High Risk High Reward Sub-thrust Prospectivity Epirus NW Greece

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  - Roberto Gambini
  - Ronaldo Miele
  - Angelos Mavromatidis
  - Jennifer Urquhart
  - Ivan Inchenko
- The presentation does not discuss in detail the studies made by Enterprise
  - Further info held by Greek state
  - I do borrow some drafting from them of public domain info/diagrams from my thesis
- This talk is nothing to do with my current employer Endeavour Energy UK
  - I'm here in a personal capacity.
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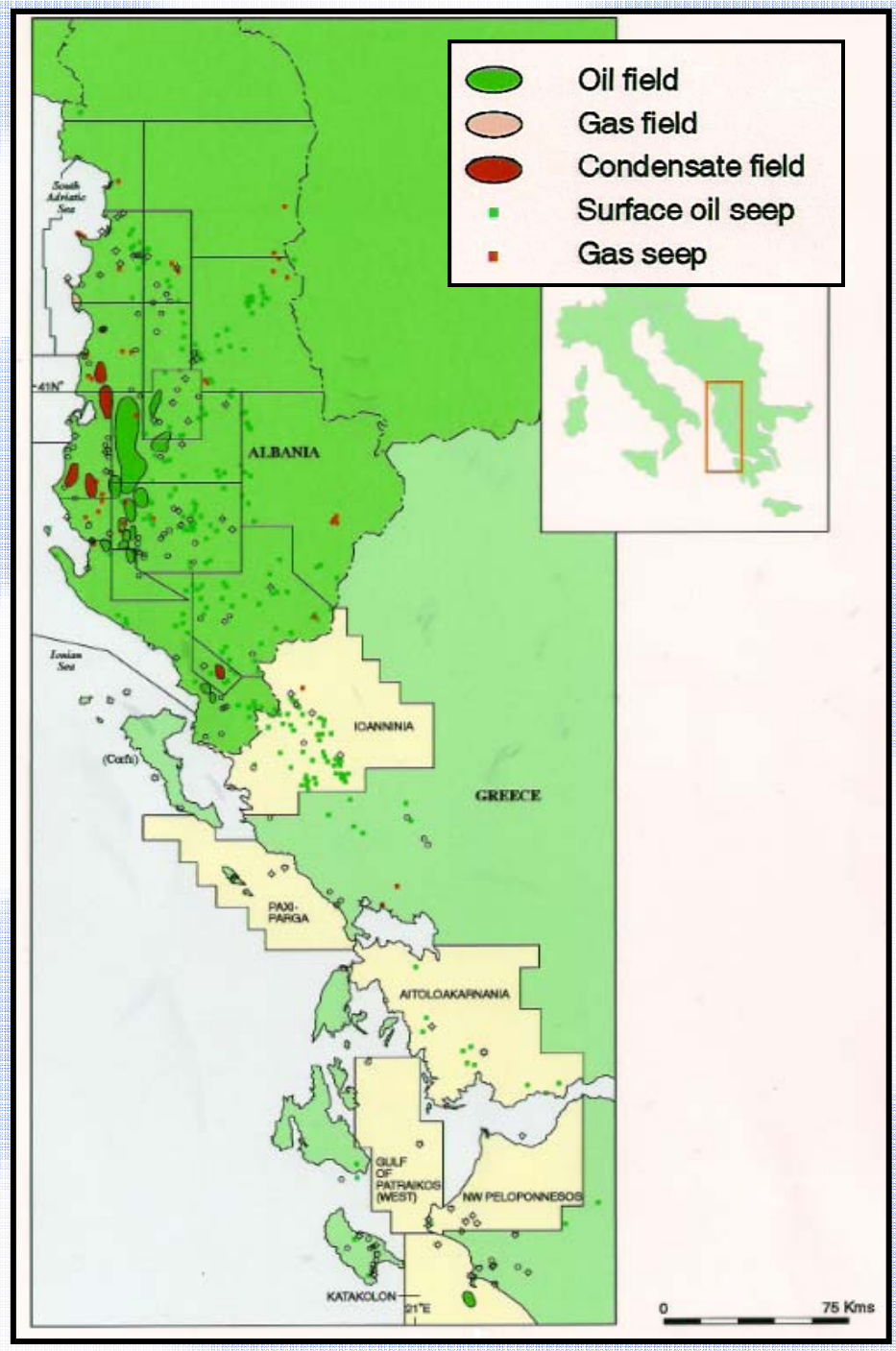
  - Inst. Nazionale. Di Geofisica e Vulcanologia, Rome, Italy

The Ionian Zone

Resource Rich

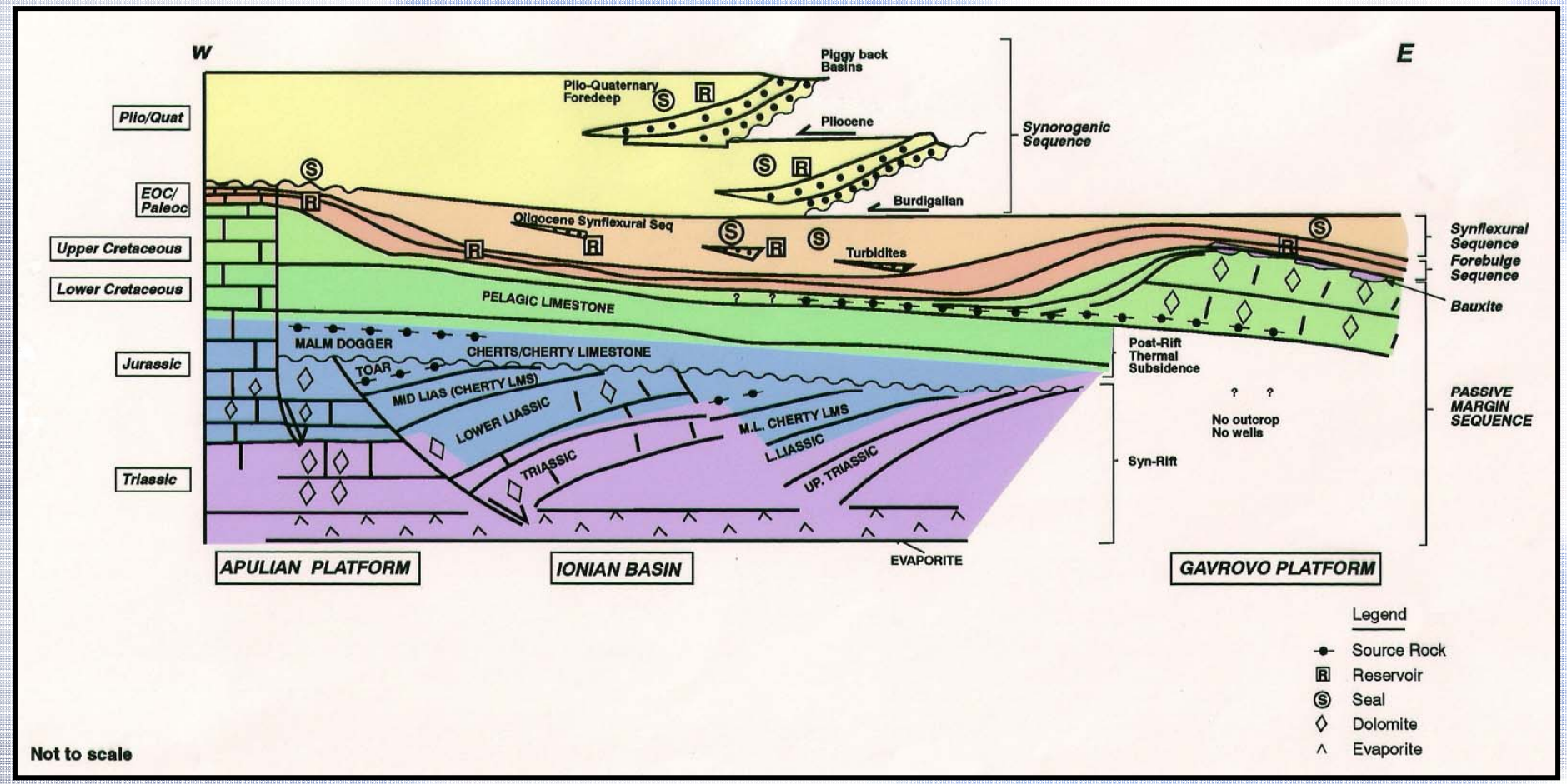
- Fold and thrust belt
- Proven HC province
- Prolific in Albania
- Seeps abound in Greece
- Katakolon field offshore Peloponnese

- Discoveries more evasive in Epirus so far



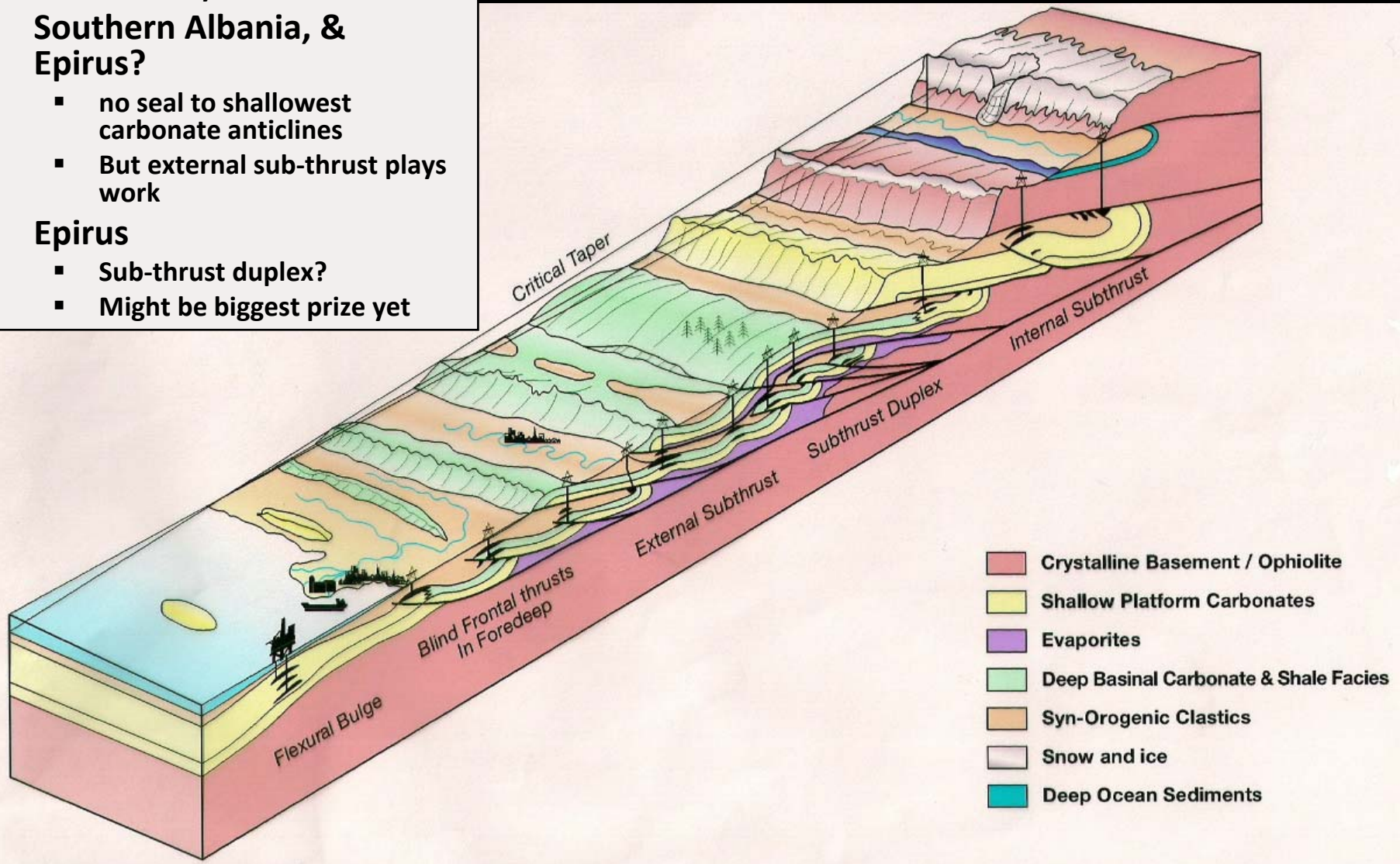
Petroleum system

- **Jurassic & Cretaceous source rock**
  - (syn & post rift)
- **Platform carbonate and calciturbidite and turbidite reservoirs**
  - (syn & post rift, syn-orogenic)
- **Triassic evaporite, pelagic carbonate, & shale seals**
  - (pre/syn rift, post rift, & syn-orogenic)
- **Ionian Basin – Tethyan rifted margin nestled between Apulian and Gavrovo platforms**



