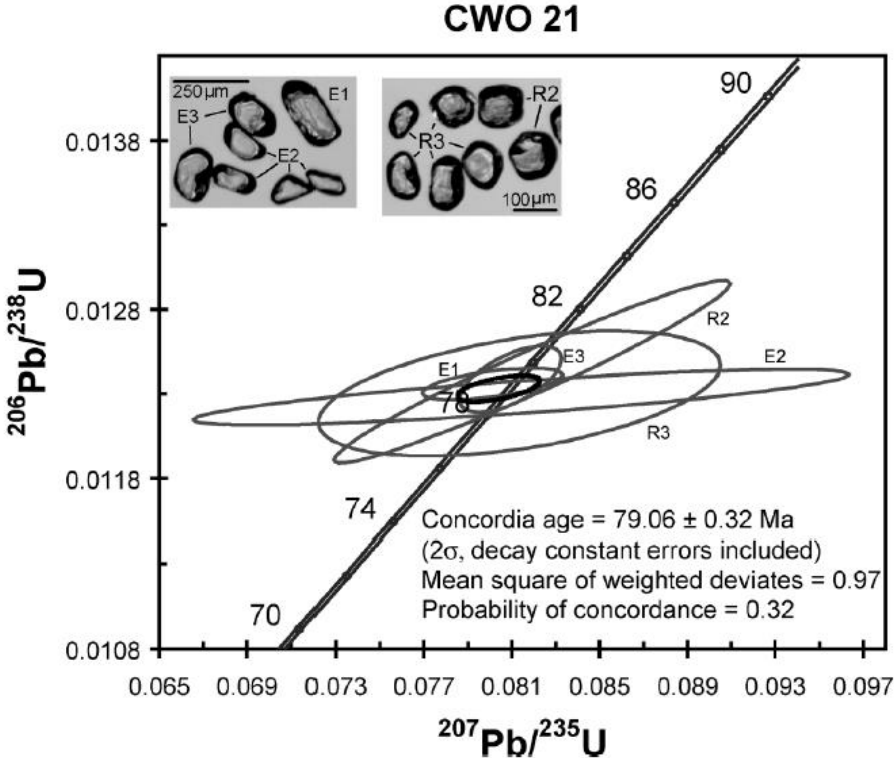


Figure 2. Backscattered-electron micrographs of sample CWO 21. A: Zircon (Zir) grains within garnet (Gt). Garnet rim has broken down to epidote (Ep). Qtz—quartz. B: Zircon grain within clinopyroxene (Cpx). Note zoning in clinopyroxene, epidote, and crossite (Crs). C: Individual zircon grain showing patchy metamorphic zoning and inclusions of quartz and rutile (Rut).

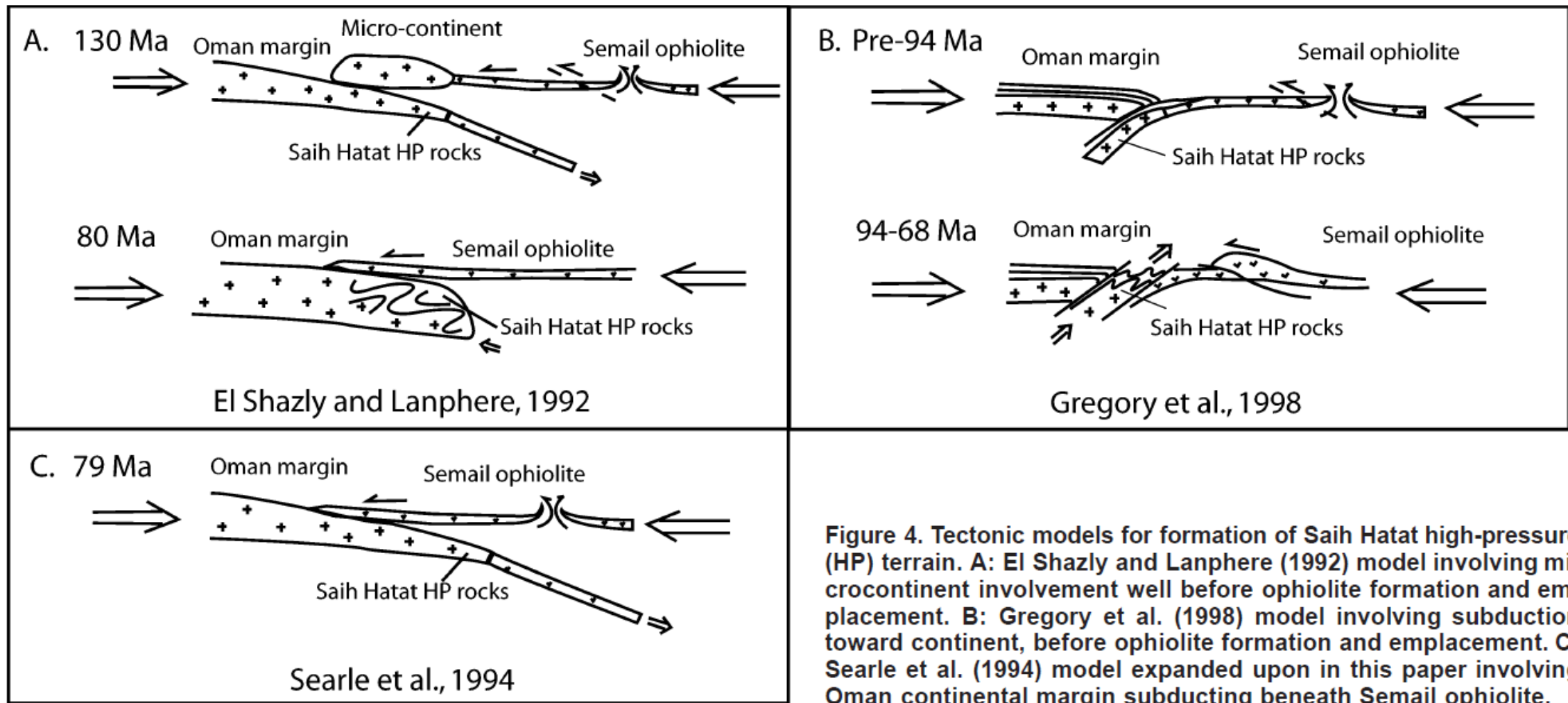


Figure 4. Tectonic models for formation of Saih Hatat high-pressure (HP) terrain. A: El Shazly and Lanphere (1992) model involving microcontinent involvement well before ophiolite formation and emplacement. B: Gregory et al. (1998) model involving subduction toward continent, before ophiolite formation and emplacement. C: Searle et al. (1994) model expanded upon in this paper involving Oman continental margin subducting beneath Semail ophiolite.

3) 系统开展构造地质研究，大比例构造地质填图工作

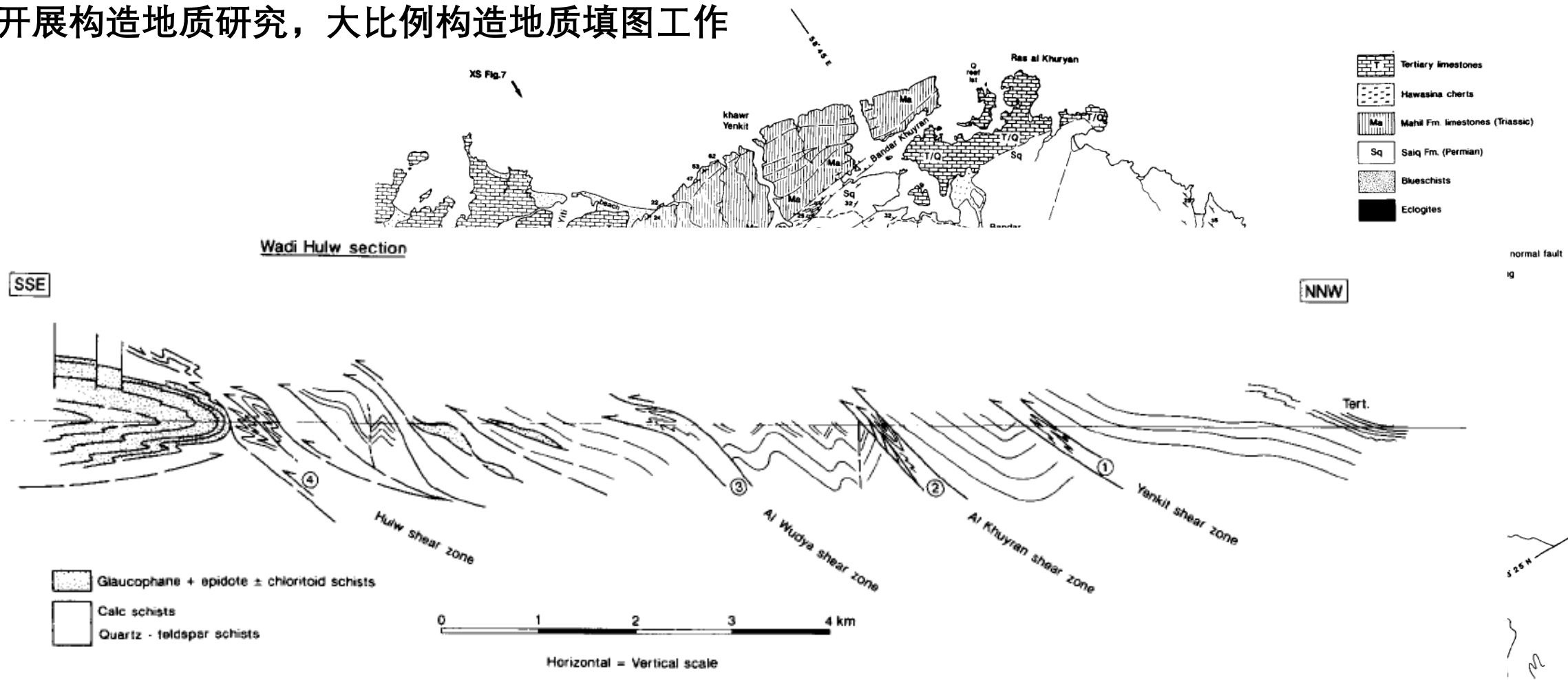


Fig. 7. Cross-section along Wadi Hulw to Yenkit, see Fig. 6 for line of section.

Searle et al., 1994



Fig. 6. Geological map of the Wadi Hulw to As Sifah area. T/Q, Tertiary and Quaternary coral limestones.





**Figure 8. Typical leucogranitic dike intruding mantle sequence harzburgites at Wadi Zikt, west of Dadnah, the United Arab Emirates. This dike contains a pegmatitic tourmaline 14 cm long, andalusite, cordierite, biotite, and muscovite.**



**Figure 9. Biotite granite dikes and veins intruding harzburgites, wehrlites, and cumulate gabbros of the uppermost mantle and lower crustal sequence of the ophiolite, Ras Dadnah cove, United Arab Emirates.**

The Oman ophiolite as a Cretaceous arc–basin complex:  
evidence and implications

BY J. A. PEARCE, T. ALABASTER, A. W. SHELTON AND M. P. SEARLE  
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the SSZ origin of the Semail ophiolite, as proposed in the initial Pearce et al. (1981) contribution, is based mainly on geochemicals such as low Ti, light-rare-earth-element depleted patterns, and low Zr/Hf ratios relative to **N-MORB**. These features are carried only by the secondary volcanism overlying the normal MORB-type crust. Moreover, the significance of the 'primitive' geochemical signature has been questioned (e.g., Hofmann 2004), especially in the case of Oman (Godard et al. 2003, 2006; Ishikawa et al. 2002, 2005).

Clare J. Warren · Randall R. Parrish  
David J. Waters · Michael P. Searle

## Dating the geologic history of Oman's Semail ophiolite: insights from U-Pb geochronology

榴辉岩 ~ 79 Ma

蛇绿岩 Trondhjemites ~ 95 Ma

**Trondhjemite** is a leucocratic (light-colored) intrusive igneous rock. It is a variety of tonalite in which the plagioclase is mostly in the form of oligoclase. Trondhjemites are sometimes known as plagiogranites.

**Abstract** Eclogites from the deepest structural levels beneath the Semail ophiolite, Oman, record the subduction and later exhumation of the Arabian continental margin. Published ages for this high pressure event reveal large discrepancies between the crystallisation ages of certain eclogite-facies minerals and apparent cooling ages of micas. We present precise U-Pb zircon ( $78.95 \pm 0.13$  Ma) and rutile ( $79.6 \pm 1.1$  Ma) ages for the eclogites, as well as new U-Pb zircon ages for trondhjemites from the Semail ophiolite ( $95.3 \pm 0.2$  Ma) and amphibolites from the metamorphic sole ( $94.48 \pm 0.23$  Ma). The new eclogite ages reinforce published U-Pb zircon and Rb-Sr mineral-whole rock isochron ages, yet are inconsistent with published interpretations of older  $^{40}\text{Ar}/^{39}\text{Ar}$  phengite and Sm-Nd garnet dates. We show that the available U-Pb and Rb-Sr ages, which are in tight agreement, fit better with the available geological evidence, and suggest that peak metamorphism of the continental margin occurred during the later stages of ophiolite emplacement.



# Tectonic setting, origin, and obduction of the Oman ophiolite

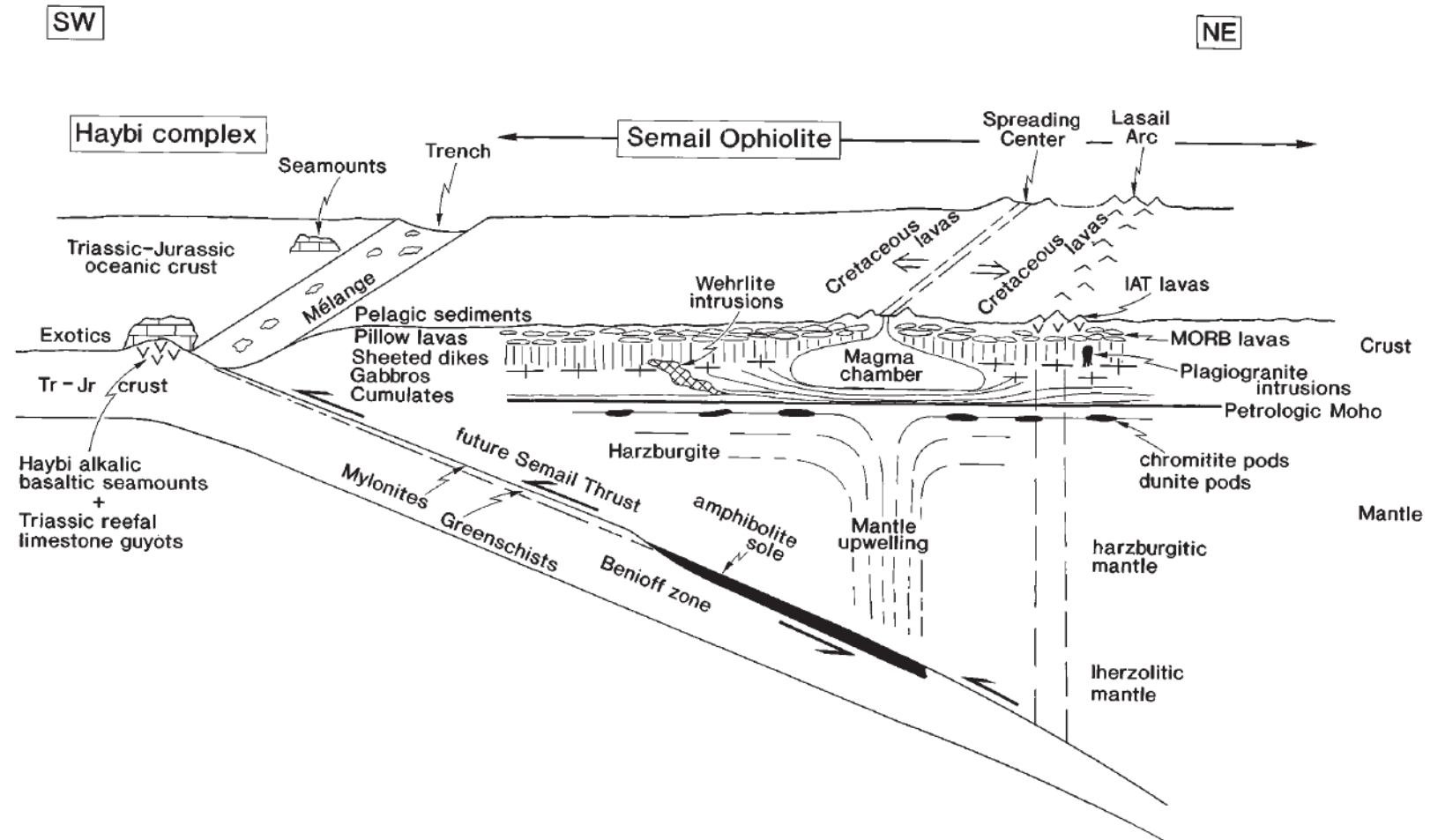
*GSA Bulletin*; January 1999; v. 111; no. 1; p. 104–122; 13 figures.

