

Tectonic Controls on 2nd/3rd Order Sequence Architecture, Istria ‘Depression’, Romanian Black Sea Shelf*

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Abstract

The Istria ‘Depression’ or sub-basin of offshore Romania lies at the intersection of the trans-European Tornquist-Teisseyre ‘Zone’ and the Black Sea back arc basin, just outboard of the East Carpathian orogenic belt ([Figure 1](#) and [Figure 2](#)). Its Late Mesozoic-Cenozoic succession records an extraordinary polyphase history of subsidence and sedimentation interrupted by several quite spectacular 2nd/3rd order erosional unconformities reflecting the interplay between these three tectonic domains. These unconformities divide the succession into a number of stratigraphic sequences ([Figure 3](#)):

- The Istria ‘Depression’ developed as a transtensional rift between the Moesian and Scythian platforms in the Triassic-Early Jurassic, evolving into a narrow oceanized trough in the later Jurassic as Moesia broke away from Europe and drifted southeast ([Figure 4](#)). The region was tilted west during the Early Cretaceous in response to uplift and rifting in the Western Black Sea when residual Late Jurassic topography was filled and buried by a west-facing continental clastic-evaporite sequence ([Figure 5](#)).
- Late Aptian-Early Albian post-rift subsidence and spreading in the Western Black Sea imposed a strong easterly tilt to the Istria ‘Depression’, encouraging the partial evacuation of its Early Cretaceous sedimentary fill by gravity-driven mass wastage. As the margin was flooded from the east, deposition was first confined by the incised valley topography but with later Cretaceous subsidence, this was gradually filled by a transgressive system tract extending out onto the bounding highs ([Figure 6](#)).
- During the Mid-Late Cenozoic, the Black Sea Basin experienced intermittent periods of partial to complete isolation from the world ocean in response to a paroxysmal Eocene phase of collision and crustal consolidation between Afro-Arabia and Eurasia ([Figure 7](#)). The first period of significant isolation and base-level drawdown occurred during the Eocene. This exposed the Black Sea shelf and slope and the Istria ‘Depression’ was once more deeply incised, to be refilled by a deeper-water carbonate-shale sequence in Late Eocene, Oligocene and Early Miocene.

- Yet another period of drawdown and exposure occurred in Mid-Miocene (Badenian), encouraging extensive shelf margin mass wastage and erosion ([Figure 8](#)). This was followed by reflooding and deposition of a transgressive back-stepping sequence in Mid-Late Miocene.
- Messinian drawdown in the Mediterranean caused a further period of isolation and falling base level in the Black Sea ([Figure 9](#) and [Figure 10](#)). Its northwestern shelf margin was again exposed and experienced widespread mass wastage and gravity driven slumping. Following Late Messinian reflooding of the Mediterranean Basin, a marine connection was re-established with the Black Sea. The earlier slumped sequence was eroded during rising sea level and buried by a Late Miocene (Pontian)-Early Pliocene lowstand prograding wedge.
- During the subsequent Pliocene and Quaternary, the shelf was buried by a brackish-marine to occasionally marine sequence, periodically interrupted by incised canyon systems testifying to climatically-imposed base level fluctuations ([Figure 11](#)). Late shelf margin listric faulting anticipates yet another period of mass wastage, perhaps encouraged by easterly tilting associated with the final docking of the Carpathian orogen and uplift of the Dobrogea peripheral bulge immediately onshore.

This analysis has identified several direct and indirect tectonic factors which have encouraged mass wasting, valley/canyon incision and headward erosion along the Romanian Black Sea shelf ([Figure 12](#) and [Figure 13](#)). These include:

- Local structural framework which controlled the location and architecture of trans-shelf depocenters.
- Direct tectonic uplift, tilting trans-shelf depocentres basinwards.
- More indirect regional tectonism responsible for increasing basin isolation and encouraging significant base level falls.

While their combined influence may be unique to the Black Sea Basin, they may individually be of significance in other semi-enclosed basins elsewhere in the world.

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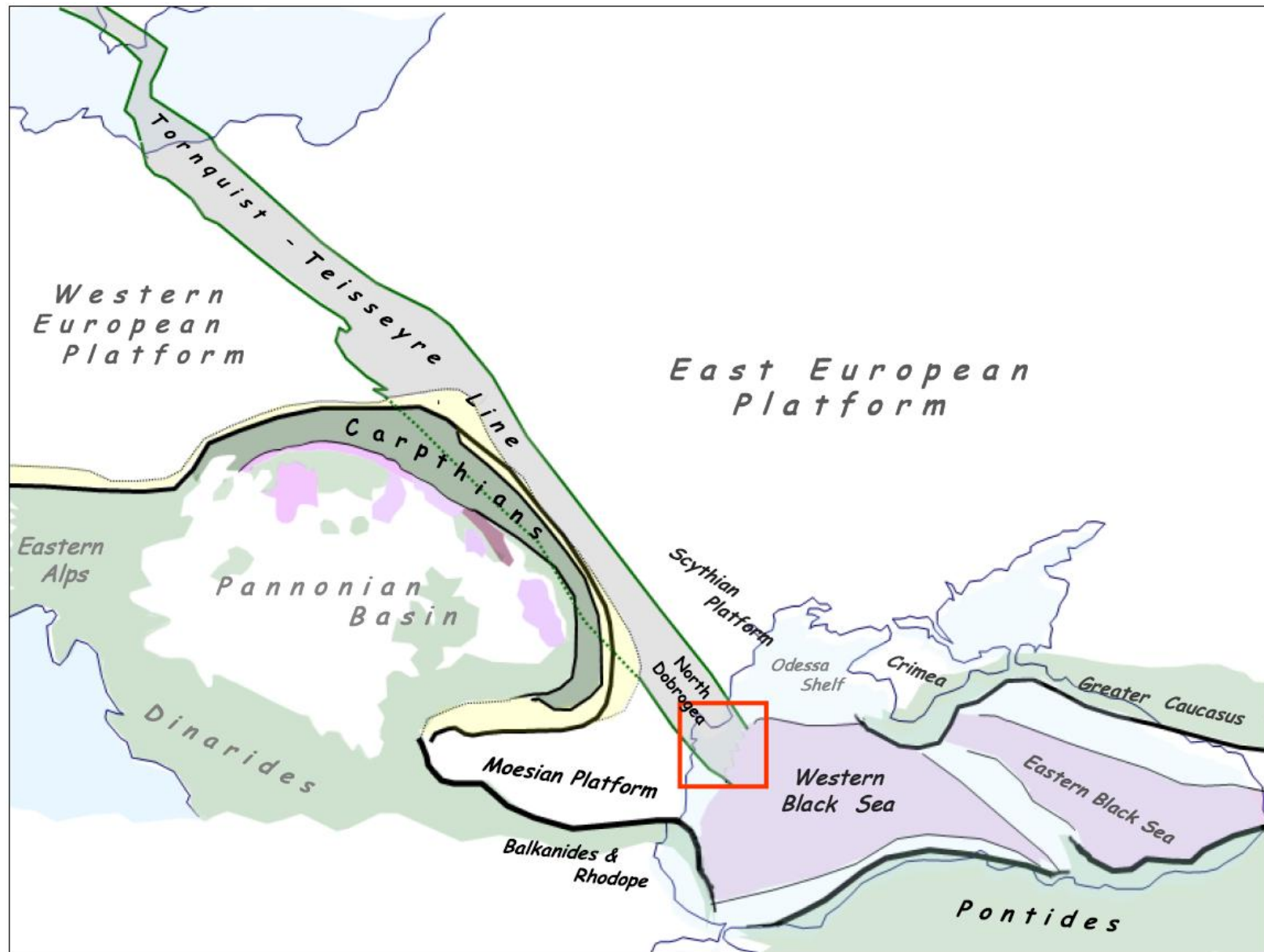


Figure 1. Regional Central European structural elements summary (schematic map) illustrating the major regional tectonic elements which influenced the Cretaceous-Cenozoic sequence architecture of the Istria Depression, Romanian Black Sea (Location of [Figure 2](#) outlined by red box).

