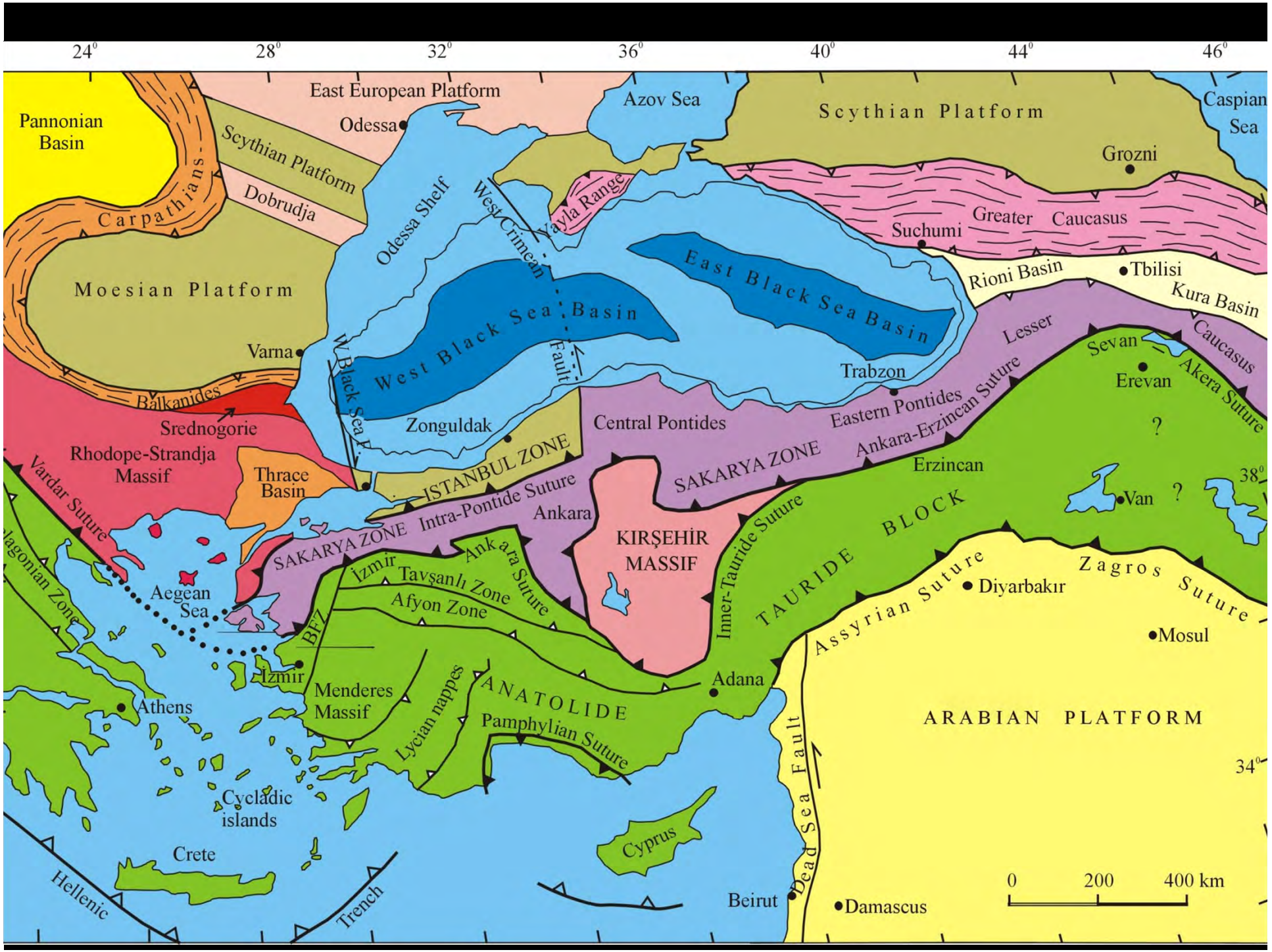
Anatolide-Tauride Block

Aral I. Okay

İstanbul Teknik Üniversitesi


24°
28°
32°
36°
40°
44°
46°
Pannonian Basin
East European Platform
Odessa
Azov Sea
Scythian Platform
Caspian Sea
Grozni
Scythian Platform
Dobrudja
Carpathians
Odessa Shelf
West Crimean
Yayla Range
Greater Caucasus
Suchumi
Moesian Platform
East Black Sea Basin
Rioni Basin
Tbilisi
Kura Basin
West Black Sea Basin
Fault
Lesser Caucasus
Varna
Trabzon
Sevan
Erevan
Akera Suture
Balkanides
W Black Sea F.
Zonguldak
Central Pontides
Eastern Pontides
Ankara-Erzincan Suture
Srednogorie
Rhodope-Strandja Massif
Thrace Basin
ISTANBUL ZONE
SAKARYA ZONE
Erzincan
Vardar Suture
Intra-Pontide Suture
Ankara
38°
Van
Aegean Sea
SAKARYA ZONE
İzmir
Tavşanlı Zone
Ankara Suture
KIRŞEHİR MASSIF
Inner-Tauride Suture
TAURIDE BLOCK
Zagros Suture
Assyrian Suture
Diyarbakır
Afyon Zone
BFZ
Mosul
İzmir
Menderes Massif
Lycian nappes
ANATOLIDE
Adana
Athens
Pamphylian Suture
ARABIAN PLATFORM
Cycladic islands
Dead Sea Fault
34°
Cyprus
Crete
Hellenic Trench
Beirut
Damascus
0
200
400 km

Anatolide-Tauride Block - platform and passive continental margin

Pontides – active continental margin

Distinguishing features of the Anatolide-Tauride Block

Late Precambrian crystalline basement

Paleozoic-Tertiary sedimentary cover

- Paleozoic - clastics and carbonates
- Mesozoic - carbonates

Volkanic rocks very rare

No evidence for Hercynian (Carboniferous) and Cimmerian (Triassic) orogenies

Alpide deformation and metamorphism start in the Late Cretaceous and continue into the Miocene.

Anatolide-Tauride Block is subdivided into zones based on the type of metamorphism and age of deformation:

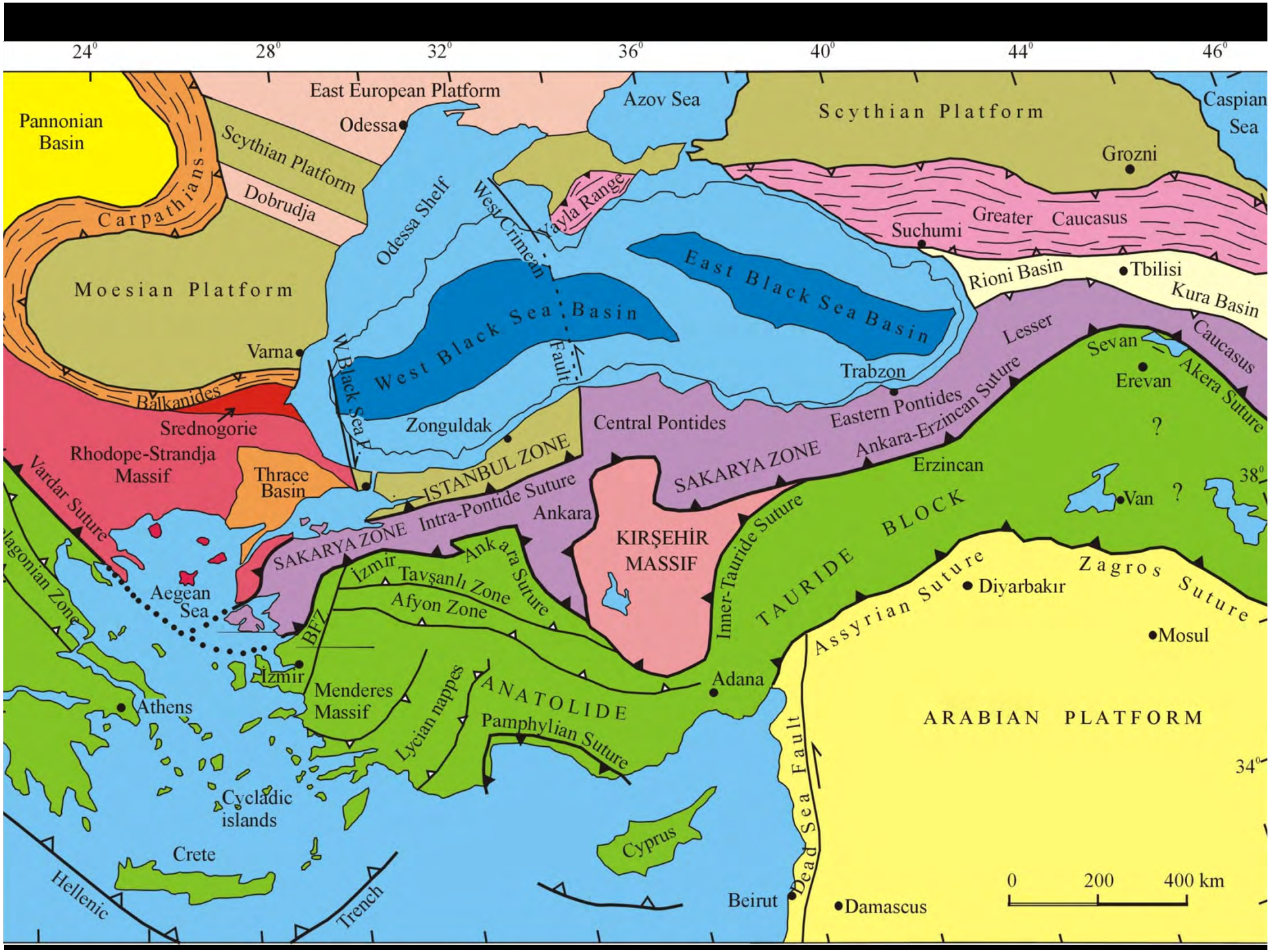
Tavşanlı Zone: high pressure metamorphism during the Late Cretaceous

Afyon Zone: high pressure metamorphism at the Cretaceous-Tertiary boundary

Menderes Massif: medium pressure metamorphism during the Eocene

Bornova Flysch Zone: a belt of melange and olistostromes

Taurides: Paleozoic-Tertiary sedimentary sequences deformed during the Late Cretaceous – Tertiary.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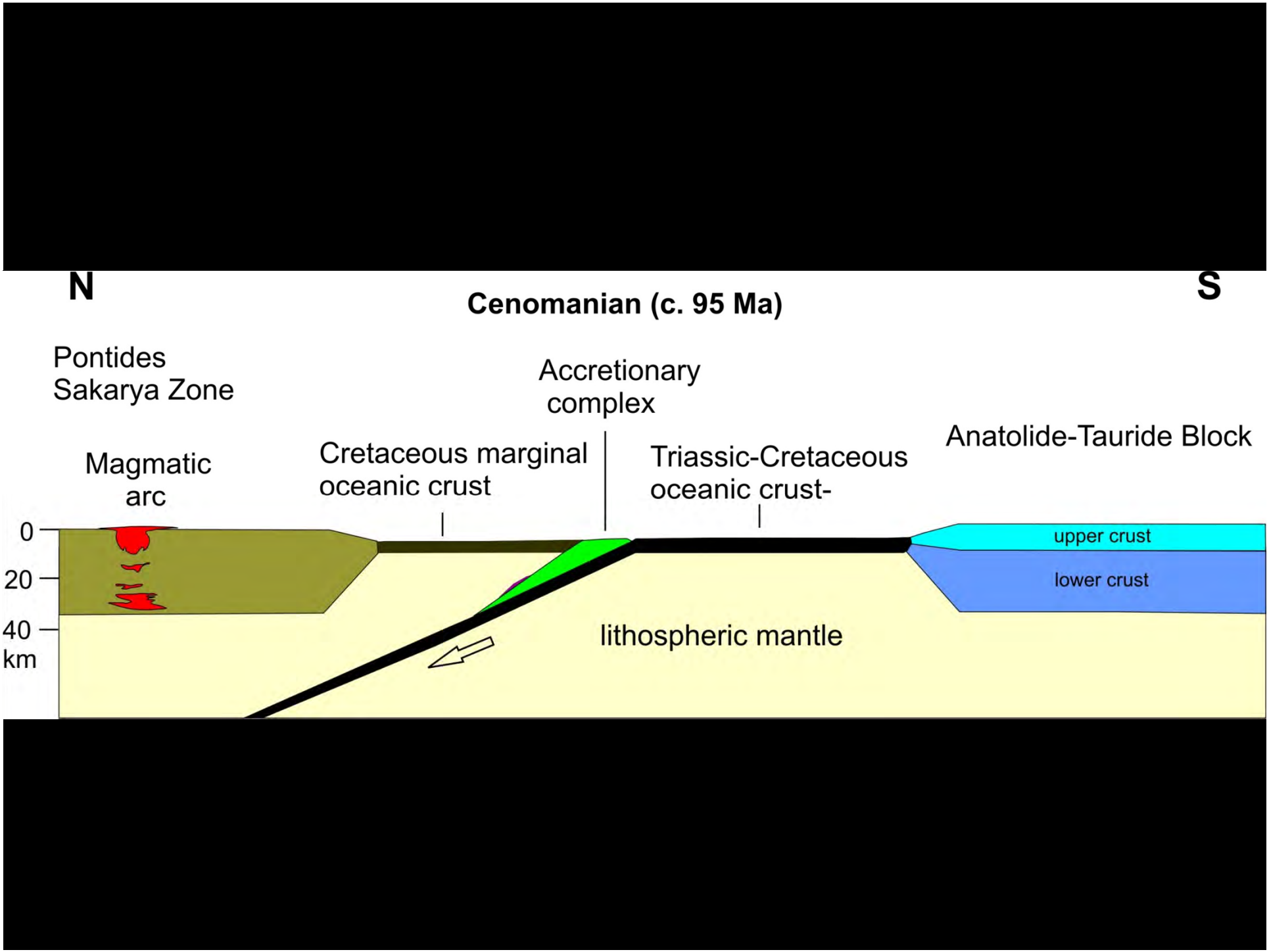
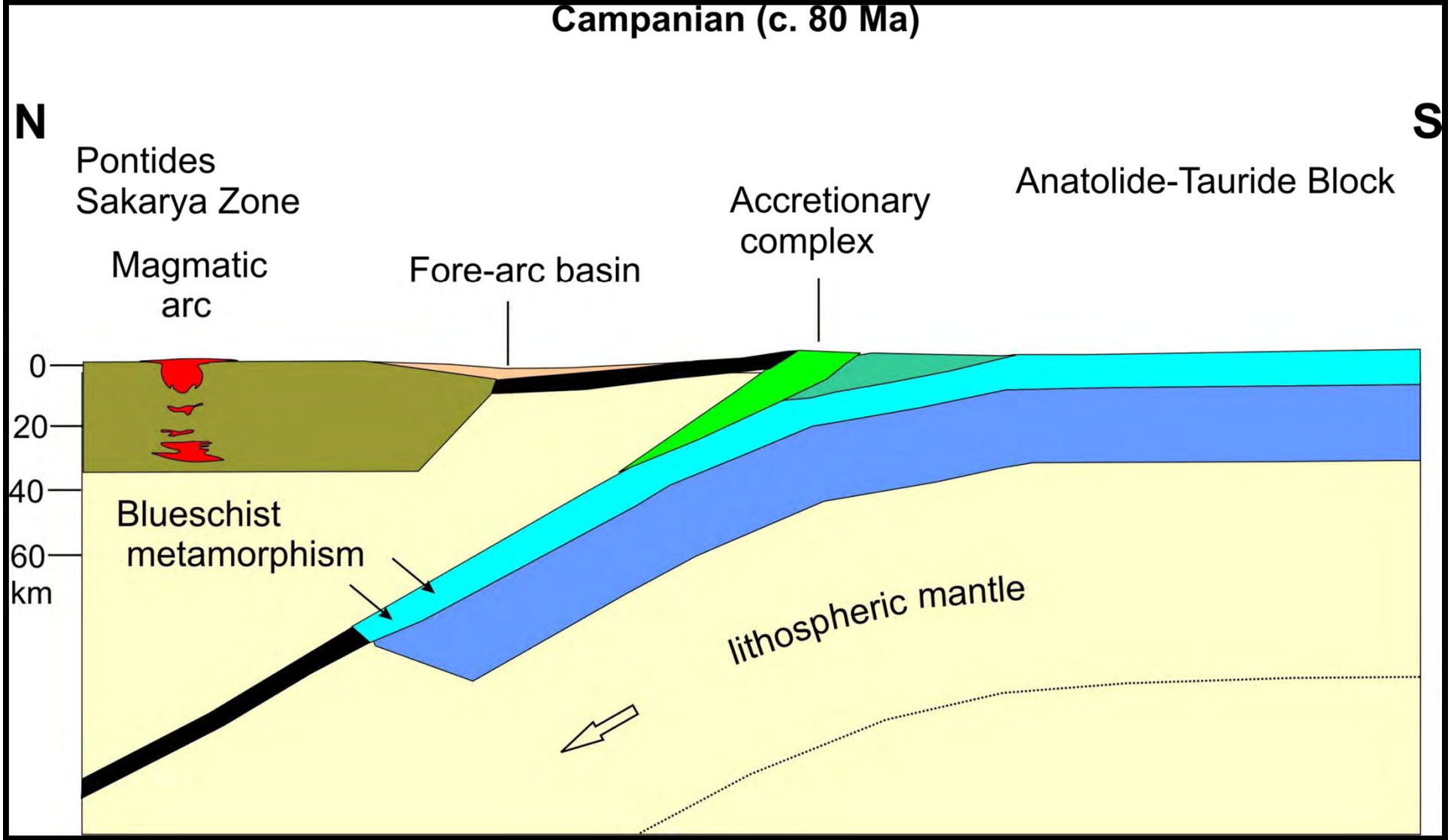
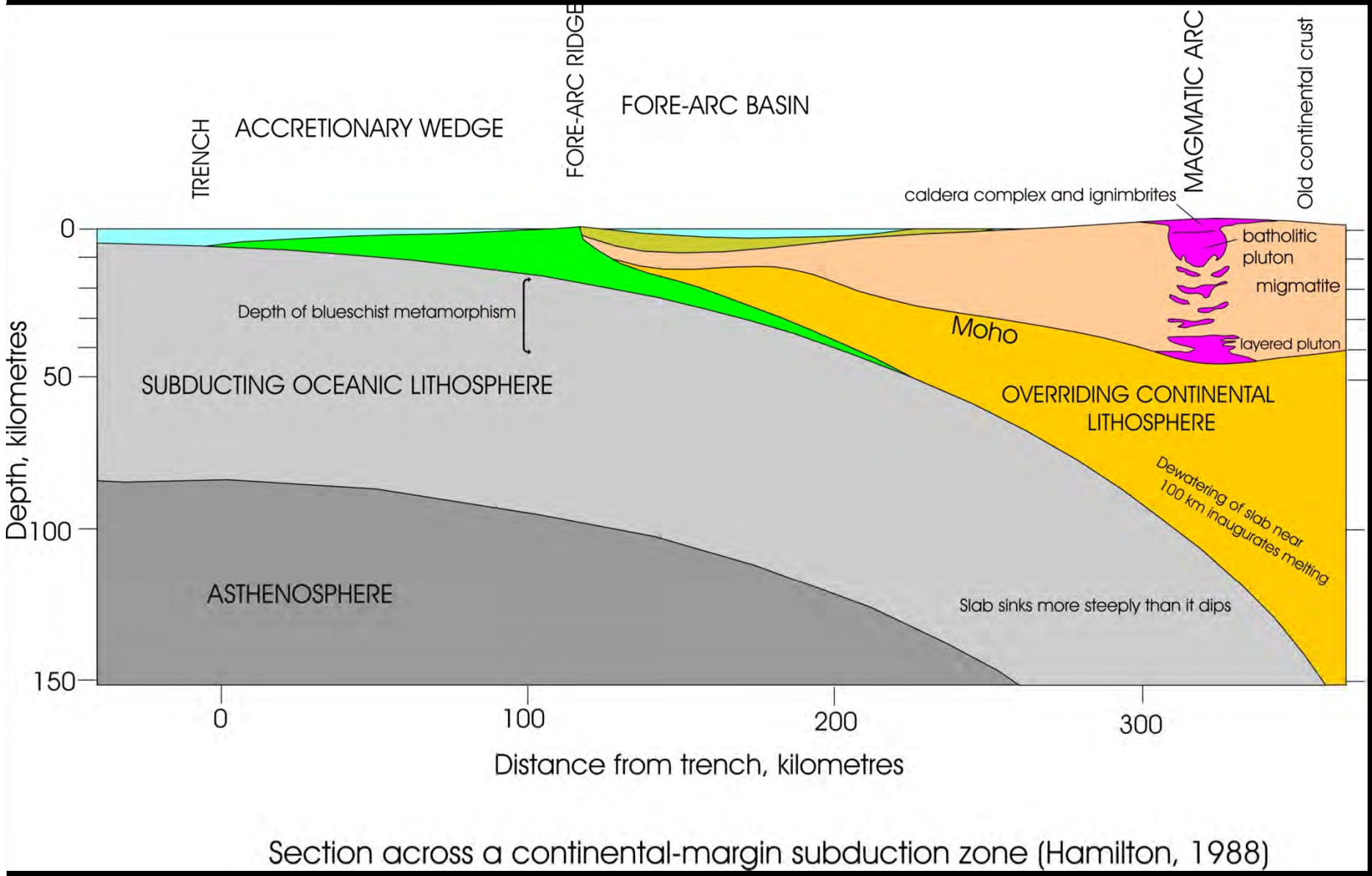
Crete
Hellenic Trench
Beirut
Damascus
0
200
400 km

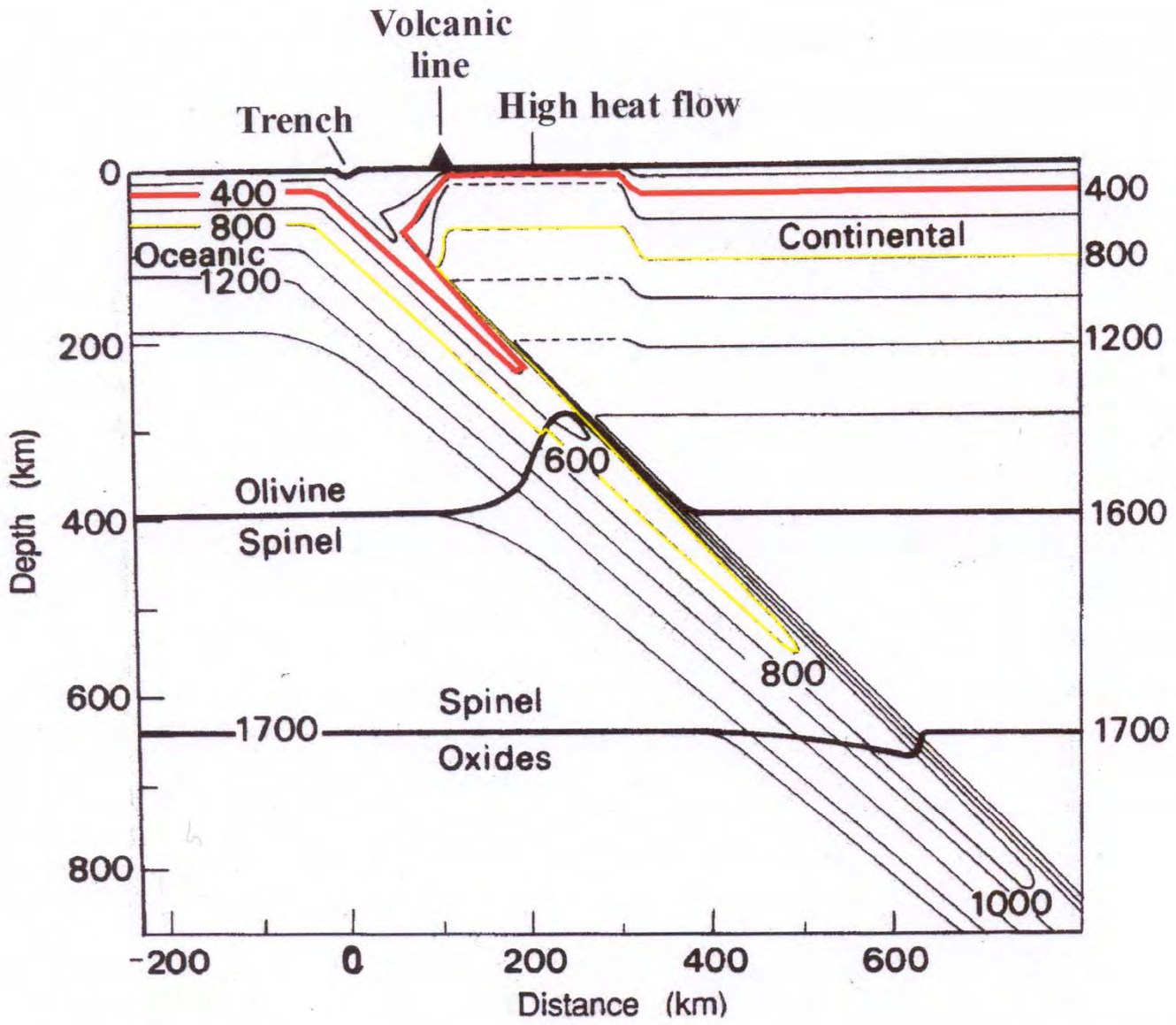
Tavşanlı Zone
The deeply subducted northern margin of the Anatolide-Tauride Block


N
S
Cenomanian (c. 95 Ma)
Pontides
Sakarya Zone
Accretionary
complex
Anatolide-Tauride Block
Magmatic
arc
Cretaceous marginal
oceanic crust
Triassic-Cretaceous
oceanic crust-
0
20
40
km
upper crust
lower crust
lithospheric mantle

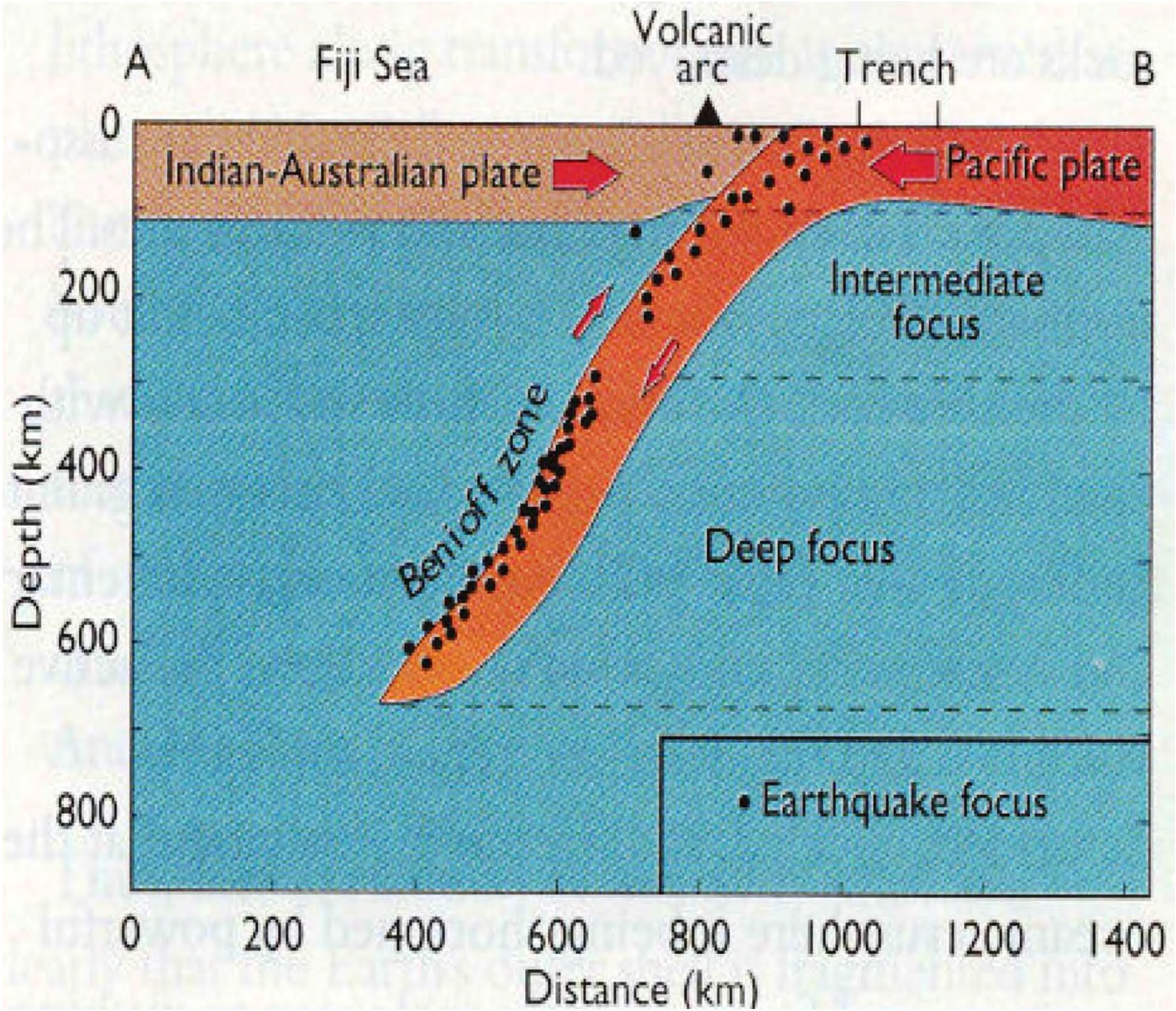

Campanian (c. 80 Ma)
N
S
Pontides
Sakarya Zone
Anatolide-Tauride Block
Accretionary
complex
Magmatic
arc
Fore-arc basin
0
20
40
60
km
Blueschist
metamorphism
lithospheric mantle

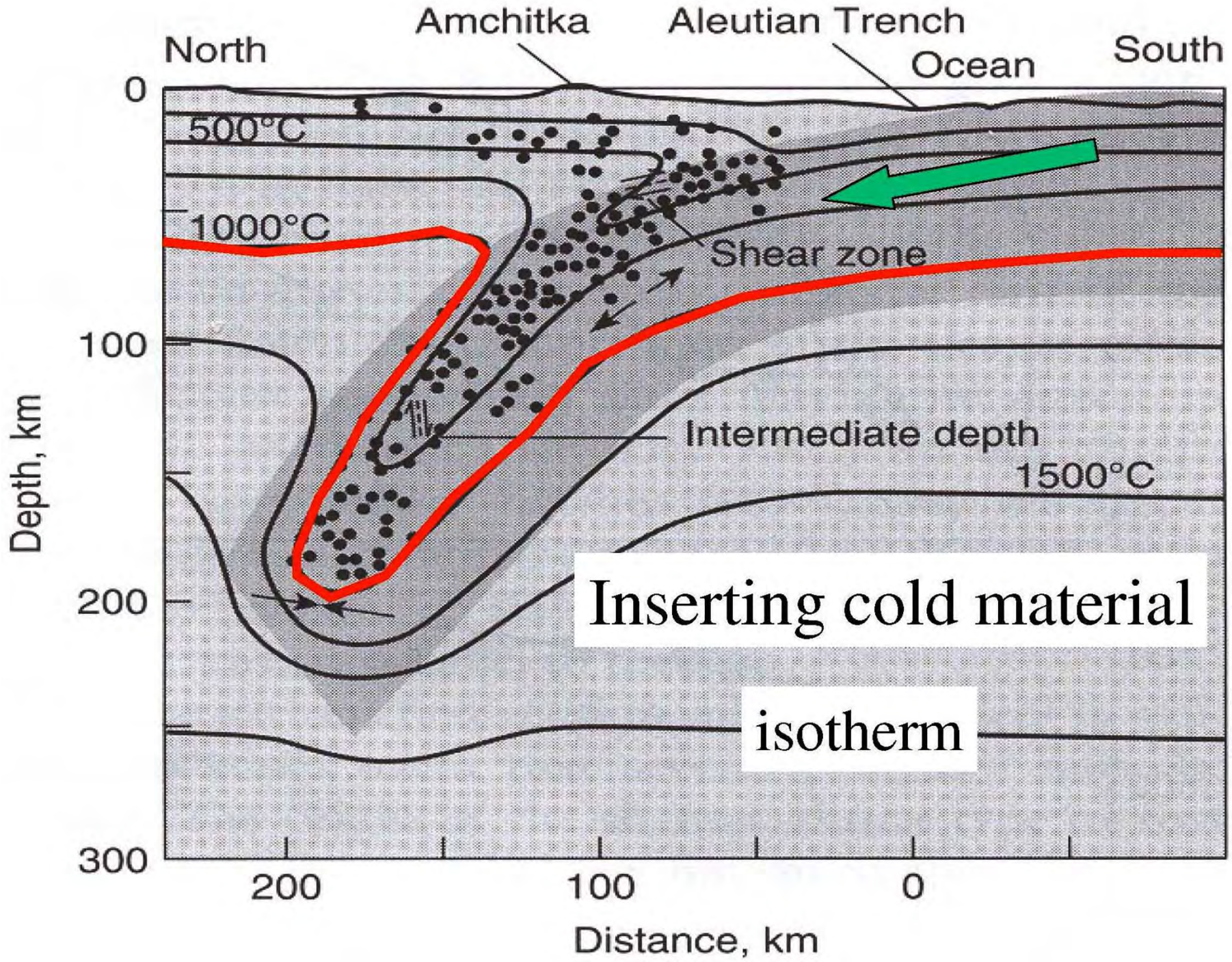


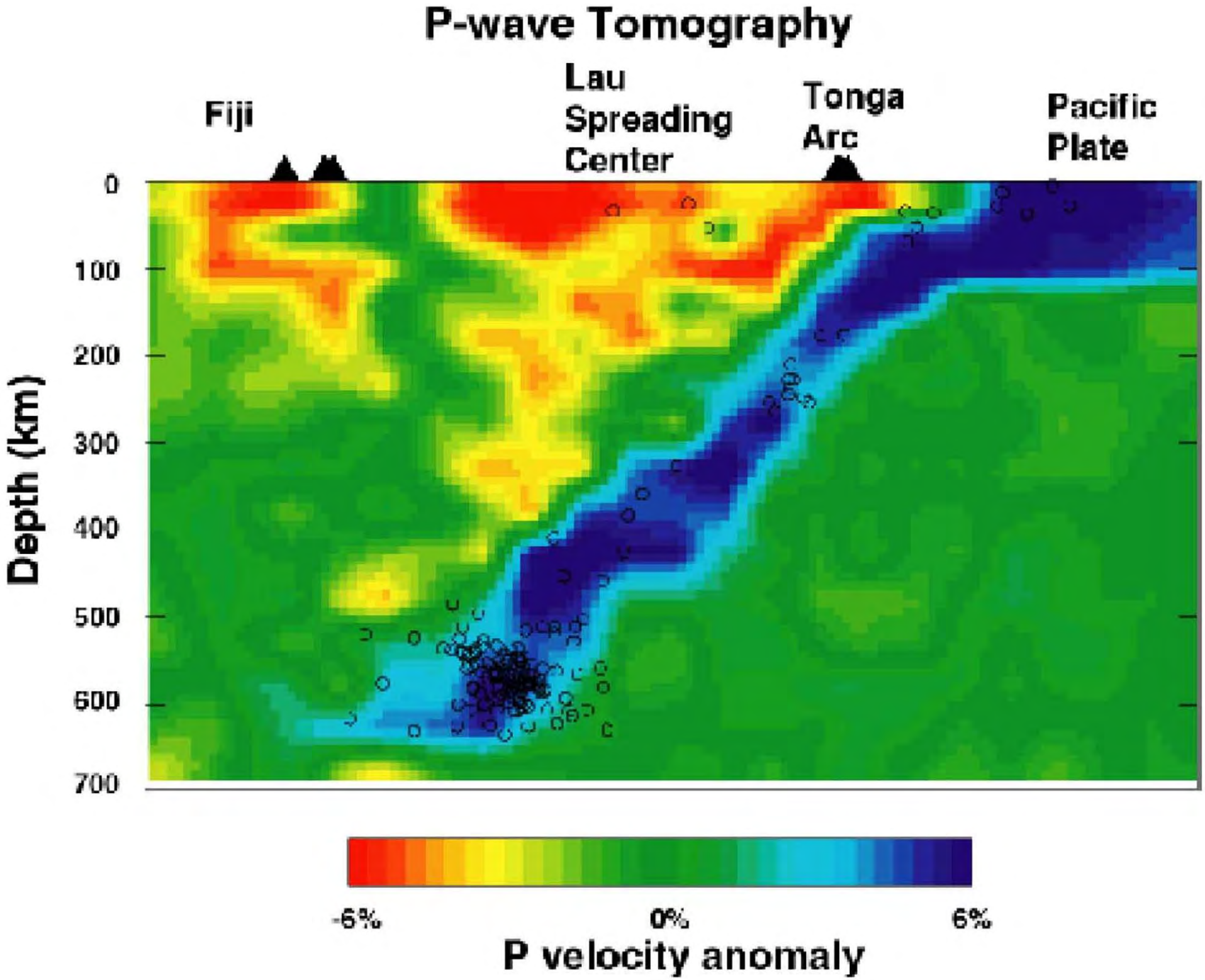
Section across a continental-margin subduction zone (Hamilton, 1988)

