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Slab detachment beneath eastern Anatolia: A possible cause for the formation of the North Anatolian fault

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Abstract

In this paper, we discuss the possibility that the North Anatolian fault (NAF) results from the deep deformation of the slab beneath the Bitlis–Hellenic subduction zone. We described the tectonic evolution of the Anatolia–Aegean area in three main steps, before, during and after the formation of the NAF. We remark that the tectonic conditions that are assumed to have triggered the formation of the NAF, i.e. collision to the east and extension to the west, was already achieved before the onset of that strike-slip fault system. We also highlight that the formation of the NAF was accompanied by the uplift of the Turkish–Iranian plateau and by a surge of volcanism in the eastern Anatolia collisional area and probably by the acceleration of the Aegean trench retreat. We show tomographic images from global P-wave model of Piromallo and Morelli [C. Piromallo, A. Morelli, P wave tomography of the mantle under the Alpine–Mediterranean area, J. Geophys. Res. 108 (2003) doi: 10.1029/2002JB001757.] showing that the slab beneath the Bitlis collisional belt is not continuous and that its possible rupture pursues to the west at least up to Cyprus and possibly up to the eastern end of the Hellenic trench. All these observations suggest that the plate tectonic re-organization occurred in the Late Miocene–Early Pliocene in the region results from slab break-off in the Bitlis area and from its lateral propagation to the West. This idea is tested in analogue laboratory experiments, which confirm that the break of the slab under the collisional belt may trigger, (1) the acceleration of slab retreat to the west due to the increase in slab pull force, (2) the indentation of the continent in the collisional area and (3) produce the conditions that permit the lateral escape of material towards the west and the formation of the NAF.

Keywords: Mediterranean; subduction; collision; analogue experiments; seismic tomography

1. Introduction

The North Anatolian fault (NAF) is a right-lateral strike-slip fault zone, which runs for about 1400 km from eastern Turkey (Karliova triple junction) to the Aegean Sea and the Peloponnese, where it splits in several branches (Fig. 1). The NAF constitutes the northern boundary of the Anatolian–northern Aegean block (e.g., [2–7]) and joins two different tectonic domains. To the east, the Bitlis-Zagros collision zone produced by the northward motion of Arabia towards

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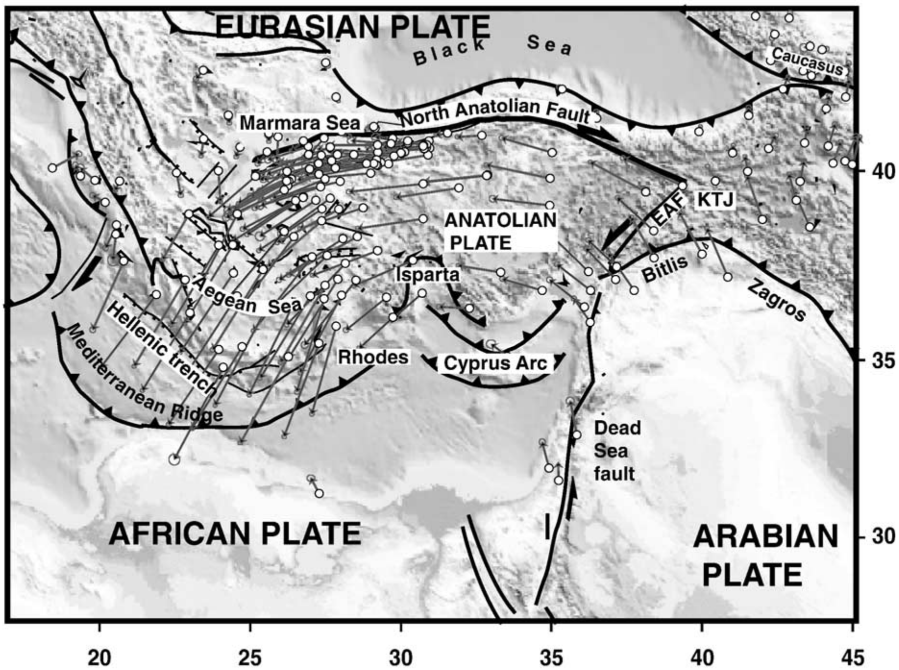

Fig. 1. Simplified tectonic map of the eastern Mediterranean–Middle East region. GPS vector with respect to Eurasia from [16]. KTJ, Karliova triple junction; EAF, Eastern Anatolian fault.

Eurasia (e.g., [2,4,8]). To the west, the Aegean extending domain related to the rollback of the Hellenic trench (e.g., [9–15]).

Geodetic data shows that the overall velocity field of the Anatolian–Aegean block relative to stable Eurasia accelerates towards the Hellenic trench (Fig. 1) [16]. Geodetic data also show that almost all the present-day westward motion of Anatolia with respect to Eurasia is accommodated by the NAF and that central Anatolia is presently suffering moderate deformations. This result suggests that rollback of the Hellenic trench plays an important role for the Anatolian block motion (e.g., [17–21]).

Although the present and past kinematics of NAF is rather well described, the cause of plate re-organization over the Middle East is debated (e.g., [2–4,22–25]). The westward motion of Anatolia has been related to the rigid "escape" away from the collisional zone [22], or to potential energy stored in the thicker crustal region of the Turkish–Iranian plateau—Greater Caucasus with respect to the Aegean low-land [25] further increased during the Messinian sea-level drop [26].