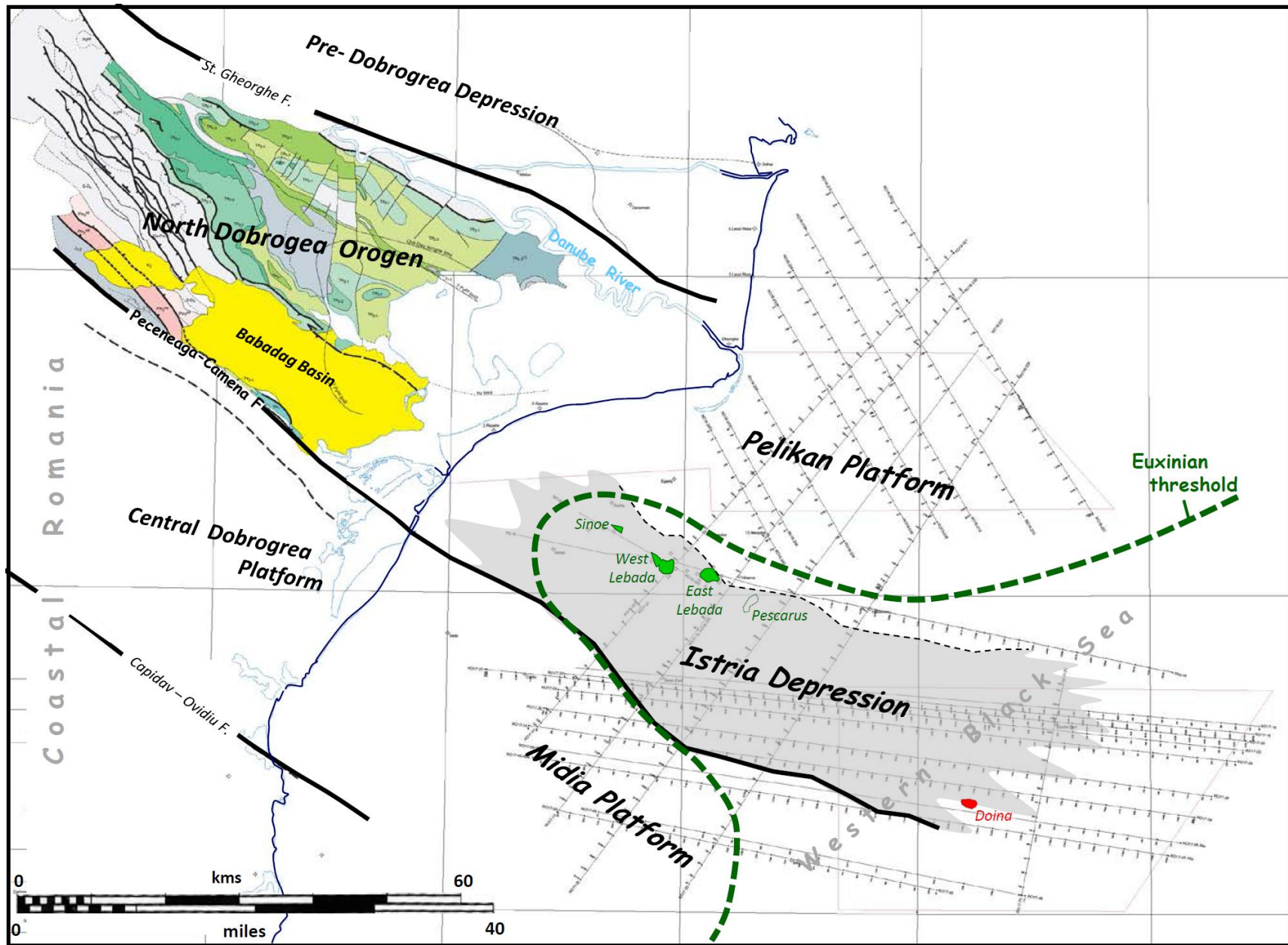


Figure 2. Major structural elements of Coastal Dobrogea and offshore Romanian Black Sea Shelf and location map for seismic, well and outcrop control constraining the analysis (oil and gas fields in green and red).

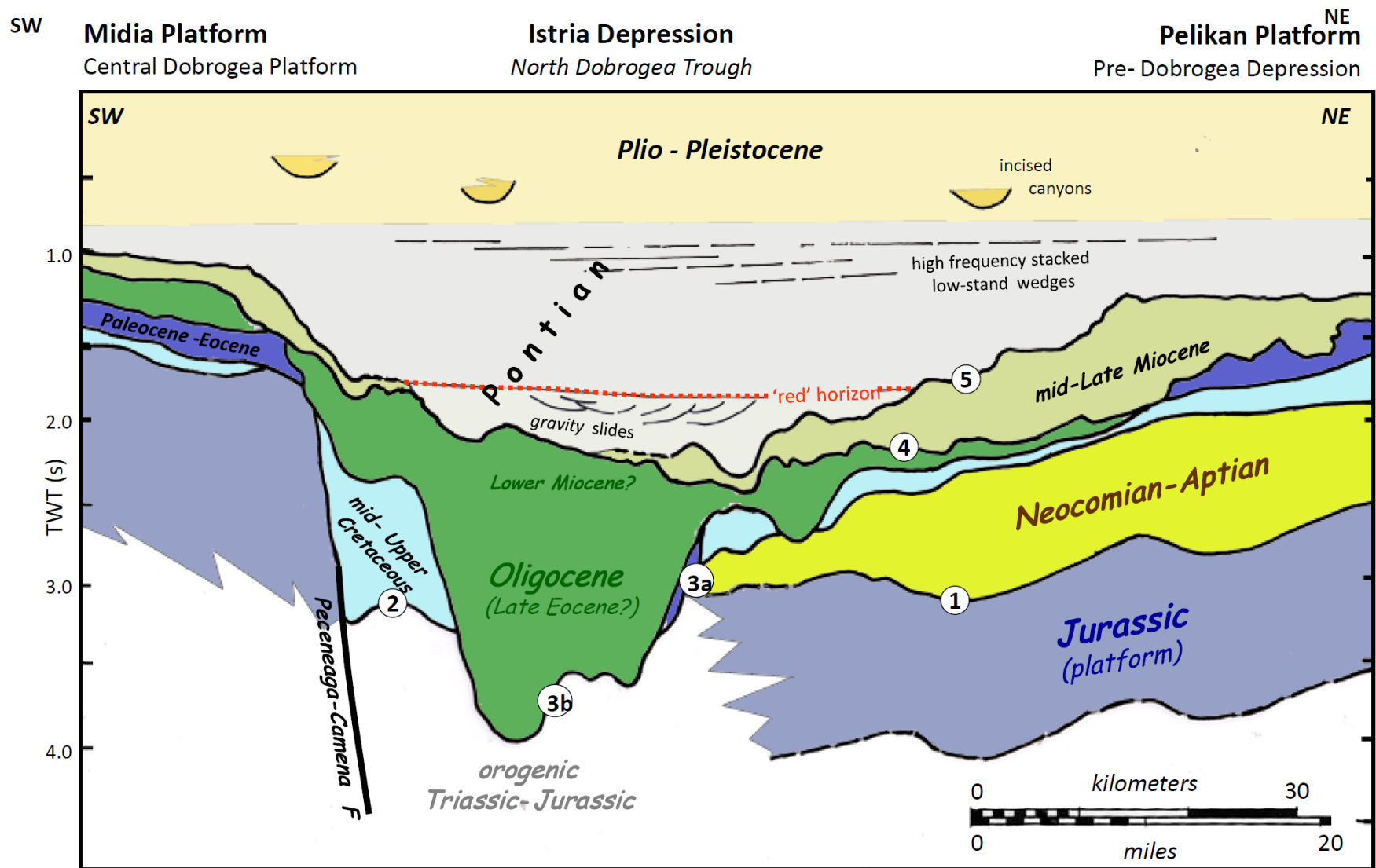


Figure 3. Sequence architecture of the Istria Depression (schematic). Cretaceous-Cenozoic 2nd/3rd order sequences and bounding sequence boundaries highlighted. Sequence 1: west facing (synrift?) Neocomian-Aptian wedge. Sequence 2: valley incision and east facing mid-Upper Cretaceous? transgressive infill. Sequence 3: composite intra-Eocene valley incision and late Eocene? – Oligocene (Lower Miocene?) valley fill. Sequence 4: intra-Badenian valley incision /shelf margin erosion and mid-late Miocene infill. Sequence 5: intra-Pontian (Messinian) shelf margin erosion, low stand wedge and late Pontian to Recent infill/healing sequence (interrupted by multiple 4th order canyon incision events). Numbers 1 to 5 refer to the basal unconformity bounding each sequence.