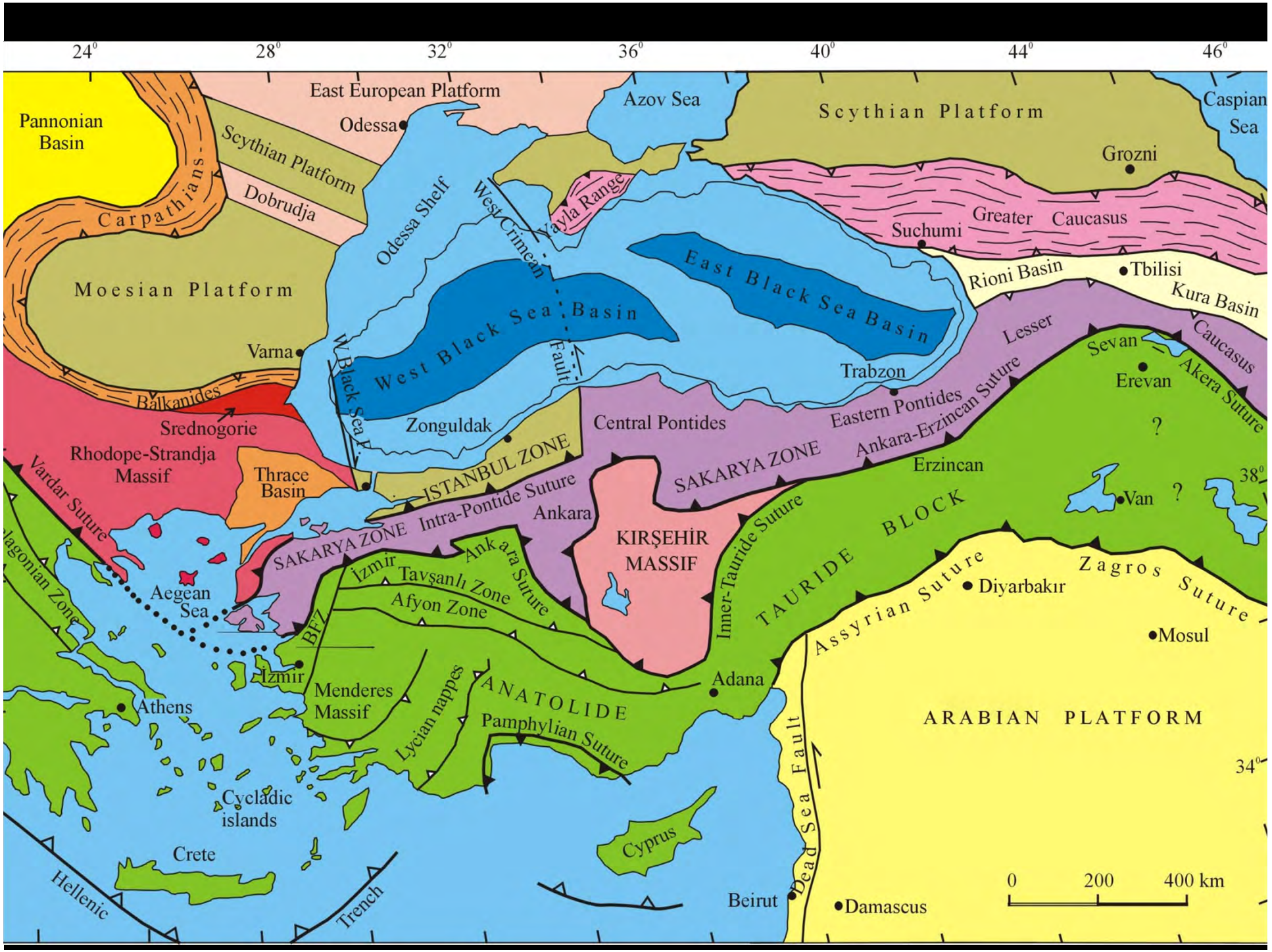


Thermal structure of a subducting oceanic lithosphere (Schubert et al., 1975). Calculations include the effects of frictional heating (to a max. value of 100 MPa)


A
Fiji Sea
Volcanic arc
Trench
B
0
200
400
600
800
Depth (km)
Indian-Australian plate
Pacific plate
Intermediate focus
Deep focus
Benioff zone
• Earthquake focus
0
200
400
600
800
1000
1200
1400
Distance (km)


North
Amchitka
Aleutian Trench
Ocean
South
0
500°C
1000°C
Shear zone
100
Intermediate depth
1500°C
Depth, km
200
Inserting cold material
isotherm
300
200
100
0
Distance, km


P-wave Tomography
Fiji
Lau
Spreading
Center
Tonga
Arc
Pacific
Plate
Depth (km)
0
100
200
300
400
500
600
700
-6%
0%
6%
P velocity anomaly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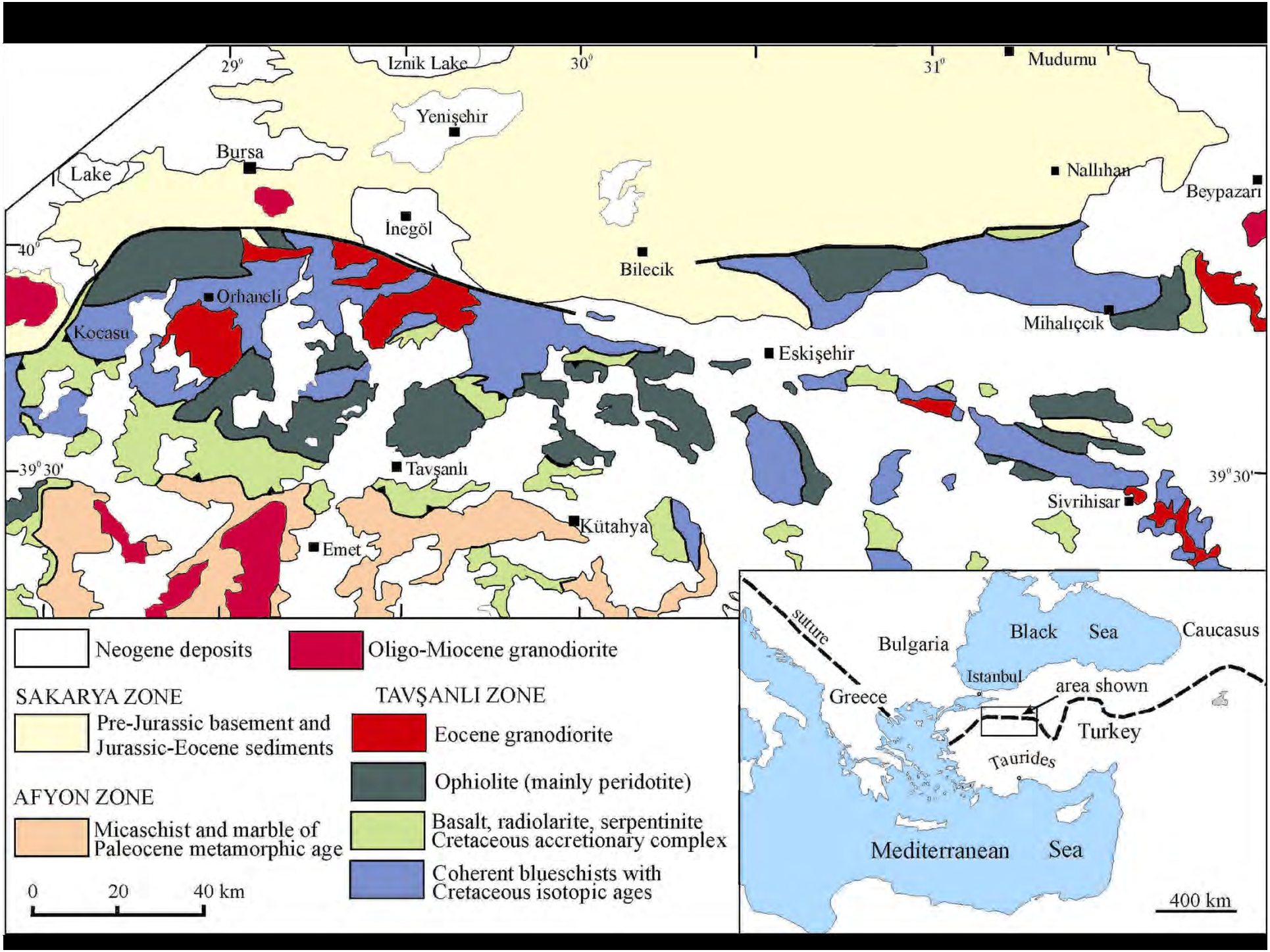
0
200
400 km


29°
Iznik Lake
30°
31°
Mudurnu
Yenişehir
Bursa
Lake
Nallıhan
Beypazarı
İnegöl
40°
Bilecik
Orhaneli
Kocasu
Mihalıççık
Eskişehir
39° 30'
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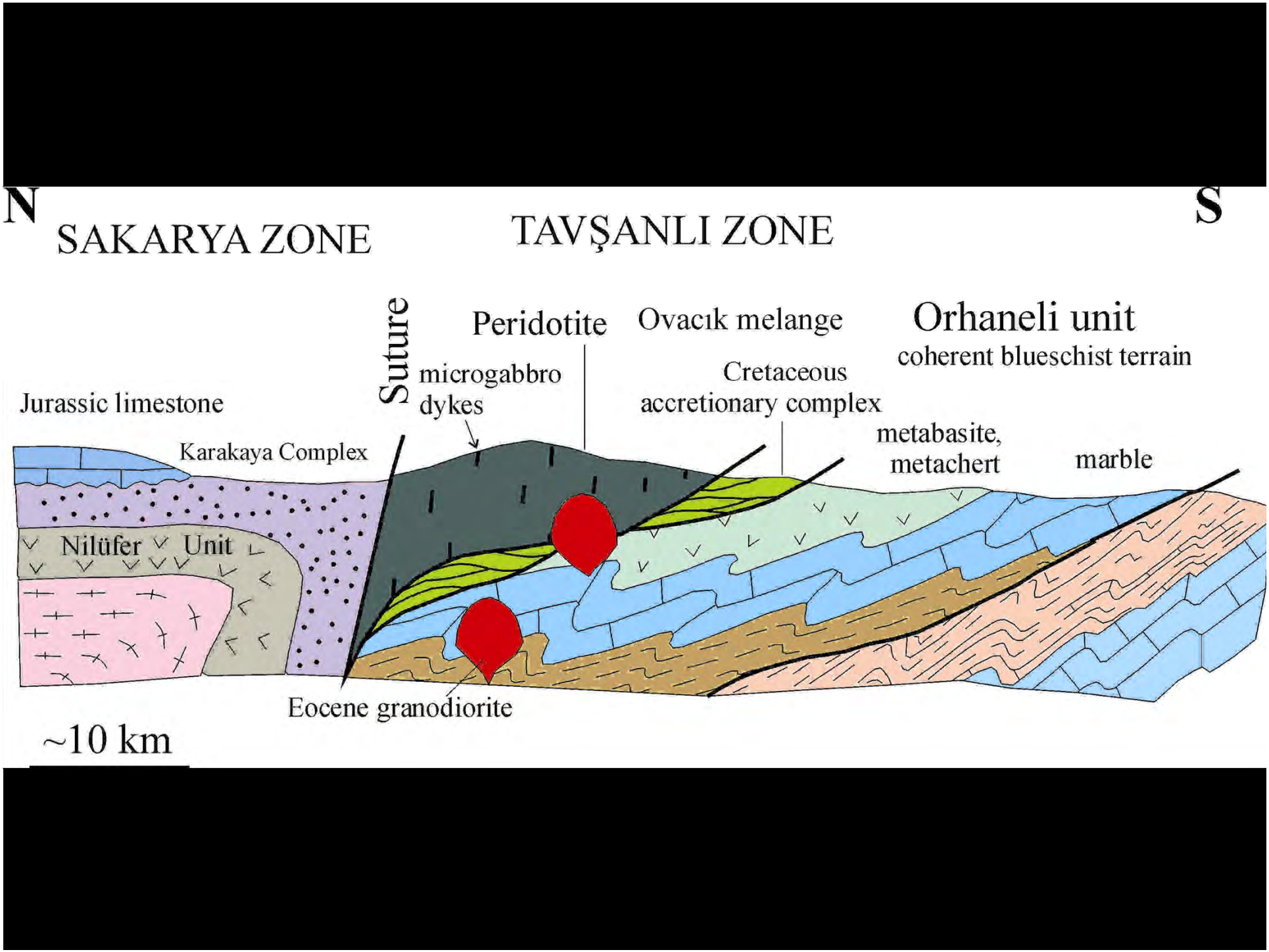
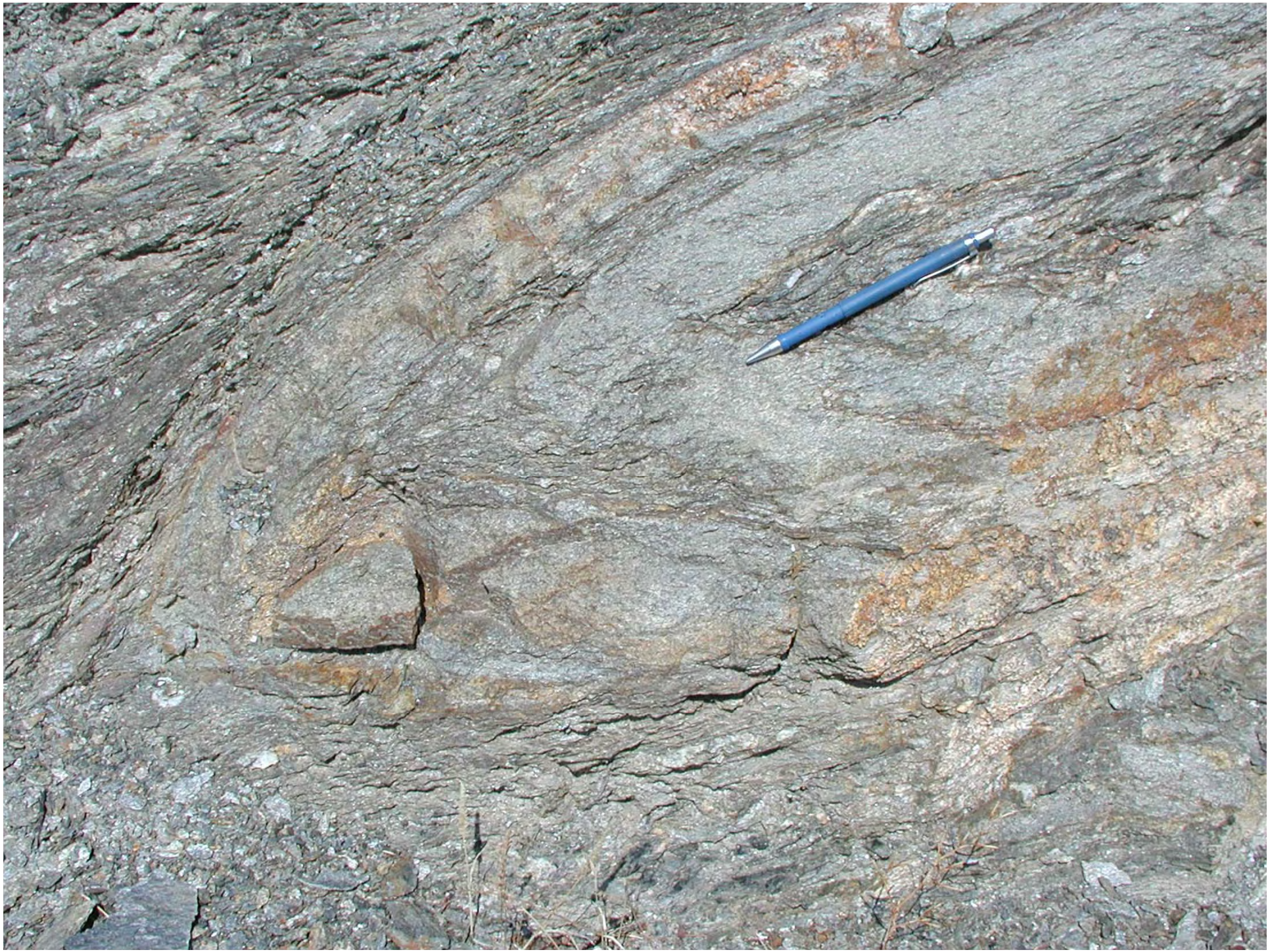
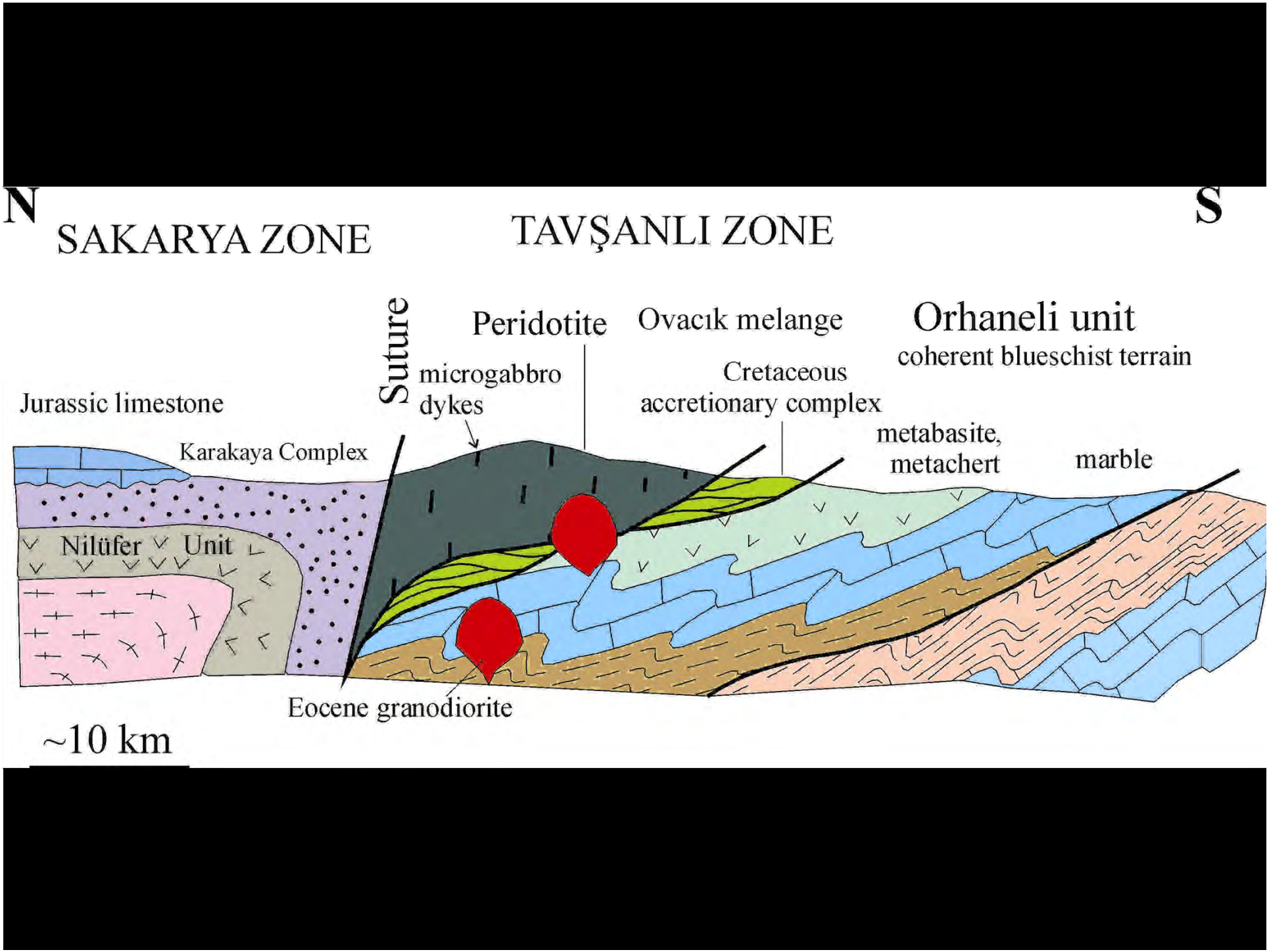
39° 30'
Sivrihisar
Kütahya
Emet
Neogene deposits
Oligo-Miocene granodiorite
SAKARYA ZONE
Pre-Jurassic basement and Jurassic-Eocene sediments
TAVŞANLI ZONE
Eocene granodiorite
Ophiolite (mainly peridotite)
Basalt, radiolarite, serpentinite Cretaceous accretionary complex
Coherent blueschists with Cretaceous isotopic ages
AFYON ZONE
Micaschist and marble of Paleocene metamorphic age
0
20
40 km
suture
Bulgaria
Black Sea
Caucasus
Istanbul
area shown
Greece
Turkey
Taurides
Mediterranean Sea
400 km


N
SAKARYA ZONE
TAVŞANLI ZONE
S
Suture
Peridotite
Ovacık melange
Orhaneli unit
coherent blueschist terrain
microgabbro
dykes
Cretaceous
accretionary complex
Jurassic limestone
Karakaya Complex
metabasite,
metachert
marble
Nilüfer Unit
Eocene granodiorite
~10 km

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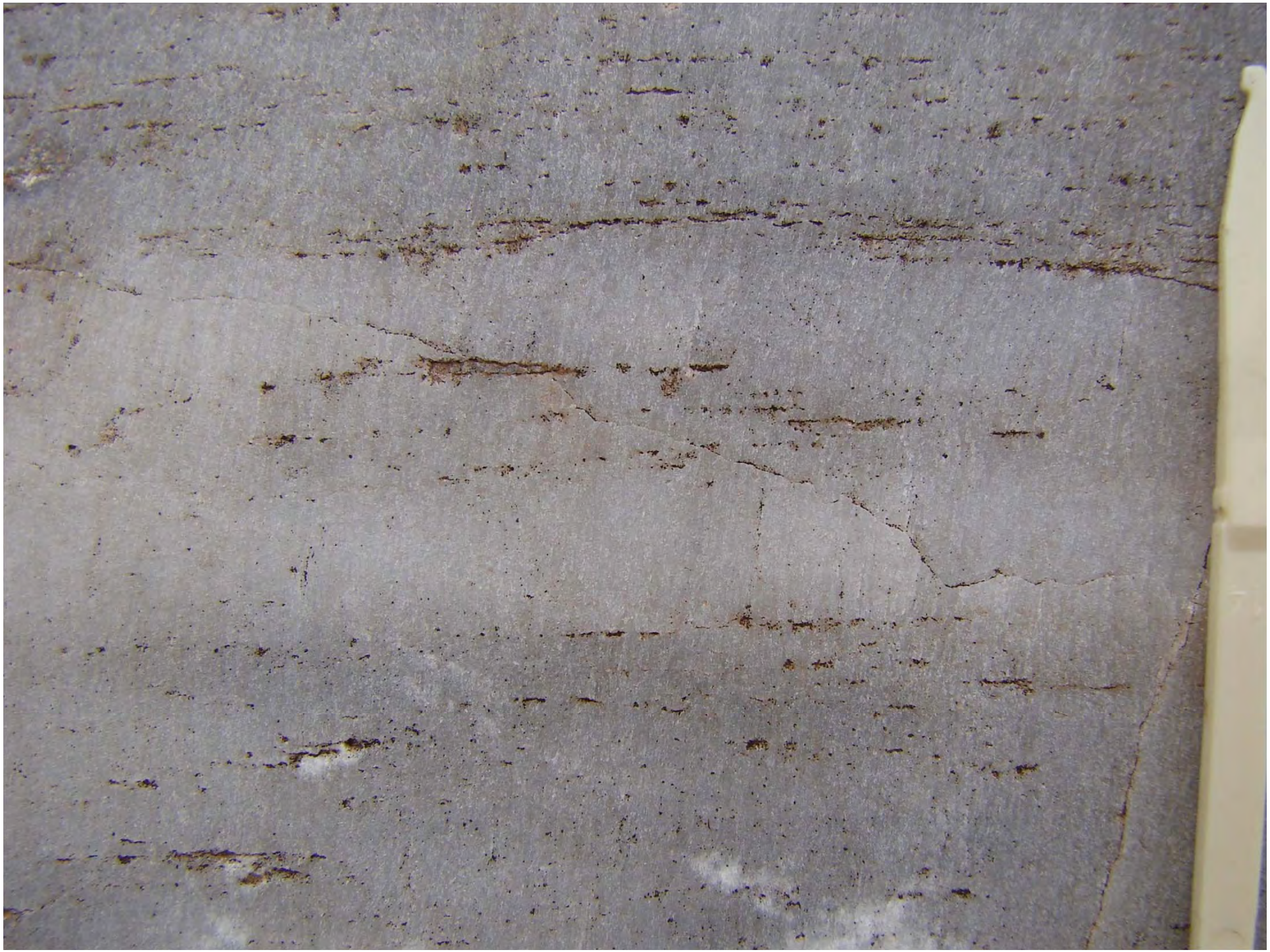