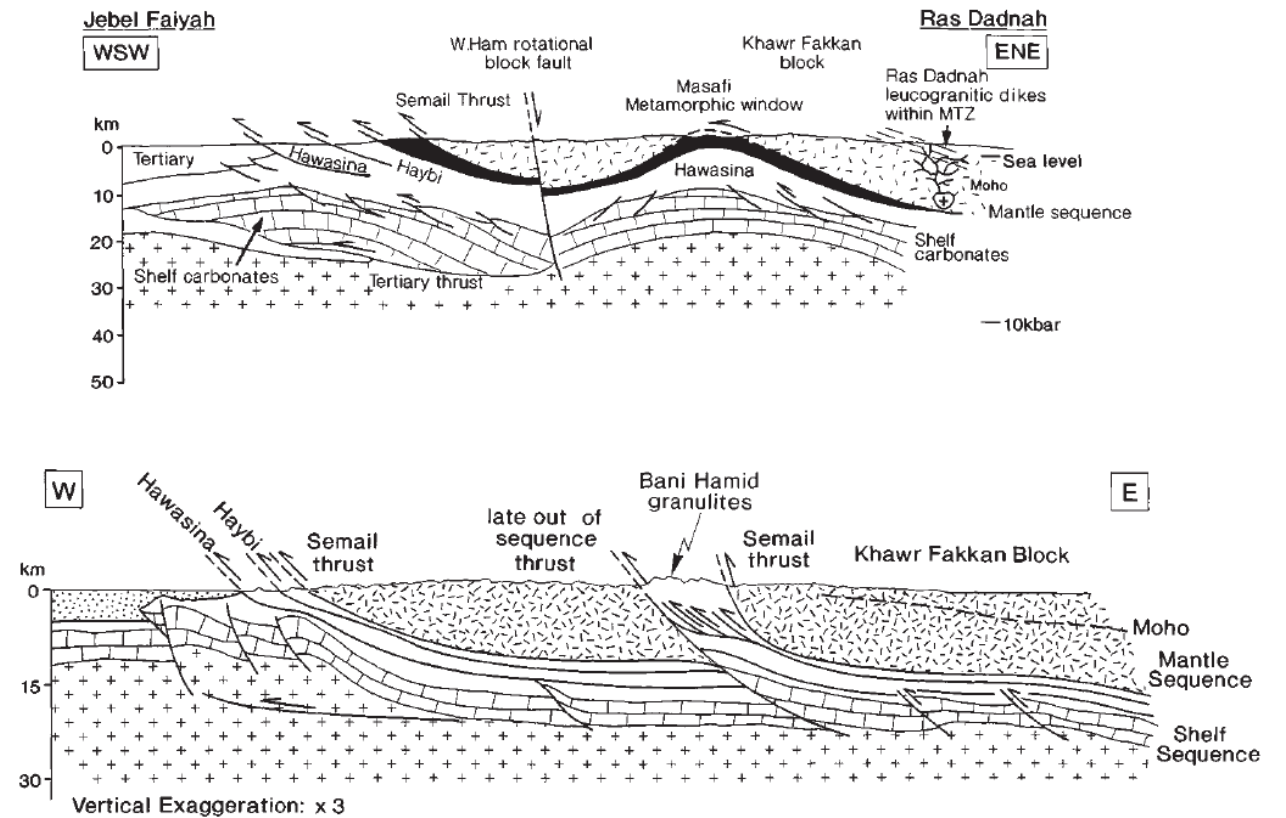
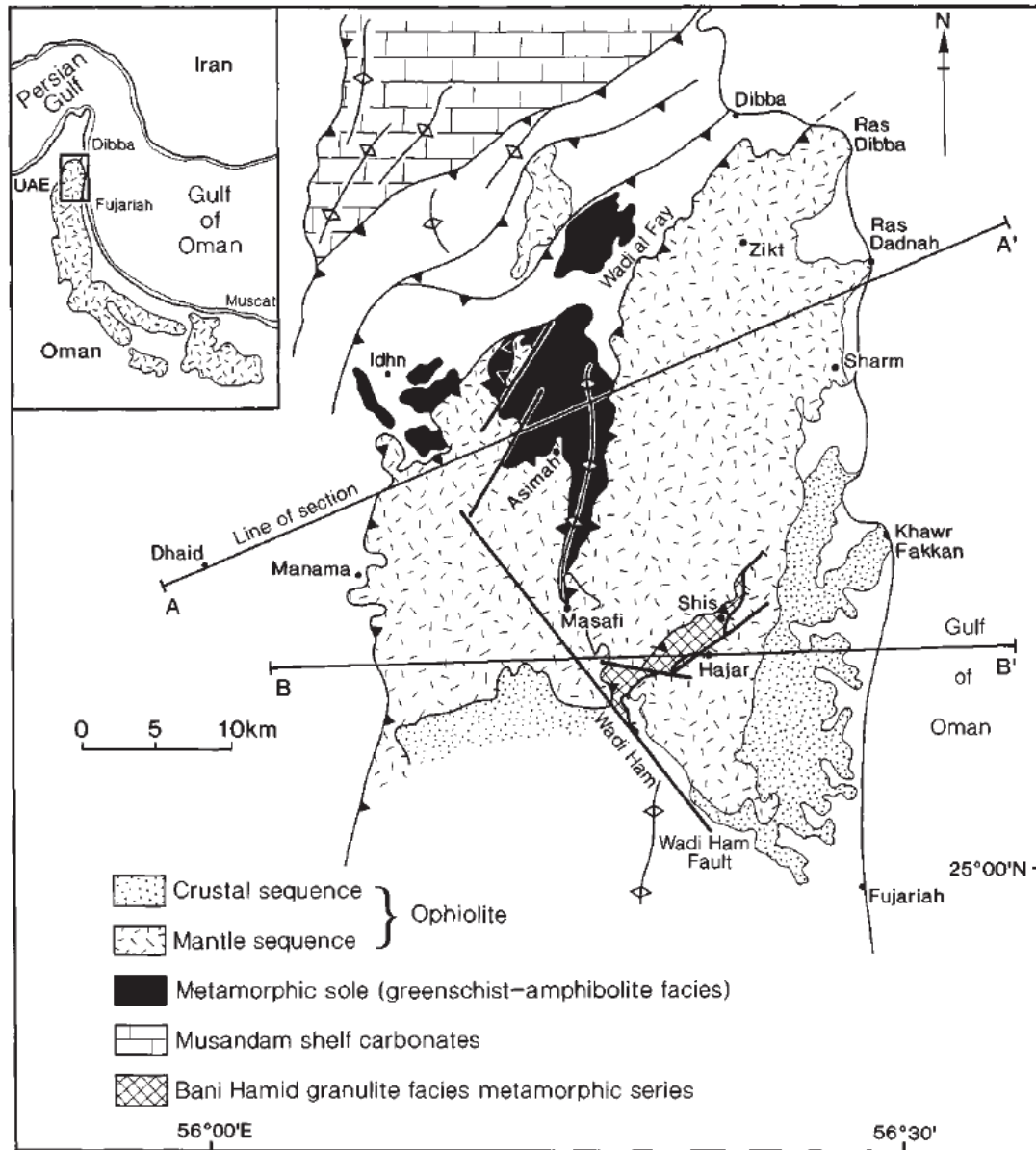
Mike Searle\* }  
Jon Cox } *Department of Earth Sciences, Oxford University, Parks Road, Oxford OX1 3PR, United Kingdom*

Two fundamental questions concern ophiolite complexes world-wide.

(1) In what tectonic setting were the ophiolites originally formed (e.g., midoceanic ridge, transform fault, or a suprasubduction zone marginal basin)?

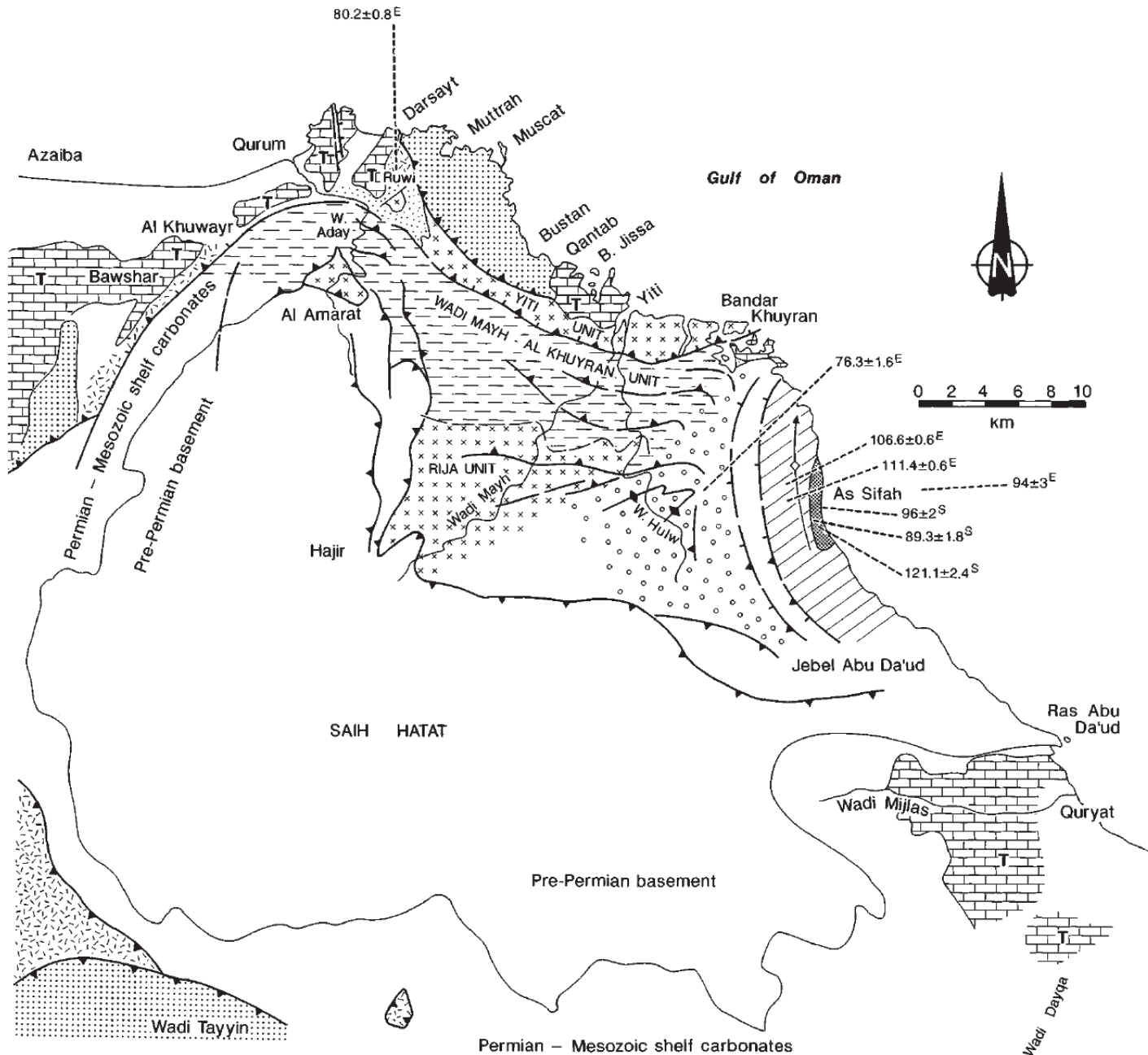
(2) How were these dense (3.0–3.3 g/cm<sup>3</sup>) oceanic mantle and crustal rocks emplaced onto more buoyant, less-dense (2.7–2.8 g/cm<sup>3</sup>) continental crust?