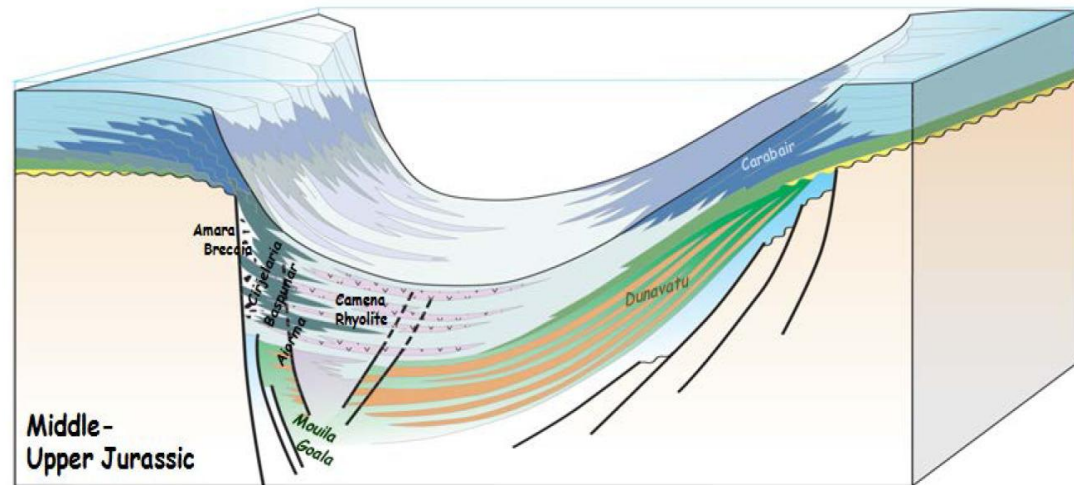
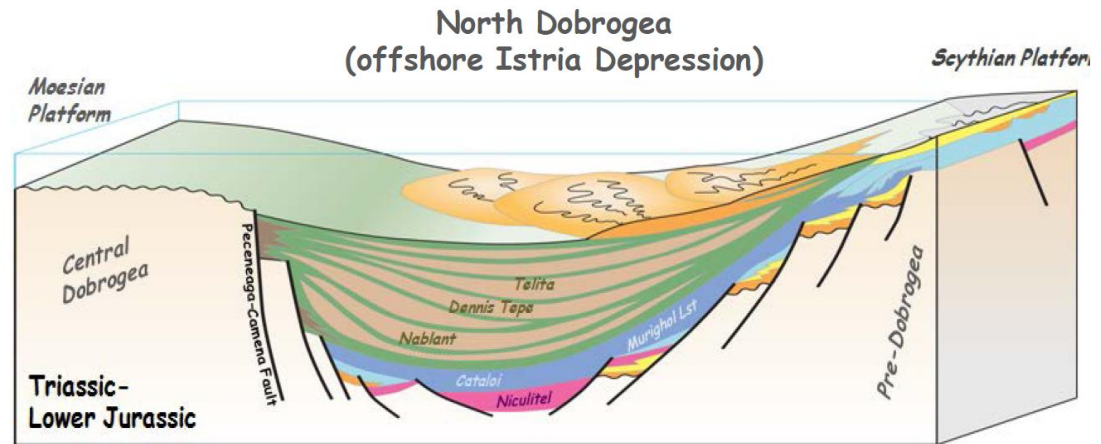


Figure 4. Istra Depression Basin Frame. Late Triassic-Early Cretaceous tectonostratigraphic evolution of the North Dobrogea Trough modified from Barrier and Vrielynck (2008). Middle Triassic crustal extension and rifting between the Moesian microplate and Bohemian Massif/Spur and Vienna Basin was followed by end Triassic compression and a second episode of rifting in the Early Jurassic. The final separation of Moesia and opening of the North Ligurian ('Magura') seaway started in Middle Jurassic, reaching its final position in Late Jurassic (Tari, 2007; Gradinaru and Barbulescu, 1994). The North Dobrogea Zone and offshore 'Istra' extension formed a narrow deep water partially oceanized basin, deformed by a paroxysmal phase of inversion in the Early Cretaceous (?Late Aptian/Early Albian) casually linked to the opening of the Western Black Sea.

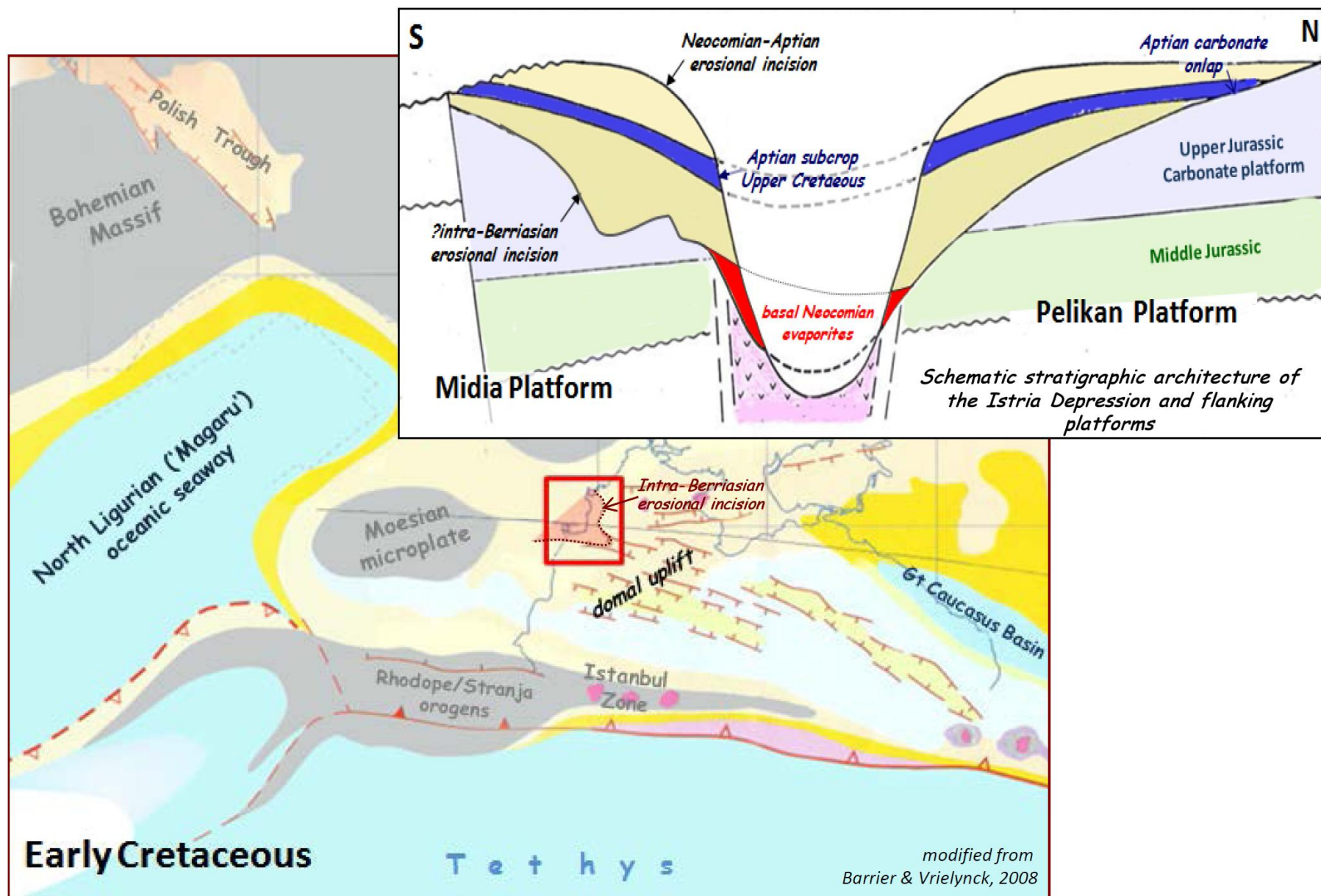


Figure 5. Sequence 1 (Neocomian-Late Aptian): Late Jurassic domal uplift encouraged significant intra-Berriasian erosion within the Istria Trough and bounding platforms subsequently infilled and buried by a west facing depositional sequence of low stand evaporites and mixed clastics and carbonates during the Hauterivian - Late Aptian onlapping eastwards onto a pre-rift/syn-rift Western Black Sea high.

