

Neotectonics and Seismicity of Turkey

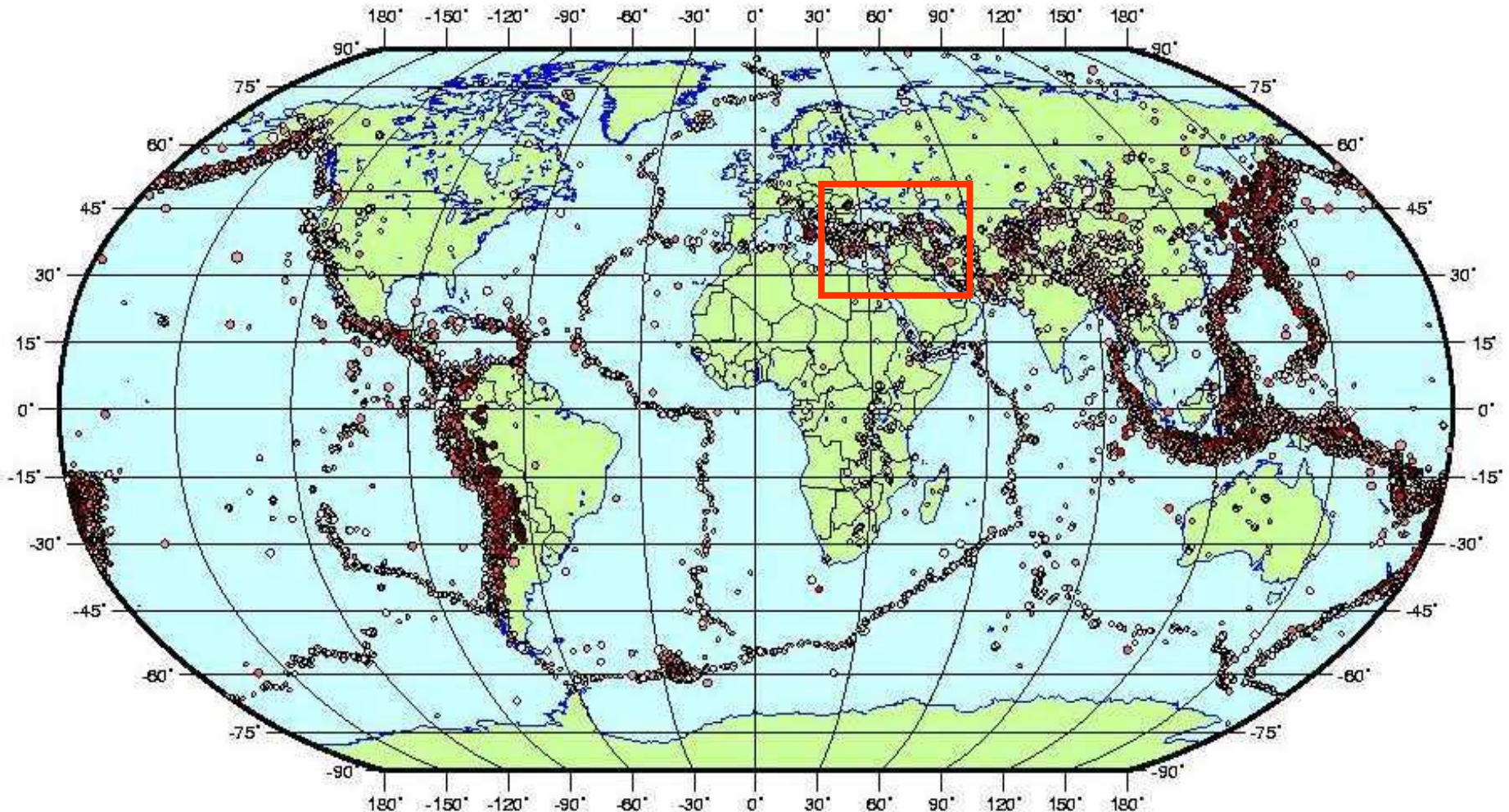
Okan Tüysüz

ITU

Eurasia Institute of Earth Sciences

2005

Turkey forms one of the youngest and most active part of the Alpide Orogenic System



TECTONICS of TURKEY

- The Alpidic orogenic system is created by the closing of different branches of Tethys Ocean
- During the closing of Tethys, different continental fragments belonging to Gondwana and Laurasia collided and amalgamated into each other.
- Turkey is an “orogenic collage” created by these amalgamated continental fragments and the remnants of oceanic environments separating them.

24°

28°

32°

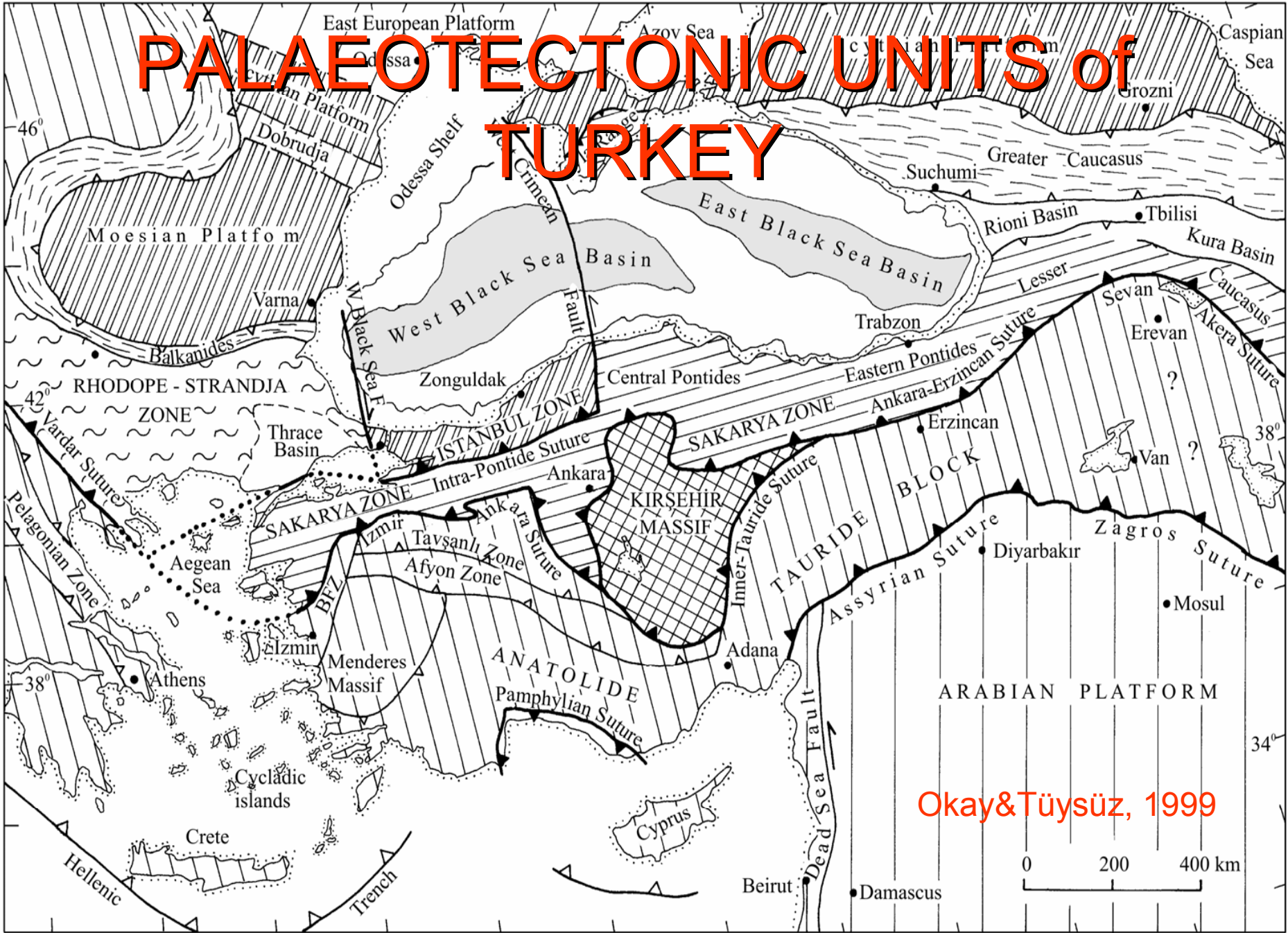
36°

40°

44°

46°

PALAEOTECTONIC UNITS of TURKEY



Okay & Tüysüz, 1999

0 200 400 km

LATE CRETACEOUS-EARLY TERTIARY (65 Ma)



EOCENE (50 Ma)



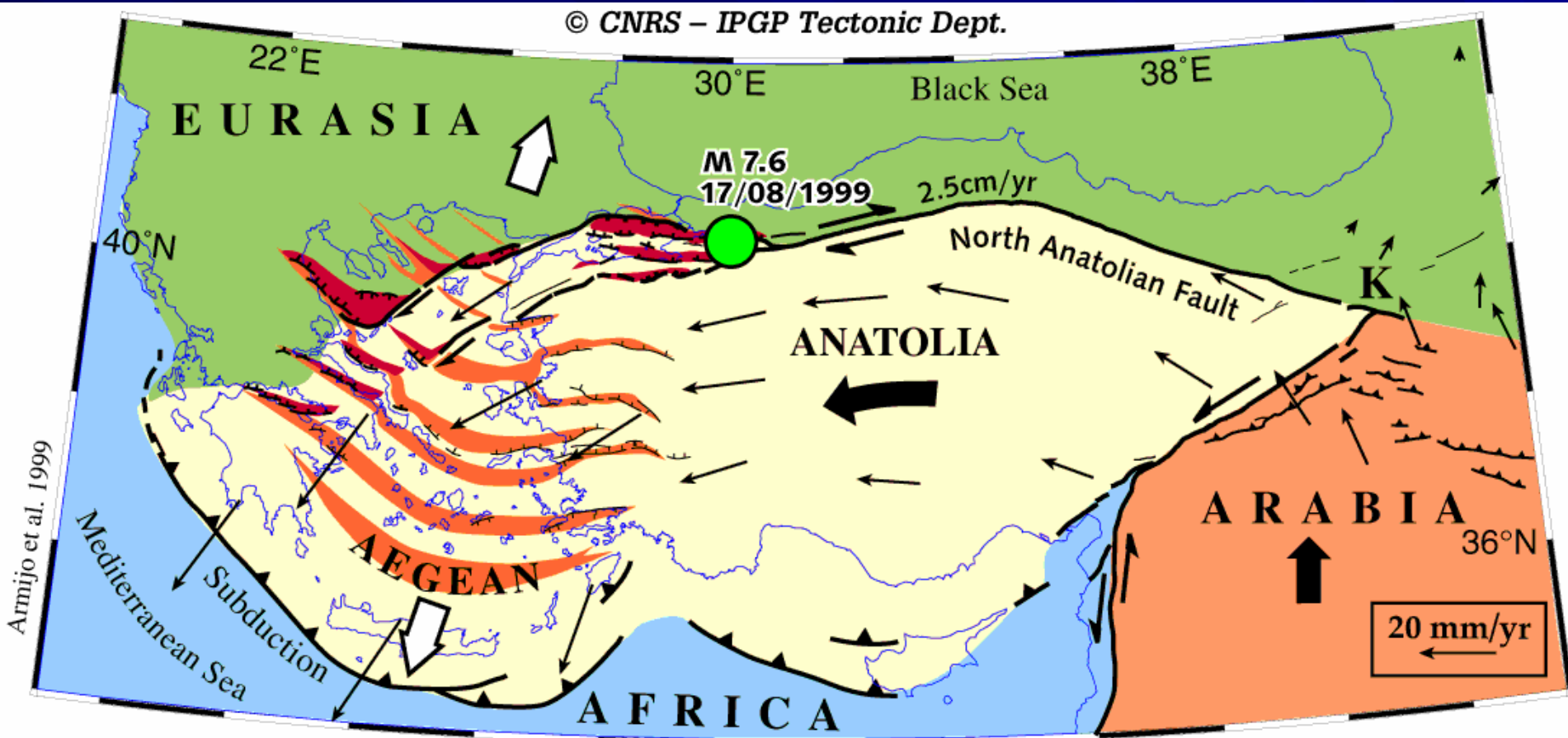
LATE MIOCENE (11 Ma)



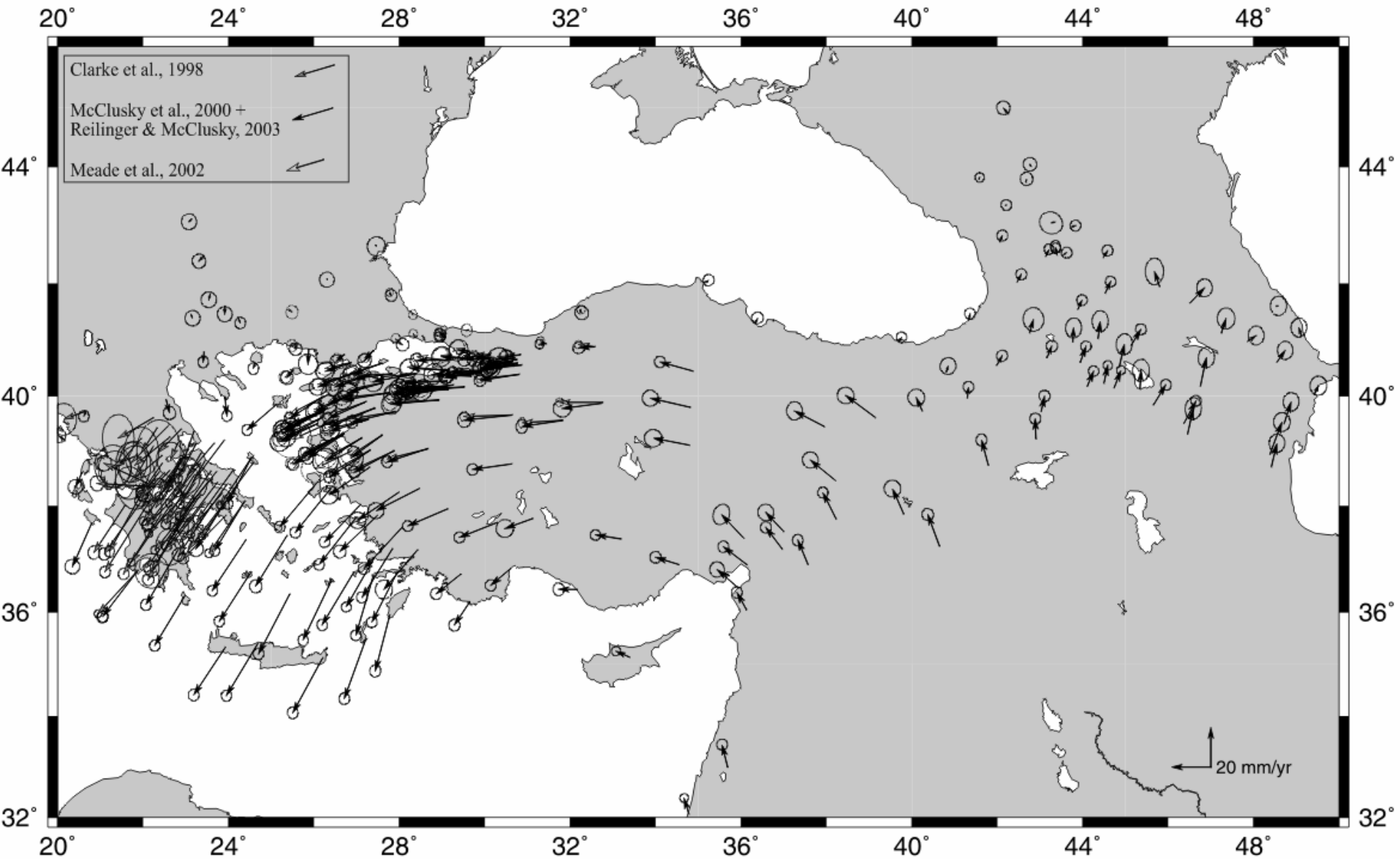
NEOTECTONIC PERIOD

- After the closing of the Tethys Ocean along the Bitlis-Zagros suture 11 Ma ago Palaeotectonic period ended and Neotectonic period has started for Turkey.
- During the neotectonic period, the Arabian Peninsula continued to move northward along the Dead Sea Fault and created a compressional tectonic regime in the Eastern Anatolia.
- This compressional regime resulted in crustal thickening and uplifting in the Eastern Anatolia between 11 and 5 Ma,
- During this time east–west trending reverse faults and thrusts, folds, and some ramp basins have been developed
- During the beginning of the Pliocene (~5 Ma) this compressional tectonic regime was replaced by escape regime

- The Anatolian Plate started to move westward along two transform faults, North Anatolian and East Anatolian Fault Zones.



The Arabian plate is moving northward at a rate of 18 mm/y and the Anatolian Plate is still moving westward and rotating anticlockwise around a pole in Sinai Peninsula

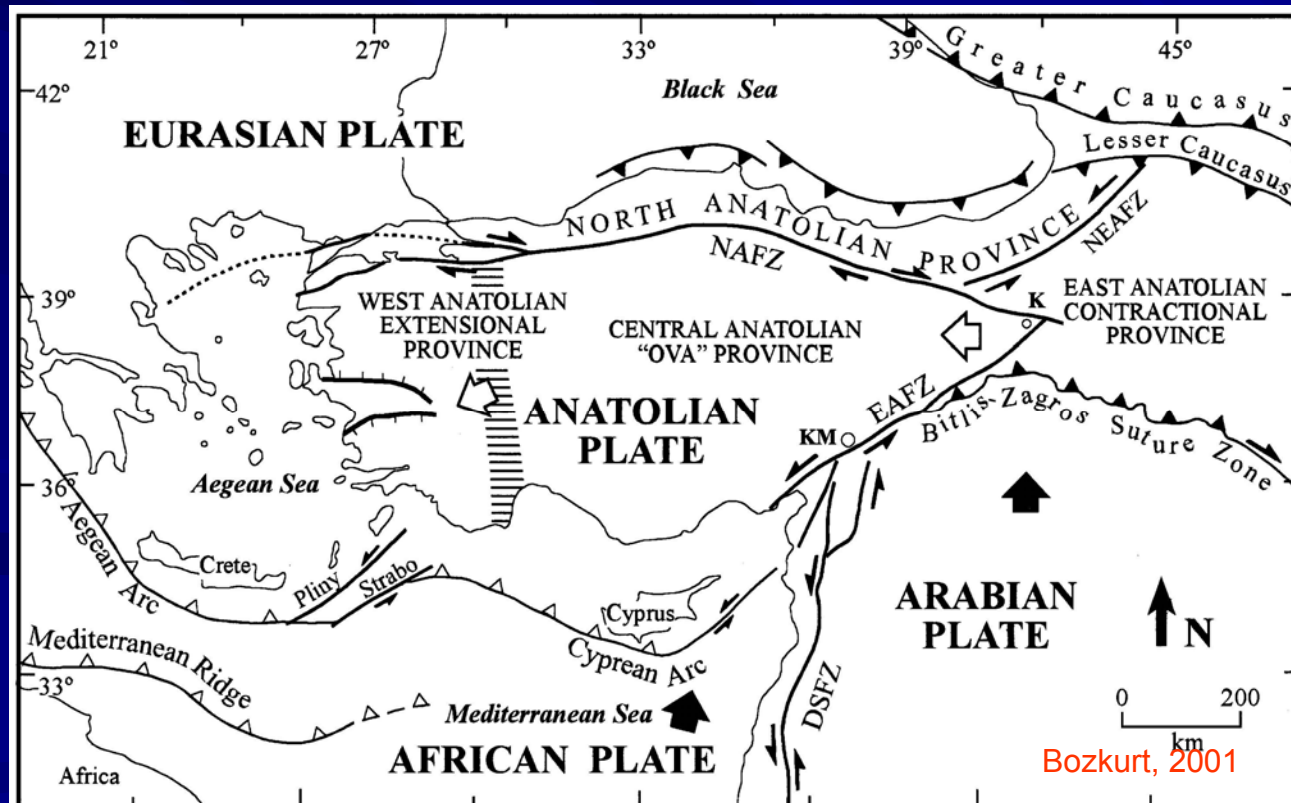


Northward moving of the Arabian Plate and westward extrusion of the Anatolian Plate created four neotectonic provinces:

1. East Anatolian Contractional Province,
2. North Anatolian Province,
3. Central Anatolian 'Ova' Province and
4. West Anatolian Extensional Province.