We here combine tectonic reconstruction and tomographic images of the upper mantle with some simple physical aspects extract from laboratory experiments, to formulate an original model for the formation of the NAF in the Aegean–Anatolian–Arabian frame. We identify as the ultimate cause for the plate tectonic reorganization of the Middle East–eastern Mediterranean the deformation (break-off) at depth of the slab beneath the Bitlis-Zagros suture and the consequent acceleration of the rollback of the Hellenic trench.

2. Tectonic evolution

In the following, we review the tectonic evolution of the Hellenic–Bitlis region through three key stages: (i) prior to onset of the NAF, (ii) during its initial growth and (iii) the recentmost-present setting.

2.1. Lower–Middle Miocene: Bitlis collision and Aegean extension prior to the NAF formation

In the Early Miocene–Late Oligocene, two major tectonic processes were active in the Middle East. In eastern Anatolia, Arabia collided with Eurasia along the Bitlis–Pontides collisional belt (Fig. 2C), piling up continental fragments, volcanic arc (Aptian to Oligocene) and a wide thin-skin accretionary complex. The age of the closure of the Bitlis ocean (part of the southern Tethys branch corresponding to the Bitlis suture) and the contact between the Arabian and Eurasian continent occurred probably during the Late Oligocene [8,23,27]. The outward younging of the

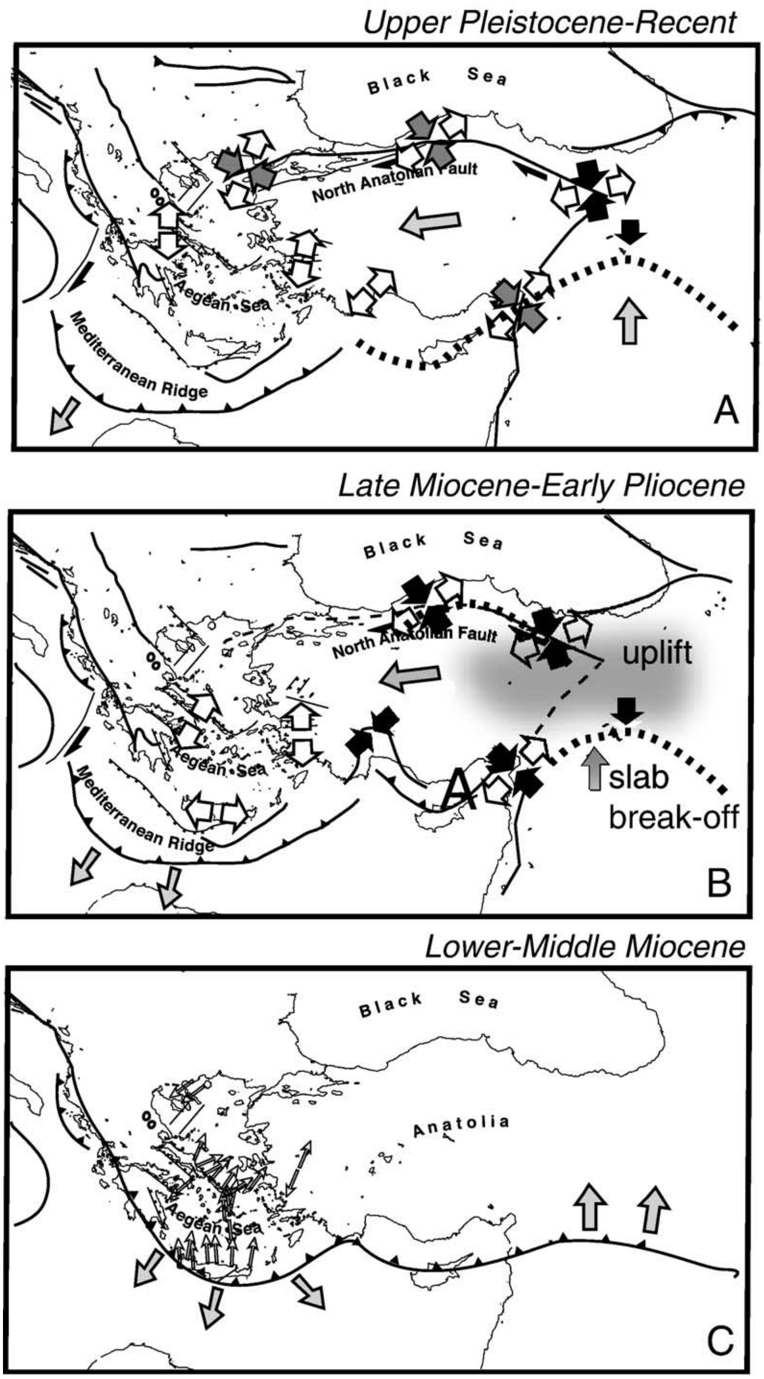

Fig. 2. Tectonic evolution of the Anatolia–Aegea region after (A, Upper Pleistocene–Recent), during (B, Late Miocene–Early Pliocene) and prior (C, Lower Middle Miocene) to the formation of the NAF. The coast line is taken fixed for reference. Plate boundary is displaced accordingly to the amount of shortening and backarc extension [13,78]. Stretching directions shown in frame C are from [15]. Grey long arrows near plate boundary indicate the displacement. Black and white arrows indicate shortening (σ_1 direction) and extensional regime (σ_3 direction), respectively; double arrows set indicate σ_1 and σ_3 orientations for transpressional (black and white arrows) or transtensional (grey and white arrows) regimes. See text for fault population analyses references. Shadow area represents the uplifted region of the Anatolia plateau. Dashed line indicates the broken slab.

foredeep deposits (from Cretaceous up to the Oligocene) indicates that, prior to this collisional episode, an efficient southward retreating subduction was operating ([28] and reference therein).