**Figure 6. Geological map of the northern (United Arab Emirates) part of the Oman ophiolite with two cross sections across the Masafi-Ras Dadnah area (A–A') and across the Bani Hamid granulites (B–B'), after Searle (1980, 1988a) and Dunne et al. (1990).**



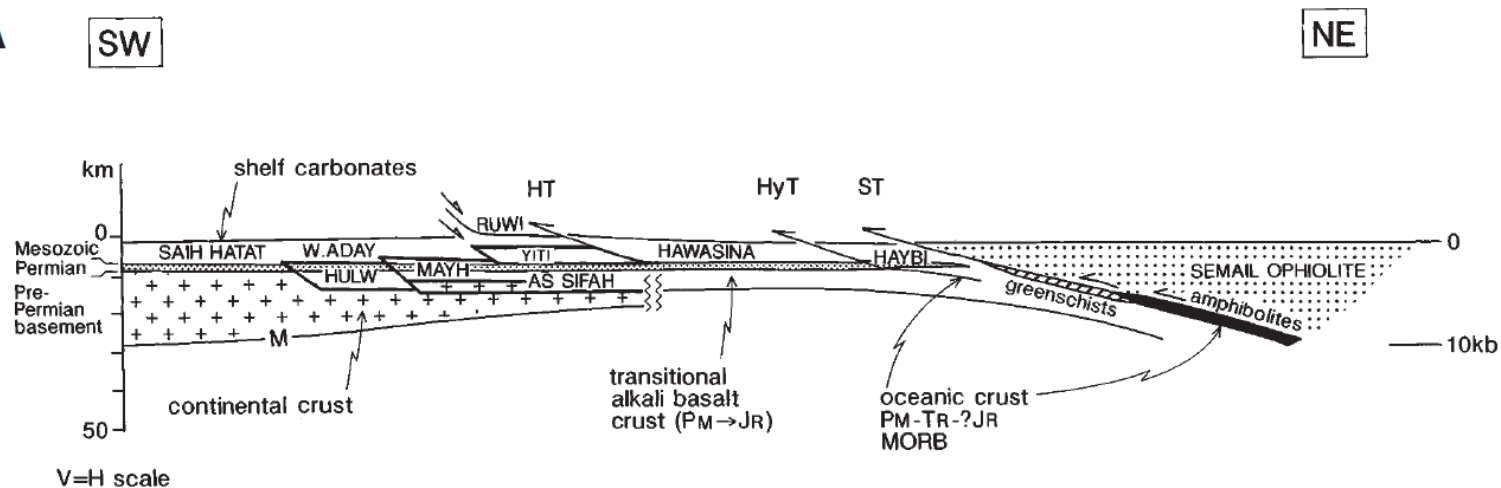


**Figure 10. Map showing the main structural and metamorphic units in the Saih Hatat area, modified after Goffé et al. (1988) and Searle et al. (1994). Numbers refer to the  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau ages of white micas from El-Shazly and Lanphere (1992) and Searle et al. (1994).**

Index minerals in	
Metapelites	Metabasites
Carpholite	Lawsonite
Carpholite + pyrophyllite	-
Carpholite + kaolinite Chlorite + kaolinite	-
Chloritoid + chlorite + ?garnet	Glaucophane + epidote
Garnet + chloritoid	Garnet + glaucophane
Garnet + chloritoid	Garnet + clinopyroxene

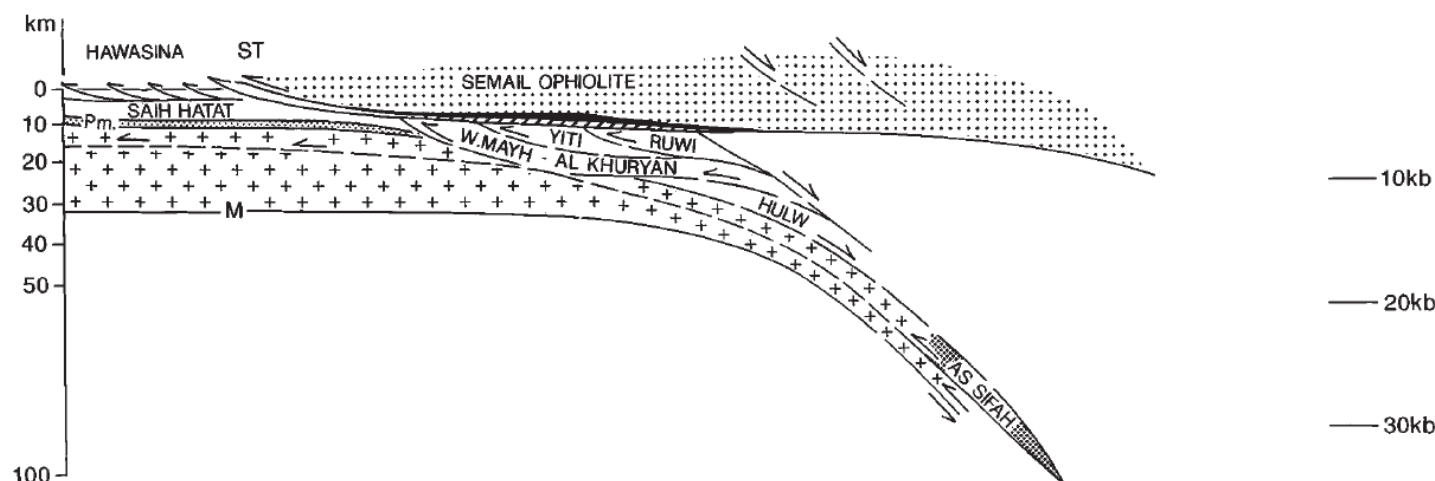


A

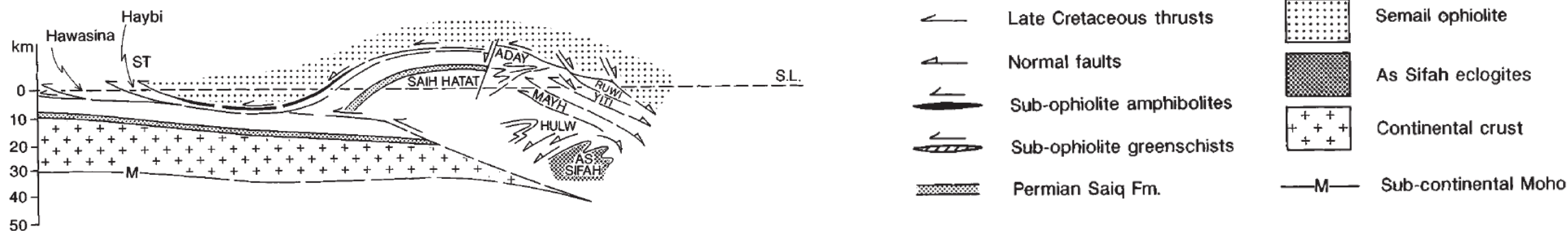


**Figure 13. Tectonic model for the subduction-obduction evolution of the Oman ophiolite in the southeastern Oman Mountains, after Searle et al. (1994).**

B



C



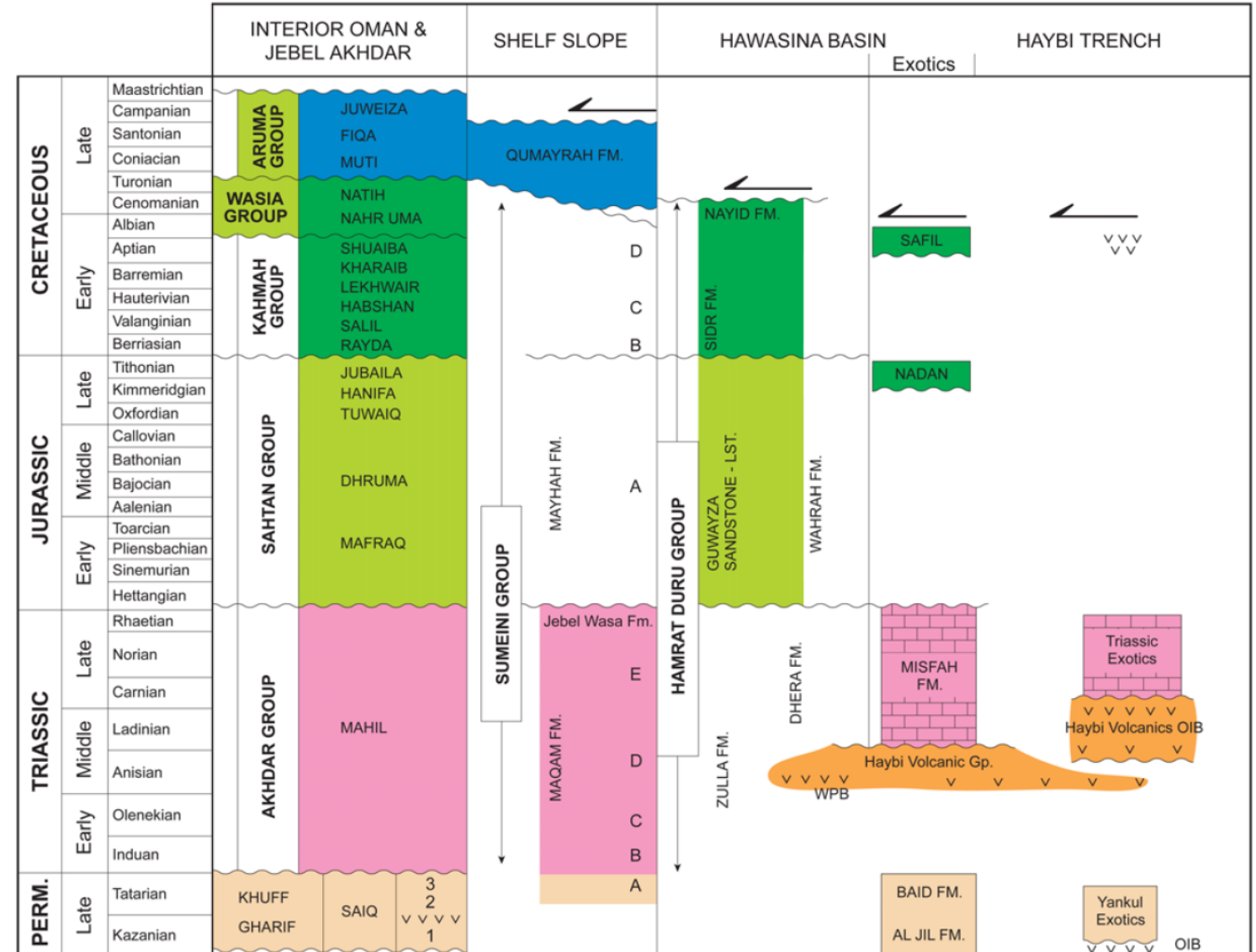
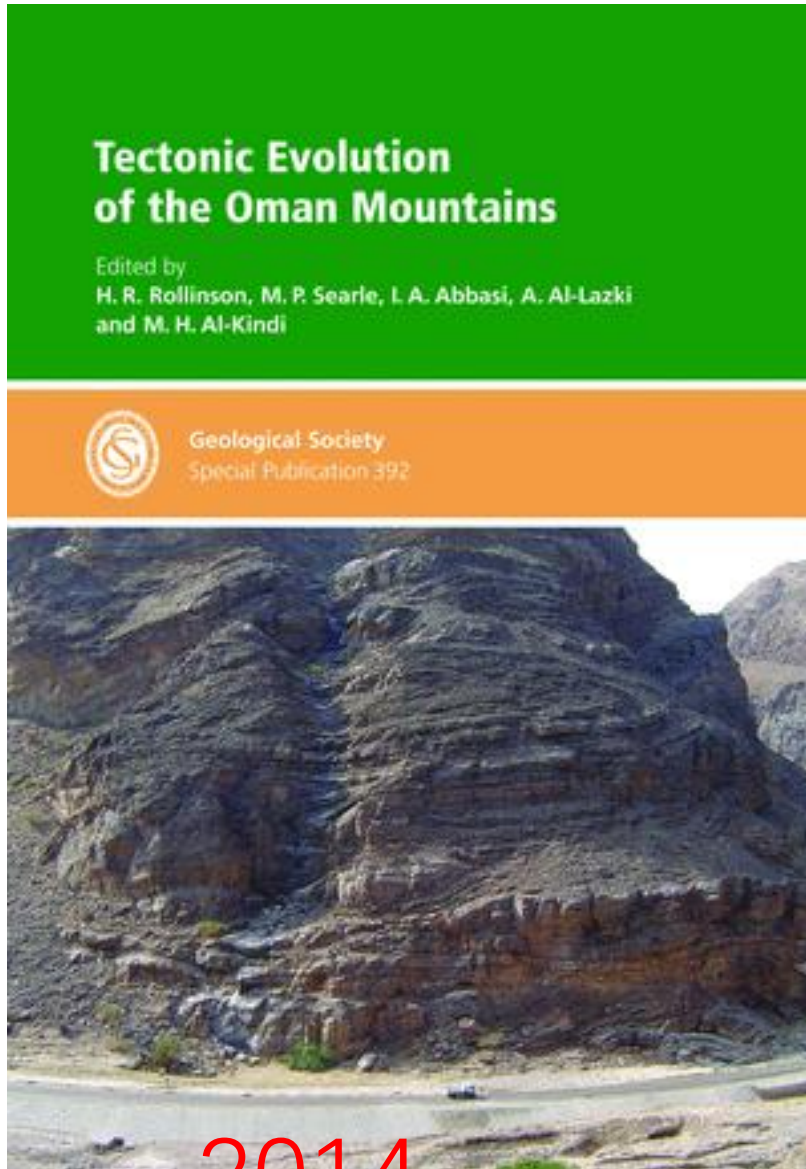
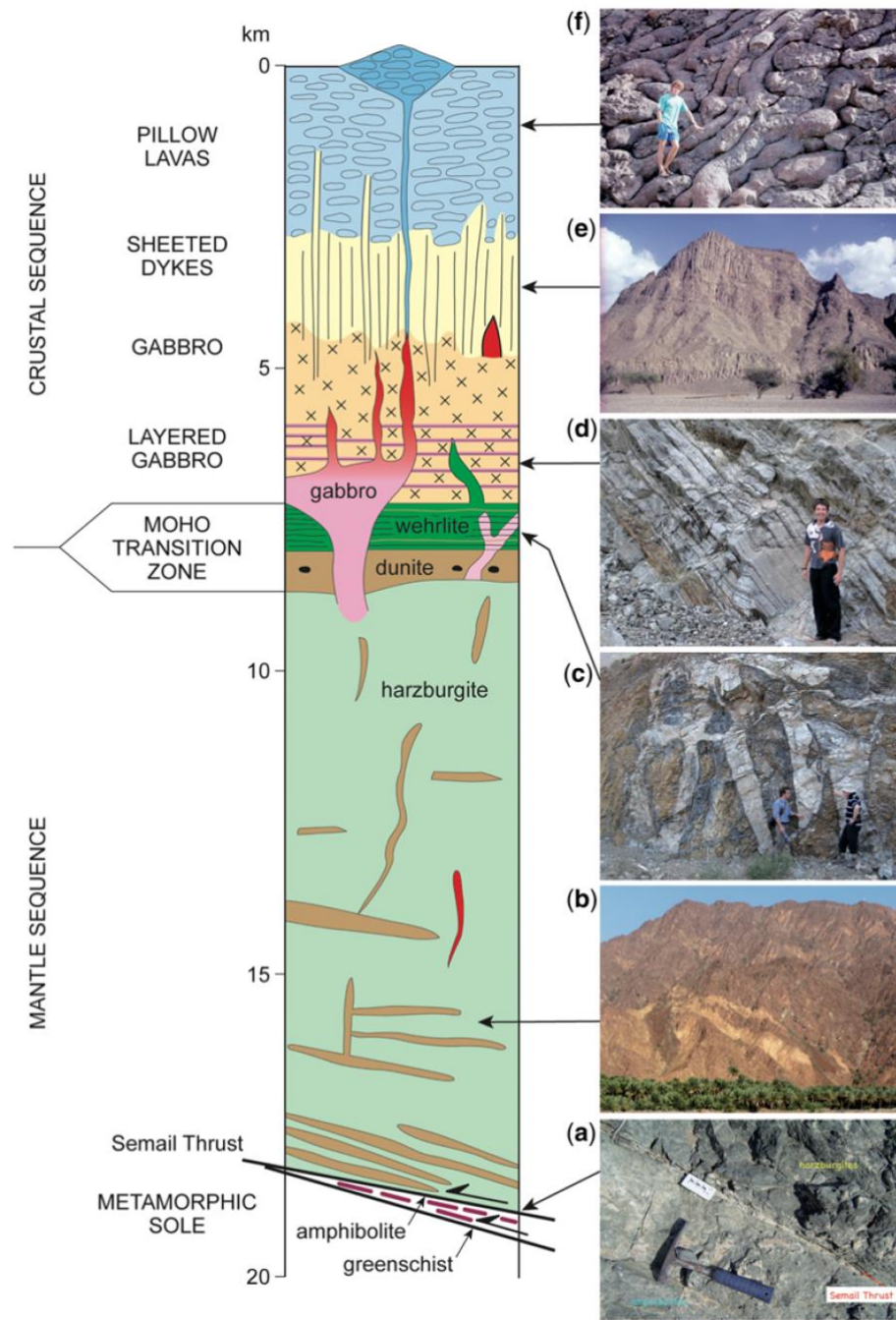
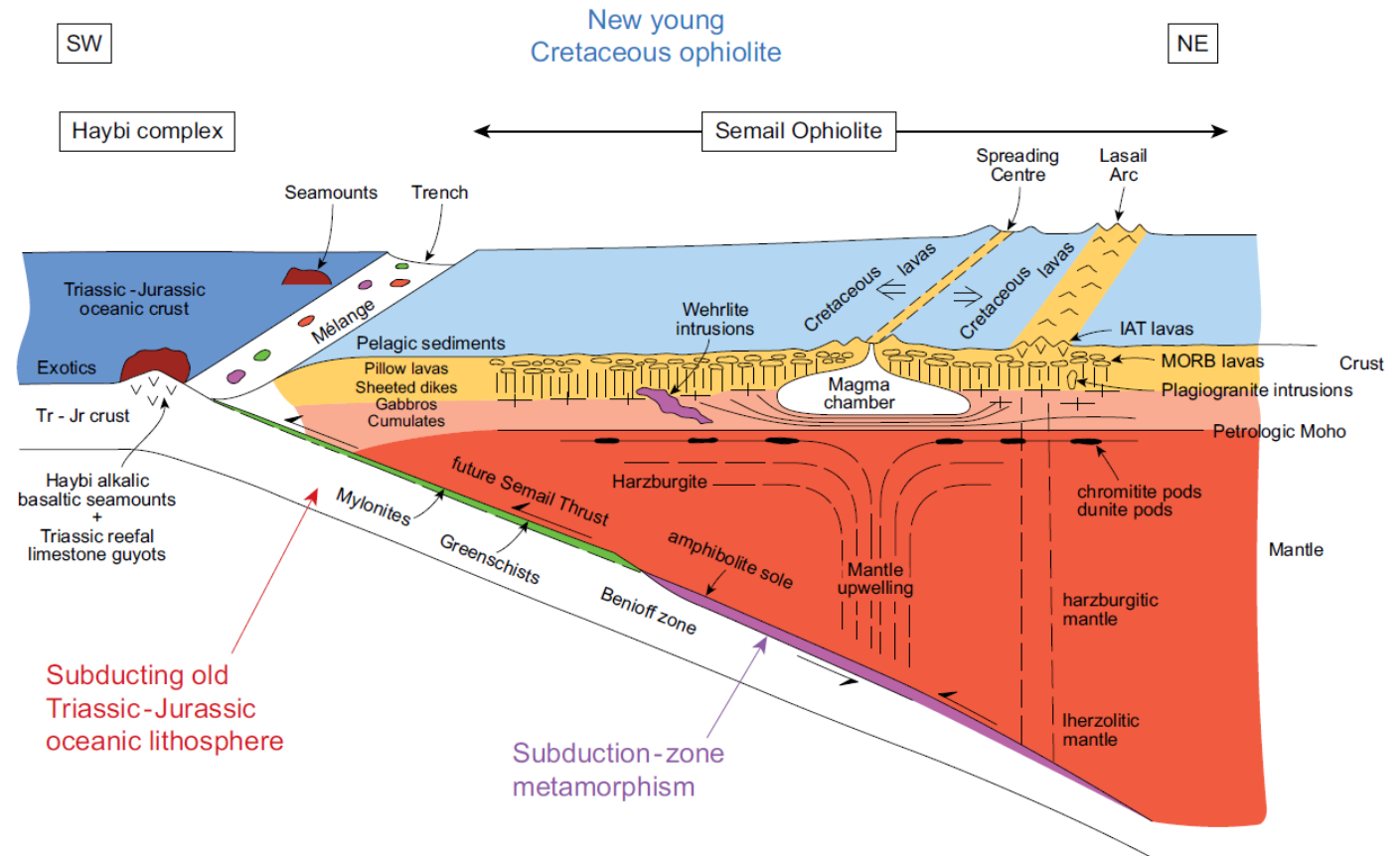


