Late Palaeozoic-Neogene sedimentary and tectonic development of the Tauride continent and adjacent Tethyan ocean basins in eastern Turkey: New data and integrated interpretation

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Late Palaeozoic-Neogene sedimentary and tectonic development of the Tauride continent and adjacent Tethyan ocean basins in eastern Turkey: new data and integrated interpretation

--Manuscript Draft--

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	Osman Parlak
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	Kemal Taslı
	Paulian Dumitrica
Abstract:	The eastern Taurus exemplifies continental rifting, passive margin development, Late Cretaceous melange genesis and ophiolite emplacement. Following Triassic rifting, a carbonate platform developed near sea level in the south (Munzur unit), whereas its northern extension (Neritic-pelagic unit) subsided into deep water during Late Jurassic-Late Cretaceous. Triassic-Cretaceous deep-water sediments and volcanics restore as distal deep-water slope/base of slope units. Jurassic-Cretaceous basic volcanics, interbedded with pelagic sediments, represent emplaced oceanic seamounts. Supra-subduction zone ophiolites formed to the north (c. 93 Ma), probably within an Inner Tauride ocean, and were emplaced southwards by trench-margin collision during latest Cretaceous (c. 75-66 Ma). The margin underwent flexural uplift/erosion and then subsidence/foredeep-infill. Part of the Tauride continent in the south (Malatya Metamorphics) deeply underthrust/subducted northwards, then exhumed rapidly by the late Maastrichtian (c. 65 Ma). To the south, oceanic lithosphere (e.g. Göksun ophiolite) was thrust northward beneath Tauride (Malatya) crust from a more southerly oceanic basin (Berit ocean), and intruded by Late Cretaceous subduction-related granitic rocks (88-82 Ma). Allochthonous units were assembled during the latest Cretaceous, followed by thick-skinned folding/thrusting, generally southwards, related to regional collision tectonics during Mid-Late Eocene. Part of the unmetamorphosed Tauride platform and its over-riding Late Cretaceous allochthon were apparently displaced >60 km northeastwards. Mid-Late Miocene regional collision drove variable folding and re-thrusting, in places northwards during the Eocene. Regional comparisons suggest that the Tauride carbonate platform (Geyik Dağ) narrowed eastwards, and that the palaeogeography of the E Taurides differed from farther west and this, in turn, influenced late Mesozoic-Cenozoic structural development.
Suggested Reviewers:	Istvan Dunkl Göttingen Academy of Sciences and Humanities: Akademie der Wissenschaften zu Gottingen istvan.dunkl@geo.uni-goettingen.de Current, experienced international researcher in Taurides geology
	Tim Kusky Wuhan University of Science and Technology tkusky@gmail.com Experienced current researcher on Tauride geology
	Yener Eyeboğlu Karadeniz Teknik Universitesi yenereyuboglu@gmail.com

	Current Turkish expert on Tauride geology
	Tamer Duman Fujiro Consulting, Ankara duman.tamer@gmail.com Long-term expert on Tauride geology and tectonics with MTA (geological survey) who recently moved to a consulting company
	Dov Avigad Hebrew University of Jerusalem Faculty of Science dov.avigad@mail.huji.ac.il
	Demir Altıner Middle East Technical University, Ankara demir@metu.edu.tr Longstanding Turkish expert on the stratigraphy and tectonics of Turkey including the Taurides.
Opposed Reviewers:	

Dear Ibrahim,

Thanks for your assistance. We have now uploaded a further revised version of our paper. We carried out the following minor revisions:

1- Please revise the highlights. Each highlight should be full-sentence and indicate the novel conclusion of your study (max 85 characters including spaces). Now provided.
2- Please write in full the author names and surnames. Now done
3- Please homogenize the font type of the text (I realized that somewhere in the text you used different font type). Now done (globally).
4- Would you please check the lines 849-851? I was not able to understand the statement very well (this would be due to my poor English). You were correct. It is now in two sentences.
5- I would recommend adding coordinates to your maps; this may help a lot to researchers who will do a further research on the locations you studied.
   We have done this (thanks to the skill of Timur Ustaömer).
6- It would be nice if you ask your co-authors to read the final version of the paper to avoid any misspelling errors etc. Although the revised paper is very well-written, there might be some errors in the text/figures/tables (for example on Fig. 24; please correct "lisvanites" to "listvaenites".
   We corrected the spelling as suggested (I two figures). Myself, Osman Parlak and Timur Ustaömer rechecked the figures and we made some minor corrections and improvements. The text was also rechecked and some minor re-editing was carried out (but no scientific changes or additions).

We hope that you will now find our paper acceptable.

Many thanks for your help and advice,

Best regards,

Alastair Robertson and co-authors

Author agreement

All of the authors have participated in this research, and are aware of and have agreed to the submission of this paper.

Research Highlights

Multidisciplinary data allow a new interpretation of a key Tethyan region in E Turkey.
Late Palaeozoic-Mesozoic rifting and passive margin development is exemplified.
Ophiolite, melange and continental margin emplacement are explained.
Stratigraphical evidence is given for latest Cretaceous metamorphic rock exhumation.
Tectonic models are tested related to the Inner Tauride ocean.

Detailed Response to reviewers

Reviewer #1:

1. Several of the Figures have 12 photos or microphotos, which makes individual photos largely unreadable (e.g., Figs. 4, 6, 20). It will be better to have nien or even less well-chosen photos per individual Figure. Please reduce the number of photos per Figure.

Reply. We have carefully considered this request. We think the problem is that the converted PDF for review is low-resolution and indeed does not show all the details of the images. However, on the high-resolution published version there should be no problem to see all the details. The images have been carefully chosen from a large available set, cropped and image processed so that key features are highlighted. Recent previous papers by largely the same authors in JAES and Sedimentary Geology have used exactly same grouped format without adverse comment from the reviewers of the editors (indeed we have been encouraged to group images to save space). Each one illustrates a feature mentioned in the text (one photograph was deleted when two figures were combined). We therefore propose to retain the present format as the photographs are central to the text (as laid out they are economical in space; readers can easily enlarge the PDFs is they to see more details).

2. In the geological map in Fig. 2, please indicate the Figure numbers of the subareas
We considered this but adding these numbers would confuse with the Areas labelled and other information (now increased). Instead in the text we refer many times to the sub-areas which are labelled on Fig. 2. The reader can thus easily see the location.

3. The type of faults in Fig. 2 should all be marked (strike-slip, thrust or normal).
This is now done.

4. It will be useful to include a regional cross-section for the map in Fig. 2.
Yes, One is now added below the map on Fig. 2.

5. On line 158 it is stated:
"Precambrian sediments (Emirgazi Formation), Cambrian shelf siliciclastics (Feke Quartzites), carbonates and some volcanics (Çal Tepe Formation),…"
As far as I know, there are no volcanic rocks in the Çal Tepe Formation, please check.

True, this was corrected.

6. İzmir-Ankara-Erzincan suture is not correctly drawn in central Anatolia in Fig. 1. The region marked as "Ankara Melange" includes mostly Pontide sequences.
True, now revised.

7. The microphotos in Fig. 6 need labeling, and the scale bar is most likely incorrect - it is unlikely that all these rocks are so coarse grained.
OK, now corrrected. Thanks. Scale bar is correct; coarse-grained sandstones were slected to show lithoclasts.

8. Please correct -. 101 - scale of Gohen et al. (2020).
Corrected

Reviewer #2:
Except that it is quite long, the paper reads well, and I noted only some small minor formal changes (see attached ms). In addition, numerous stratigraphic and sedimentological (including palaeontological) data are provided, which adds significantly on previous knowledge. The discussion and reasoning are generally well written.
Reply: Thanks, the 'minor formal changes' listed on the attached MS have all been made (see below).

The major problems lie in the structural sketches, geological maps and cross-sections (problems of topography, basic structural relationships, see on attached file), that should be enhanced for the comprehension of the structural relationships and tectonic history.
Reply: The specific comments refer to three of the maps. Changes and corrections have been made (see also explanation below).

Especially the general interpretation figure (Fig 28), which I failed totally to understand, should be enhanced. It is a shame because in my opinion the paper will miss to convince and help clarify the tectonic evolution of that sector. The authors should re-draft it taking into account a more realistic geometry of tectonic blocks, shape of oceans, etc...
Reply: This diagram shows alternatives published before. It is not essential and so was deleted to save space (the reader can refer to the published works if interested).

For the integration of previous works, some things are missing (see attached doc). Notably, Age data when they are available.

Reply: We have noted these points and e.g. the additional age data are now added with supporting references (and the references to the Rolland et al. group).

Considering the discussion section, here are several problems that should be adressed (or clarified), which could enhance the insights on a wider regional scale:

-1. The ophiolite obduction occurred on a long distance. Apart from the Kirshehir Block there is no evidence of any suture zone within the whole E Anatolia until the Izmir Ankara Suture. The age of metamorphic sole below ophiolites is very similar in all the region, so there should be one obduction coming from the north (the Kirshehir block is only in the W part). I do not quite understand the arguments used to disqualify the 'northern ophiolite origin' and of one main obduction. The arguments based on ophiolite transport direction that is from N-> S do not disagree with a main northern origin. The fact that no suture-zone rocks like HP rocks etc is observed in between is a major problem for defining a suture. The fact that ophiolites have different ages (C vs. J) can be explained by the size of the obducted sequence. Part of the explanation on the age could also be that amphibole from the gabbro close to the base of the ophiolite recrystallized during obduction ... (so some 'Cretaceous' ophiolites could be jurassic). The observation of a passive margin deepening towards the north is also in agreement with a N origin, etc... you should also take into account that the TIME of emplacement is the same for all E Anatolia ophiolites (except for the southern maden etc ophiolites), and that is quite hard to make these two obductions occurred at the same time...

Reply. We agree that there is no suture zone between S and N ophiolites in E Anatolia and that they were all emplaced generally from N to S. Therefore, taking the evidence from this region alone a northerly origin as one oceanic system can’t be ruled out. However, we do not think that the radiometrically dated ophiolites in E Taurides are wrongly dated Jurassic ones (we include references to the age data). The E Anatolian ophiolites (e.g. Pinarbaşı and Divriği ophiolites) correlate laterally to the west with e.g. the Aladağ, Alihoca (PozantI-Karsantı ophiolites, which structurally overlie blueschist facies rock of the Bolkar nappe (Afyon zone) and lie to the south of the Niğde-Kırşehir massif which has not undergone such HP-LP metamorphism. Many authors (e.g. Okay et al., Pourteau et al.) have inferred that the Anatolide HP-LT metamorphic rocks represent a suture zone, related to closure of the Inner Tauride ocean. It is true that the metamorphic soles of the N vs. S ophiolites give similar ages. However, this could be explained by rapid on-going subduction-related contraction affecting a wide area. The information we give in this paper cannot fully distinguish between the alternative models of ophiolite genesis and emplacement (nor was it intended to do so). However, we have revised our discussion and summary of the tectonic alternatives taking into account the points made by reviewer 2, supported by additional references (please see also below).