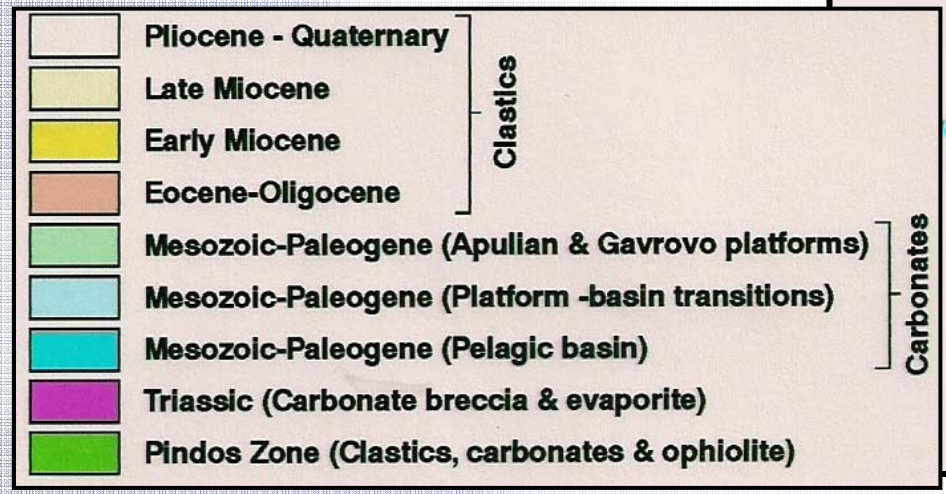
Tethyan thrust belt plays

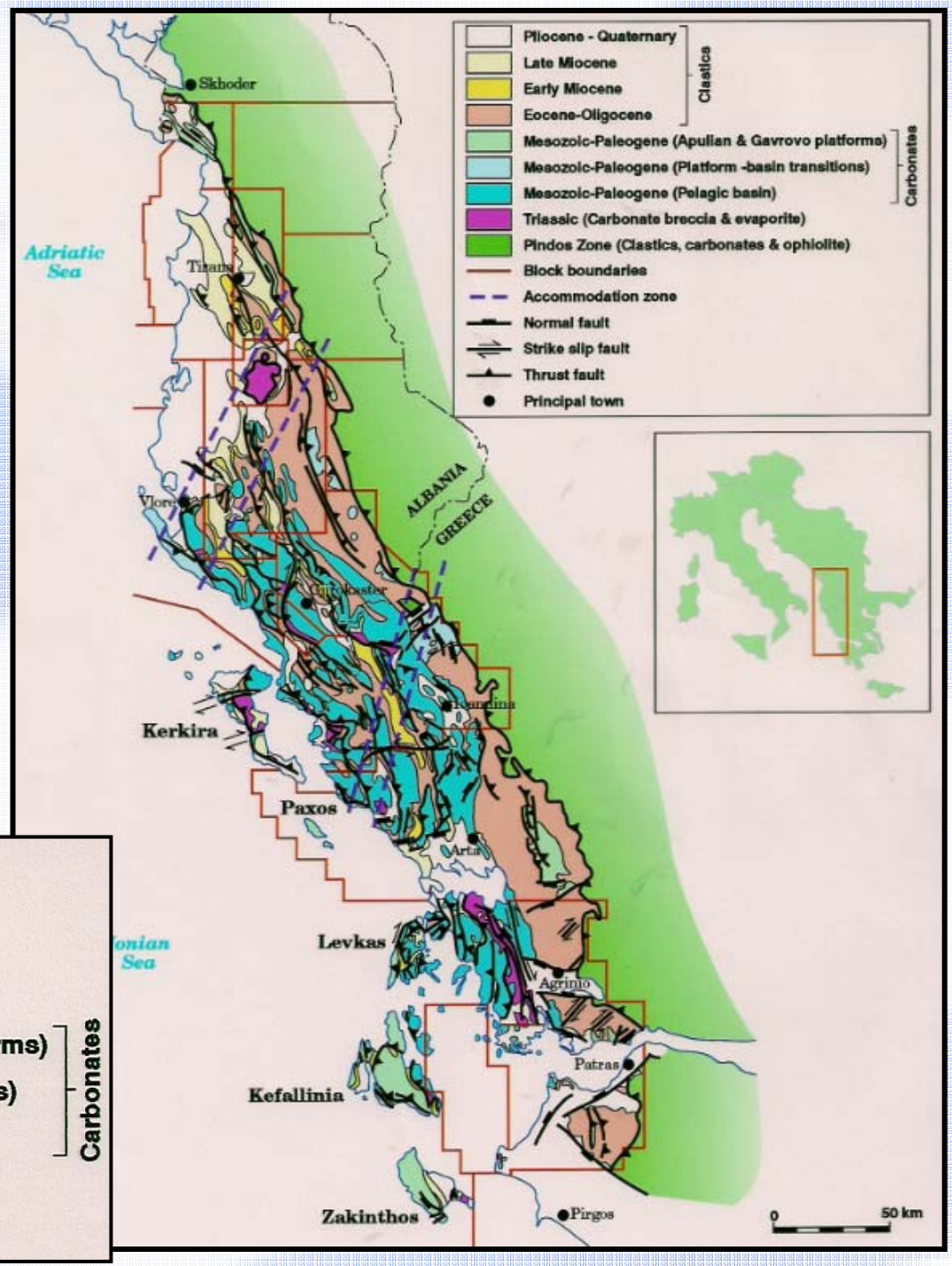
- **Central Albania**
  - many blind frontal thrusts buried by clastics
- **Southern Albania, & Epirus?**
  - no seal to shallowest carbonate anticlines
  - But external sub-thrust plays work
- **Epirus**
  - Sub-thrust duplex?
  - Might be biggest prize yet



Basic structure

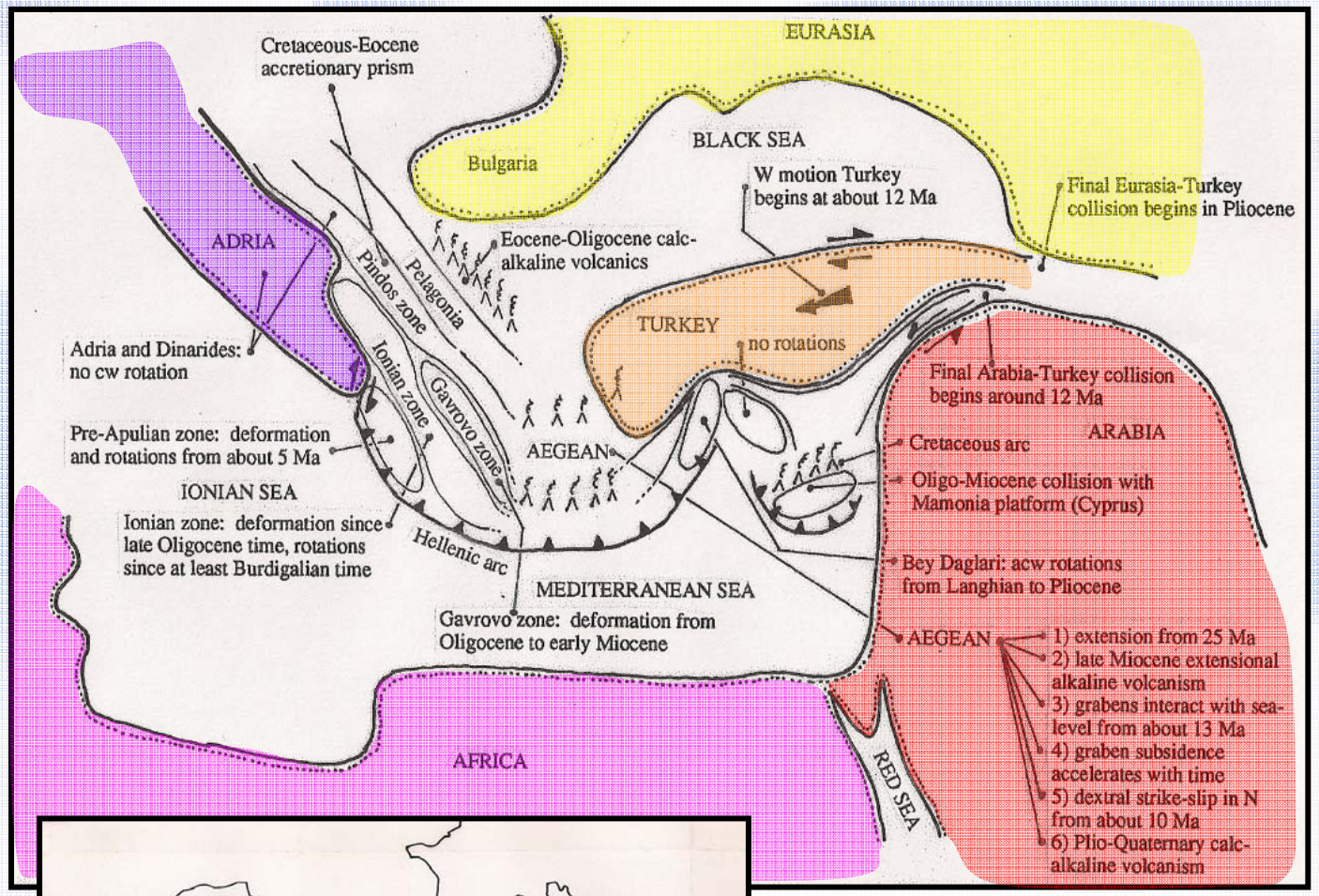
- To East: Pindos zone Cret-Eocene acc. prism with ophiolites, & Gavrovo zone platform
- Apulian zone platform to west
- Subduction and back arc extension to south
- Ionian Zone
  - Triassic evaporitic detachment
    - Nothing older exposed
  - Jurassic syn-rift carbonates
  - Cretaceous-Eocene thermal subsidence & flexural bulge basinal carbonates
  - Eocene-present clastics
  - Transverse shear zones

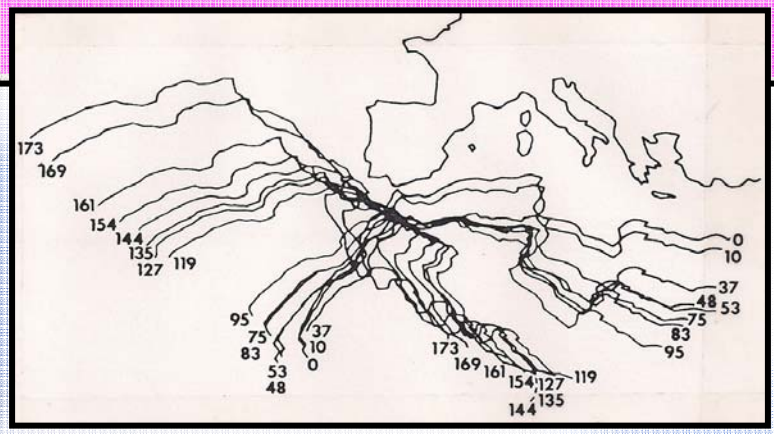




The dance of giants

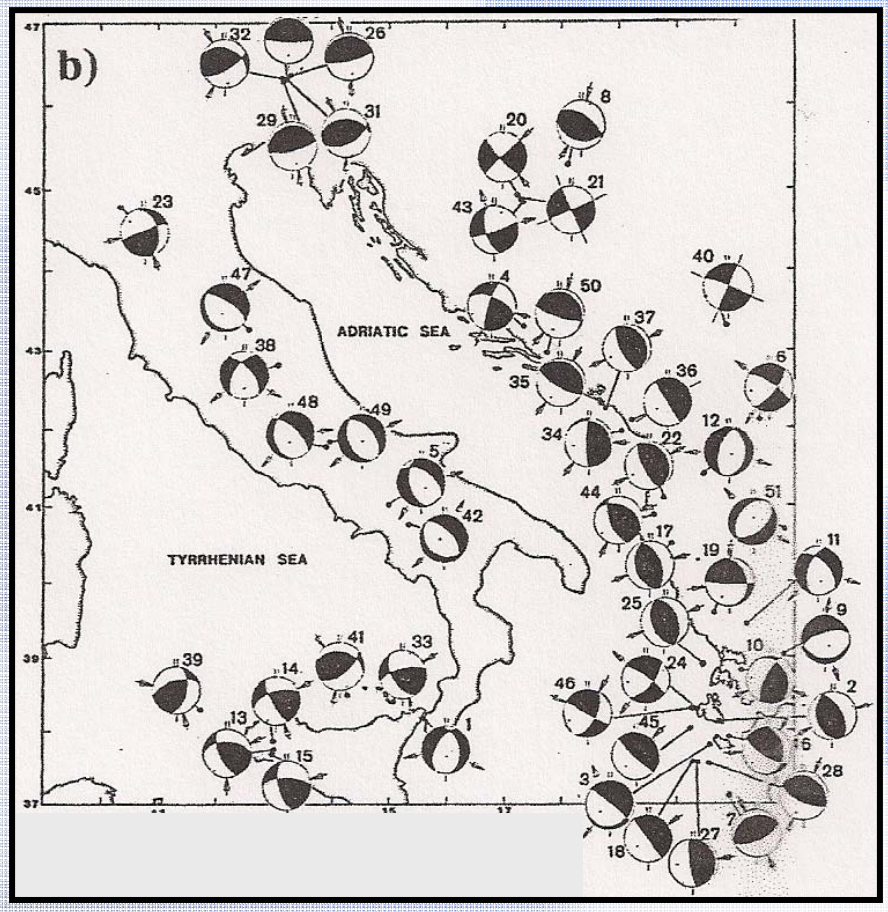
- Steady Africa-Eurasia convergence since Cretaceous
- Obduction of Late Jurassic ophiolites
- Eo-Oligocene Collision Pindos acc prism and Adriatic promontory of Africa
- Related calc-alkaline volcanics
- Oligo-Miocene contraction of Ionian zone & formation of Aegean Arc
- Arabia-Turkey collision and lateral expulsion from Mid Miocene
- Rapid migrations and rotations of evolving Hellenic arc
- Incorporation of Pre-Apulian zone into Hellenic arc deformation from latest Miocene
- Today – onset of Med. Ridge collision with Africa

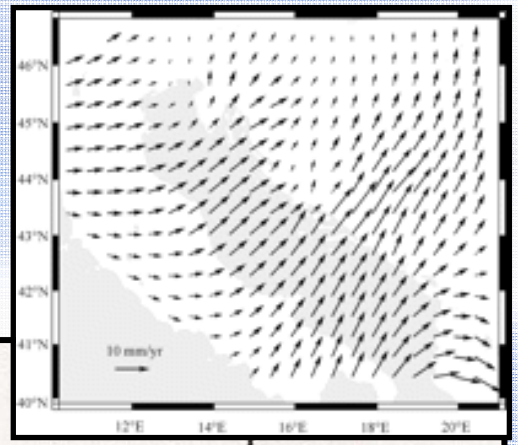


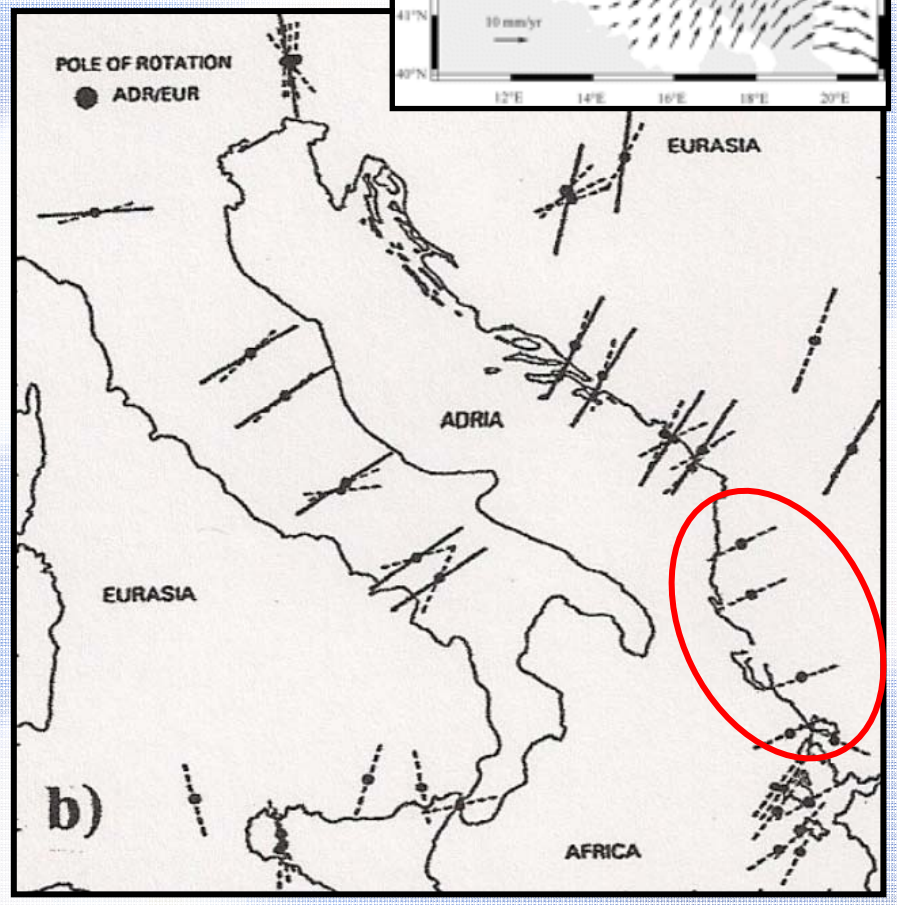


Adria micro-plate?