Fig. 2. Stratigraphy of the Oman Mountains region, mainly after Glennie *et al.* (1973, 1974) and Sharland *et al.* (2004).

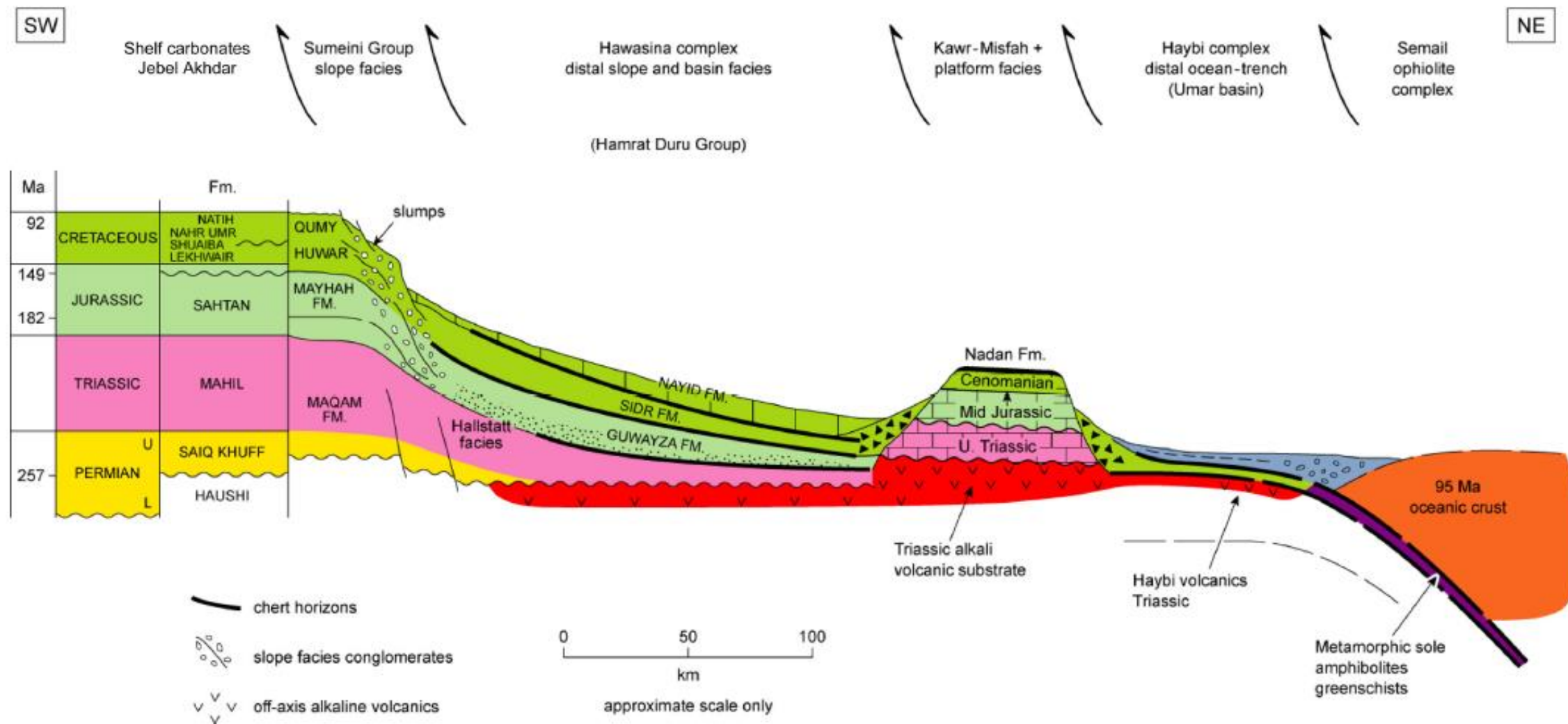


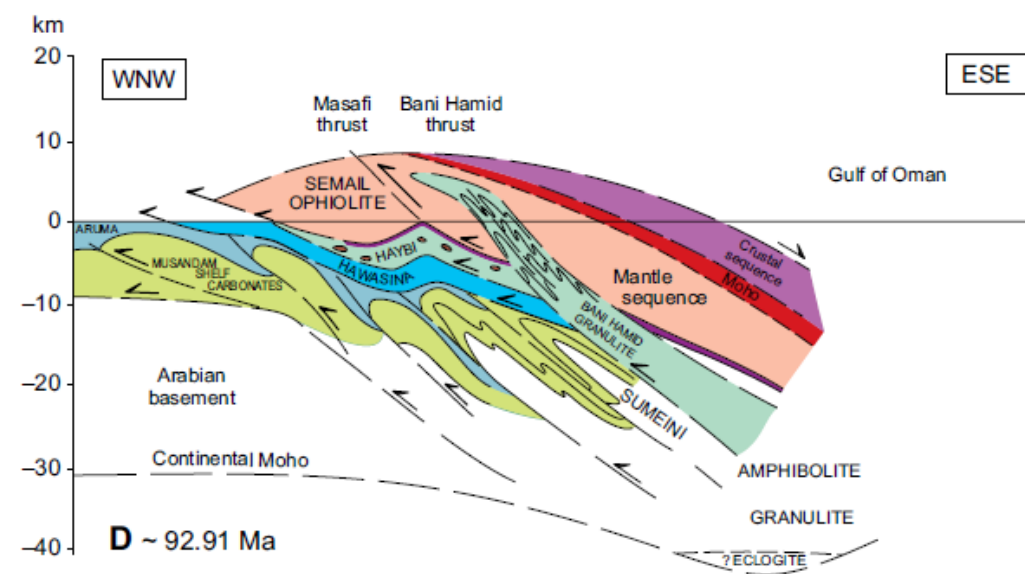
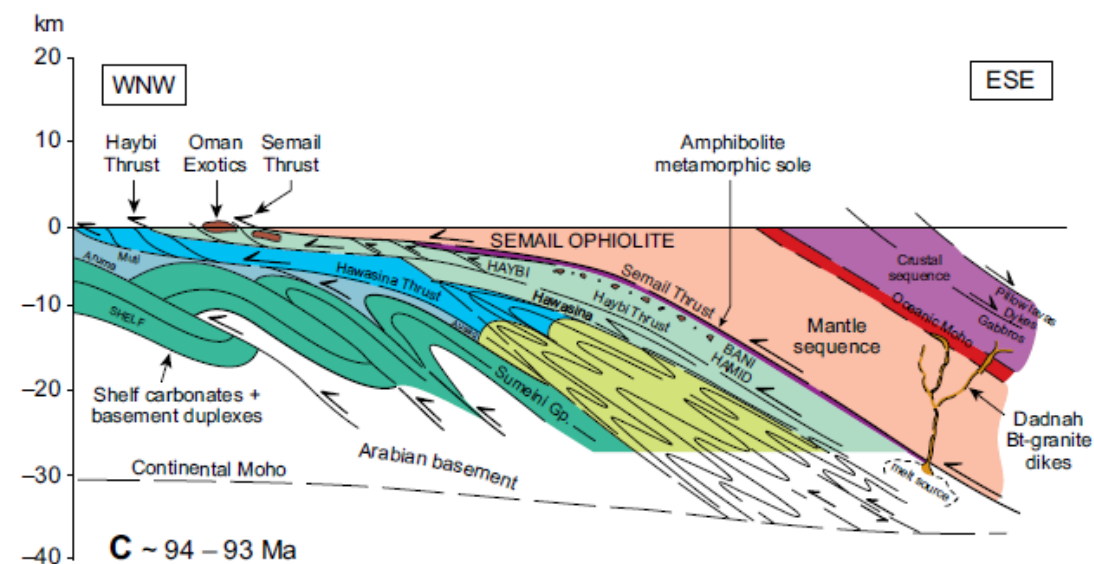
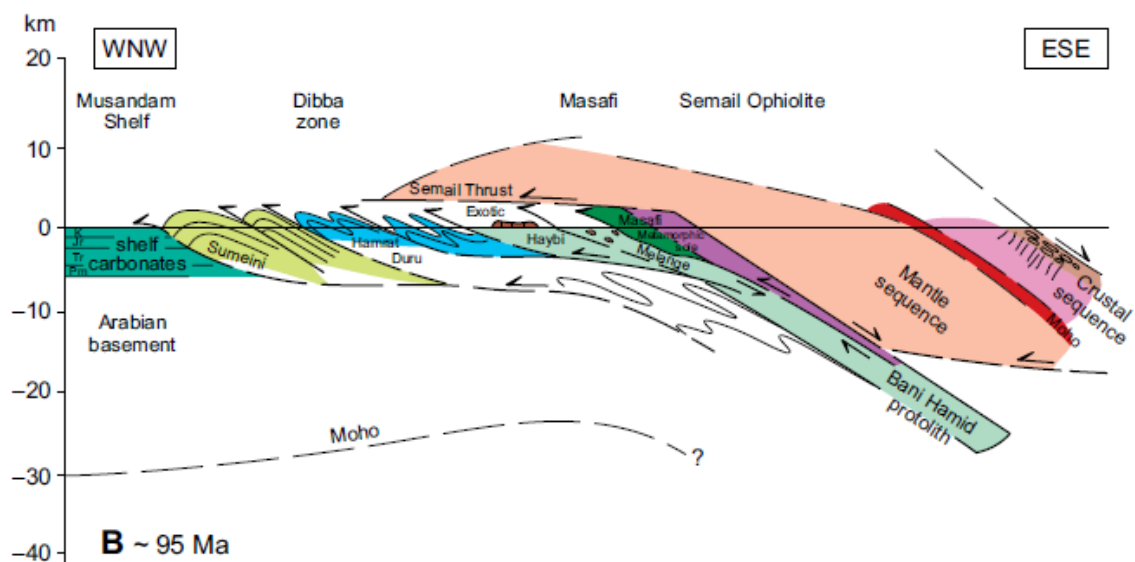
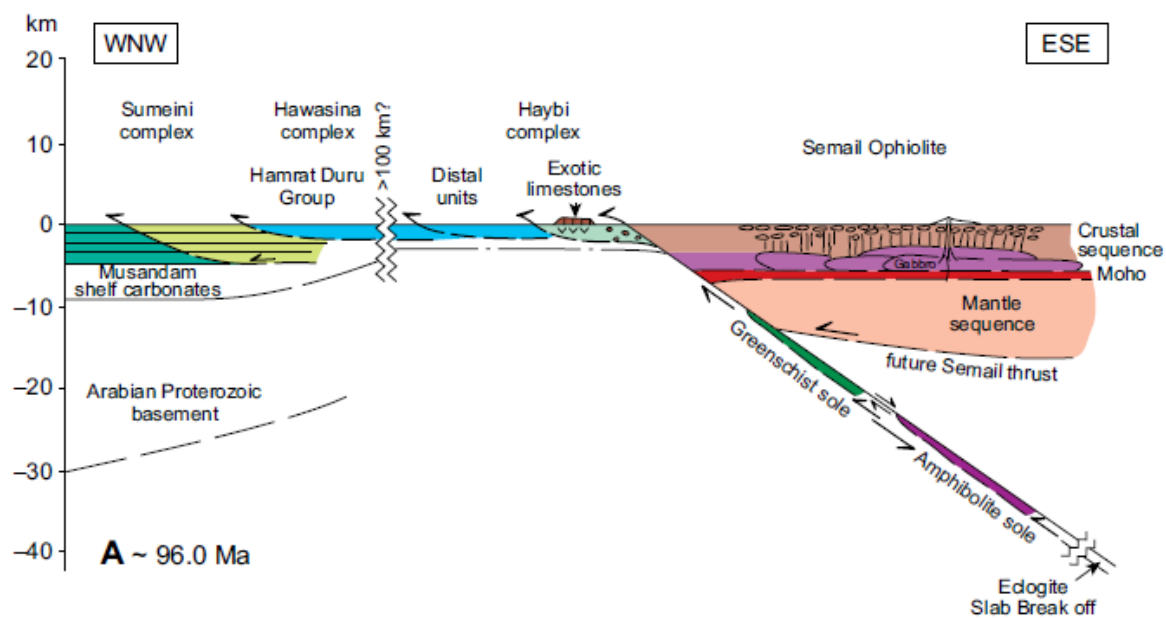
# Origin and Emplacement of Ophiolite: **Supra-Subduction zone model**





# Sedimentary profile of the Mesozoic Arabian continental margin, Central Oman Mountains.





### 三、2000s以来的争论：

- 蛇绿岩的成因： MORB vs SSZ?
- 蛇绿岩的侵位： 洋中脊拆离断层？ 洋脊-海沟碰撞？
- 大洋洋壳消亡的方式？

## COMMENT

### **Comment on “dating the geologic history of Oman’s Semail ophiolite: insights from U–Pb geochronology” by C. J. Warren, R. R. Parrish, D. J. Waters and M. P. Searle**

Françoise Boudier · Adolphe Nicolas

The Mid-Ocean Ridge (MOR) model (e.g. Boudier and Coleman [1981](#); Boudier et al. [1988](#); Nicolas [1989](#)) suggests that:

1. The ophiolite originated at a Mid-Ocean Ridge.
2. The detachment originated at or close to the spreading centre.
3. The detachment was shallow-dipping, shown as only 10–15 km deep in its present position.