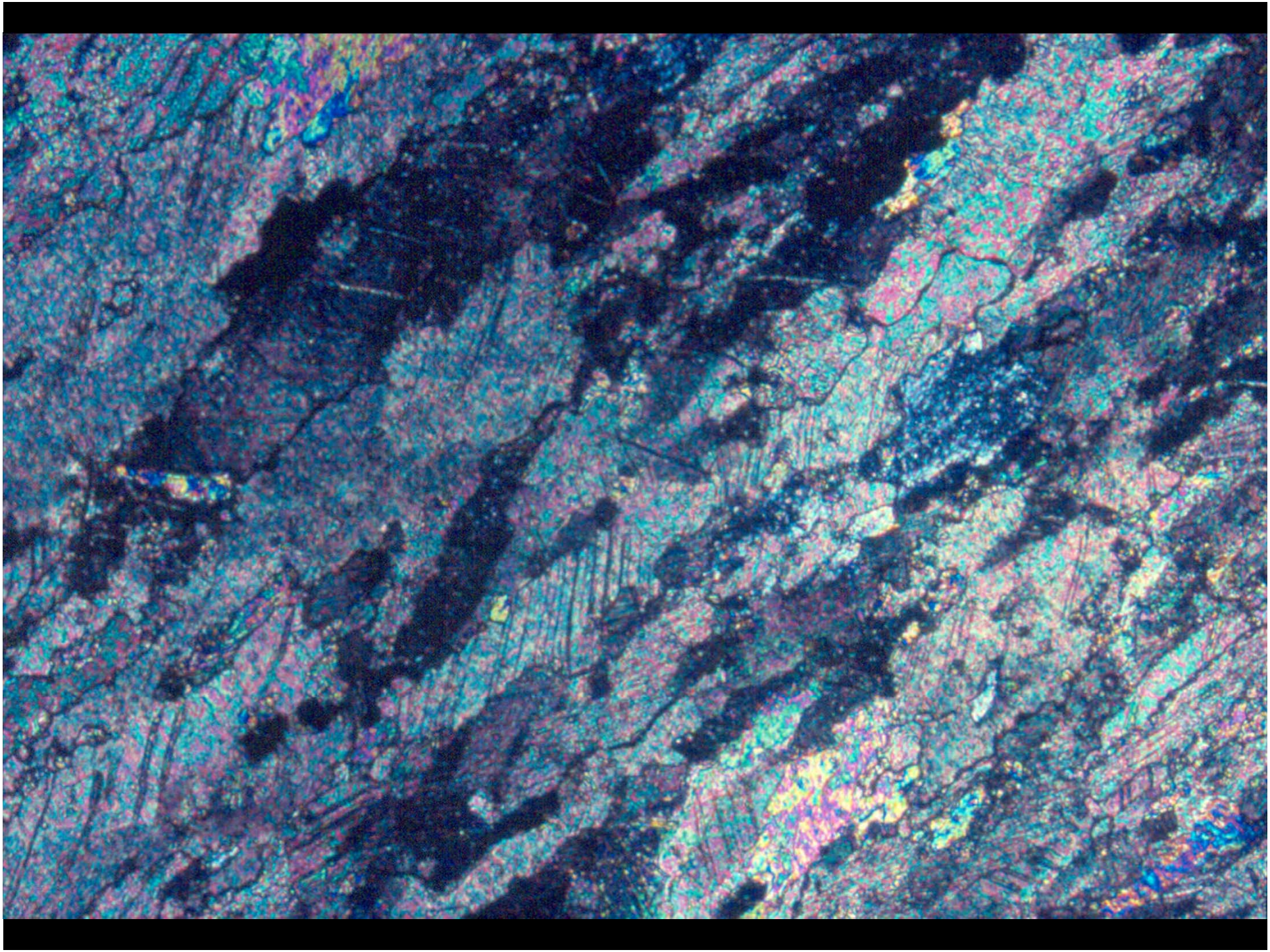

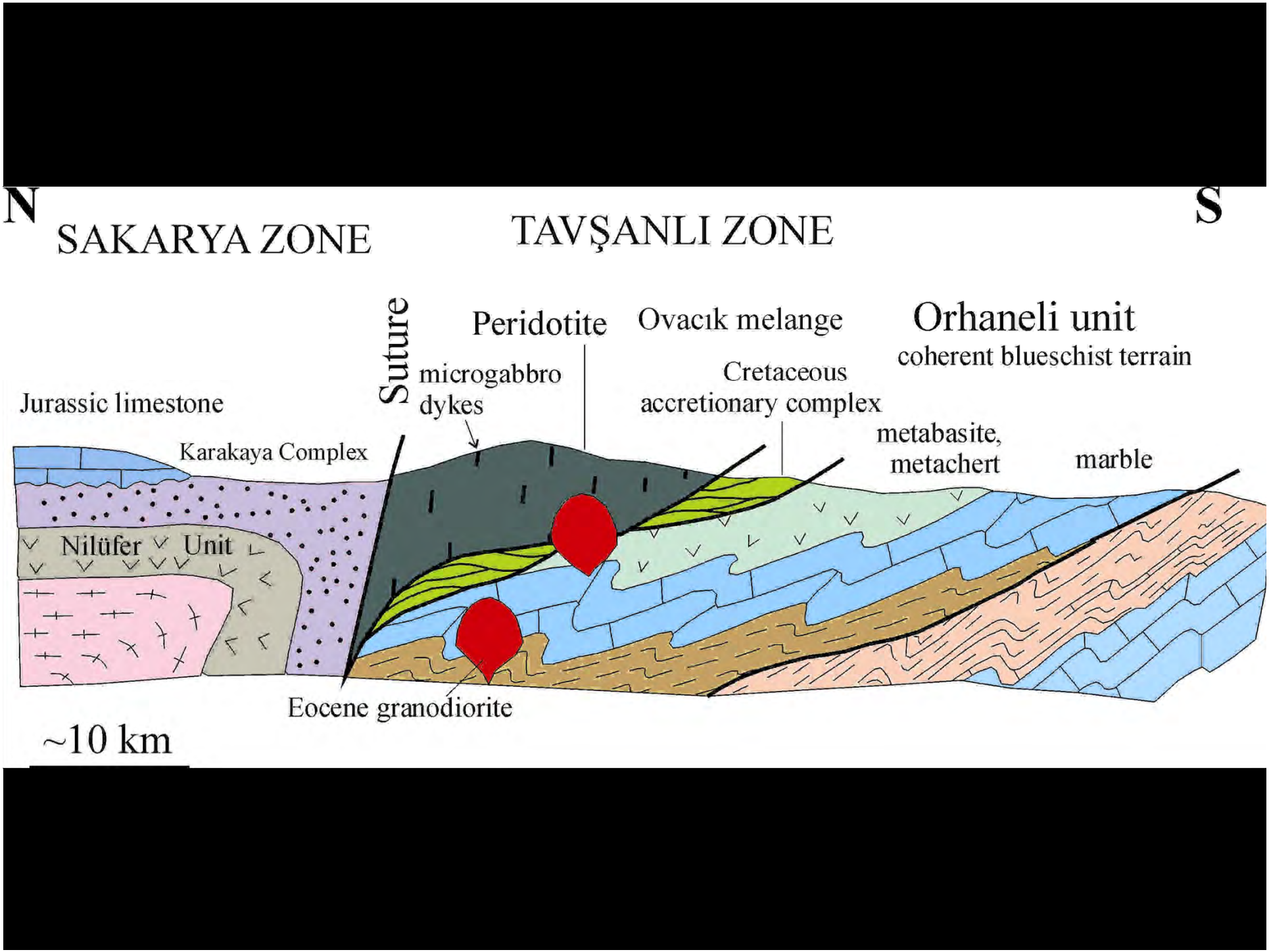
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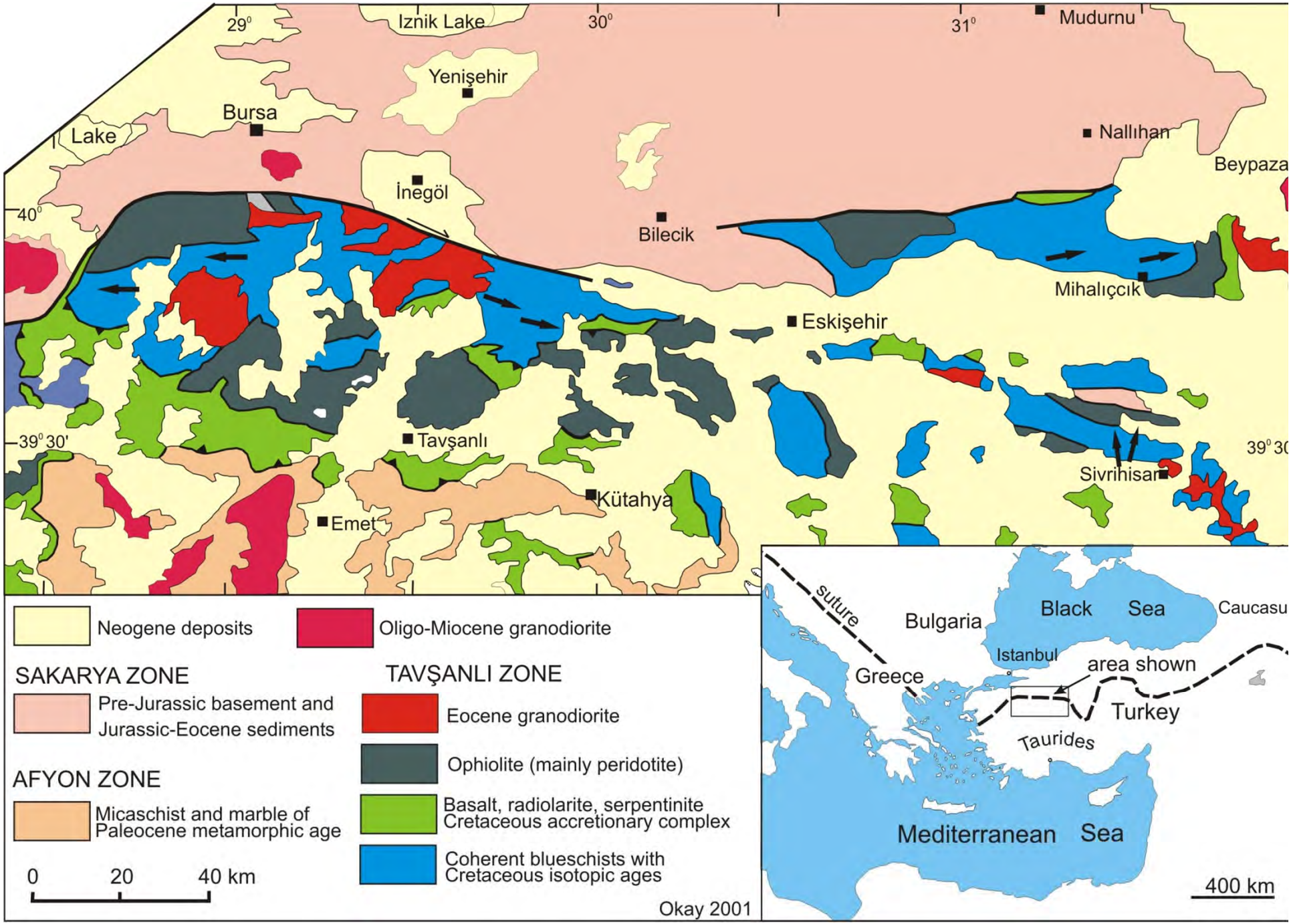
Structural features of the coherent blueschist sequence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Caucasu
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area shown
Greece
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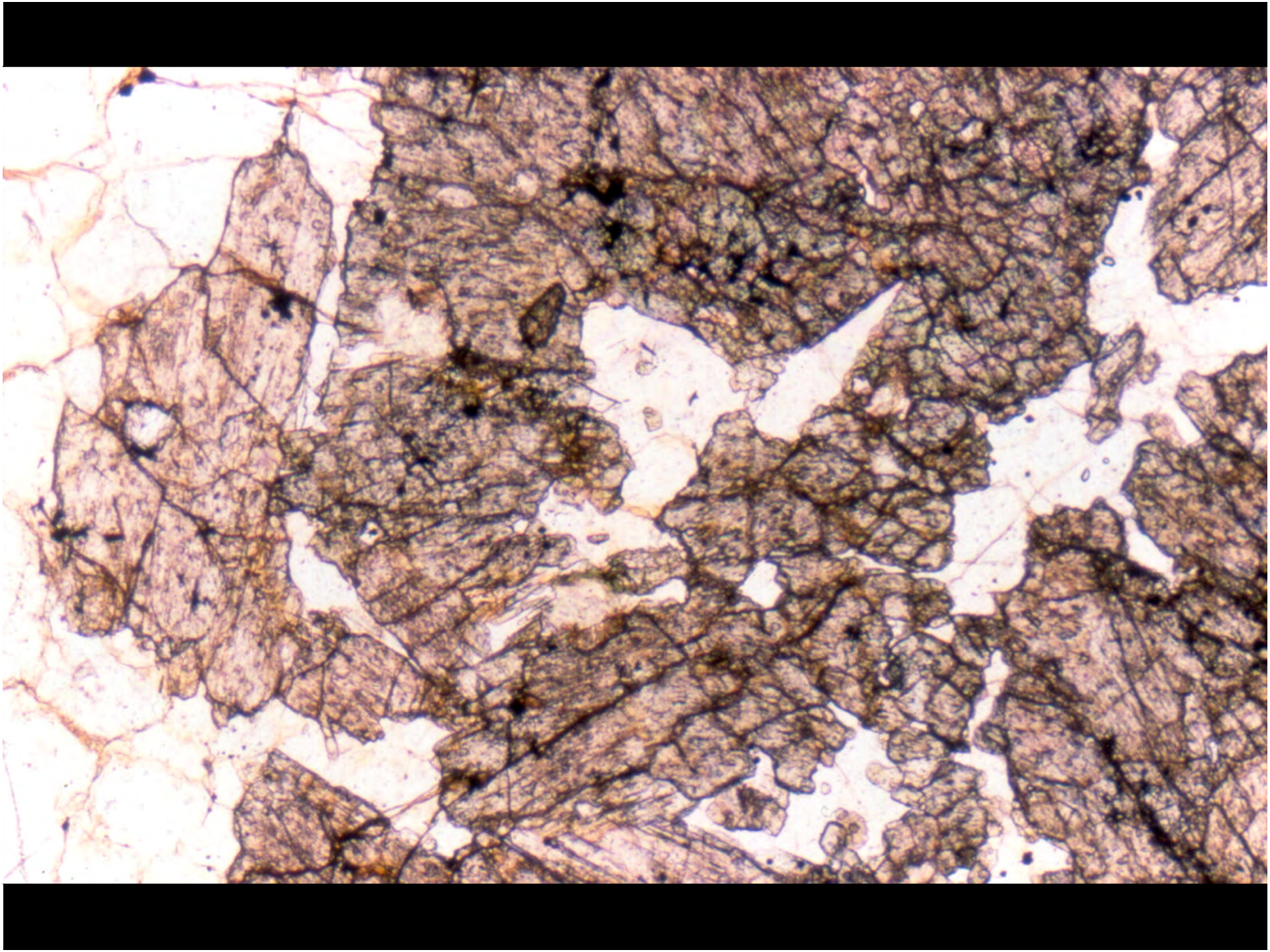
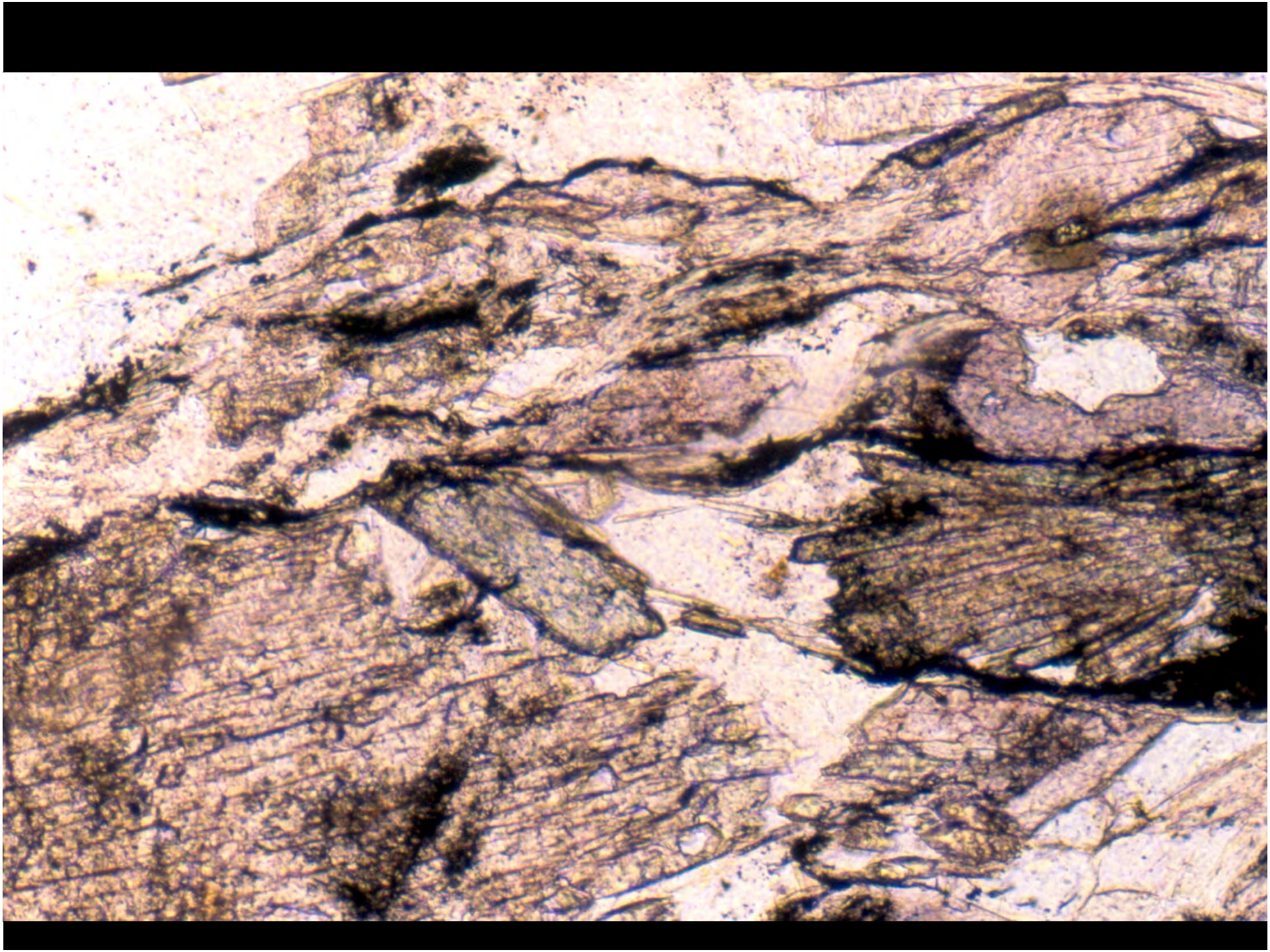
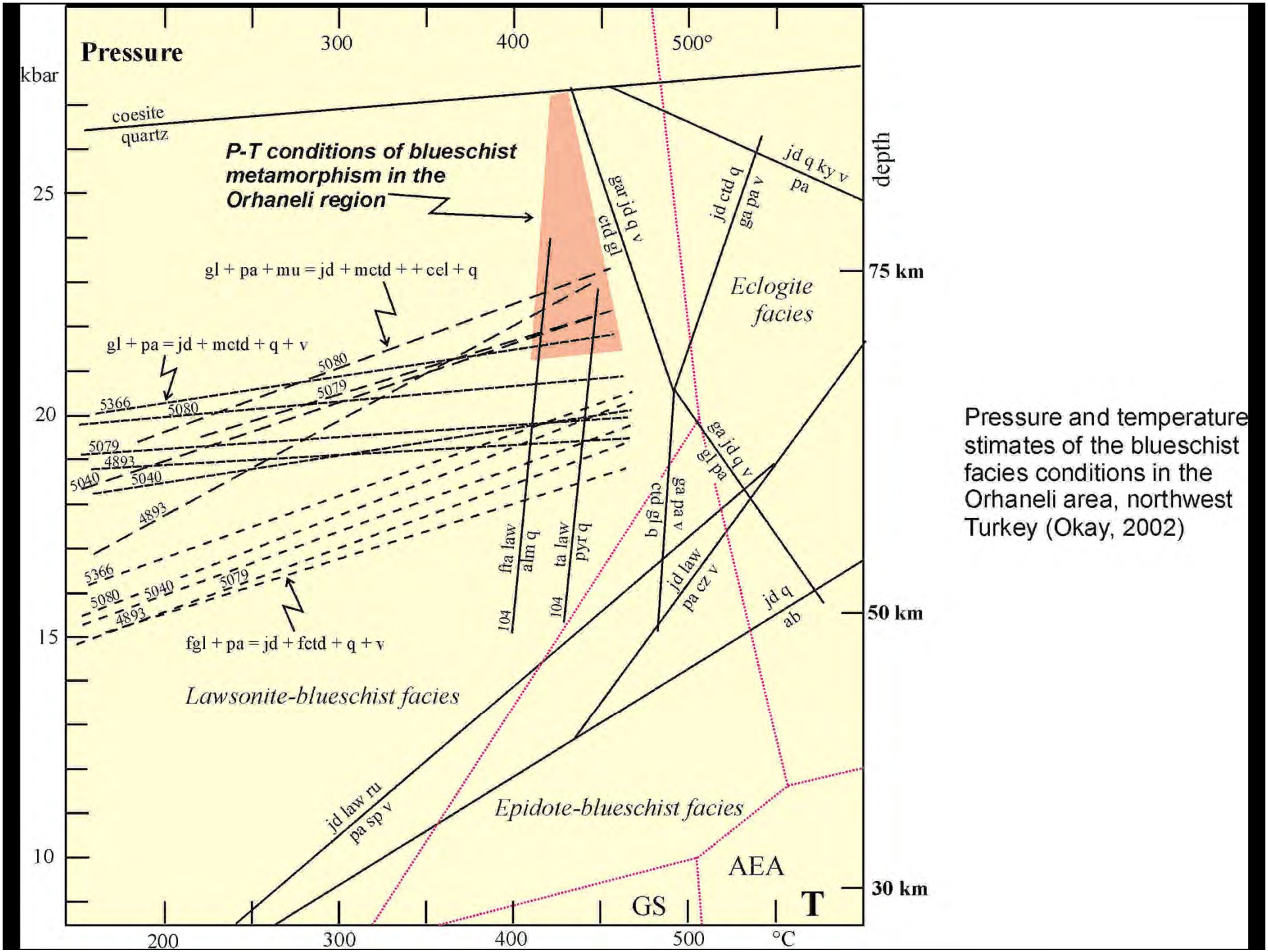
400 km


0.7 mm

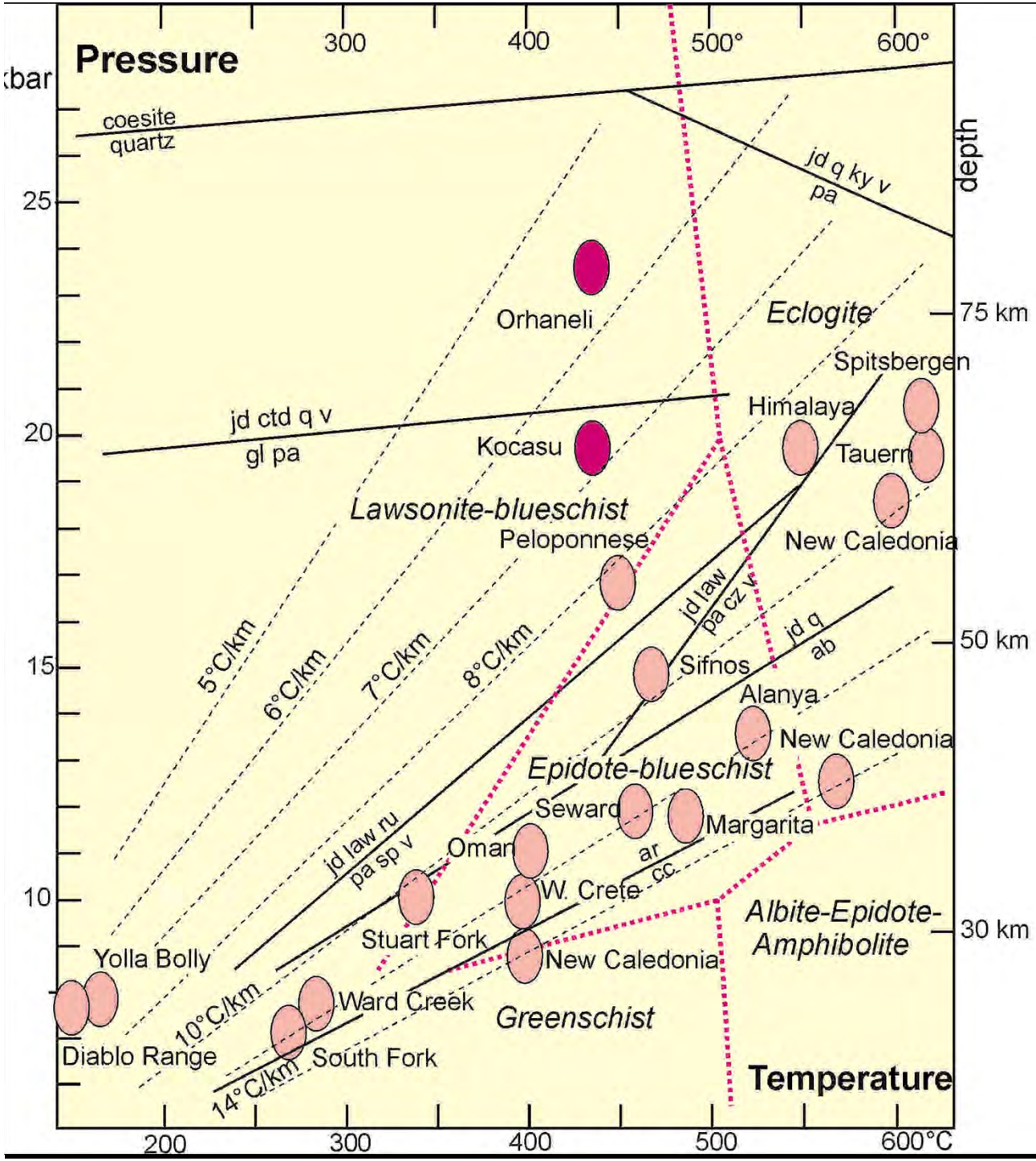
Pressure – temperature conditions of the blueschist metamorphism



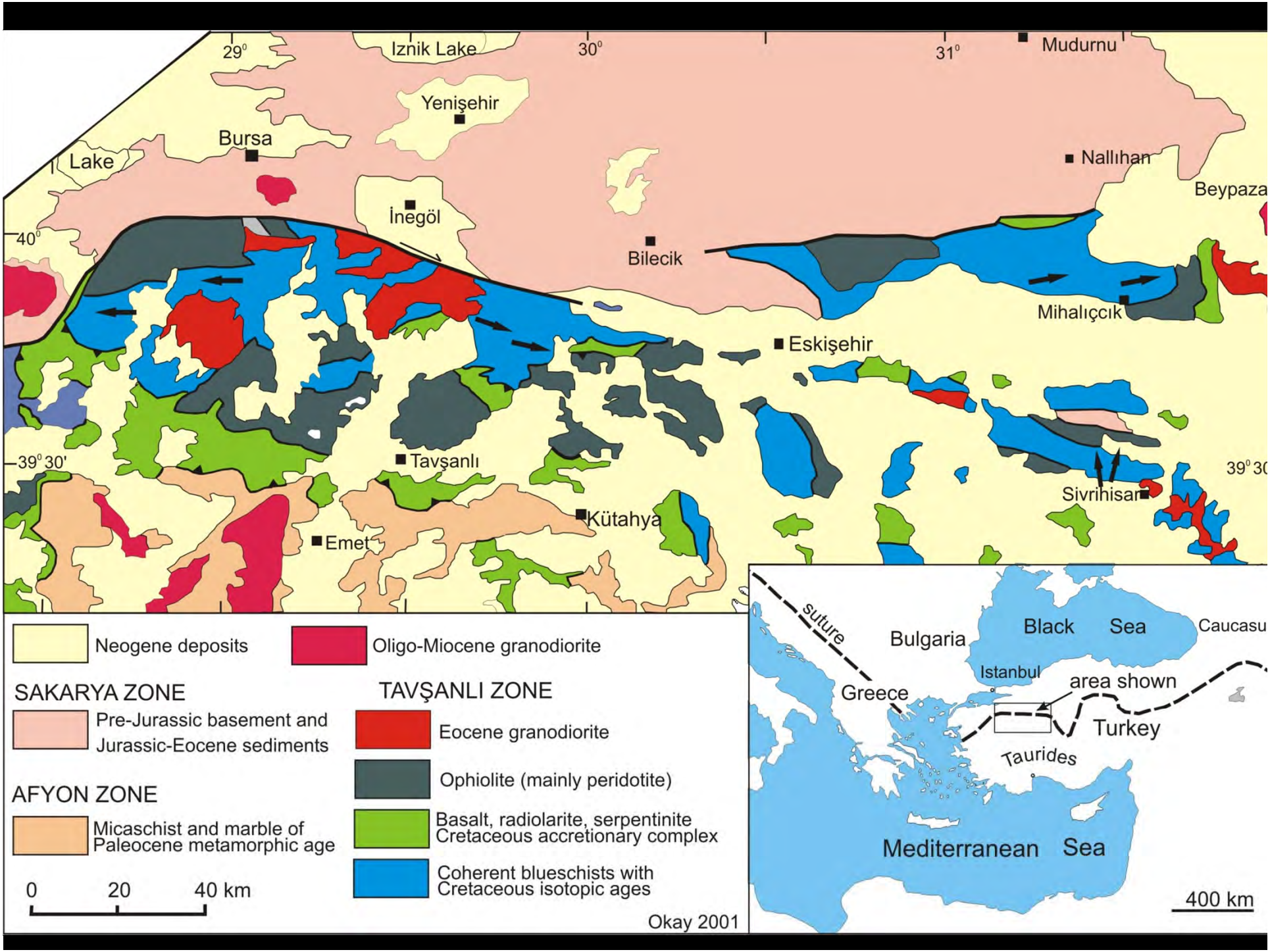




Pressure and temperature stimates of the blueschist facies conditions in the Orhaneli area, northwest Turkey (Okay, 2002)



Estimates of peak P-T conditions of various blueschist and eclogite terrains in the world with the respective geothermal gradients (Okay, 2002).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20
40 km
Okay 2001
suture
Bulgaria
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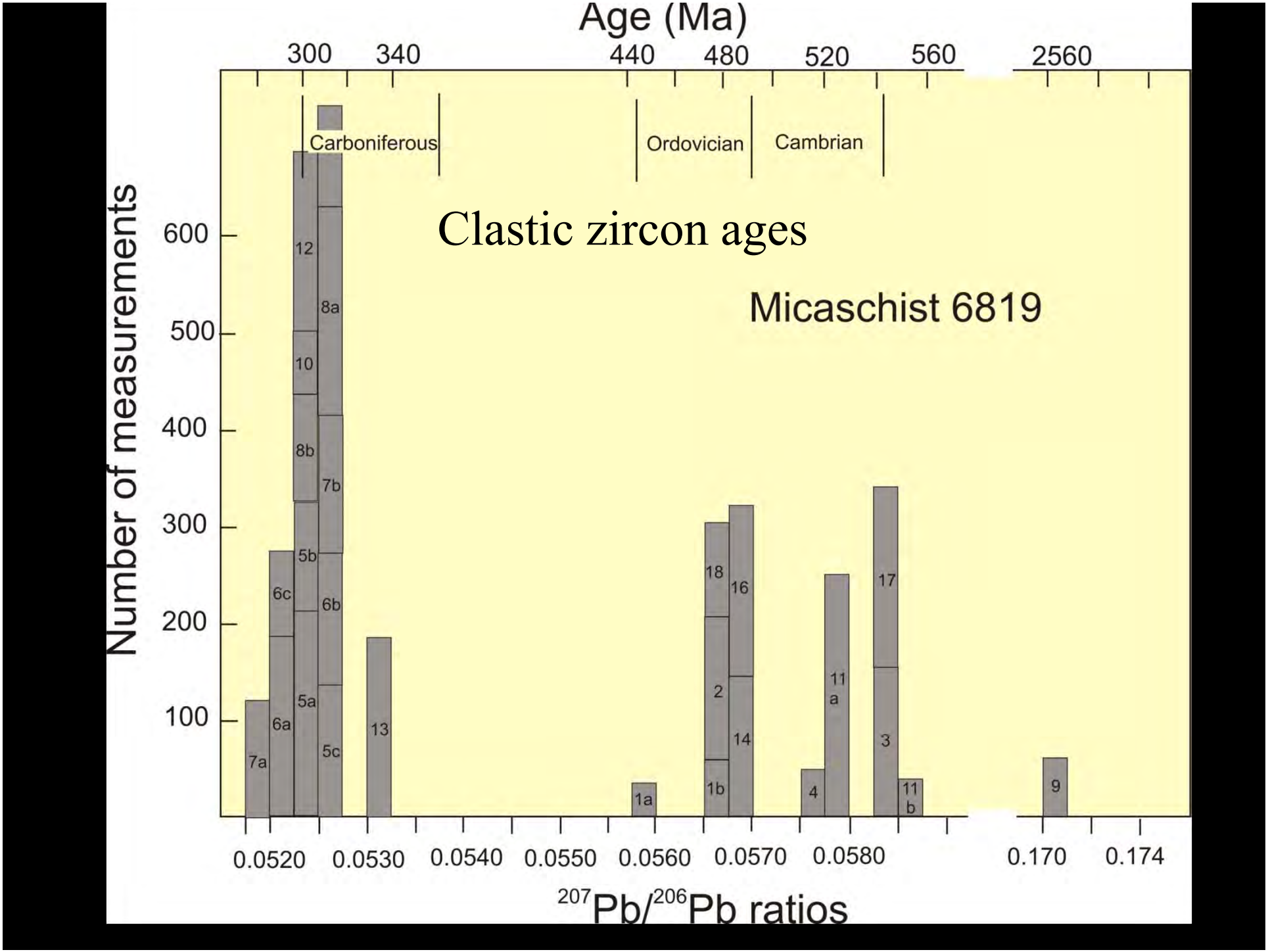
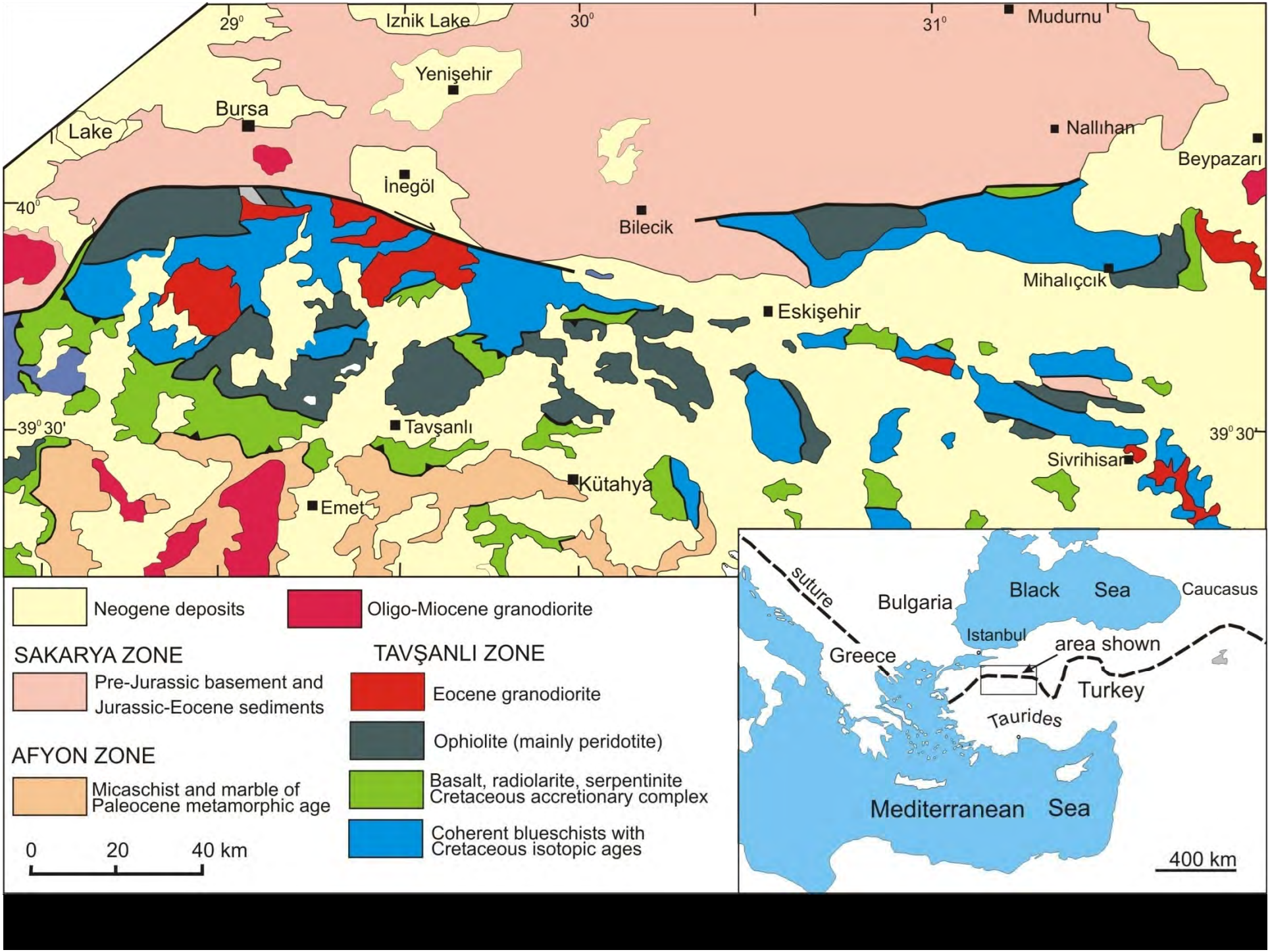
Greece
Turkey
Taurides
Mediterranean Sea
400 km

Age of the coherent blueschist sequence (Orhaneli Group): depositional age


Age (Ma)
300
340
440
480
520
560
2560
Carboniferous
Ordovician
Cambrian
Clastic zircon ages
Micaschist 6819
Number of measurements
600
500
400
300
200
100
12
8a
10
8b
7b
5b
6c
6b
5a
5c
6a
7a
13
1a
18
16
2
14
1b
4
11
a
17
3
11
b
9
0.0520
0.0530
0.0540
0.0550
0.0560
0.0570
0.0580
0.170
0.174
207Pb/206Pb ratios