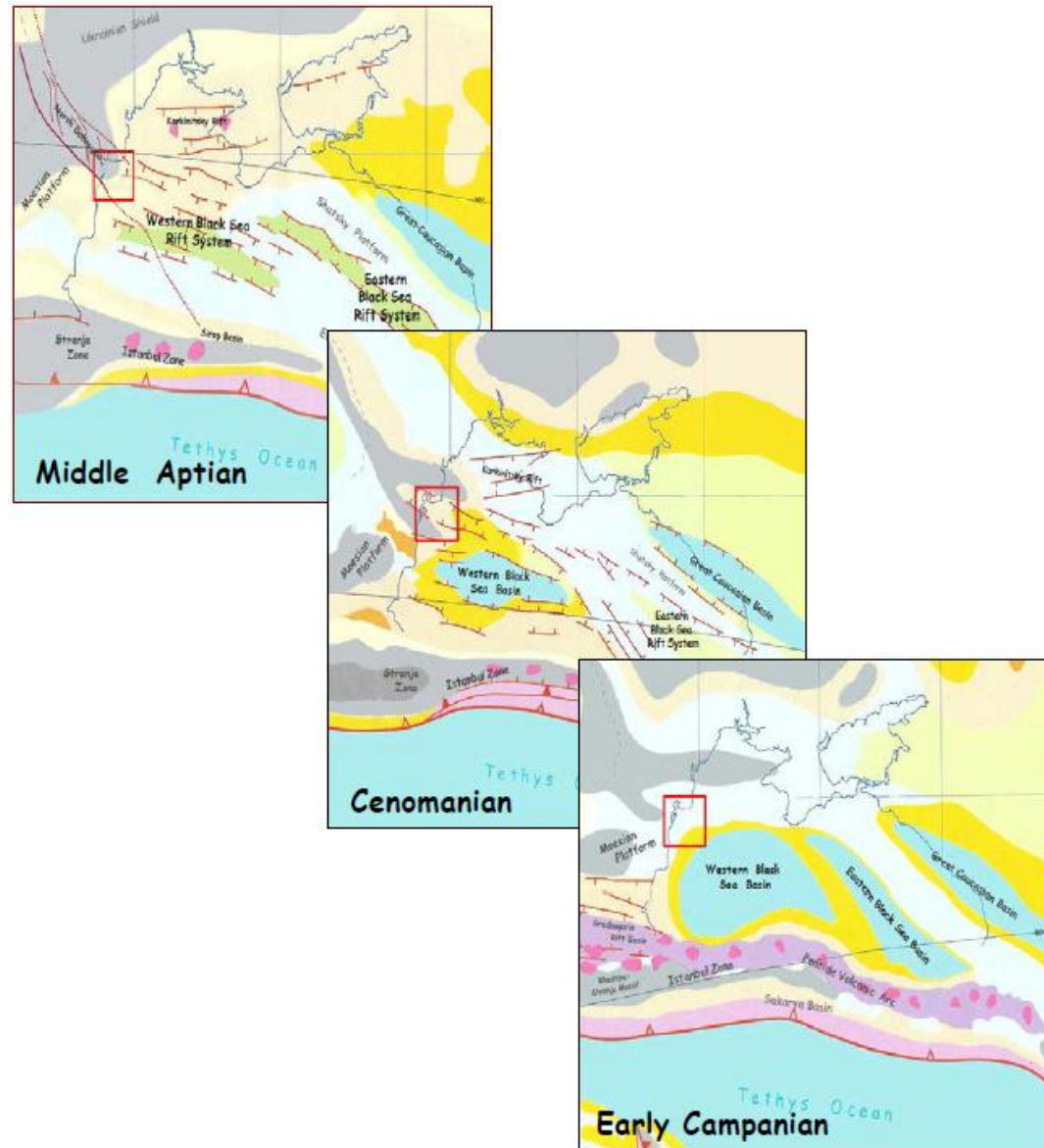
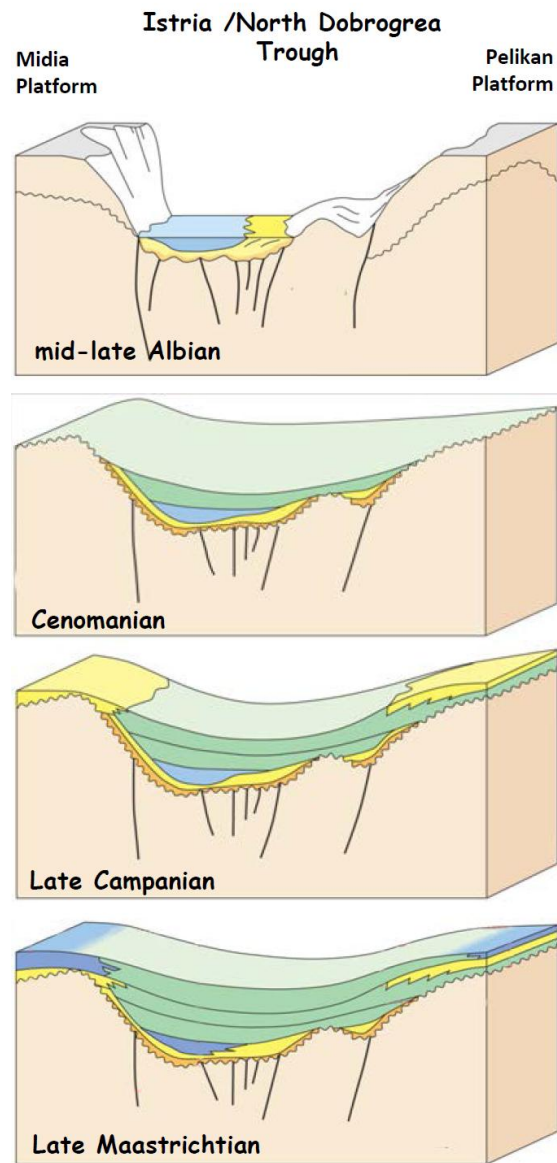
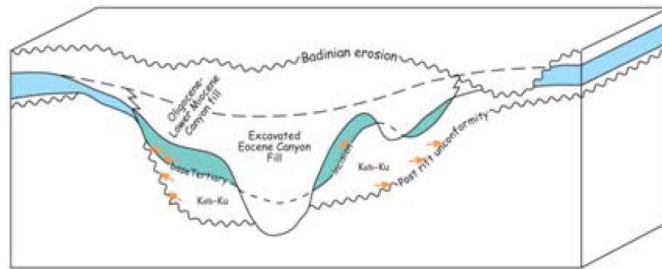
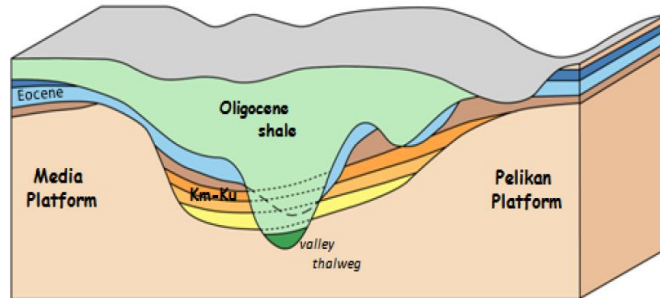


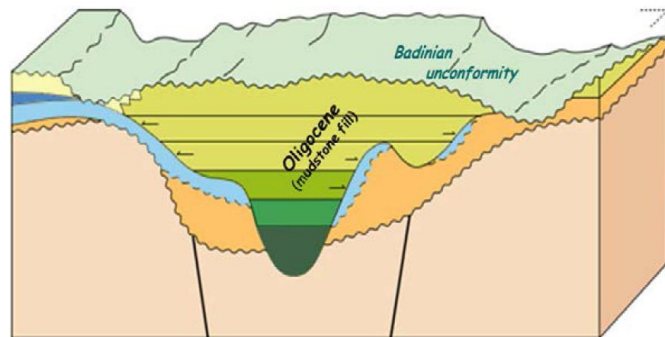
Figure 6. Sequence 2 (Albian-Paleocene): Paroxysmal rifting and uplift of the Western Black Sea was associated with inversion of the North Dobrogea/Istria Trough and erosional incision. As the Western Black Sea opened by back-arc spreading, the evacuated trough was transgressed from the east and onlapped and infilled by clastic dominated sediments during the later Cretaceous (paleogeographic reconstructions after Barrier and Vrielynck, 2008).