-2. One major problem is the ophiolite thickness that you show to be very thin in many places, as is generally observed, so there is a need for a thinning process of the obducted lithosphere section (A <1-km thick ophiolite does not travel for long on continental crust... our group published several papers on that topic that should not be avoided (cf Hassig et al., 2016, terra nova, j. of Geody....)), which matches very well with the extensional core complexe phase that we described in NE Anatolia (see also Rolland et al., 2020, Geosc Frontiers). There, HT metamorphism at 80+/- 3 Ma was followed by rapid exhumation below a top-to-the-North detachment sealed by the Early Maastrichtian unconformity (ca. 70.6 Ma), which is ascribed to extension and thinning of the ophiolite. You also seem to describe a similar post-obduction extension here (on top of the Goskun ophiolite and on Malatya. However, its significance still lies unclear, so I think you should at least discuss themodel proposed in this paper.

Reply. This is indeed an interesting interpretation and a potentially valid way to explain why some of the ophiolites (e.g. Divriği) are relatively thin. Unfortunately, so far there have been no detailed structural studies on any on the E Anatolian ophiolites which could test this hypothesis. Also, we are the southern end of the inferred extensional collapse and so the evidence could be unclear there. However, published estimates suggest the Pınarbaşı and Divriği ophiolites in particular could be quite thick (c. 5 km). We now mention (and cite) this copllapse hypothesis, which could be tested by future work. However, this is still not our preferred interpretation.

On figure 30 I see the melange reworking ophiolite fragments, but where is the ophiolite?
Reply; the related maps show that ophiolites are exposed to the north and as such are a suitable source area. However, there is no field evidence that the ophiolite reached far to the south; only melange emplaced into a Late Cretaceous flexural foredeep is seen there.

Fig. 33. You propose several phases of thrusting on the same structure. It is OK when a deeper rock thrust over a more superficial one, however, it seems the final deformation phase could be accommodated on other structures, it is probably related to the hard collision phase (see Cowgill et al. tectonics 2016). How does that Eocene compressional deformation not produce any folding in the upper unit? Note also that Rolland et al., 2012 described collisional deformation also in the Eocene at the base of Puturge unit (dated by Ar/ Ar on amphibole at 48 /- 0.8 Ma). further, this figure looks somehow strange because the same surface is first an unconformity, becomes a thrust, then a detachment and ends up again to be an unconformity before being reactivated again by a thrust... Is this realistic? Any alternatives?
Reply: the arrows should indicate the Eocene convergence was thick skinned not focussed on the former detachment. Eocene folding is seen in places. We cannot be sure how exactly the Eocene thrusting was accommodated because there is little overlying Eocene sedimentary cover

in this area. We know the Malatya/Keban metamorphics were exhumed (extension) and later overthrust by allochthonous Mesozoic, presumably related to Eocene convergence. The Cowgill et al. 2016 paper has been checked and the wording here has been slightly revised to emphasise that the Eocene and Miocene convergence events are collision-related. However, we decided to delete this paper to save space as it is not essential.

Check: There is a problem in the order of figure numbers and captions (they do not match). Thanks for noting this; figures were checked for number and order (now revised).

Reviewer 2 Comments in stickie notes on PDF

l. 56 Reference added as requested:

Rolland, Y., Hässig, M., Bosch, D., Bruguier, O., Melis, R., Galoyan, G., ... & Sosson, M. (2020). The East Anatolia–Lesser Caucasus ophiolite: An exceptional case of large-scale obduction, synthesis of data and numerical modelling. Geoscience Frontiers, 11(1), 83-108.

l. 60 Reference added as requested:

Hässig, M. Y. M. M., Rolland, Y., Sosson, M., 2017. From seafloor spreading to obduction: Jurassic–Cretaceous evolution of the northern branch of the Neotethys in the Northeastern Anatolian and Lesser Caucasus regions. Geological society, London, special publications, 428(1), 41-60.

l. 68 Reference added as requested:

Hässig, M., Rolland, Y., Duretz, T., & Sosson, M. (2016b). Obduction triggered by regional heating during plate reorganization. Terra Nova, 28(1), 76-82.

l. 84 a ' unique combination of palaeogeographic and tectonic features.'

*Reviewer 2 'Q*ualitative. Explain the specificity of the region.'

We now hint at this here by adding: 'The palaeogeography differs significantly from that of the central and western Taurides. Also, the structural development, while showing many common features with areas further west, has some specific features especially the contrasting Eocene deformation.' We also emphasise the specificity in the Discussion and Conclusions.

*l. 92 '*sedimentary petrographic' Deleted as suggested.

l. 101 'In this paper, we use the time scale of Gohen et al. (2020).' Comment 'A little bit out of place'

Reply: Now relocated.

l. 111 provide informations on datings of Malatya Rolland et al. (2012) : 78.7 +/- 1 Ma and 81.8 +/- O.6 Ma Ar-Ar on Hbd

Reply-now added and cited.

l. 125 suggested rewording 'by two main and temporally distinct sedimentary basin successions'... is now edited in with minor addition.

l. 139 'relatively allochthonous' is now changed to simply, 'allochthonous.'

l. 200 'the Malatya Metamorphics (the type area; S of Elbistan)'

provide informations on datings of Malatya Rolland et al. (2012) : 73.8 +/- 0.3 Ma

Reply-now added and cited.

l 1259 add 'to lower amphibolite facies...

(cite also Rolland et al., 2012 here'

-Reply Now done

l. 1377 'However, these units are separated, structurally by the Göksun and related ophiolites, which might be explained by strike-slip displacement after the Late Cretaceous but evidence for this is lacking.'

Reply-This option is removed (no evidence either way).

Reply-or alternatively a back-arc basin related to slab roll-back (Rolland et al., 2012)

This option is now cited.

l. 1377 add Rolland et al., 2012; done

-Reply Now done

l 1381 please also provide time constrains for HP metamorphism 70.7+/- 0.3 Ma (Ar-Ar phengite), Rolland et al., 2012.

-Reply Now done

Figures

Fig. 5 cross-sections are misplaced/ do not cross the same units? Topography could be more realistic.

Reply: The lines of sections have been slightly corrected and made bolder to show the correct units. These are intended to show sedimentary and structural relationships; in fact they are rock-relations diagrams rather than true-scale sections. The captions have been changed to say rock-relations diagrams rather than sections. A true-scale section is now included in Fig. 2.

Fig. 8 section c 'put in conformity the shape of blocks and the stripped lines

OK: revised

Fig. 9 this rectilinear vertical fault geometry is not suggested by the map.

Reply: It is OK; the map contact is linear like a steep fault.

Are you sure it cross-cuts the bedding like that? It should be a late fault (later than thrusts), but the map shows it as ante- and post- regarding the N- and S- thrusts of the map.

Reply: The high-angle fault fits OK with the cross-cutting map relations. Limits of access and outcrop make it difficult to know the angle of dip of this fault at the surface. However, it was mapped by MTA as a cross-cutting feature, likely as a post-thrust strike-slip fault.

Fig. 9' The fold structure is dissected by the thrust? This structure looks weard'

Reply: On checking photographs this bedding orientation is uncertain so this was changed to a more expected fabric. However, the fold in B is indeed truncated as ahown.

Fig. 28 what is here in the north? Ocean? why suture zone then?

Reply: This whole figure is now deleted as not essential.

Fig. 30 I do not understand here, if this were a thrust, there would be older rocks on top of younger ones. Here you just have a ‚normal succession…. Essentially lacking is the obduction that is thrusted on a large distance and, hence the ophiolite on top of the mélange. Afterwards, the obducted sheet has been significantly thinned out by the extension?

Reply: This whole figure is now deleted as not essential.

Main deletions (to shorten the text)

Section 2 deleted because it is covered before and after adds little (Reference to Cohen et al., was moved);

l. 196-202. ‘ Below, we work upwards through the regional tectono-stratigraphy, beginning with the Gürün autochthon, followed by the Malatya Metamorphics, and then by the allochthonous Tauride units including melanges and ophiolites. For each major tectono-stratigraphic unit, existing evidence is summarised, followed by presentation of new data (where available), and a local interpretation. The mutual relationships of the major tectono-stratigraphic units is considered in the wider regional context, including the central and western Taurides in the discussion section of the paper.’

l. 202-205 ‘Our observations and interpretations are supported by geological maps and local cross-sections of each of the above five sub-areas, together with sedimentary logs, field photographs and photomicrographs. Additional illustrations are included in the Supplementary material.’

l. 780-790 ‘Using the same name for this deep-sea succession as the Gülbahar Nappe in the western Taurides is potentially misleading for several reasons: (1) Unlike the western Taurides, there is no intact, regionally extensive, nappe in the Eastern Taurides, but instead, there are isolated outcrops of small thrust slices, broken formation and/or blocks. (2) The restored succession is not identical to the Gülbahar Nappe in the western Taurides, which, for example, includes long, intact Triassic volcanic successions (e.g. Turunç unit) (Şenel et al., 1989; Collins and Robertson, 1998; Sayıt et al., 2015) that are not known in the eastern Taurides (although some Triassic volcanics exists; see below); (3) Identical palaeogeographic settings cannot be assumed give the widely separated occurrences (c. 1000 km apart).'

'l. 1046-51 In places, the uppermost exposed Malatya (Keban) Metamorphics are associated with calc-mylonites, suggesting intense shearing prior to formation of the Kemaliye Formation unconformably above. The unmetamorphosed Kemaliye Formation contrasts with the Karaböğürtlen Formation, which is part of the intact succession of the Malatya Metamorphics.'

l. 1130 -1140. 'in the following respects: (1) The sediments overlie unmetamorphosed carbonate platform units, whereas the type Kemaliye Formation overlies the Malatya Metamorphics (see above); (2) The sediments are dominated by talus derived from the unmetamorphosed carbonate platform beneath (see below), whereas much of the siliciclastic material in the type Kemaliye area is metamorphic, derived from the Malatya (Keban) Metamorphics; (3) The type area Kemaliye Formation is composite, with several different tectono-stratigraphic elements (e.g. debris-flow deposits; Triassic basalts; serpentinite). However, a more coherent, although variably deformed, sedimentary succession is exposed within the Munzur and Köseyahya thrust sheets. The upper levels of the Kemaliye Formation succession are intercalated with tectonic slices and blocks of other units (e.g. neritic shelf limestone).'