The age of blueschist metamorphism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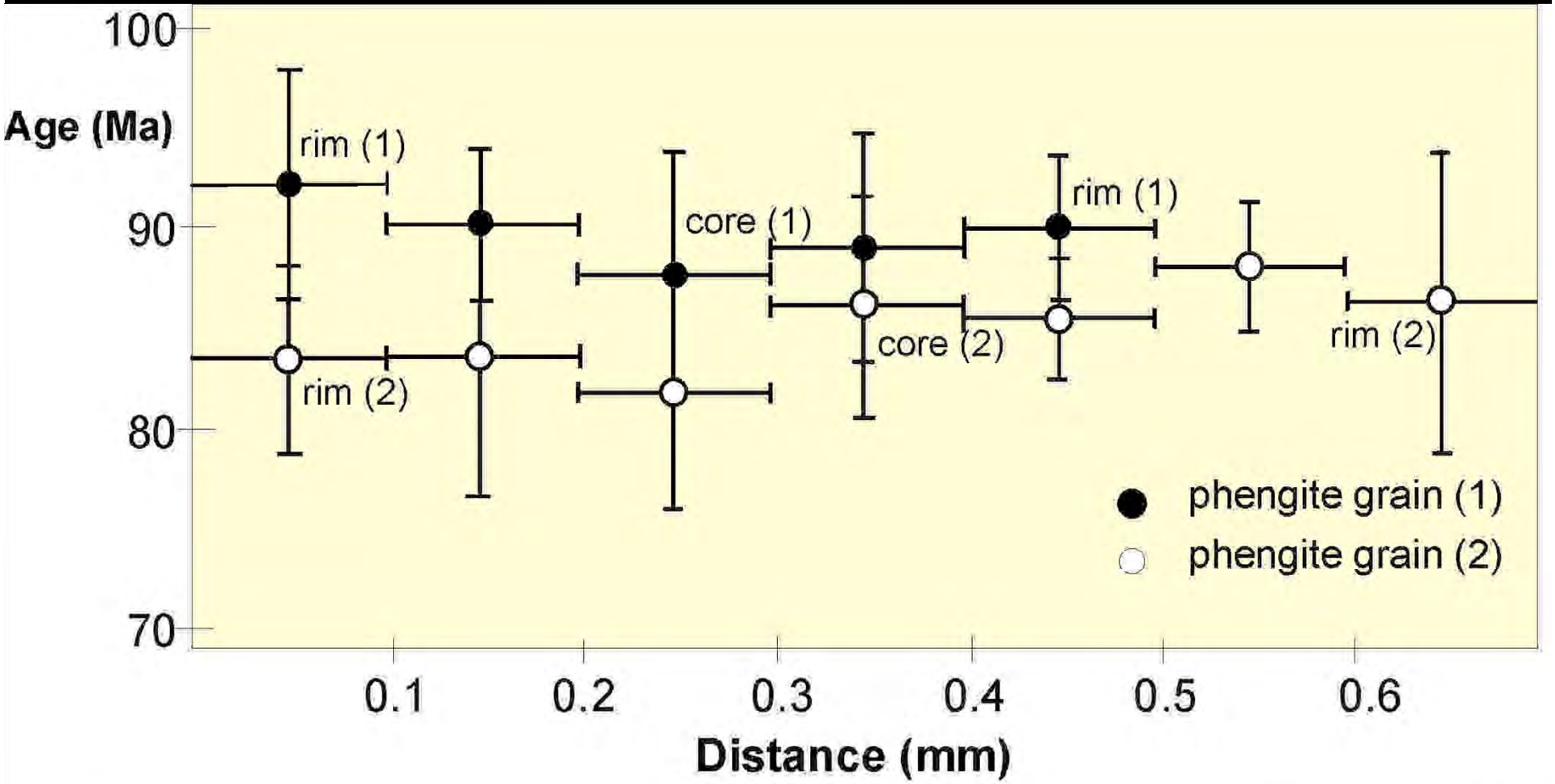
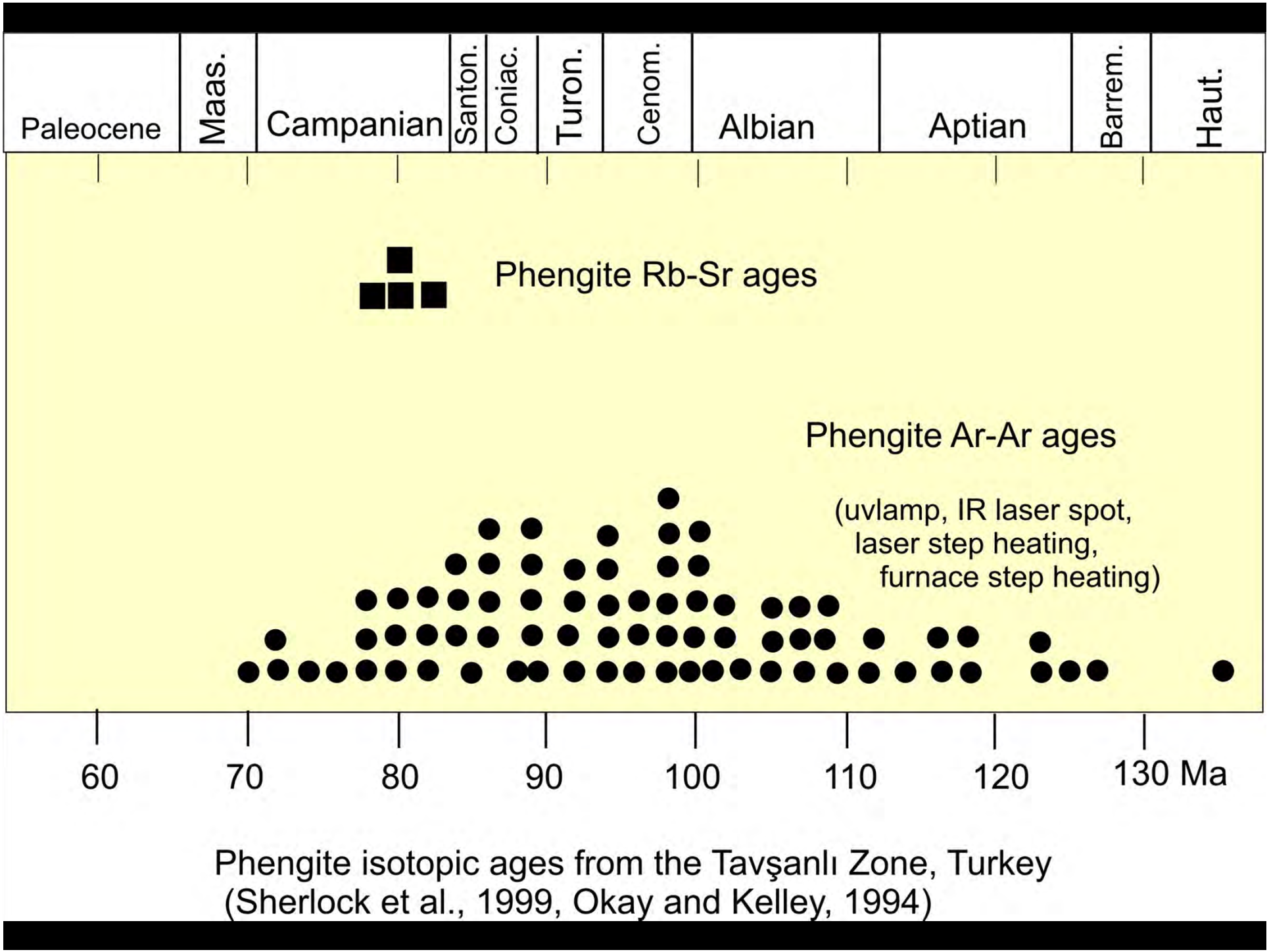
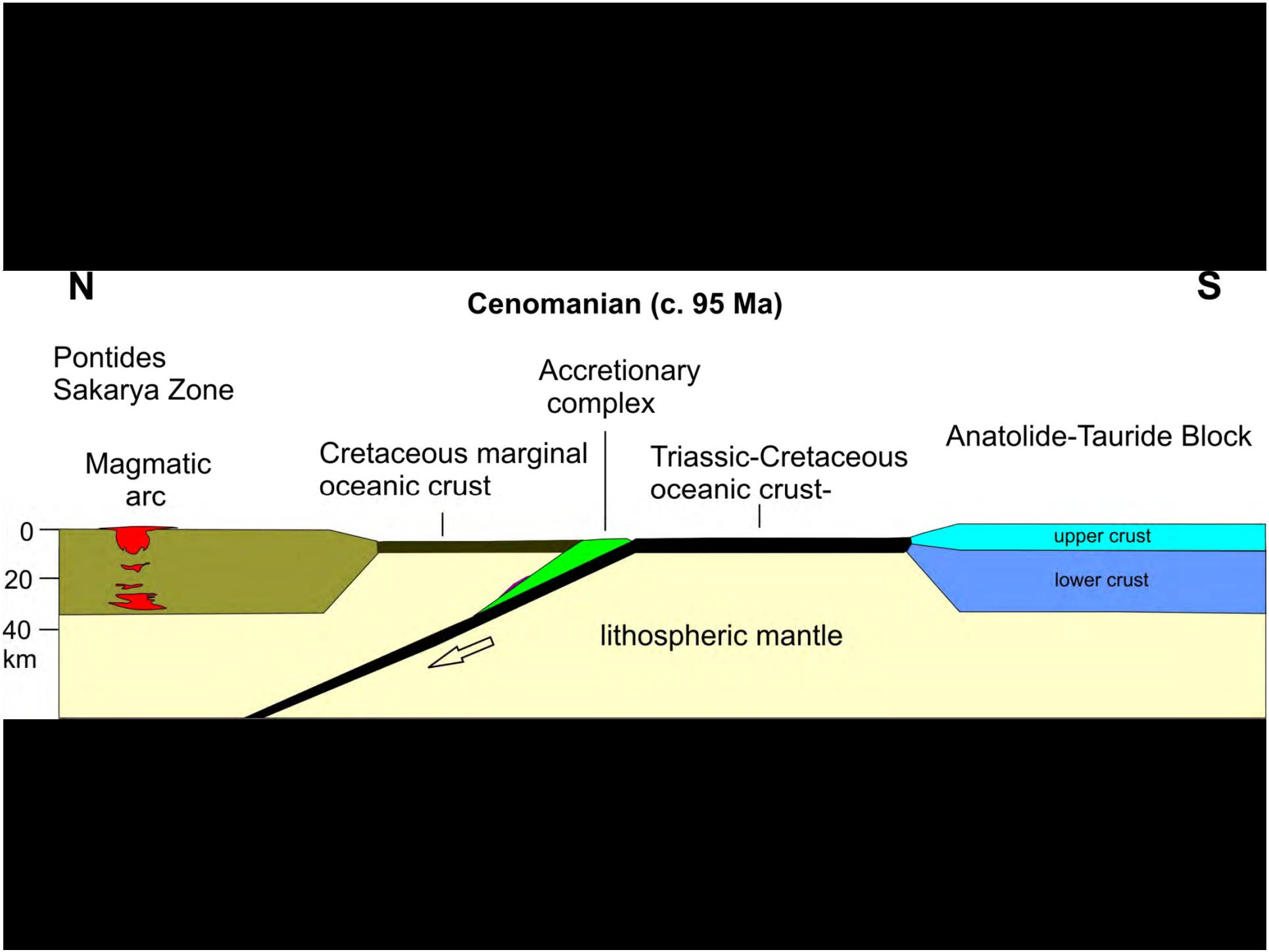


Argon laser ages obtained from two phengite grains from jadeite schist (Okay et al., 1998)



Phengite isotopic ages from the Tavşanlı Zone, Turkey
(Sherlock et al., 1999, Okay and Kelley, 1994)

Tectonic model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Magmatic
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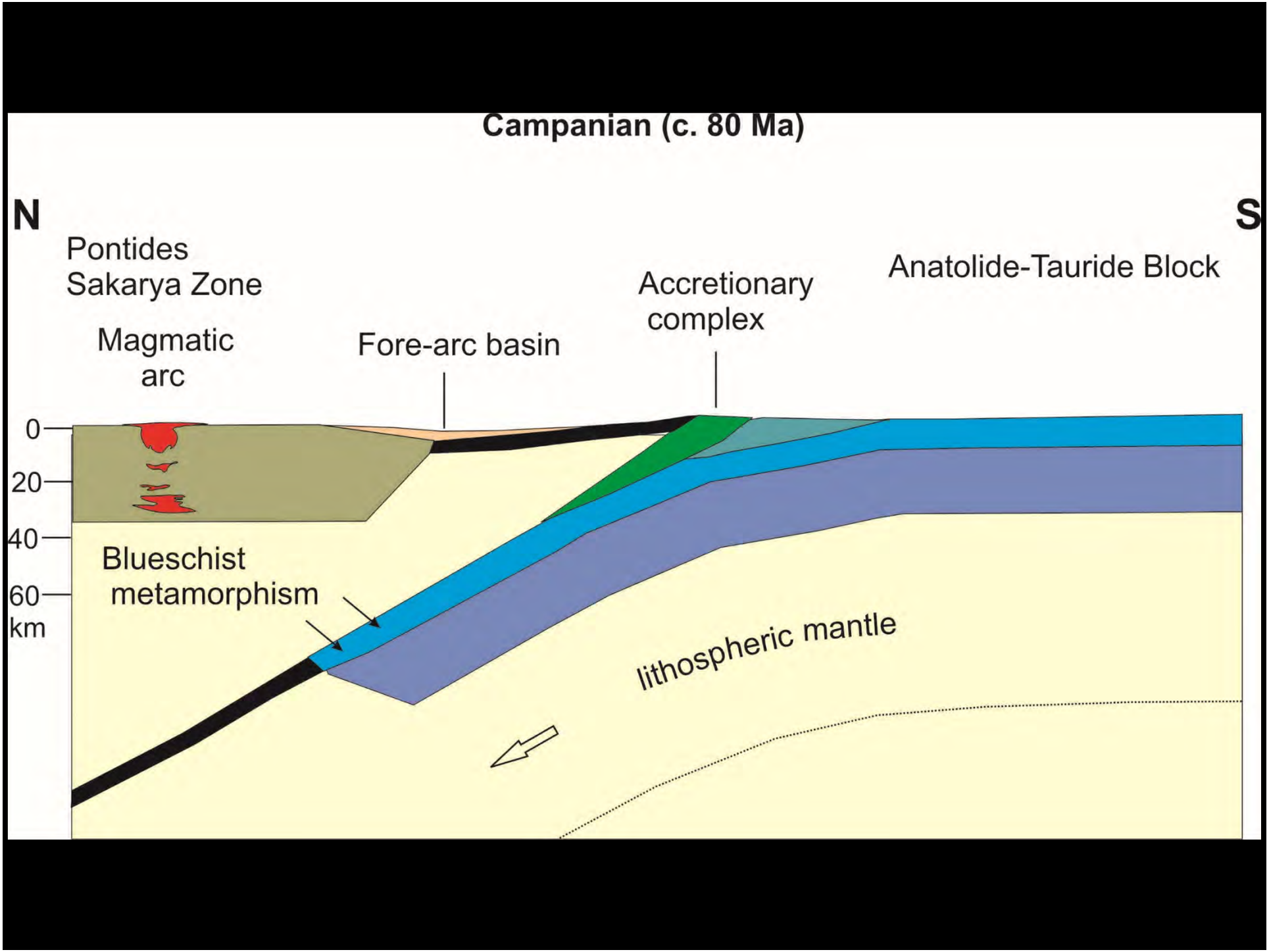
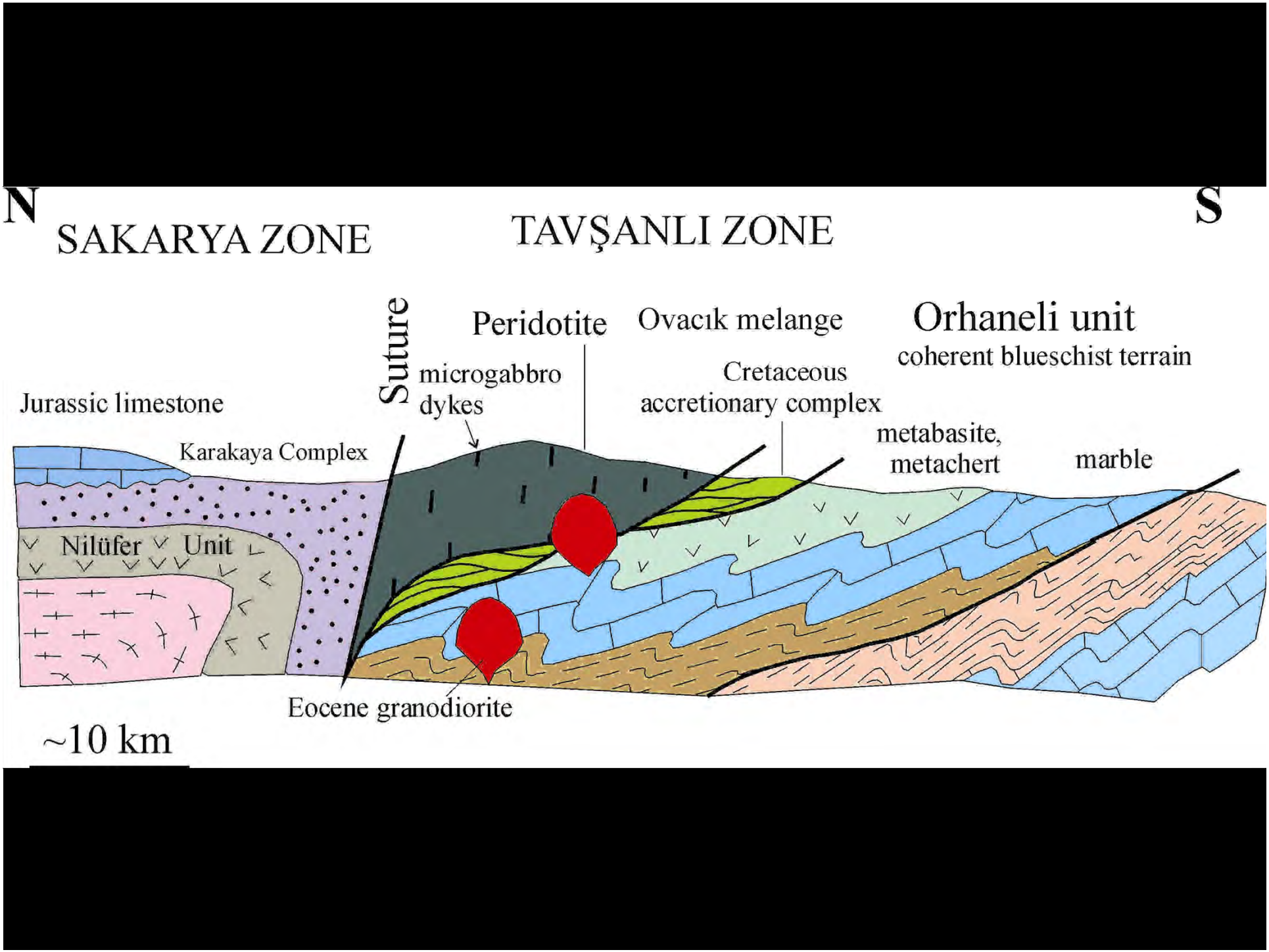
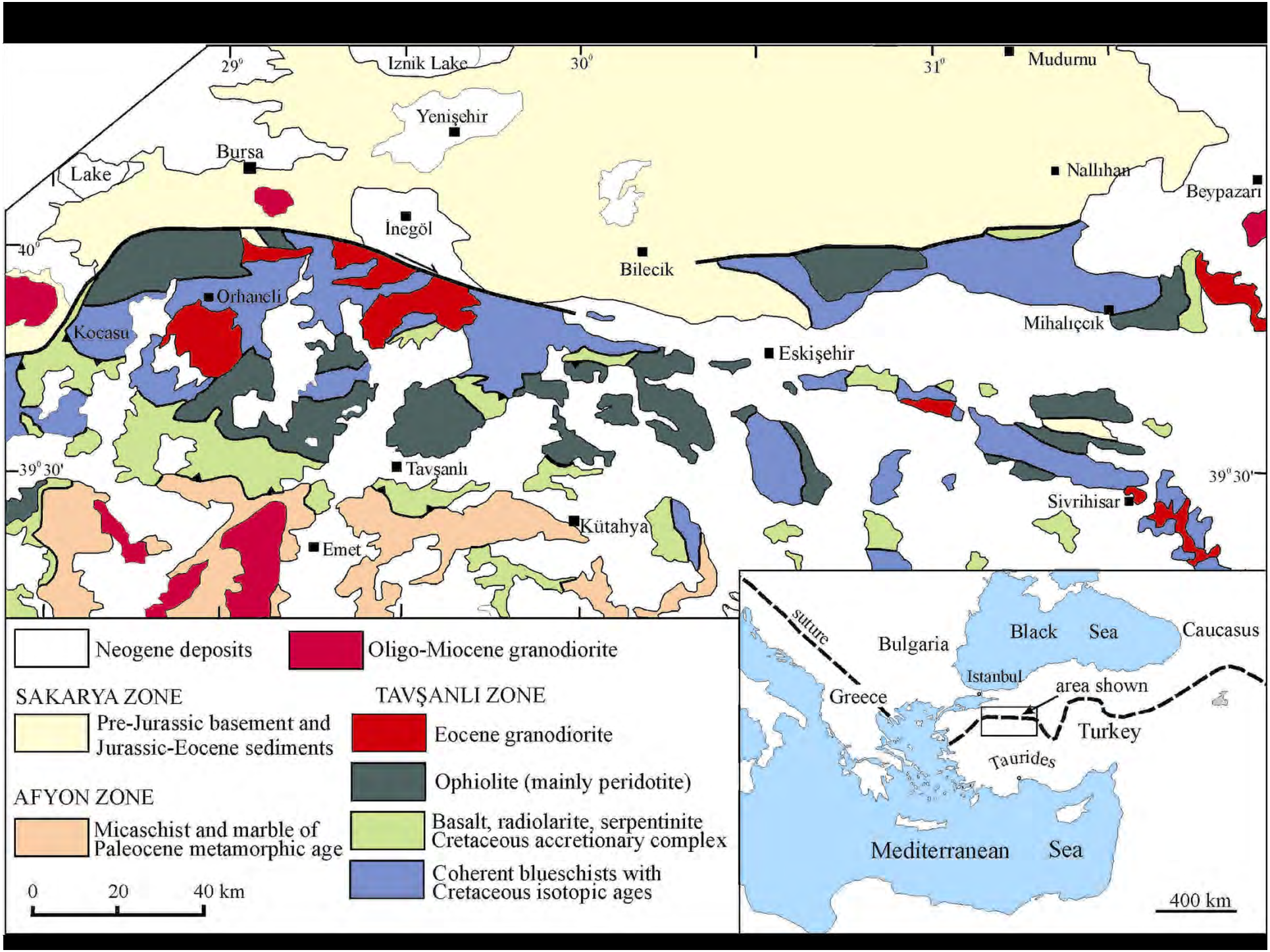
oceanic crust
Triassic-Cretaceous
oceanic crust-
0
20
40
km
upper crust
lower crust
lithospheric mantle

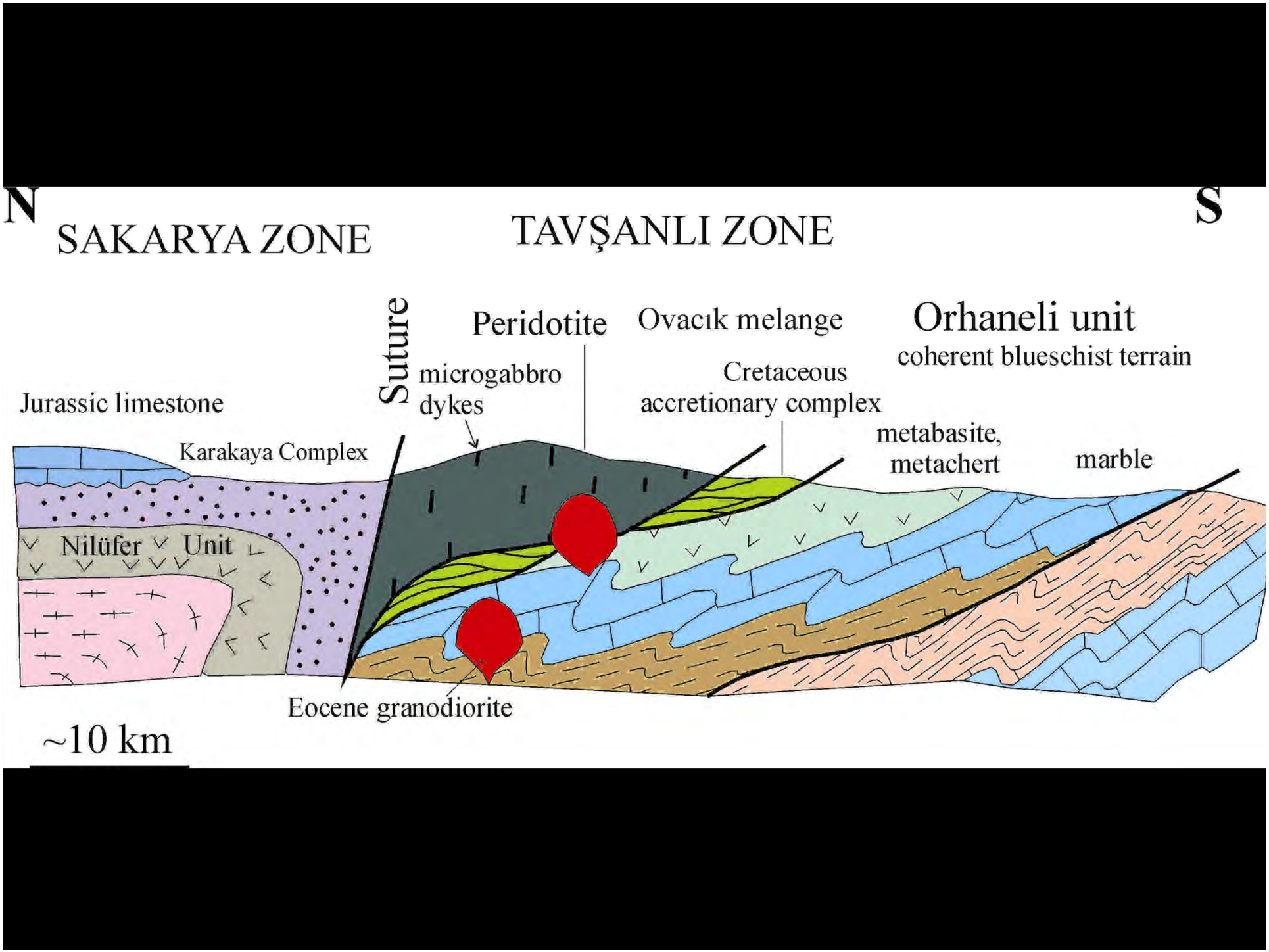

Campanian (c. 80 Ma)
N
S
Pontides
Sakarya Zone
Magmatic
arc
Fore-arc basin
Accretionary
complex
Anatolide-Tauride Block
0
20
40
60
km
Blueschist
metamorphism
lithospheric mantle

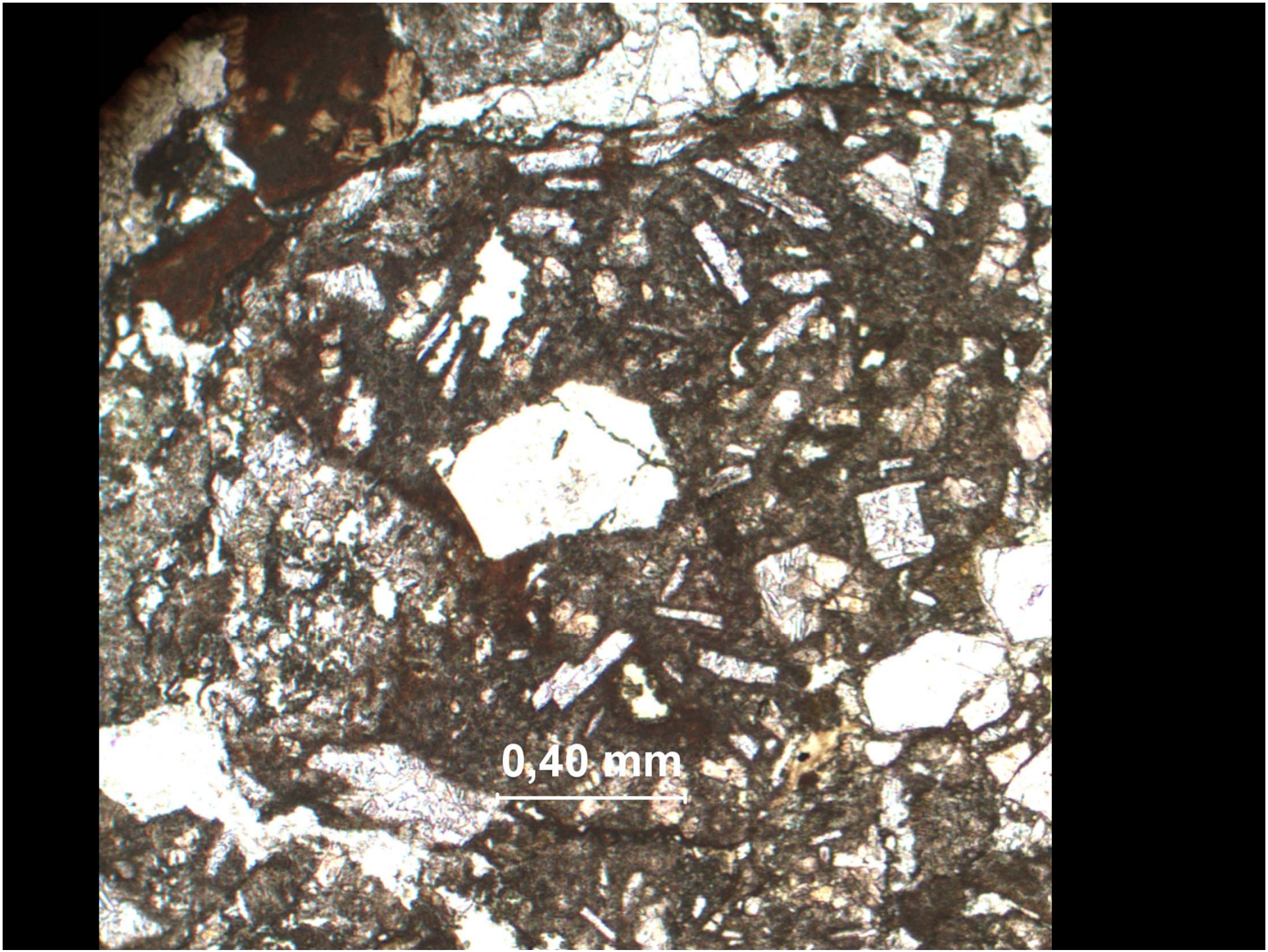

N
SAKARYA ZONE
TAVŞANLI ZONE
S
Suture
Peridotite
Ovacık melange
Orhaneli unit
coherent blueschist terrain
microgabbro
dykes
Cretaceous
accretionary complex
Jurassic limestone
Karakaya Complex
metabasite,
metachert
marble
Nilüfer Unit
Eocene granodiorite
~10 km

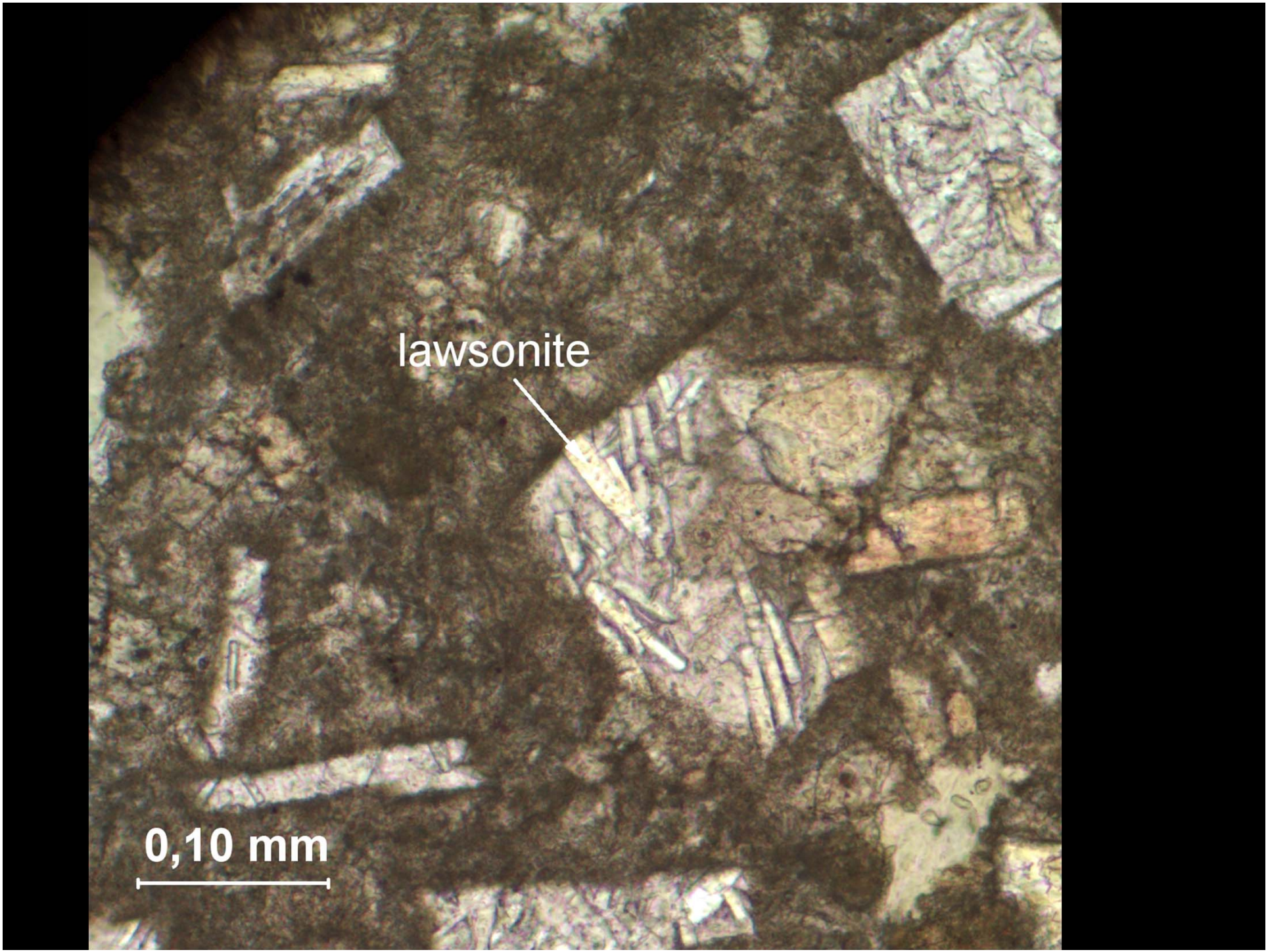
Accretionary complex
(Ophiolitic melange)

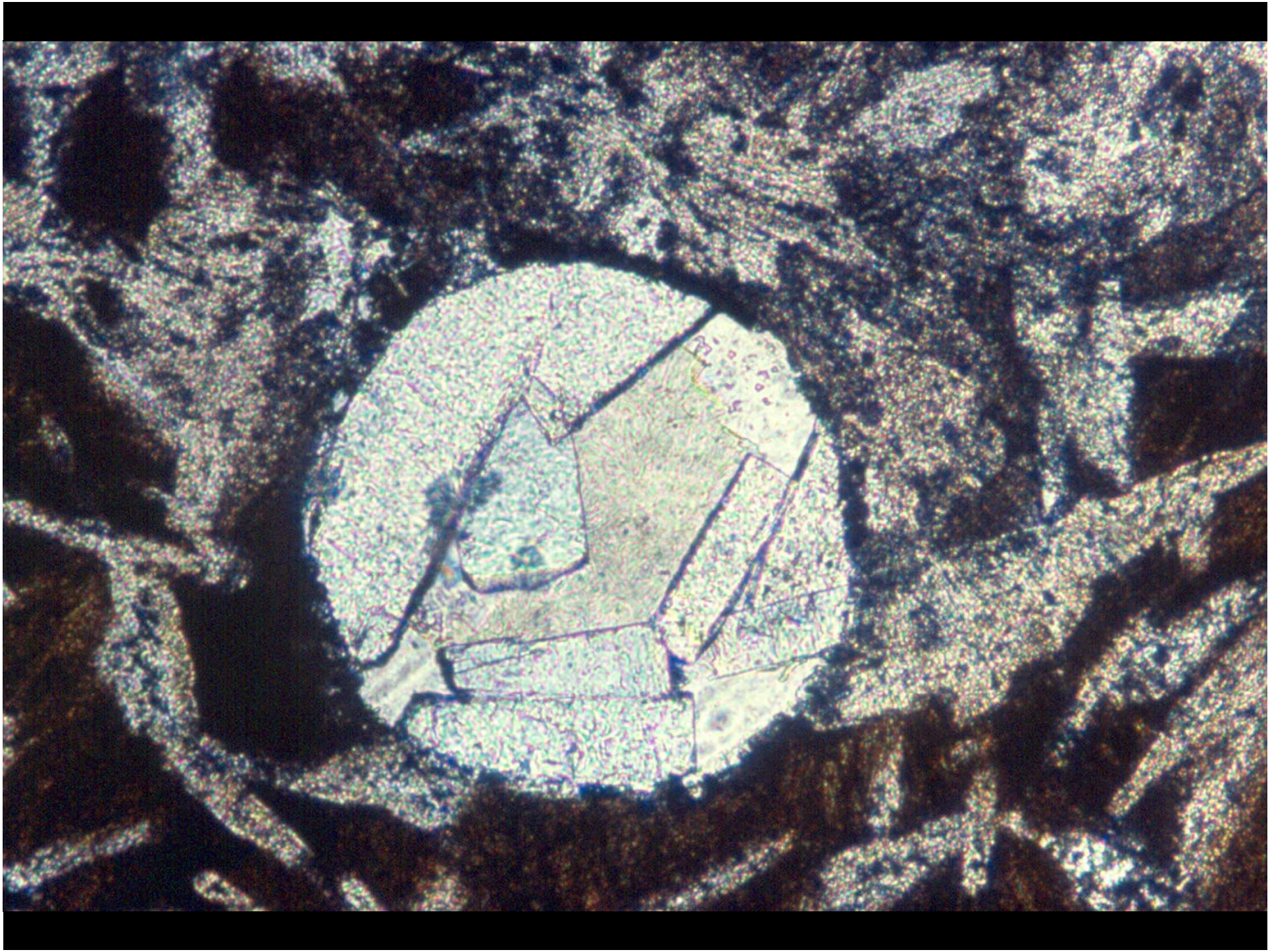
An accretionary complex made up of the upper crustal sections of the Tethyan ocean