- Andersen & Jackson 1987, Altiner et al 2005
- Focal mechanisms consistent an Adriatic micro-plate pole of rotation
- But –changes as you get to the Ionian zone – something different going on – need another pole of rotation to explain things
- And no focal mechanisms to help us know what's going on in seismically quiescent Italian Apulia



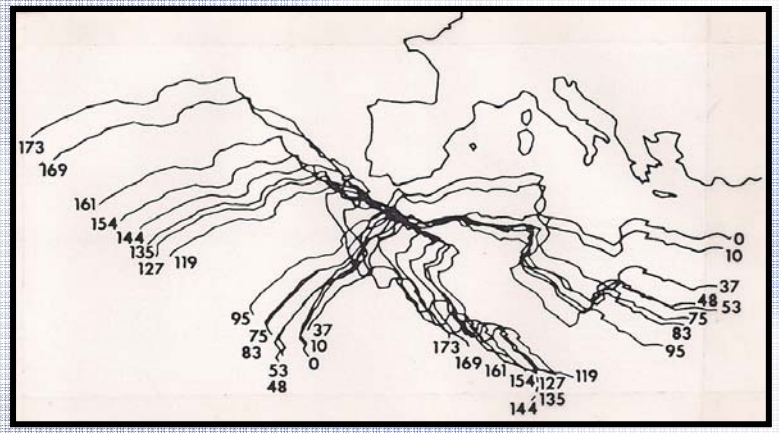


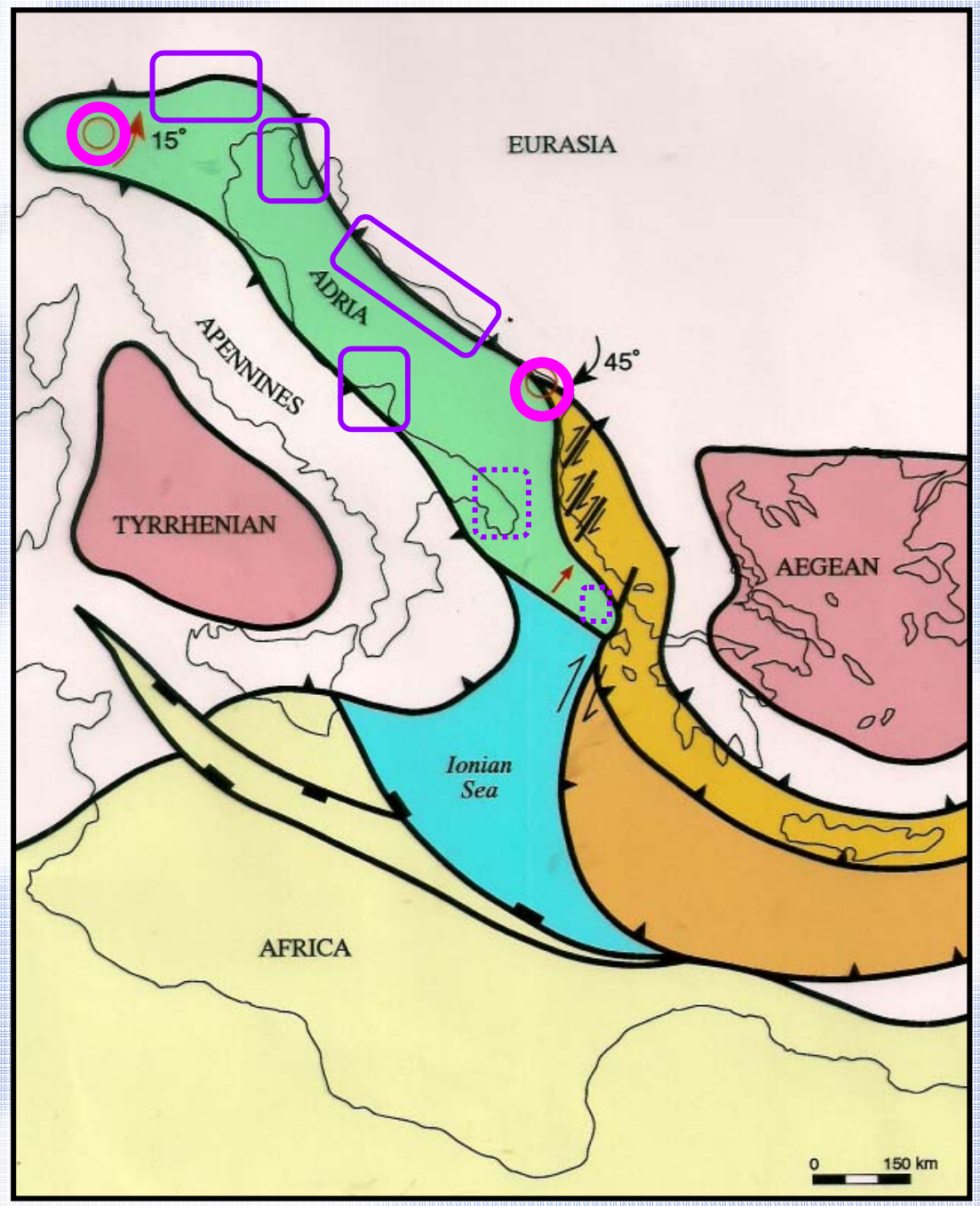


Ionian Zone Rotations

Rotation model

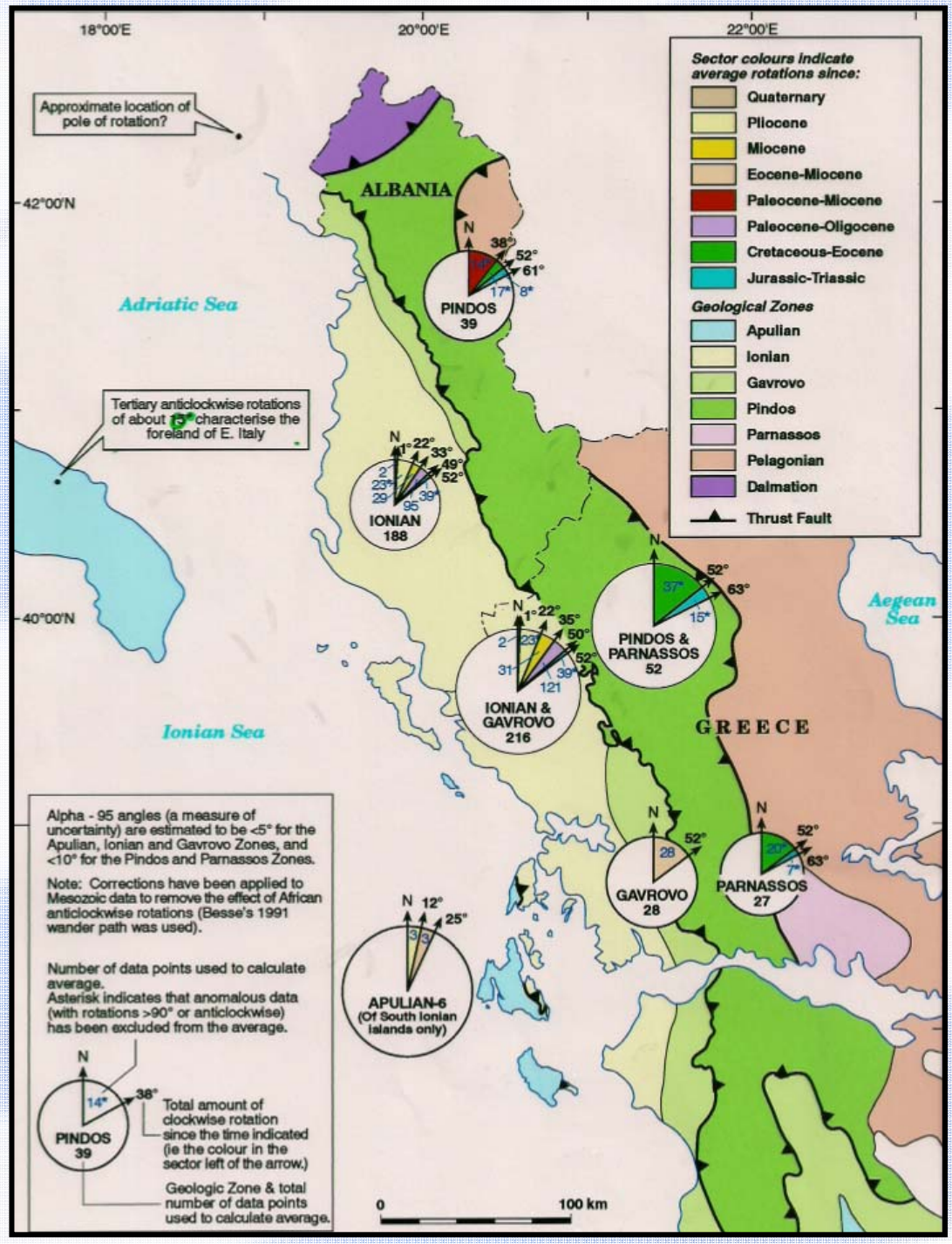
- Adria 15 degrees (0-25) acw wrt Africa since 100Ma
- My own study relative to Besse's Africa curve => ~ 15 degrees acw
- More or less like a promontory of Africa – but a bit detached
- Ionian zone 45 degrees wrt Africa since 30 Ma
- => 45-60 deg rotation wrt each other in Ionian zone since 30 Ma
- BUT don't have reliable data from southern areas of Adria
- Is it rotating as one or is it segmented?





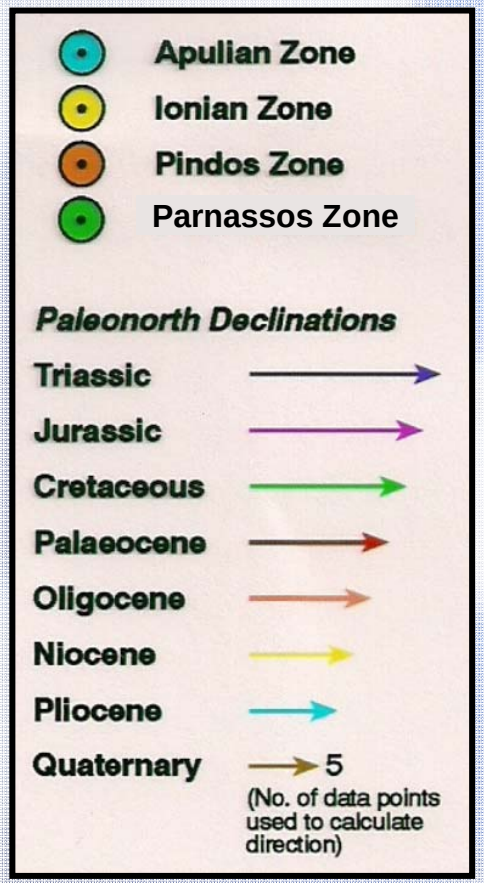
Ionian zone rotations

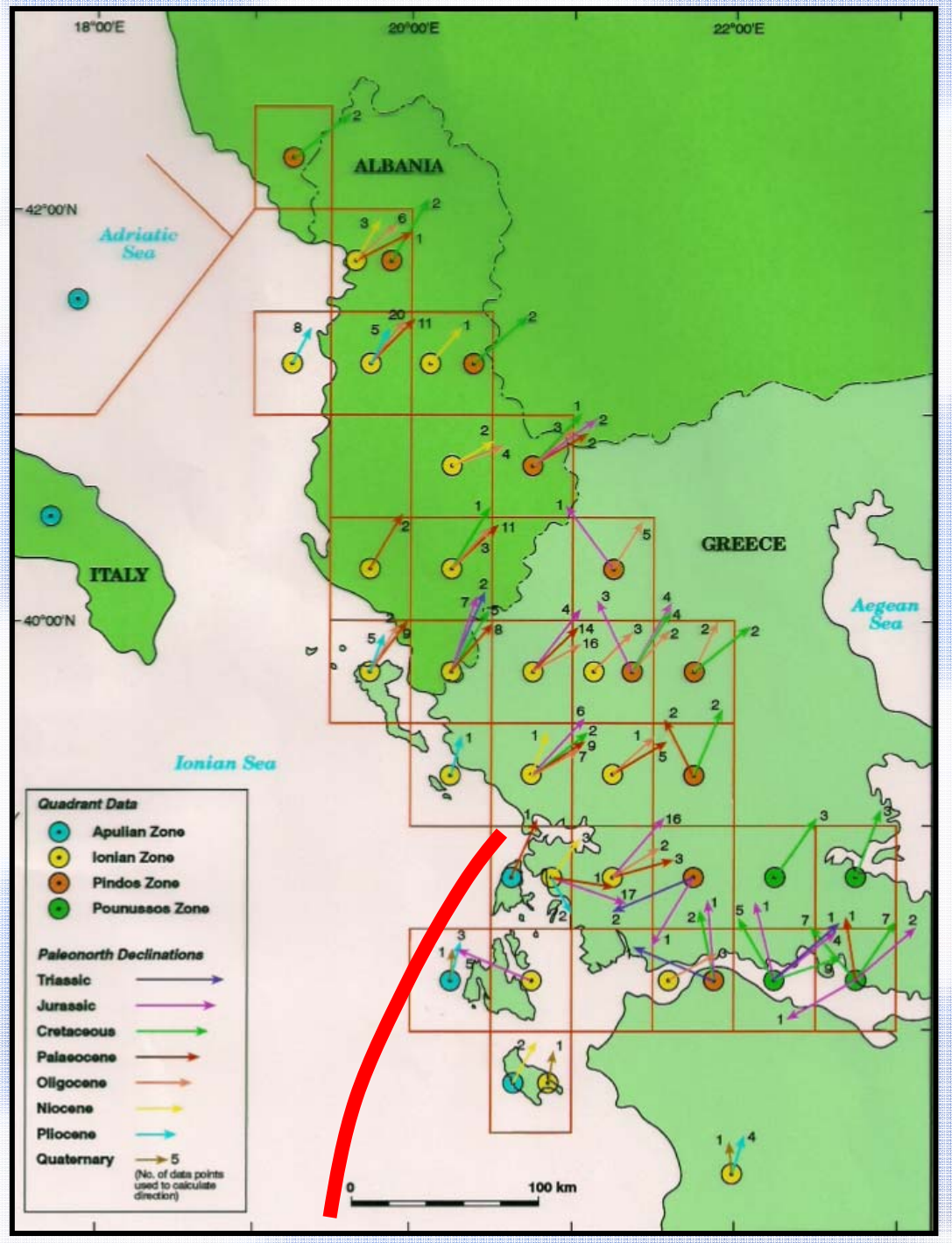
- Rotations here are special
- Probably the best documented in the world
- Both in terms of the number of different rock types and ages sampled which agree…
- …& number of different authors who have published consistent results.
- We can believe them.