Middle- Late Eocene



Late Eocene -Early Oligocene



Oligocene-Early Miocene

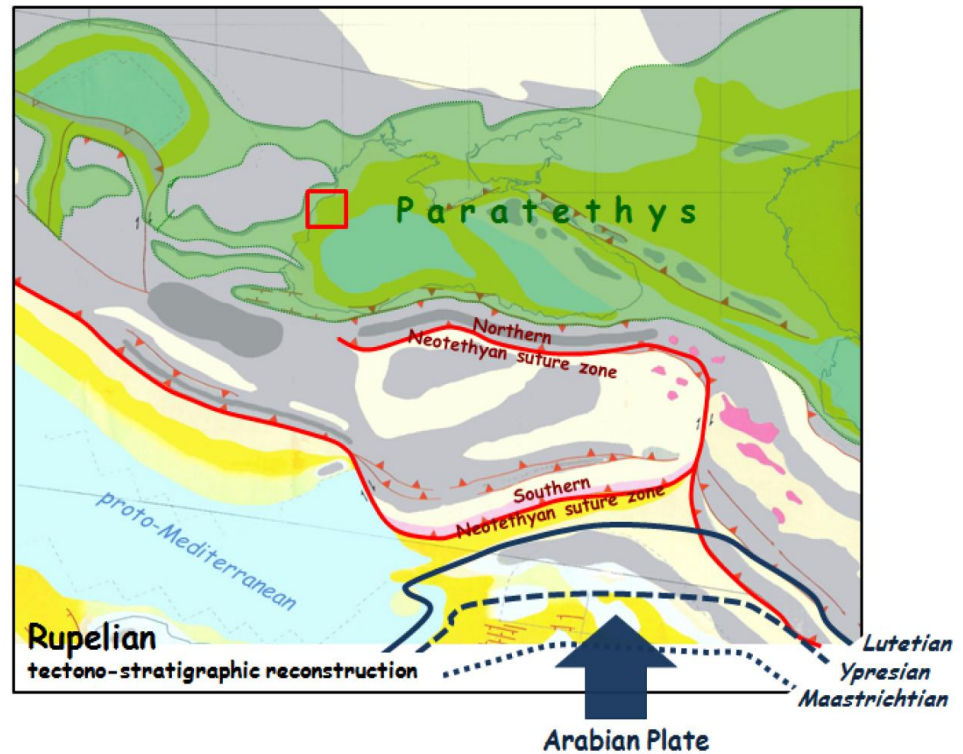
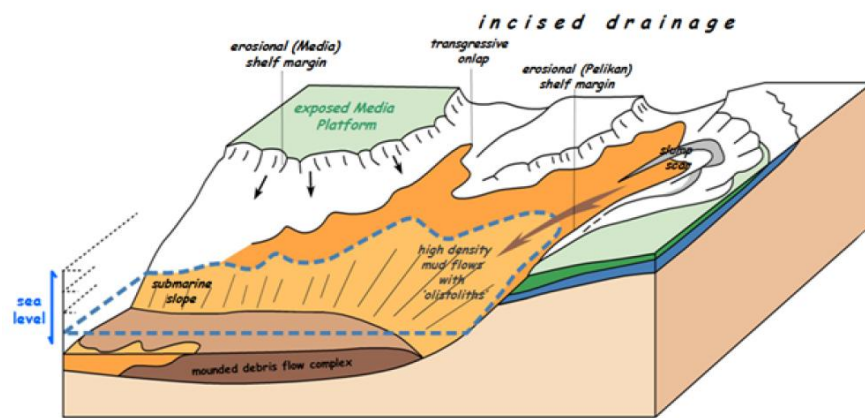
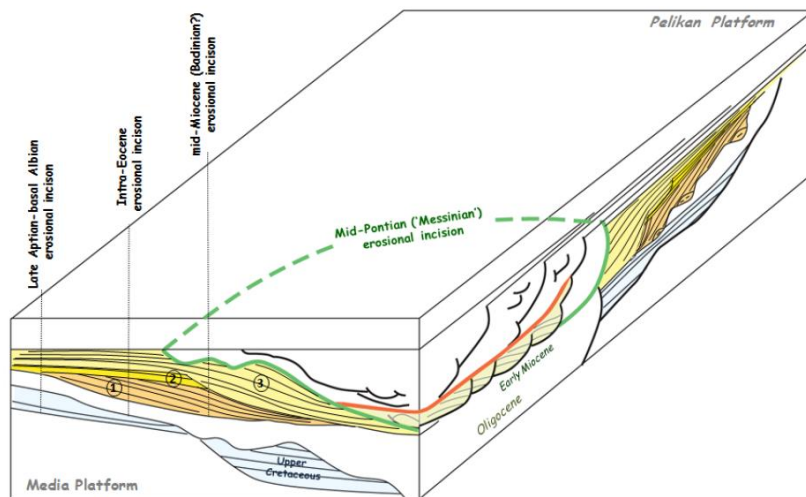


Figure 7. Sequence 3 (Eocene-Mid Miocene): Collision of the Pontide and Tauride-Anatolide microplates and closure of ‘northern’ Neotethys during the Late Cretaceous- Eocene culminated with regional suturing (Gorur and Tuysuz, 2001; Okay and Sahinturk, 1997; Robertson and Ustaomer, 2004; Sengor and Yilmaz, 1981) establishing a series of linked basins – the ‘Paratethyan’ seaway. Intra-Eocene isolation of this seaway triggered dramatic fluctuations of base level, responsible for at least two periods of deep erosional incision within the Istria Trough. An initial infill sequence is dominated by carbonates and marls, incised and buried beneath younger Oligocene shales, basal turbidite clastics and anoxic shales (‘Maycok ‘ and equivalent) further outboard in the Western Black Sea Basin as the Paratethyan Basin was reflooded (Schutz et al., 2005; Tari et al., 2013; Vincent et al., 2007). Kinematic reconstruction based upon Barrier and Vrielynck 2008).



mid-Badenian (Serravalian) lowstand systems tract



Sarmatian-Pannonian (Tortonian) transgressive -highstand systems tract

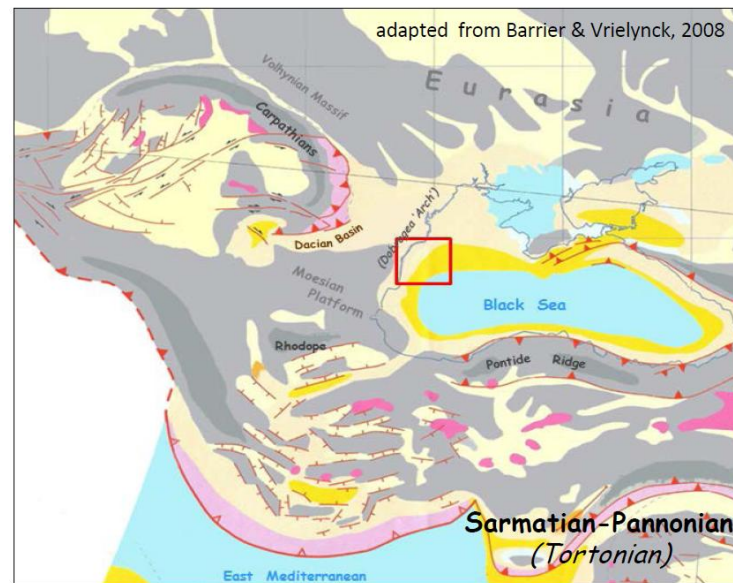
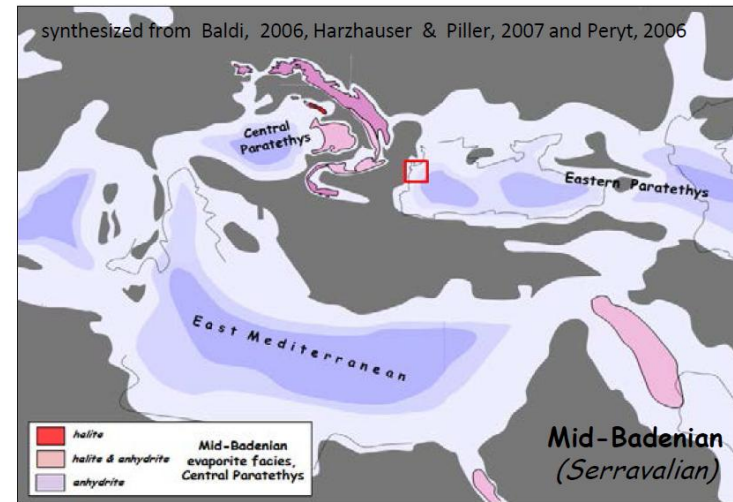


Figure 8. Sequence 4 ('Badenian-Sarmatian'): A significant intra-'Badenian-Sarmatian' base level fall is suggested by shelf margin erosion, incised valleys and canyons. The adjacent platforms suffered exposure and karstification and shed Eocene carbonate detritus and Oligocene shale clasts to be redeposited as mounded debris flow deposits further outboard. This lowstand is causally related with a more regional intra-Badenian base level fall responsible for lowstand evaporite deposition in Carpathian foredeep and associated incised drainage and valley incision on the flanking foreland. Base level rise and reflooding is reflected by a Late Badenian-Sarmatian transgressive systems tract represented by several backstepping high frequency sequences within the Istria Depression.