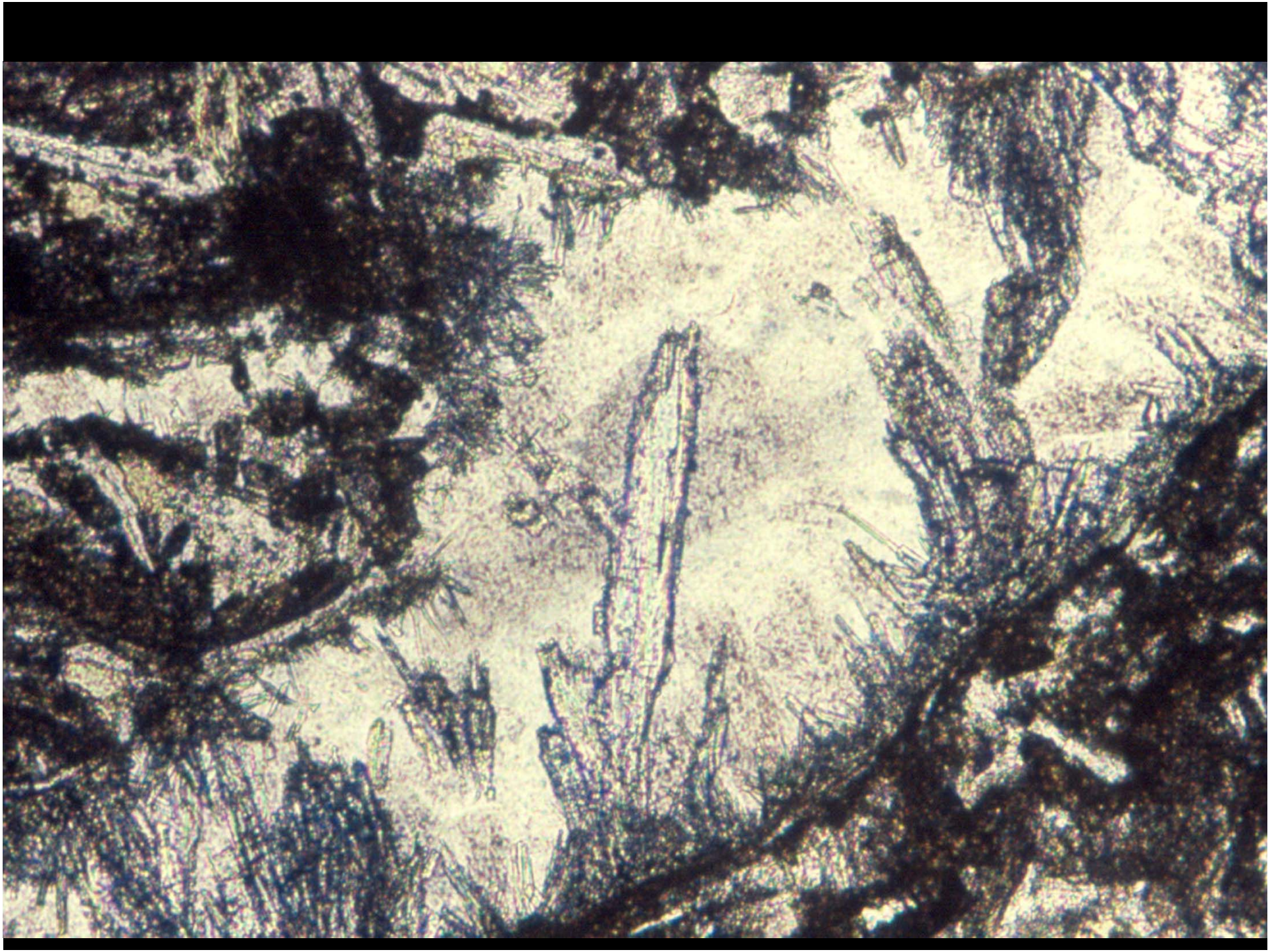

29°
Iznik Lake
30°
31°
Mudurnu
Yenişehir
Bursa
Lake
Nallıhan
Beypazarı
İnegöl
40°
Bilecik
Orhaneli
Kocasu
Mihalıççık
Eskişehir
39° 30'
Tavşanlı
39° 30'
Sivrihisar
Kütahya
Emet
Neogene deposits
Oligo-Miocene granodiorite
SAKARYA ZONE
Pre-Jurassic basement and Jurassic-Eocene sediments
TAVŞANLI ZONE
Eocene granodiorite
Ophiolite (mainly peridotite)
Basalt, radiolarite, serpentinite Cretaceous accretionary complex
Coherent blueschists with Cretaceous isotopic ages
AFYON ZONE
Micaschist and marble of Paleocene metamorphic age
0
20
40 km
suture
Bulgaria
Black Sea
Caucasus
Istanbul
area shown
Greece
Turkey
Taurides
Mediterranean Sea
400 km

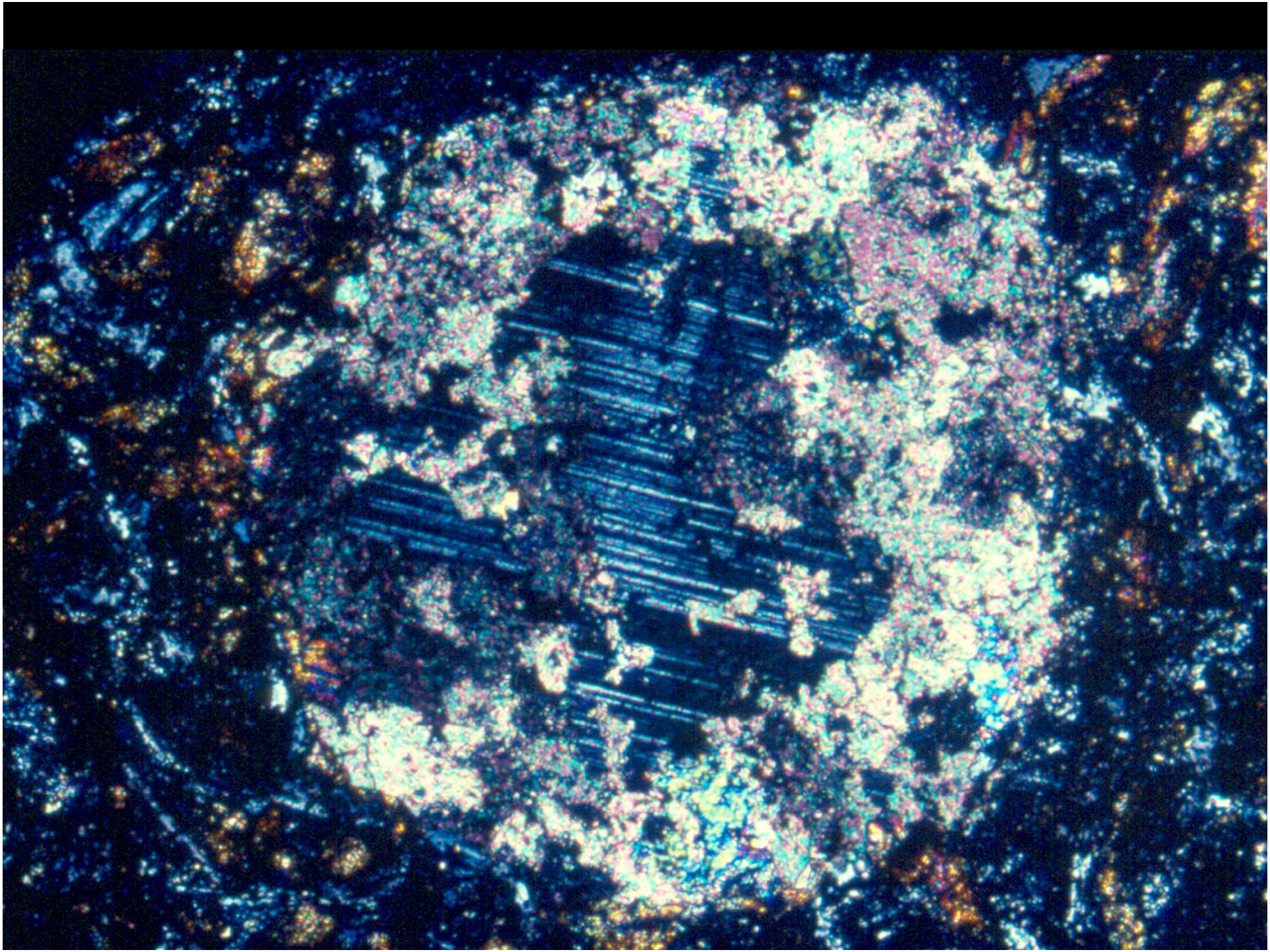

N
SAKARYA ZONE
TAVŞANLI ZONE
S
Suture
Peridotite
Ovacık melange
Orhaneli unit
coherent blueschist terrain
microgabbro
dykes
Cretaceous
accretionary complex
Jurassic limestone
Karakaya Complex
metabasite,
metachert
marble
Nilüfer Unit
Eocene granodiorite
~10 km


0,40 mm

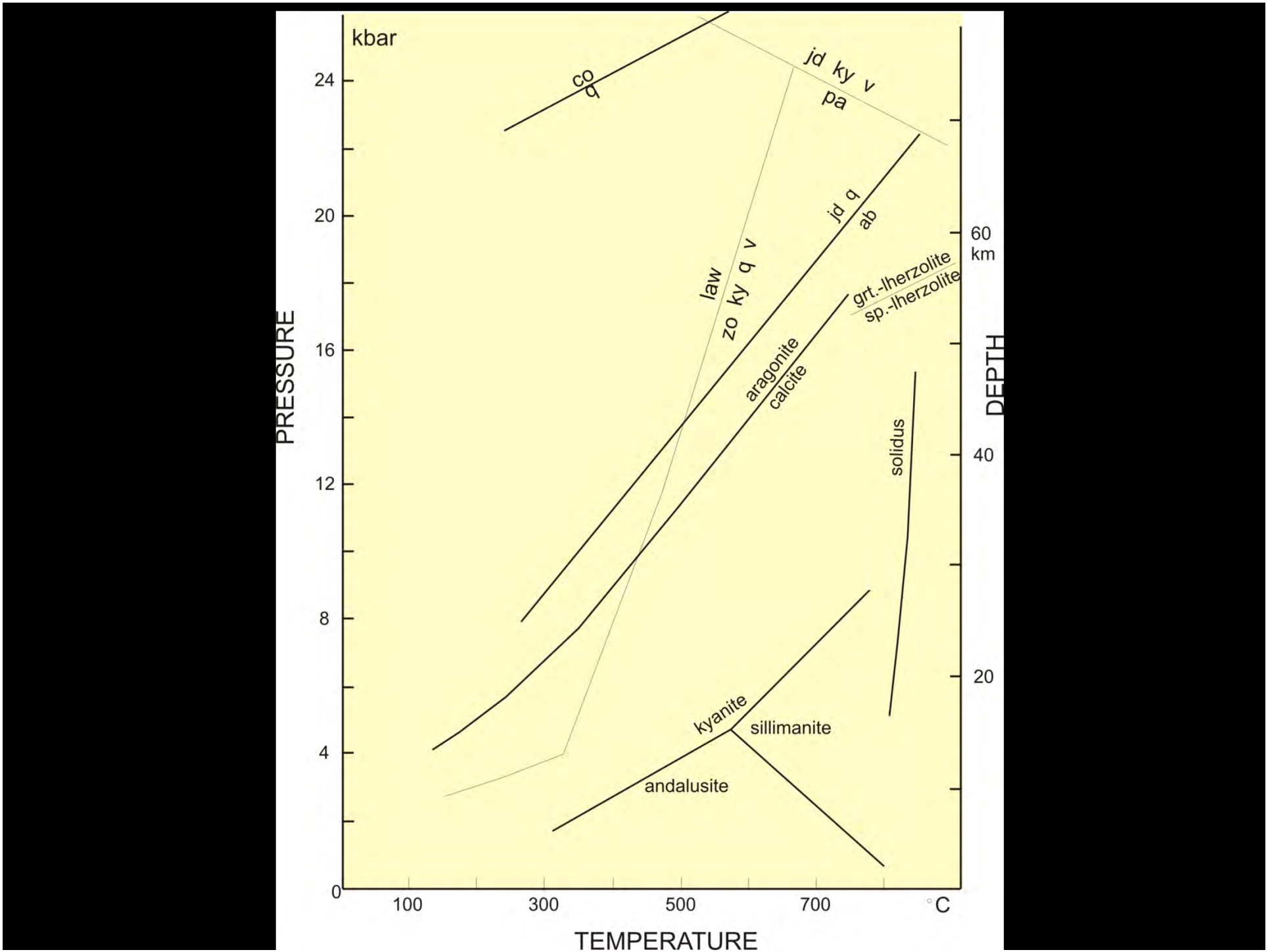

lawsonite
0,10 mm

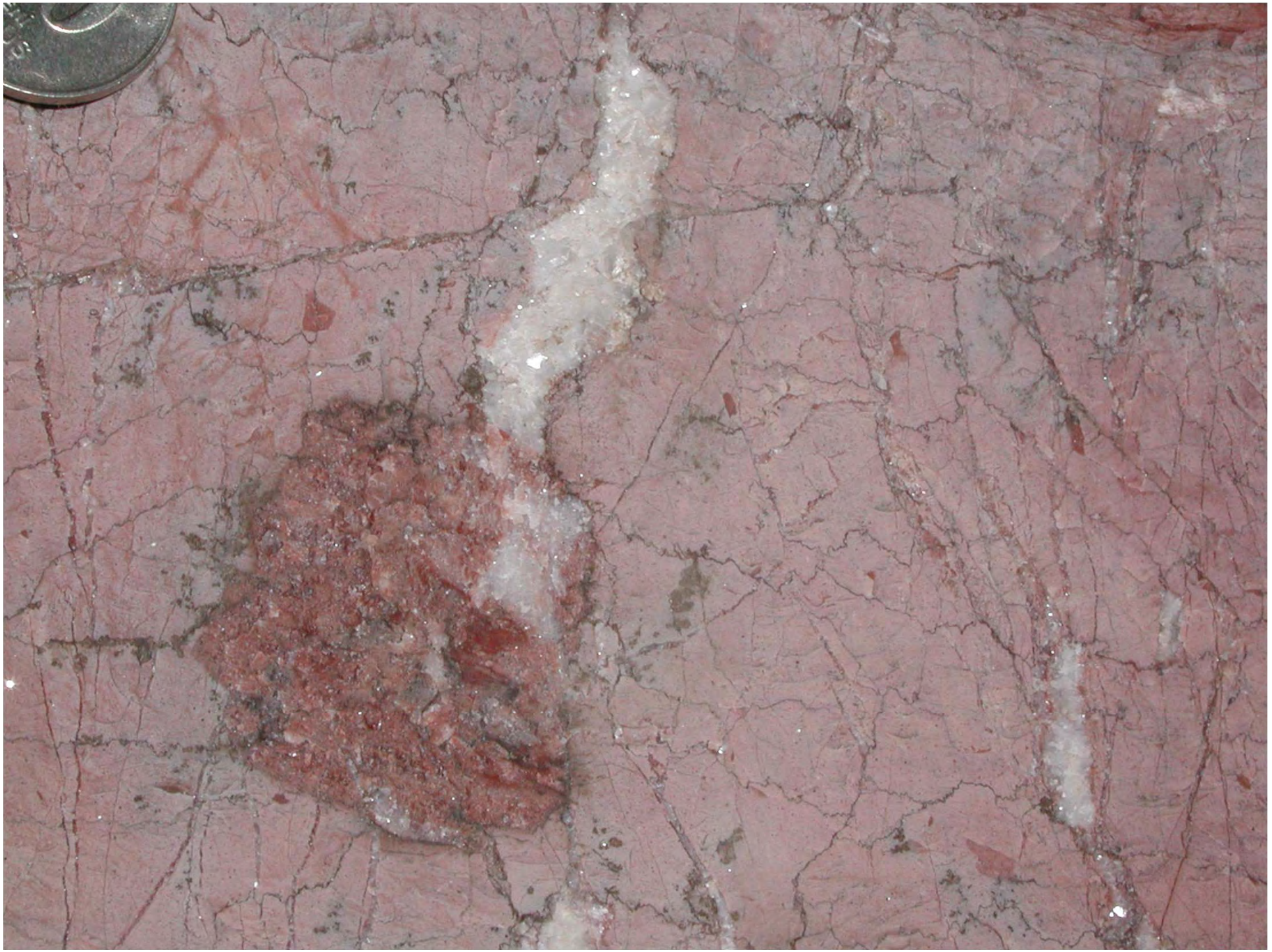






Partially aragonitised micritic limestones

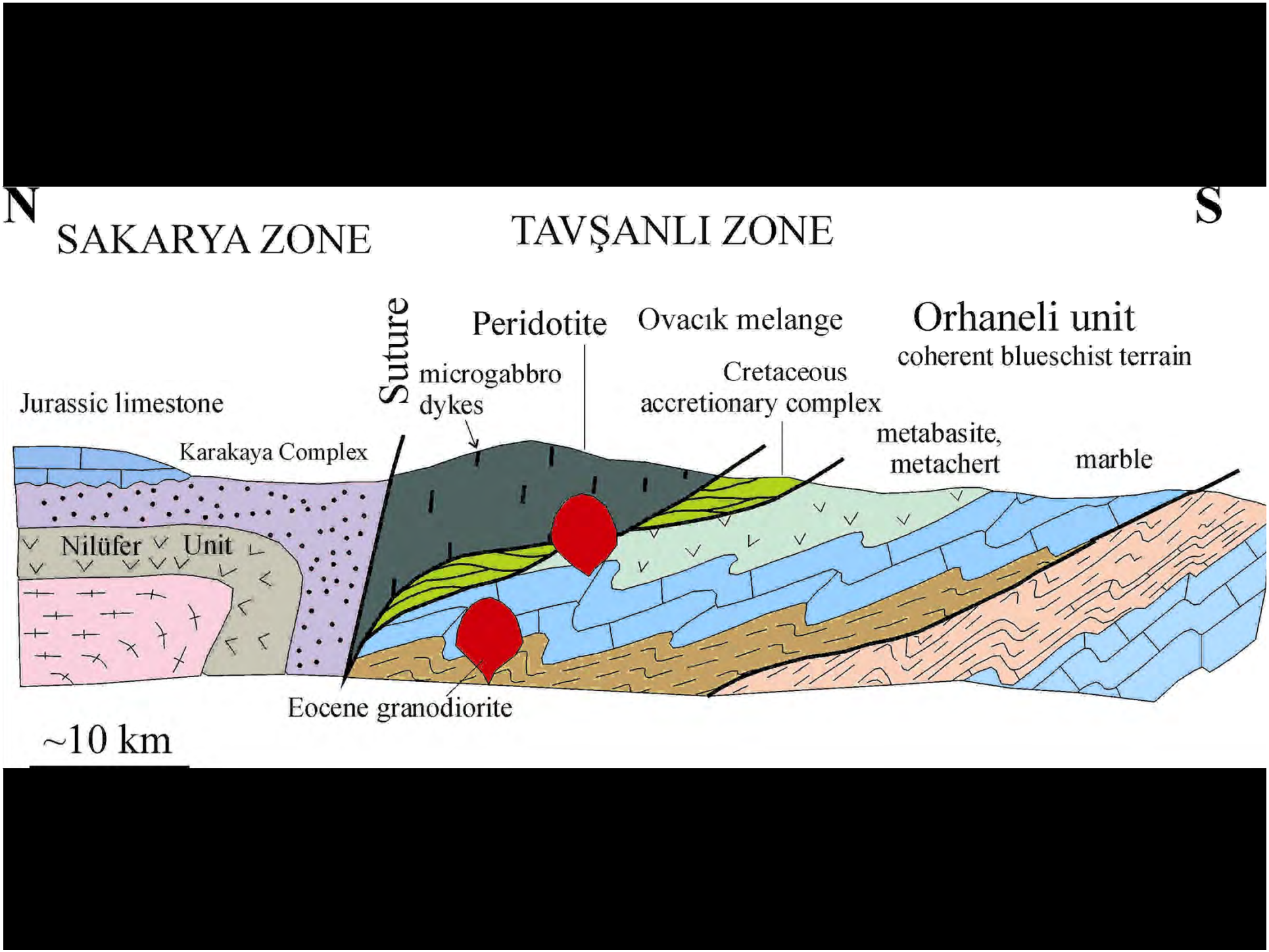

kbar
24
20
16
12
8
4
0
PRESSURE
co
q
jd ky v
pa
jd q
ab
law
zo ky q v
grt.-lherzolite
sp.-lherzolite
aragonite
calcite
solidus
kyanite
sillimanite
andalusite
60
km
40
20
DEPTH
100
300
500
700
°C
TEMPERATURE

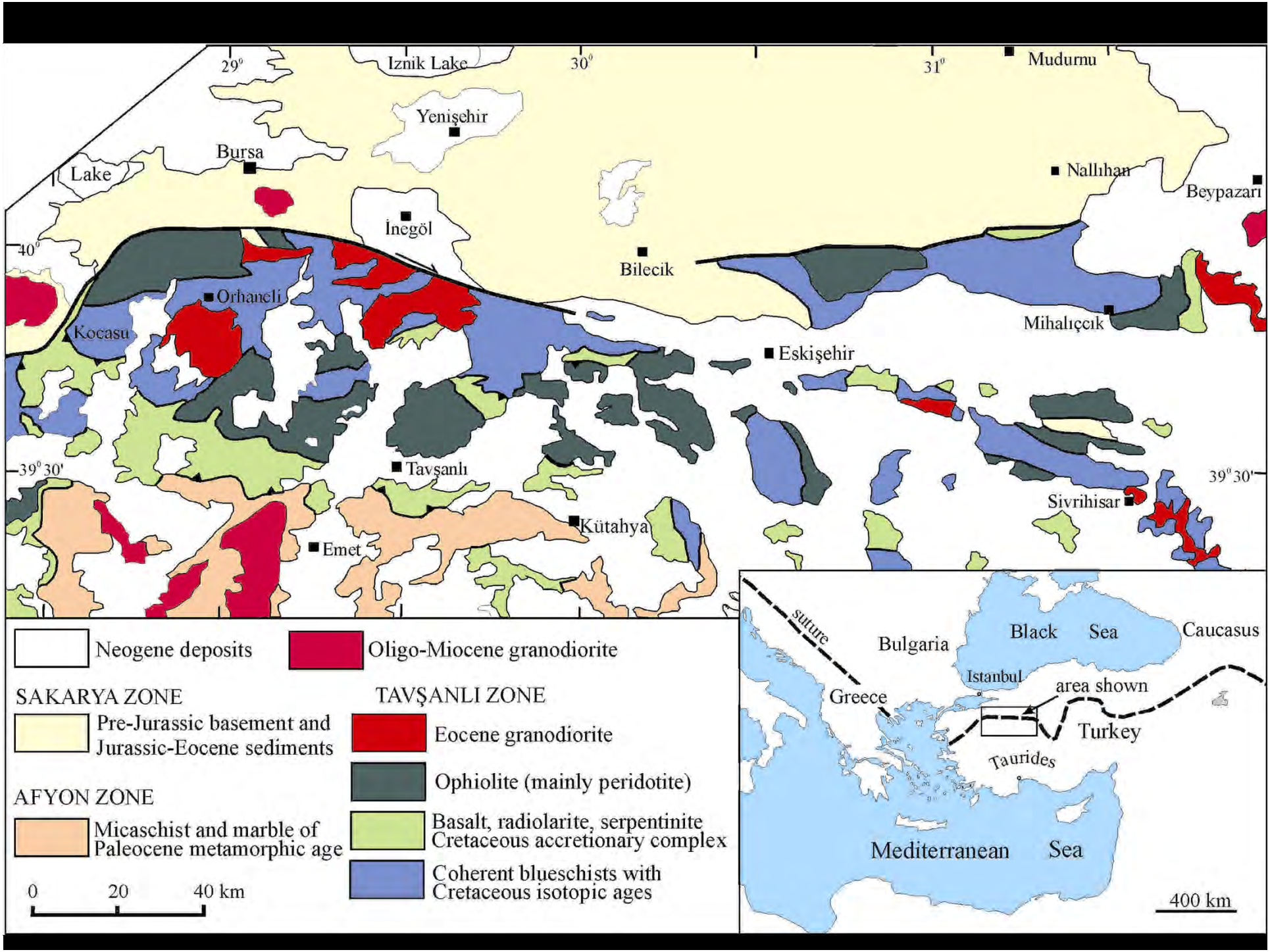



Estwing

Peridotite
(Ophiolite)

Ultramafic rocks with minor gabbro and diabase dykes – upper mantle section of the Tethyan ocean


N
SAKARYA ZONE
TAVŞANLI ZONE
S
Suture
Peridotite
Ovacık melange
Orhaneli unit
coherent blueschist terrain
microgabbro
dykes
Cretaceous
accretionary complex
Jurassic limestone
Karakaya Complex
metabasite,
metachert
marble
Nilüfer Unit
Eocene granodiorite
~10 km


29°
Iznik Lake
30°
31°
Mudurnu
Yenişehir
Bursa
Lake
Nallıhan
Beypazarı
İnegöl
40°
Bilecik
Orhaneli
Kocasu
Mihalıççık
Eskişehir
39° 30'
Tavşanlı
39° 30'
Sivrihisar
Kütahya
Emet
Neogene deposits
Oligo-Miocene granodiorite
SAKARYA ZONE
Pre-Jurassic basement and Jurassic-Eocene sediments
TAVŞANLI ZONE
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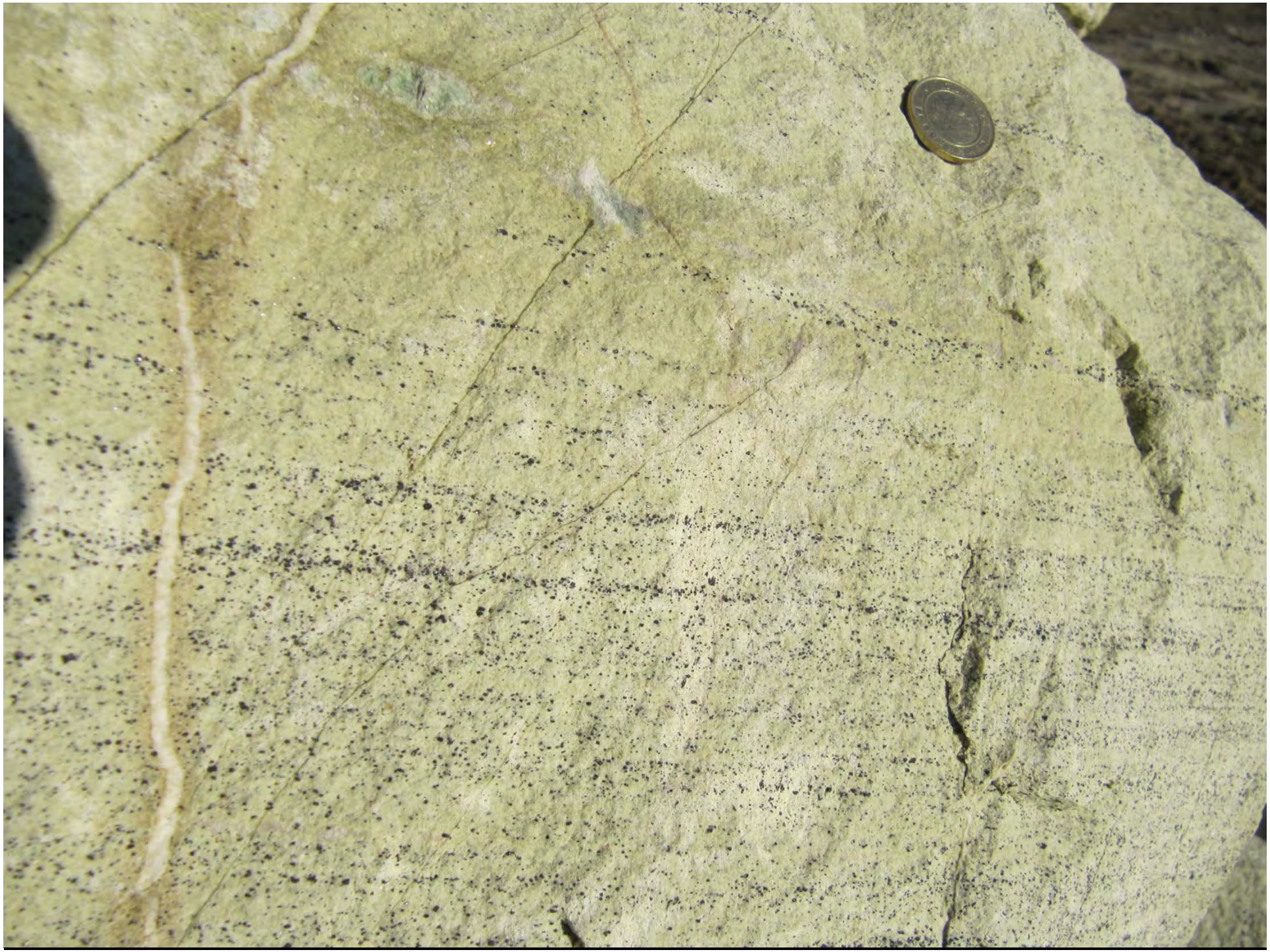
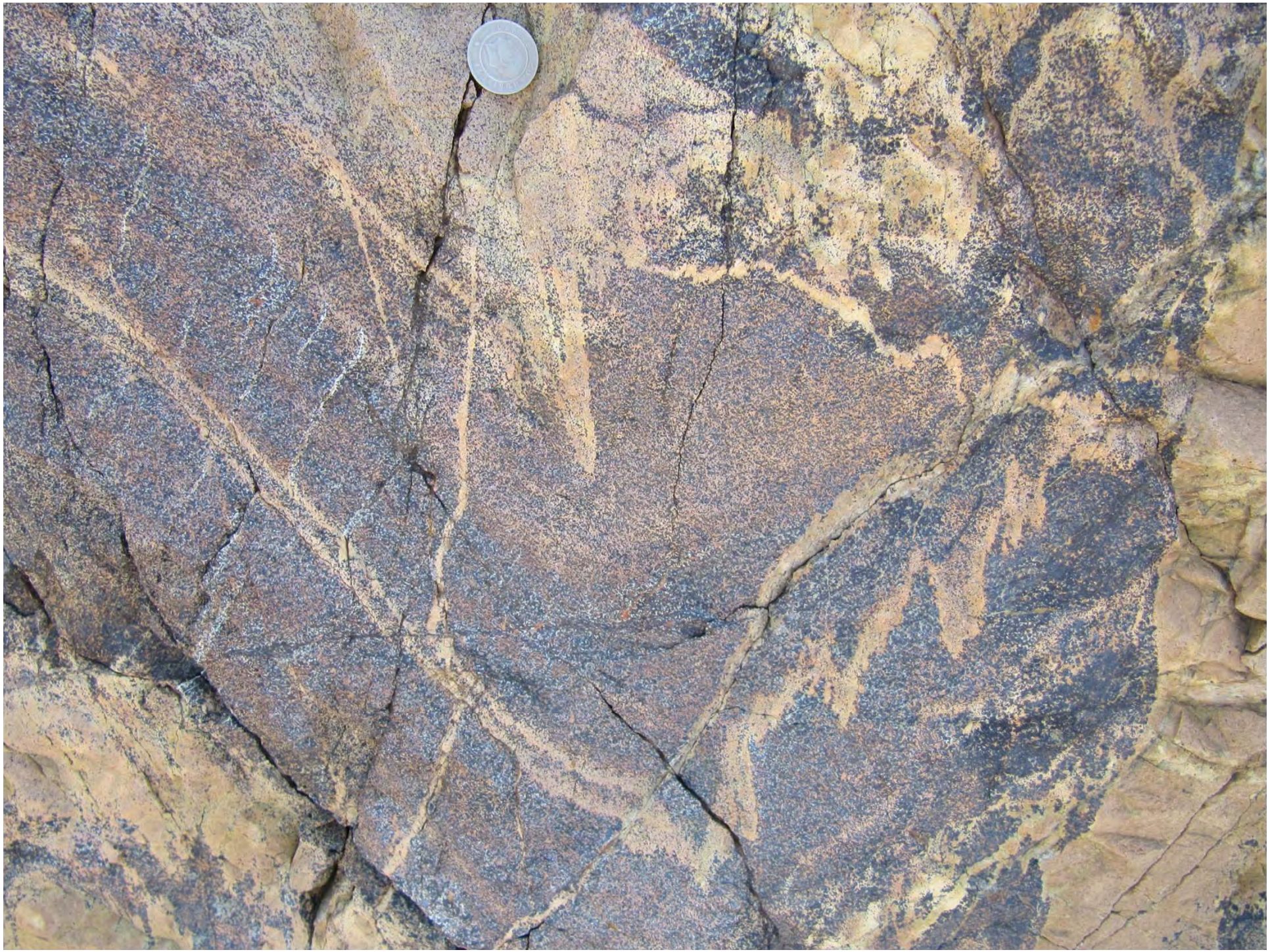
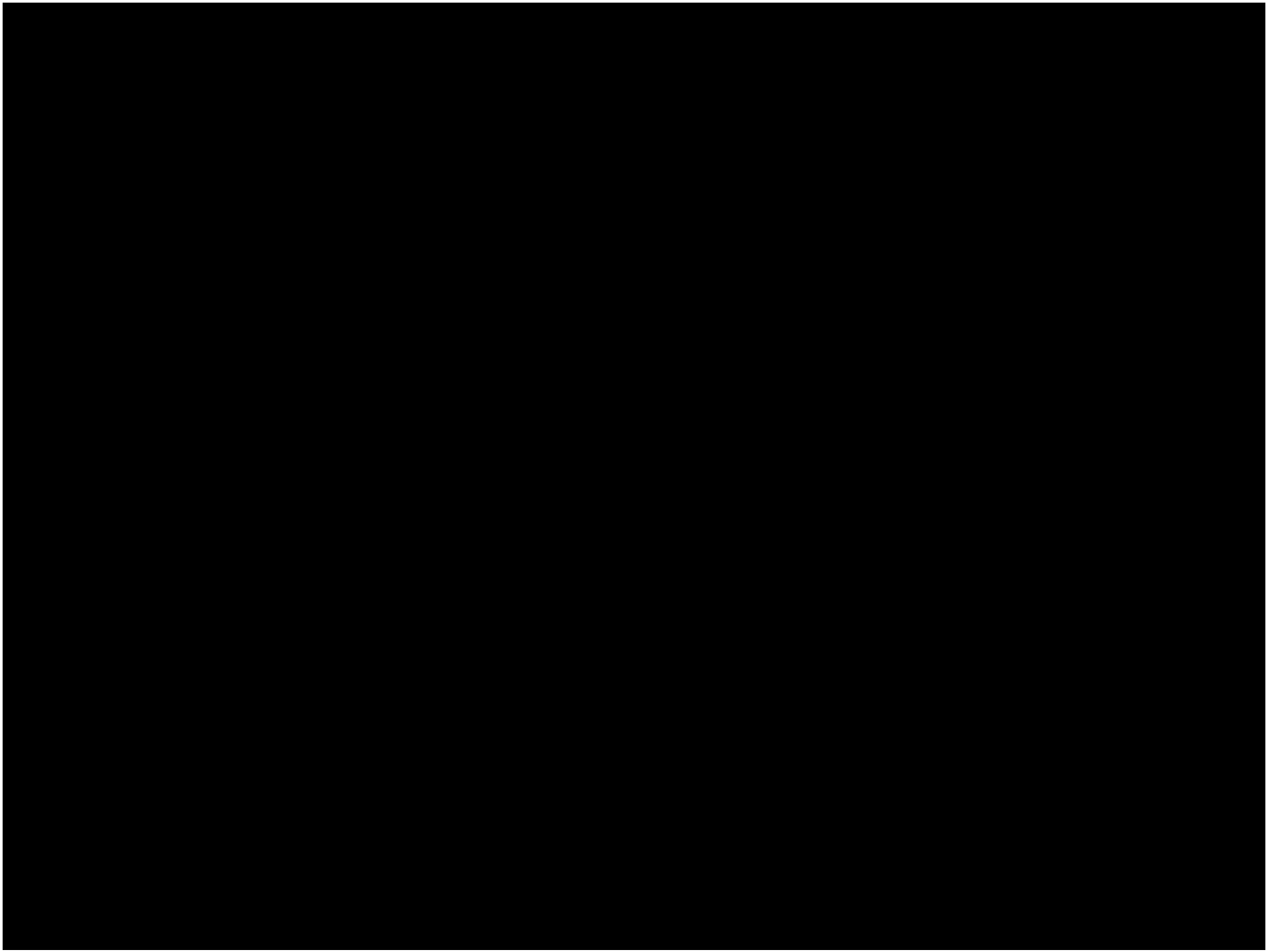
Ophiolite (mainly peridotite)
Basalt, radiolarite, serpentinite Cretaceous accretionary complex
Coherent blueschists with Cretaceous isotopic ages
AFYON ZONE
Micaschist and marble of Paleocene metamorphic age
0
20
40 km
suture
Bulgaria
Black Sea
Caucasus
Istanbul
area shown
Greece
Turkey
Taurides
Mediterranean Sea
400 km