Also Fig. 23 (photos combined with another figure or deleted).

l. '1348 ahead of advancing Tauride allochthons, including carbonate platform, slope, basin and ophiolitic rocks…. Some of neritic blocks and slices can be correlated with the limestone successions of the over-riding Munzur and/or Köseyahya thrust sheets.'

l. 1695-1698 'The more northerly-formed platform slope lithologies (Pelagic (Gülbahar) unit) were detached and bulldozed southwards, in places, putting the ophiolite directly above the neritic carbonate platform.'

'1706-1712 Farther south, the Munzur and Köseyahya platforms subsided and were covered by the Kemaliye Formation, probably contemporaneously. The scattering of blocks and dismembered thrust sheets of the Pelagic (Gülbahar) unit, and also of ophiolitic rocks, suggests that these lithologies were emplaced by gravity sliding into the distal (southerly) part of the foredeep. Munzur and Köseyahya-derived thrust sheets, broken formation and limestone blocks were then emplaced above.'

l. 1918 ‘Below, we discuss and interpret the mutual relationships of the main tectonic units in the region studied (Fig. 2)’.

l. 1964 ‘The two units are separated by debris-flow units, correlated with the Kemaliye Formation, that include ophiolitic rocks and radiolarian chert.’

l. 2003 ‘This unit could be a fragment of the Gürün autochthon that was detached, probably during the regional Mid-Late Eocene emplacement event’

l. deleted 2118 ‘However, the right-lateral displacement appears to pre-date some, or all, of the dominantly left-lateral displacements related to the regional Sürgü–Misis Fault system.’

l. 2268-2274 ‘Although the western margin of the Darende Basin is, in places, folded and displaced eastwards related to Mid-Late Eocene deformation there is no evidence of deformation within the basin related to regional-scale southward thrusting, together with the underlying Tauride allochthonous units (Booth et al., 2013). Indeed the Eocene sediments are everywhere mapped as being transgressive on the emplaced Mesozoic allochthons (MTA, 2011; Bedi and Yusufoğlu, 2018).’

l. 2295-2299 ‘The Northern and Southern allochthons may therefore represent two different continental margin segments, both with similar allochthonous units in the south (i.e. Munzur and Neritic-pelagic (Köseyahya) thrust sheets, and also ophiolites and related melanges in the north.’

Deleted Fig. 28 as the text is adequate to state the alternatives; two of the three options are illustrated by Robertson et al. 2013c.

l. 2423 ‘The inferred latest Cretaceous extensional detachment, the Kemaliye Formation and the basal thrust of the over-riding Mesozoic platform/slope units were re-activated by compressional deformation during the Mid-Late Eocene, as seen in the south (Area 3B, Nurhak Dağı) (Fig. 30c)’

l. 2427 These crustal units are restored as the northern part of the Tauride continent and its northward-facing, rifted passive margin (> 150 km wide)

l. 3532 ‘The Neritic-pelagic succession is, therefore, restored to the north of the Neritic (Munzur) succession in both the Southern and Northern allochthons’

l. 2565 ‘This also explains the intense internal deformation within the Neritic-pelagic (Köseyahya) thrust sheet compared to the main Munzur thrust sheet’.

l. 2927 ‘During latest Cretaceous emplacement, the upper stratigraphic levels of the distal, northerly part of the neritic platform were detached and bulldozed towards the foredeep. As

as result, the platform is directly over-ridden by or over-ridden, such that the proximal foredeep was directly juxtaposed with the over-riding ophiolite (Divriği melange) in places'.
l. 2457 'The platform potentially stepped northwards along transcurrent faults that were re-activated as major c. N-S neotectonic strike-slip faults'
l. 2458 'The distinctive Gürün curl structure is attributed, mainly to the combined effects of a changed palaeogeography eastwards and late Miocene post-suture oblique contraction.
-While the neotectonic deformation of the region was dominated by left-lateral strike-slip related to the westward tectonic escape of Anatolia, a localised c. NE-SW to ENE-WSW lineament (Göksu fault zone) of dominantly right-lateral displacement appears to predated this westward displacement.....The distinctive Gürün curl structure is attributed, mainly to the combined effects of a changed palaeogeography eastwards and late Miocene post-suture oblique contraction.
On the other hand, some small sections have been added to answer queries and the Discussion is partly re-written in response to comments by Reviewer 2 (please see MS with red lettering).

Dear Ibrahim,

Thanks for your assistance. We have now uploaded a further revised version of our paper. We carried out the following minor revisions:

1- Please revise the highlights. Each highlight should be full-sentence and indicate the novel conclusion of your study (max 85 characters including spaces). Now provided.
2- Please write in full the author names and surnames. Now done
3- Please homogenize the font type of the text (I realized that somewhere in the text you used different font type). Now done (globally).
4- Would you please check the lines 849-851? I was not able to understand the statement very well (this would be due to my poor English). You were correct. It is now in two sentences.
5- I would recommend adding coordinates to your maps; this may help a lot to researchers who will do a further research on the locations you studied.
   We have done this (thanks to the skill of Timur Ustaömer).
6- It would be nice if you ask your co-authors to read the final version of the paper to avoid any misspelling errors etc. Although the revised paper is very well-written, there might be some errors in the text/figures/tables (for example on Fig. 24; please correct "lisvanites" to "listvaenites".
   We corrected the spelling as suggested (I two figures). Myself, Osman Parlak and Timur Ustaömer rechecked the figures and we made some minor corrections and improvements.
   The text was also rechecked and spelling and punctuation errors were corrected. A paragraph (marked in red) in the Discussion was relocated to improve the flow; also the Conclusions were streamlined (also marked in red), but no scientific changes or additions were made.

We hope that you will now find our paper acceptable.

Many thanks for your help and advice,

Best regards,

Alastair Robertson and co-authors

Late Palaeozoic-Neogene sedimentary and tectonic development of the Tauride continent and adjacent Tethyan ocean basins in eastern Turkey: new data and integrated interpretation

Alastair Harry Forbes Robertson[1], Osman Parlak[2], Timur Ustaömer [3], Kemal Taslı[4], Paulian Dumitrica[5]

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Abstract

The eastern Taurus exemplifies continental rifting, passive margin development, Late Cretaceous melange genesis and ophiolite emplacement. Following Triassic rifting, a carbonate platform developed near sea level in the south (Munzur unit), whereas its northern extension (Neritic-pelagic unit) subsided into deep water during Late Jurassic-Late Cretaceous. Triassic-Cretaceous deep-water sediments and volcanics restore as distal deep-water slope/base of slope units. Jurassic-Cretaceous basic volcanics, interbedded with pelagic sediments, represent emplaced oceanic seamounts. Supra-subduction zone ophiolites formed to the north (c. 93 Ma), probably within an Inner Tauride ocean, and were emplaced southwards by trench-margin collision during latest Cretaceous (c. 75-66 Ma). The margin underwent flexural uplift/erosion and then subsidence/foredeep-infill. Part of the Tauride continent in the south (Malatya Metamorphics) deeply underthrust/subducted northwards, then exhumed rapidly by the late Maastrichtian (c. 65 Ma). To the south, oceanic lithosphere (e.g. Göksun ophiolite) was thrust northward beneath Tauride (Malatya) crust from a more southerly oceanic basin (Berit ocean), and intruded by Late Cretaceous subduction-related granitic rocks (88-82 Ma). Allochthonous units were assembled during the latest Cretaceous, followed by thick-skinned folding/thrusting, generally southwards, related to regional collision tectonics during Mid-Late Eocene. Part of the unmetamorphosed Tauride platform and its over-riding Late Cretaceous allochthon were apparently displaced >60 km northeastwards. Mid-Late Miocene regional collision drove variable folding and re-thrusting, in places northwards. Regional comparisons suggest that the Tauride carbonate platform (Geyik Dağ) narrowed eastwards, such that the palaeogeography of the E Taurides differed from farther west, influencing the late Mesozoic-Cenozoic structural development.

Key words: E Anatolia, Tethys, palaeogeography, tectonics, ophiolites, melange, deep-sea sediments

1. Introduction

The geological development of Tethys within and around Anatolia remains of current interest, with several alternative tectonic models being recently proposed (Moix et al., 2008; Robertson et al., 2012, 2013a; Rolland et al., 2012, 2020; Maffione et al., 2017; Parlak et al., 2019; Hinsbergen et al., 2020). In addition to ophiolites, continental margin units and melanges need to be taken into account. The Taurides represent a key part of Anatolia (Fig. 1), where ophiolites were emplaced onto a regional-scale carbonate platform during latest Cretaceous time (Juteau, l980; Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Ricou et al.,1984; Dilek and Moores, 1990; Robertson, 2002; Parlak, 2016; Barrier et al., 2018). There have been several attempts to explain the emplacement of the ophiolites and related continental margin units as a whole in the western Taurides (Hayward and Robertson, 1982; Woodcock and Robertson, l982; Yılmaz and Maxwell, l984; Şenel, l984; Marcoux et al., 1989; Collins and Robertson, 1998), in the central Taurides (Demirtaşlı et al., 1984; Özgül, l997; Dilek and Whitney, l997; Andrew and Robertson, 2002; Parlak and Robertson, 2004; McPhee et al., 2018a), and also in the eastern Taurides (Yılmaz, 1993; Yılmaz et al., 1993, Robertson et al., 2006, 2007, Robertson et al., 2013a b; Rolland et al., 2012, 2020).

The ophiolites, melanges and related continental units of the İzmir-Ankara-Erzincan (northern Neotethyan) suture zone in the Eastern Turkey have also received a considerable amount of attention in recent years (e.g., Yılmaz et al., 1997; Okay and Şahintürk, 1997; Rice et al., 2009; Ustaömer and Robertson, 2010, 2013; Robertson et al., 2013c; Topuz et al., 2013a, b; Rolland et al., 2012, 2020; Hässig et al., 2013, 2017). However, there have been few integrated studies that focus on the carbonate platforms, slope/basin facies and the related melange units in the Eastern Taurides (Fig. 2). These units are located in a critical position between the Arabian Platform (African plate) to the south and the Pontides (Eurasian plate) to the north. The eastern Tauride region has some distinctive features, notably an extraordinary NE-verging fold-like structure, up to 200 km long x 250 km wide (MTA, 2011), termed the Gürün curl after a town in the core of this structure (Lefebvre et al., 2013a) (Fig. 2; Supplementary Fig. 1). Is this a primary palaeogeographic feature, or related to tectonic emplacement, or to some combination of both?