While collision was initiating to the east, extension was taking place to the west, in the Aegean, producing the collapse of the orogenic belt, the formation of deep basins and the rise up of metamorphic core-complexes [13,15,29,30]. In the Cyclades, the first outcropping syn-rift sediments date back to the Aquitanian but the onset of extension took place earlier in the Late Oligocene [12,13], as attested by the radiometric dating of green-schist LP–LT metamorphism fabric related to the extensionally driven exhumed metamorphic cores. Sense of shear are N- or NNE-oriented (e.g., [15] and references therein) (Fig. 2c). Further north, in the Rhodope, extension initiated earlier in the Late Eocene [31].

2.2. The Upper Miocene–Pliocene re-organization: initiation of the NAF

The Upper Miocene (Fig. 2b) marks a change in the style of deformation over the Middle East. To the east, the deformation related to northward motion of Arabia distributed away from the suture zone, from the Greater Caucasus to the northern Arabian plate [25]. A large portion of the collisional belt was uplifted to an elevation of 1.5–2 km forming the Turkish–Iranian plateau. The age of uplift is not precisely defined but the change from marine to terrestrial sedimentation occurred during or soon after the Serravalian (12 Ma) [23,32]. Meanwhile, a new pulse of volcanism took place [33]. Volcanic complexes migrated from northern Bitlis suture (around 11 Ma) to the southern one (around 3 Ma) to the Arabian lithosphere (Pleistocene) while changing composition from calc-alkaline to alkaline and within plate [34]. Volcanism and plateau uplift have been interpreted as surface manifestation to the erosion of the mantle root caused by delamination of the mantle lithosphere and/or slab break-off [28,34].

The timing of the onset of the NAF strike-slip tectonics is controversial (see [6,35] for review). In eastern Anatolia, the appearance of the fault is bracketed between Late and Middle Miocene [23]. In the central part of the NAF, sediment filling pull-apart basins suggests that the onset of strike-slip deformation occurred between Upper Miocene and Early Pliocene [36–41]. To the west, the NAF affects the Marmara region and the Aegean Sea from the Uppermost Miocene [42,43] or the Pliocene [44,45].

Evidences of a change in the tectonic regimes is registered by crustal deformations over the whole the Anatolian–Aegean regions. In the East Anatolian plateau and Lesser Caucasus, a drastic change from thrusting (NNW-trending compressional axis) to strike-slip faulting has been documented between Upper Miocene and Early Pliocene [35,46]. In the Cyclades, extensional axis is NNE-trending [9–11,47,48], whereas in Crete turns to E–W (possibly due Hellenic trench arching [11] or incipient collision with the African margin [49]). In Western Anatolia, the Miocene WNW-trending extensional regime is followed during Pliocene by a N-NNE extension (e.g., [11,48]).

2.3. Recent tectonic setting

The Upper Pleistocene to present-day deformational pattern presents some differences with the previous stage (Fig. 2a). Locally, it is separated by the previous one by short-lived N–S-trending compression episodes recorded in Ionian islands and moderately in Lokris, Evvia, Corinthia [50] and/or by a strike-slip episode in the south central Anatolia [51].

Along the eastern portion of NAF, the present-day state of deformation is dominantly right-lateral strike-slip. Over et al. [37] provide evidence for an Early Quaternary change from regional transpressional to transtensional regime, preserving a NNW-trending orientation of the maximum horizontal stress axis. Geodetic data (e.g., [16]), structural analyses [51] and earthquake focal mechanisms [52,53] show widespread heterogeneous extensional regime also in south central Anatolia, with NNE- and NE-trending extension axes [54].

Seismic activity in the region is mostly released along the NAF seismic belt, locus of a series of large ($M>6$) earthquakes accompanied by surface ruptures during the last century (e.g., [6,55,56]). Focal mechanisms and fault ruptures show a complete range of mechanism spanning from strike-slip to reverse oblique-slip in the northeastern Anatolia (NS-trending σ_1 axis), to dominantly strike-slip in the central part (NW-trending σ_1 axis) [41]. In western Anatolia, inversions of the seismic fault-slip, in agreement with fault population analysis shows a NNE-oriented extensional regime both around the NAF zone [45] and in the southern region in the western Anatolia graben system [48] turning to NS in the Aegean [9,11,47,57]. The NAF propagation pursued further west in the North Aegean trough during the Late Pliocene and possibly in central Greece [24,44]. Summing up, the tectonic regime along the NAF progressively changes from transpression to transtension both in space (moving westward) and in time.

Spatial geodetic measurements (GPS and SLR) report a mean westward motion of Anatolia with respect to Europe of about 22 mm/yr along the NAF [16,17,58–60] (Fig. 1). The geodetically determined Anatolia mean displacement approximately corresponds to a rigid rotation (internal deformation less than 2 mm/yr) with an Euler pole located near the Nile delta [16,17]. The long-term displacement rate along the NAF could have been slower, 5–10 mm/yr [5,6,38], considering a total amount of displacement in the order of 80 ± 30 km during the last 10 My [5,6,42] but, as discussed before, the exact age of initiation of NAF is still debated. GPS data identifies also another block, southern Aegea, which moves coherently towards the Hellenic arc at a larger speed than the central Anatolia block (30 mm/yr vs. 20 mm/yr) [16,17,60]. These two blocks (southern Aegea and central Anatolia) are indeed separated in western Anatolia by a ~N–S stretching area, where extension is accommodated by a system of E–W-trending grabens. The present-day extension disposition is roughly symmetrical to that of the northern Aegean trough-Corinth Gulf system with respect to the axis of the Hellenic arc. This overall geometry suggests that the extra-relative speed of central Aegea with respect to Europe is due to the pull resulting from the Hellenic subduction zone.