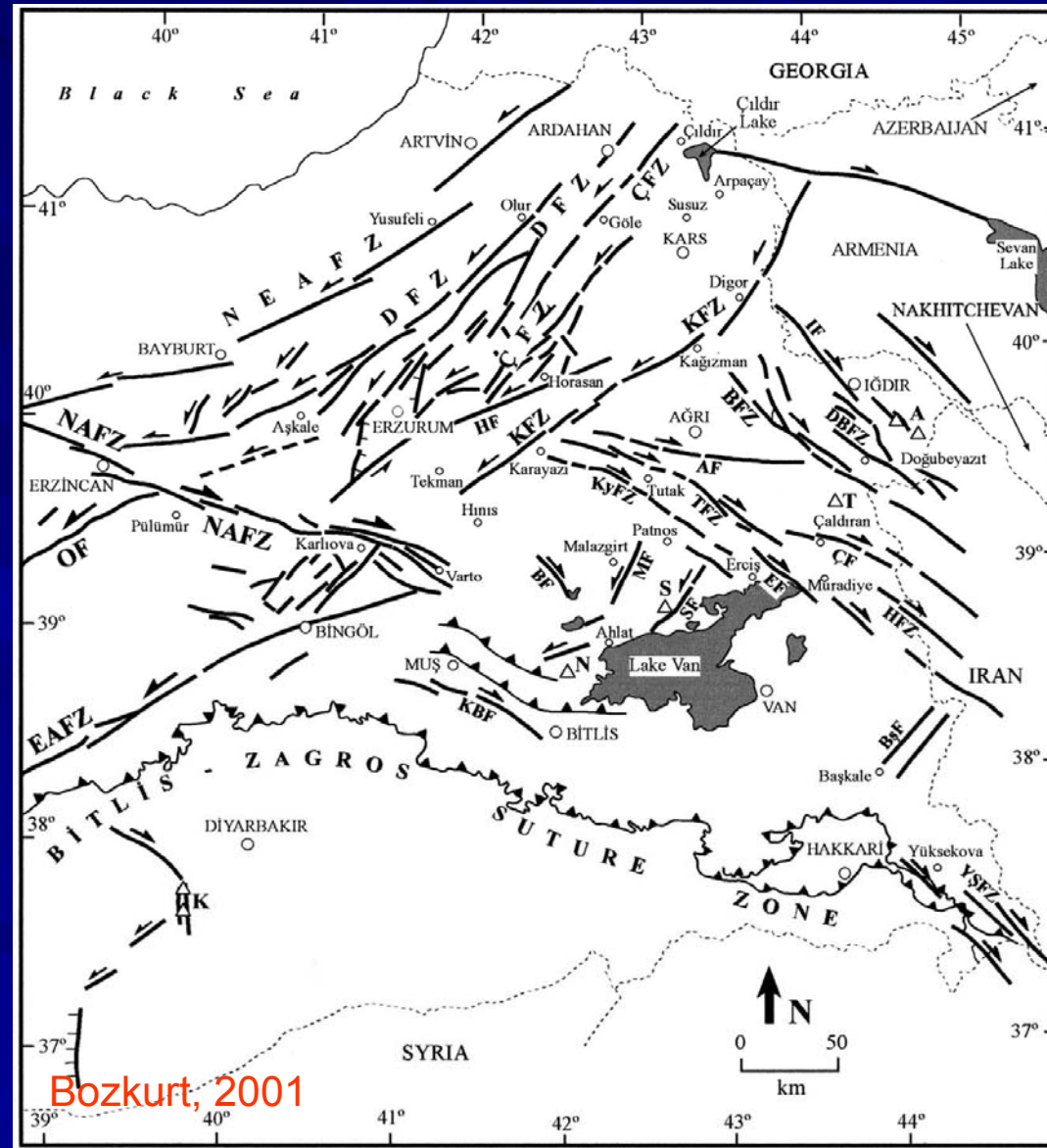
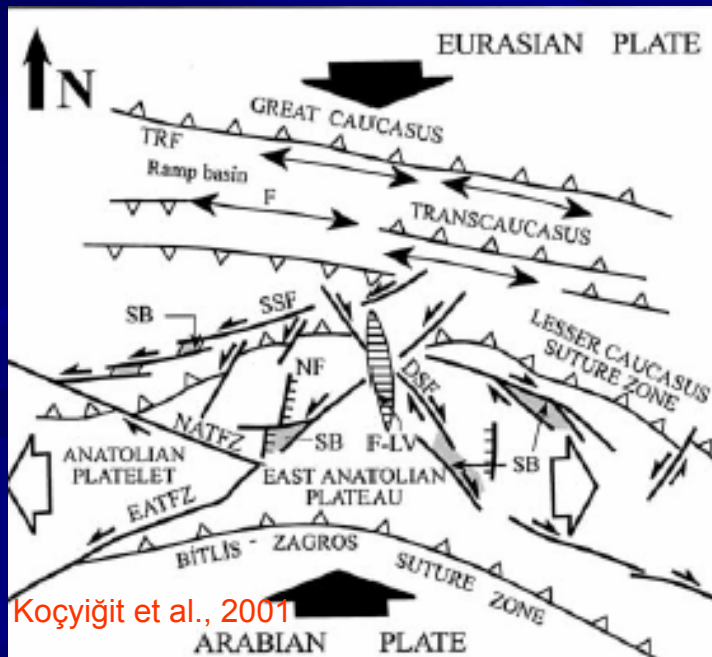
These provinces are delimited by

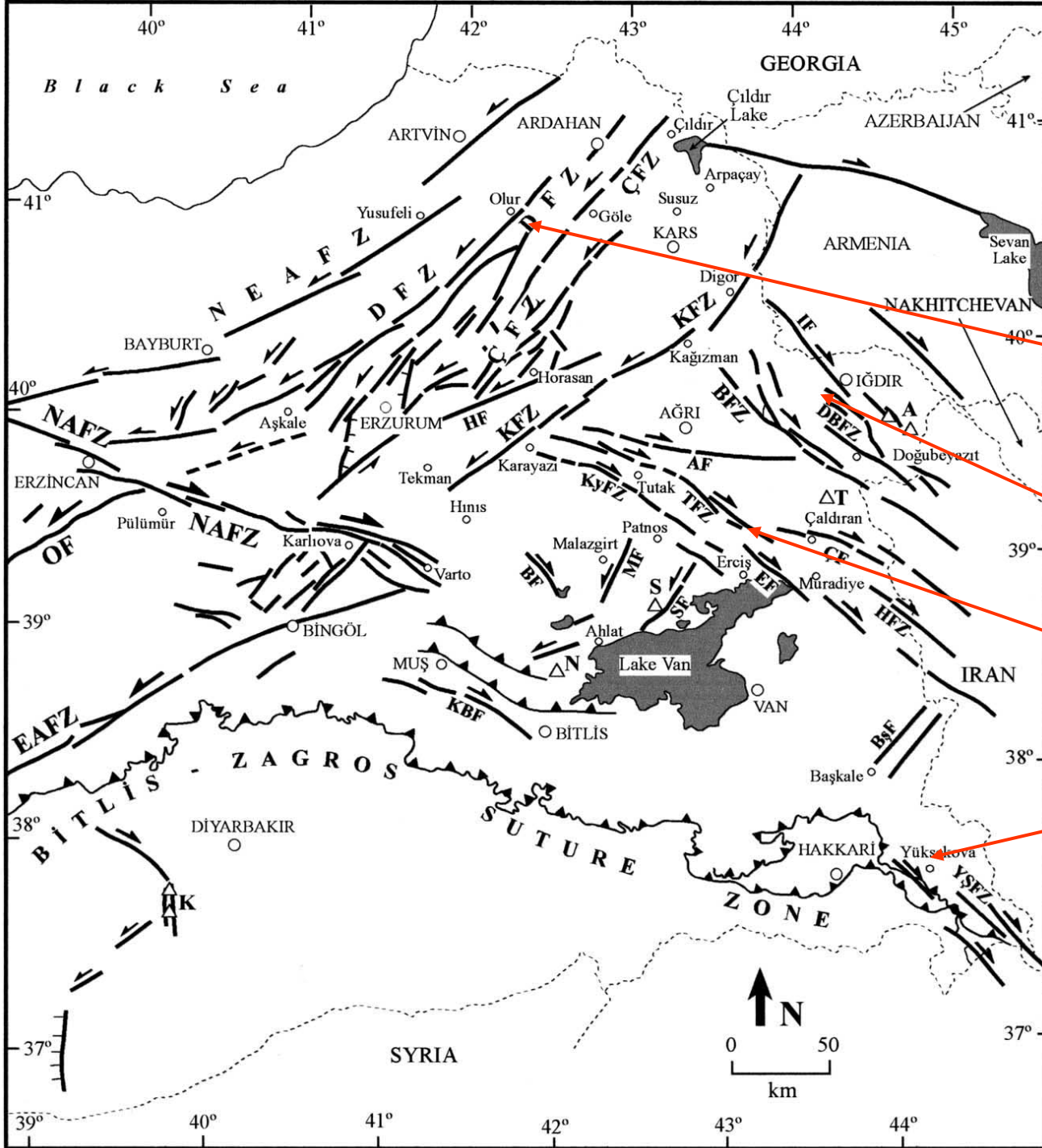
1. The North Anatolian Fault Zone
2. The East Anatolian Fault Zone
3. Dead Sea Fault Zone
4. The Aegean–Cyprus Arc



East Anatolian Contractional Province

- NE- and NW-trending conjugate strike-slip faults
- Pull-apart basins (Erzurum and Ağrı basins) along the strike-slip faults
- E–W trending compressional ramp basins (Muş, Van and Pasinler)
- N-S trending tensional cracks



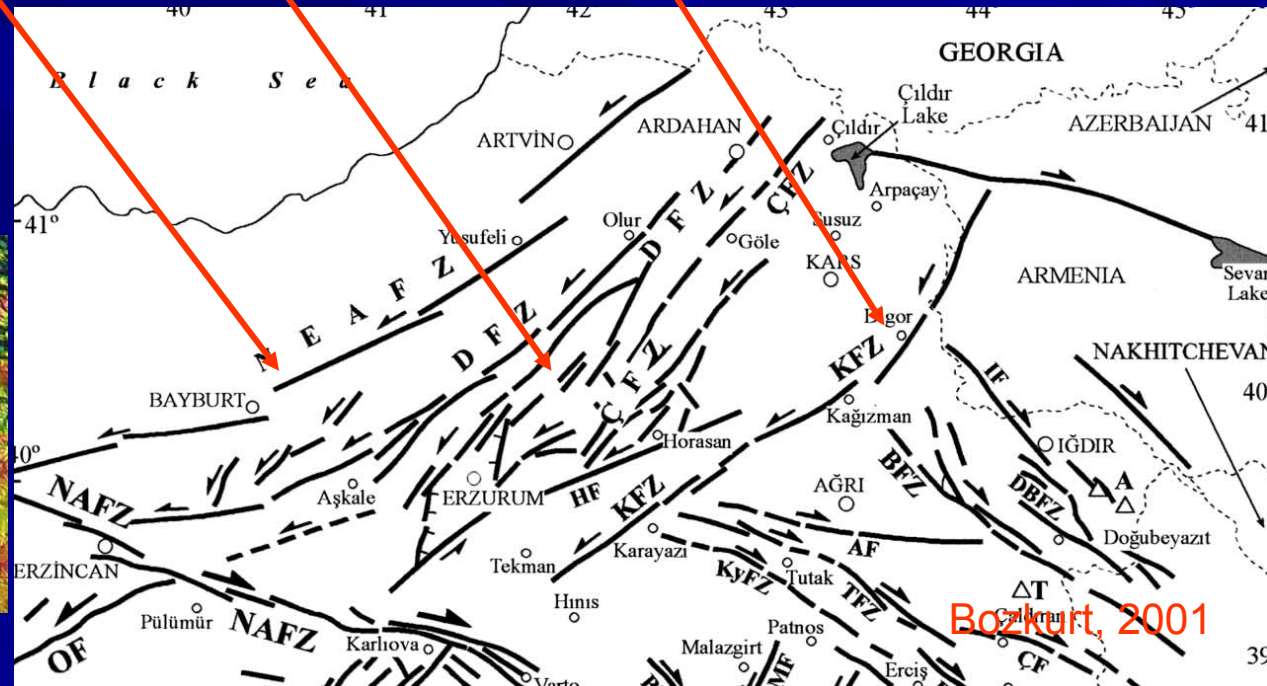


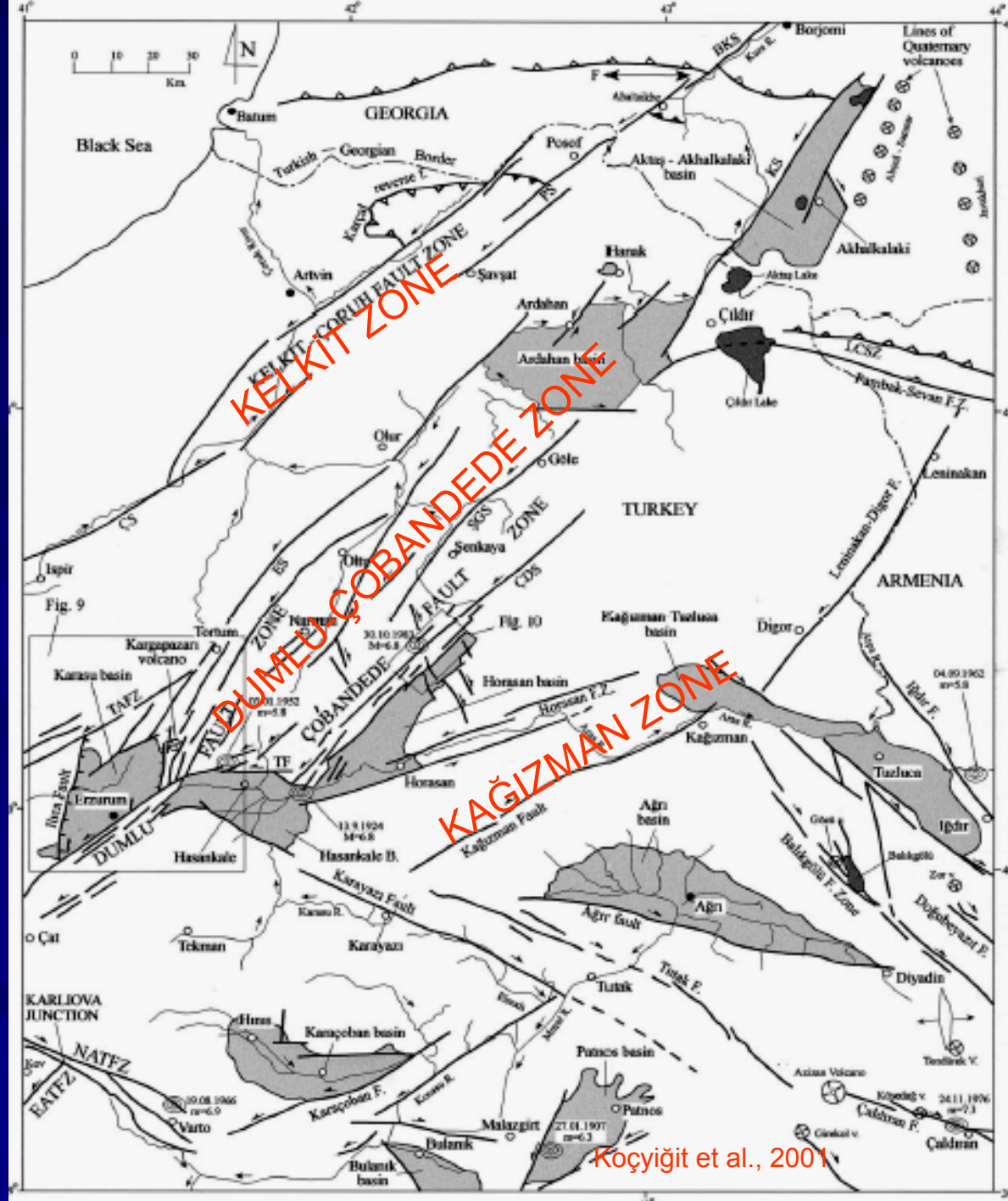
IMPORTANT ACTIVE FAULTS

- Northeastern Anatolian Fault
- Iğdır, Balıkgölü and Doğubayazıt
- Ağrı, Karayazı, Çaldıran, Horasan and Erciş
- Yüksekova-Şemdinli

Northeastern Anatolian Fault Zone

- Left-lateral
- 350 km-long
- Slip rates of 8 mm/a according to GPS measurements
- Average 18–25 mm/a according to geological data
- Consists of **Kelkit**, **Dumlu-Çobandede** and **Kağızman** Fault Zones





Koçyiğit et al., 2001

Major earthquakes in the East Anatolian Contractional Province during the 20th Century

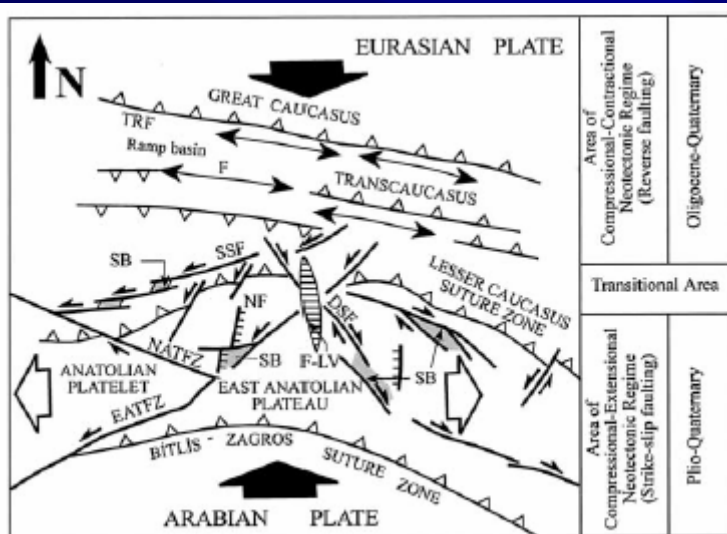
- 12 July 1900 Kağızman (M= 5.9)
- 8 November 1901 Erzurum (M=6.1)
- 28 April 1903 Patnos (M=6.3)
- 28 May 1903 Ardahan (M= 5.7)
- 4 December 1905 Malatya (M= 6.8)
- 13 September 1924 Horasan (M = 6.8)
- 1 May 1935 Digor (M= 5.8)
- 10 September 1941 Erciş (M= 5.9)
- 6 September 1975 Lice (M = 6.6)
- 24 November 1976 Çaldıran (M = 7.3)
- 30 October 1983 Horasan–Narman (M = 6.8)

East Anatolian Contractional Province

- N-S compression also created N-S trending tensional cracks, which have functioned as magma conduits.
- Plio-Quaternary distinct volcanoes are Nemrut, Süphan, Ağrı, Tendürek etc.