A synthesis of the Tethyan geology of the Eastern Taurides is given here, utilising a combination of new data and also the available literature on this region (Perinçek and Kozlu, 1984; Robertson et al., 2013b; Bedi et al., 2004, 2005; Bedi and Yusufoğlu, 2018). The region studied includes a Late Palaeozoic-Mesozoic metamorphosed carbonate platform, an unmetamorphosed carbonate platform and deeper-water marginal units, several types of melange, and also Late Cretaceous ophiolites with their metamorphic soles. Latest Cretaceous-Miocene cover successions help to constrain the distribution and timing of tectonic events, especially the exhumation of the metamorphic rocks. The assembled information will be used to test alternative tectonic models for the wider region (Kozlu et al., 1990; Robertson et al., 2013a, b; Barrier et al., 2018; van Hinsbergen et al., 2020; Rolland et al., 2012, 2020). We will demonstrate that the geology of eastern Anatolia represents a unique combination of palaeogeographic and tectonic features. The palaeogeography differs significantly from that of the central and western Taurides. Also, the Late Cretaceous ophiolites and related melange units differ significantly from Jurassic counterparts farther north in the E Pontide-Lesser Caucasus region.

In this paper, we use the time scale of Cohen et al. (2020).

2. Regional tectono-stratigraphy

We utilise a modified version of the tectono-stratigraphy based on mapping by the Turkish Petroleum Company (TPAO) (Perinçek and Kozlu, 1984), including changes and additions based on mapping by the Maden Tektik ve Arama (MTA) (Bedi et al., 2009; Bedi and Yusufoğlu, 2018), related studies (Robertson et al., 2013b) and this work.

Moving northwards, the Arabian platform is tectonically overlain by a Miocene imbricate thrust belt, with, to the north of this, the Bitlis and Pütürge allochthonous continental units (Yılmaz, 1993; Yılmaz et al., 1993; Yazgan, 1984) (Fig. 1). These units are tectonically overlain by Late Cretaceous ophiolitic rocks, variously known as the Göksun (Berit), Kömürhan, İspendere or Yüksekova ophiolites. Our study effectively begins in the south with the Late Palaeozoic-Mesozoic Malatya Metamorphics (including the Keban and Binboğa metamorphic rocks; see below). To the north, these metamorphic rocks are over-ridden by allochthonous, unmetamorphosed Tauride carbonate platform, melanges and ophiolitic units. The allochthonous outcrop in the west of the region is split into two parts, termed the Northern and the Southern allochthon (Robertson et al., 2013b). Both the Northern and the Southern allochthon include emplaced thrust sheets of Mesozoic carbonate platform, slope and deeper-water facies, melanges and ophiolitic rocks. The relationships between the two allochthonous assemblages is debatable as they are separated by a relatively autochthonous Tauride platform succession, termed the Gürün autochthon (Kozlu et al., 1990; Atabey, 1993; Atabey et al., 1994, 1997; Robertson et al., 2013b) (Fig. 2).

The Mesozoic-Paleogene units within our study area are unconformably overlain by two geographically and temporarily distinct types of sedimentary basin. The first is represented by latest Cretaceous-latest Eocene basins, including the Darende, Hekimhan and Malatya basins; the second comprises Neogene-Recent sediments (Salyan Formation) and volcanics (Kepezdağ volcanics), notably within the Afşin-Elbistan basin, the Pınarbaşı-Kangal basin and the upper part of the large Malatya basin (Fig. 2). The area is dissected by through-going neotectonic faults, principally the westward-curving Sürgü-Misis Fault (Duman and Emre, 2013), and also three main NNE-SSW-trending faults, the Sarız, Gürün and Malatya-Ovacık faults. Of the latter, by far the largest is the Malatya-Ovacık fault, which is estimated to have accommodated 29 km of left-lateral movement (Fig. 2) (Westaway and Arger, 2001; Kaymakçı et al., 2006; Sancar et al., 2019). In addition, part of the area is transected by lesser known, c. SSW-NNE to SW-NE trending faults (Göksu faults of Kozlu et al., 1990) that are important because they straddle the contact between the Gürün autochthon and the Southern allochthon (Robertson et al., 2013b)

To facilitate description and interpretation, we subdivide our study region into 5 sub-areas (Fig. 2). *Area 1,* NW of Elbistan (Afşin); *Area 2,* Dağlıca; *Area 3,* E of Elbistan (subdivided into *Area 3A* in the west and *Area 3B* (Nurhak Dağı) in the east; *Area 4,* S of Elbistan, and finally, Divriği-Kemaliye in the north-east (subdivided into *Area 5A*, Kemaliye and *Area 5B,* Divriği farther north).

3. Tauride carbonate platform

To the SW of our study area (Tufanbeyli-Saimbeyli-Sarız) (Fig. 2), the autochthonous Tauride platform succession encompasses Precambrian sediments (Emirgazi Formation), Cambrian shelf siliciclastics (Feke Quartzites) and mixed carbonate-siliciclastic sediments (Çal Tepe Formation), which are overlain by Ordovician mainly argillaceous and silty shelf sediments (Seydişehir, Bedivan and Halit Yaylası formations) including some glacial deposits. Fine-grained siliciclastic sediments with calcareous intervals (e.g. Nautiloid limestones) dominate the Silurian (Puşçu Tepe Shale and Yukarı Yayla formations). The Devonian is mainly shelf carbonates, with minor basaltic volcanics, including a reef-bearing horizon (Şafak Tepe Formation). The lower interval (Alitepesi Formation) and the upper interval (Gümüşali and Naltaş formations) are relatively quartz rich. Above a quartz-rich base, the Permian is dominated by algal carbonates (Yığılı Tepe Formation) (Özgül et al., 1973; Metin et al., 1986; Kozlu and Göncüoğlu, 1997; Özgül and Kozlu, 2002; Göncüoğlu et al., 2004; Bedi and Usta, 2006; Bedi et al., 2017).

The Palaeozoic succession accumulated on a continental platform, punctuated by unconformities that were probably tectonically influenced; i.e. at the Precambrian-Cambrian boundary (?), the Early-Late Ordovician boundary, the Silurian-Devonian boundary, the Early-Middle Devonian boundary and the Carboniferous-Permian boundary. There was an increased sedimentation rate during the late Carboniferous (Göncüoğlu et al., 2004). This represents a period of enhanced tectonic subsidence that may relate to Variscan collisional orogeny farther west, in the Aegean-Balkan region.

The Mesozoic succession is dominated by shelf carbonates, with stratigraphic breaks that are likely to have been tectonically controlled; i.e. during the Middle Triassic, the Early-Mid Jurassic, the Late Cretaceous (Turonian-Santonian(?)), and the Early Eocene (Kozlu et al., 1990). Devonian to Permian, and locally also Triassic, siliciclastic and carbonate rocks crop out in the northwest of the Gürün autochthon, where they are unconformably overlain by Early Jurassic to Late Cretaceous shelf carbonates. The Cretaceous carbonates pass upwards into Cenozoic facies without a structural break (Özgül et al., 1973). The succession continues with deeper-water (but still shelf-depth) hemipelagic carbonates, siltstones, mudrocks and sparse sandstones, dated as Maastrichtian-Middle Eocene (Lutetian) (Aziz et al., 1982; Perinçek and Kozlu, 1984; Yılmaz et al., 1991, 1994; Atabey, 1995; Robertson et al., 2013b). Locally, Eocene or older sediments in the Gürün autochthon are unconformably overlain by Miocene sediments (e.g. non-marine conglomerates), and also by Plio-Quaternary volcanics and sediments (Perinçek and Kozlu, 1984; MTA, 2011). There is no evidence of any major structural break or suture zone within, or between, the outcrops that extend northeastwards from the Saimbeyli-Tufanbeyli-Sarız region to the Gürün autochthon (MTA, 2011). This whole crustal unit can, therefore, be correlated with the relatively autochthonous Tauride carbonate platform in the central Taurides (Geyik Dağ).

The Jurassic-Cretaceous carbonates accumulated on a gently subsiding shelf, followed by accelerated subsidence that was probably tectonically controlled during the latest Cretaceous and Palaeocene-Early Eocene. There is no evidence of emplacement of any allochthonous units over the Gürün autochthon, at least until the Mid-Late Eocene (Perinçek and Kozlu, l984; Kozlu et al., 1990; Robertson et al., 2013b); this observation is critical to any tectonic reconstruction.

4. Malatya metamorphics

The regionally extensive Late Palaeozoic (Devonian?) to Late Cretaceous Malatya Metamorphics (Figs. 2, 3) are widely exposed in the south of the study area (Karaman et al., 1993; Yılmaz et al., 1991, 1994; MTA, 2011; Bedi and Yusufoğlu, 2018). The outcrops are variously referred to as the Malatya Metamorphics in the type area (S of Elbistan), the Binboğa Metamorphics (NW of the Sürgü-Misis Fault; i.e. west of Afşin) and the Keban Metamorphics (east of the Malatya-Ovacık Fault) (Perinçek and Kozlu, 1984; Bedi et al., 2005, Bedi and Usta, 2006; Kaya, 2016). The Keban Metamorphics have been locally dated (south of Keban Lake) as 73.8±0.3Ma (Campanian) based on ^{40}Ar/^{39}Ar dating of muscovite within fluorite-bearing marble (Rolland et al., 2012). However, it is unclear whether this age is representative of the Malatya Metamorphics as a whole (see below).

The outcrop to the east of the Malatya-Ovacık Fault was recently remapped as three different units, separated by thrusts (Bedi and Yusufoğlu 2018). The first unit, termed the Bodrum nappe (named after a type area in the western Taurides) is a metamorphosed Middle Devonian to Late Cretaceous succession (Fig. 3). The mineral assemblages in this unit (Bodrum nappe) are mainly suggestive of greenschist facies metamorphism (Perinçek and Kozlu, 1984). Local intercalations of basic metavolcanics rock (west of Afşin) are indicative of amphibolite facies conditions (Robertson et al., in press b). However, reported occurrences of glaucophane (Bedi et al., 2009) hint at high pressure-low temperature (HP-LT) metamorphism. The second, structurally overlying, unit is a metamorphosed Carboniferous to Late Cretaceous succession that is exposed SW of Malatya. This is correlated with the Yahyalı nappe, which has its type area further west, near Yahyalı. The Yahyalı nappe in its type area has undergone HP-LT metamorphism, based on the occurrence of carpholite

(Pourteau et al., 2010). Structurally above comes as third unit with a Late Devonian to Late Cretaceous succession, which is correlated with the Aladağ (Hadim) nappe in the central Taurides (Bedi and Yusufoğlu 2018).