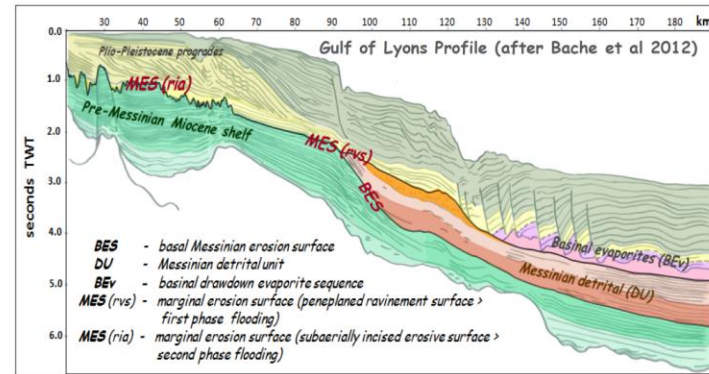
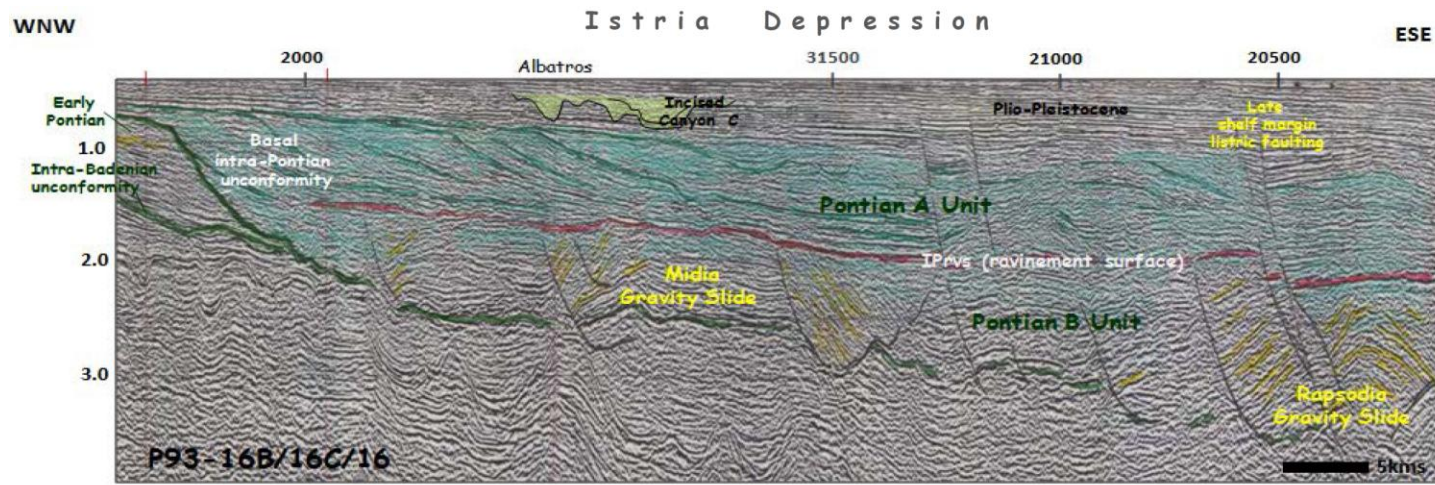


Figure 9. Sequence 5 (Late Miocene-Early Pliocene): Seismic Traverse P93-16B/16C/16. Oblique-dip section highlighting the intra-Pontian erosional event and fill (healing) architecture. The basal intra-Pontian erosional unconformity (bIPu) terminates within the Pontian section to the west. The erosional topography was infilled by Pontian Unit B, partially deformed and transported to the south/southeast in two large gravity slides and subsequently erosionally truncated and peneplained by an intra-Pontian ravinement surface (Iprvs) during a comparatively slow base level rise. The residual erosional topography was eventually filled by a complex wedge (Pontian Unit A) of high frequency progradational cycles characterized by south facing oblique-sigmoidal foresets and local incision, passing upwards into a more uniform flat lying shelf System interrupted by several canyon incision events. Late stage listric faulting is apparent to the east, displacing the Pliocene and Pontian section and soleing out within older Oligo-Miocene. These faults parallel the shelf margin and may signal incipient intra-Pleistocene (?) mass-wasting collapse. The stratigraphic architecture of this profile is broadly comparable to the Messinian drawdown sequence described from the Gulf of Lyons by Bache et al. (2012) with a lower lowstand clastic unit, terminated by a transgressive ravinement surface and overlain locally by basinal evaporites (Mediterranean) stromatolitic dolomite (SDSP 380, SW Black Sea) and distinctive late lowstand prograding wedges above.