## REPLY

### **Reply to Comment by F. Boudier and A. Nicolas on “Dating the geologic history of Oman’s Semail Ophiolite: insights from U–Pb geochronology” by C.J. Warren, R.R. Parrish, M.P. Searle and D.J. Waters**

C. J. Warren · M. P. Searle · R. R. Parrish ·  
D. J. Waters

The Supra-Subduction (SSZ) model (e.g. Pearce et al. [1981](#); Searle and Malpas [1980](#), [1982](#); Searle and Cox [1999](#), [2002](#); Warren et al. [2003](#), [2005](#)) alternatively suggests that:

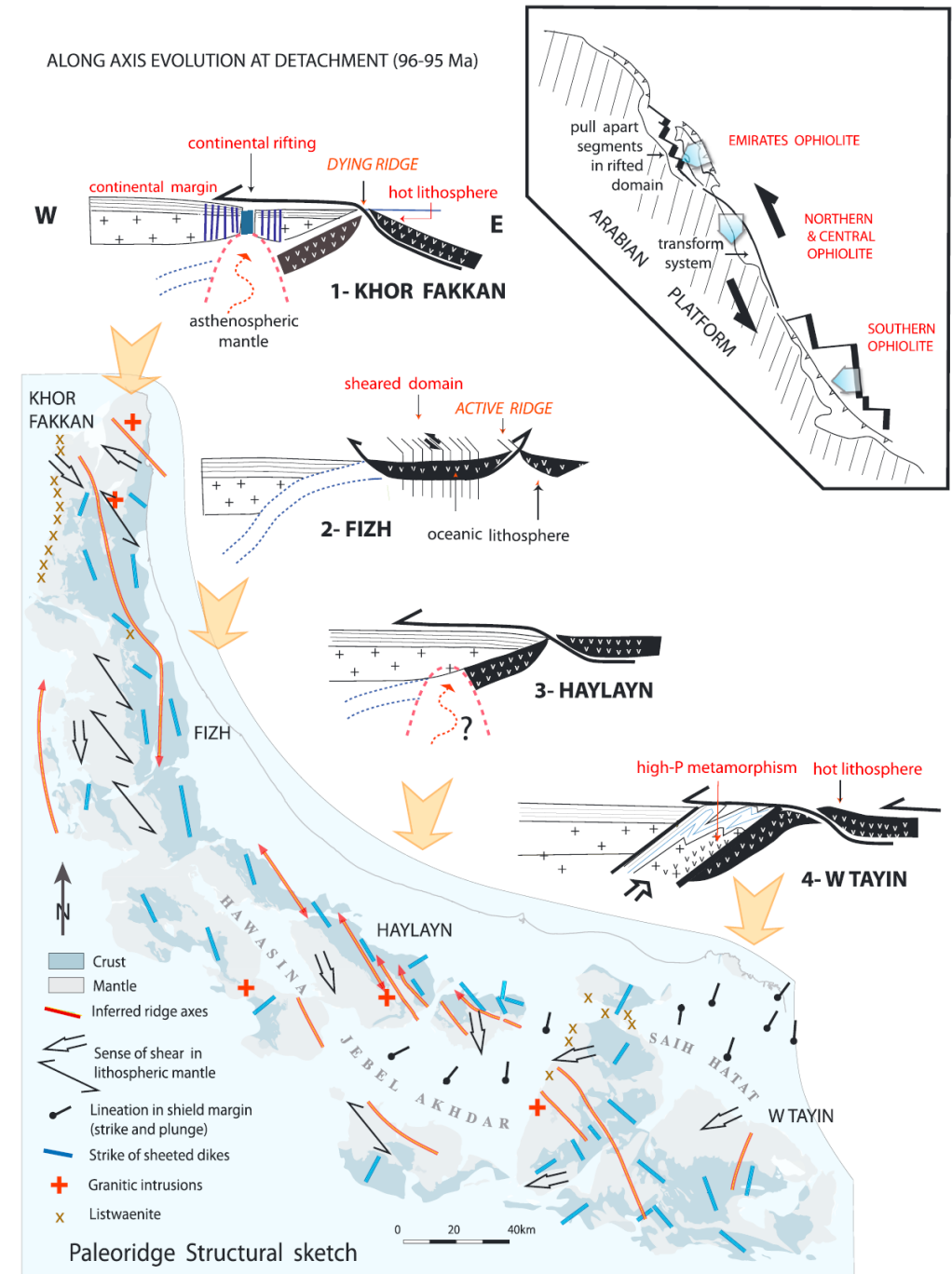
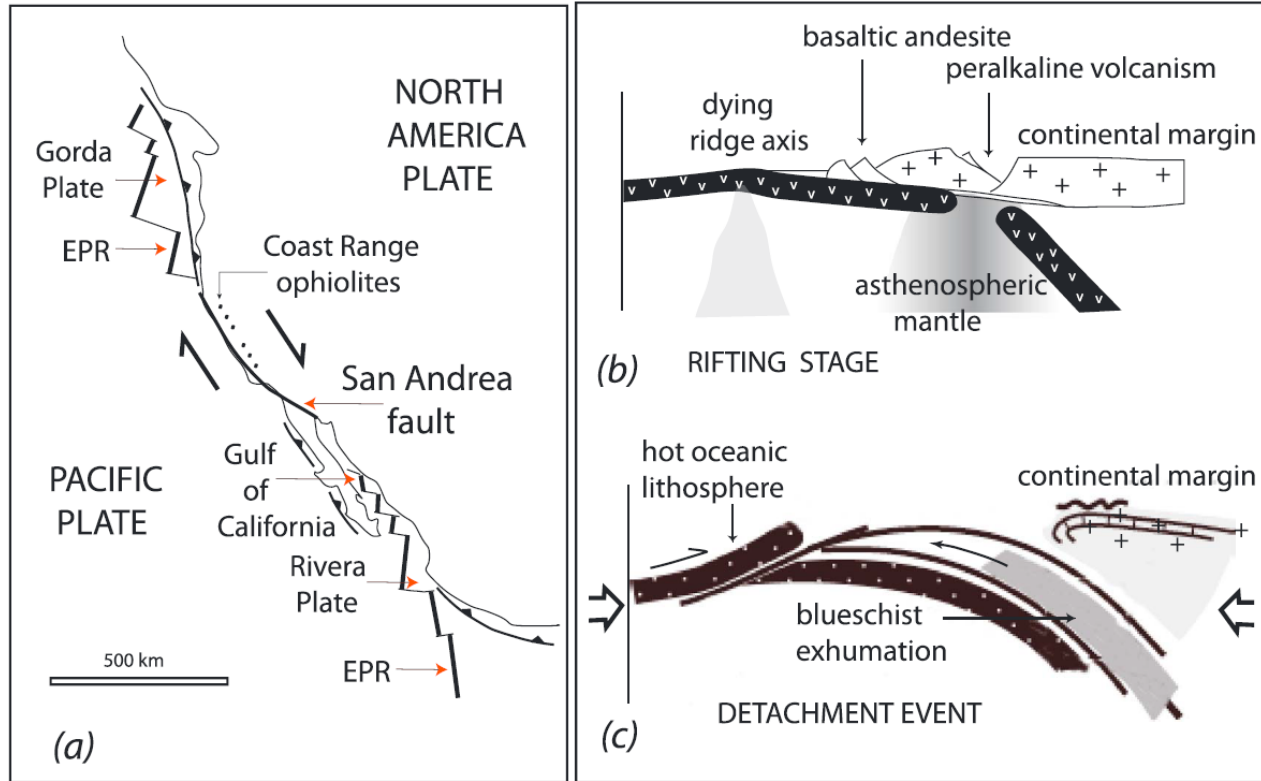
1. The ophiolite originated at a spreading centre above a NE-dipping subduction zone.
2. The detachment initiated at the subduction zone where old, cold oceanic crust was underthrust beneath young, hot oceanic lithosphere
3. The detachment was initially steeply dipping to account for the high pressures recorded in the metamorphic sole
4. The subduction zone was still active 16 My after ophiolite when the Arabian continental margin was subducted and metamorphosed under eclogite facies conditions



# 洋脊-海沟碰撞模型：蛇绿岩侵位

Boudier, F., Nicolas, A., 2018. Synchronous seafloor spreading and subduction at the paleo-convergent margin of Semail and Arabia. *Tectonics*, 37

Nicolas, A., Boudier, F., 2017. Emplacement of Semail-Emirates ophiolite at ridge-trench collision. *Terra Nova*, 29(2): 127-134.



# Geometry and significance of internal windows and regional isoclinal folds in northeast Saih Hatat, Sultanate of Oman

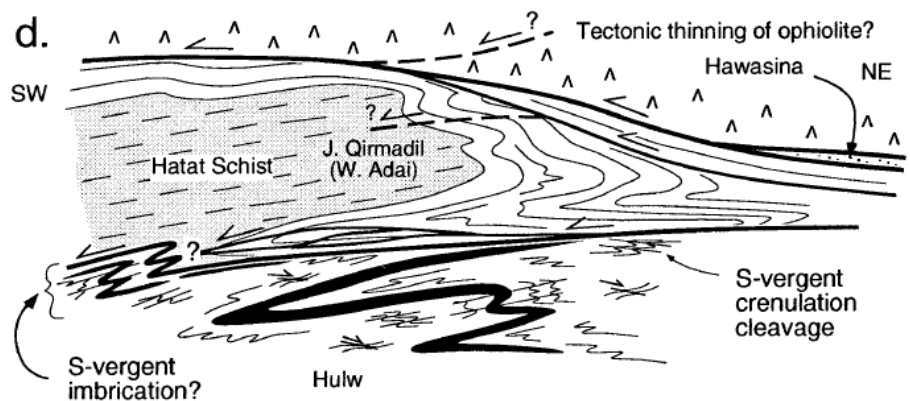
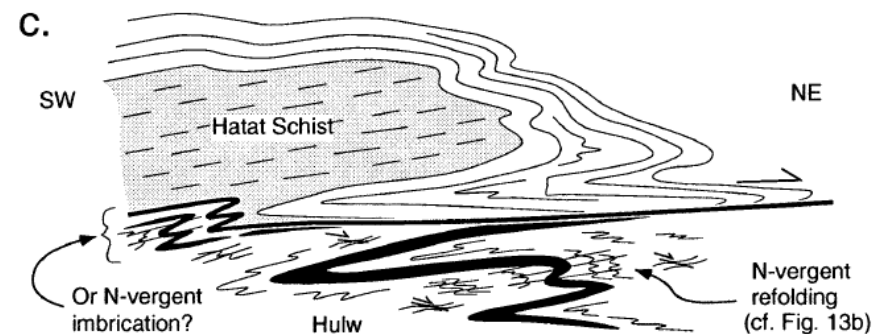
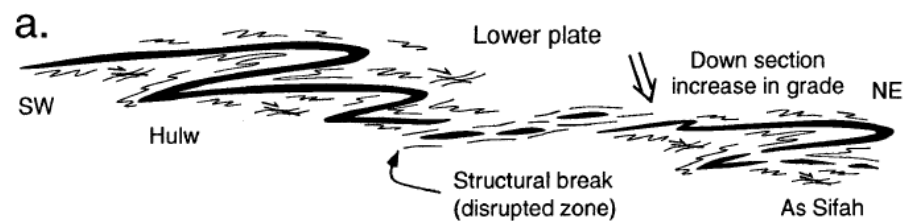
John McL. Miller<sup>a,b,\*</sup>, David R. Gray<sup>a</sup>, Robert T. Gregory<sup>c</sup>

<sup>a</sup>Department of Earth Sciences, Monash University, Melbourne 3800, Australia

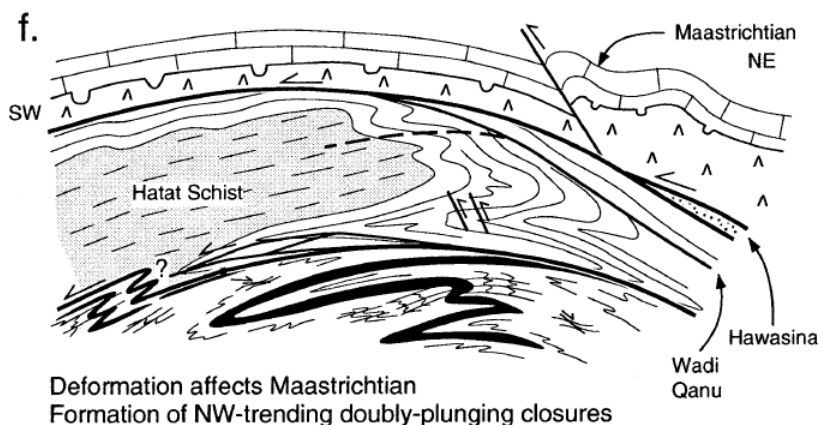
<sup>b</sup>School of Earth Sciences, University of Melbourne, Victoria 3010, Australia

<sup>c</sup>Stable Isotope Laboratory, Department of Geological Science, SMU, Dallas, TX 75275, USA