The thrust sheets, as summarised above, are intruded by Late Cretaceous arc-type granitoid rocks (Baskil Granitoids). These are mainly I-type, calc-alkaline hornblende-biotite granodiorites and 'normal' granites, with both mantle and crustal-derived chemical features. The granitoid rocks are dated, radiometrically, as 88-82 Ma (Santonian-Campanian) (Parlak, 2006; Yazgan and Chessex, 1991; Rızaoğlu et al., 2009; Karaoğlan et al., 2016). The Malatya Metamorphics are structurally underlain, directly, by the relatively intact Göksun ophiolite (Parlak, 2006; Parlak et al., 2004, 2020), also known in this area as the Berit meta-ophiolite (Genç et al., 1993; Yılmaz et al., 1987; Yılmaz, 1993), the North Berit ophiolite (Robertson et al., 2006), and the Kömürhan ophiolite (Bedi et al., 2005, 2009).

The Malatya Metamorphics (Bodrum nappe) are unconformably overlain by Middle Palaeocene to Middle Eocene shallow-water calcareous sediments (Seske Formation), as exposed near, and to the west of Afşin (Perinçek and Kozlu, l984; Yılmaz et al., 1991, 1994; Robertson et al., 2006) (Fig. 4a). The succession begins with conglomerate, with clasts including schist and marble and then passes upwards into shallow-water limestones, commonly rich in large foraminifera (e.g. *Alveolina* sp.) and ooids (see below).

The protoliths of the Malatya Metamorphics (Bodrum nappe) within our main study area, namely the Binboğa Mountains west of Afşin (Area 1) and the Doğanşehir and Kemaliye areas farther east (Areas 3B, 5A) (Fig. 2), are dated with variable precision, mainly using benthic foraminifera and some small gastropods (Bedi et al., 2005, 2009). The overall succession (Fig. 3) begins with mixed meta-clastic and meta-carbonate rocks (Yoncayolu Formation) that are dated as Middle Devonian-mid Carboniferous. Meta-volcanic rocks (Fig. 4b) and meta-rudites (Fig. 4c) are intercalated in places (Fig. 5 logs 1, 2). Within the Keban metamorphics farther east, basic meta-dykes cut the Late Palaeozoic succession; also, foliated meta-diabase occurs within the upper part of the early Carboniferous (?) succession (Kaya, 2016). Overlying meta-limestones and meta-dolomitic carbonates (Çayderesi Formation) (Fig. 4d) contain a relatively rich, well-dated Late Permian fauna and flora. Above a meta-bauxite, representing a hiatus, calc-schist and meta-carbonate alternations

(Alıçlı Formation) are dated as Early-Mid(?) Triassic (Özgül et al., 1981). Meta-carbonates, commonly dolomitic, of Mid-Triassic to Early Jurassic age, follow above this (Kayaköy Formation) (Figs. 5 log 2, 4e). The succession passes upwards into shelf carbonates, with common nodular chert of diagenetic replacement origin (Ulu Formation), dated as Mid-Jurassic and Early Cretaceous. There is then a prominent unconformity, followed by meta-siliceous limestone, meta-mudrock and meta-conglomerate, termed the Karaböğürtlen Formation (Bedi et al., 2005, 2009). This unit is named after a Late Cretaceous chaotic 'blocky flysch' in the western Taurides (Denizli-Burdur area) (Özgül et al., 1981; Şenel et al., 1989).

4.1. Late Cretaceous syn-tectonic sediments

The succession in the Malatya Metamorphics (Bodrum nappe) extends through the Cretaceous in the form of mainly siliceous meta-limestones, meta-mudrocks and subordinate meta-conglomerates (Bedi and Yusufoğlu, 2018). Within Area 1 (east of Afşin), the meta-carbonates are mapped as locally ending in the Triassic (e.g. at Ballık Tepe), or in the Late Permian (e.g. at Abaz Tepe) (Fig. 5 section b) (Bedi et al., 2009). In several sections, the platform carbonate succession ends with an unconformity, marked by fissuring with red iron-oxide infills (Fig. 4f) and an iron-rich layer (up to several cm thick). An intact succession of mixed meta-carbonate and meta-siliciclastic rocks follows above this, with subordinate metadebris-flow deposits (Figs. 4g-i; 5 log 3), representing the Karaböğürtlen Formation. Clasts and blocks of Jurassic-Cretaceous meta-neritic limestone are present, and also, rarely, clasts of metabasalt. The matrix includes abundant monocrystalline and polycrystalline quartz, muscovite, carbonate and, locally, basaltic detritus (Fig. 6a-c). A Late Cretaceous (Cenomanian age) is inferred, at least for the lower part of this formation, based on local occurrences of rudist bivalves (Fig. 4k). Similar metamorphosed rudists occur in the Menderes Massif (Özer, 1998).

Thick-bedded meta-debris-flow deposits (calcirudites) are well exposed in a key section, c. 16 km north of Afşin (3 km S of Tanır) (Fig. 2; also Supplementary Fig. 2), where they include abundant deformed and fragmented recrystallised rudist bivalves. The meta-limestones pass into a thin (1m) interval of green meta-chert, formed by diagenetic replacement of carbonate, followed by reddish-brown meta-conglomerate (several m thick), with abundant rounded pebbles (<10 cm in size) of red radiolarian meta-chert and also meta-limestone (recrystallised), set in a sandy matrix. After further meta-limestone conglomerate, with rounded clasts (<10 cm in size), there is a return to thick-bedded detrital meta-carbonates before the section ends. This section is important as it indicates that relatively deep-water facies (radiolarian cherts) were redeposited onto the Malatya carbonate platform during the Late Cretaceous (see below).

In another key section, c. 20 km to the NW (near İncirli), where the Malatya Metamorphics (Bodrum nappe) are thrust northwards over the Southern allochthon (see below), the Karaböğürtlen Formation (up to 300 m thick) comprises lenses (up to >100 m long by 20 m thick) of medium-thick bedded meta-limestone (marble), alternating with sheared and folded meta-mudrock (phyllite.) Both the blocks and the matrix have undergone similar metamorphism. Near the thrust contact there are marble blocks (tens of cm-to m-sized) within sheared matrix-supported conglomerates (Fig. 4j). This section confirms that the Karaböğürtlen Formation includes meta-debris-flow ('olistostromes') related to Late Cretaceous tectonic instability.

4.2. Interpretation of the Malatya Metamorphics

During Middle Devonian to Carboniferous, the Malatya Metamorphics (Bodrum nappe) accumulated on a mixed carbonate-clastic-depositing shelf, punctuated by tectonic instability, basaltic volcanism and localised mass-flow deposition. Marine transgression characterised the Late Permian, followed by rift-related tectonic instability and subsidence during the Early-Mid Triassic. A relatively stable, gently subsiding carbonate platform developed during the Late Triassic-Cretaceous, deepening during the Early Cretaceous, as suggested by increased chert content. The rudist reefs signify shallowing during the Cenomanian. The carbonate platform was uplifted and variably eroded, in places down to the Late Permian, resulting in a regional unconformity that was capped by metalliferous oxides during a hiatus in deposition. The unconformity was then covered by a Late Cretaceous (but poorly dated), mixed carbonate-siliciclastic succession, including local debris flow-deposits. The siliciclastic detritus, largely derived from metamorphic and plutonic igneous rocks, was probably recycled from the underlying Malatya succession. The well-rounded nature of many of the pebbles, especially meta-chert (Fig. 6a, b) is indicative or reworking in a high-energy shallow-marine or fluvial setting prior to redeposition as debris flows. The pebbly conglomerates with red chert (near Tanır) show that deep-sea material, typical of the Southern allochthon to the north, was redeposited into the subsided Malatya platform.

The Late Cretaceous Karaböğürtlen Formation is interpreted as the proximal (southerly) part of a regional-scale, flexurally-controlled foredeep related to Late Cretaceous emplacement of continental margin and ophiolitic rocks. However, ophiolitic material is absent from the Karaböğürtlen Formation, in contrast to structurally higher units (see Discussion).

The timing of metamorphism of the Malatya Metamorphics is stratigraphically constrained as postdating the youngest deposition (Late Cretaceous (?) Karaböğürtlen Formation) but predating the Eocene sedimentary cover (Seske Formation) (Özgül et al., 1981; Perinçek and Kozlu, 1984; Kozlu et al., 1990; Robertson et al., 2006; Bedi et al., 2009). East of the Malatya-Ovacık Fault, the Keban metamorphics are locally dated radiometrically as 73.8±0.3Ma (Campanian) (Rolland et al., 2012). In this area the metamorphics are unconformably overlain by latest Cretaceous sediments, known as the Gündüzbey Formation, which correlates with the regional Harami Formation (Erdoğan, 1975). The Gündüzbey Formation begins with polymictic conglomerates, followed by sandstone-shale-conglomerate alternations (generally Santonian-Campanian in age) and then shelf carbonates (Campanian-Maastrichtian) (Bedi and Yusufoğlu, 2018). Along the eastern margin of the Malatya basin, the late Cretaceous sediments are unconformably overlain, directly, by Eocene conglomerates, limestones and turbidites (Yeşilyurt Formation) (Bedi et al., 2017; Bedi and Yusufoğlu, 2018). The 88-82 Ma (Santonian-Campanian) Baskil Granitoids that cut the Malatya Metamorphics are inferred to have taken 6–10 Ma to cool below 300 °C, based on ^{39}Ar–^{40}Ar dating of amphibole, biotite and K-feldspar (Karaoğlan et al., 2016).

The Malatya metamorphics as a whole are intruded by the Baskil granites (unmetamorphosed). The long period of time (6-10 Ma) taken to cool below 300^{o} suggests that the granites were intruded into crust with a high heat flow, presumably related to arc magmatism. The U-Pb age (88-83 Ma) of the granitoid intrusions is significantly older than the reported age of metamorphism (73.8±0.3Ma) (Rolland et al., 2012). However, the fluorite-bearing marble that was dated by these authors could represent a late-stage metasomatic event. The Malatya Metamorphics including the granite-bearing units were tectonically imbricated after intrusion (e.g. E of Doğanşehir) (Bedi and Yusufoğlu, 2018), probably during the Eocene.

5. Late Triassic-Late Cretaceous unmetamorphosed platform carbonates

5.1. Neritic thrust sheets

The mainly neritic Munzur thrust sheet (Fig. 2) is equivalent to the Munzur nappe of Özgül et al. (1981) and Bedi et al. (2004, 2009), to the Andırın Limestone of Perinçek and Kozlu (1984) and to the Neritic nappe of Robertson et al. (2013b). Similar successions are exposed in both the Northern allochthon and the Southern allochthon, respectively, to the north and the south of the Gürün autochthon (Fig. 2). South of the Gürün autochthon, in Area 2 (Dağlıca), the Munzur thrust sheet comprises two main units; first, an extensive, relatively intact, lower Munzur thrust sheet, and secondly a thinner, internally disrupted upper Munzur thrust sheet (transitional to broken formation). The succession in the lower Munzur thrust sheet is widely exposed in Area 2 (Dağlıca) (Fig. 7 sections a-f), in Area 3A (E of Elbistan) (Fig. 8 sections a-e) and in Area 4 (S of Elbistan (Fig. 9). The Munzur thrust sheets are entirely Mesozoic, with no preserved Late Palaeozoic substratum, in contrast to the Malatya Metamorphics (Bodrum nappe). The complete Late Triassic to Late Cretaceous succession is exposed in the lower Munzur thrust sheet (Bedi et al., 2004, 2009; Bedi and Yusufoğlu, 2018), whereas Cretaceous facies are commonly exposed in the more localised upper Munzur thrust sheet, mainly in Area 2 (Fig. 7) and Area 3A (Fig. 8). During this study, bioclastic limestones in the upper Munzur thrust sheet were dated as late Barremian-early Aptian (near Küçük Tatlar) (see Supplementary table 1). Higher stratigraphic levels are rich in Cenomanian rudist bivalves.