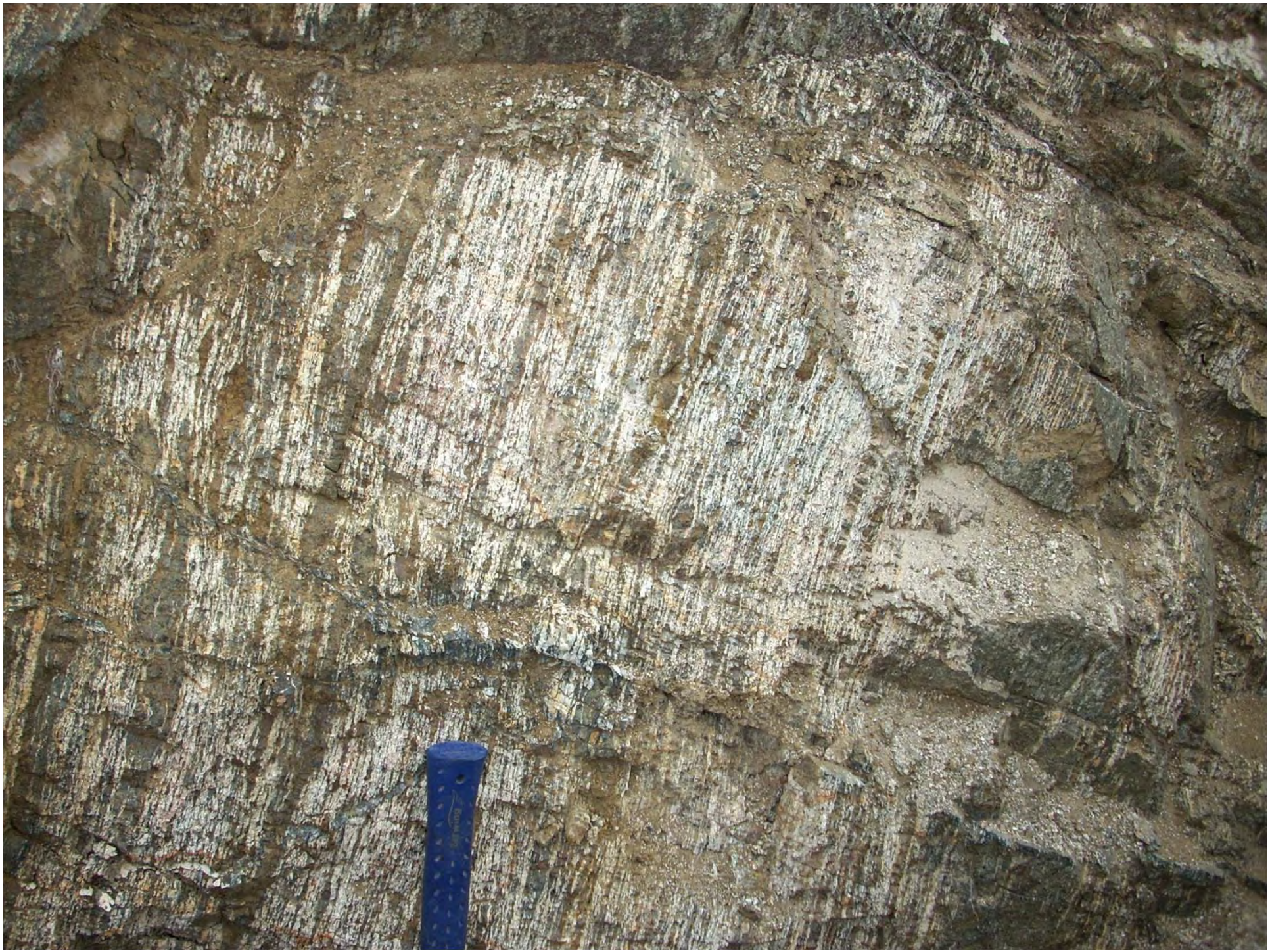
Chromite deposits

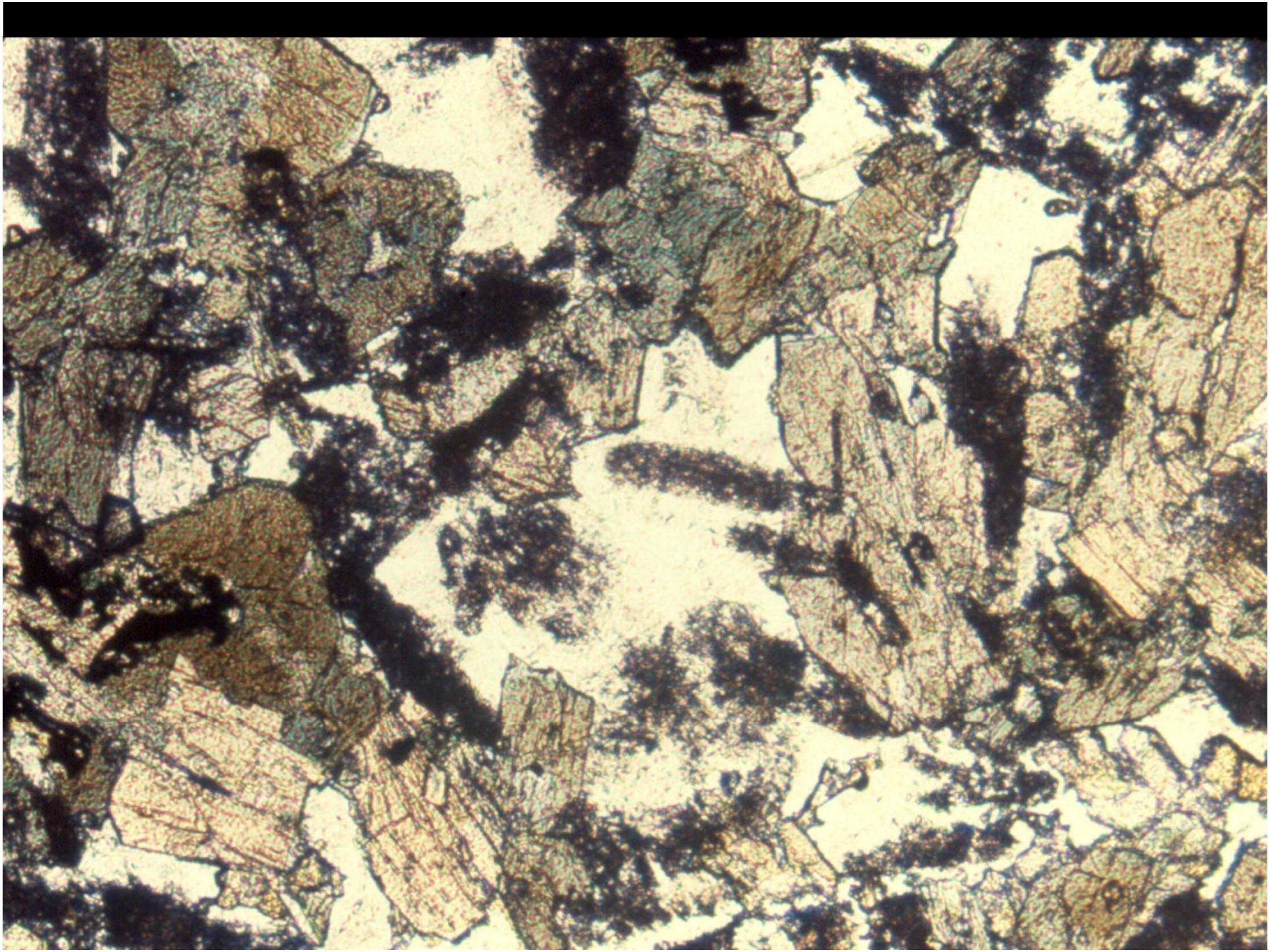






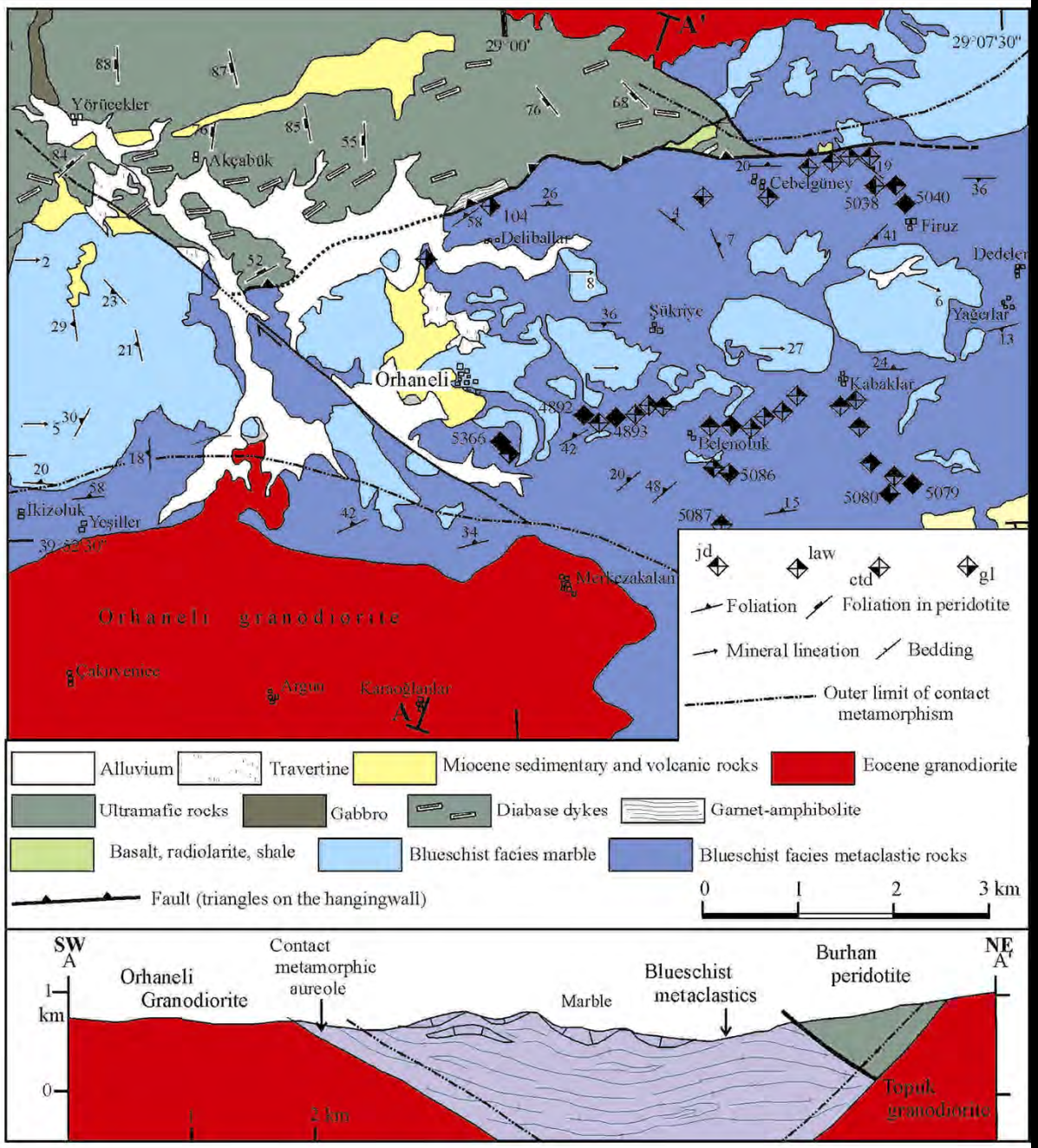
Gabbro and diabase dykes



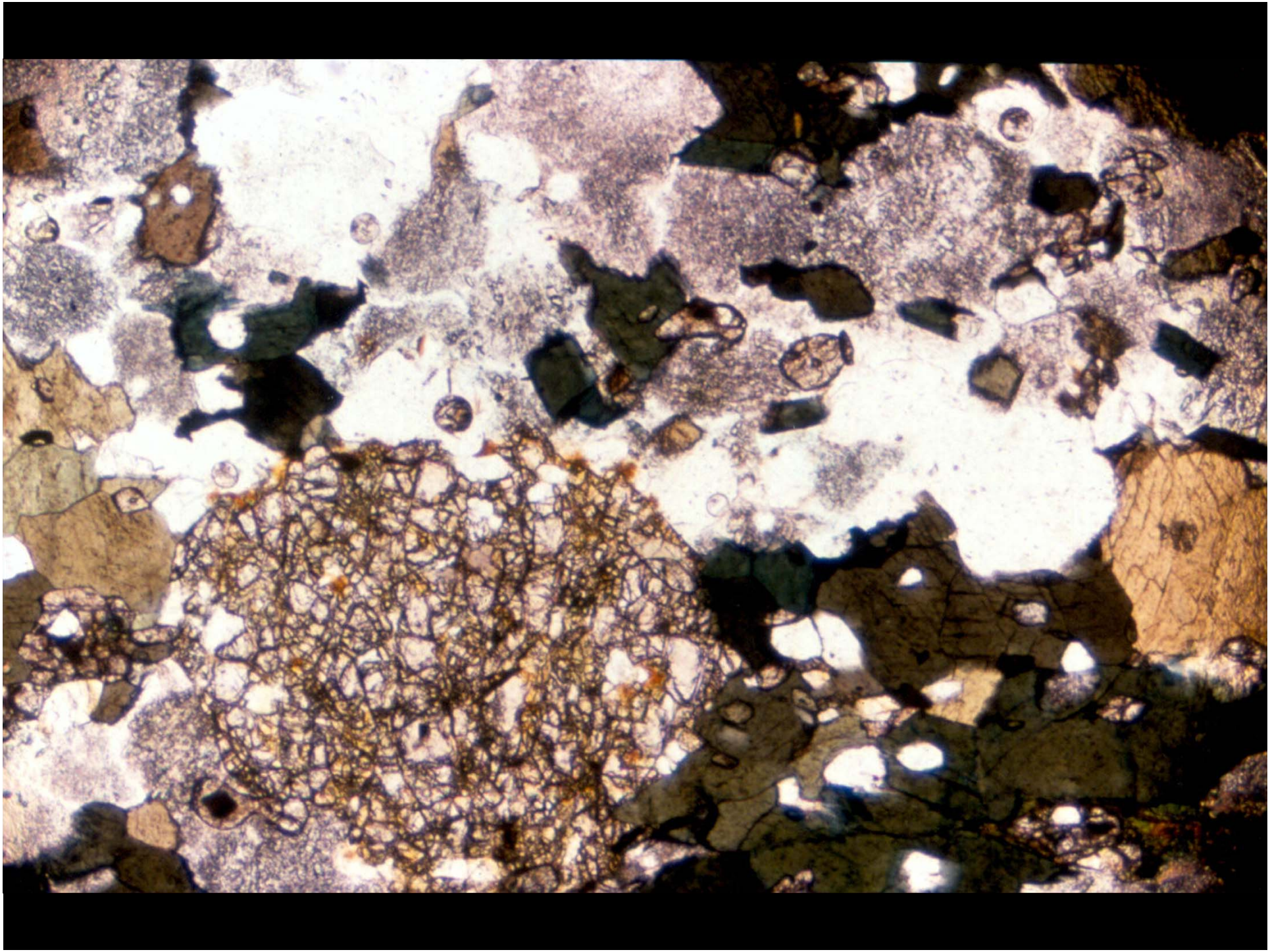


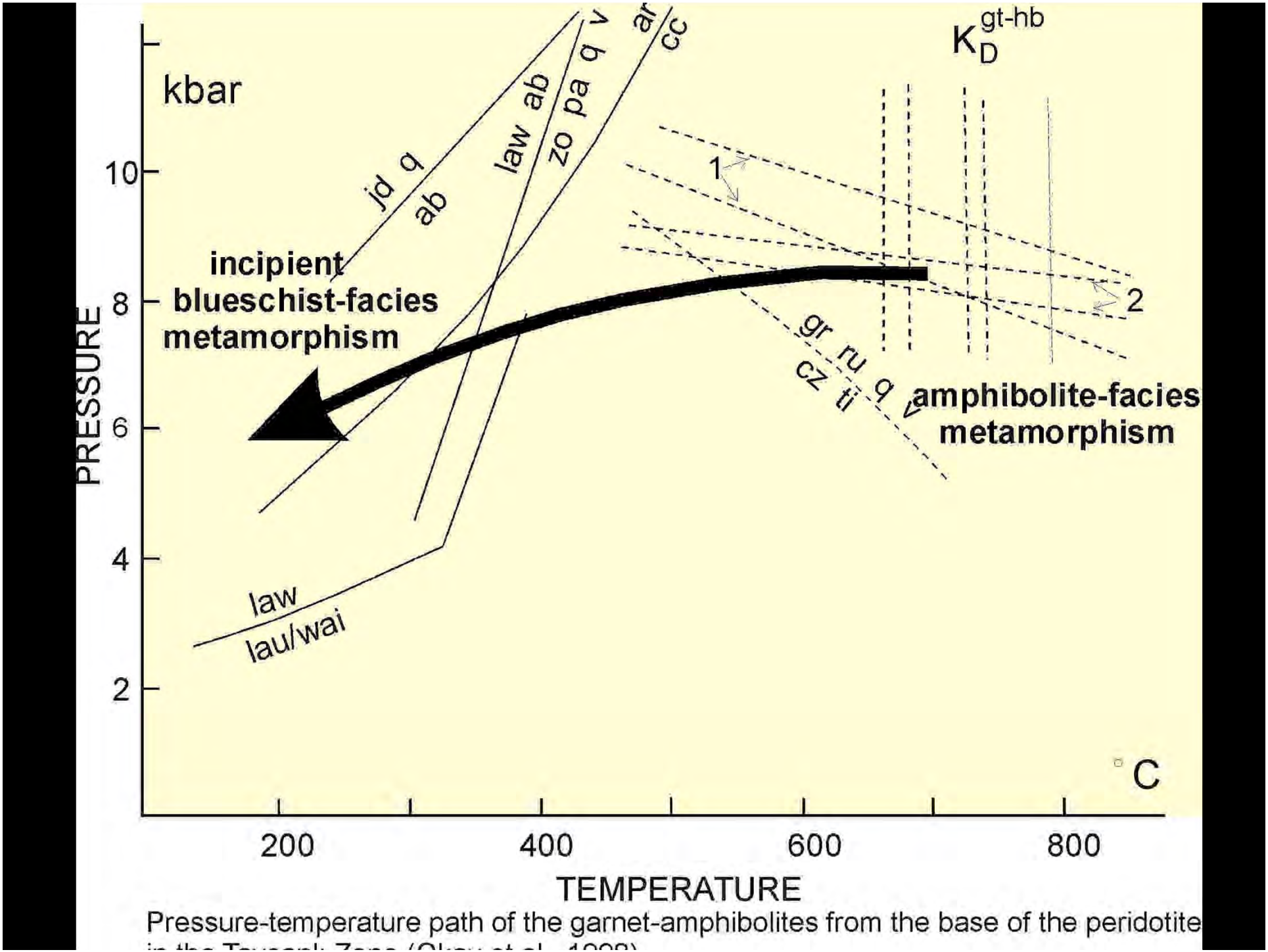
Sub-ophiolite metamorphic rocks

Metamorphism during the initial stages of ophiolite obduction

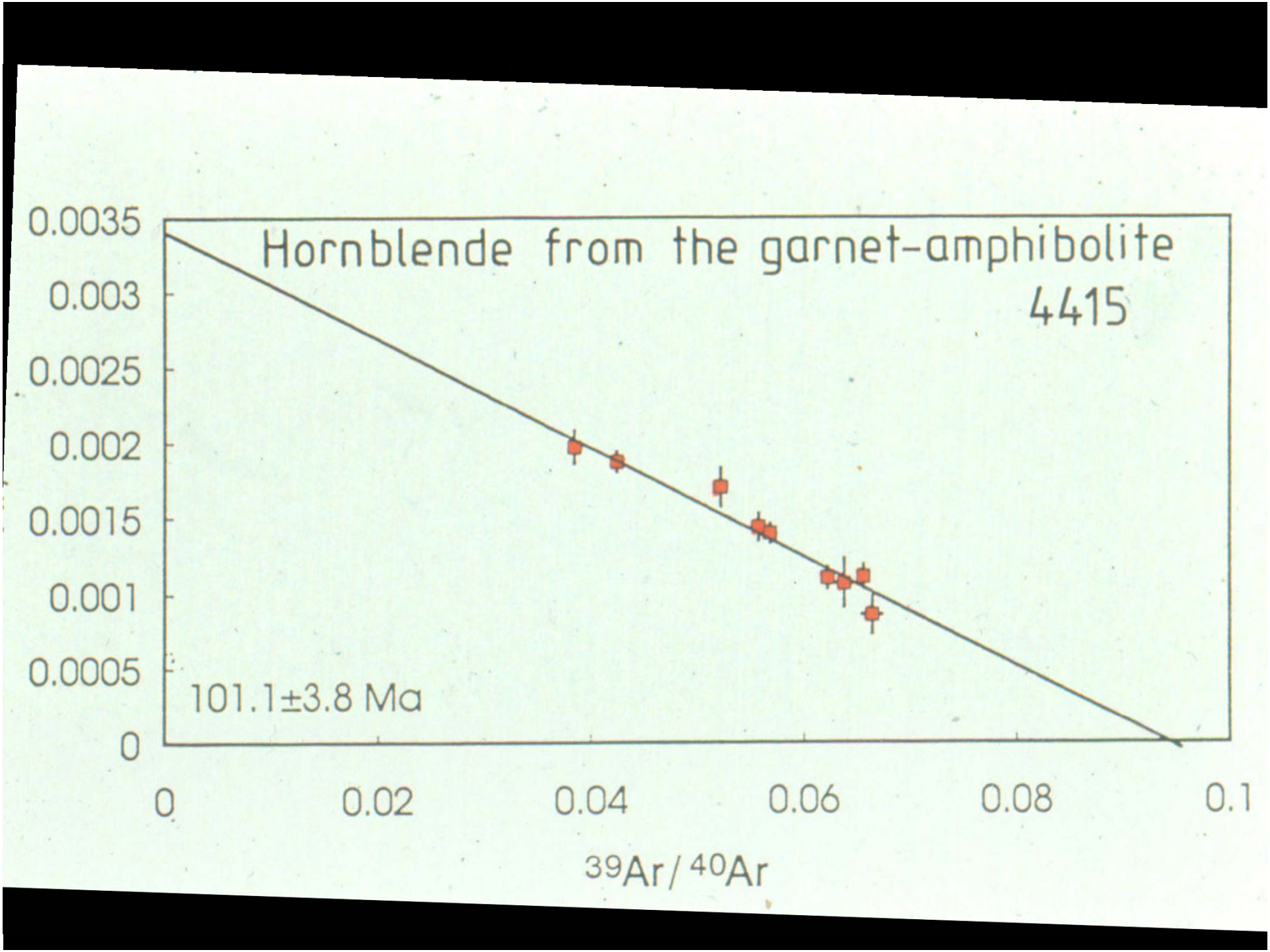


Geological map and cross-section of the Orhaneli region (Okay, 2002)





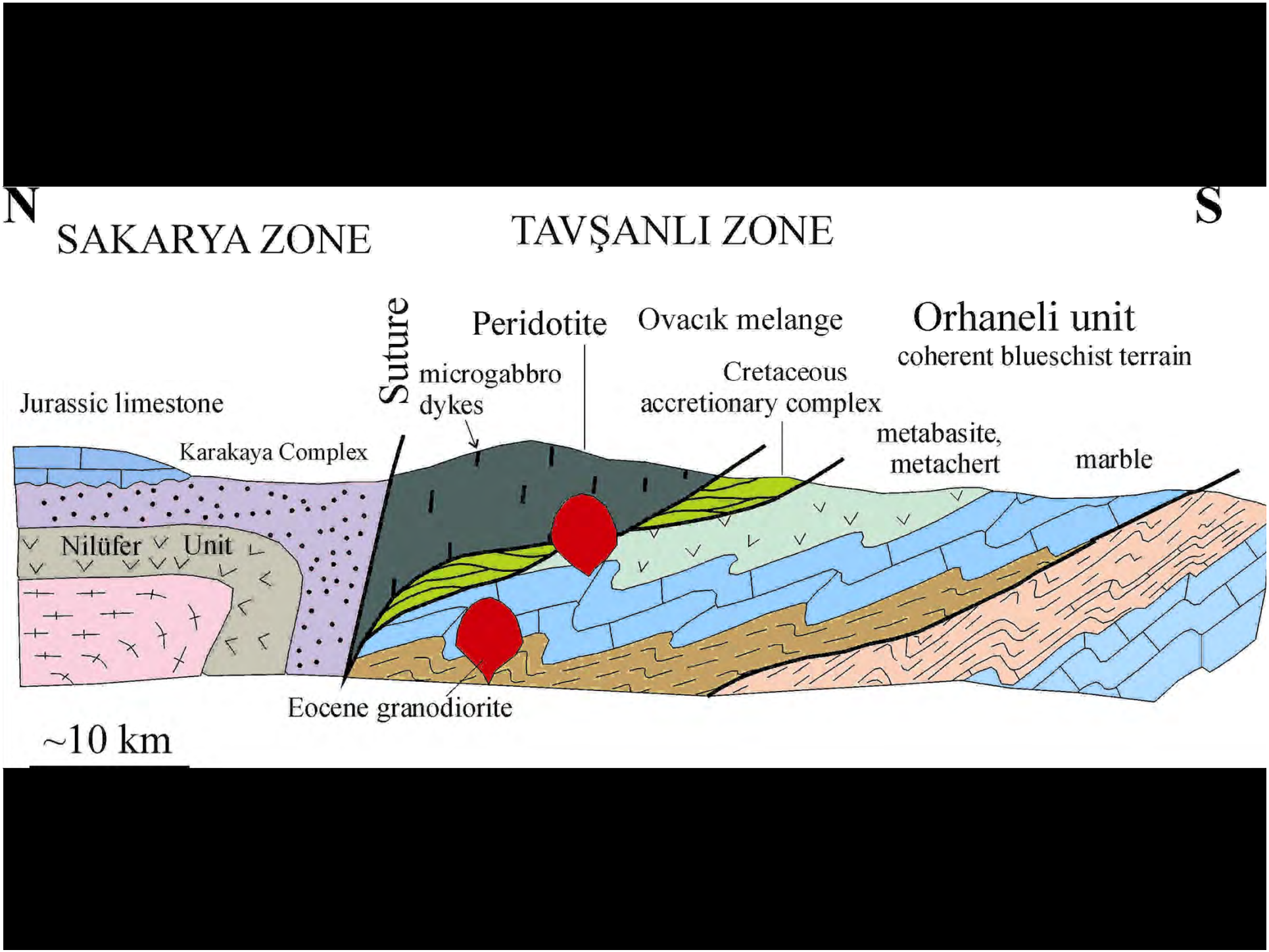
Pressure-temperature path of the garnet-amphibolites from the base of the peridotite

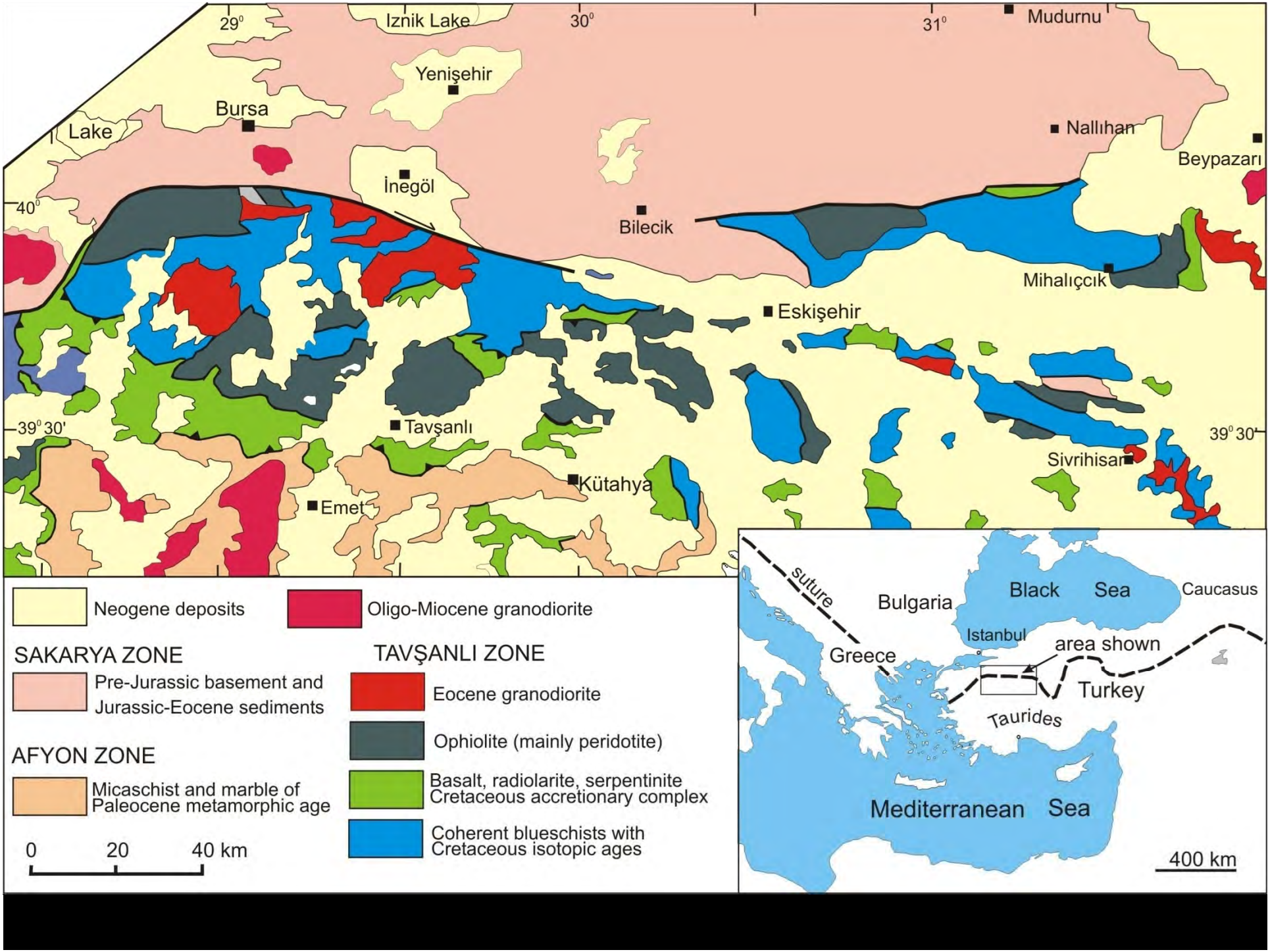

Hornblende from the garnet-amphibolite
4415
101.1±3.8 Ma
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
0.02
0.04
0.06
0.08
0.1
39Ar/40Ar

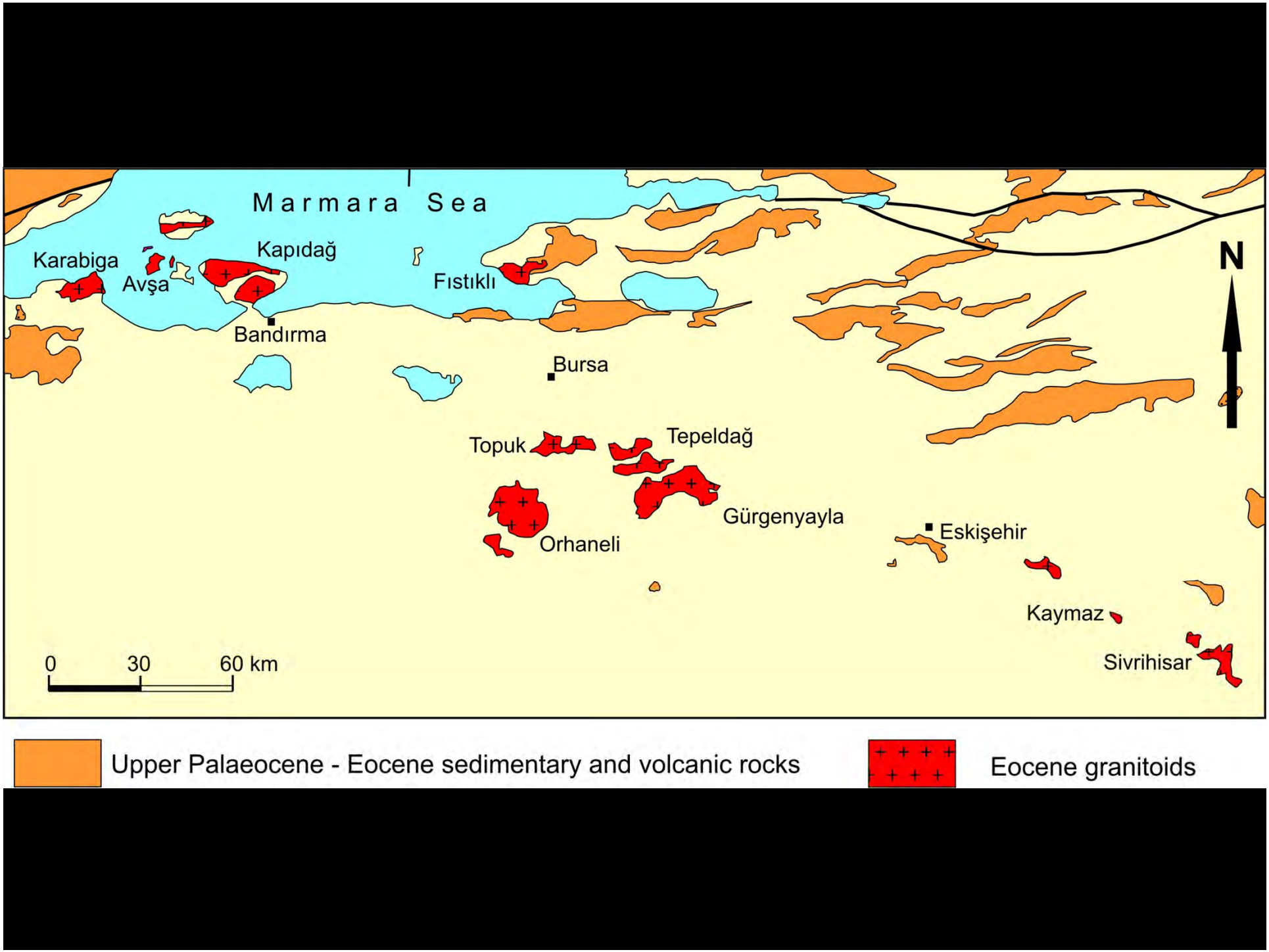
When did the blueschists and ophiolite came together?