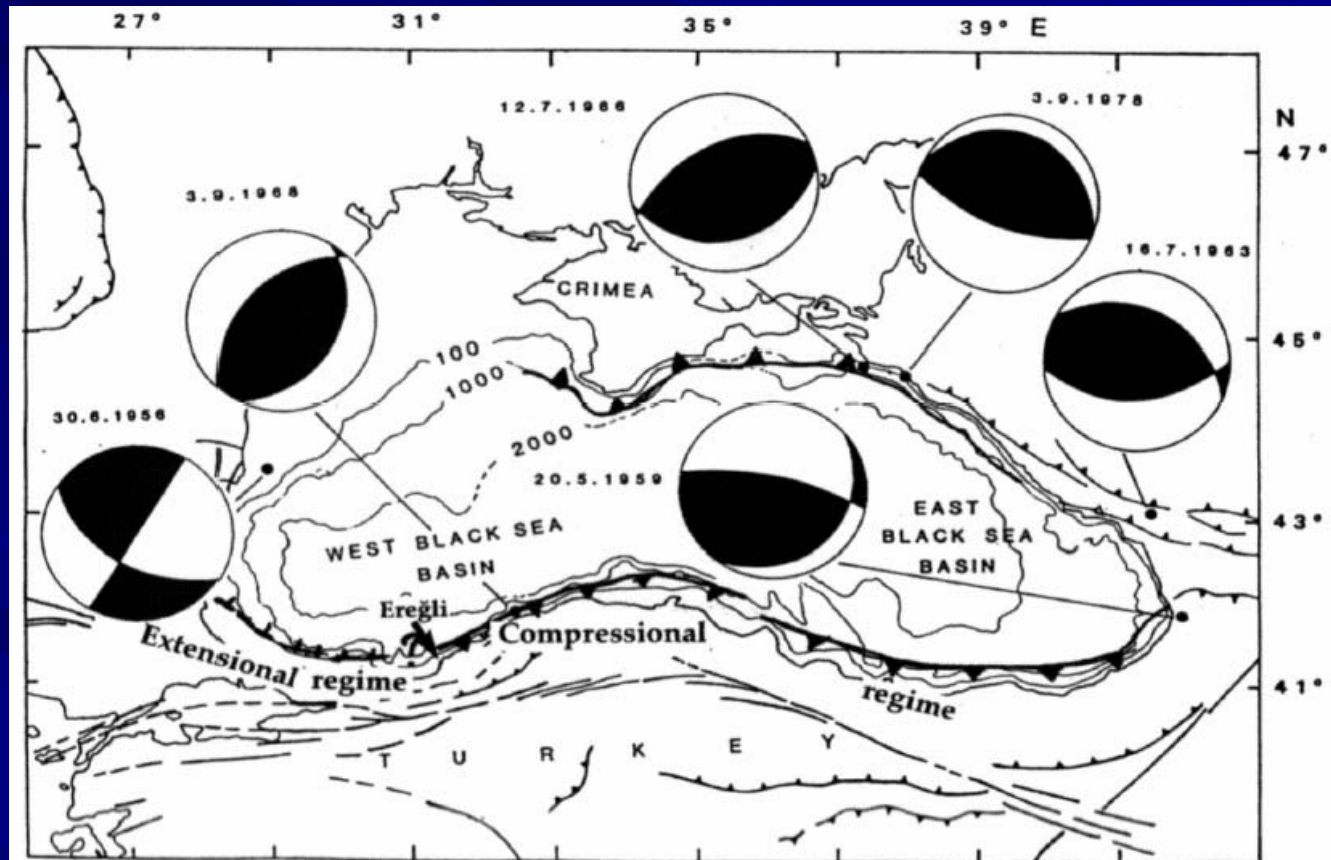


NEMRUT



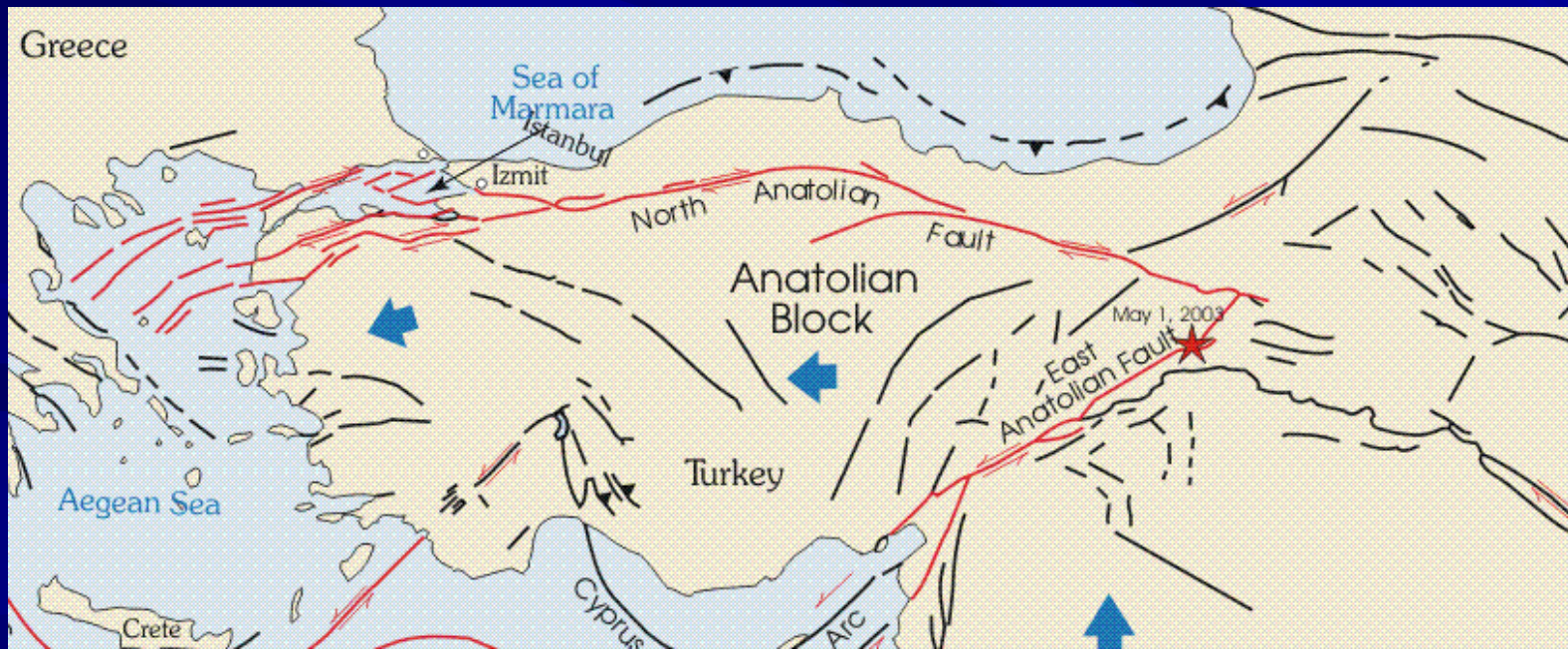
North Anatolian Province

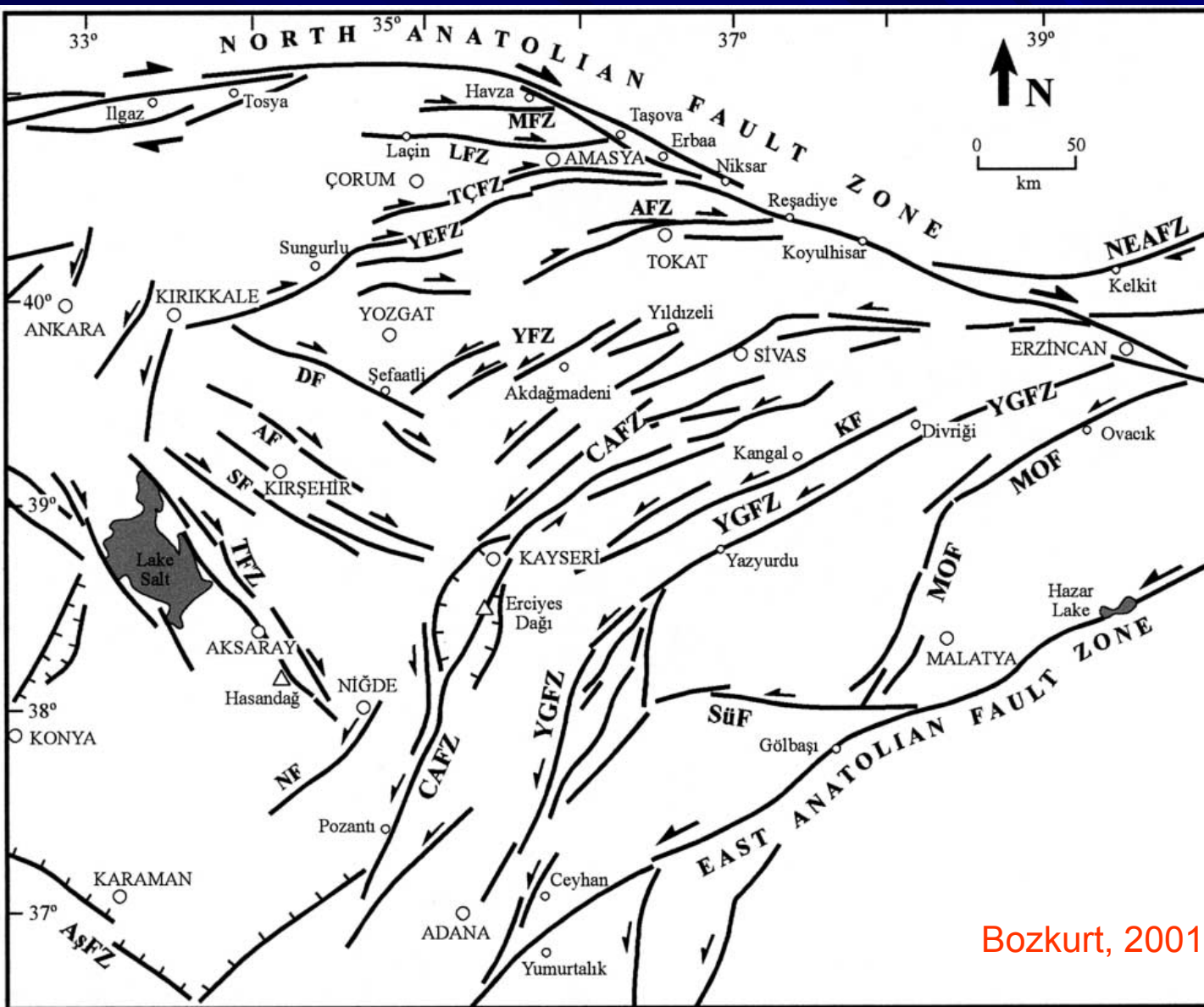
- Delimited by NAF and NEAF
- E-W trending fold and thrust belt.
- The slip rates are less than 5 mm/y
- 3 September 1968 Bartın earthquake (M = 6.8)



Central Anatolian 'Ova' Province

- Delimited by NAF and EAF
- Characterized by extensional basins called 'ovas',
- Basin bounding oblique faults.
- Eastern part is deformed by a number dextral and sinistral strike-slip faults, which are splays of the NAFZ, and form a fishbone structure
- Normal faults are dominant in the western part.





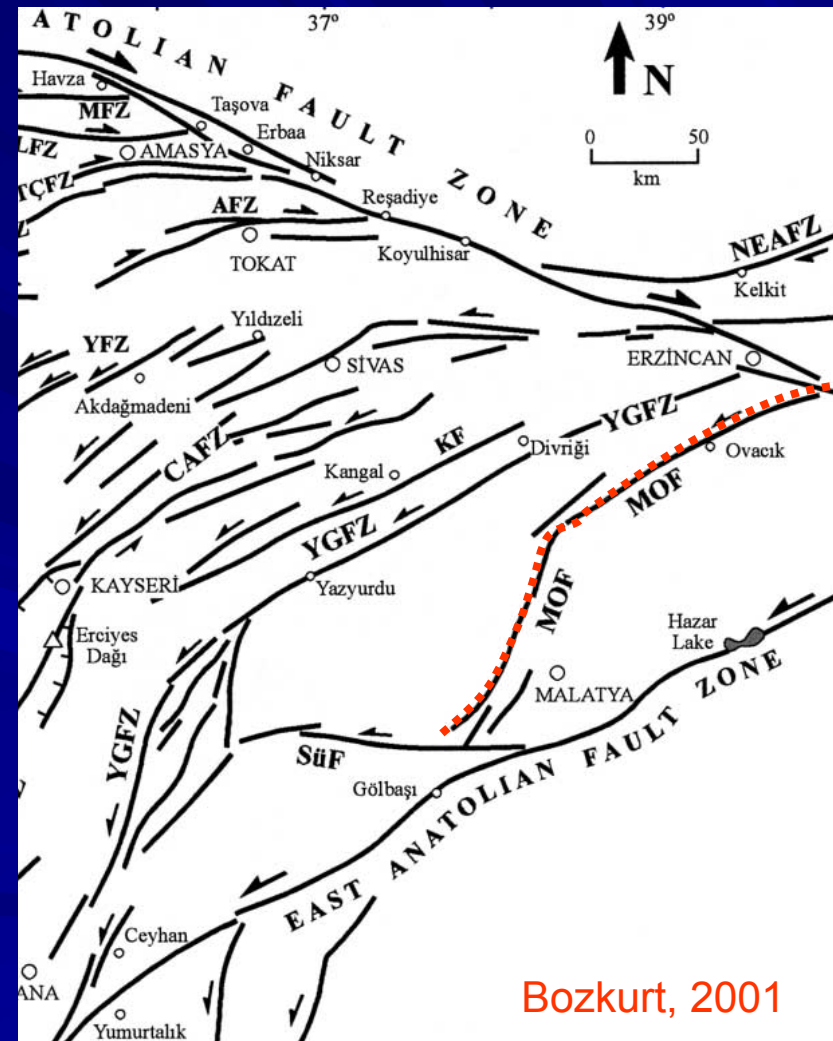
IMPORTANT ACTIVE FAULTS

- Ecemiş
- Ovacık-Malatya
- Yakapınar-Göksun and Kangal
- Ezinepazar-Sungurlu
- Laçın-Merzifon
- Kırşehir
- Almus
- Tuzgölü

Bozkurt, 2001

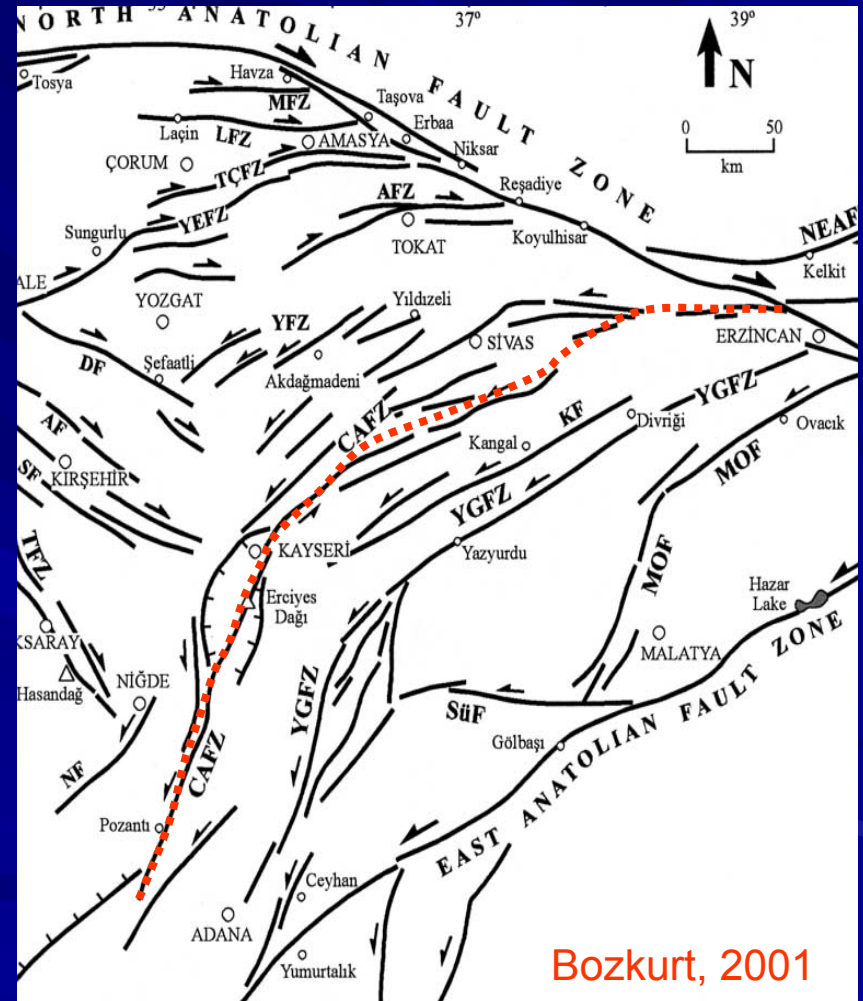
The Ovacık–Malatya Fault Zone

- **Sinistral**
- 250 km long.
- **Splays from the NAF near Erzincan.**
- **Consists two main segments;**
 - **Ovacık segment**
 - **Malatya segment**



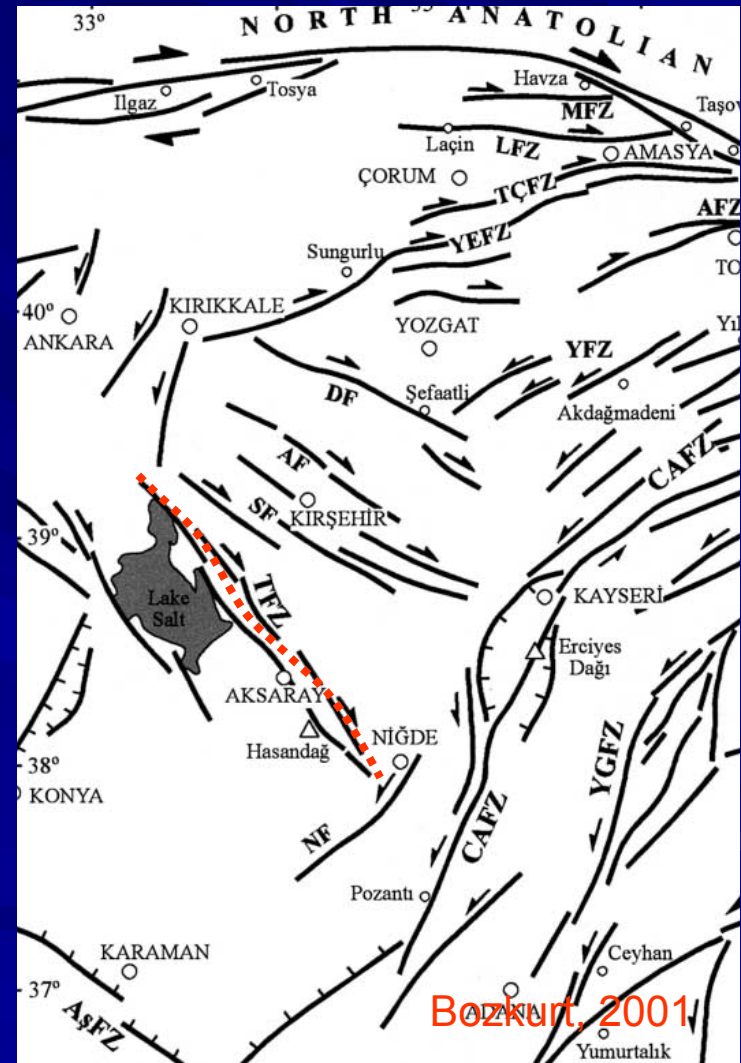
The Ecemiş Fault Zone

- Sinistral
- 700 km long
- Formed by the reactivation of a palaeotectonic structure in the Plio-Quaternary.
- Seismically less active
- Total displacements during the palaeotectonic and neotectonic periods are 70 km and 24 km, respectively.
- Some pull-apart basins (Erciyes, Tuzla, Sultansazlığı)



The Tuzgölü Fault Zone

- **Dextral**
- 200 km long,
- **The initiation is Late Cretaceous, became active during the Miocene.**
- The N–S and NE–SW trending volcanic cones along the fault are attributed this fault