Taking the Munzur thrust sheets together, the succession begins with Norian thick-bedded neritic limestone, rich in calcareous algae (Fig. 10a) and Megalodonts, with local evidence of intraformational reworking and tectonic instability (Fig. 10b, c). Above an unconformity, the Early Jurassic begins with a conglomerate, overlain by pinkish nodular micritic limestone, up to 40 m thick, rich in crinoids, algae, ammonites and gastropods. The Middle Jurassic to Early Cretaceous interval is neritic, commonly oolitic and/or rich in benthic foraminifera. The neritic succession typically culminates in a Cenomanian interval rich in rudist bivalves (Fig. 10d), as well-exposed in the upper Munzur thrust sheet in Area 2 (Dağlıca) (Fig. 10e).

The neritic limestones are covered by Albian-Santonian pinkish pelagic carbonates, with sparse thin-bedded bioclastic calcarenites, known as the Kızılkandil Formation (equivalent to the Kırmızı Kandil Formation of Perinçek and Kozlu 1984) (Fig. 10 f). In places (e.g. Küçük tepe-Gerdekes yayla), rudist-bearing neritic limestones are reported to grade laterally and vertically into *Globotruncana*-bearing pelagic limestones (Bedi et al., 2009). The pelagic carbonates include thin (several cm) interbeds of fine to medium-grained, neritic-derived calciturbidites; locally (e.g. near Erikli) these include redeposited Late Jurassic-Early Cretaceous benthic foraminifera (see Supplementary Table 1). The succession ends with an unconformity, which is covered by a ferruginous oxide crust in some sections (Fig. 10g); this is overlain by latest Cretaceous syn-emplacement facies (Kemaliye Formation; see below).

In one area (e.g. E of Tavla), a small thrust sheet is dominated by limestone breccia-conglomerate (mass-flow accumulations) and calciturbidites (c. 150 m thick) (Fig. 10h). This unit is tentatively interpreted as proximal platform-slope facies.

For the Late Triassic, there is widespread evidence of tectonic instability related to regional rifting. The Jurassic-Cenomanian succession accumulated on the inner part of a gently subsiding carbonate platform (Yılmaz, 1994), mainly influenced by global sea-level change. The Albian-Santonian pelagic carbonates (Kızılkandil Formation) accumulated during a time of overall relatively high global sea level (Miller et al., 2005). However, the presence of interbedded bioclastic calciturbidites points to sub-aqueous erosion that was probably triggered by contemporaneous tectonic instability. There was then a hiatus (up to c. 8 Ma), allowing local precipitation of ferruginous oxide from seawater, before syn-emplacement facies (Kemaliye Formation) began to accumulate. The hiatus is likely to be coeval with the break in deposition that affected the adjacent Malatya Metamorphics, and is interpreted to represent the southward passage of an emplacement-related flexural bulge (see below).

5.2. Late Triassic-Late Cretaceous Neritic-pelagic (Köseyahya) thrust sheet

The traditional Munzur nappe (Perinçek and Kozlu, 1984) is made up of two separate regional-scale thrust units. The first comprises the Munzur thrust sheets, which are neritic throughout Late Triassic-Cenomanian, as summarised above. The second is the Köseyahya thrust sheet, as defined near Köseyahya, to the south of the Gürün autochthon (Bedi et al., 2005, 2009) (Fig. 8). A similar succession, termed the Neritic-pelagic nappe is exposed to the north of the Gürün autochthon (Robertson et al., 2013b). The successions in both areas can be correlated and are here referred to as the Neritic-pelagic (Köseyahya) thrust sheet.

The most complete succession (Fig. 3) through the Neritic-pelagic (Köseyahya) thrust sheet is exposed in the type area, near Köseyahya (Area 3A, near log lll) (Fig. 8 sections a, e, f) (Bedi et al., 2009), with an additional outcrop in Area 4, south of Elbistan (Fig. 9 sections a, b) and Area 4B, Nurhak Dağı). The type section is located 750 m south of Köseyahya (near Burmakaya Tepe) (Tekin and Bedi, 2007a, b; Dumitrica et al., 2013). There, the succession begins in the Middle Carnian, as dated by radiolarians, with alternations of fine-grained sandstone, calcareous siltstone, marl, mudstone and micritic limestones. Volcaniclastic interbeds and chert of diagenetic replacement origin are also present, mainly in the higher levels. The succession continues with Late Carnian pink to red calcilutites (4.6 m thick), rich in ammonoids, crinoids, conodonts and pelagic bivalves (*Halobia* sp.) ('Hallstatt limestone') (Fig. 10i, j) (Bedi et al., 2016). Medium to thick-bedded Norian white limestones above ('Dachstein limestones') (Fig. 10k) include abundant Megalodonts and benthic foraminifera (Tekin and Bedi, 2007a, b). Above a discontinuity, the Early Jurassic is made up of relatively thin, stratigraphically condensed (c. 20 m), nodular, ammonite-rich micritic limestone ('Ammonitco Rosso'). The Mid-Late Jurassic is dominated by redeposited limestones (calciturbidites), with pelagic carbonate interbeds that are commonly silicified. The redeposited limestones are rich in neritic grains, especially ooids and are extensively silicified. Radiolarian chert increases in abundance during the Tithonian-Cenomanian interval. The Early Cretaceous (Tithonian-Berriasian) is dated using calpionellids within pelagic interbeds (Area 3A, E of Elbistan) (Fig. 10l) (see Supplementary table 1).

The upper part of the succession (Özbey Formation), where exposed, is depositionally overlain by pinkish pelagic carbonates with radiolarian chert intercalations. The pinkish pelagic carbonates are similar to those of the Munzur thrust sheets (see above) and have been given the same name (Kızılkandil Formation), although only those in the Neritic-pelagic (Köseyahya) thrust sheet are siliceous. The type section (near Kızılkandil mezrası), c. 40-50 m thick, depositionally overlies a layer of redeposited oolitic limestone (Özbey Formation). In a nearby succession, the Kızılkandil Formation unconformably overlies older neritic facies (Demirlitepe Formation), and includes both planktic foraminifera of Turonian-Santonian age and also radiolarians of Turonian-Santonian age. Another section, which is faulted against Late Triassic neritic facies (Ortakandil Tepe), contains Turonian planktic foraminifera and radiolarians; a further section (Han tepe-Toklu tepe) contains Turonian-Santonian radiolarians (Bedi et al., 2009).

The Kızılkandil Formation has been variously dated as Turonian-early Campanian (Perinçek and Kozlu, 1984), Coniacian-Campanian (Pehlivan et al., 1991), or Albian-Santonian, using a combination of nannofossils, radiolarians and planktic foraminifera (Bedi et al., 2009). The shortest-ranging planktic foraminifera, determined by Dr. A. Hakyemez, are *Rotalipora ticinensis*, *Rotalipora apenninica* (upper Albian), *Helvetoglobotruncana helvetica* (lower-middle Turonian) and *Dicarinella asymetrica* (Santonian) (Robaszynski and Caron, 1995). Radiolaria range from Albian-Santonian (Bedi et al., 2009). The pelagic limestones are unconformably overlain by the syn-emplacement Kemaliye Formation (see below).

The succession in the Neritic-pelagic (Köseyahya) thrust sheet began to accumulate during the Carnian on a submerged shelf, in the form of stratigraphically condensed, hemipelagic limestones and siliceous sediments, which are variably rich in ammonites, crinoids, foraminifera, calcareous algae and radiolarians. Condensed ammonite-rich, red pelagic carbonate deposition persisted during the Early Jurassic. During the Late Jurassic, the carbonate platform developed into a gently sloping carbonate ramp on which redeposited ooid-rich facies accumulated. The probable source was the adjacent shallow-water Munzur carbonate platform. The greatly increased abundance of chert in the Tithonian-Albian interval points to further deepening. This probably resulted from tectonic subsidence because global sea-level rise is not inferred during this time interval (Haq, 2014). Where the pelagic limestones (Kızılkandil Formation) overlie older parts of the succession (Demirlitepe Formation), tectonically induced uplift and submarine erosion are inferred. The pelagic carbonates accumulated during the mid-Late Cretaceous (Albian-Santonian), as in the Munzur thrust-sheet succession. The sea floor was already deep, favouring continuing radiolarian deposition. The appearance of pelagic carbonate probably represents increased planktic productivity (Bosellini and Winterer, 1975).

The Late Cretaceous pelagic carbonates in both the Munzur and Köseyahya successions are similar to those overlying the Tauride carbonate platform elsewhere, including the Bey Dağları (Poisson, 1977, 1984) and the Geyik Dağ (Sarı and Özer, 2002; Sarı et al., 2004). In the Geyik Dağ (central Taurides), Cenomanian rudist-rich facies are overlain by pelagic carbonates that accumulated until the Eocene (Solak et al., 2017, 2019), similar to the Gürün autochthon (Fig. 2).

6. Late Permian-Late Cretaceous Pelagic (Gülbahar) unit

Widely distributed, dismembered Late Permian to Late Cretaceous deep-water successions, including both pelagic and coarser-grained redeposited facies, and also basaltic rocks were previously included within the Dağlıca Complex ('flysch with blocks'), together with dismembered ophiolitic rocks (Kozlu et al., 1990; Perinçek and Kozlu, 1984). However, more recent mapping and stratigraphical studies indicate the presence of an originally intact Triassic to Late Cretaceous deep-water platform-margin succession. This has been named the Gülbahar Nappe (Bedi et al., 2009, 2018), based on a proposed correlation with comparable deep-sea successions including basaltic volcanics in the western Taurides (Şenel et al., 1989; Collins and Robertson, 1998; Sayıt et al., 2015). The deep-sea platform-margin succession in the Eastern Taurides has also been termed, informally, as the Pelagic nappe, in contrast to the traditional Munzur thrust-sheet neritic succession (Robertson et al., 2013b).