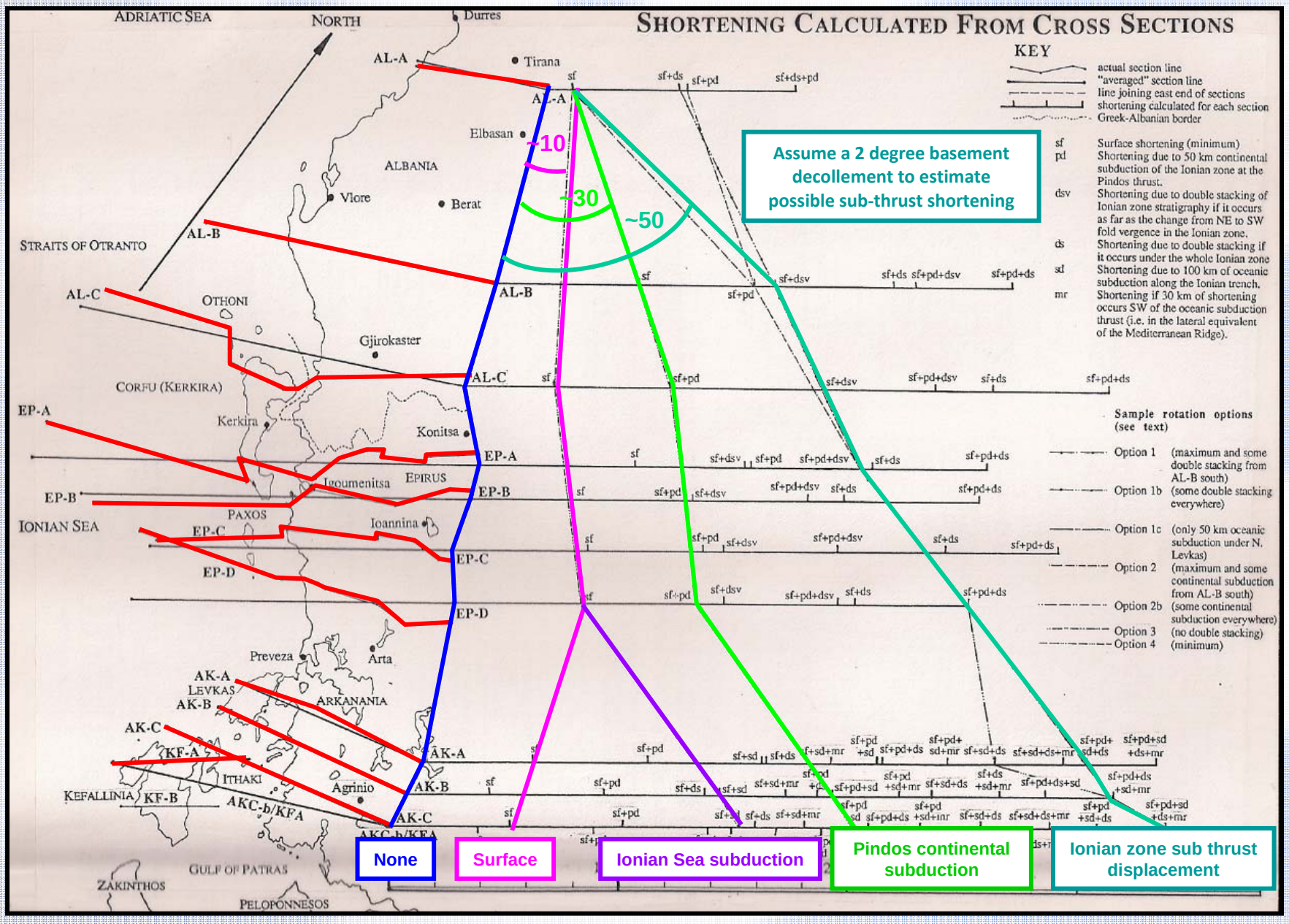
Ionian zone rotations

- Areally consistent within Ionian zone
- Except for extremely rapid rotations near Kefallinia line termination of subduction zone



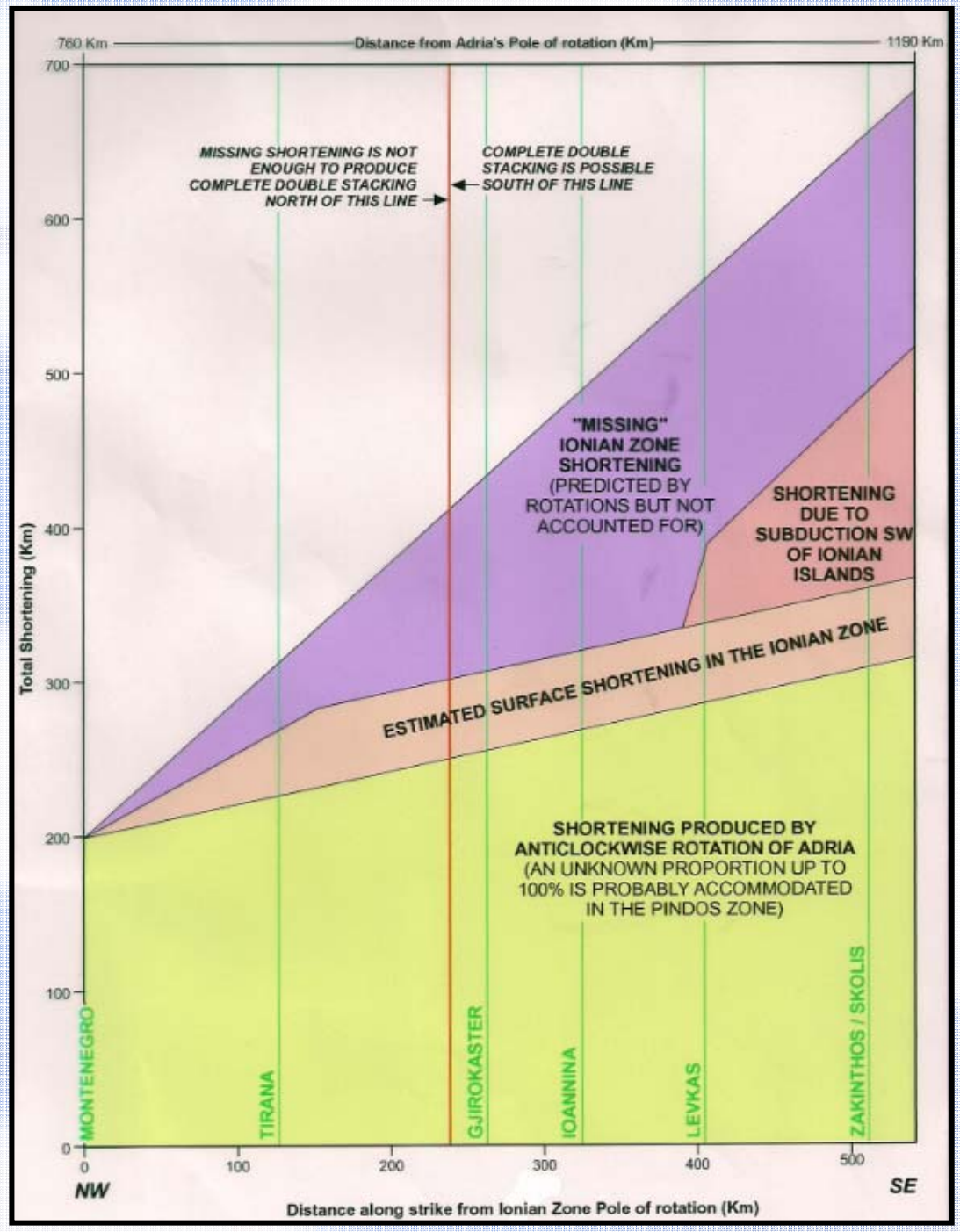


The case of the missing shortening

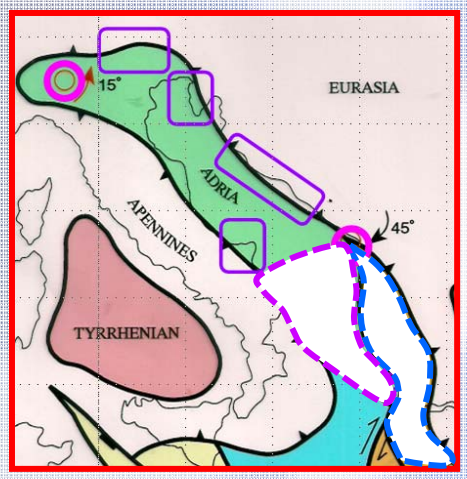


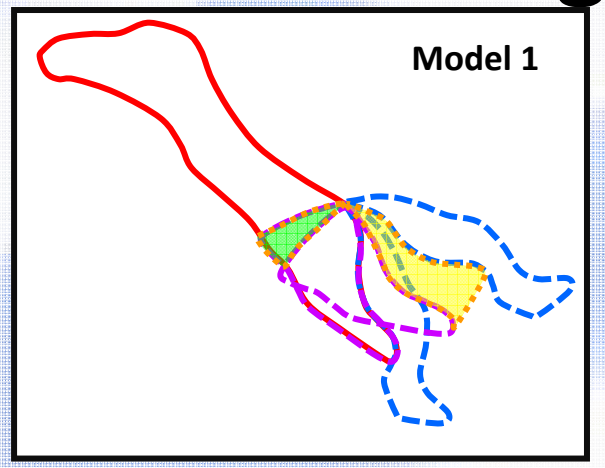
Missing Shortening

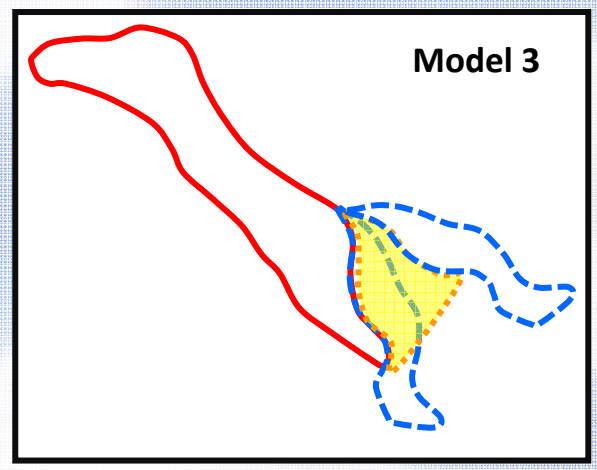
- X axis = distance along strike of Ionian zone from a rotation pole ~ Montenegro
- Y axis = shortening predicted by Adria-Ionian zone rotations
- Purple = shortening unaccounted for
- Only deformation zones within Adria or the Ionian zone can accommodate this

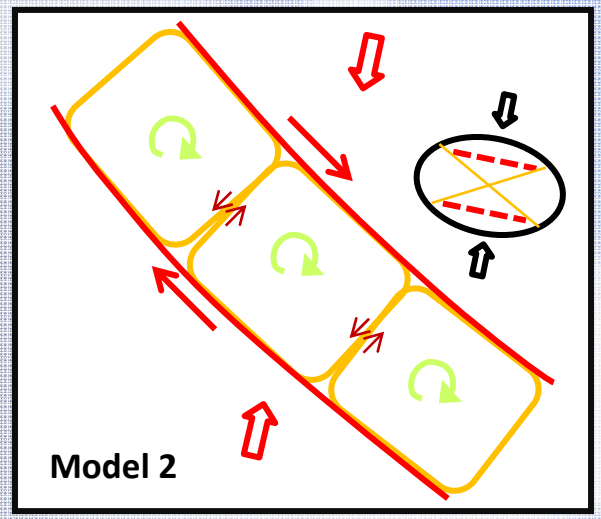


Rotation & shortening - models







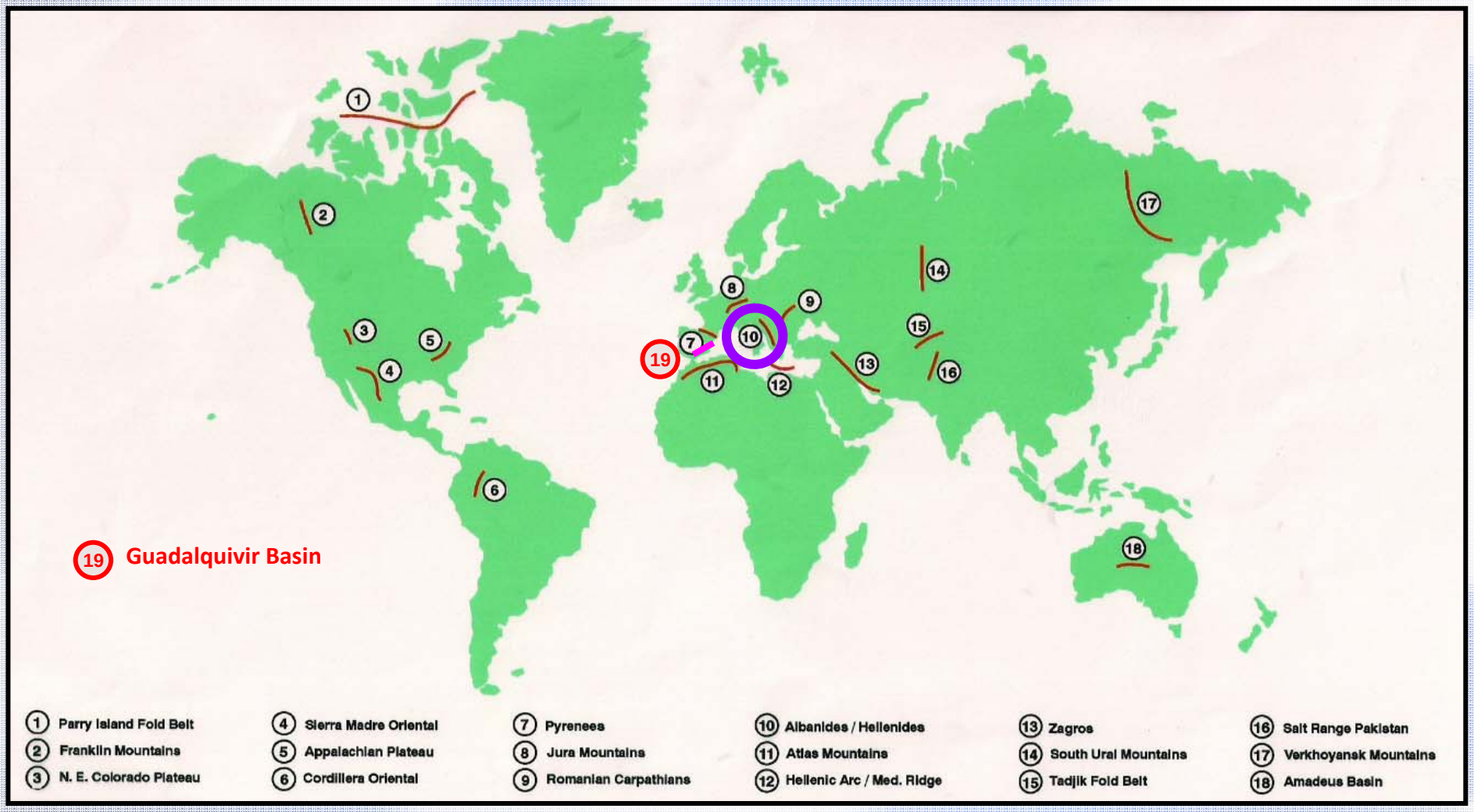


- Only three models which can explain all of the discrepancy
- Model 1: Southern Adriatic rotates in sympathy (here ~ 25deg) with Ionian zone
  - implying shortening both in the Ionian zone and within the Adriatic
  - Little direct evidence from structures or seismicity for this intra-Adriatic shortening
  - Paleomagnetic rotations in Apulia inconclusive
- Model 2: A dextral strike slip component to the thrusting rotates separate fault blocks within the thrust belt a similar amount clockwise
  - Implies a large number of internal sinistral tear faults showing offsets of similar magnitude to the shortening
  - Implies a stress ellipse and fold axes oblique to the trend of the fold belt – inconsistent with structures and seismicity
  - Really very difficult to imagine this being an efficient way mechanically of accommodating dextral shear – more typically happens with partitioning discrete strike slip faults
- Model 3: Shortening associated with rotations accommodated entirely within Ionian zone,
  - through subduction, large displacement decollements, and sub-thrust duplexing