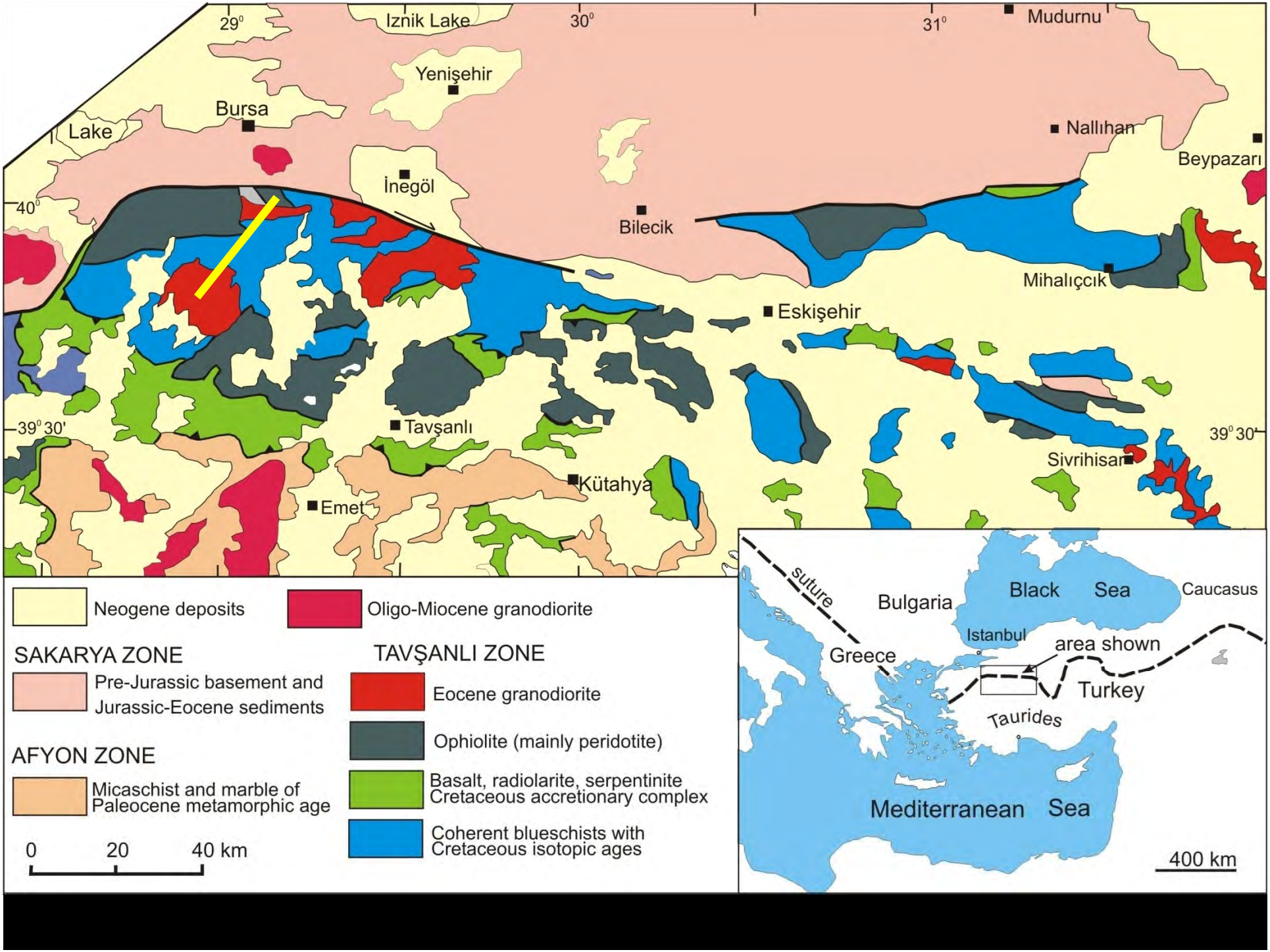
Eocene granodiorites

Post-collisional intrusions cutting both the blueschists and ophiolite


N
SAKARYA ZONE
TAVŞANLI ZONE
S
Suture
Peridotite
Ovacık melange
Orhaneli unit
coherent blueschist terrain
microgabbro
dykes
Cretaceous
accretionary complex
Jurassic limestone
Karakaya Complex
metabasite,
metachert
marble
Nilüfer Unit
Eocene granodiorite
~10 km


29°
Iznik Lake
30°
31°
Mudurnu
Yenişehir
Bursa
Lake
Nallıhan
Beypazarı
İnegöl
40°
Bilecik
Mihalıççık
Eskişehir
39° 30'
Tavşanlı
39° 30'
Sivrihisar
Kütahya
Emet
Neogene deposits
Oligo-Miocene granodiorite
SAKARYA ZONE
Pre-Jurassic basement and
Jurassic-Eocene sediments
TAVŞANLI ZONE
Eocene granodiorite
Ophiolite (mainly peridotite)
Basalt, radiolarite, serpentinite
Cretaceous accretionary complex
Coherent blueschists with
Cretaceous isotopic ages
AFYON ZONE
Micaschist and marble of
Paleocene metamorphic age
0
20
40 km
suture
Bulgaria
Black Sea
Caucasus
Istanbul
area shown
Greece
Turkey
Taurides
Mediterranean Sea
400 km


Marmara Sea
Karabiga
Avşa
Kapıdağ
Bandırma
Fıstıklı
Bursa
Topuk
Tepeldağ
Gürgenyayla
Orhaneli
Eskişehir
Kaymaz
Sivrihisar
N
0
30
60 km
Upper Palaeocene - Eocene sedimentary and volcanic rocks
Eocene granitoids


29°
Iznik Lake
30°
31°
Mudurnu
Yenişehir
Bursa
Lake
Nallıhan
Beypazarı
İnegöl
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Bilecik
Mihalıççık
Eskişehir
39° 30'
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Kütahya
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SAKARYA ZONE
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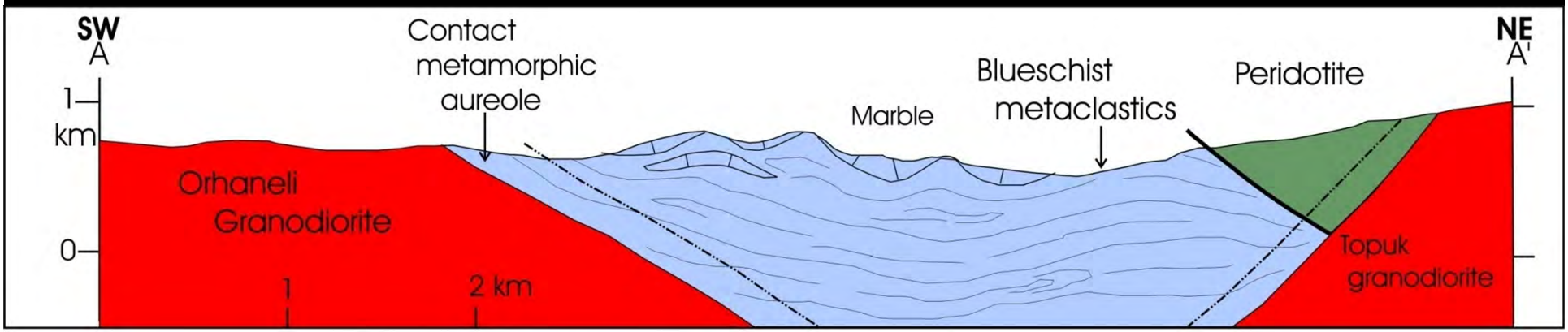
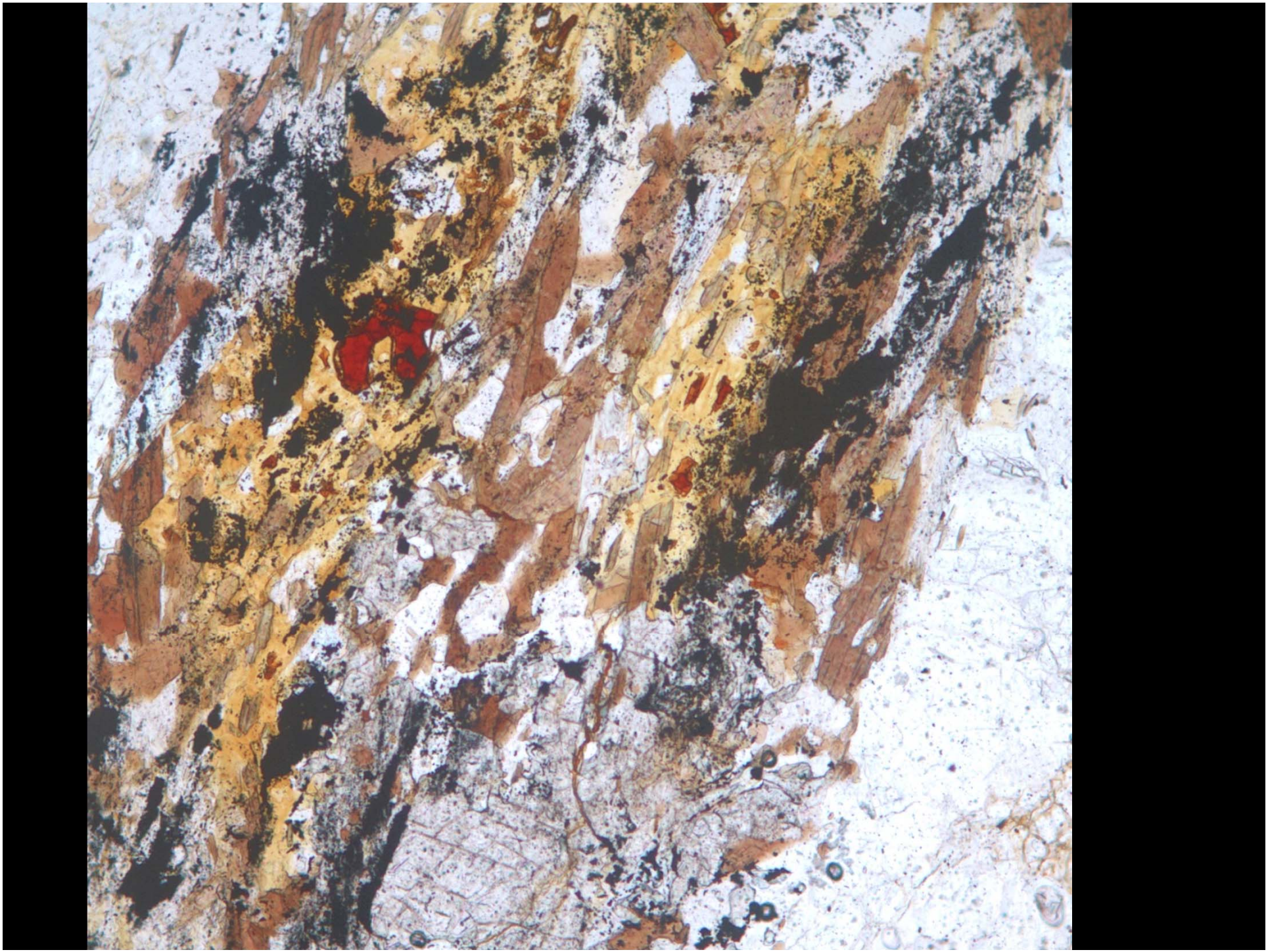
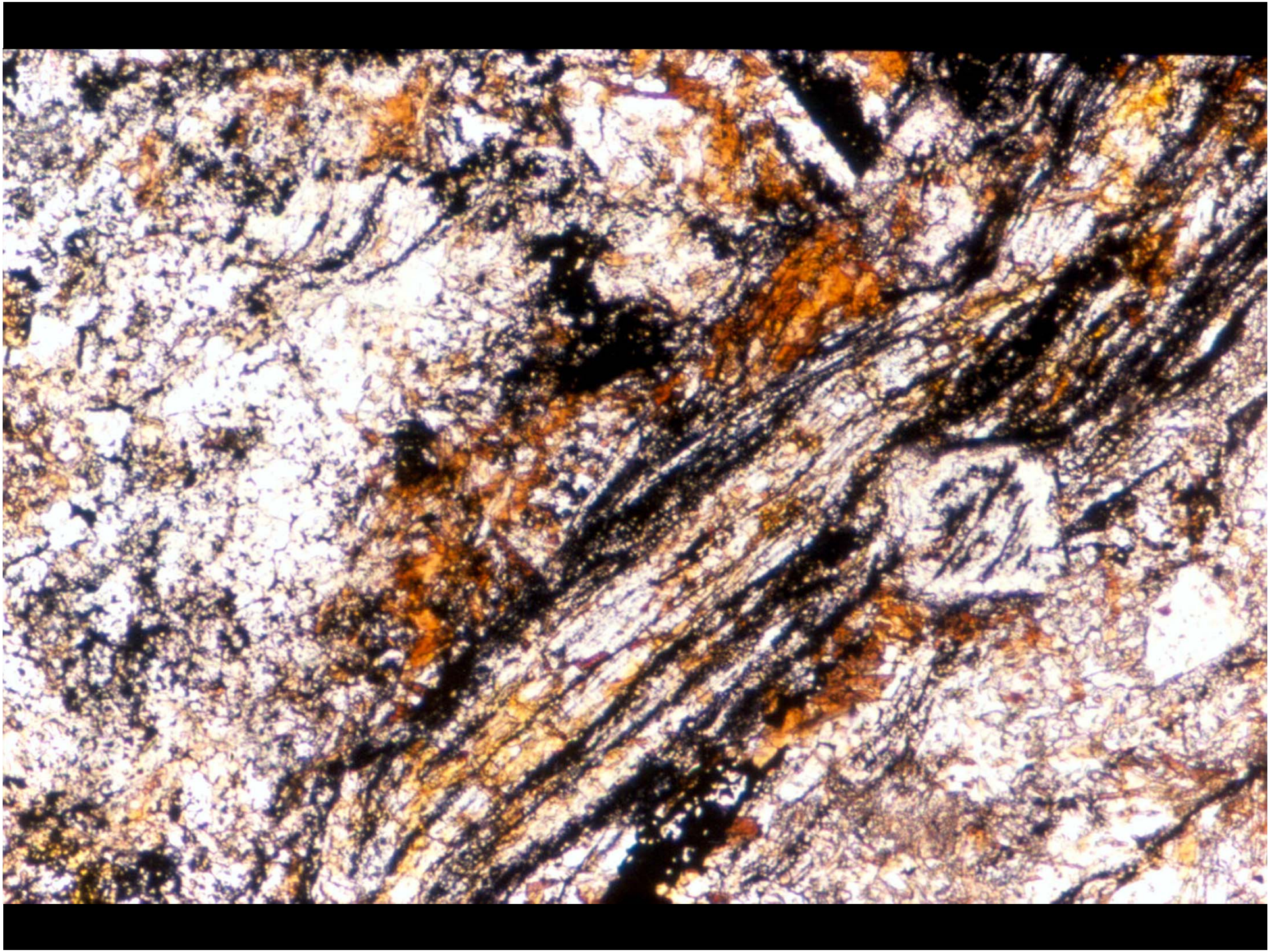
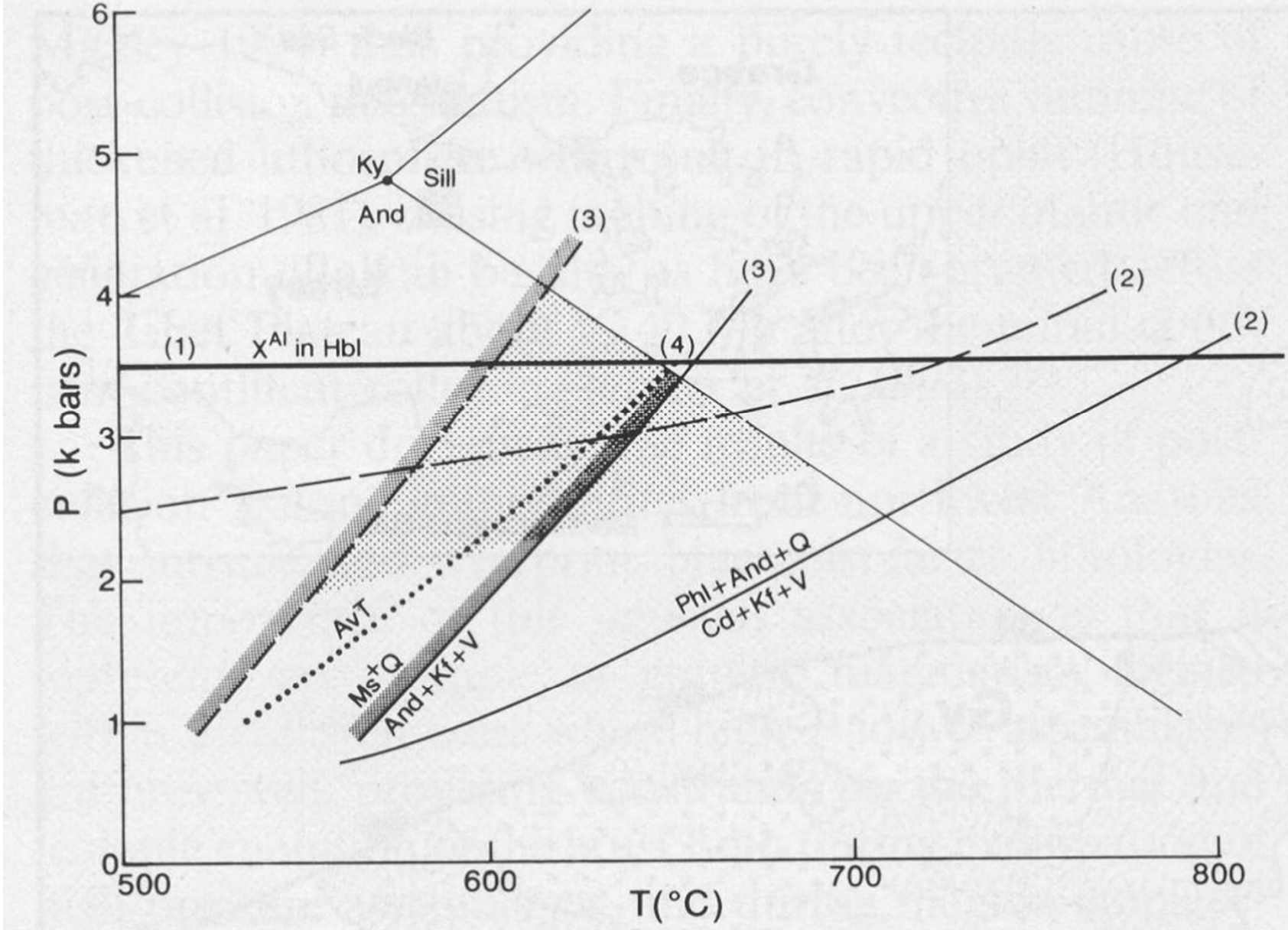
Micaschist and marble of
Paleocene metamorphic age
0
20
40 km
suture
Bulgaria
Black Sea
Caucasus
Istanbul
area shown
Greece
Turkey
Taurides
Mediterranean Sea
400 km

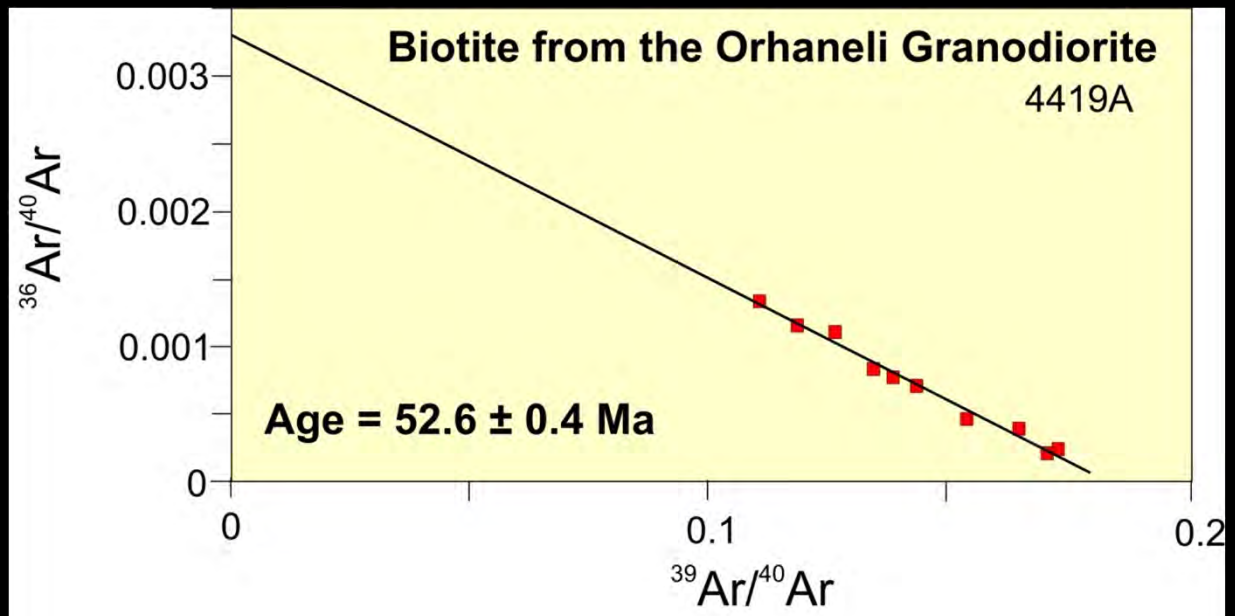


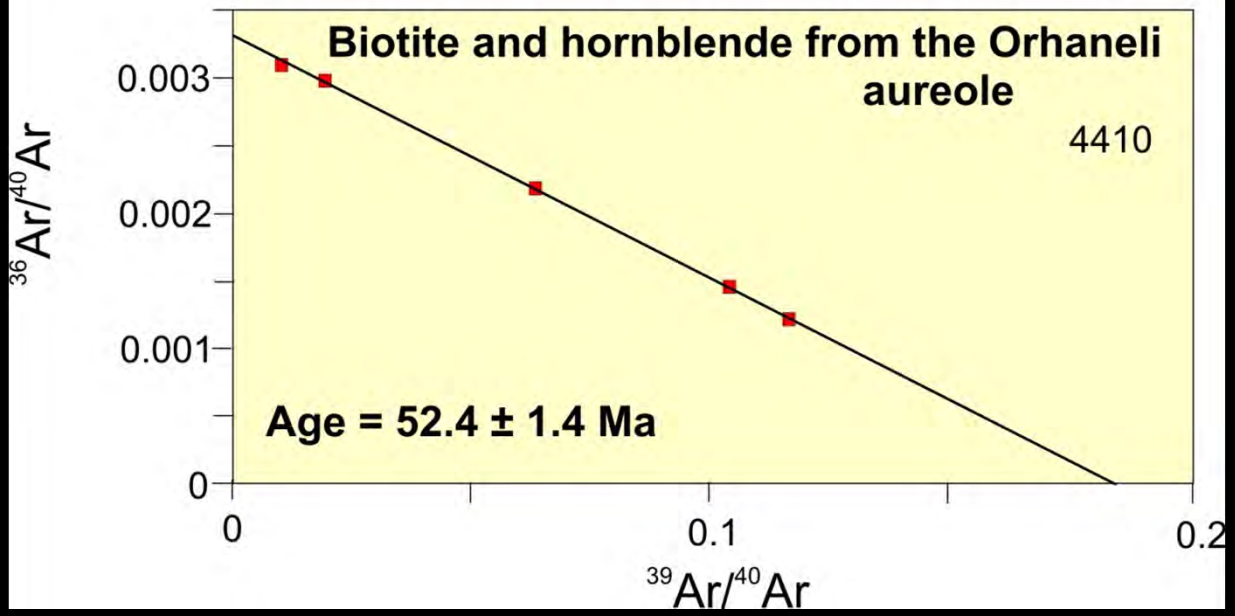
Geological cross-section from the Orhaneli region (Okay, 2002)



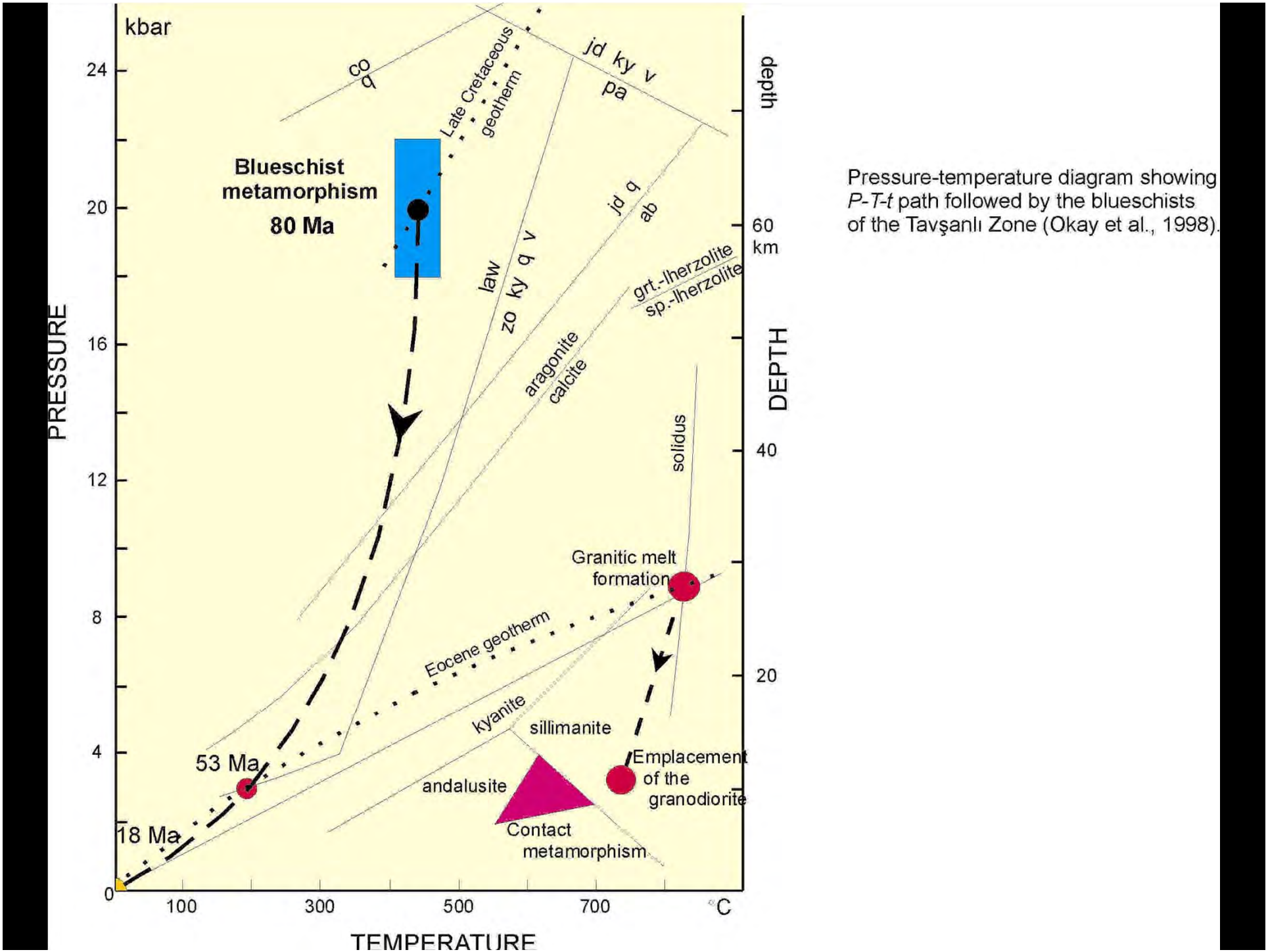



P (k bars)
T(°C)
Ky
Sill
And
(1)
X^{Al} in Hbl
(2)
(3)
(4)
AvT
Ms+Q
And+Kf+V
Phl+And+Q
Cd+Kf+V


Biotite from the Orhaneli Granodiorite
4419A
Age = 52.6 ± 0.4 Ma
0.003
0.002
0.001
0
0
0.1
0.2
$^{36}Ar/^{40}Ar$
$^{39}Ar/^{40}Ar$

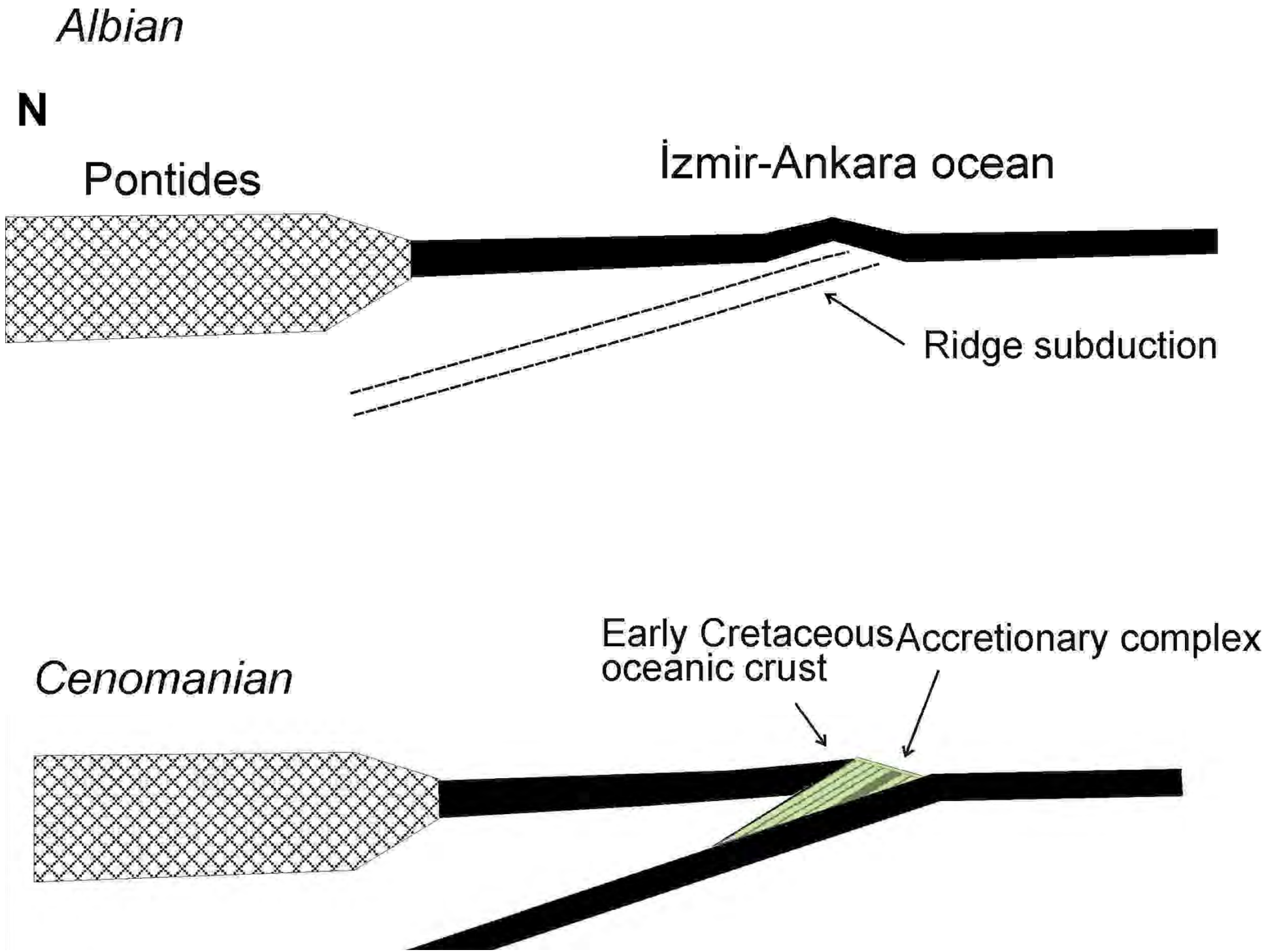

Biotite and hornblende from the Orhaneli aureole
4410
Age = 52.4 ± 1.4 Ma
0.003
0.002
0.001
0
0
0.1
0.2
$^{36}Ar/^{40}Ar$
$^{39}Ar/^{40}Ar$