No complete succession of the Pelagic (Gülbahar) unit is known in any one section, although an overall stratigraphy can be pieced together (Fig. 3). Local sections show considerable facies variation and may represent combinations of lateral variation and/or proximal-distal changes. The most intact sequences are mainly located to the south of the Gürün autochthon in Area 2 (e.g. Büyük Tatlı), whereas, within the Northern allochthon, the Pelagic unit is mainly represented by blocks of Mesozoic deep-water facies within melange (Robertson et al., 2013b).

During the present study, local sequences of the Pelagic (Gülbahar) unit were studied in Areas 2-4 (Figs. 7-9). Relatively intact and continuous sequences (up to c. 80 m thick) are exposed between the lower and the upper Munzur thrust sheets in Area 2 (Dağlıca) (Fig. 7; e.g. near Tatlar, specifically Büyük Tatlı), although these are too small and localised to show effectively on regional-scale maps. Up to tens of m-thick sequences are widely exposed beneath the Köseyahya thrust sheets in Area 3A (E of Elbistan) (Fig. 8), and also occur beneath both the Munzur and Köseyahya thrust sheets in Area 4 (south of Elbistan) (Fig. 9). In addition, variable-sized, isolated blocks of similar lithologies are strewn through the late Cretaceous syn-tectonic Kemaliye Formation, as exposed in each of the above areas (see below).

The oldest known lithologies in the Pelagic (Gülbahar) unit are Late Permian siltstones, marls, siliceous limestones and thin-bedded limestones, including fusilinids and benthic foraminifera (Bedi et al., 2009) (Fig. 11, logs II, III; see Fig. 8 for locations). There are also short, highly deformed intervals of Triassic sandstone and shale (Fig. 12a, b). Jurassic-Cretaceous facies are mainly non-calcareous radiolarites and radiolarian mudstones, interbedded with pelagic carbonates (Fig. 12c), variably silicified calciturbidites (Fig. 12 d, e) and carbonate debris flow-deposits, variably rich in chert clasts (Fig. 12 f-i). The redeposited limestones are rich in redeposited ooids, oolitic limestone, pisoliths, benthic foraminifera (with oolitic coatings) and calcareous algae. Reworked pelagic limestone, radiolarian chert, monocrystalline quartz and muscovite are also present.

Variably preserved radiolarians, identified during this study (see Table 1), yielded the following Late Triassic to Late Cretaceous ages for local sections or blocks: Late Norian (block in serpentinite, near Yoksullu mezra (Area 4; Fig. 11, log I); Middle Jurassic (Bajocian), near Büyük Tatlı (Area 2) and near Yoksullu mezra; Late Oxfordian near Yoksullu mezra; Late Oxfordian-Tithonian near Kayseri (Area 2, log VII) and near Topaktaş (Area 2, log Vlll); Kimmeridgian-early Tithonian near Büyük Tatlı and near Yuksullu mezra; Late Tithonian-Berriasian near Büyük Tatlı); Late Valanginian-Hauterivian (block in debris-flow deposit) near Kabaktepe; Early Albian at Kırandere (near İncelik köy; Area 2); Aptian at Kırandere; and Late Albian-Cenomanian also at Kırandere. In addition, redeposited benthic foraminifera are dated more generally as Late Jurassic-Early Cretaceous (at Kaşanlı, Küçük Tatlı and Büyük Tatlı, all in Area 2 (see Supplementary Table 1).

An overall deep-marine, lower slope to base of-slope setting is inferred for the Pelagic (Gülbahar) unit. Late Permian pelagic carbonates with relatively fine-grained siliciclastic turbidites were followed by Early to Middle Triassic hemipelagic mudrocks, fine-grained sandstone turbidites and thin-bedded hemipelagic carbonates. Middle to Late Triassic hemipelagic limestones (Halobia limestones), radiolarian sediments, calciturbidites, quartzose sandstone/siltstone turbidites and, locally redeposited conglomerates, followed above this. The Jurassic-Early Cretaceous encompassed non-calcareous radiolarian muds, variably silicified calciturbidites and also debris-flow deposits with reworked neritic clasts (e.g. oolitic limestone) and/or pelagic clasts (radiolarite; pelagic limestone). Deposition locally culminated in large-scale gravity collapse of slope facies, leading to redeposition, with clasts of neritic/pelagic limestone and radiolarite in a matrix of lithoclastic debris-flow deposits, sandstone turbidites, ophiolite-derived debris-flow deposits, calciturbidites and muds. The ophiolite-bearing mass-flow units represent a depositional-tectonic link between the passive margin slope lithologies and the emplacement-related mass-flow units which are located higher in the tectono-stratigraphy (see below).

In places (e.g. Dağlıca, Area 2), short, highly deformed sequences of basalt, volcaniclastic sandstone and/or hyaloclastite are interbedded with Middle-Late Triassic deep-water calcareous and siliceous facies (Kozlu et al., 1990; Bedi et al., 2009; Robertson et al., 2013b). Chemically, the basalts are of enriched, alkaline, within-plate type (Robertson et al., 2013b). A sample of radiolarian chert from Area 2 (Bakış) gave a Norian (Late Triassic) age (Fig. 11 log ll; see Table 1). In addition, in Area 5A (Kemaliye) (Fig. 2) basaltic lavas of the Pelagic (Gülbahar) unit are interbedded with Late Triassic pelagic limestones (dated) and radiolarian cherts (see Supplementary Table 1).

The Pelagic (Gülbahar) unit accumulated adjacent to the Munzur and Köseyahya thrust sheet successions, taken together. The Permian siliciclastic material is likely to have been derived from an original, but now tectonically detached, substratum of the carbonate platform units. The Triassic records subsidence, localised alkaline basaltic volcanism (rift-related), terrigenous sand/silt gravity input, hemipelagic carbonate deposition (periplatform ooze) and radiolarian accumulation in a fertile sea. The Jurassic-Cretaceous was characterised by 'background' radiolarian and siliceous pelagic carbonate deposition (diagenetically altered to chert), beneath (or near) the carbonate compensation depth (CCD). The calciturbidites and carbonate debris-flow deposits accumulated on an unstable slope, derived from the adjacent carbonate platform. The Late Cretaceous is characterised by pelagic limestone, marl and chert that accumulated above the CCD, with *Globotrunca* sp., as in the adjacent carbonate platform units (equivalent to the Kızılkandil Formation). The presence of ophiolite-derived debris-flows within a sequence affected by slumping and soft-sediment deposition suggests that the distal platform slope over-steepened and collapsed related to ophiolite emplacement.

7. Late Cretaceous emplacement-related Kemaliye Formation

In different areas, the Malatya Metamorphics and both the Munzur and Köseyahya platform units are depositionally overlain by Late Cretaceous syn-tectonic lithologies that provide key information concerning the nature and timing of both tectonic emplacement and exhumation in the region. In general, the lithologies form coherent to highly disrupted successions, which are characterised by matrix-supported conglomerates, blocks, or dismembered thrust sheets, all set within an argillaceous and/or sandy matrix. The syn-tectonic units occur at two different structural levels in the regional thrust stack. The higher-level unit overlies the Munzur/Köseyahya platform units, whereas the lower-level unit overlies the Malatya (Keban) metamorphics.

In the northeast of the region studied, near Kemaliye (Figs. 13, 14 Area 5A), meta-carbonate rocks (Kaletepesi limestone) that are correlated with the lower part of the Keban metamorphics (Bilgiç, 2008b, c) are mapped as being unconformably overlain by 'olistostromes', named the Kemaliye Formation, after the town in this area (Figs. 13, 14) (Özgül et al., 1981; Özgül and Turşucu, 1984; Perinçek and Kozlu, 1984; Bilgiç, 2008b, c). The formation has been inferred to be Late Senonian (Özgül et al., 1981), or more specifically Late Campanian-Early Maastrichtian (Bilgiç, 2008b, c), based on the youngest datable fossiliferous material (i.e. *Globotruncana*-bearing pelagic limestone). In general, the succession has been described as beginning with localised conglomerates, with clasts of dark grey limestone, chert and diabase, passing into sandstone, with common basic igneous rock and limestone grains, and also interbeds of sandstone and marl (Perinçek and Kozlu, 1984). In its type area, the Kemaliye Formation is locally overlain, unconformably, by Early Eocene lithologies (Subaşı formation) (Bilgiç, 2008b, c). The Kemaliye Formation appears to correlate with the latest Cretaceous Gündüzbey Formation, to the south of Malatya.

The term, Kemaliye Formation was later adopted for all of the Late Cretaceous unmetamorphosed syn-tectonic facies in the region, including those associated with the allochthonous Munzur and Köseyahya successions (Bedi and Yusufoğlu, 2018). However, this is problematic for several reasons: (1) The underlying units differ strongly in different areas (i.e. Malatya (Keban) Metamorphics in the type area, versus Munzur-Köseyahya unmetamorphosed carbonate platform elsewhere); (2) The Kemaliye Formation in its type area includes lithologies (e.g. basalt-pelagic limestone-radiolarite) that are assigned to the Pelagic (Gülbahar) unit elsewhere (i.e. it is a composite unit); (3) The Kemaliye Formation, as previously mapped, is, in part, tectonically assembled rather than an intact sedimentary succession.

Although we retain the general name, Kemaliye Formation here for consistency with previous work, the occurrences in three different tectono-stratigraphic settings are discussed separately below. These are: (1) Unconformably overlying the Malatya (Keban) Metamorphics in Area 5A (Kemaliye) (Figs. 15a, 16a); (2) Unconformably overlying the Munzur and/or the Köseyahya thrust sheets, and also underlying the Munzur and Köseyahya thrust sheets where no basement is exposed. Consideration of these two main contrasting settings allows a more refined interpretation in terms of syn- versus post-emplacement tectonics.

7.1. Late Cretaceous Kemaliye Formation overlying the Malatya (Keban) Metamorphics

An unconformity is mapped between the Kemaliye Formation and the Malatya (Keban) Metamorphics west of Keban Lake (Bilgiç, 2008b, c) (Fig. 14). The meta-carbonate rocks near the contact are in places converted to calc-mylonite, indicating high-strain conditions (Fig. 16b). In some areas, the lower part of the formation is dominated by crudely bedded debris-flow conglomerates (Fig. 15a; 16c), as logged locally (Fig. 17). These contain abundant clasts of metamorphic rocks (Fig. 16d), together with radiolarian chert (Fig. 16e), deformed limestone (Fig. 16f), granite (locally), coral and large bivalves (rudists). Above this, much of the outcrop is dominated by blocks and dismembered thrust sheets (Fig. 16a). Many of the blocks are well-bedded, commonly dark, organic-rich limestones (typically 10s of m in size). Short, intact sequences of well-bedded limestones are intercalated with limestone conglomerates (calcirudites) that locally include well-rounded clasts and rudist debris of probable Cenomanian age. Neritic limestones of Triassic-Cretaceous age, chert (undated) and Late Cretaceous pelagic limestones are also present. A neritic limestone block (near Yuva; Fig. 14) is dated as Triassic based on benthic foraminifera (Fig. 18a, b; see also Supplementary Table 1). In one area, slices and/or large blocks of basaltic lava are exposed above the contact with the metamorphics (Fig. 15b). The lavas are interbedded with pelagic limestones that contain a typical Triassic fauna, including *Halobia* sp. and radiolarians (see

Supplementary Table 1). Although mapped as Kemaliye Formation (Bilgiç, 2008b, c) this volcanogenic unit belongs to the Pelagic (Gülbahar) unit (see above).