3. Mantle structure between the Aegean subduction and the Bitlis collision

Fig. 3 show images from PM0.5, a high-resolution tomographic model of the mantle beneath the Euro–Mediterranean region by Piromallo and Morelli [1] obtained by inversion of International Seismological Centre (1964–1995) P-wave delay times. For a comprehensive description of the model and its reliability the reader is referred to [1].

In the Aegean area, the subduction zone is marked by a northward dipping Wadati-Benioff plane down to a depth of 180 km [61,62]. The tomographic images show a marked positive velocity anomaly that follows the Hellenic Arc and prosecutes, at shallow depth to the northwest, below the Dinaric chain and to the east below the southwestern Turkey (Fig. 3). Cross-section Cc (Fig. 3e) across western Crete shows a continuous NNE dipping high velocity anomaly from shallow lithospheric depths down to the bottom of the transition zone, where it assumes a steeper dip of about 45°. Similar results have been obtained by previous tomographic models [61,63,64]. At 100 km depth, the Hellenic arc positive anomaly is definitively interrupted to the east of the Isparta reentrant and are replaced by a widespread and marked negative anomaly below Anatolia and Cyprus arc (Fig. 3a). Previous *Pn* tomography and anisotropy studies [65,66], regional wave attenuation of *Sn* [67], *S*-velocity structure [68] confirm our image and all indicate higher than average mantle temperatures beneath the eastern part of the plateau. This has been interpreted as due to the presence of asthenospheric material at subcrustal depths, caused by delamination of the mantle lithosphere and/or slab break-off [28,34].

At larger depth (Fig. 3b,c), a positive below southern Anatolia, a positive anomaly can be detected also north of Cyprus although its connection to the west with the Hellenic structure is not defined. Vertical cross-section (Bb in Fig. 3f) indeed shows a loose vertical continuity beneath Cyprus. East of Cyprus, the trace of the slab on the upper 200 km of mantle below Anatolia is totally lost. This is best illustrates by section Aa crossing the Bitlis suture (Fig. 3g). The positive velocity anomaly here accumulated in the transition zone, as also observed below the western Mediterranean region and the Alps [1,69,70,71]. This broad deep anomaly beneath Anatolia merges with the one beneath the Aegean Sea, suggesting the presence of a once continuous structure.

Summing up, tomographic results show the trace of a shallow angle slab-like shape high velocity body turning around the Hellenic arc. This well-defined structure looses resolution and continuity between Rhodes and Cyprus and is totally lost east of Cyprus. There, the shallower layers of the upper mantle are dominated by a negative velocity anomaly, whereas in the transition zone it is possible to distinguish the presence of a broad high velocity anomaly merging the Hellenic structure with the Bitlis one. These images suggest that there was a continuous, possibly oceanic, subducting slab extending from the Hellenic to the Bitlis. It preserved its integrity below the Hellenic arc, where it can be followed from the trench to the upper–lower mantle transition zone. Conversely, beneath below central and eastern Anatolia, it was broken because of the entrance at trench of the Arabian continental block.

4. A model of subduction–collision lateral transition

We performed 3D laboratory experiments at the scale of the upper mantle to investigate the lateral transition between an oceanic subduction adjacent to a continental one. Though the model has not been specifically designed for reproducing any particular case, it can be applied to the transition between the