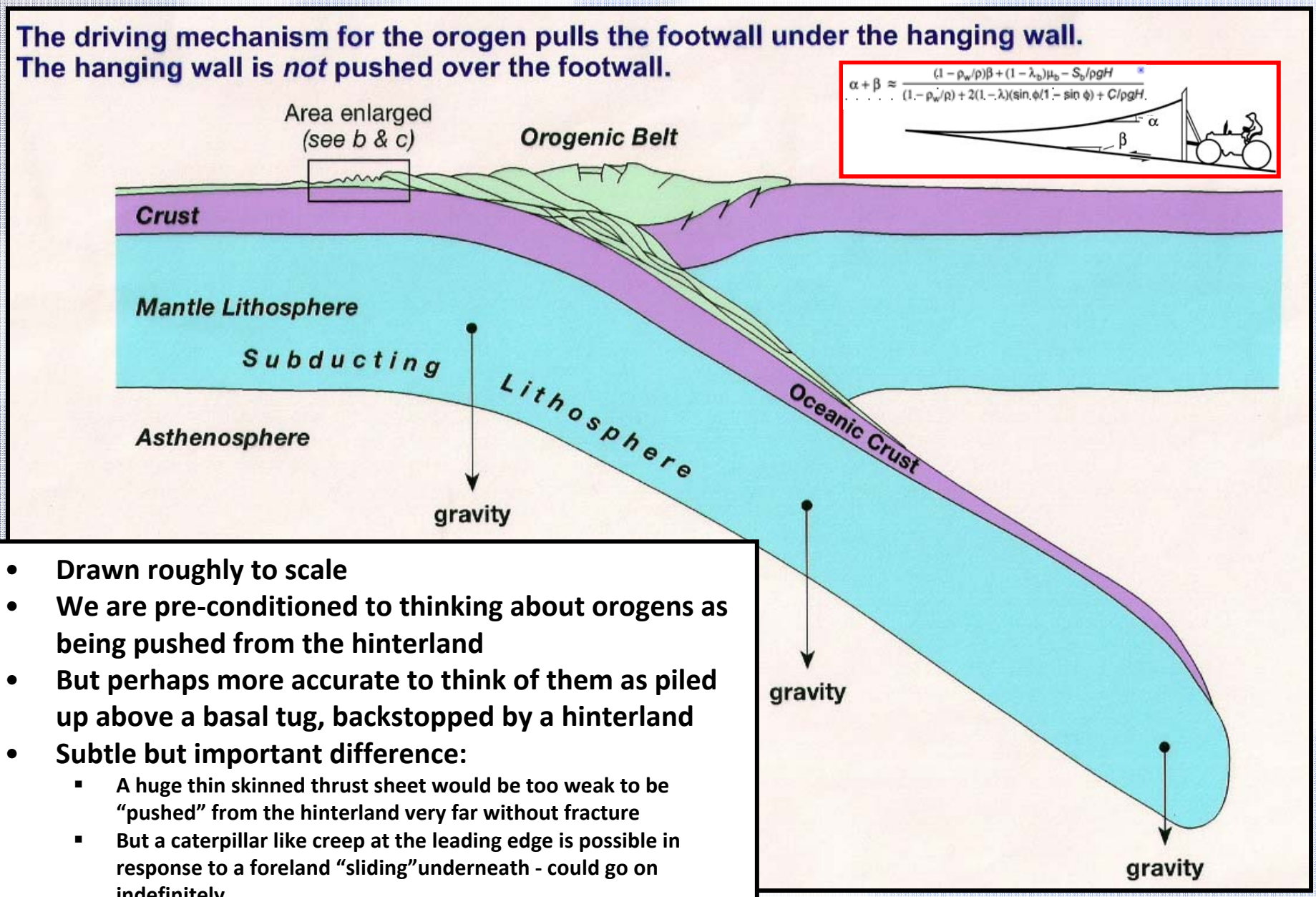
Evaporitic detachments

Evaporite detachments globally

- Major global evaporite detachments in fold & thrust belts
- Ionian Zone is only one associated with a rapidly migrating active subduction zone hinterland with lateral transition to continental collision
  - => its pretty unique – we should expect the unexpected/unusual
- But Guadalquivir Basin in the Betic thrust belt may be a past analogue



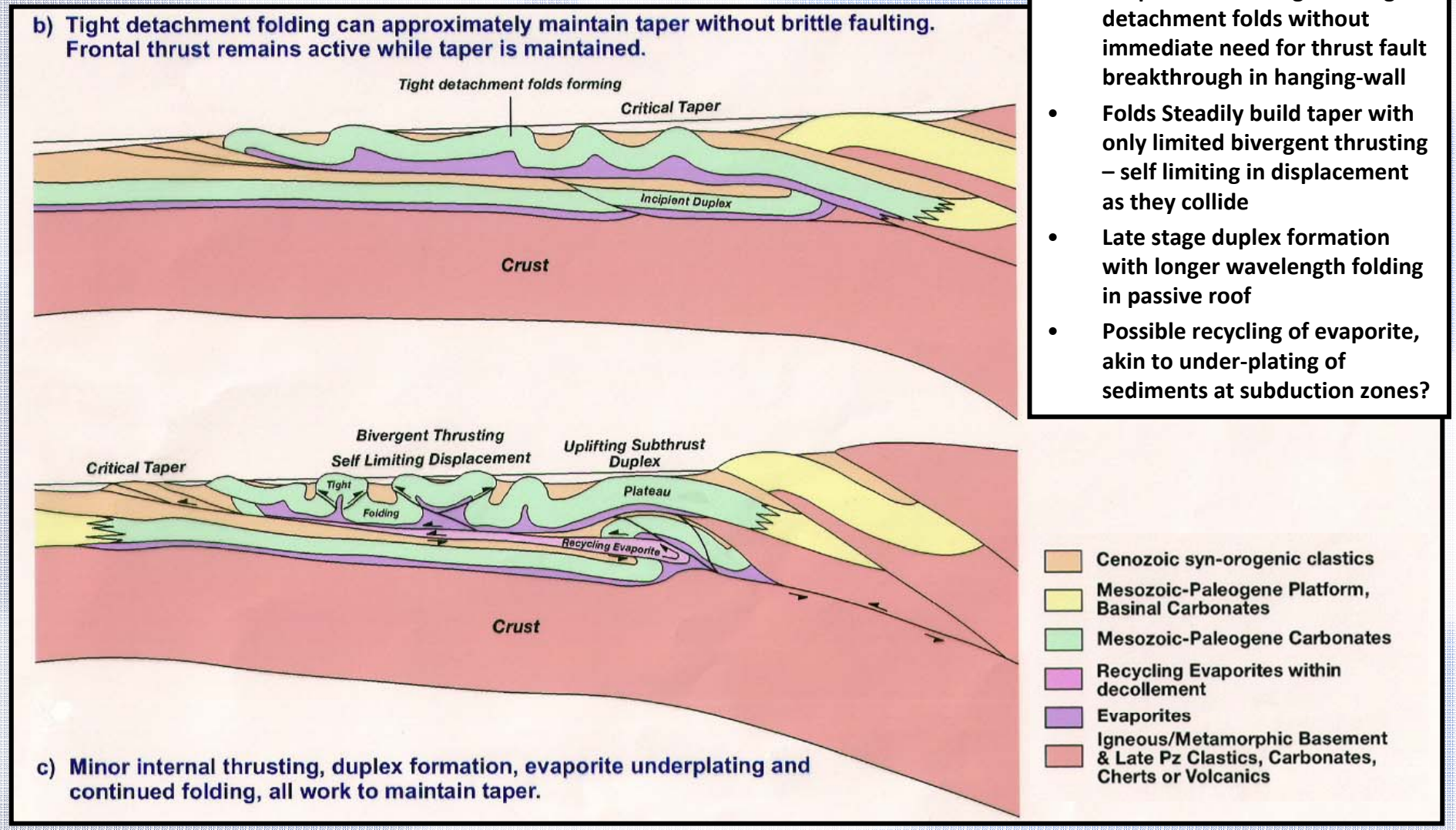
Evaporite detachments - Context



- Drawn roughly to scale
- We are pre-conditioned to thinking about orogens as being pushed from the hinterland
- But perhaps more accurate to think of them as piled up above a basal tug, backstopped by a hinterland
- Subtle but important difference:
  - A huge thin skinned thrust sheet would be too weak to be "pushed" from the hinterland very far without fracture
  - But a caterpillar like creep at the leading edge is possible in response to a foreland "sliding"underneath - could go on indefinitely

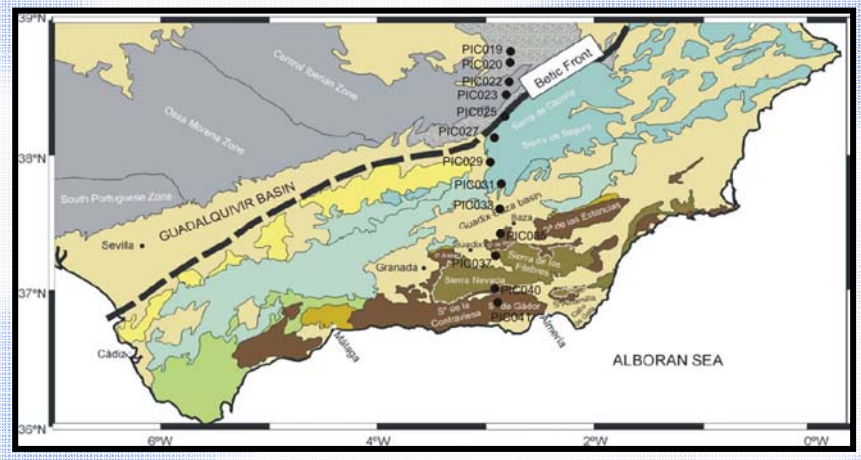
Evaporite detachments - Features

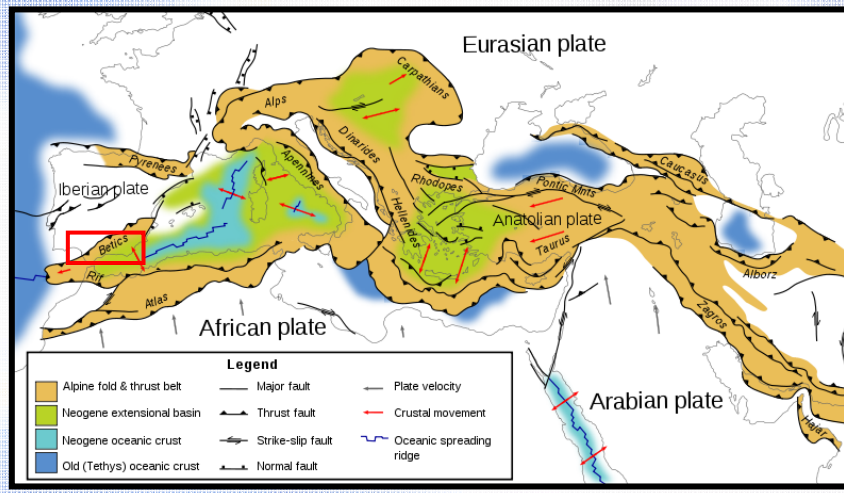
- Ongoing caterpillar like creep at frontal thrust, backstopped by hinterland
- Evaporites allow tight bivergent detachment folds without immediate need for thrust fault breakthrough in hanging-wall
- Folds Steadily build taper with only limited bivergent thrusting – self limiting in displacement as they collide
- Late stage duplex formation with longer wavelength folding in passive roof
- Possible recycling of evaporite, akin to under-plating of sediments at subduction zones?

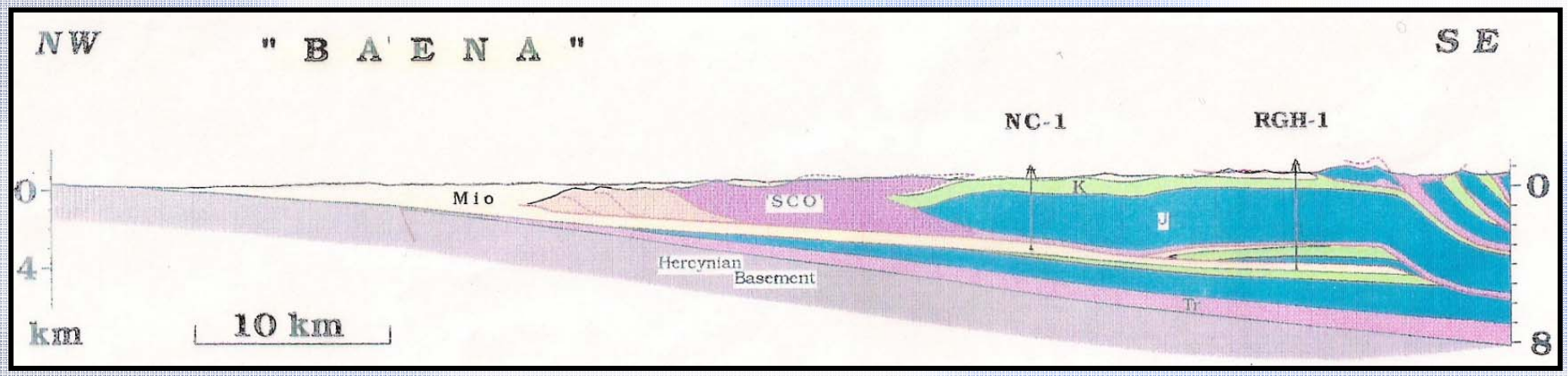


Betic Guadalquivir Analogue

- Was once also at the limit of a migrating subduction zone
- Collision with Iberian continent
- Drilling has confirmed ~ 50-70 km offset on an evaporitic detachment
- Below an relatively undeformed thrust sheet
- These “mega-detachments” are possible and documented.