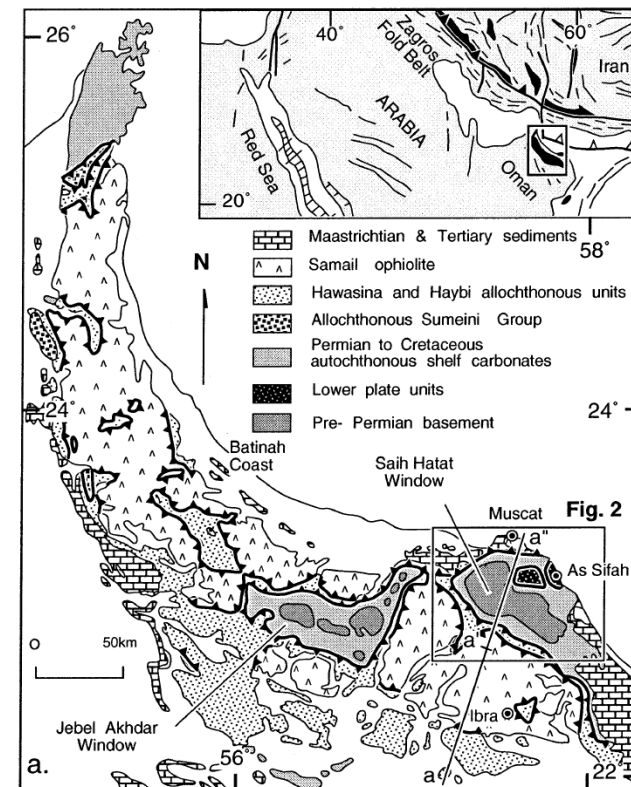
Received 20 April 2001; accepted 21 April 2001



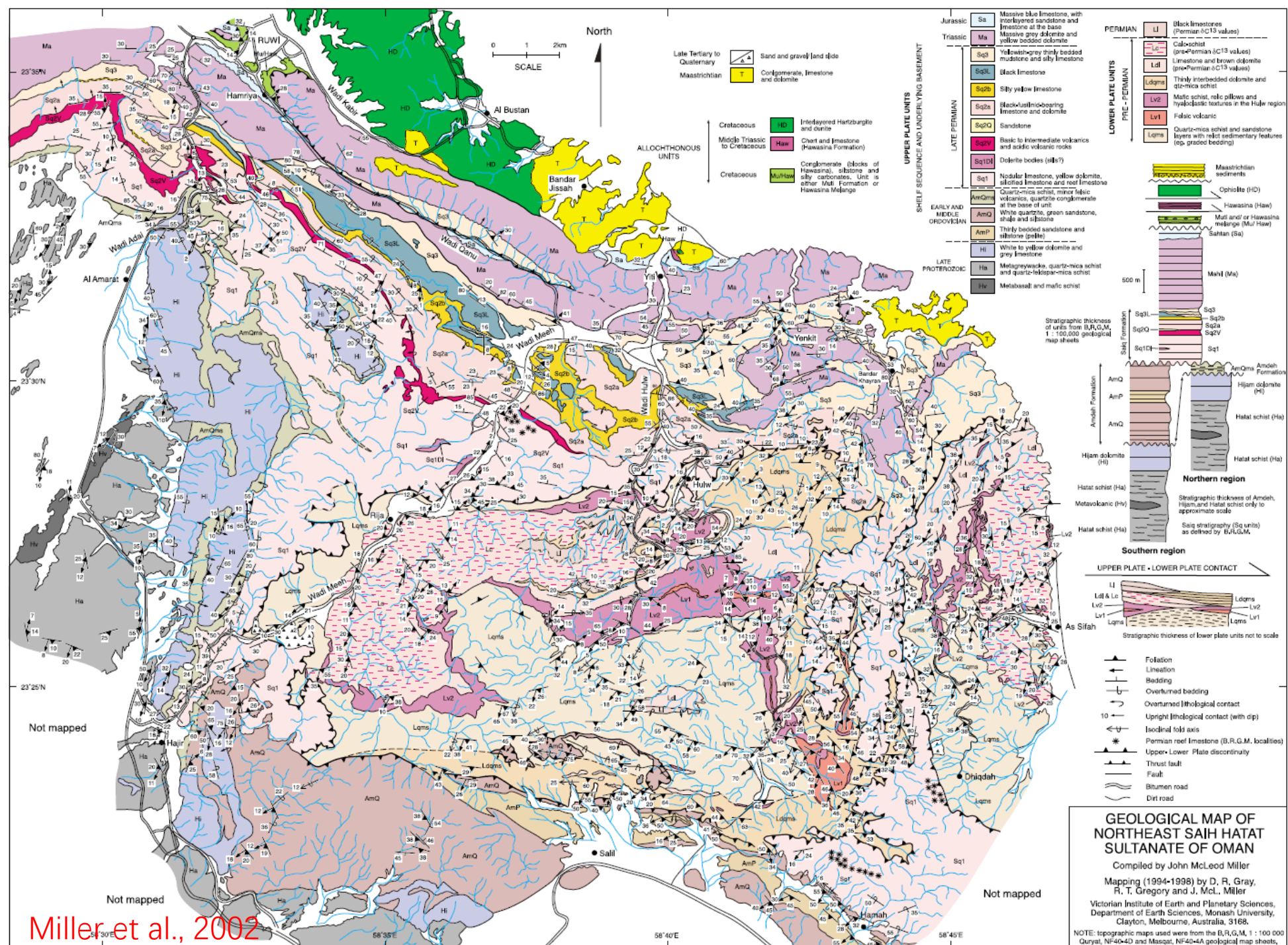
e. N-trending E-vergent folding (between As Sifah and Hulw windows)  
Deposition of Maastrichtian sediments



g. Late, steeply dipping, normal faults (see Figs. 2a and 2b)







Structural evolution, metamorphism and restoration of the Arabian continental margin, Saih Hatat region, Oman Mountains

M.P. Searle<sup>a,\*</sup>, C.J. Warren<sup>a</sup>, D.J. Waters<sup>a</sup>, R.R. Parrish<sup>b,c</sup>

<sup>a</sup>Department of Earth Sciences, Oxford University, Parks Road, Oxford OX1 3PR, UK

<sup>b</sup>Department of Geology, University of Leicester, Leicester LE1 7RH, UK

<sup>c</sup>NERC Isotope Geosciences Laboratory, Keyworth, Nottingham NG12 5GG, UK

Received 17 December 2002; received in revised form 20 June 2003; accepted 9 August 2003

Gray, D.R., Gregory, R.T., Miller, J.M., 2005. Comment

Searle, M.P., Warren, C.J., Waters, D.J., Parrish, R.R., 2005. Reply to

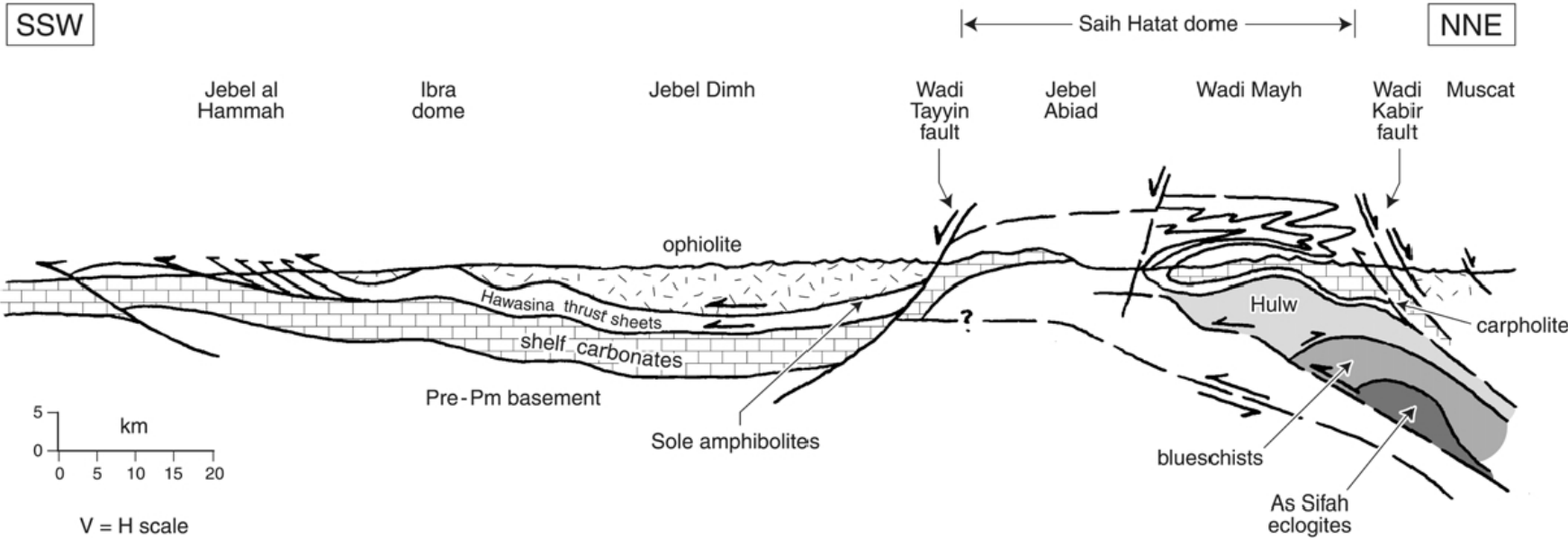
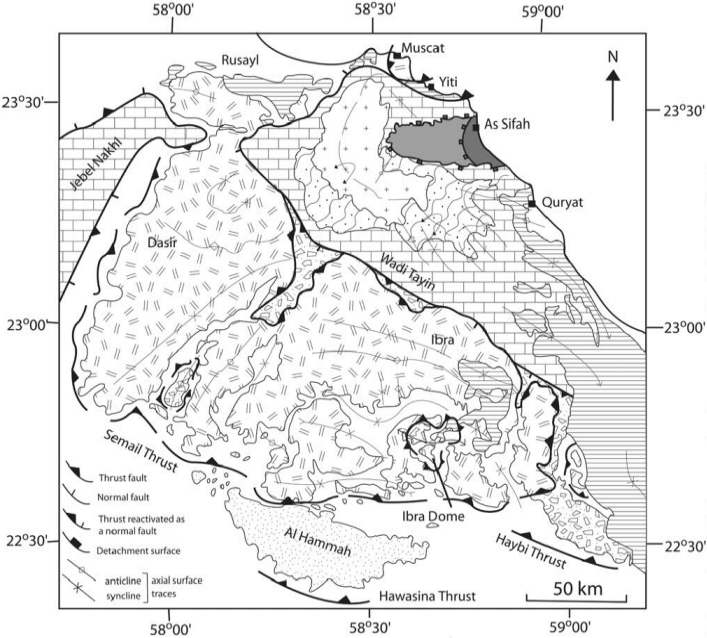


Fig. 11. Geological section across the southeastern part of the Oman mountains including the Saih Hatat window and Ibra ophiolite block.