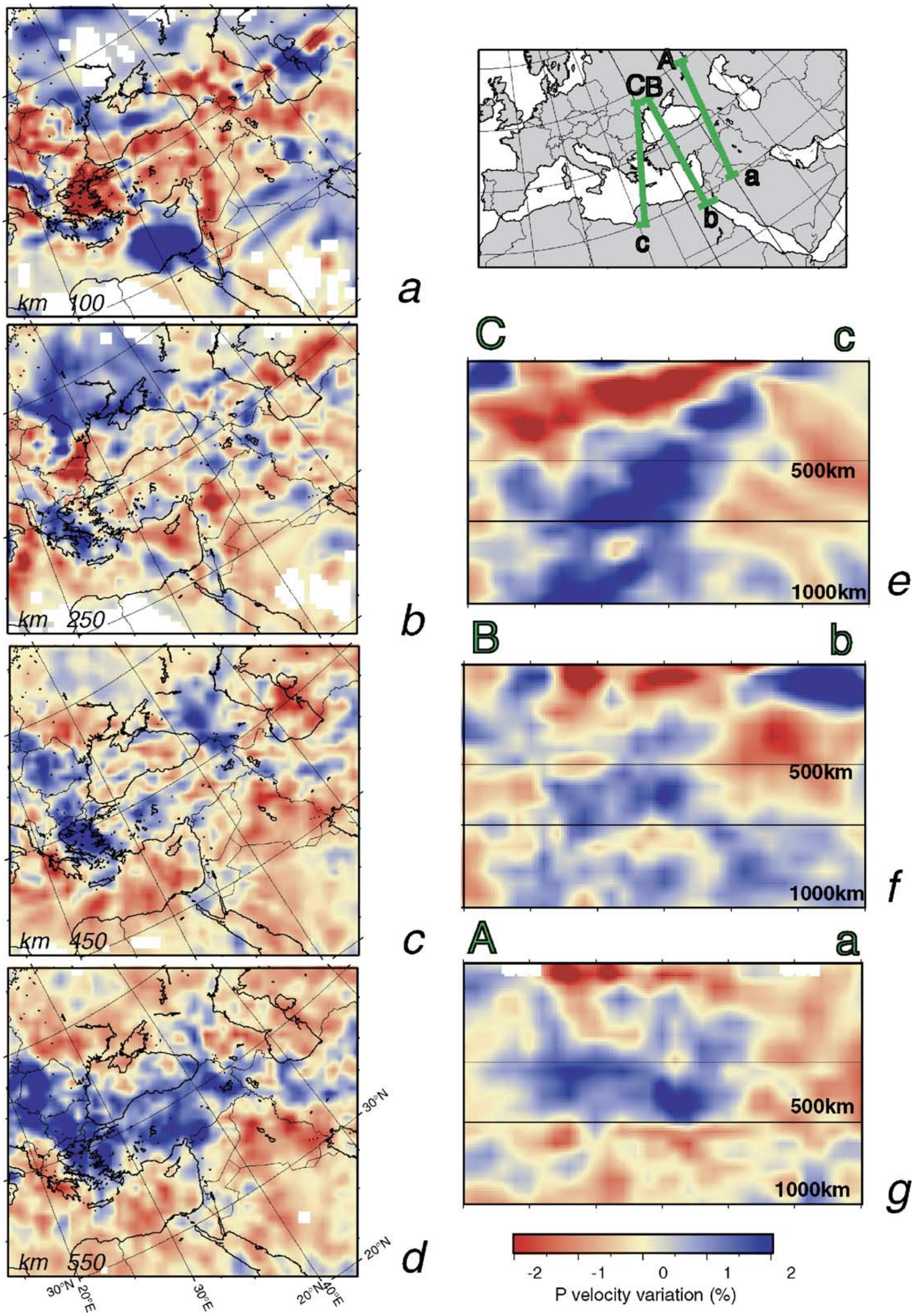

Fig. 3. Map views (a–d) of tomographic results at 150, 250, 450 and 550 km and (e–g) cross-sections from model PM0.5 [1]. Velocity anomalies are displayed in percentages with respect to the reference model sp6 [81].

Arabian continental indenter flanked by the eastern Mediterranean oceanic subduction. The experiment has been built up following a classical scheme for simulating lithospheric deformation (e.g., [72]), where sand is placed on the top of a viscous Newtonian silicone putty layer, to simulate the brittle–ductile behavior of the lithosphere (Table 1, Fig. 4a). These layers float over glucose syrup with a viscosity three to four orders of magnitude smaller than the silicone one to simulate the upper mantle–lithosphere viscosity jump (Table 1). The layers have different densities and viscosities to simulate the oceanic (denser than glucose syrup) and continental lithosphere (lighter than glucose syrup). Model is deformed inside a 50 cm long and 30 cm wide tank, and shortening is achieved by displacing a rigid piston at constant speed perpendicular to the plate margins (Table 1). For convenience, we shall refer hereafter to regions of the experiment in terms of geographical directions, the southern boundary corresponding to the piston. The scaling of our experiments is imposed by the length (1 cm in our experiments represents 70 km in Nature), stress and viscosity. The corresponding scale for time is 1 h of model run should represent about 1 My in Nature. The convergence velocity is set to simulate the Arabia–Eurasia convergence velocity, the 4.4 mm/h of our model stand for 2.5 cm/yr in Nature.

We show here the result of only one experiment (Fig. 4b–e), specifically designed to analyze the influence of slab break-off beneath a collisional system (after entrance of a small continent) laterally flanked by an oceanic subduction zone.

Table 1
List of physical parameters used in the experiment

Thickness (10^{-3} m)	
Silicon layers	9
Continental sand layers	2
Oceanic sand layer	4
Honey	195
Length (10^{-3} m)	
Southern continent	150
Ocean (western part)	70
Northern continent	280
Viscosity (Pa s)	
Oceanic silicone	$2.1 \cdot 10^5$
Continental silicone	$1.3 \cdot 10^5$
Honey	50
Density (kg m^{-3})	
Oceanic silicone	1470
Oceanic sand	1500
Continental silicone	1310
Continental sand	1250
Honey	1425
Time	
Piston velocity (m/s)	$1.2 \cdot 10^{-6}$
Total duration (h)	42

The initiation of oceanic subduction last about 10 h of experiment and is followed by a stage of mature oceanic subduction characterized by slow trench retreat and small back-arc extension [73]. The oceanic closure is achieved in the eastern part of the experiment after about 18 h. The entrance of continent does not produce an immediate change on surface strain regime, as moderate back-arc extension pursues, although more pronounced in correspondence of the oceanic subduction zone (Fig. 4c).

After 30–31 h of experiment, the slab breaks in the eastern side of the model (Fig. 4c,f). On the surface, the slab rupture is marked by a sudden appearance of compressional structures such as folds and thrust inverting the previously formed extensional structures (Fig. 4d,e). On the western side, conversely, the extra-load exerted by detached portion of the slab causes a sudden increase in the velocity of trench rollback and of the back-arc extensional. Rapidly, the edge of the break propagates westward and stops near the continent–ocean transition (Fig. 4h). Although the slab is totally detached beneath the collisional zone and continuous on the oceanic side, its lateral deep continuity is preserved (Fig. 4e,h). This causes an oblique load pulling down faster the subducting slab on the western oceanic side of the model. The combined effect of trench rollback on the western side and of continental indentation in the eastern side shapes the plate boundary, which attains an arc and cusp geometry, respectively. At the continent–ocean boundary, the transition between the two regimes generates on the upper plate and EW strike-slip fault zone accommodating the transition from transpression to transtension (Fig. 4l,m). The total strike-slip displacement is of about 1 cm, corresponding to about 70 km, distributed over a 100–150 km wide zone (Fig. 4m).