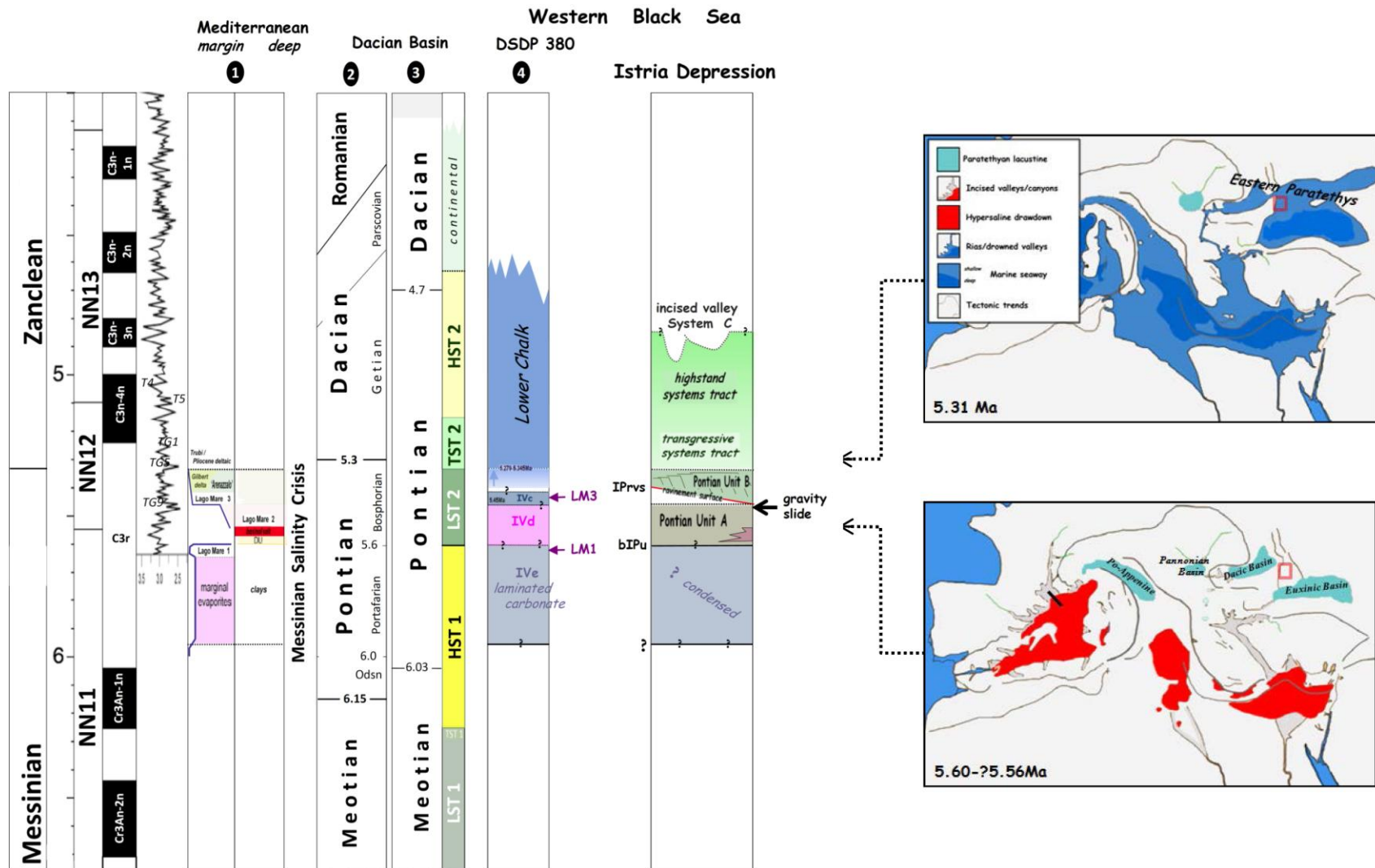


Figure 10. Tentative Late Miocene-Early Pliocene chronostratigraphy of the Istria Depression and correlation with the Mediterranean and Eastern Tethyan (Dacian and Euxinic Basins) realms. Chronostratigraphic schemes summarized from (1) Bache et al., 2012; Clauzon et al., 2005; Roveri et al., 2008, (2) Snel et al., 2006, (3) Leever et al., 2009, (4) Gillet et al., 2007; Popescu, 2006; Popescu et al., 2010. The Istria Depression chronostratigraphy proposed here assumes a causal relationship between the Mediterranean and Eastern Paratethyan drawdown events, during the Late Messinian and has been constrained by biostratigraphic, palynological and magneto-stratigraphic correlations between the Mediterranean, Dacian and Euxinic (DSDP 380A) basins. The Istria Depression and Messinian sequences of the Mediterranean appear broadly correlative, although reflooding of Eastern Paratethys (Black Sea) occurred slightly later.

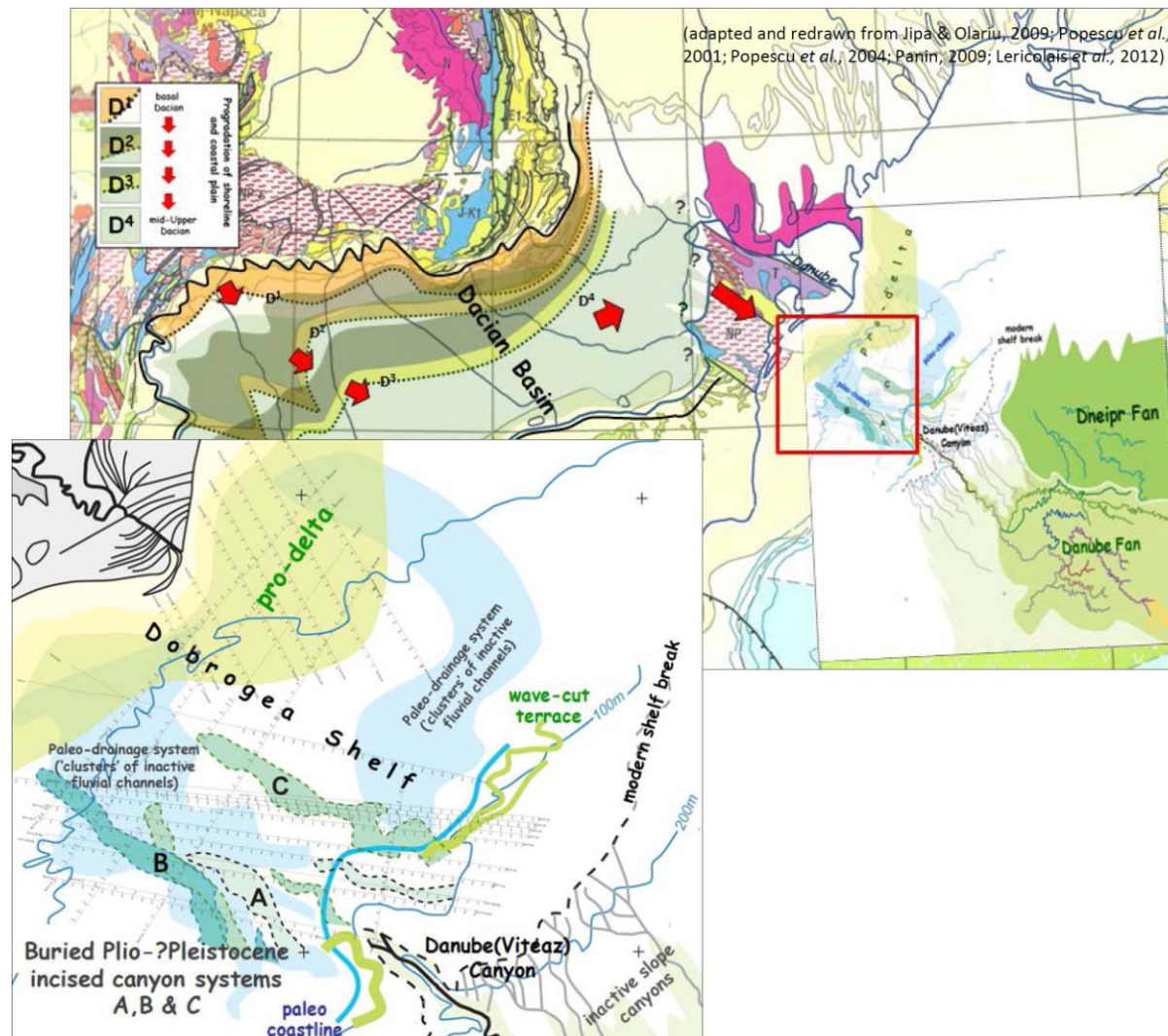


Figure 11. Sequence 5 (Plio-?Pleistocene): Several NW-SE trending canyon systems (C/oldest, B and A/youngest) were incised into the offshore Romanian shelf during the Plio-Pleistocene of comparable size and geometry to the Pleistocene-Holocene Viteaz (Danube) canyon, funneling sediment from the Dacian Basin across the Romanian shelf into the deep water Black Sea/Danube Fan during periods of relative low stand. The onshore basin was a sediment trap in Late Miocene-Early Pliocene but by Mid-Late Dacian time was filled and bypassed by the paleo-Danube drainage system. The orientation and location of the shelf canyons suggests this initially extended directly east across the North Dobrogea and offshore Romanian shelf, only to be diverted north as the Dobrogea region was arched upwards in response to crustal loading driven by the southwards emplacement of the Carpathian orogen in the Quaternary.