Evaporitic detachments – effect on thrust rotations

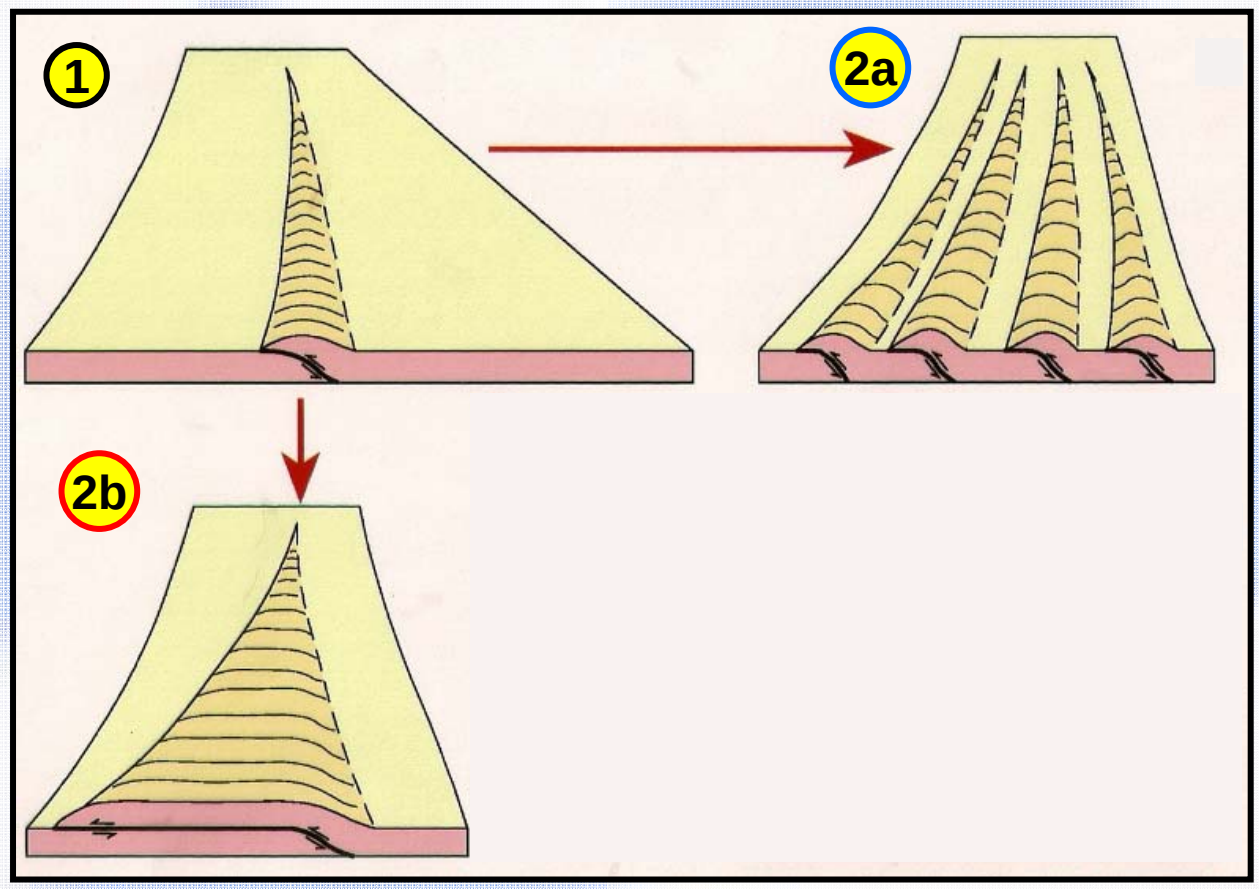
1. Rotations about a pole producing shortening increasing towards us
2. With time, continued rotation and shortening can manifest in different ways:

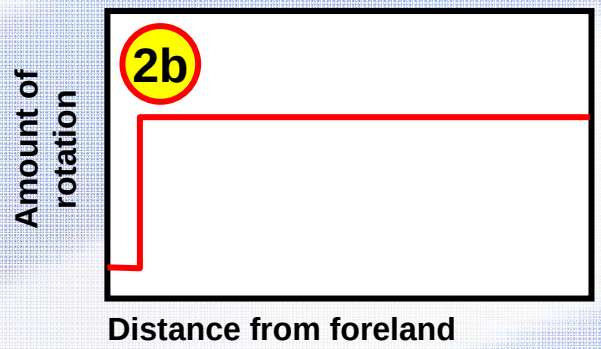
a) Production of additional thrusts – normal situation

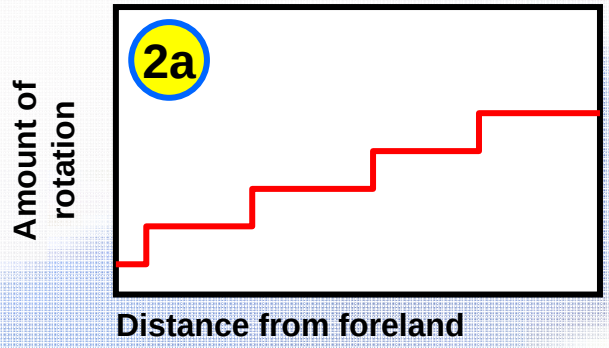
b) Ongoing shortening on one main thrust facilitated by a very efficient decollement

c) A hybrid between a & b with intervening transfer faults, perhaps as lubricating lithologies in decollement become more developed

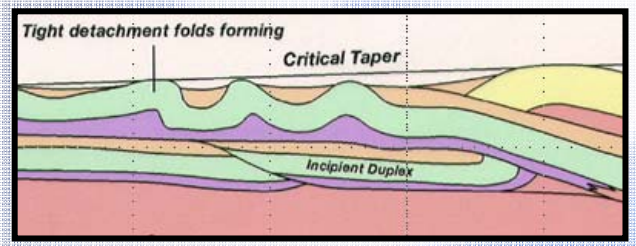
- Rotations => ~2b in Epirus

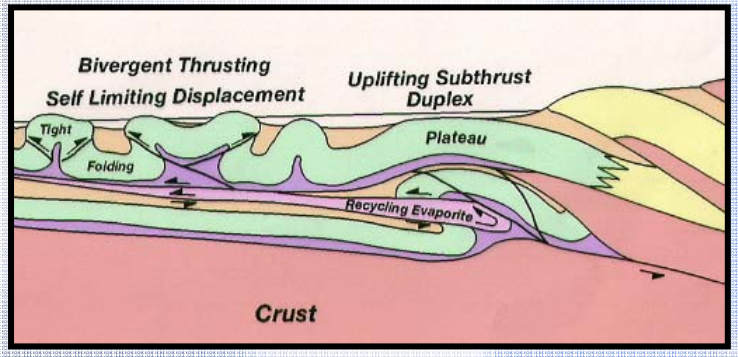


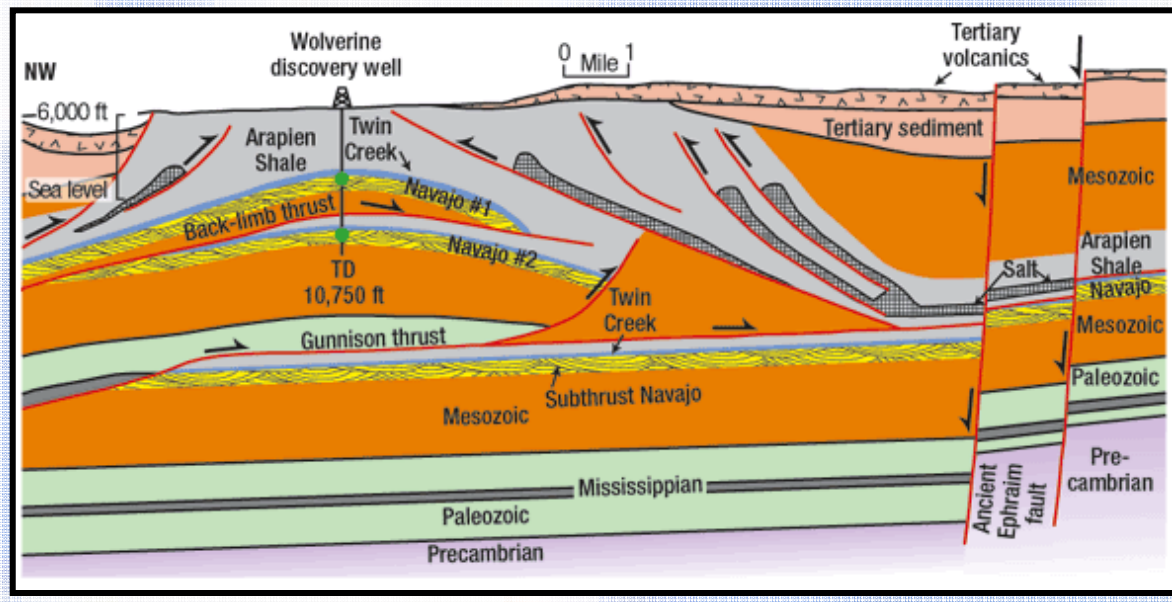




Recognition of sub-thrust duplexes







- Well developed detachment(s)
- Gentle large wavelength high amplitude structural high, sub regional in extent
- Changes in frequency of thrust faults above duplex as cover is passively "cushioned" above duplex
- Changes in fold and thrust vergence on edges of structural high
- Frequently near a basement thrust
- Gravimag anomalies
- Folded piggy-back basins
- Exhumation of early fold and thrust belt piggy back basin depocentres & associated changes in metamorphic grade
- Abnormal rates of uplift
- Normal faulting possible above neutral surface of gently folding cover

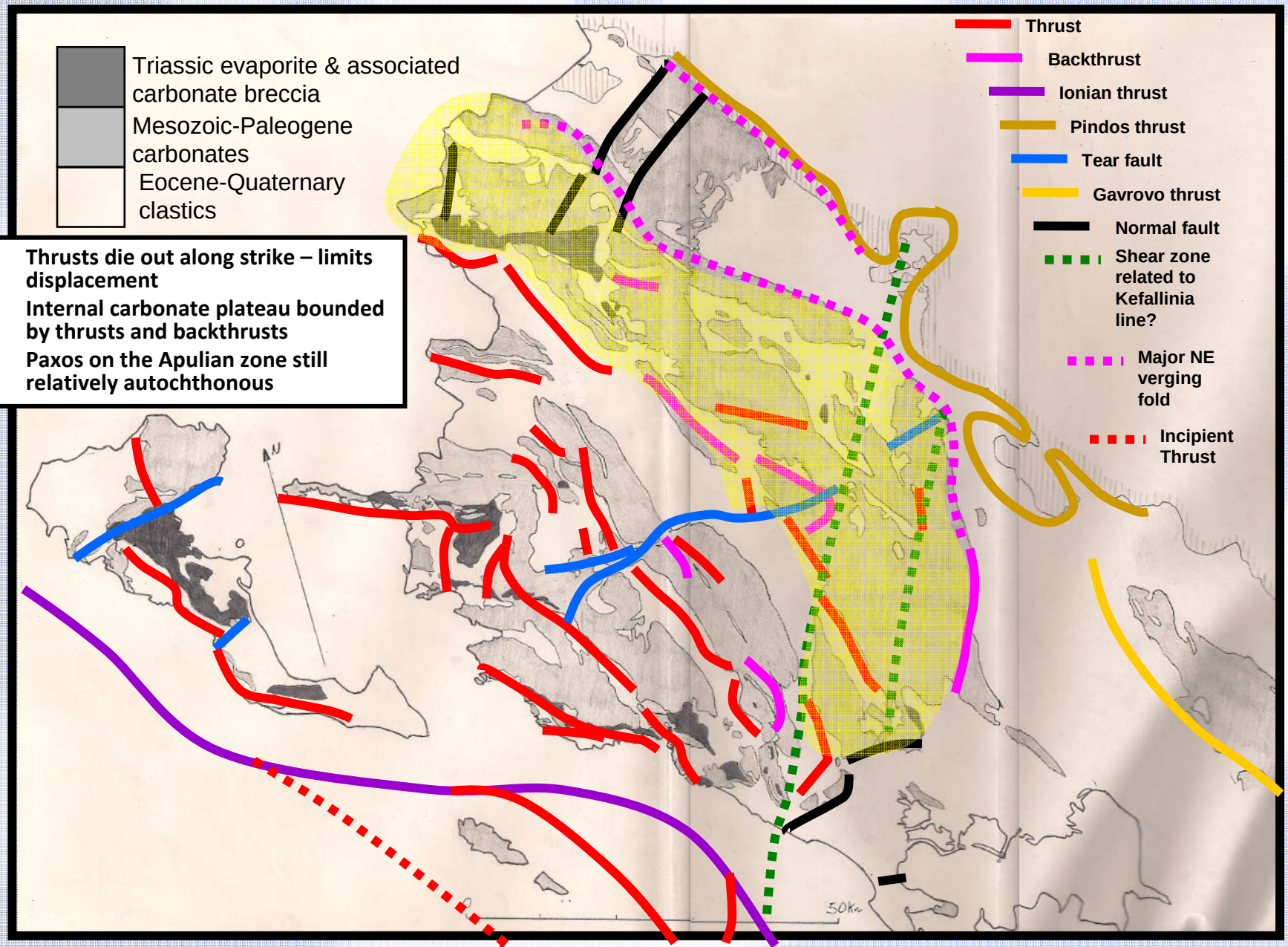
Is Utah's "Jurassic Wedge" a major petroleum province?

R. Sorkhabi and G. Nash

The recent discovery and development of a new oil field in the central Utah fold-and-thrust belt has put Utah in the spotlight for renewed onshore exploration in the Rocky Mountain region of North America, Fig. 1. This would not have been surprising a few decades ago, but after major oil companies drastically reduced their ventures in the Rockies, the discovery, by the Wolverine Oil & Gas Corp., has amplified significance. I

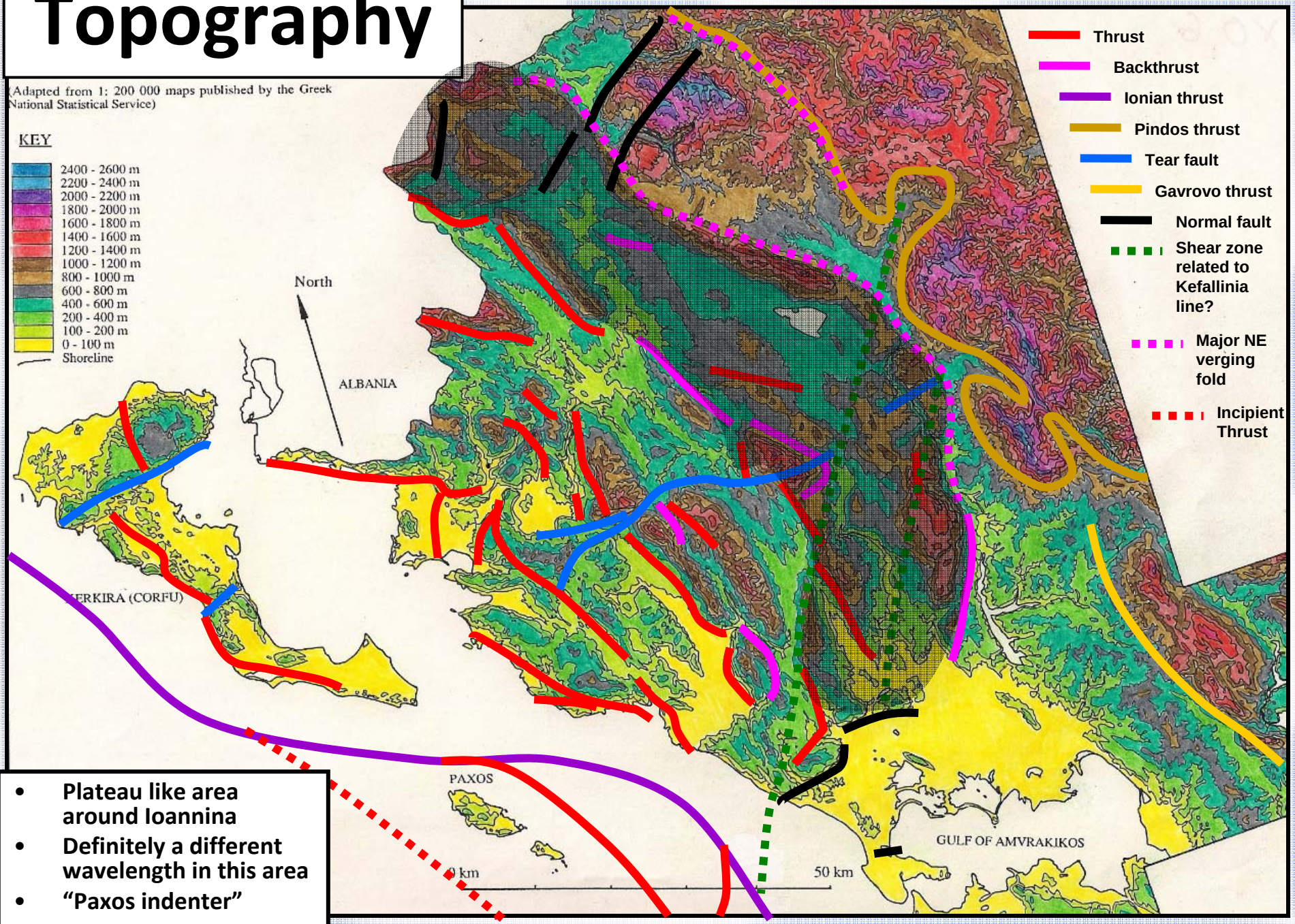
Structure of Epirus

Basic geology & Structure



- **Thrusts die out along strike – limits displacement**
- **Internal carbonate plateau bounded by thrusts and backthrusts**
- **Paxos on the Apulian zone still relatively autochthonous**