The velocity field after the break-off integrated over the last 3 h of model run (33–35 h) is shown in Fig. 4n. It highlights the heterogeneous deformation of the upper plate: to the west, the continent moves at high speed towards the subduction zone, whereas to the east it moves much slower away from the collisional zone. Westward lateral motion is restricted at the boundary between the two domains.

Summing up, the detachment of the oceanic deep subducted portion of the slab from the shallower continental portion produces a twofold effect. It inhibits further continental subduction causing a surge of compressional deformation and indentation on the surface

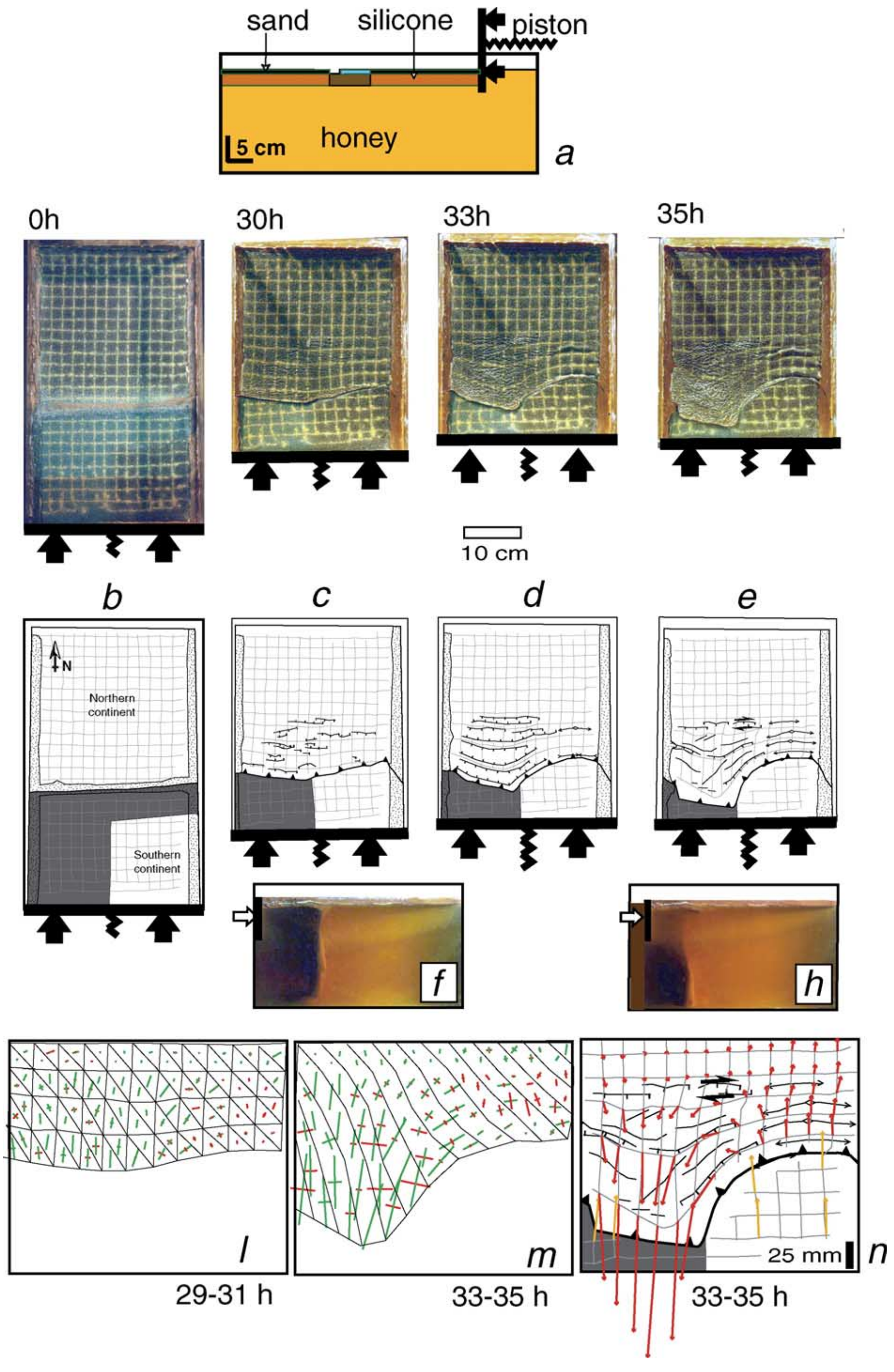

Fig. 4. Evolution of laboratory experiment performed to test the lateral transition from subduction to collision in the case that slab can break-off below collision zone. (a) Experimental set up; (b–e) surface view picture and corresponding line-drawing of the model at 0 (b), 30 h (c), 33 h (d) and 35 h (e) of experimental run (note that 1 h of the experiment roughly corresponds to 1 Ma in natural system); (f–h) lateral view of the experiment of the eastern side (right) of the tank prior (30 h) and after (35 h) slab break-off, respectively; (l–m) strain field on the upper plate of the model during the 29–31 h and 33–35 h, respectively; (n) velocity field for the 33–35 h time interval.

on continental side, and it increases the pull of the subducting slab on the oceanic side causing a faster trench rollback. This mechanism then produces the torque necessary to let mantle material flow laterally from the contractional domain towards the extensional one. Test experiments [74] designed to avoid slab break-off (higher slab strength [73]), in fact, show a limited amount of compression and extension in the continental and oceanic side, respectively, and no lateral strike-slip motion.