## 四、个人思考

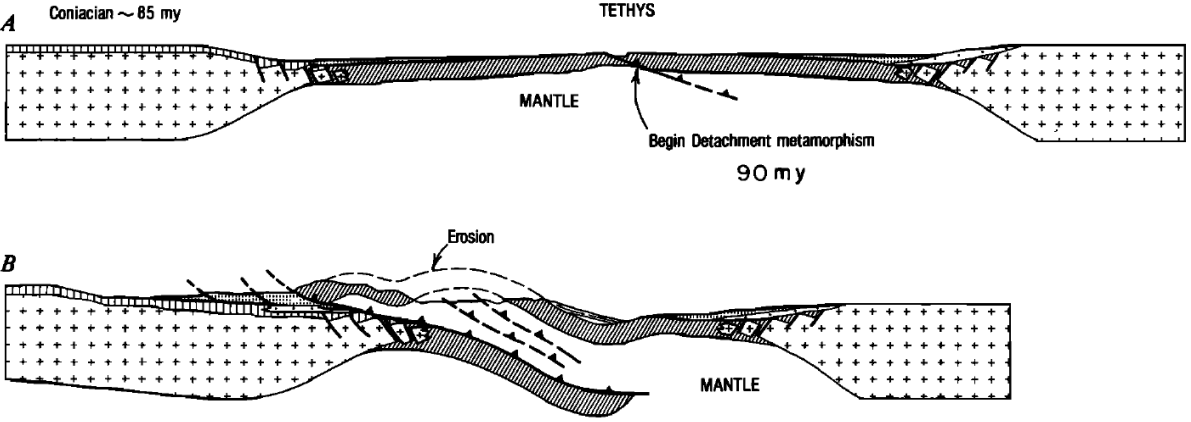
1 蛇绿岩仰冲之前是否需要大洋俯冲及随后的大陆俯冲？

-----洋壳存在的证据：海山可以存在大陆边缘环境。

-----变质岩的成因：洋中脊环境，比如变质底板还是需要俯冲？还是两者兼而有之，早期变质底板洋中脊环境，后期大陆俯冲形成榴辉岩？

个人观点：洋中脊超基性岩石拆离（95-93 Ma），然后在~85-80 Ma左右仰冲到阿拉伯板块之上，同时大陆边缘发生深俯冲？



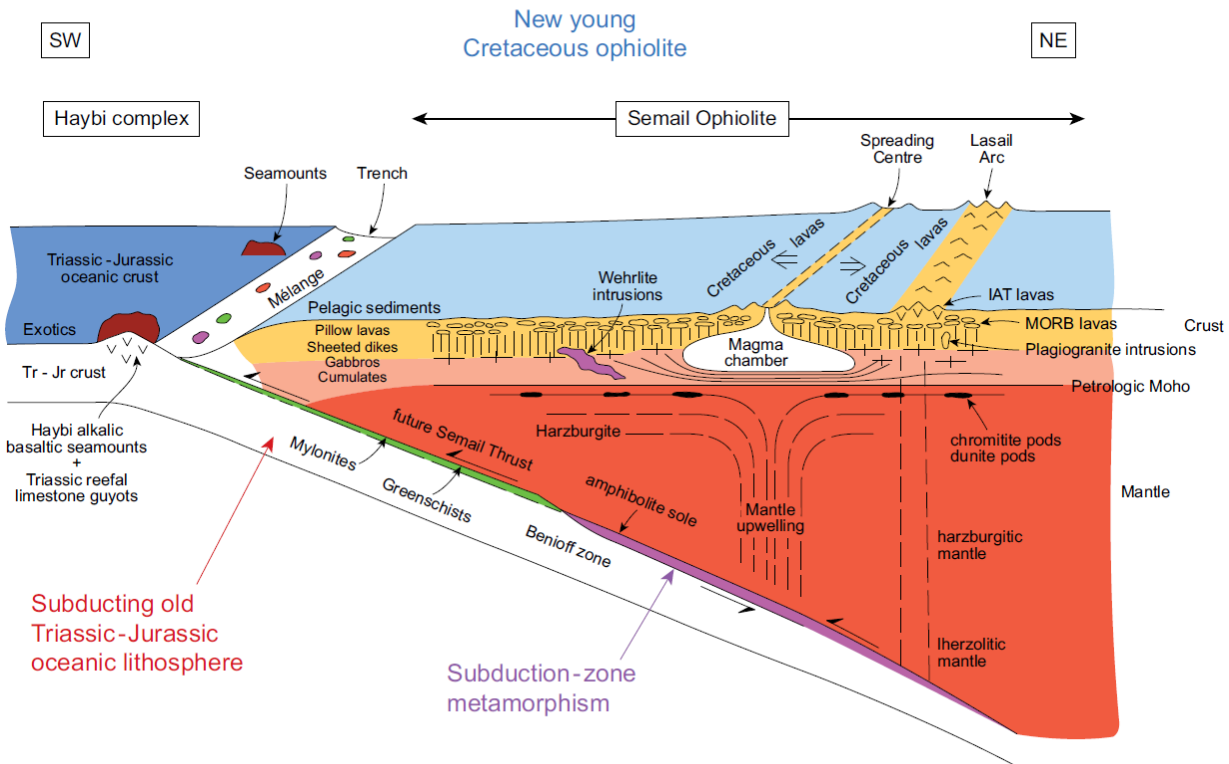


OMAN

IRAN

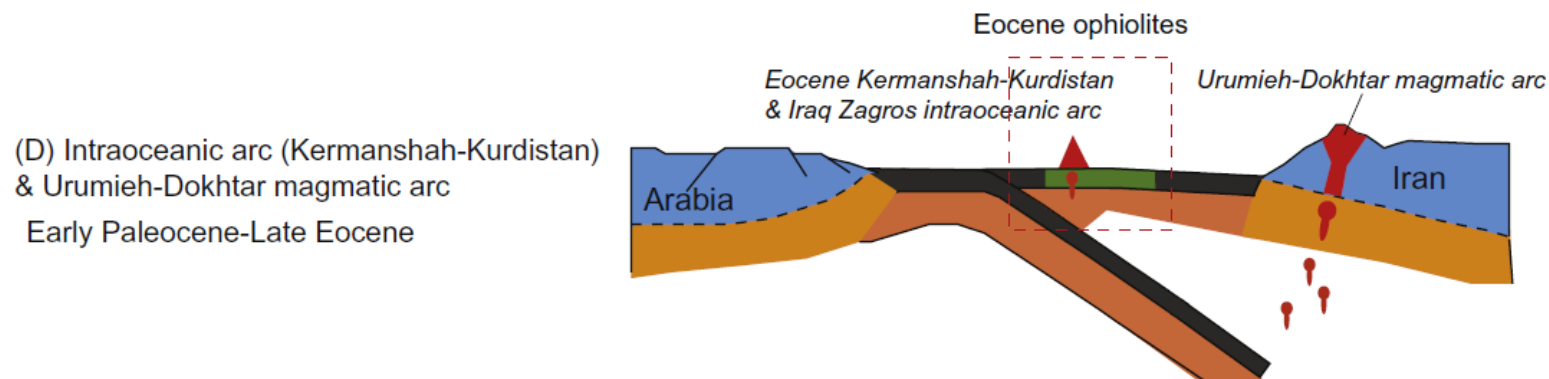
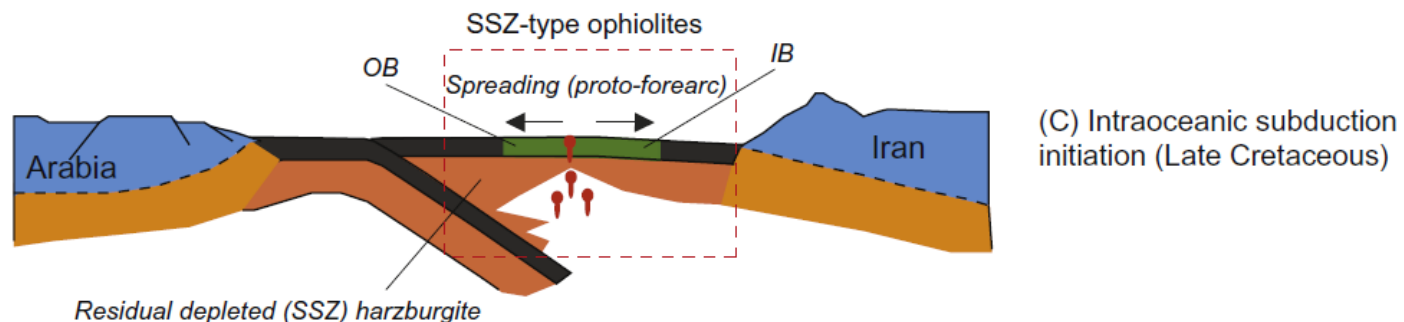
Fig. 6. Schematic diagrams depicting detachment and initial emplacement of the Samail ophiolite. (a) Beginning of detachment in Cenomanian time where crust is thin and upper mantle is still hot near active spreading along a Tethyan ridge crest. Detachment is initiated by closure of Tethyan ocean as Africa (Arabia) moves northward. (b) continued closure of the Tethyan ocean exposes oceanic crust to extensive erosion above sea level. Continental margin along Oman is depressed, and some oceanic and continental material is underthrust. Some gravity sliding of the pelagic sediments accompanies the emplacement of the Samail ophiolite nappe. Final configuration of the Samail ophiolite in relationship to the Gulf of Oman and present-day northward subduction under the Makran coastline is shown in Figure 5. Patterns used in the diagrams are the same as those explained in Figures 3 and 5.

Origin and Emplacement of Ophiolite: Supra-Subduction zone model



## 个人思考2:

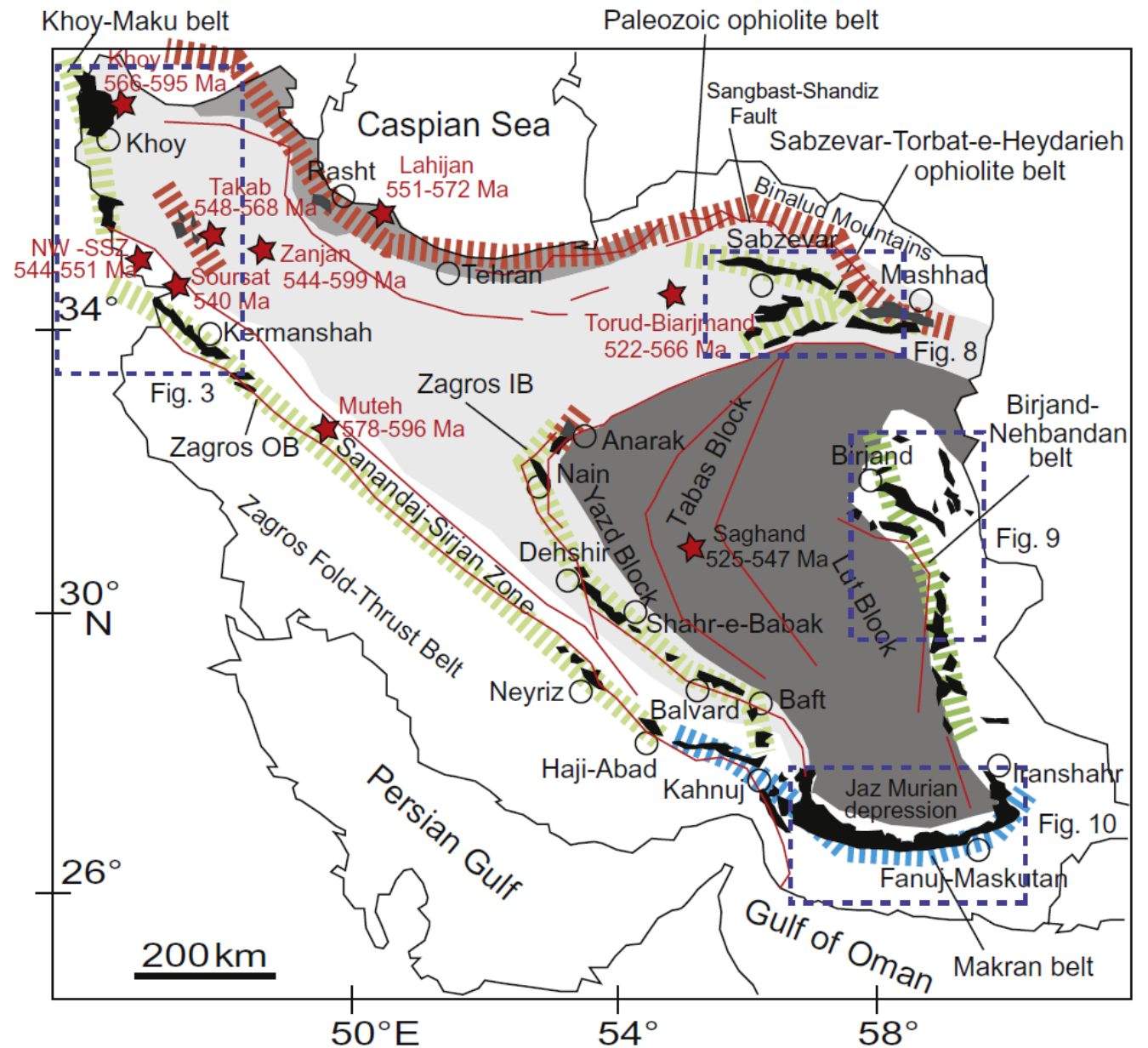
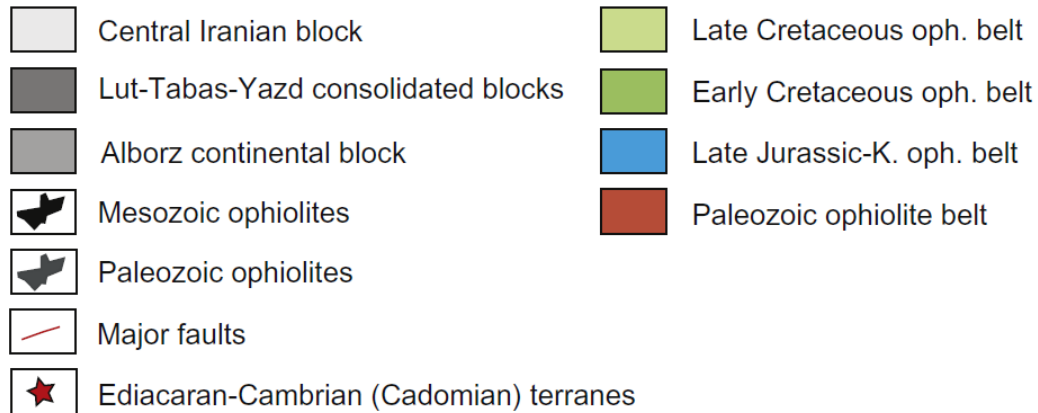
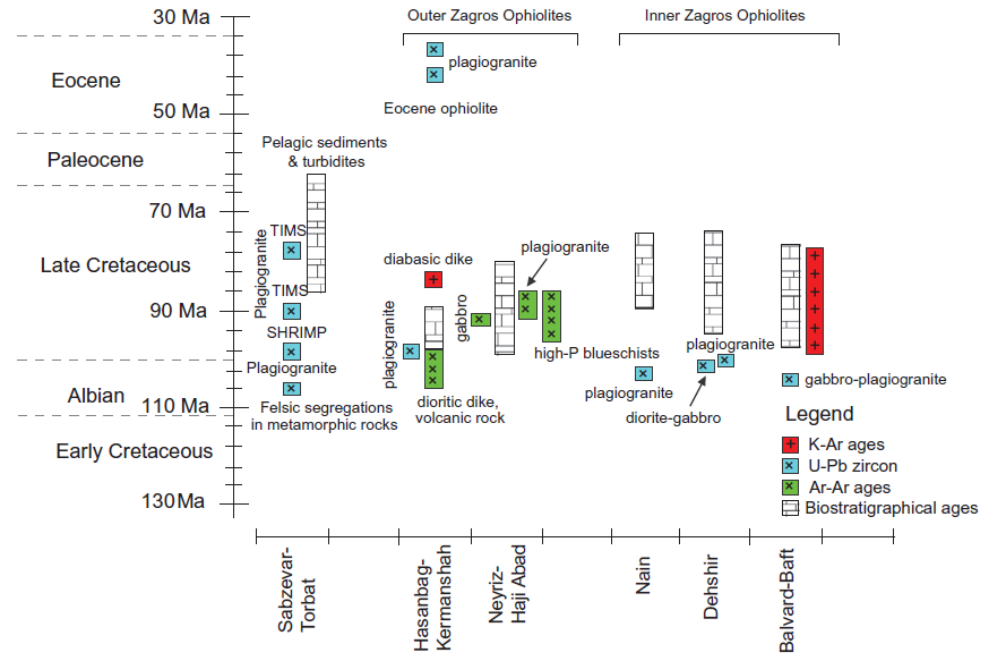
- 伊朗南侧大陆边缘的性质如何？在蛇绿岩仰冲事件前后，是否存在大洋俯冲？
- 蛇绿岩仰冲事件后，阿拉伯大陆边缘与伊朗大陆边缘之间是如何演化的？是否存在残留的洋壳？



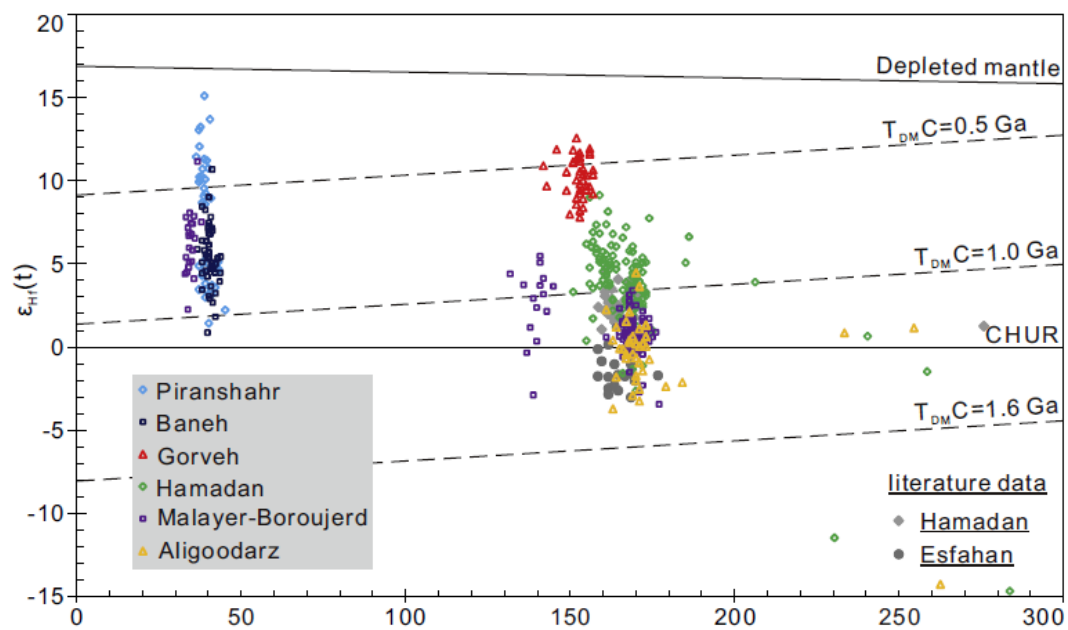
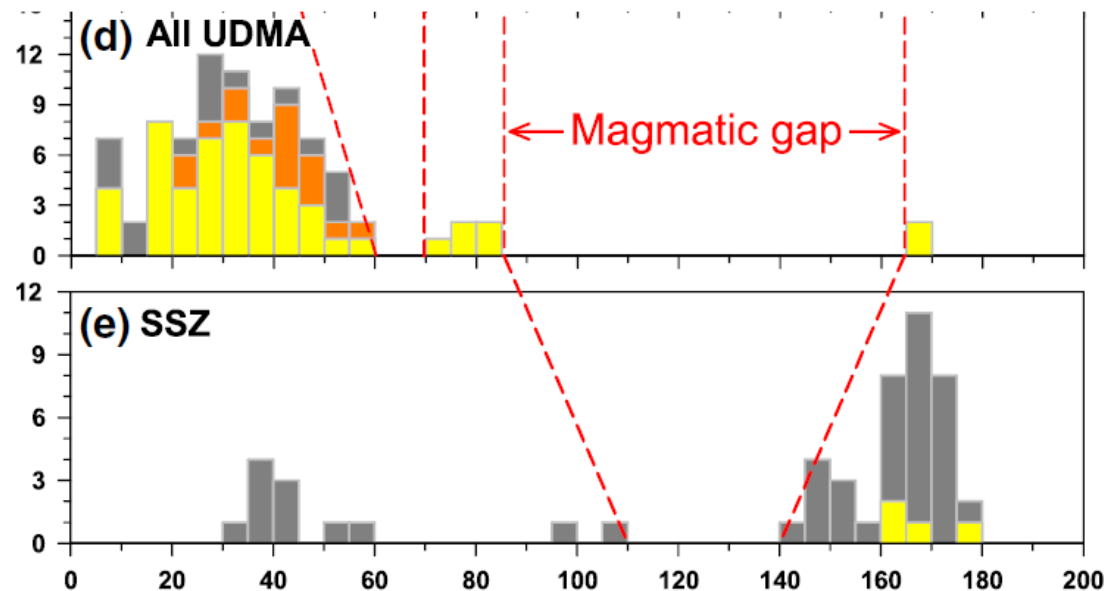
Moghadam, H. S. and R. J. Stern (2015).  
Journal of Asian Earth Sciences **100**: 31-59