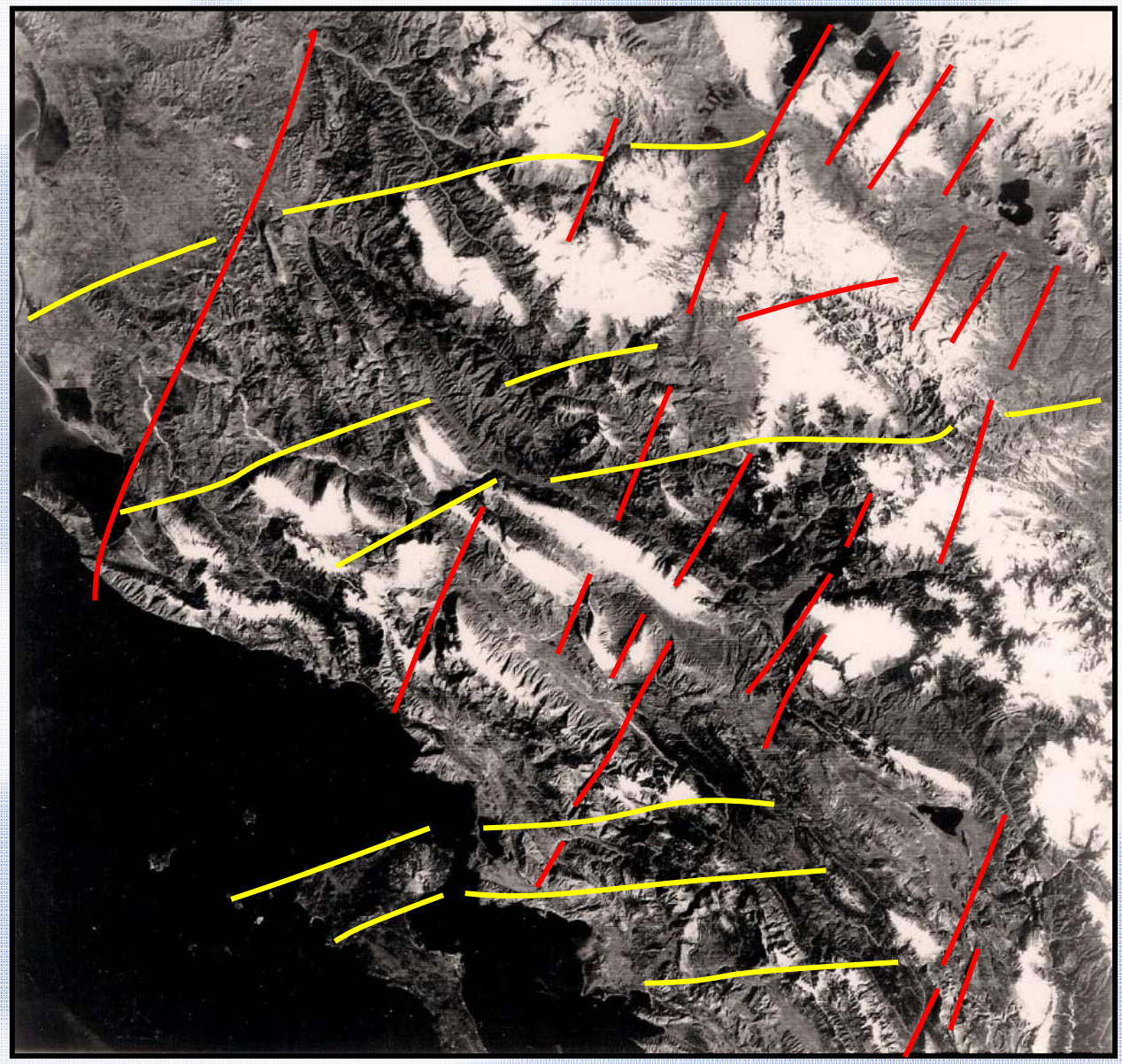
Topography



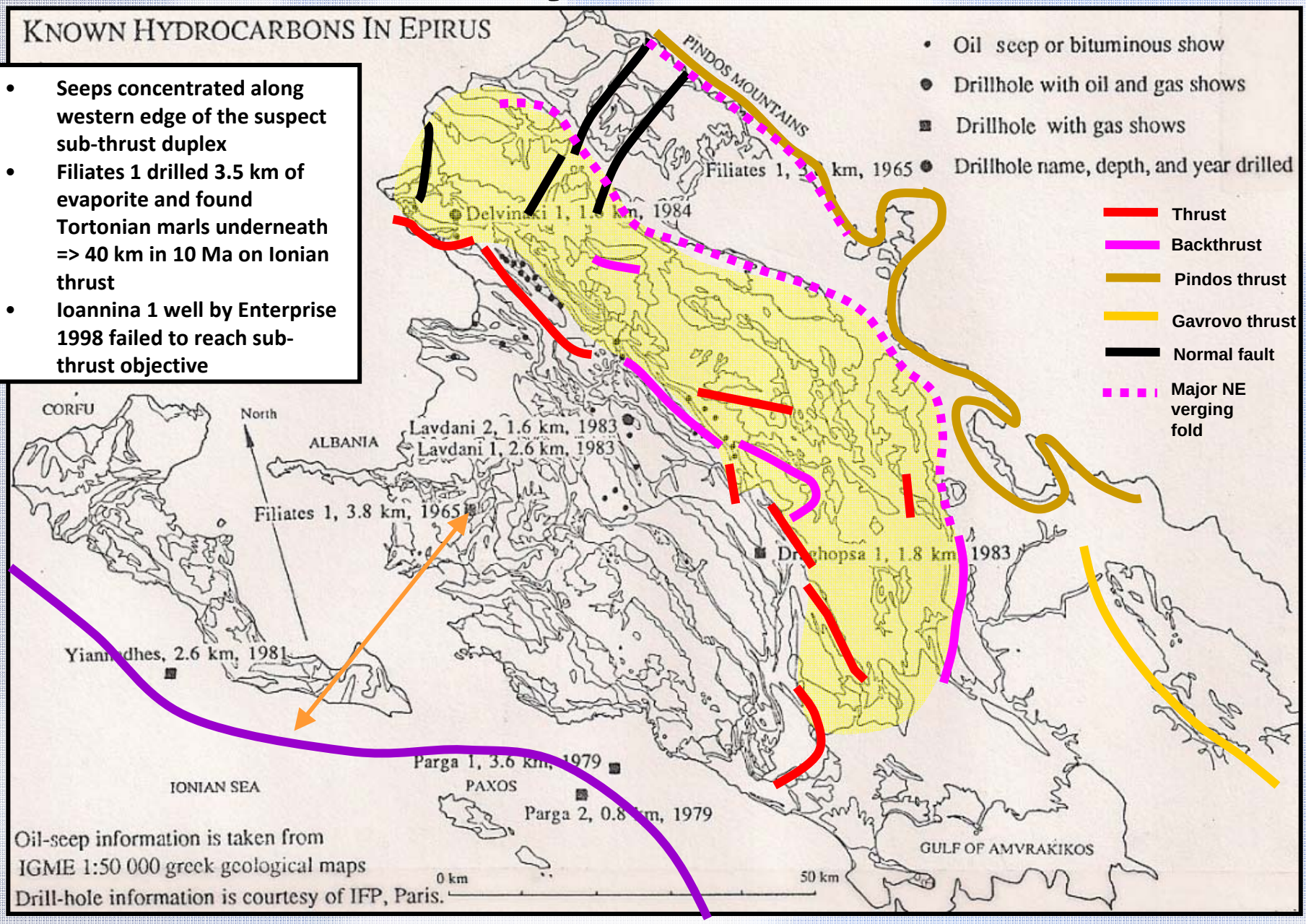
- Plateau like area around Ioannina
- Definitely a different wavelength in this area
- "Paxos indenter"

Lithospheric shear zones?

- A word of caution – some lineaments seem to transect all zones in NW Greece
- Evident even in Ionian zone despite the evaporitic detachment
- Suggests they are active
- Probably related to large scale lithospheric motions
  - Aegean extension
  - Underlying subducted paleo-slab detachment & orogenic collapse
  - Hellenic arc migration along Kefallinia line
  - Ongoing Adria-Eurasia collision
- Represents a seal risk

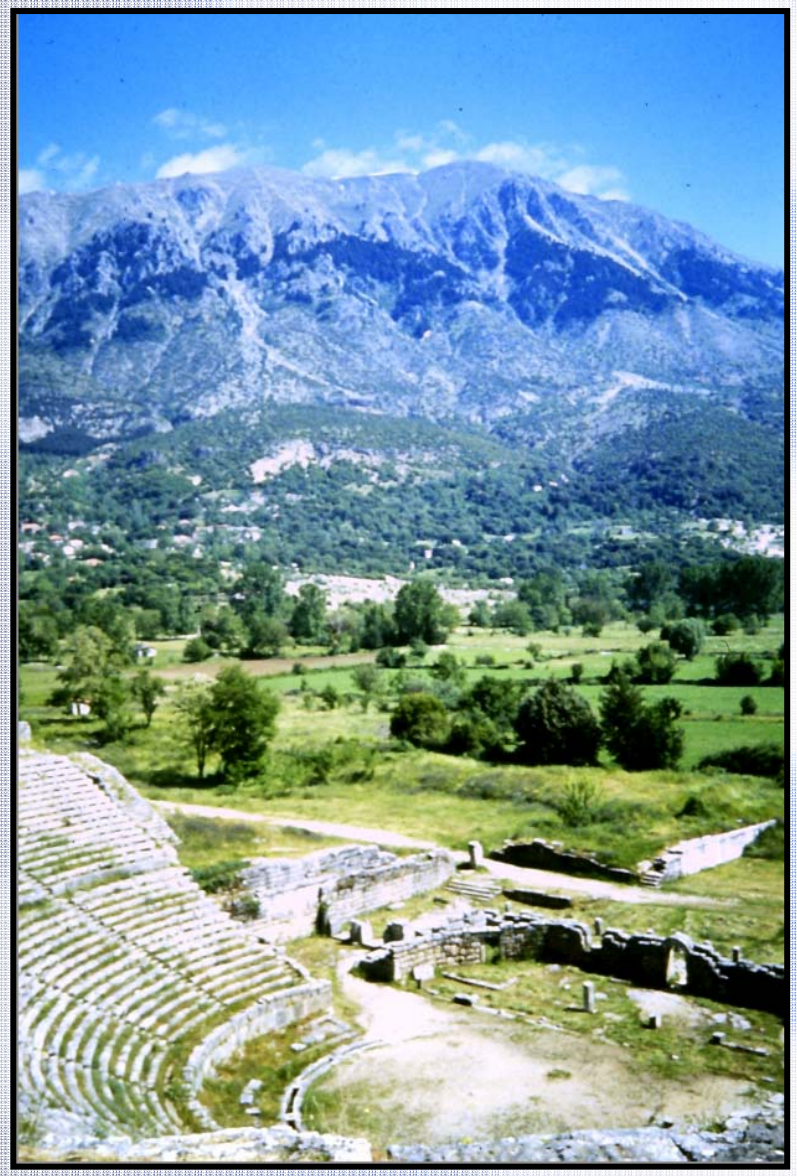


Hydrocarbons & wells



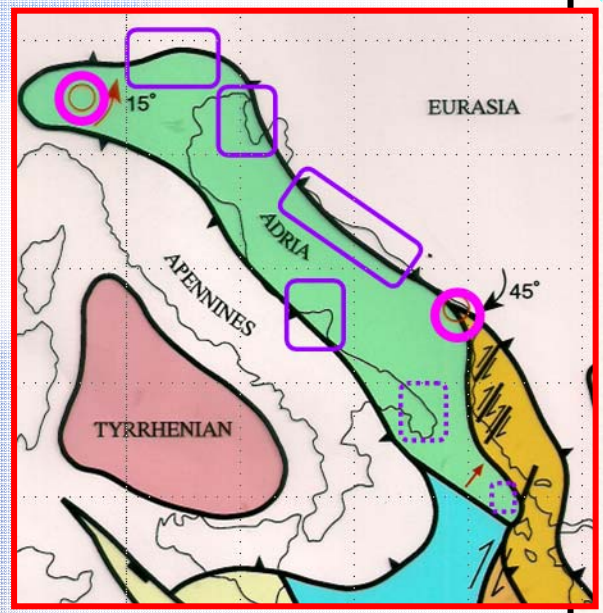
- Seeps concentrated along western edge of the suspect sub-thrust duplex
- Filiates 1 drilled 3.5 km of evaporite and found Tortonian marls underneath => 40 km in 10 Ma on Ionian thrust
- Ioannina 1 well by Enterprise 1998 failed to reach sub-thrust objective

“Derisking”