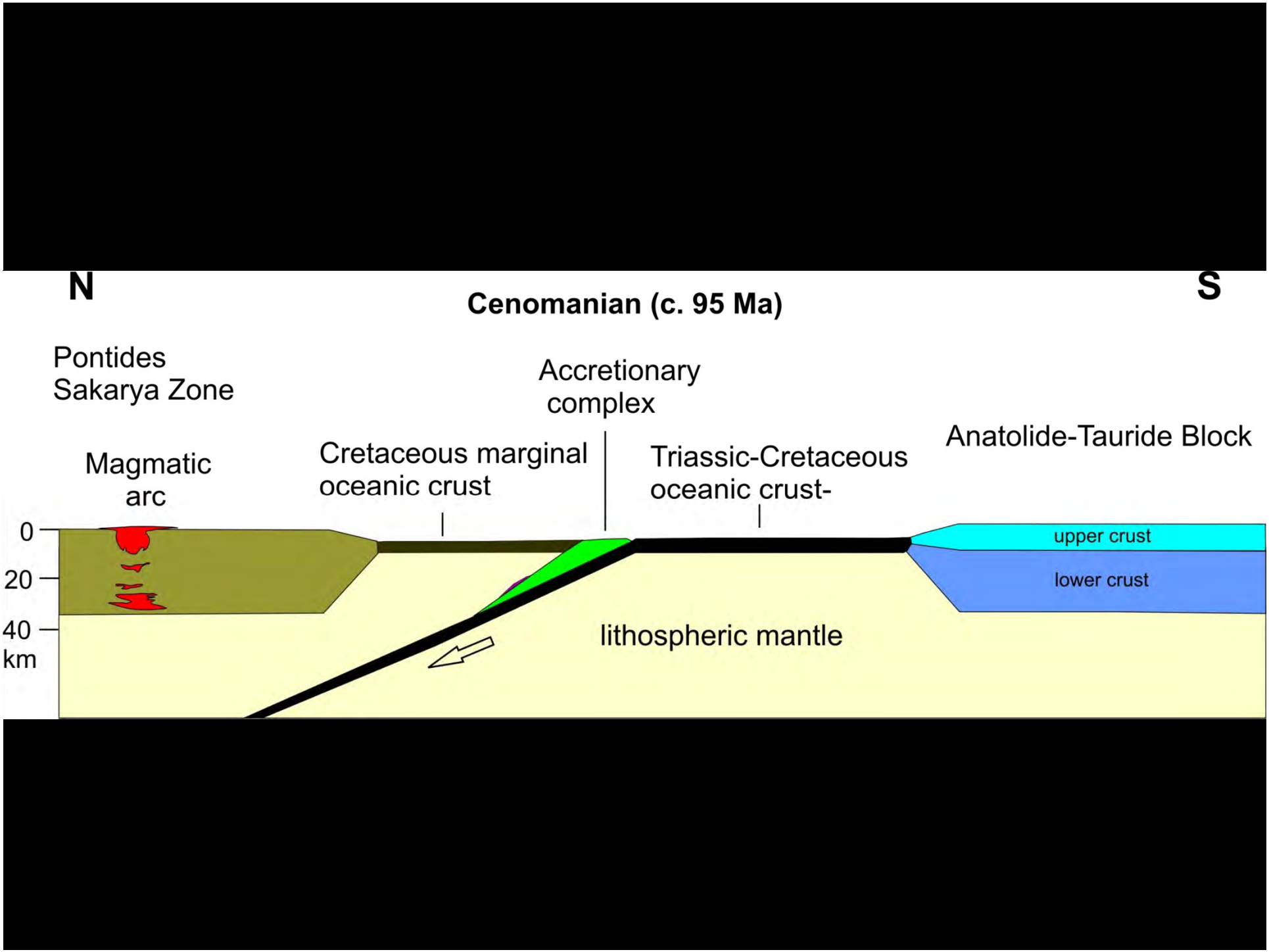
In the Early Eocene (53 Ma) the blueschist-ophiolite tectonic stack was essentially in their present position and within 10 km of the surface

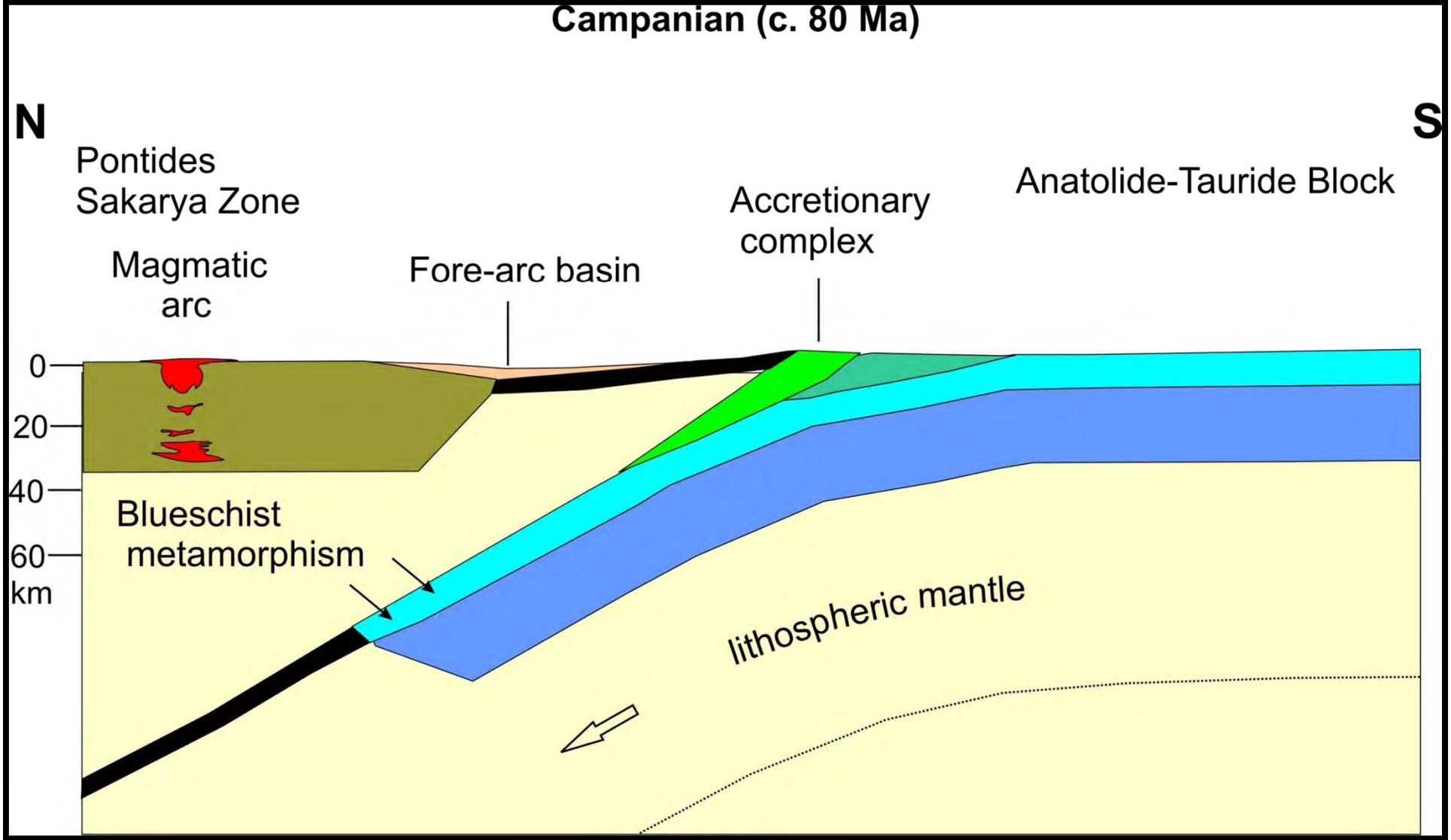


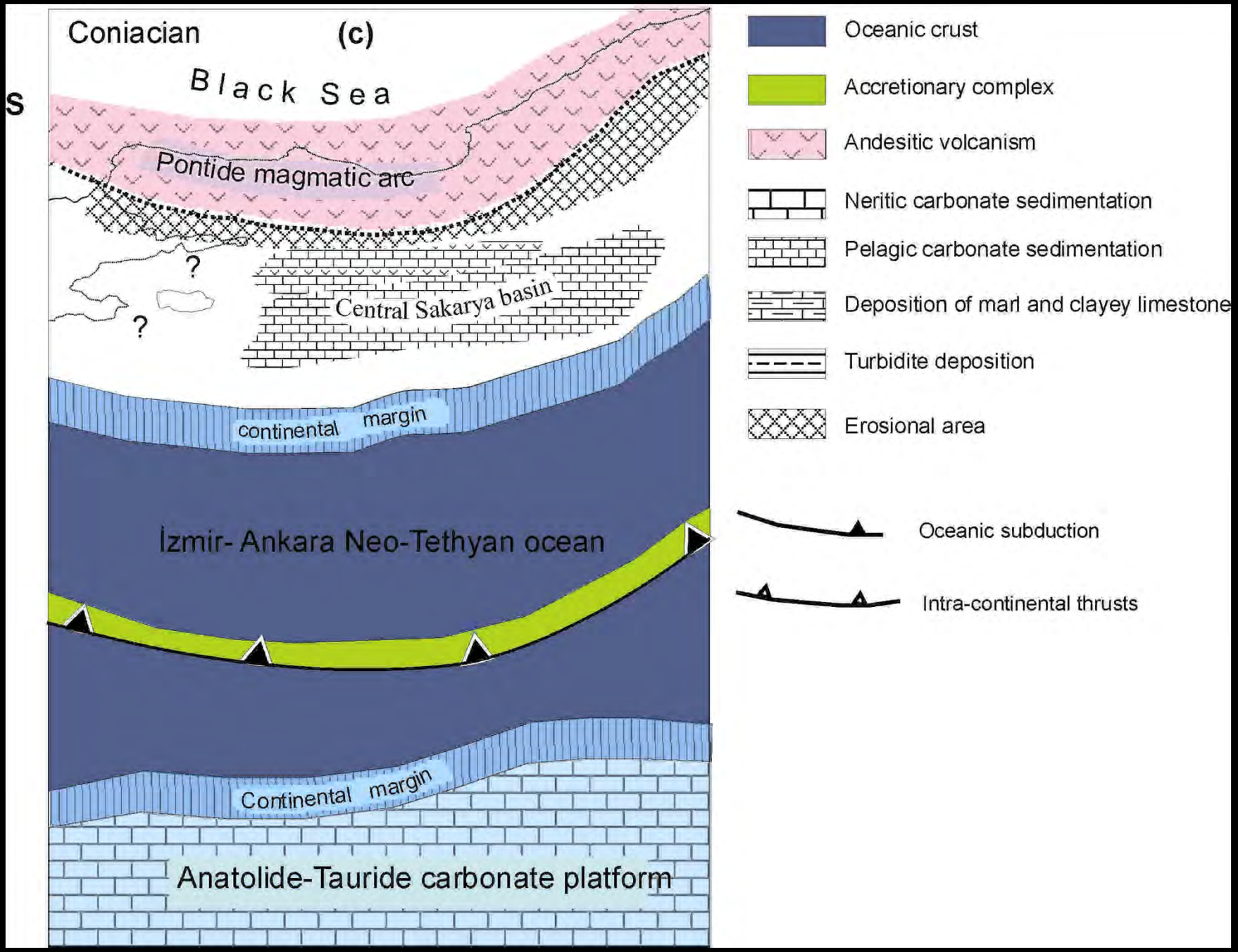
Pressure-temperature diagram showing *P-T-t* path followed by the blueschists of the Tavşanlı Zone (Okay et al., 1998).

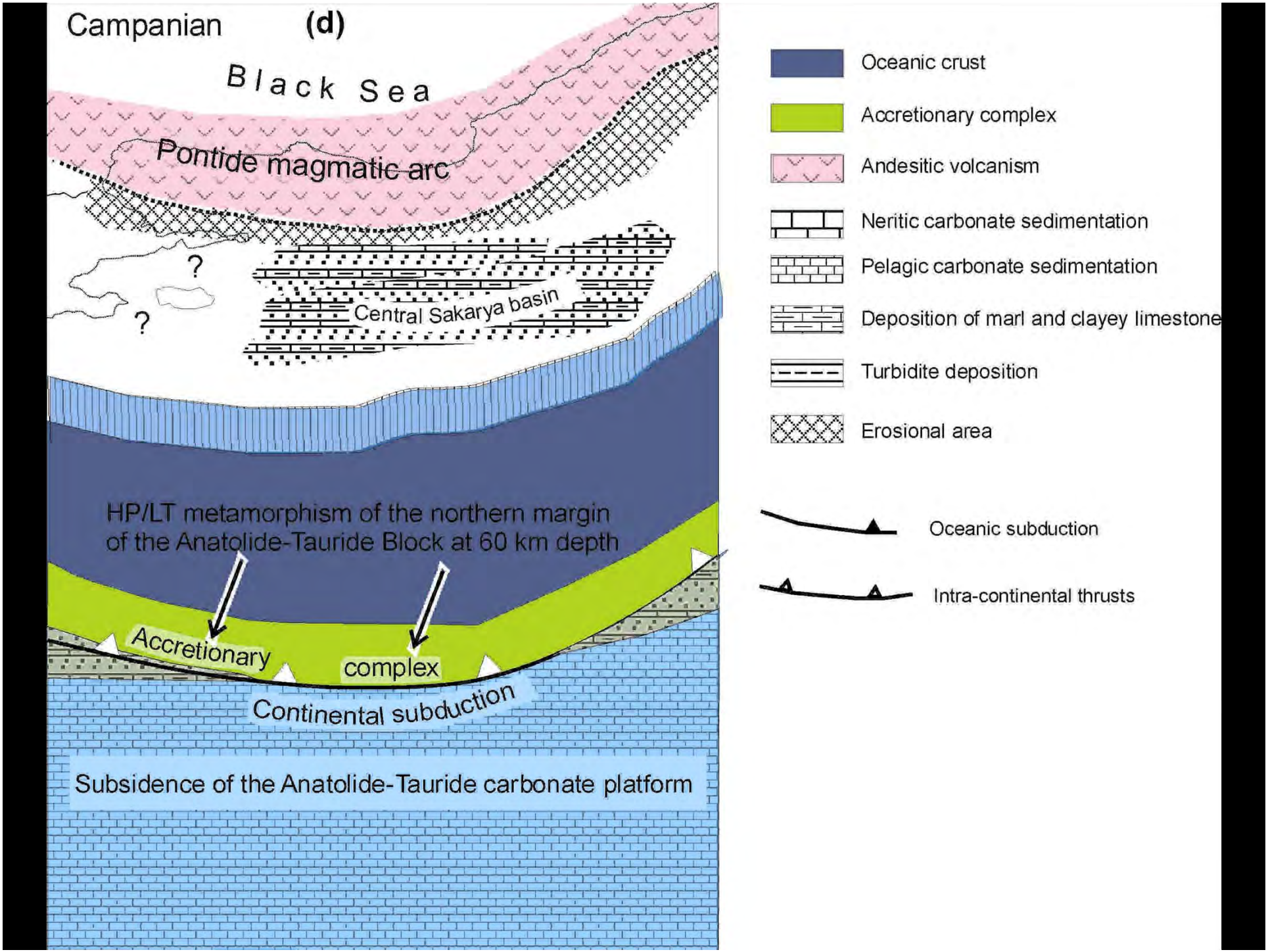
Tectonic evolution

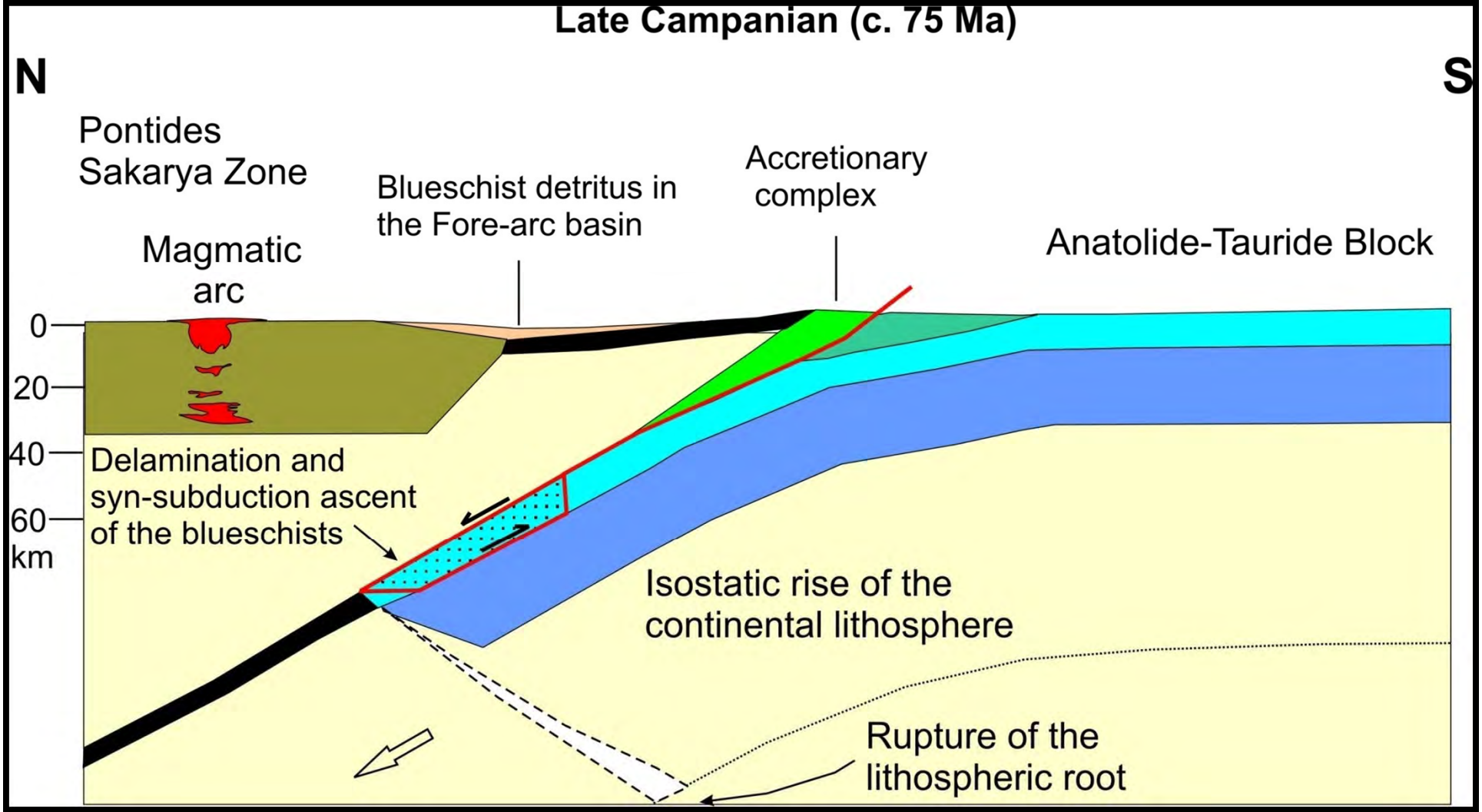

Albian
N
Pontides
İzmir-Ankara ocean
Ridge subduction
Cenomanian
Early Cretaceous
oceanic crust
Accretionary complex

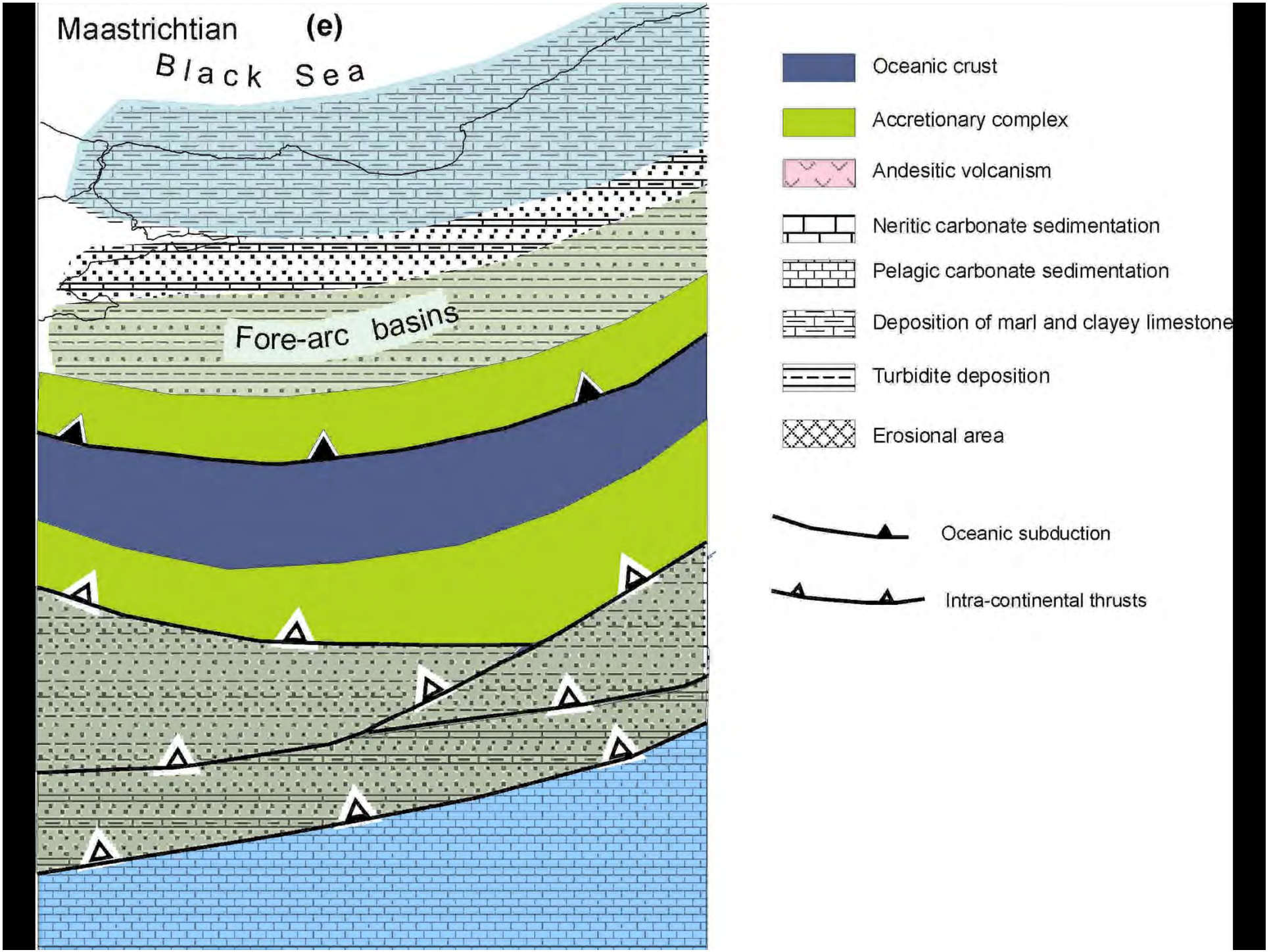

N
S
Cenomanian (c. 95 Ma)
Pontides
Sakarya Zone
Accretionary
complex
Anatolide-Tauride Block
Magmatic
arc
Cretaceous marginal
oceanic crust
Triassic-Cretaceous
oceanic crust-
0
20
40
km
upper crust
lower crust
lithospheric mantle

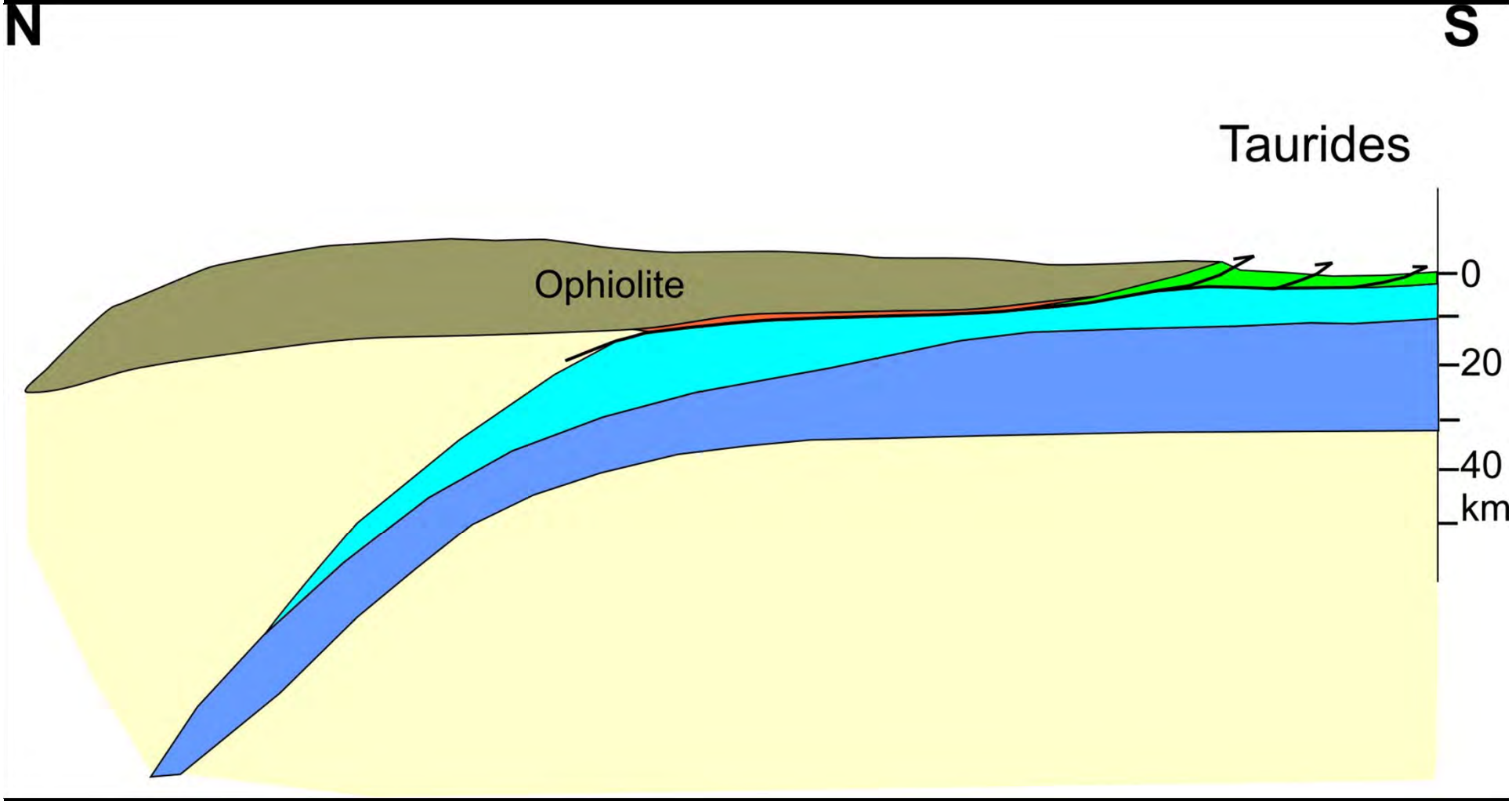

Campanian (c. 80 Ma)
N
S
Pontides
Sakarya Zone
Anatolide-Tauride Block
Accretionary
complex
Magmatic
arc
Fore-arc basin
0
20
40
60
km
Blueschist
metamorphism
lithospheric mantle

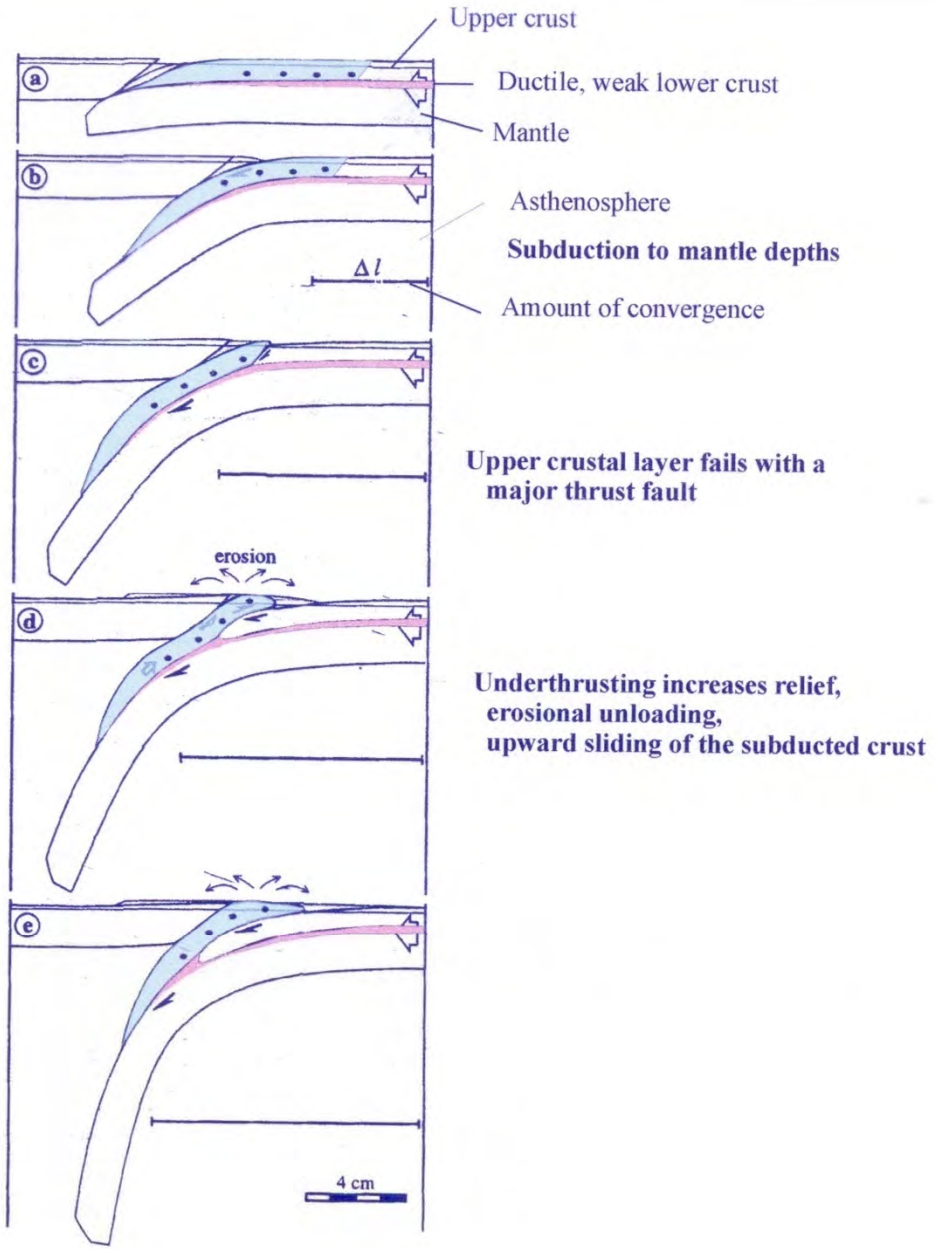

Coniacian
(c)
Black Sea
Pontide magmatic arc
?
?
Central Sakarya basin
continental margin
İzmir- Ankara Neo-Tethyan ocean
Continental margin
Anatolide-Tauride carbonate platform
Oceanic crust
Accretionary complex
Andesitic volcanism
Neritic carbonate sedimentation
Pelagic carbonate sedimentation
Deposition of marl and clayey limestone
Turbidite deposition
Erosional area
Oceanic subduction
Intra-continental thrusts


Campanian (d)
Black Sea
Pontide magmatic arc
?
?
Central Sakarya basin
HP/LT metamorphism of the northern margin
of the Anatolide-Tauride Block at 60 km depth
Accretionary
complex
Continental subduction
Subsidence of the Anatolide-Tauride carbonate platform
Oceanic crust
Accretionary complex
Andesitic volcanism
Neritic carbonate sedimentation
Pelagic carbonate sedimentation
Deposition of marl and clayey limestone
Turbidite deposition
Erosional area
Oceanic subduction
Intra-continental thrusts


Late Campanian (c. 75 Ma)
N
S
Pontides
Sakarya Zone
Magmatic
arc
Blueschist detritus in
the Fore-arc basin
Accretionary
complex
Anatolide-Tauride Block
0
20
40
60
km
Delamination and
syn-subduction ascent
of the blueschists
Isostatic rise of the
continental lithosphere
Rupture of the
lithospheric root


Maastrichtian (e)
Black Sea
Fore-arc basins
Oceanic crust
Accretionary complex
Andesitic volcanism
Neritic carbonate sedimentation
Pelagic carbonate sedimentation
Deposition of marl and clayey limestone
Turbidite deposition
Erosional area
Oceanic subduction
Intra-continental thrusts


N
S
Taurides
Ophiolite
0
20
40
km



Drawing of an analogue experiment of subduction of continental lithosphere (Chemenda et al., 1995). The model includes a strong upper crust, a weak ductile lower crust and a strong mantle part.

Some unanswered questions