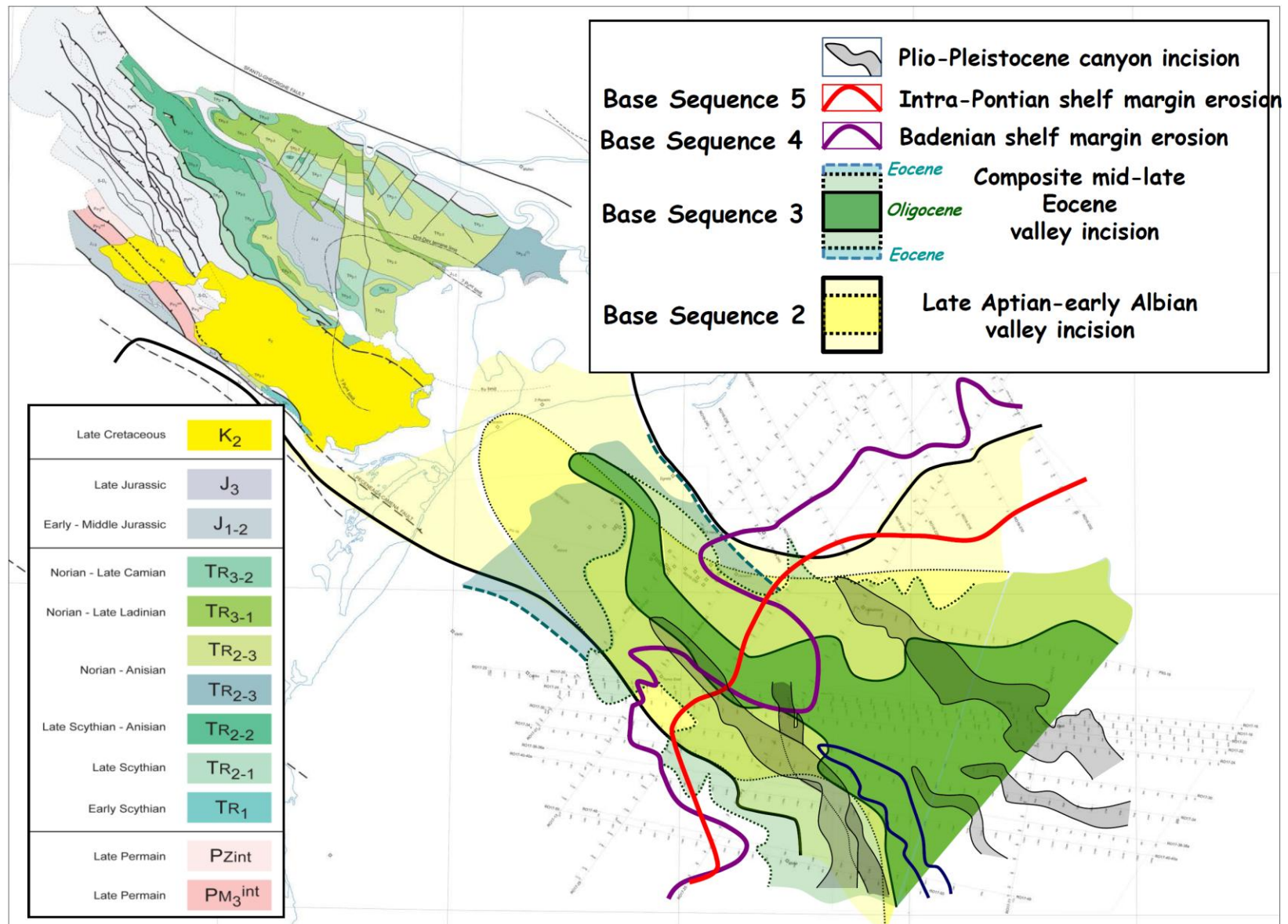


Figure 12. Summary of Cretaceous-Cenozoic 2nd/3rd order sequence boundary surfaces, Romanian Black Sea Shelf. The approximate erosional limits of Sequences 2 to 5 basal unconformities are highlighted in colour. Sequences 2 (yellow) and 3 (blue green/green) are bounded by deeply incised erosional surfaces contrasting with shelf margin dominated erosion characteristic of Sequences 4 (purple line) and 5 (red line). The Plio-Pleistocene canyon system (grey) appears to cluster together above the underlying incised valleys.

Earth's Era	System Period	Series Epoch	Stage Age	Myrs
Cenozoic	Neogene	Holocene		
		Pleistocene	Upper	
			Middle	
			Lower	
		Pliocene	Gelasian	
			Piacenzian	
			Zanclean	
		Miocene	Messinian	9
			Tortonian	
			Serravallian	
Langhian				
Paleogene	Oligocene	Burdigalian	19	
		Aquitainian		
		Chattian		
		Rupelian	31	
	Eocene	Priabonian		
		Bartonian		
		Lutetian		
	Paleocene	Ypresian	45	
		Thanetian	52	
		Selandian		
Mesozoic	Cretaceous	Upper	Danian	
			Maastrichtian	66
			Campanian	82
			Santonian	
			Coniacian	
		Lower	Turonian	
			Cenomanian	96
			Albian	
			Aptian	
			Barremian	118
Jurassic	Upper	Hauterivian		
		Valanginian		
		Berriasian		
	Middle	Tithonian	146	
		Kimmeridgian		
		Oxfordian		
		Callovian	164	
		Bathonian		
	Lower	Bajocian		
		Aalenian		
Toarcian		179		
Triassic	Upper	Pliensbachian		
		Sinemurian		
		Hettangian		
	Middle	Rhaetian	204	
		Norian		
Lopingian	Carnian			
	Ladinian			
	Anisian			
Permian	Lower	Olenekian		
		Induan		
	Changhsingian			
Wuchiapingian				

Sequence 5

Sequence 4

Sequence 3

Sequence 2

Sequence 1

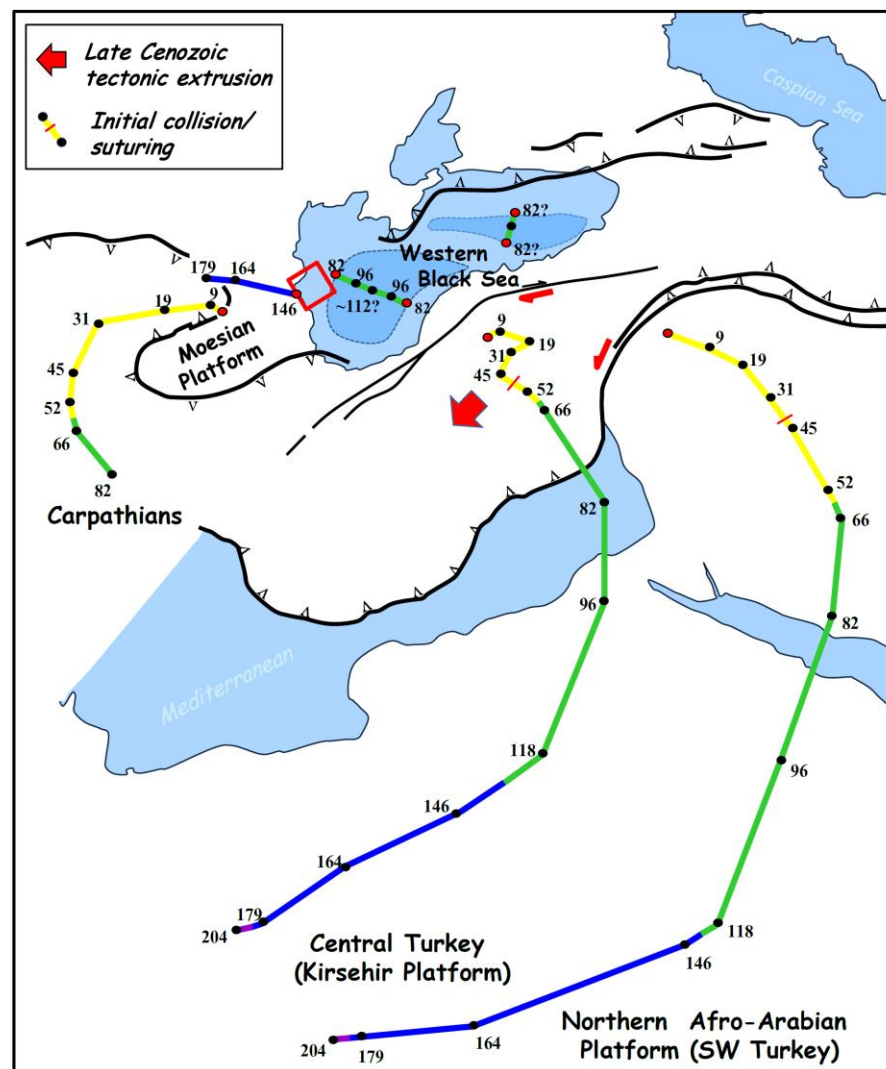


Figure 13. Mesozoic-Cenozoic Neo-Paratethyan plate kinematics, western Black Sea shelf margin. The relative motion of Afro-Arabia (SW Turkey), Central Turkey Kiresehir (Platform) and Moesian Platform with respect to the Romanian Black Sea shelf (red box) from the Late Triassic to the present time are summarized by the several trackways based upon paleogeographic reconstructions by Barrier and Vrielynck (2008). Their relative position at particular times is shown in million years during the Triassic (mauve), Jurassic (blue), Cretaceous (green) and Cenozoic (yellow). The opening of the Western Black Sea and movement of the Carpathian orogenic front up the North Ligurian embayment is also highlighted. Key tectonic events associated with this complex regional tectonic evolution appear to be causally linked to the several 2nd/3rd order unconformities interrupting the fill sequence of the Istria Trough.