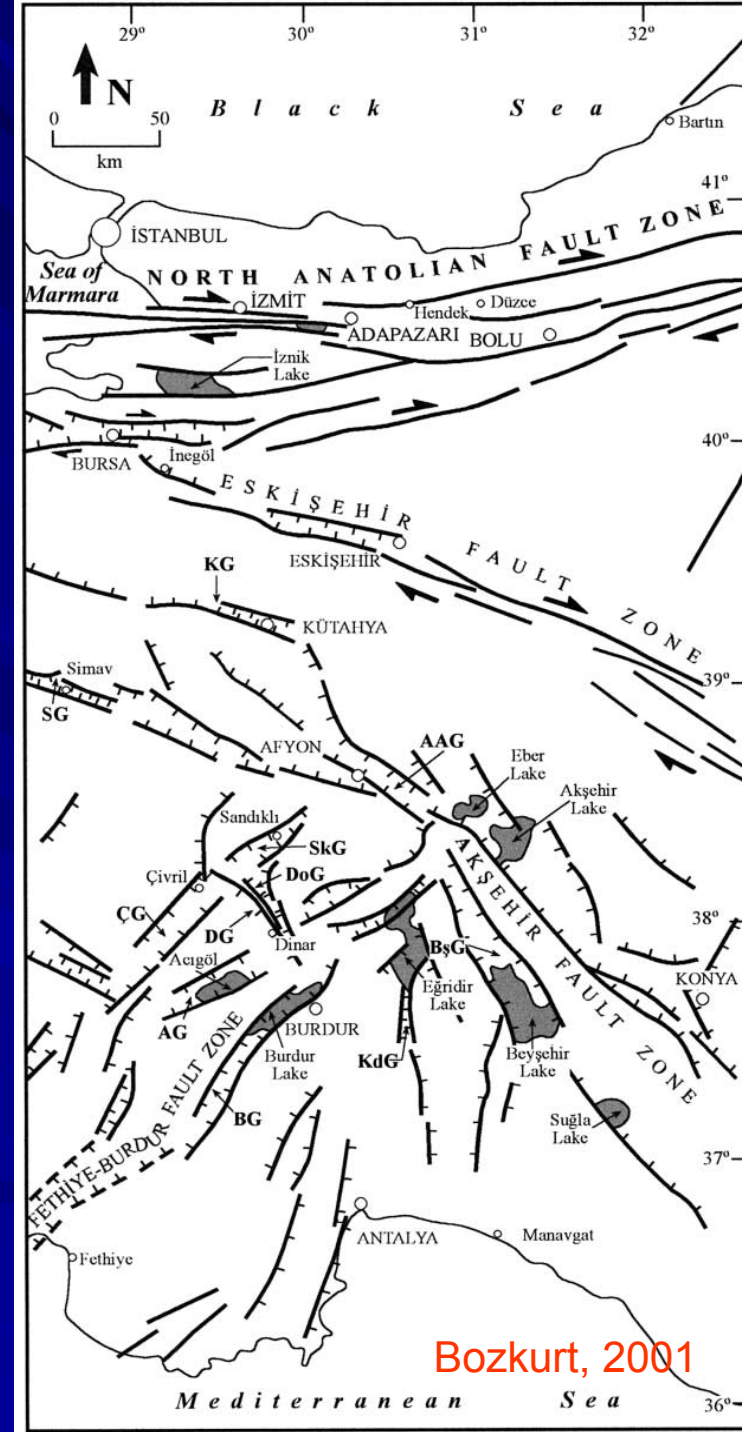


Seismicity of the eastern part of the Central Anatolian Province

- 1717 and 1835 Ecemiş
- 9 March 1902 Çankırı ($M_s=5.5$)
- May 1914 Gemerek ($M = 5.6$)
- 1938 Kırşehir ($M = 6.8$)
- 21 February 1940 Erciyes ($M = 5.1$)
- 13 April 1940 Yozgat-Kayseri ($M = 5.3$)
- 4 August 1996 Mecitözü–Çorum ($M = 5.6$)

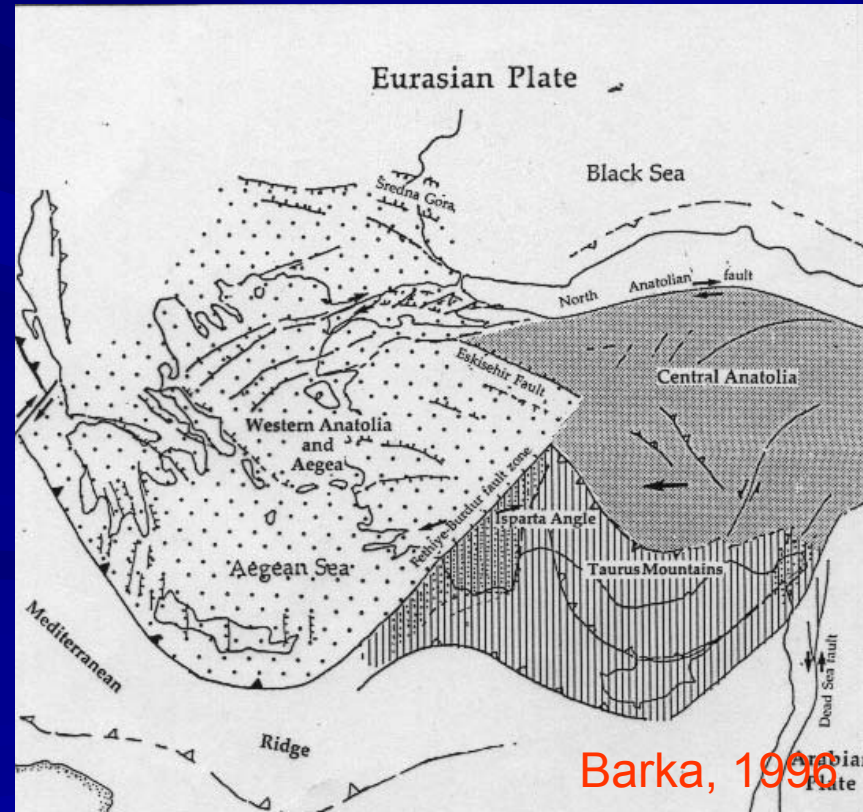
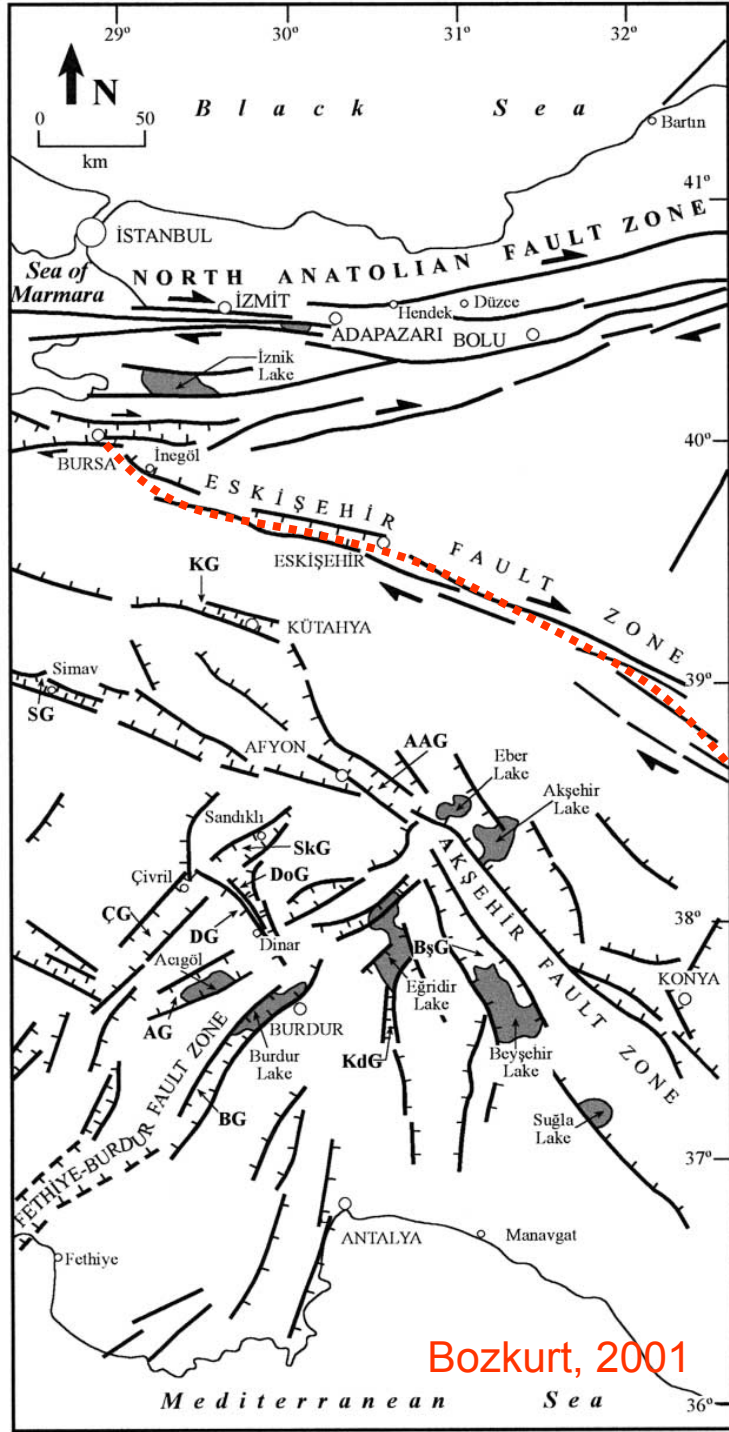
Western Part of the Central Anatolia

- **NE–SW** (Burdur, Acıgöl, Sandıklı, Çivril and Dombayova) and **NW–SE-trending** (Dinar, Beyşehir, Akşehir–Afyon) **cross-grabens and horsts**
- Forms a transition between the **Aegean Extensional Province** and the **strike-slip dominant eastern part** of the Central Anatolia.
- **Southern part** of this region is known as the **Isparta angle**.



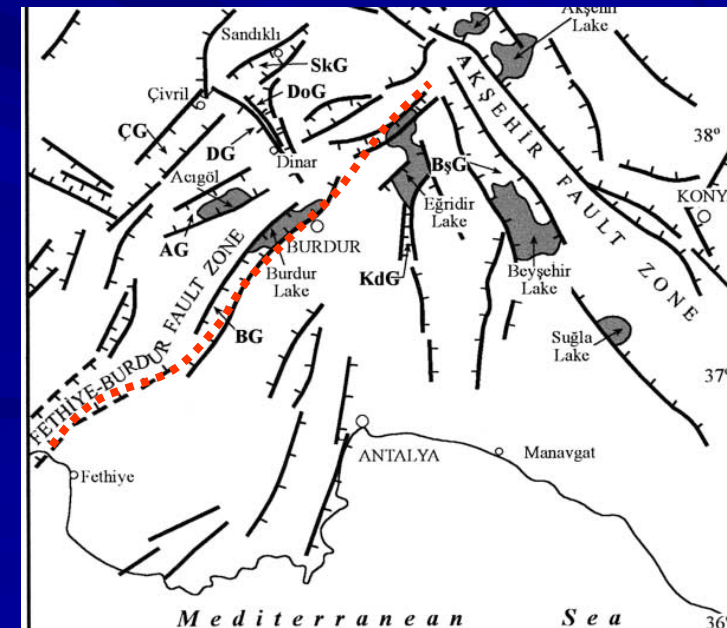
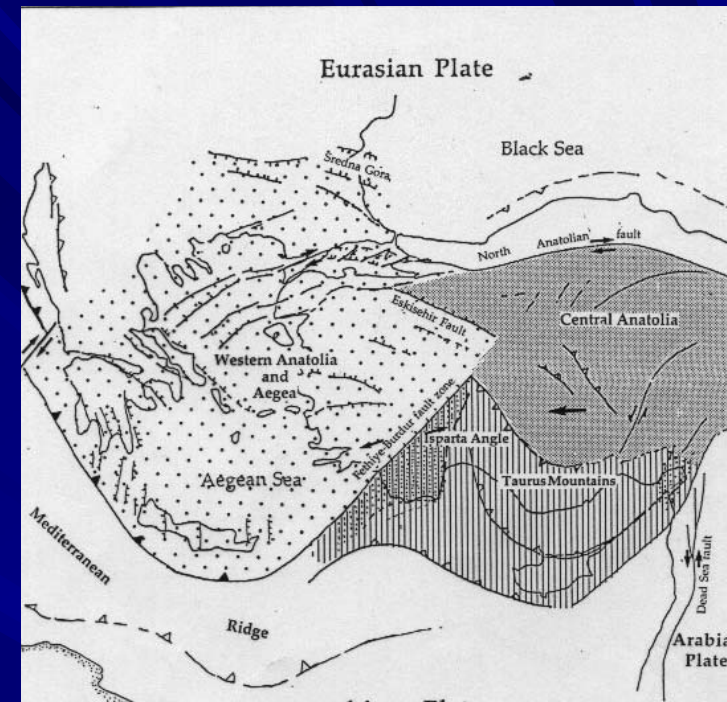
Eskişehir Fault

- Dextral with normal component.
- Ruptured during the 1956 Eskişehir earthquake ($M = 6.5$)
- Forms boundary between Central and Western Anatolia



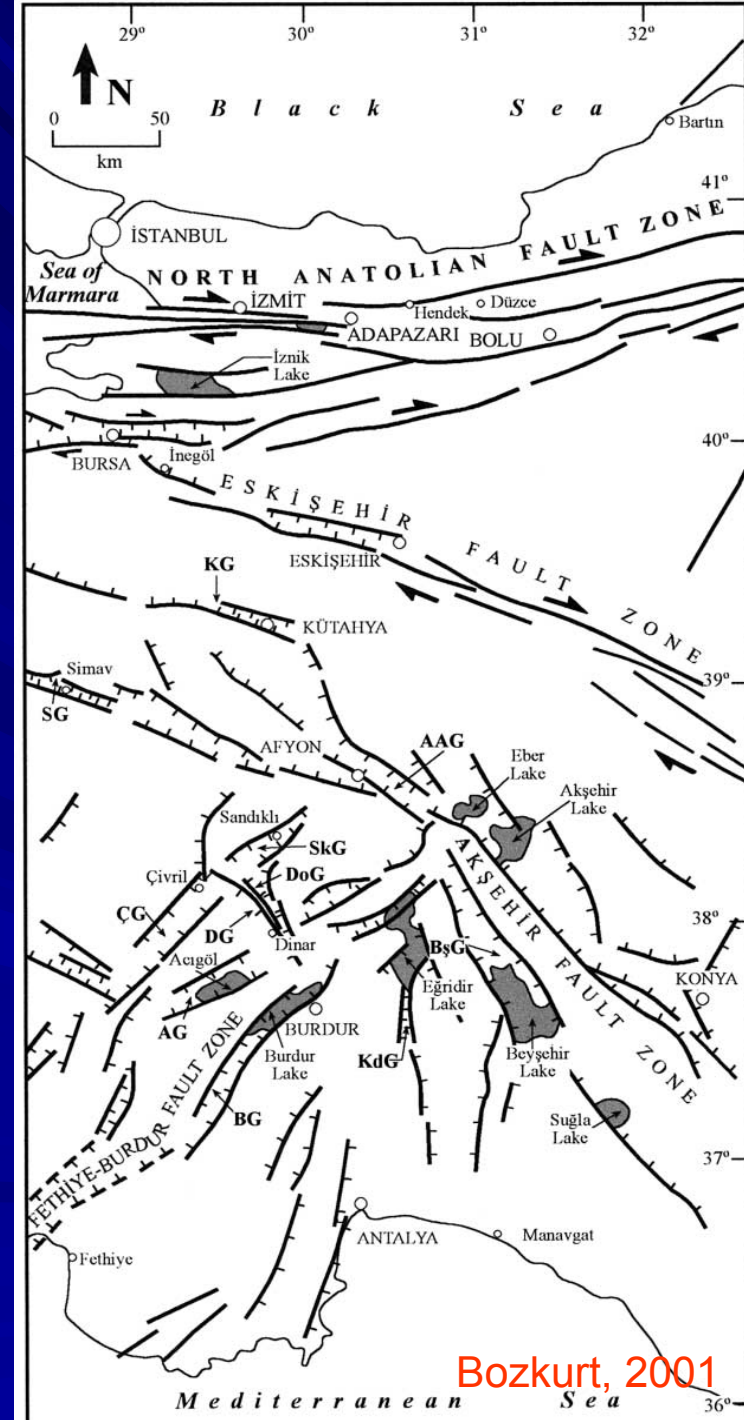
Fethiye–Burdur Fault Zone

- Left-lateral
- Forms the boundary between the Western Anatolia and the Isparta Angle area.
- GPS measurements indicate slip rates of 15 mm/a
- Produced 1914 and 1971 Burdur and 1962 and 1957 Fethiye earthquakes