We remind that this experiment has not been designed to reproduce the Anatolia–Aegean case but to test physically the lateral propagation of the edge of a breaking slab from a heterogeneous subducting plate. For that, we take inspiration from Yoshioka and Wortel [75], who provided a numerical solution for the lateral propagation of the edge of a breaking slab, and from Wortel and Spakman [76], who first applied this mechanism to the Mediterranean area. The convergence between the numerical solution and experimental one, in fact, encourage the application of this mechanism to the natural case. The comparison between tank experiment and natural tectonic case is constrained by assumptions commonly listed in previous studies simulating tectonic processes at the scale of the mantle (e.g., [18,72,73]). Some drawbacks are, for example, the lack of an appropriate scaling for mantle temperature, phase changes and elasticity in the crust. These limitations can cause a non-appropriate result in terms of strain distribution and/or localization. Moreover, in our experiment, we reproduce the whole Tertiary history of subduction of the Ionian and Bitlis ocean be-

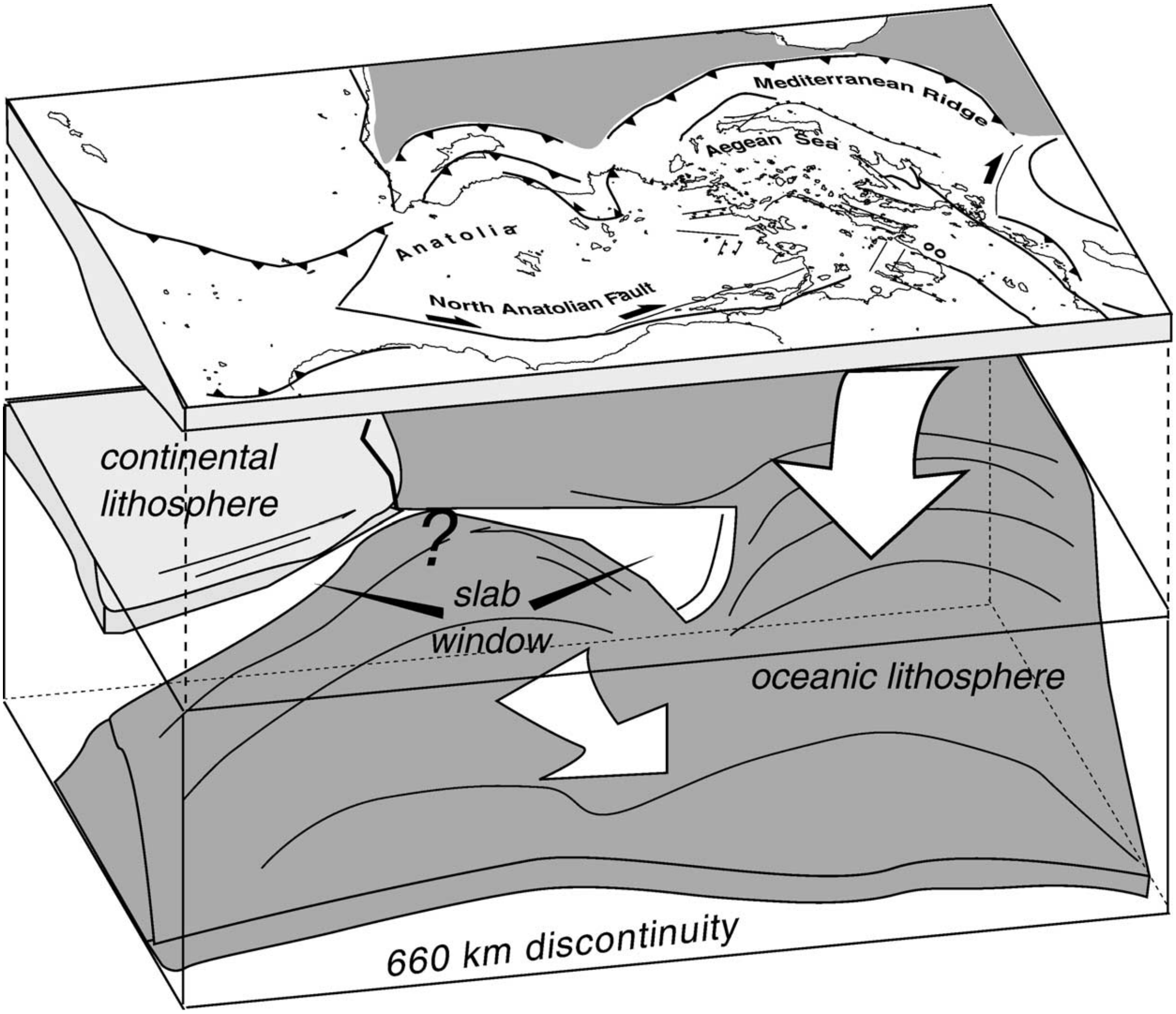

Fig. 5. Cartoon illustrating the connections between surface tectonics and the deep upper mantle. The detachment of the slab below Bitlis propagated at least to Cyprus and possibly further to the west to the eastern end of the Hellenic arc, favoring indentation and resulting in an increase of the slab pull force on the Hellenic trench. This mechanism could have been responsible for the Miocene–Pliocene re-organization in the Anatolian–Aegean region that resulted in the westward motion of Anatolia.

neath Eurasia. This has the advantage to obtain a more realistic simulation of the total amount of subduction and then of the slab pull-level, necessary for back-arc extension and slab break-off. On the other hand, this setting precludes the possibility to reproduce the less than 1 cm/yr differential motion attained in the Neogene between Arabia and Nubia plate [77,78]. Nevertheless, the imposed velocity (piston velocity, which should simulate the Arabia speed over the whole model) is smaller with respect to the back-arc area velocity field (after slab break-off) and halving its level on the western side (to correctly reproduce the Neogene speed of Nubia) would produce only minor change in the overall kinematics of the system. If we now compare the scaled size of the area westward moving block in the experiment is far smaller than that of Anatolia. This discrepancy could be due to: (1) lack of strength differentiation within the lithosphere [20]; (2) the position of the edge of the broken slab located at the collision–subduction transition zone in experiment, whereas it seems to be placed further to the west, inside the Ionian oceanic plate.