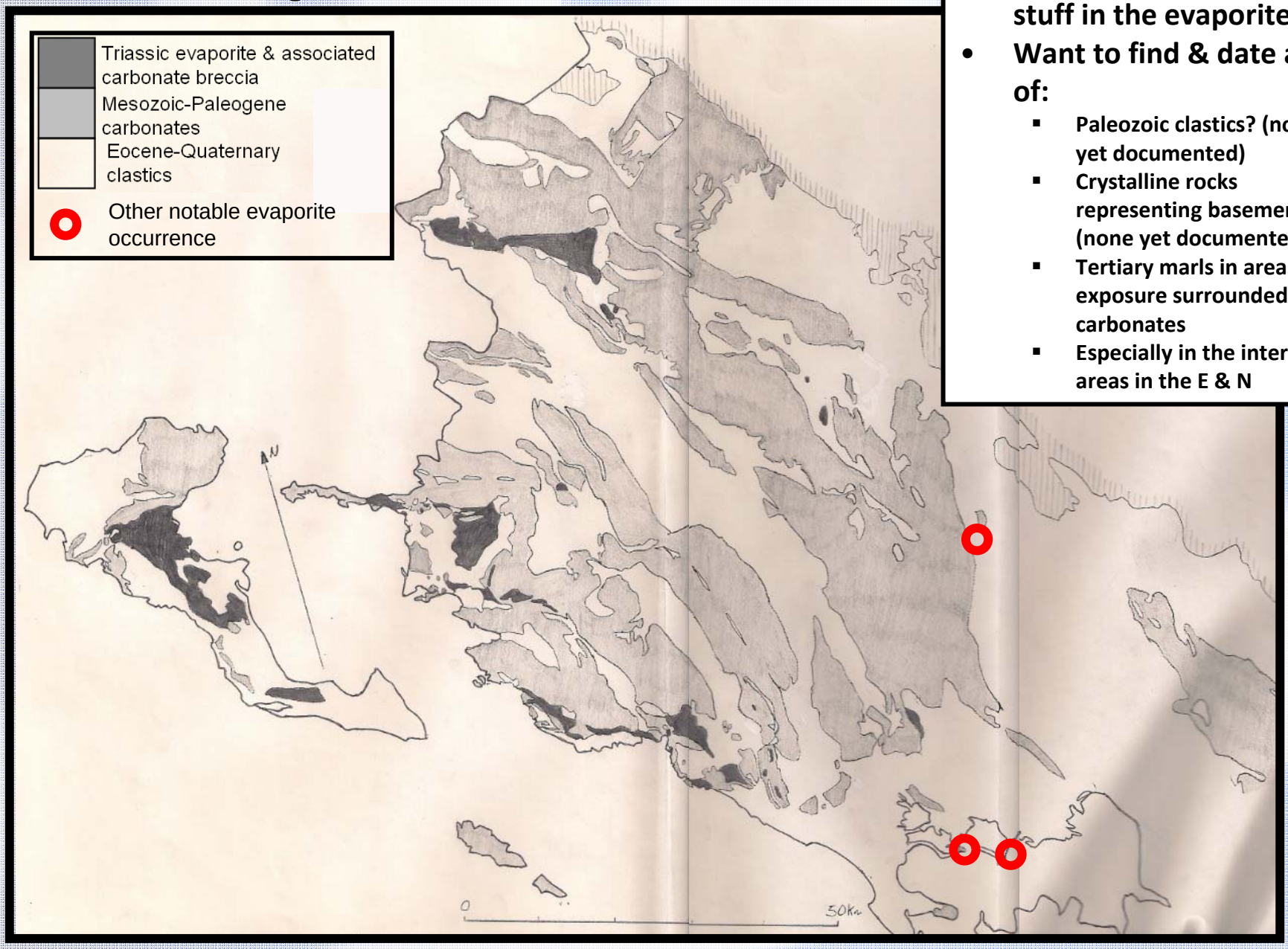
Paxos & Apulian paleomag studies

- This beautiful island:
  - Only emergent part of Apulian platform close to the Ionian thrust but in the foreland to it
  - May have some minor thrusting seaward of it, but nothing on the scale of the Ionian thrust
  - Implies that if model 3 is correct (and regional sub thrust play is implied), it should have something akin to Adriatic rotations in Gargano, Istria, Dalmatia
  - But if model 1 is correct (and no regional sub-thrust play is implied), will probably show 25-30 degrees clockwise rotation relative to Africa since the Tertiary



- Getting pmag results out of the platform carbonates is not easy – but things have moved on over the last decade – could be possible
- More reliable data from Italian Apulia & Greek pre-Apulian zone would help too.

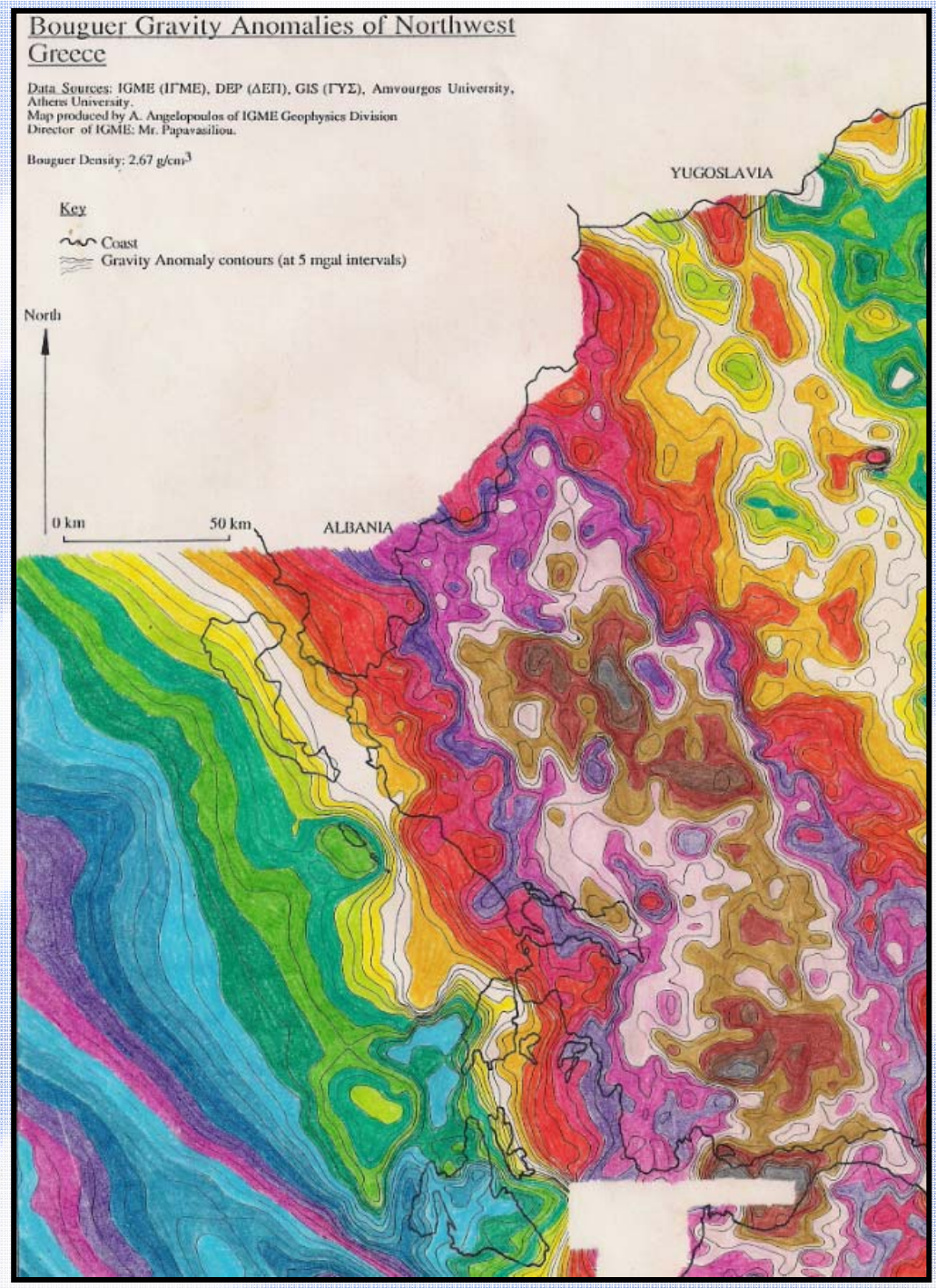
Evaporite xenoliths



- Occasionally some pretty exotic looking stuff in the evaporites
- Want to find & date any of:
  - Paleozoic clastics? (none yet documented)
  - Crystalline rocks representing basement (none yet documented)
  - Tertiary marls in areas of exposure surrounded by carbonates
  - Especially in the internal areas in the E & N

Gravimag

- Previous explorers in the area have thrown a wide variety of geophysical tools at Epirus
- Gravimag studies have been conducted.
- Not rocket science to see that gravimag should be able to differentiate between a sub-thrust duplex of Ionian zone stratigraphy and one of crystalline basement
  - => definitely worth doing the exercise
- But might have more difficulty distinguishing Ionian zone carbonates & clastics from Paleozoic carbonates & clastics.

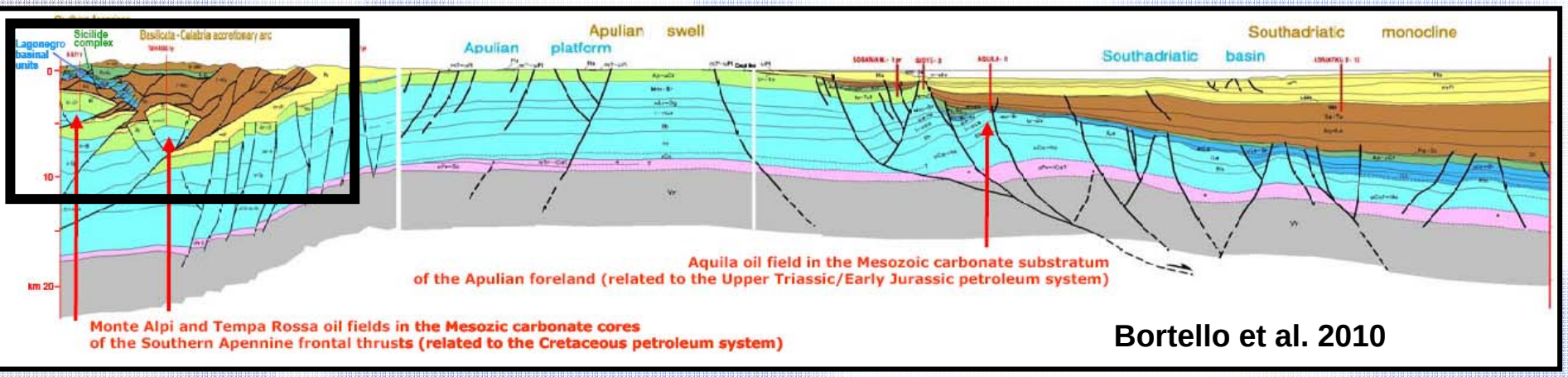


De-risking the Ionian zone sub-thrust play

- **Always going to be high risk**
- **But 16% sounds a lot more attractive than 8%**
- **This is just play risk**
- **Will be doing well to get any prospect to ~ 10-12%**

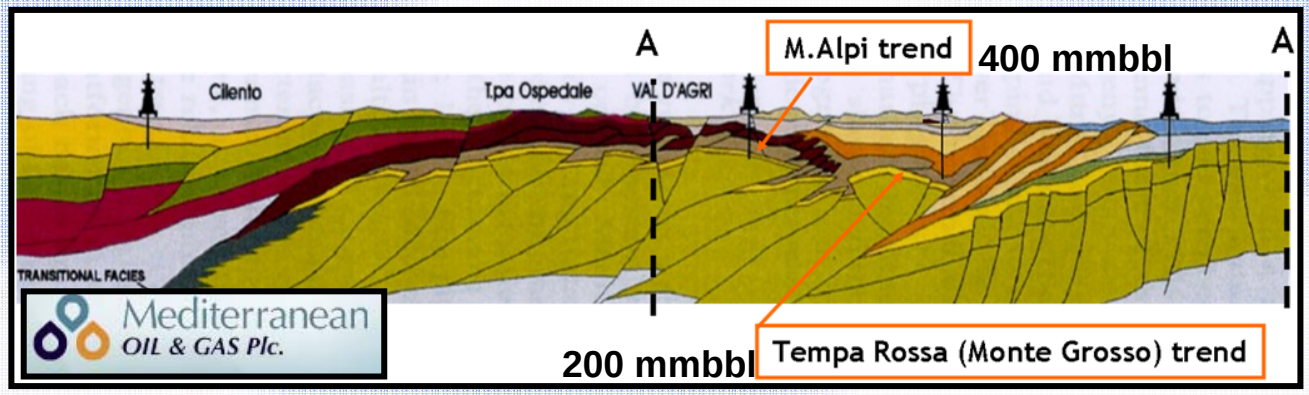
Risk element	NOW	Comment	Post de-risking	Comment on change
Source presence	0.4	50/50 model 1 & 3 80% chance of source in Ionian zone, but even if Ionian zone absent sub-thrust, could still be an unknown source sytem down there	0.8	If double stacked Ionian zone is present, source rocks will be too.
Source maturity	0.9	If present will have entered oil & gas maturity window in sub thrust	0.9	
Charge timing	0.7	Might be overmature at time of trap formation	0.7	
Reservoir Presence	0.4	50/50 model 1 & 3 80% chance of reservoir in Ionian zone, but even if Ionian zone absent sub-thrust, could still be an unknown reservoir down there	0.7	If double stacked Ionian zone is present, opportunties for reservoir presence abound
Reservoir Quality	0.4	If present its deep - may rely on fractures	0.4	
Geometry	0.6	Strong hints of sub-thrust duplexing, structures likely sub-thrust	0.7	Gravimag, Sesimic, tomography, magentotellurics have give some more confidence on geometries
Seal	0.8	Evaporites a great seal for sub-thrust, but may be some virogus active tectonics going on.	0.8	
TOTAL	**7.7%**		**15.7%**	

Analogues & size of the prize

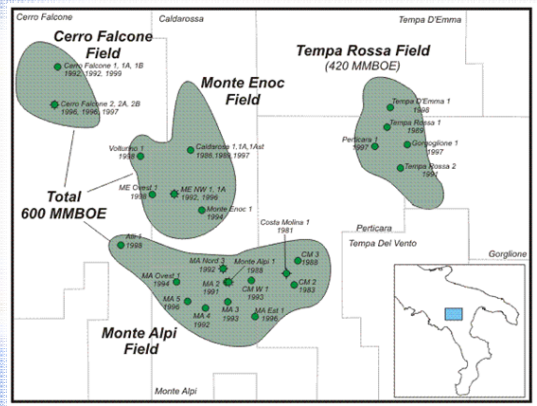


Bortello et al. 2010

- **TCF scale prize not unreasonable**



- Oil fields of the Val d'Agri area in S Italy have reserves of ~ 600 mmbl in fractured carbonate reservoirs
- These are Apulian platform carbonates on the other side of the Adriatic from Greece, that have been overthrust by the Apennines
- While not a direct analogue in terms of likely phase and reservoir carbonate facies, they are about as close as we can get in the area from a depth and crude lithology point of view.
- Ionian zone could have early Tertiary clastic, or calciturbiditic reservoirs as well as platform carbonates
- From the size of the envisaged Ionian zone duplex "anticlinorium", TCF scale gas seems not unreasonable



Conclusions

- The Ionian zone in Greece & Albania is a proven HC province with multiple sources and reservoirs – good hunting ground
- Structural and paleomagnetic considerations are suggesting a large gas prone sub-thrust play may be regionally present under onshore Epirus.
- This is feasible due to an relatively unique tectonic situation at the termination of the Hellenic arc.
- Analogues exist for the amounts of decollement displacement required to produce such a play.
- The limited alternative interpretations which are possible can potentially be ruled out by relatively cheap paleomagnetic studies on Paxos and Italian Apulia.
- Evaporite xenolith studies in Epirus, Gravimag, & seismic may provide additional de-risking.
- TCF scale potential can probably be de-risked at play level pre-drill from ~ 8% today to ~ 16%.
- Prospect level risking pre-drill of 10-12% may be feasible.

Knowing which way to turn can sometimes be difficult…

A new dawn over Epirus ?