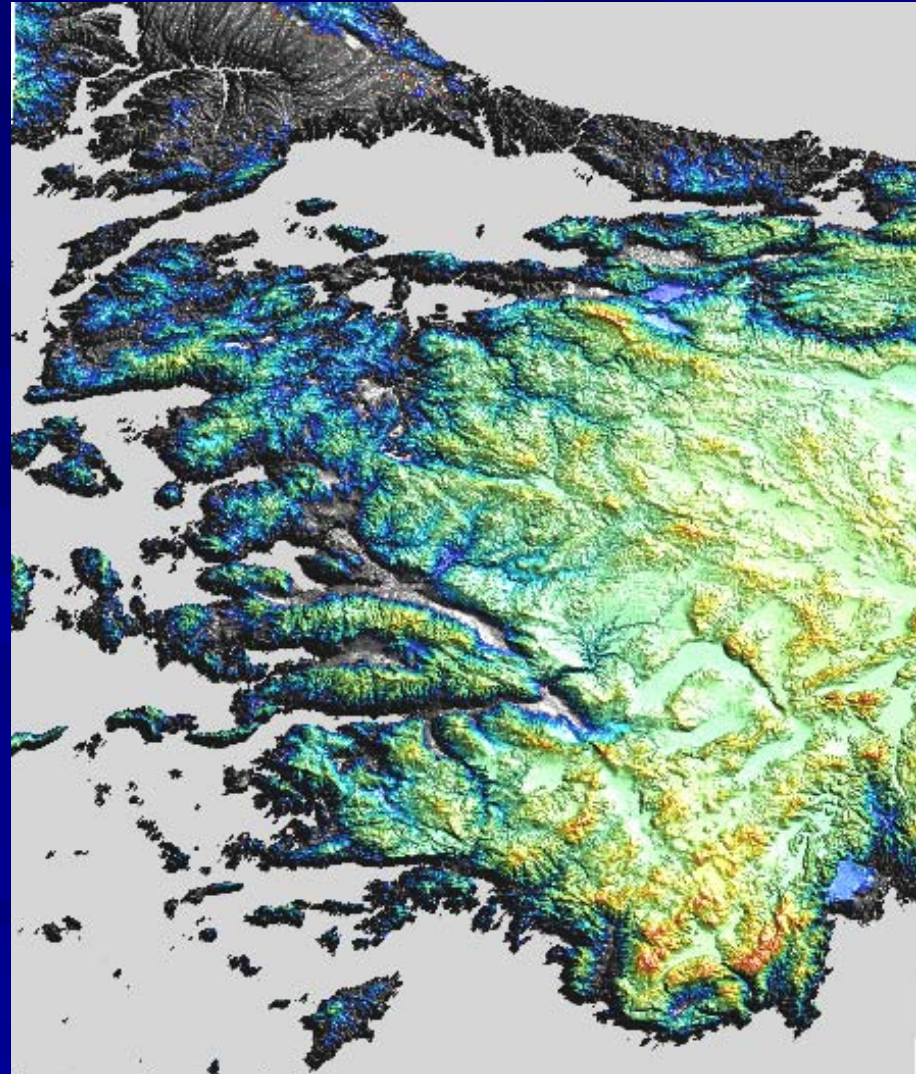
■ Biggest earthquakes in this region

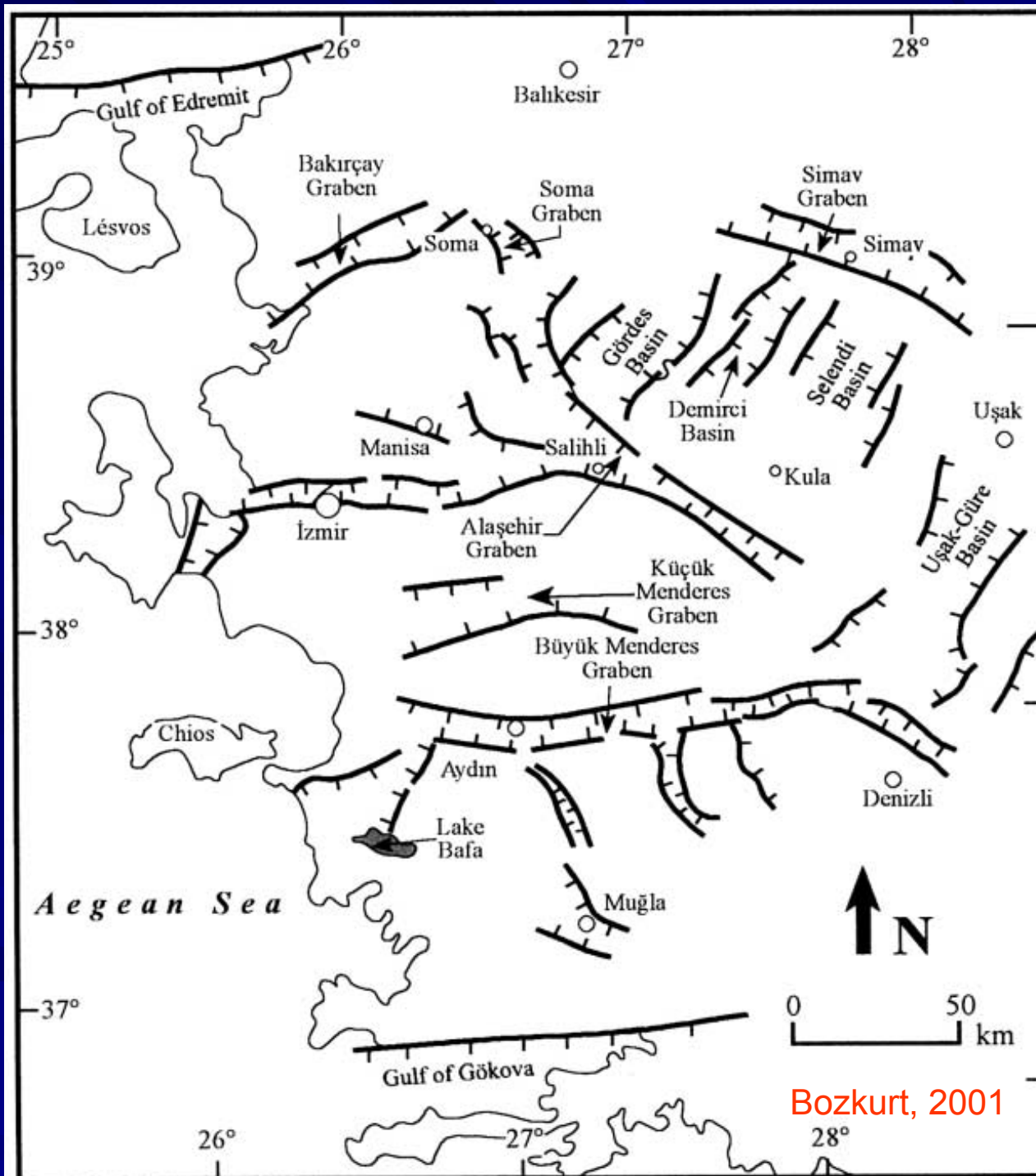
- 3 October 1914 Burdur ($M=7.1$)
- 7 August 1925 Dinar ($M=5.8$)
- 18 March 1926 Finike ($M=6.8$)
- 19 July 1933 Çivril ($M=5.8$)
- 25 April 1957 Fethiye ($M=7.1$)
- 22 November 1963 Tefenni ($M=5.1$)
- 12 May 1971 Burdur ($M=6.2$)
- 1 October 1995 Dinar ($M=6.1$)
- 15 December 2000 Akşehir ($M=5.8$)



Western Anatolia

- One of the most seismically active and rapidly extending regions of the world (>30 mm/a).
- **E–W trending grabens** (Edremit, Bakırçay, Kütahya, Simav, Gediz, Küçük Menderes, Büyük Menderes, and Gökova).
- **NNE- and NNW- trending grabens** (Uşak, Selendi, Demirci, Gördes, Soma)

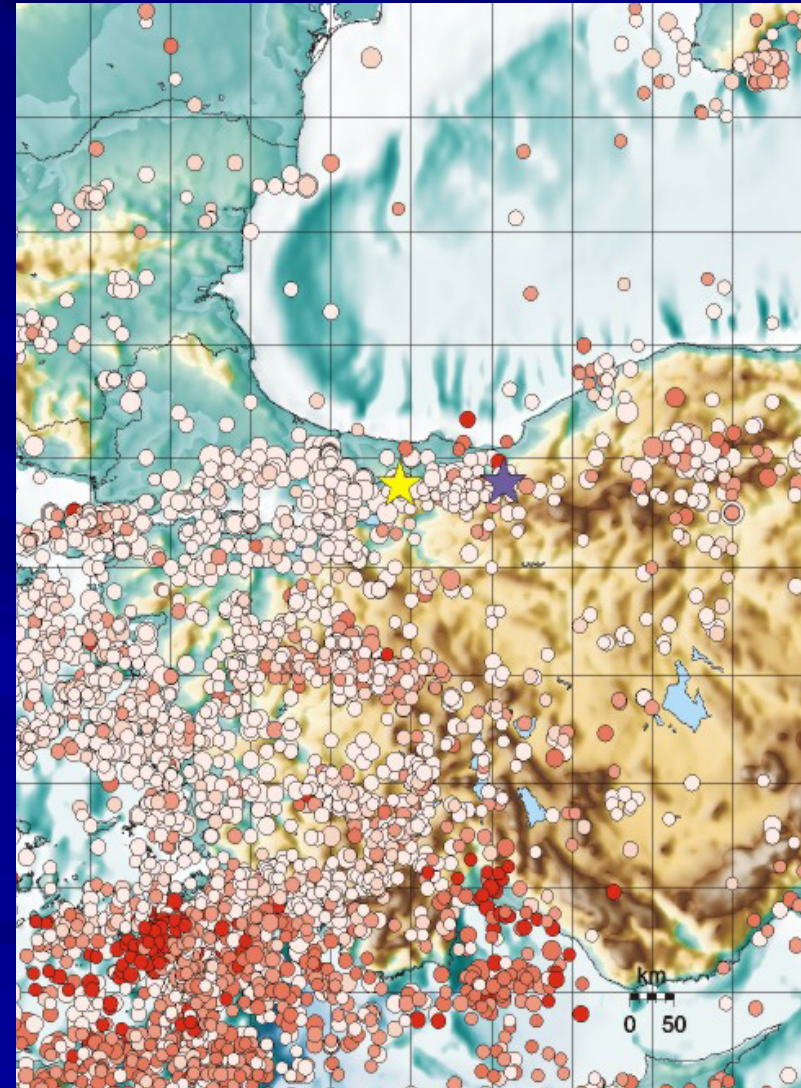




Bozkurt, 2001

Biggest earthquakes of Western Anatolia

- 20 September 1899 Menderes
- 19 January 1909 Foça ($M = 6.0$)
- 18 November 1919 Soma ($M = 6.9$)
- 31 March 1928 Torbalı ($M = 6.3$)
- 2 May 1928 Emet ($M = 6.2$)
- 23 April 1933 Gökova ($M = 6.5$)
- 19 July 1933 Denizli ($M = 5.8$)
- 22 September 1939 Dikili-Bergama ($M = 6.5$)
- 23 May ($M = 6.2$) and 13 December 1941 Muğla ($M = 6.0$)
- 6 October 1942 Edremit Körfezi–Ayvacık ($M = 6.8$)
- 24 June 1944 Gediz ($M = 6.0$)
- 21 December 1945 ($M = 6.0?$)
- 16 July 1956 Söke–Balat ($M = 7.1$)
- 25 April 1959 Köyceğiz ($M = 6.3$)
- 11 March 1963 Denizli ($M = 5.5$)
- 2 March 1965 Salihli ($M = 5.8$)
- 13 June 1965 Honaz ($M = 5.3$)
- 25 March 1969 Demirci ($M = 5.9$)
- 28 March 1969 Alaşehir –Sarıgöl ($M = 6.5$)
- 28 March 1970 Gediz ($M = 7.2$)
- 11 October 1986 Çubukdağ ($M = 5.5$)

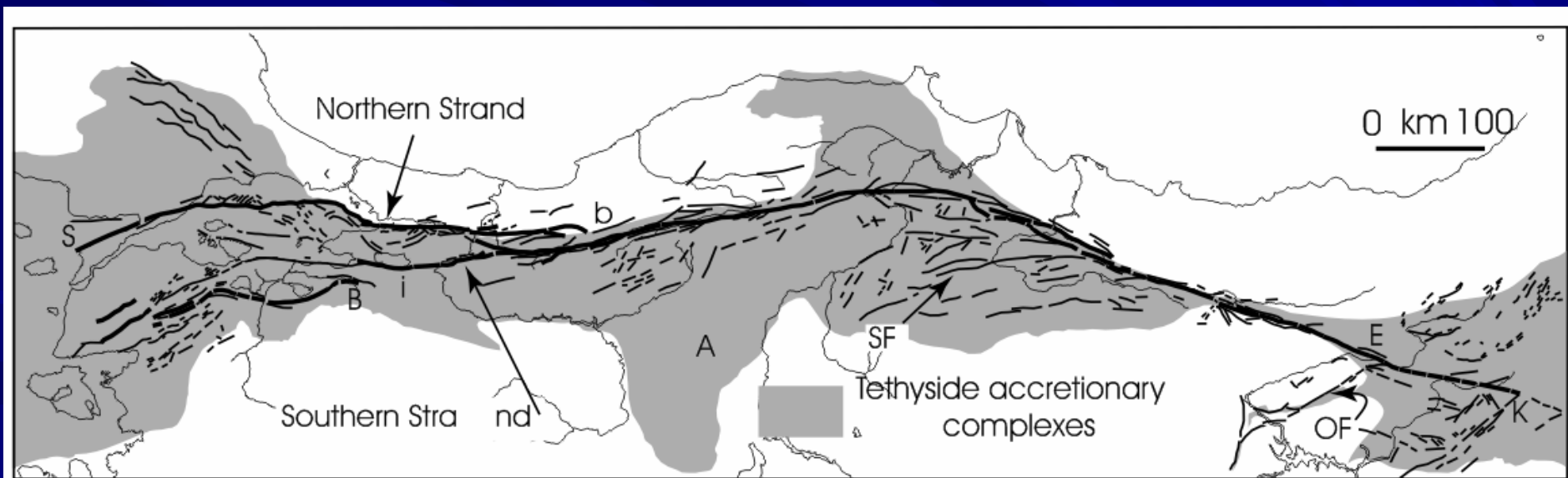


Cause and origin of crustal extension in the Aegean Province

- **Tectonic escape** : *westward extrusion of the Anatolian block since 11 Ma*
- **Back-arc spreading** : *back-arc extension caused by the roll-back effect of the Aegean (Hellenic) Trench system*
- **Orogenic collapse** : *spreading and thinning of over-thickened crust following the late Tertiary collision across Neotethyan sutures during the Oligocene–Early Miocene (~25 Ma).*
- **Episodic**: *Miocene–Early Pliocene (~5 Ma) orogenic collapse, and a Plio-Quaternary (~3 Ma) westward escape and of N–S extension.*

North Anatolian Fault Zone

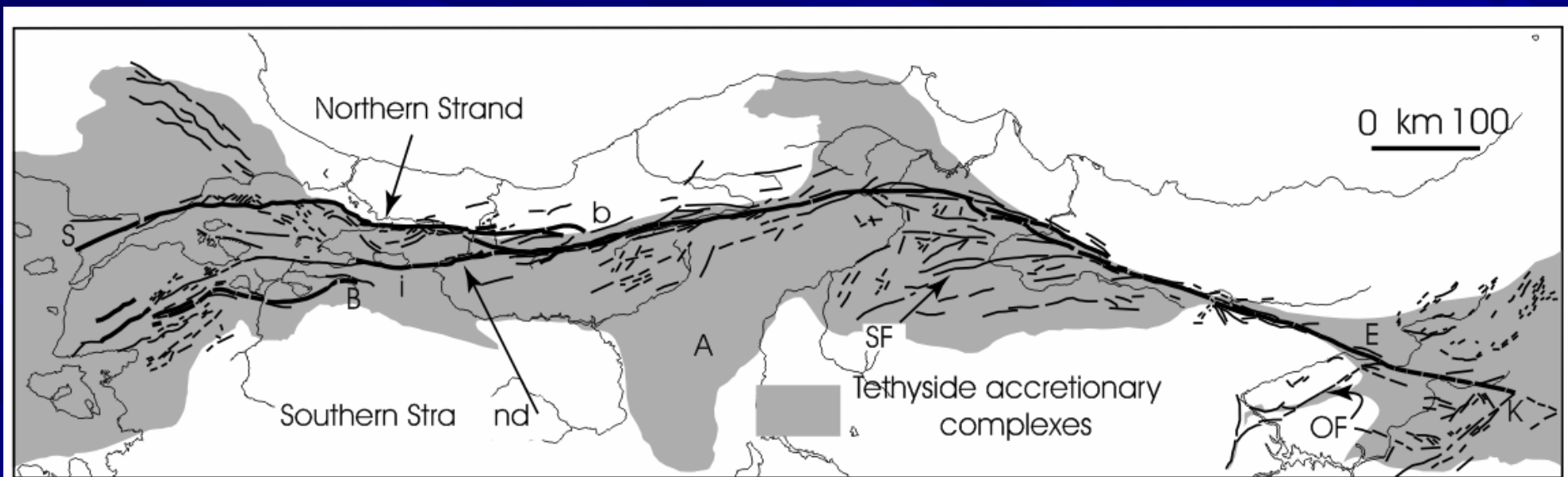
- 1200 km-long, broad arc-shaped, dextral strike-slip fault system
- Extends from Karliova in the east to Greece in the west.
- Forms the boundary between the Eurasian and Anatolian Plates
- The North Anatolian Fault is only a member of a much larger right-lateral shear zone consisting of a large number of dextral shear-related structures.
- This shear zone extends along mostly a bimaterial interface juxtaposing subduction-accretion material of the Tethysides and older and stiffer continental basements to its north



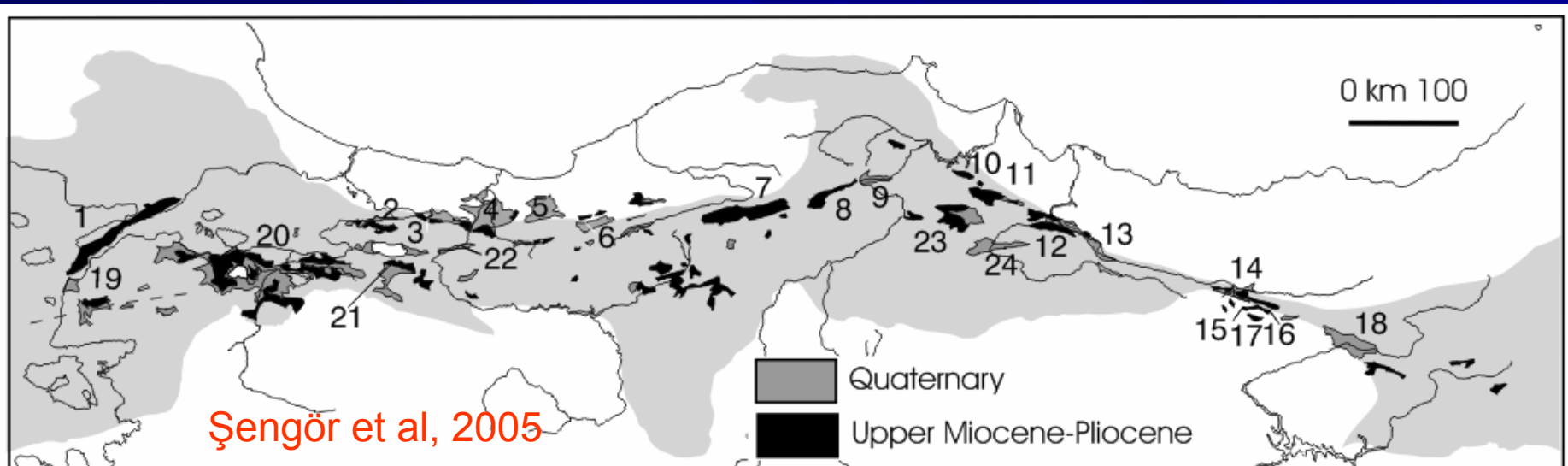
Şengör et al, 2005

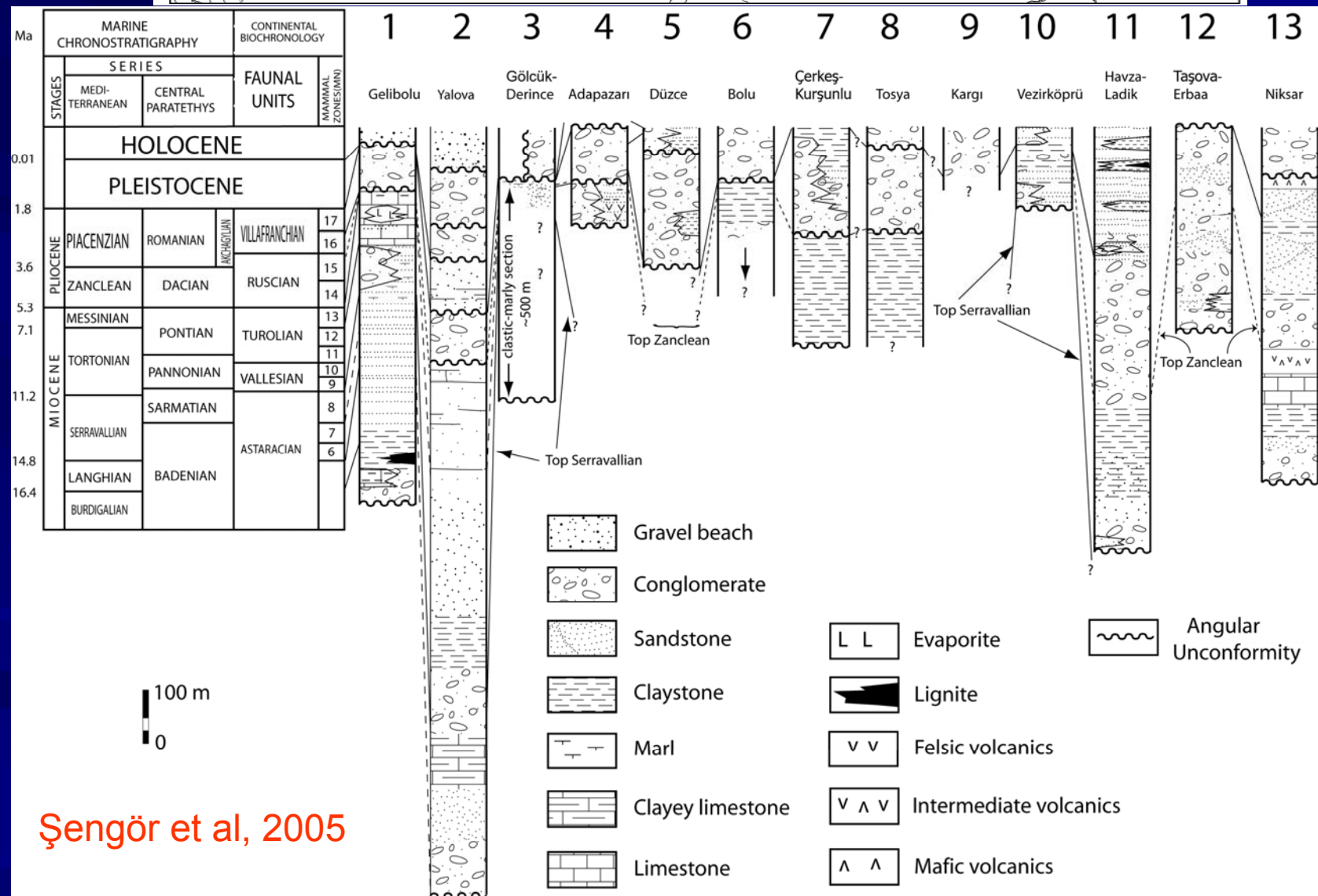
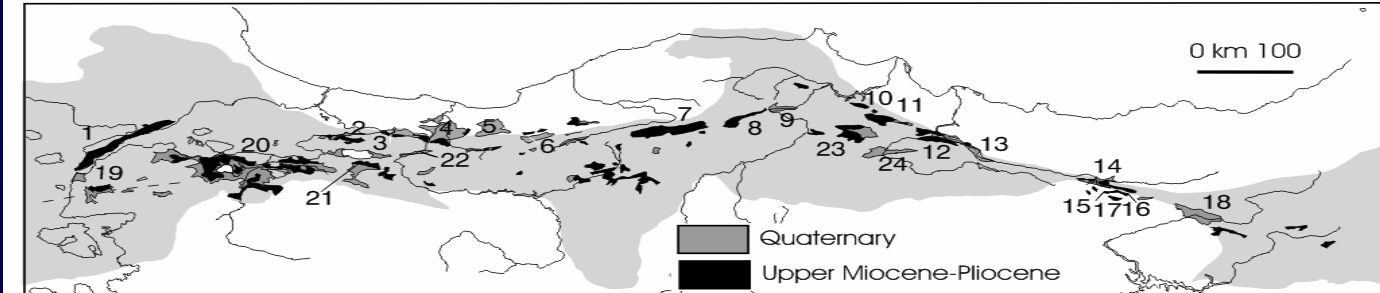
■ The NAF splays into two major strands to the east of Almacik mountains