Despite these limitations, the experimental results suggest that the break-off of the slab under the collisional zone causes the end of continental subduction, triggering indentation on one side and accelerating slab retreat on the other side, favoring the rapid lateral motion of continental material on the upper plate. In addition, one can also speculate that the potential energy increase related to the slab break-off related uplift favors the westward lateral motion.

5. Discussion

Several models have been proposed to explain the formation of the NAF and the westward motion of the Anatolian block. Those models span from rigid extrusion related to Arabia–Eurasia indentation [22], to suction exerted by the retreating Hellenic subducting slab and to the gravitational collapse of the collisional belt [25]. Laboratory experiments, for example, have shown that the Aegean pattern of extension can be reproduced by the collapse of a gravitationally unstable plate towards a free surface, simulating the subduction zone [13]. In this frame, adding compression on one side of the experiment produces also second-order arc similar to the Cyprus one [18]. Numerical models show that the present-day velocity field can be reproduced by the combined action of the Arabia indentation and of the Hellenic trench rollback [19–21,79]. These models successfully reproduce the present-day kinematics of the Aegean–Anatolian region, but they do not explore the cause of the sudden plate re-organization.

Here, we propose that the trench rollback of the Hellenic trench and the Arabia indentation are produced by a unique mechanism able to explain the major crustal features in the collisional areas, such as the uplift of the Turkish–Iranian plateau, the surge of alkaline volcanism and the pattern of velocity anomaly in the mantle below eastern Anatolia. This model suggests that the deep deformation of the Bitlis–Hellenic slab may have caused the Neogene plate re-organization in the Middle East. In particular, we propose that the onset of the NAF strike-slip deformation can be triggered by the break-off of the slab under Bitlis and by the westward propagation of rupture edge up the Rhodes–Cyprus area (Fig. 5). In this frame, the renewal of alkaline magmatism in the collisional area (started at 11 Ma with major pulses at 6 Ma) and the uplift of the Anatolian plateau can be interpreted as surface manifestation of the slab rupture occurred in the Middle–Late Miocene [28,34]. Evidence of this derives also from the lack of intermediate-deep seismicity, the low velocity of the *Pn* suggesting the absence or partially molten lid beneath the Anatolia plateau [67] and from the tomographic images presented here where the transition between the continuous (Hellenic) versus broken slab (Bitlis) can be approximately identified between Rhodes and Cyprus. The exact location of the slab rupture edge cannot be defined, because below Cyprus there is some indication of active subduction and tomographic images are unclear in defining if the slab is attached to the surface or not. However, the fact that extensional system in central Aegea is limited to western Anatolia (Fig. 2) suggests that the active pull of the oceanic slab is restricted to the Hellenic arc as a result of partial slab rupture to the east [80].

In this model, the lateral westward propagation of the slab break-off at shallower depth could have produced, on the one hand, the acceleration of collisional processes in the Bitlis area and the rapid uplift of the Anatolian Plateau, and on the other hand, the rapid Hellenic trench rollback due to the extra-pull furnished laterally by the detached portion of the slab, as previously suggested by numerical and analytical solution [75]. The increased pull exerted on the Hellenic trench could have triggered the tectonic re-organization of the whole system, with the formation of the Anatolia microplate moving to the west and the extension between central Aegea and Anatolia.

The validity of this model can be tested by increasing the time resolution of two key processes: the Anatolian plateau uplift, which should directly be related to break-off of the slab, and the rollback rate of the Hellenic trench, which is expected to rapidly speed-up from the Late Neogene-onward.

6. Conclusion

We described in three main steps the Neogene–Quaternary tectonic evolution of the Aegea–Anatolia–Arabia–Africa circuit. We illustrate that the tectonic scenario prior to the formation of the NAF was dominated by the collision in the Bitlis-Zagros area and by extension in the Aegean region from at least the Upper Oligocene. We remark that the formation of the NAF is accompanied or slightly preceded by the uplift of the Turkish–Iranian plateau, by a surge of volcanism in the collisional zone and by an acceleration of the slab retreat along the Hellenic trench. Inspection of tomographic images show that deep slab is detached from its upper portion beneath the Bitlis-Zagros collisional belt and that the rupture can be prolonged to the west at least till Cyprus and probably till the Hellenic trench. We performed a 3D experimental model at the scale of the upper mantle to investigate the evolution of the lateral transition zone from collision to subduction in case the slab beneath the collision zone breaks.

The integration of these different sources of data suggests that the ultimate cause for the plate re-organization of the area and the formation of the NAF is related to the break-off of the slab beneath the Bitlis-Zagros collisional belt. This mechanism, tested by simple analogue experiments, is able to explain the increasing velocity of the Arabia indentation and of slab retreat along the Hellenic trench. This, in turn, creates the conditions triggering the lateral escape of Anatolia away from the collisional belt towards the retreating trench and the formation of the NAF.

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