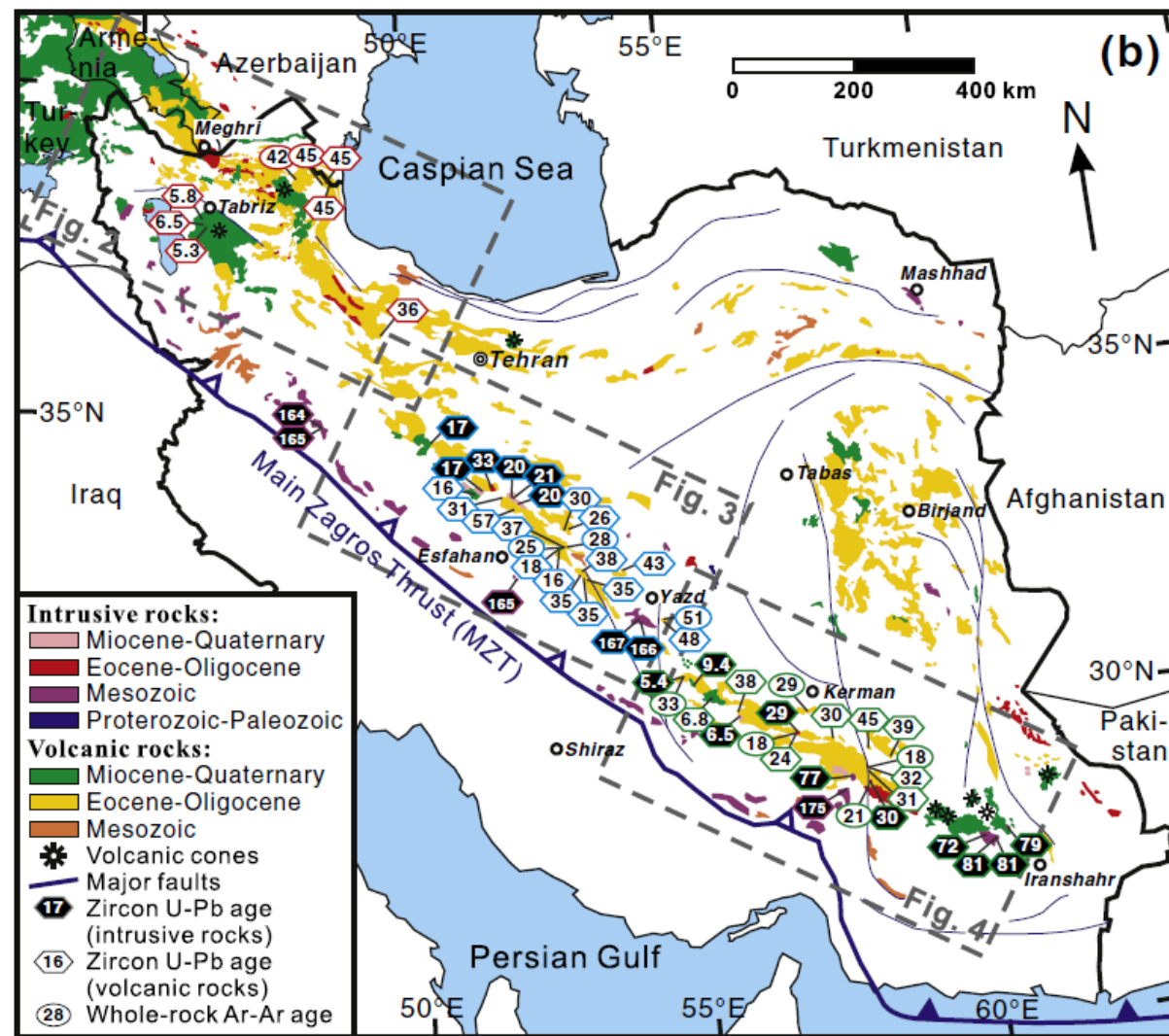
A) Mesozoic Sabzevar, Outer and Inner Belts Zagros Ophiolites



Moghadam, H. S. and R. J. Stern (2015).  
 Journal of Asian Earth Sciences **100**: 31-59



intrusive rocks from the SSZ, Iran.



Chiu, H.-Y., et al. 2013 *Lithos* **162**: 70-87.

Zhang, Z., et al. 2018 *Gondwana Research* **62**: 227-245.

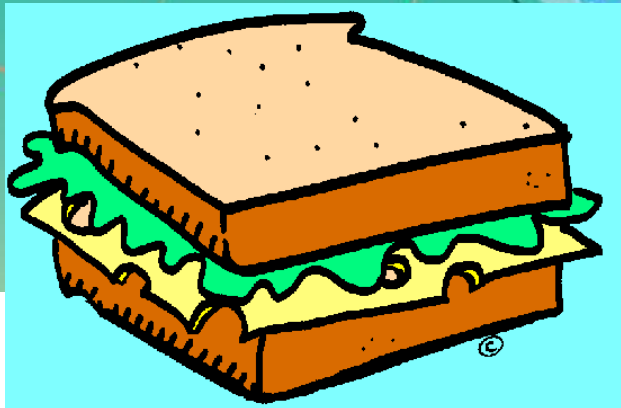
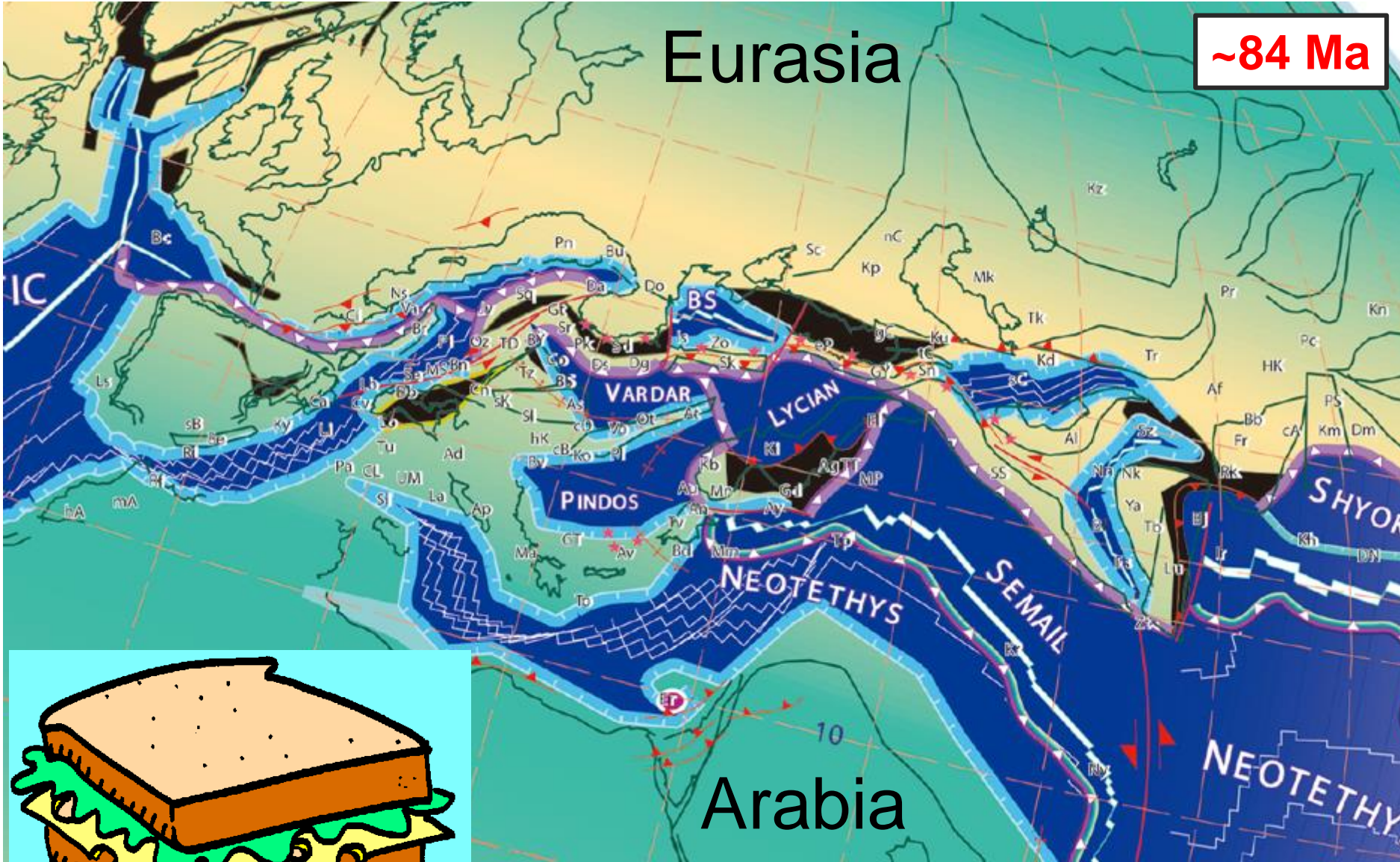


- **Micro-terranes/ribbon-continent:**

Stampfli & Borel (2004)

Eurasia

~84 Ma



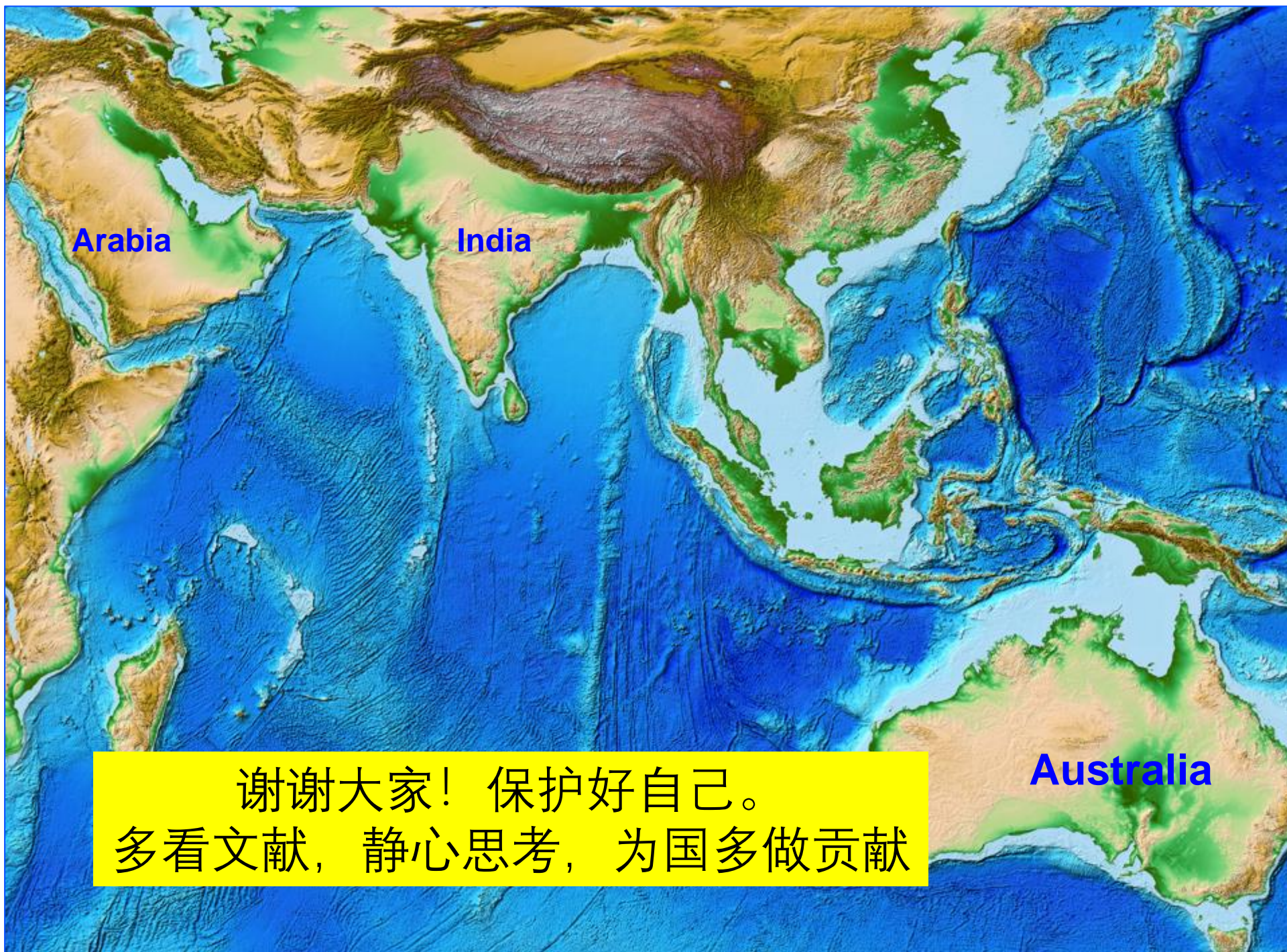
“**Turkic-type**” orogeny = “sandwich” orogeny

钟老师的片子 2018 广州

## 个人思考3:

- 仰冲事件发生白垩纪晚期到始新世，波斯湾地区是如何演化的？从仰冲到大陆碰撞是如何过渡的？
- 如果没有大洋俯冲，类似红海、南中国海的这种小洋盆关闭，如何定义大陆碰撞？





洋壳关闭  
是如何进  
行的？

红海？

南中国海？

谢谢大家！保护好自己。  
多看文献，静心思考，为国多做贡献