- The northern strand is more active
- The southern strand bounds the southern margin of Sea of Marmara, then bends southward and runs into the Aegean Sea

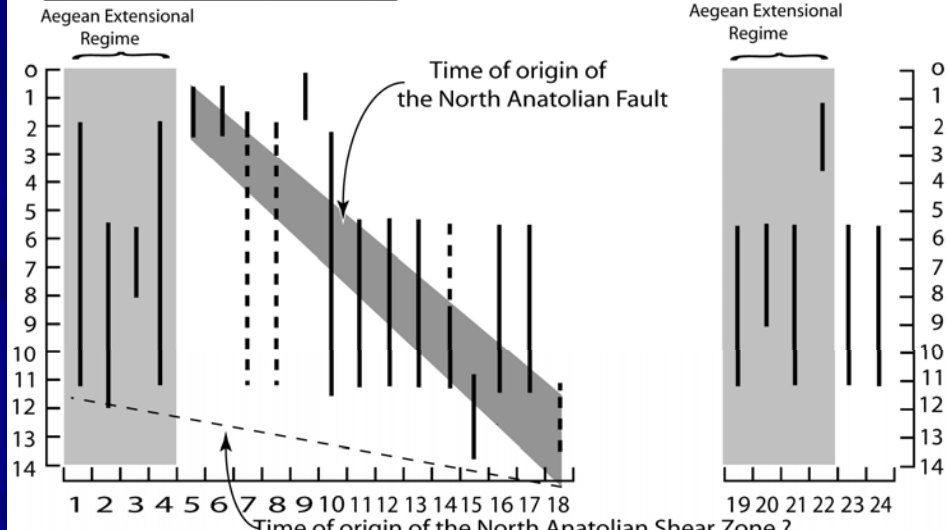
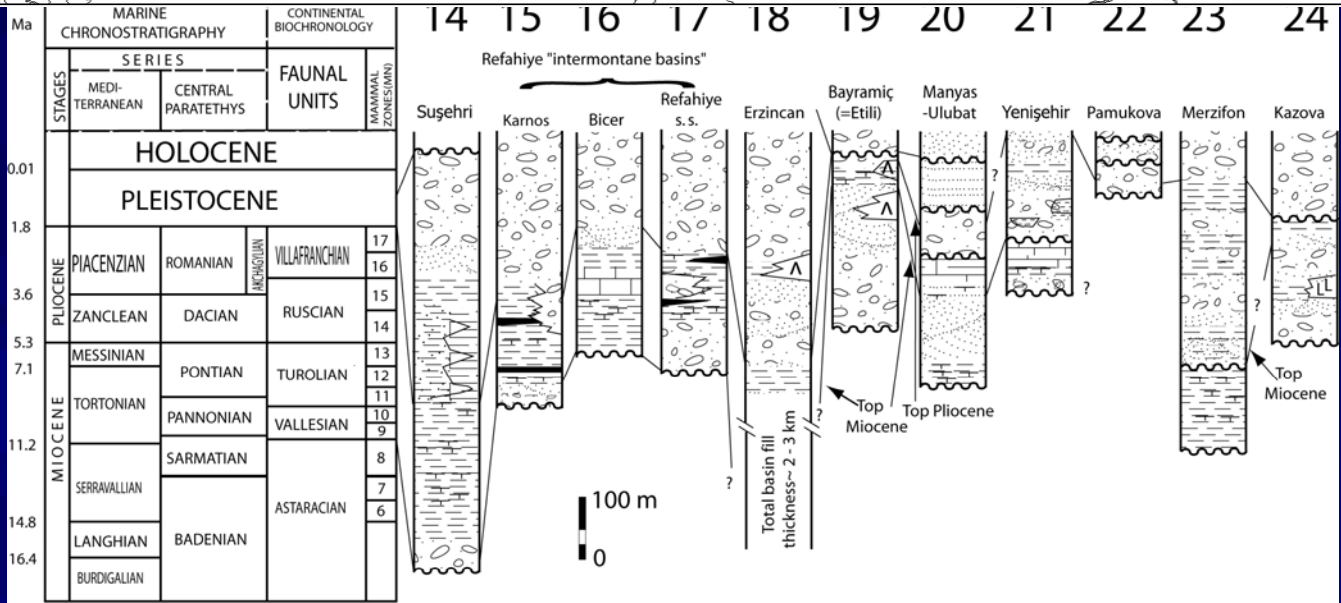
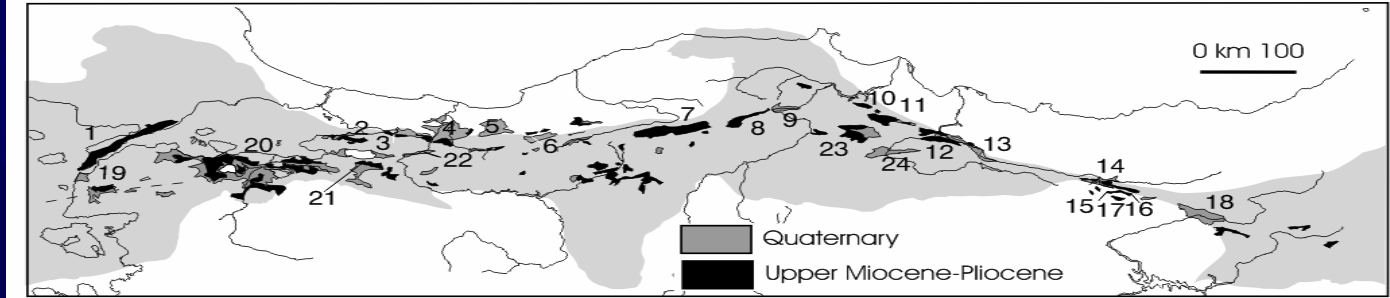


- There are several depressions filled with Neogene-Quaternary sediments along the NAF and its major splays.
- These basins were developed as pull-apart and fault wedge basins and negative flower structures.





Şengör et al, 2005



Şengör et al, 2005

Age of the North Anatolian Fault

- The oldest basins along the NAFZ are medial to late Miocene (11 Ma) in age, whereas the youngest are hardly older than the Pleistocene (1.6 Ma)
- Judging from the basins directly associated with it, the NAF clearly becomes younger westward.
- The North Anatolian Shear Zone as a whole is medial to late Miocene in age (11 Ma), *but not the NAF*.
- The NAF formed about 11 Ma ago in the east, near Erzincan, and may have propagated westward at a rate of 11 cm/a
- NAF reached the Sea of Marmara no earlier than 200 ka ago, although the NASZ-related deformation here has already commenced in the late Miocene (10 Ma).

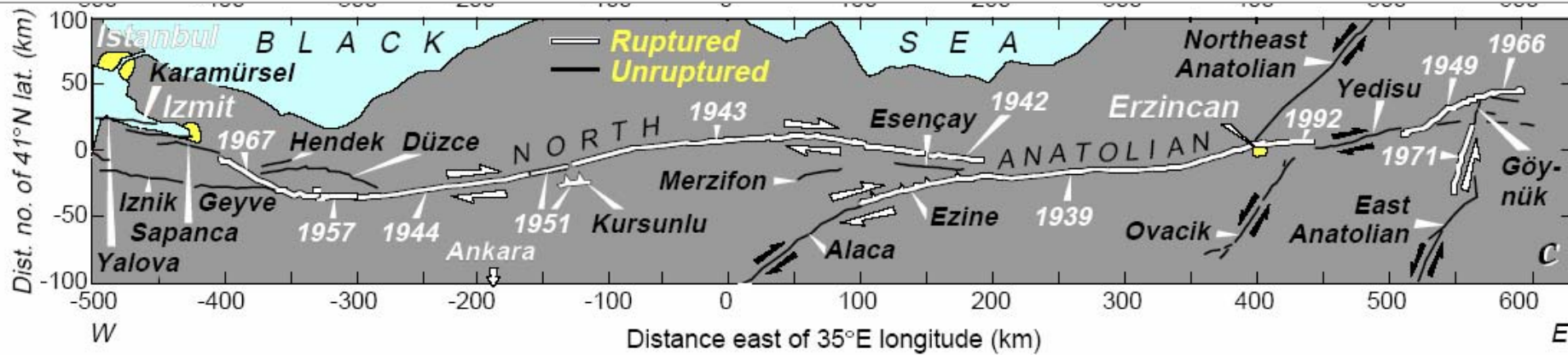
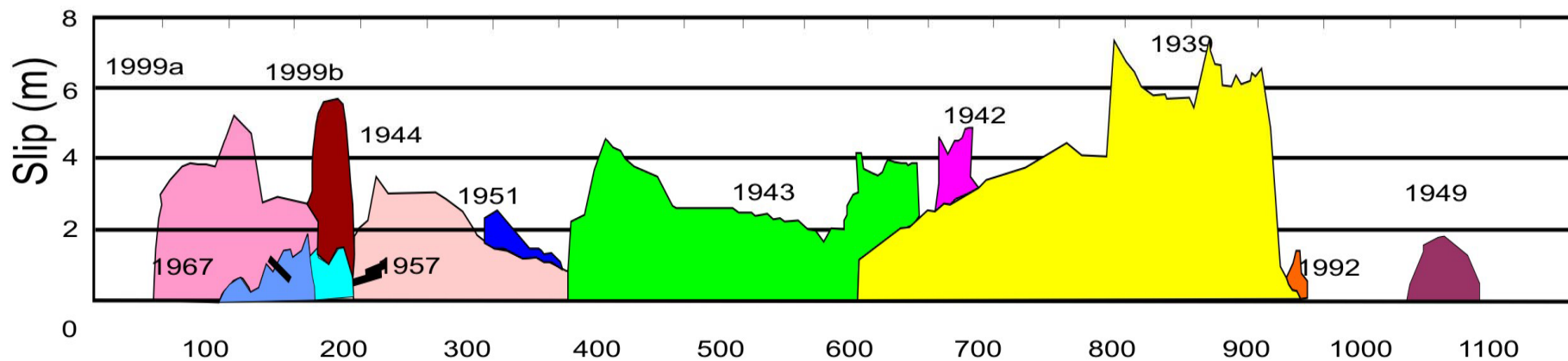
Offset of the North Anatolian Fault

- Geological data indicate a total offset ranging from 85 to 20–25 km.
 - Offset of the Elmalı-Periçay System 60 km.
 - The Yedisu Offset 50 km
 - Offset of the Karasu River (Euphrates tributary) 50 km
 - Turhal-Amasya Plain deflection of the Yeşilırmak 30 km.
 - Amasya Plain-Lâdik deflection 50-75 km.
 - The Kargı offset 40 km
 - Mudurnu Çayı offsets 50 km
 - The Pamukova river diversion 26 km
 - Sea of Marmara 4 km
 - Western margin of the Central Basin of the Sea of Marmara 4 km since 200 ka ago
- Recent GPS data indicate present-day rates of about 24 mm/a

■ Beginning with 1939 Erzincan earthquake, the NAF ruptured by 8 earthquakes ($M > 6.7$) propagating in a westward progression

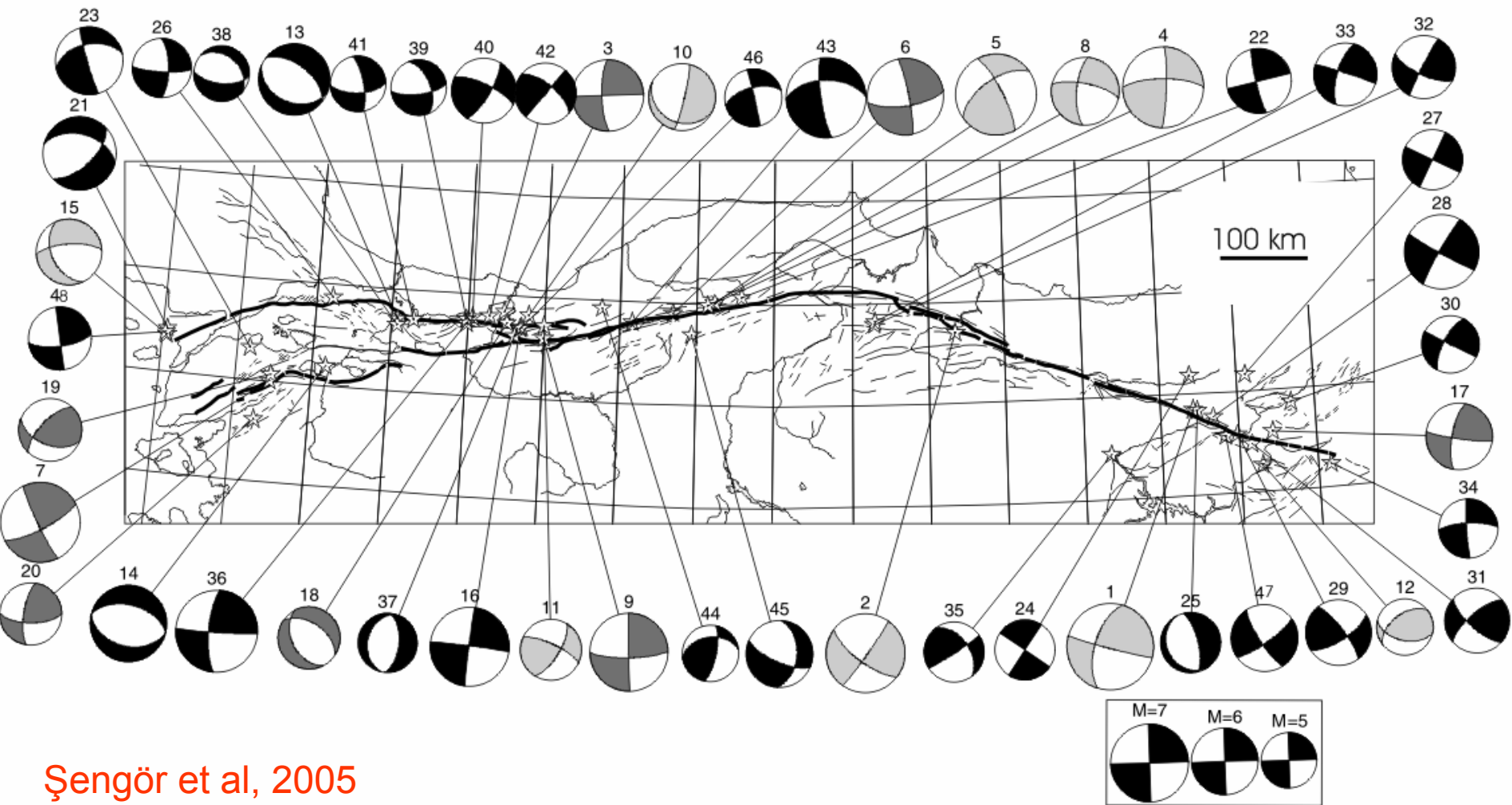
- 26 December 1939 Erzincan ($M = 7.9$)
- 20 December 1942 Erbaa-Niksar ($M = 7.1$)
- 26 November 1943 Tosya ($M = 7.6$)
- 1 February 1944 Bolu–Gerede ($M = 7.3$)
- 26 May 1957 Abant ($M = 7.0$)
- 22 July 1967 Mudurnu ($M = 7.1$)
- 17 August 1999 Kocaeli ($M = 7.4$),
- 12 November 1999 Düzce ($M = 7.2$)

■ This westward propagation has been interpreted in terms of a Coulomb failure model, whereby every earthquake concentrates the shear stress at the western tip of the broken segments leading to westward migration of the large earthquakes.



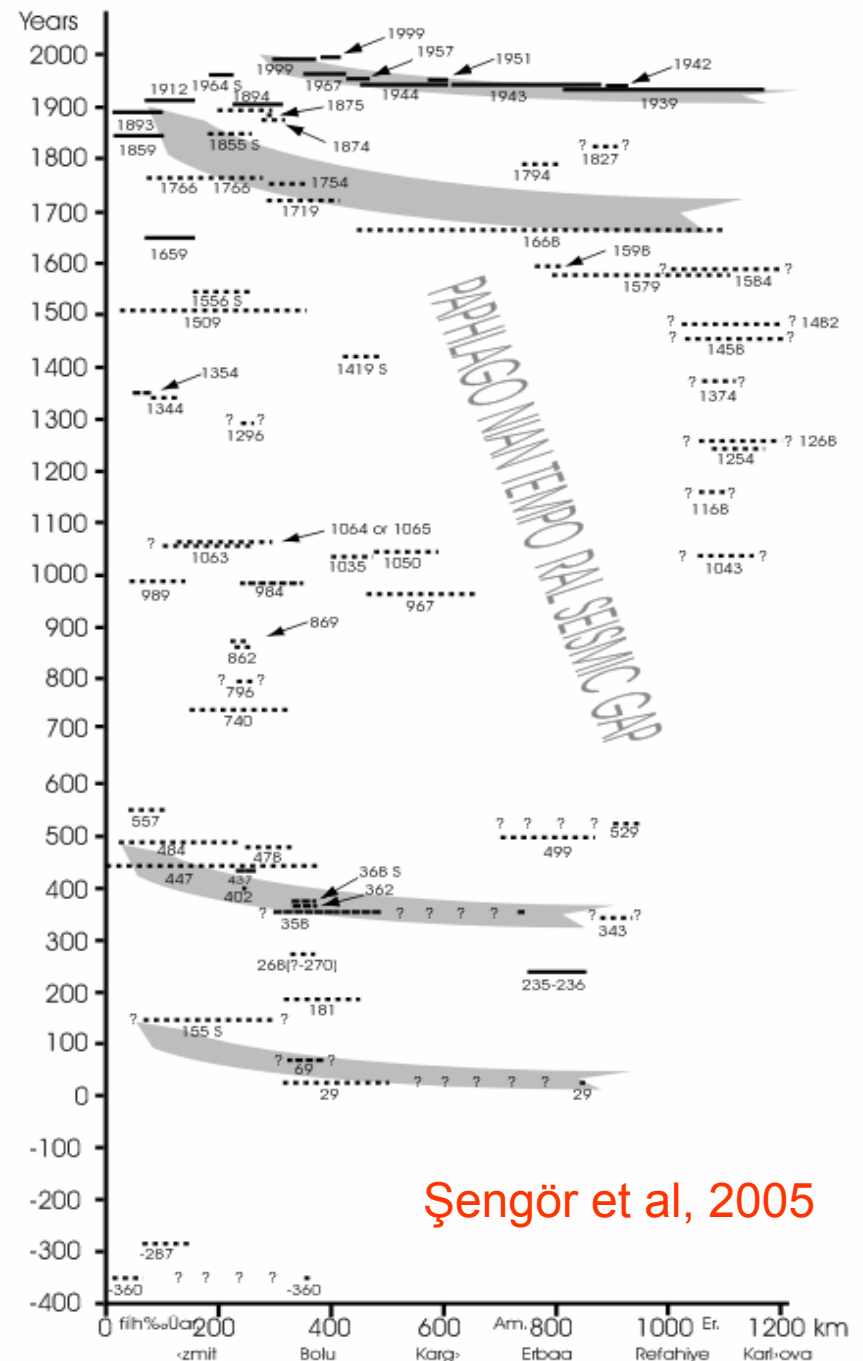
Stein et al, 2001

Main branch and its splays produced destructive earthquakes



Şengör et al, 2005

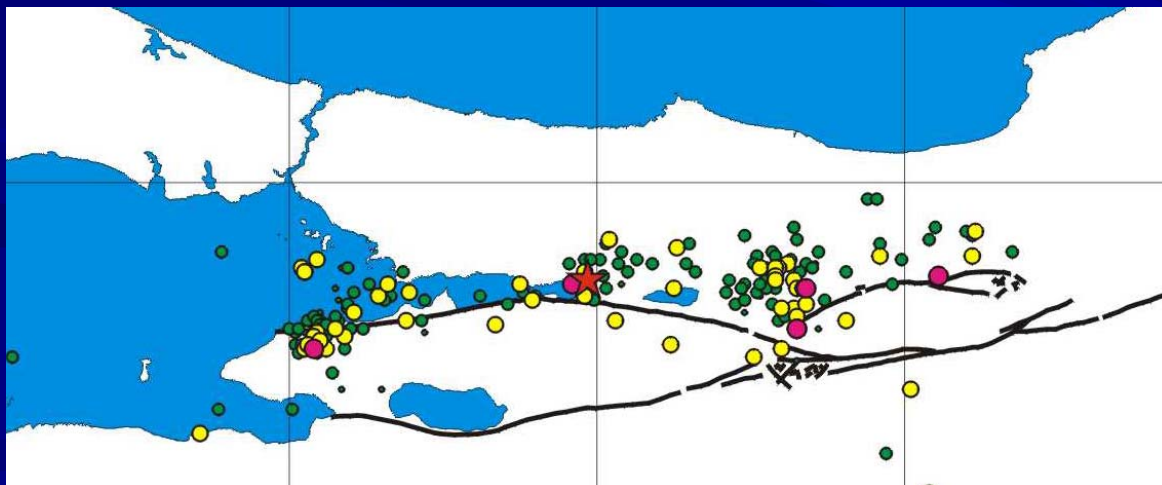
Since the 17th century, the NAF shows a cyclical seismic behaviour, with century-long cycles beginning in the east and progressing westward. For earlier times, the record is less clear but does indicate a lively seismicity.



17 August and 12 November 1999 Earthquakes

17 August ($M=7.4$) and 12 November ($M=7.2$) 1999 events killed more than 20,000 people and ruptured about 160 km of the northern branch of the NAF.

These earthquakes have also loaded the Marmara segment(s?) of the fault and a major ($M \leq 7.6$) event is expected in the next half century with an about 50% probability on this segment.





3.85m



LPG

4.95m

DİKKAT!

YAKARAK KULLANMAYI
KURUTMAK VE YAKARAK
KULLANMAYI
YASAKLADIK



AY TIZ

34 R
3381

AY TIZ





4.90m



4.65m



4.80m







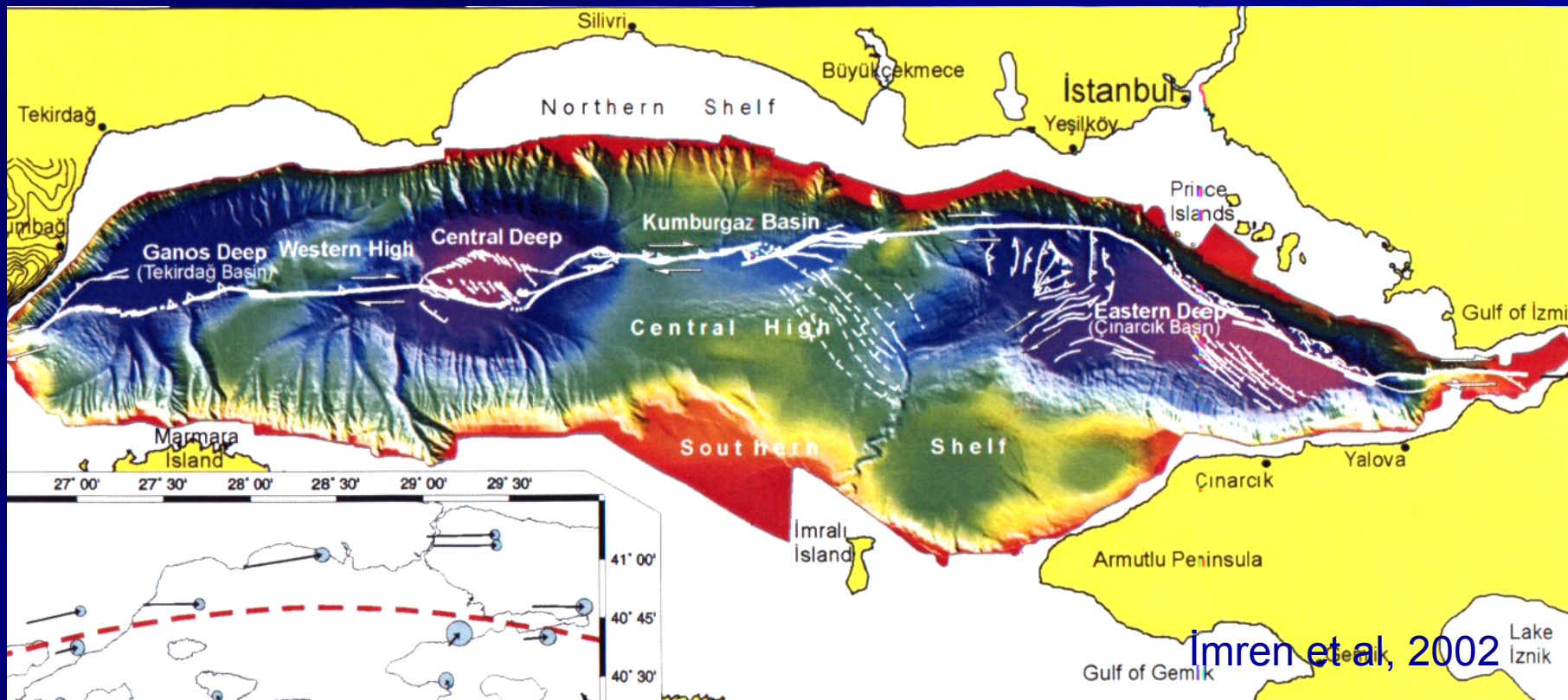


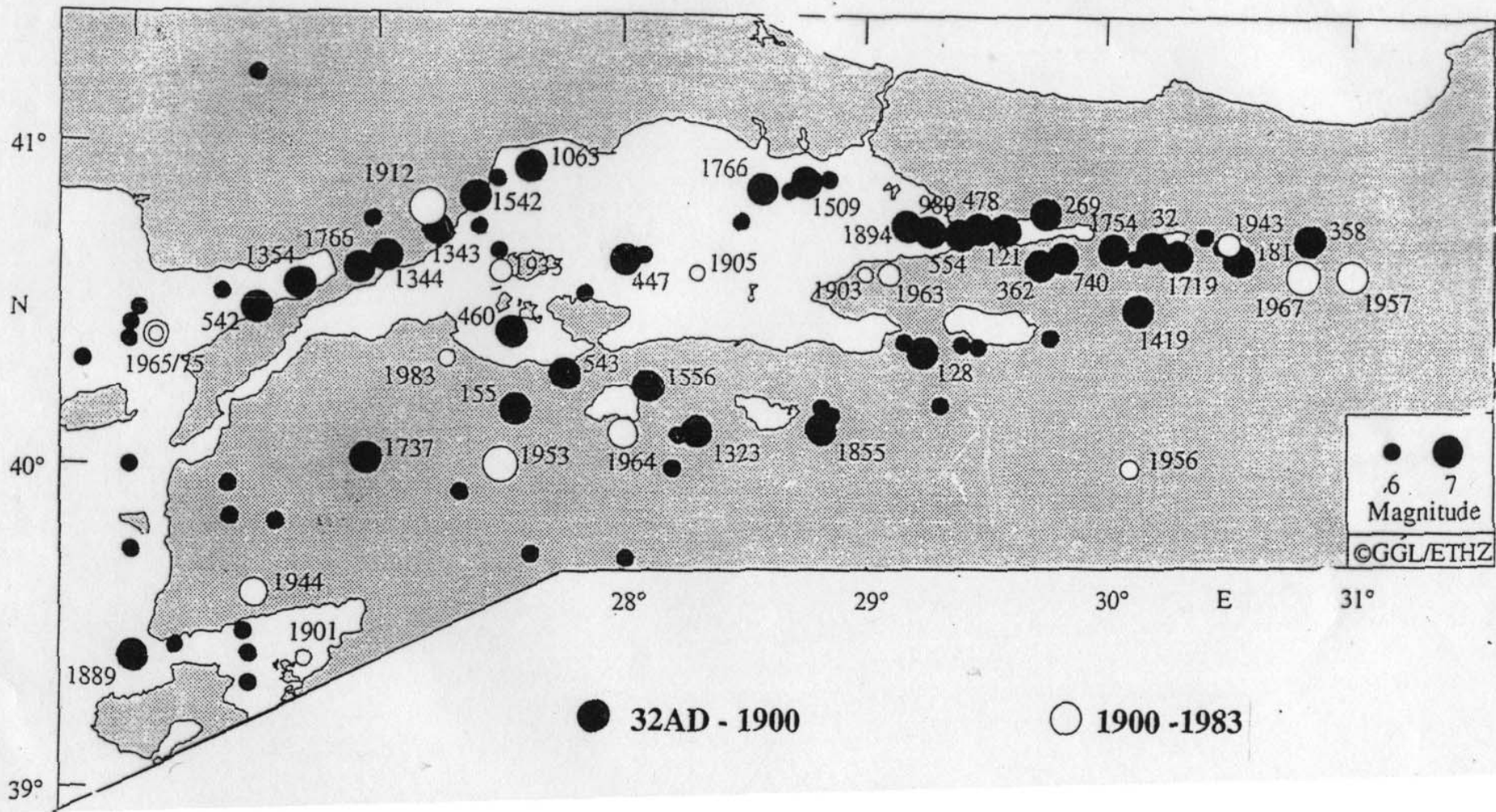




Sea of Marmara

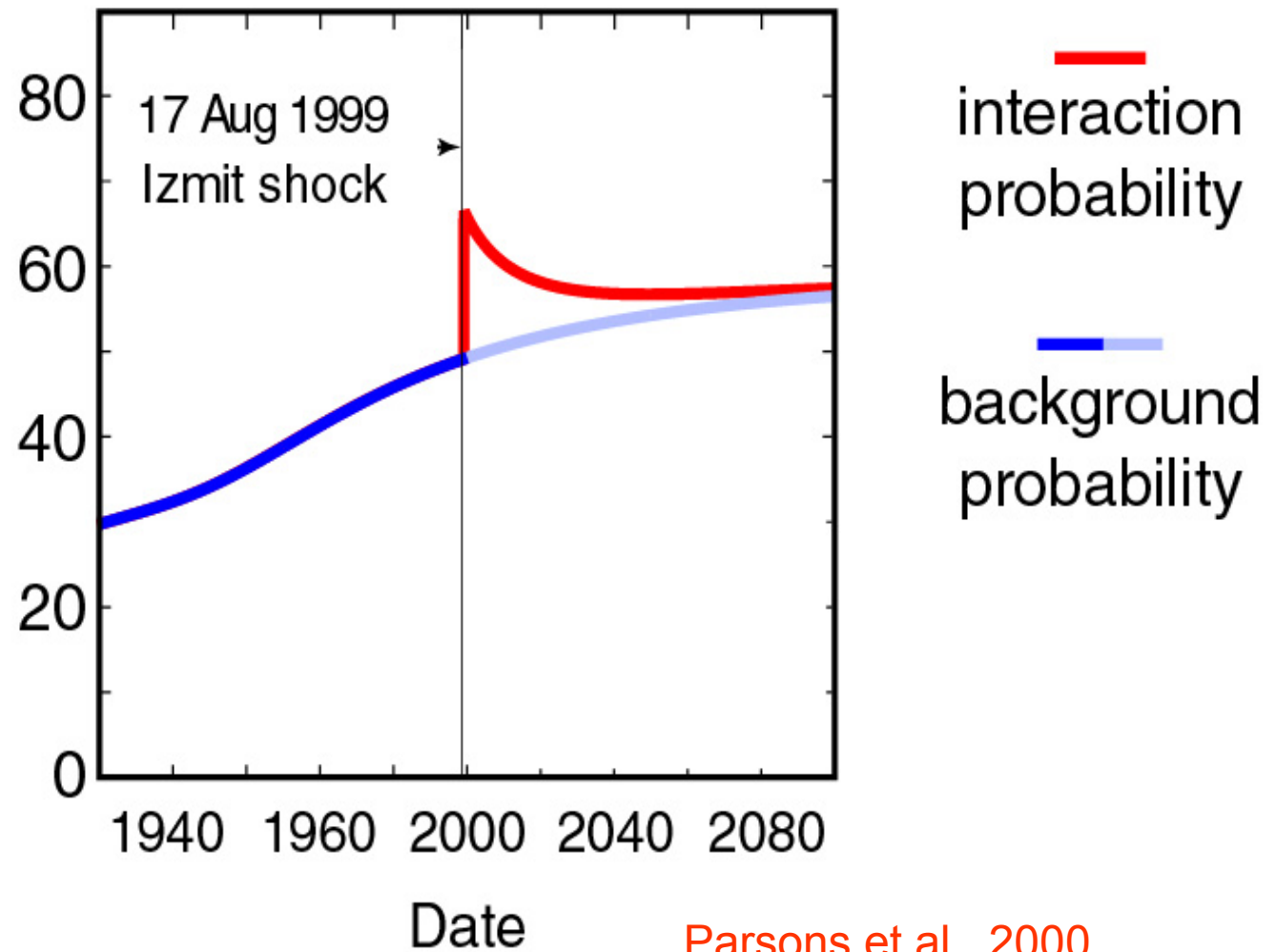
- The Marmara region forms a transition zone between the area of pure strike-slip deformation and Aegean Extensional region
- Deep and asymmetric strike-slip basins (Çınarcık, Central Marmara, Tekirdağ)
- The basins consist of Plio-Quaternary sediments reaching over 3 km.





Calculated probability of strong earthquake shaking in Istanbul

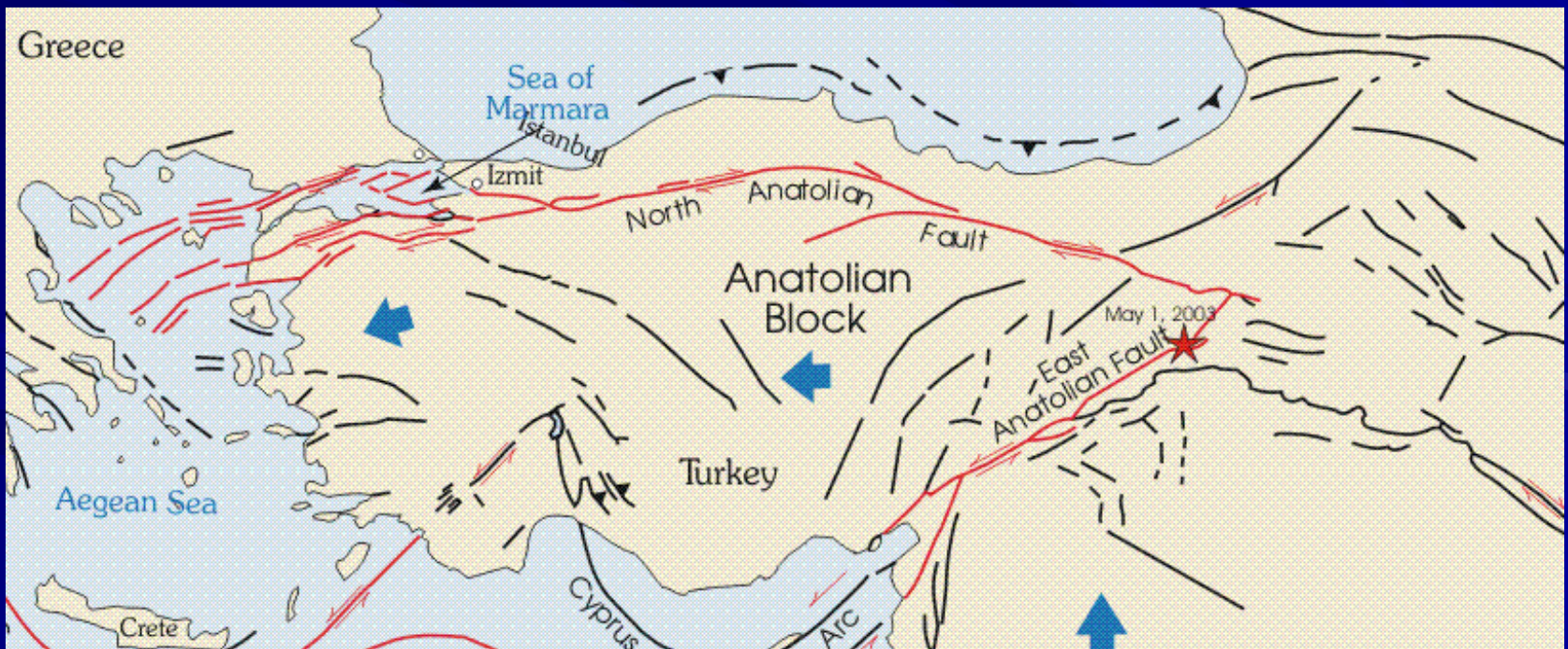
Thirty-year
probability (in %)
of a $M \geq 7$ shock
within 50 km
of Istanbul



Light blue line gives probability had the 1999 earthquake not occurred

East Anatolian Fault Zone

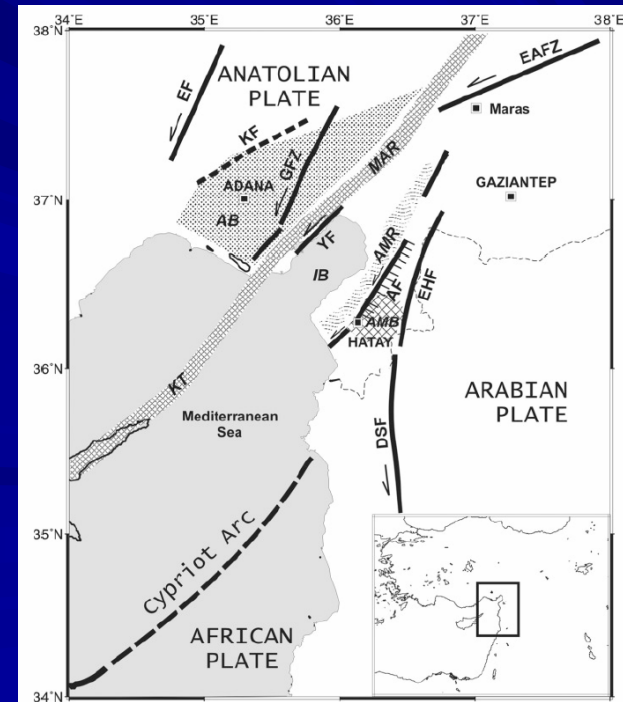
- 600 km-long,
- Sinistral
- Accommodates to the westward extrusion of Anatolia.
- Forms the boundary between the Anatolian Arabian plates.



AGE, OFFSET and RATE of EAFZ

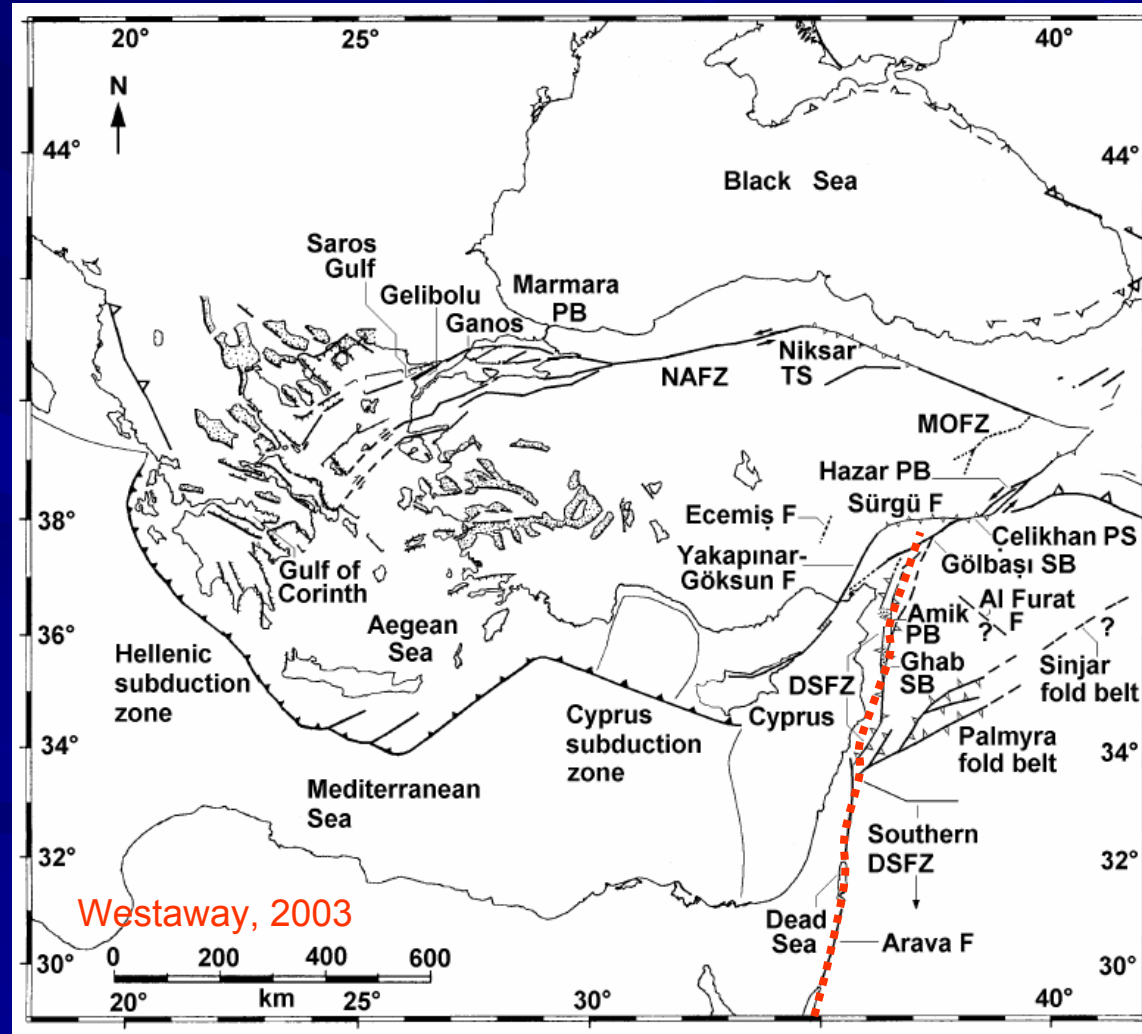
- A left-lateral displacement of 3.5–13 km and 15–27 km have been proposed by using geological data.
- The rate of slip is 10 mm/a according to the GPS data.
- Different ages have been proposed:
 - Late Miocene–Early Pliocene (~5 Ma);
 - Late Pliocene (~3 Ma)
 - Late Pliocene (~1.8 Ma)

- The EAFZ has ruptured during many destructive earthquakes, but most part of it is silent since 100 years
 - 22 May 1971 Bingöl ($M = 6.8$)
 - 5 May 1986 ($M = 5.8$) and 6 June 1986 ($M = 5.6$) Doğanşehir-Malatya
- The continuation of the EAFZ to the SW is more complicated. This section of the fault produced medium-big earthquakes
 - 1945 and 1952 Adana–Misis ($M = 5.7$ and $M = 5.3$)
 - 1979 Adana–Kozan ($M = 5.1$)
 - 1986 Gaziantep ($M = 5.0$)
 - 1989 Iskenderun ($M = 4.9$)
 - 1991 Kadirli–Adana ($M = 5.2$)
 - 1994 Adana–Ceyhan ($M = 5.0$)
 - 1994 Adana–İskenderun ($M = 4$)
 - 27 June 1998 Adana–Ceyhan ($M = 6.2$)
 - 17 January 2001 Osmaniye ($M = 4.9$)



Dead Sea Fault Zone

- 1000 km-long,
- Sinistral
- Plate boundary of transform type
- Separates the African and Arabian plates
- Different views about its age ranging 10 to 20 Ma



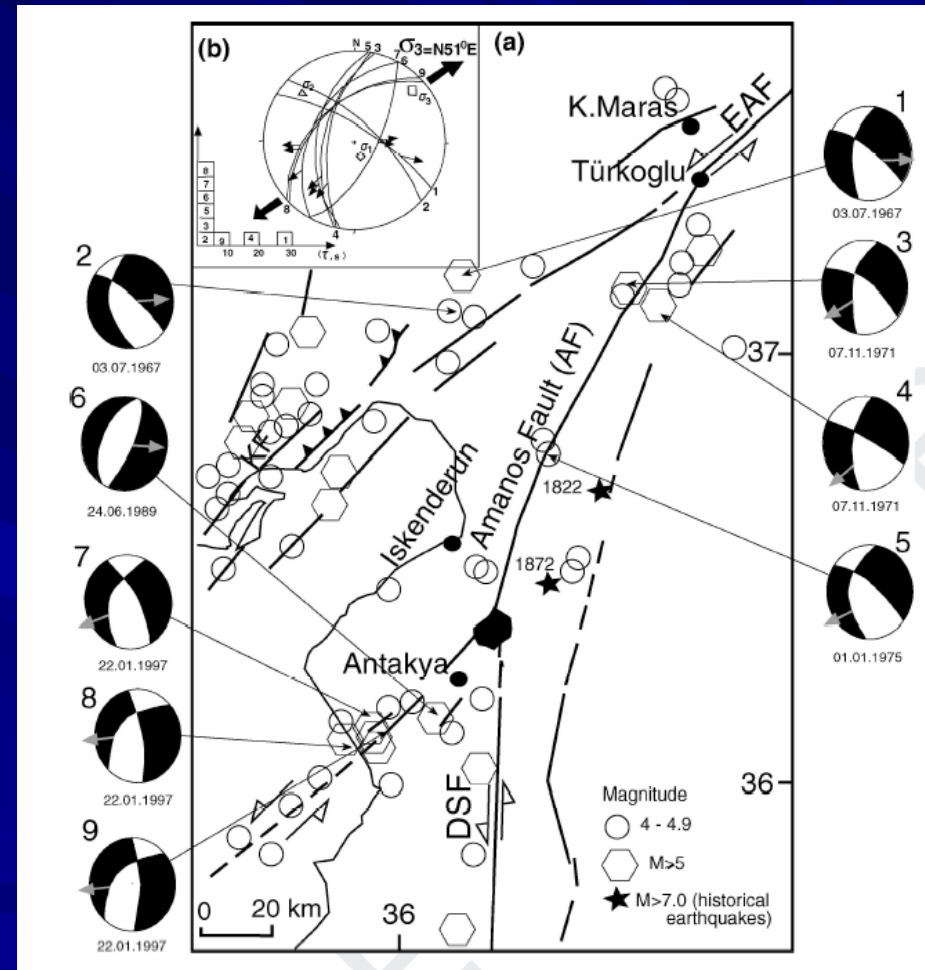
OFFSET of the DSFZ

- 100-110 km for the southern part and 70–80 km for the northern part.
- Recent studies indicate 10–20 km of total slip.
- Two stages of offset
 - 60–70 km offset during 25–15 Ma
 - 40–50 km offset during the last 4.5 Ma.

Big Earthquakes on the DSFZ

DATE	INTENSITY
BC 69	IX
13.12.115	IX
245	X
334	IX
14.09.458	IX
10.09.506	IX
29.05.526	IX
29.11.529	IX
30.09.587	IX
08.04.859	IX
867	IX
10.08.1114	IX
13.08.1822	X
02.04.1872	IX

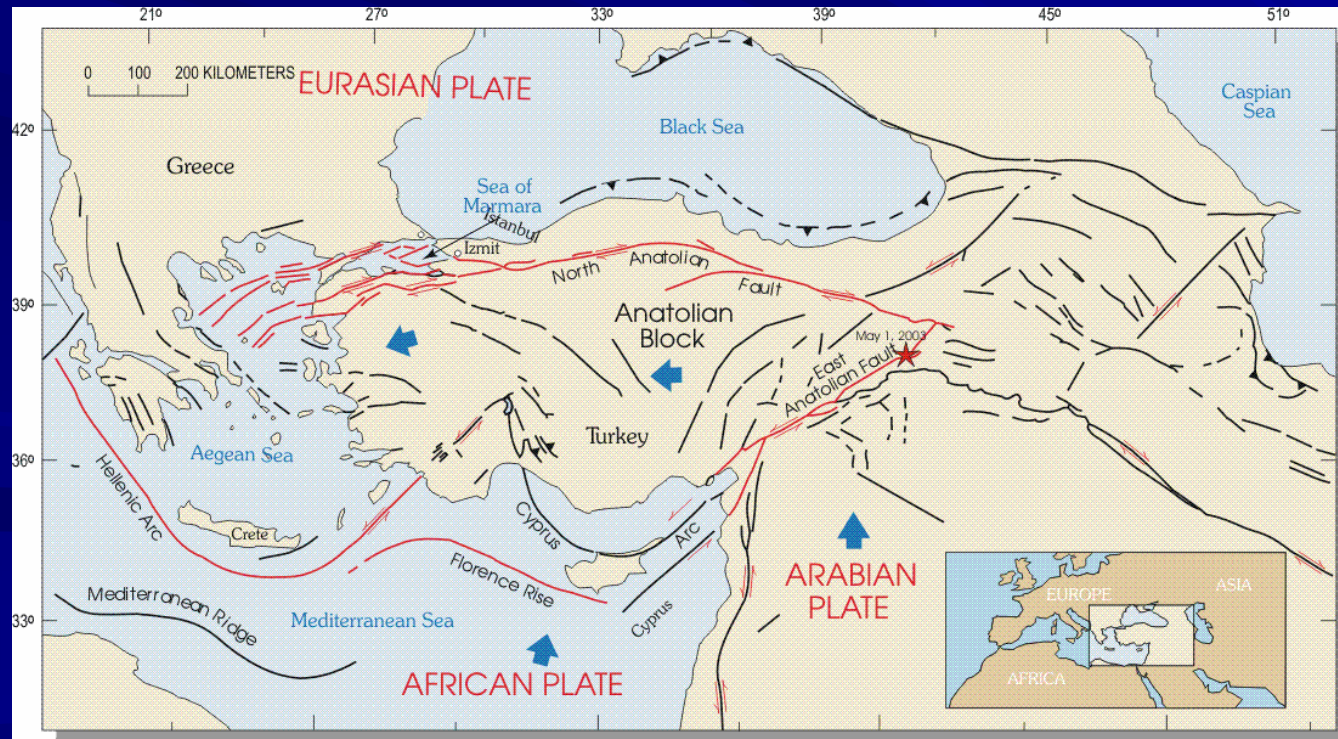
Historical period



Instrumental period

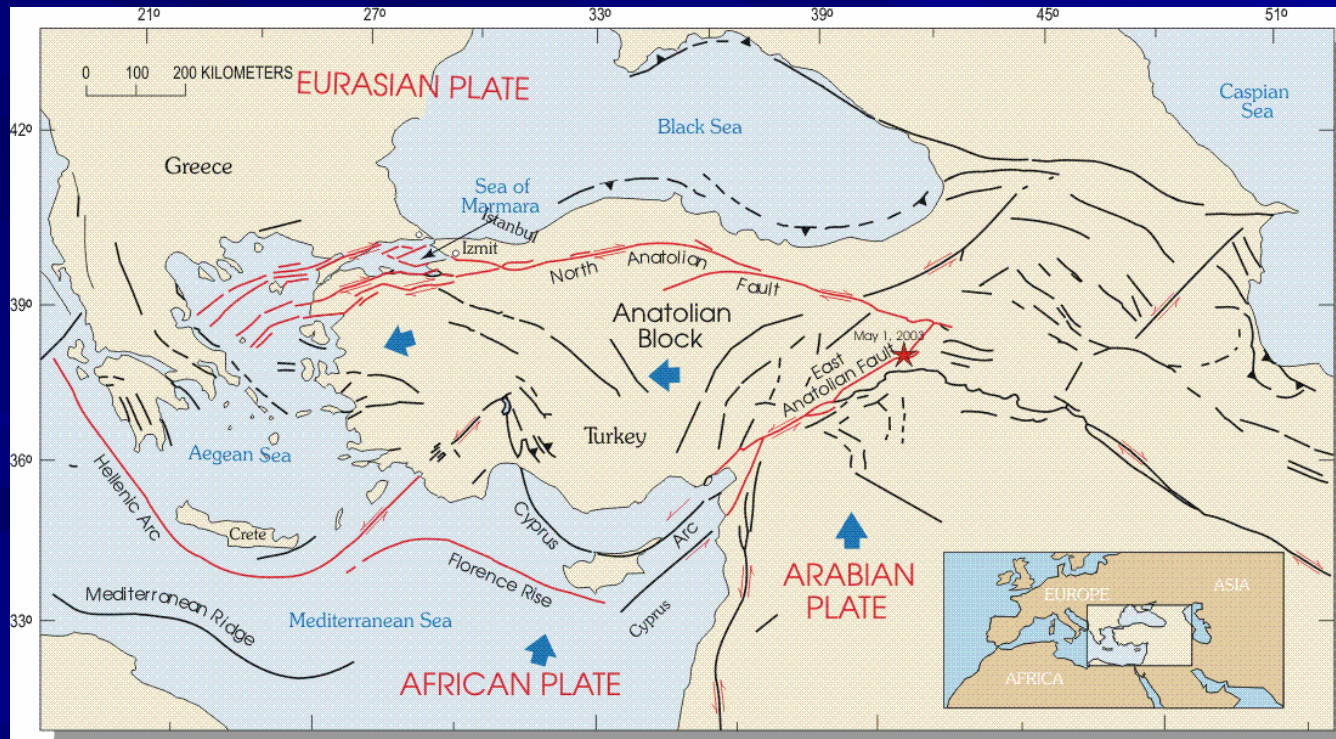
Aegean Arc

- The African Plate is descending northward beneath the Anatolian Plate
- Convergence between the African and Anatolian plates in the Eastern Mediterranean takes place by subduction along the Aegean and Cyprus arcs
- Roll-back effect created extensional regime in the Aegean Province
- Deep earthquakes and volcanoes created by this subduction

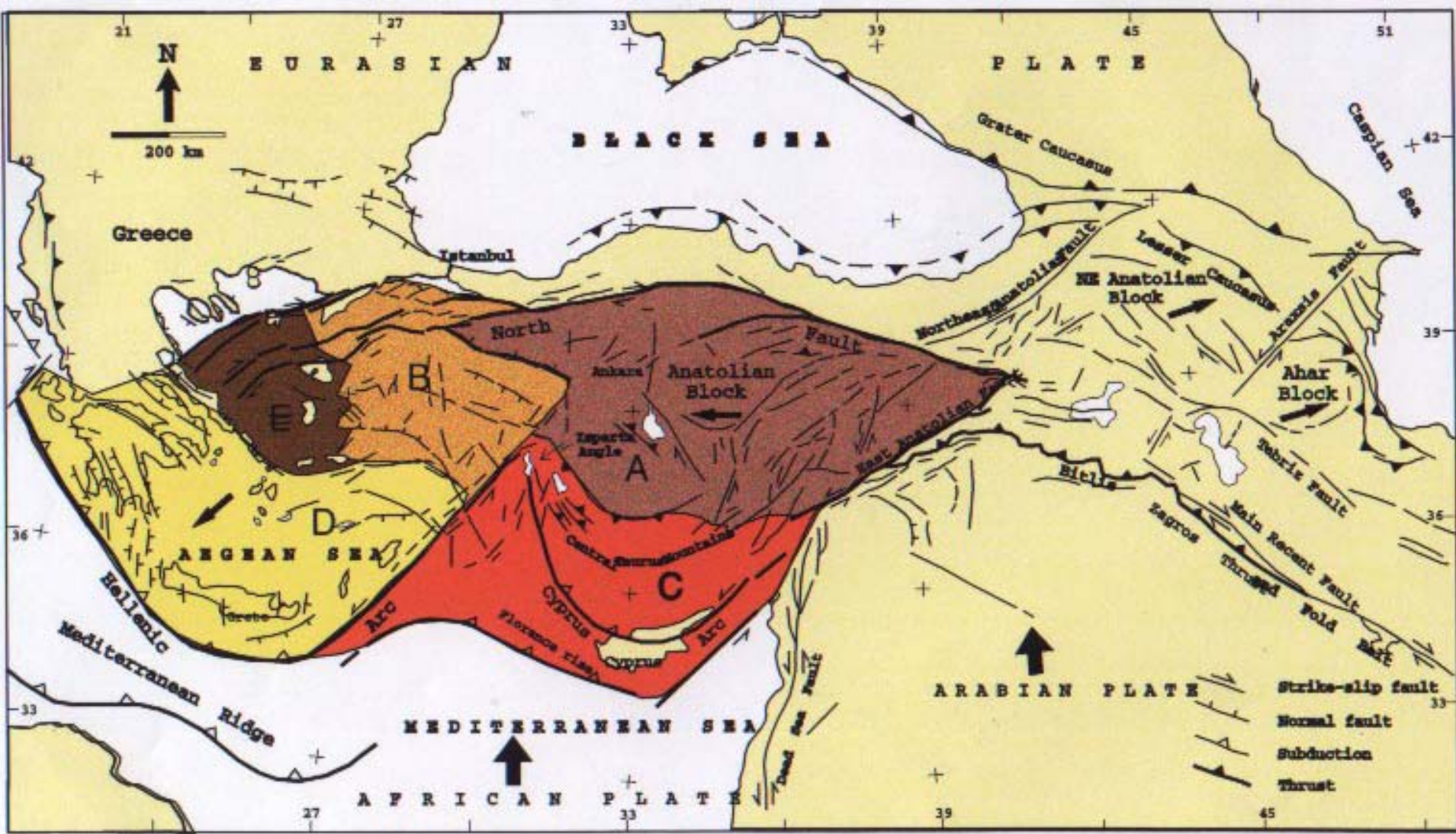


Cyprus Arc

- Collision of Eratosthenes Seamount with the trench caused uplifting of Cyprus and stopping of subduction
- In the east of Cyprus strike-slip deformation is dominant
- M = 6.0 or larger earthquakes occurred during the instrumental period.



PRESENT STRUCTURE of TURKEY



Thank You