The matrix of the Kemaliye Formation in the type area is extremely heterogeneous, including variable abundances of monocrystalline quartz, polycrystalline quartz, plagioclase (altered), muscovite, biotite, epidote, clinopyroxene, hornblende, chlorite (including blue chlorite), zircon, apatite and opaque grains, in generally decreasing order of abundance. Lithoclasts are mainly micaschist, quartzite, chert, neritic limestone, basalt (with orientated microphenocrysts), altered basic volcanic glass (palagonite), felsic volcanics (recrystallised), dacite (with plagioclase phenocrysts), granite, bioclastic carbonate, marble, dolomite, sandstone (with parallel-orientated muscovite laths), siltstone (locally iron-rich), shale (partly recrystallised), serpentinite, gabbro, diabase, phyllite, phyllonite and mylonite (Fig. 6d-g). Bioclasts include micritic grains with shell fragments, pellets, benthic foraminifera, algal grains (pisoliths) and/or oolitic limestone (with clear, plutonic quartz cores). The matrix is either calcareous (partly recrystallised), or siliciclastic (with fine quartz and muscovite). Most grains are angular although a few are well-rounded. Some samples have a calcite spar cement.

In the northeast, where the Kemaliye Formation is mainly covered by younger volcanics (Fig. 14; NE of Yaka), small exposures of debris-flow deposits include clasts and blocks of altered lava, serpentinite and platy grey-pink Triassic pelagic limestone (see Supplementary Table 1). Farther northeast again, towards Ovacık (Fig. 13), the formation includes a large (c. 5 km-long) tabular body of Permian limestone that is tectonically overlain by serpentinised ultramafic rocks (Bilgiç, 2008b, c; MTA, 2011).

7.2. Kemaliye Formation associated with the Munzur and Köseyahya thrust sheets

Previous authors reported that the Munzur limestones, including the Late Cretaceous pelagic limestones (Kızılkandil Formation), pass unconformably upwards into syn-tectonic calcareous siltstones and sandstones, followed by an incoming of limestone blocks. This unit was termed the Binboğa Formation by Perincek and Kozlu (1984), named after the Binboğa Mountains 20 km west of Afşin. However, the term Binboğa Formation was later applied to the entire Early Triassic-Early Cretaceous succession of the Munzur thrust sheet (Kozlu et al., 1990), complicating the use of this name. The latest Cretaceous syn-tectonic interval was later correlated with the Kemaliye Formation (Bedi et al., 2009; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018), although, as noted above, this unit differs strongly from the type Kemaliye area.

Planktic foraminifera from the Kemaliye Formation above the Munzur limestones (Bedi et al., 2009) are long-ranging throughout Campanian-Maastrichtian. The shortest-ranged taxon is *Globotruncana dupeublei*, whose first occurrence (base) is within the *Gansserina gansseri* Zone (71.75-72.97 Ma; late Campanian-early Maastrichtian), whereas the last occurrence (top) is within the *Abatomphalus mayaroensis* Zone (67.30-69.18Ma; top of Maastrichtian stage) (microtax.org/pforams/index.php). In addition, nannoplankton data support a late Campanian-late Maastrichtian age for the Kemaliye Formation within the Munzur and Köseyahya thrust sheets (Bedi et al., 2009).

During this study, six sections of the Kemaliye Formation within the main Munzur thrust sheet were logged in Area 2 (Dağlıca), where they show considerable facies variation (Fig. 19 logs 1-6). The formation is typically dominated by alternations of calcareous mudstone-siltstone-sandstone (Fig. 19 logs 1, 2, 4). In places, sandstone, limestone conglomerates (calcirudites) and limestone breccias appear near the base of the succession (Fig. 19; logs 3, 5, 6; Fig. 20a, b). During this study, intervals of pinkish pelagic limestone were dated as Campanian-Maastrichtian (near Kapaklı; see Supplementary Table 1). Benthic foraminifera within a limestone block, near Kaşanlı, yielded an Early Cretaceous age (Supplementary Table 1). Other blocks are rich in rudist bivalves (Fig. 20c, d).

The upper levels of the succession are commonly tectonically disrupted and include neritic and pelagic limestone blocks (Fig. 19 log 6; Fig. 20d, e). Clasts of bioclastic calcarenite yielded reworked Middle-Late Jurassic benthic foraminifera (see Supplementary Table 1). In places, the outcrop is chaotic with limestone blocks strewn through a sheared mudstone-sandstone matrix.

The sandstone interbeds are heterogeneous and include both monocrystalline and polycrystalline quartz, muscovite, neritic carbonate, chert, quartzose siltstone and basalt (Fig. 6h-i). The calcarenites comprise variable mixtures of platform-derived material (e.g. pisoliths, shells, echinoderm debris, ooids), chert (microcrystalline quartz), altered basalt, vesicular volcanic glass (with plagioclase microphenocrysts), serpentinite, microgabbro and dolerite, together with rare monocrystalline quartz, siltstone (terrigenous), phyllite, plagiogranite, amphibolite, muscovite, altered plagioclase and pyroxene. Many grains are well-rounded. Planktic foraminifera (e.g. *Globotrunca* sp.) occur rarely.

Comparable sequences of the Kemaliye Formation are also exposed unconformably overlying the Late Cretaceous pelagic carbonates of the Köseyahya platform/proximal slope succession (Kızılkandil Fm.), as well exposed in Area 3A (E of Elbistan) and Area 4 (S of Elbistan). The succession in Area 3A encompasses interbedded mudstones, siltstones, sandstones and clasts of limestone (Triassic-Cretaceous), chert and serpentinite (Fig. 6j). Overlying debris-flow deposits ('blocky flysch') include clasts and blocks that can be correlated with the platform succession beneath, including micritic, oolitic and pisolitic limestone, and also pelagic limestones (Kızılkandil Formation). Other lithologies can be correlated with the over-riding Pelagic (Gülbahar) unit (e.g. radiolarite and volcanic material). Blocks of pink, chert-bearing pelagic limestone in Area 3A, east of Elbistan (near Odunluk Tepe and Yumru Tepe) are dated as Campanian-Maastrichtian based on planktic foraminifera (see Supplementary Table 1). A chalky debris flow-deposit farther northeast (near Dağdam) includes Late Cretaceous planktic foraminifera (see Supplementary Table 1). Facies equivalents of the Kemaliye Formation are also well exposed south of Elbistan (Area 4), beneath the Köseyahya thrust sheet and/or the Munzur thrust sheet, with no exposed stratigraphic base (Fig. 8). In the southern part of Area 4, pelagic limestone blocks contain Campanian-Maastrichtian planktic foraminifera, as in the Kemaliye Formation generally (Fig. 21a-d). However, a sample from the same local outcrop contains Globigerinidae (Fig. 21e, f), and also Rotaliidae, indicating a post-Cretaceous (Cenozoic) age, and thus that the Kemaliye Formation underwent post-depositional reworking in this area (see below).

The Kemaliye Formation is also exposed farther east, as a narrow c. NE-SW-trending strip in Area 3B, Nurhak Dağı which exhibits some critical additional field relationships (Figs. 2, 16g, 22a, b). The uppermost exposed levels of the Malatya Metamorphics there are represented by well-bedded calc-schists, in places transformed to calc-mylonite (Fig. 16h), or are isoclinally folded (Fig. 16i). Above a low-angle tectonic contact, meta-carbonate rocks are overlain by meta-serpentinite (Fig. 22a, b). Both the calc-schist and the meta-serpentinite are cut by small granitic intrusions (Figs. 22a). The Malatya Metamorphics were isoclinally folded prior to intrusion (Fig. 16j). The contact between the meta-serpentinite and the granitic intrusion is brecciated indicating subsequent brittle deformation (Fig. 16k). Although not dated specifically, these intrusions are likely to form part of the Eocene

Doğanşehir granitoids (MTA, 2011; Kuşcu et al., 2013; Karaoğlan et al., 2012, 2016; Bedi and Yusufoğlu, 2018). The serpentinite is overlain, with a low-angle thrust contact, by a thin facies equivalent of the Kemaliye Formation that includes blocks of Triassic red crinoidal limestone, similar to the Köseyahya platform/slope succession (see above), and also blocks of limestone and limestone breccia set in a sandy matrix (Fig. 22b). Further south (near Beğre), the serpentinite is overthrust by a thin slice of neritic limestone and limestone debris-flow deposits with rudist debris, of probable Cenomanian age, capped by Fe-oxide (Figs. 16l; 22a; see also Supplementary Fig. 3). This unit is interpreted as a small thrust slice of the contact between the Köseyahya platform/slope succession and the overlying Kemaliye Formation.

In thin section, some of the matrix sandstones of the Kemaliye Formation in Area 3B (Nurhak Dağı) have a well-developed shear fabric, in which large quartz grains are fractured and veined, with a calcite spar infill at right angles to the shear fabric. Foliated muscovite is present along shear bands indicating partial recrystallisation. Two phases of deformation are indicated by the presence of extensional calcite veins orientated at right angles to each other. *En echelon* cracks are interpreted as riedel shears.

7.3. Interpretation of the syn-tectonic Kemaliye Formation

The type area of the Kemaliye Formation (near Kemaliye; Area 5A) is a composite unit, dominated by gravity-controlled deposition, mainly by mass-flow processes. The rudist bivalves and *Globotruncana*-bearing limestones within slices and blocks indicate a Late Cretaceous age, although the matrix remains poorly dated. The lower part of the succession includes debris-flow conglomerates (‘olistostromes’), sandstones, shales and exotic blocks that covered the Malatya metamorphic rocks. The metamorphic and local granitic detritus were derived from the subjacent Malatya (or Keban) Metamorphics, confirming that they were exhumed prior to deposition (see Discussion). However, the dominant sources of the exotic material were the over-riding Munzur thrust sheet, the Pelagic (Gülbahar) unit, and ophiolitic rocks (e.g. serpentinite). The limestone conglomerates with well-rounded clasts and rudist debris were sourced from the Munzur platform. The Triassic basalts with Halobia-limestone and radiolarite are correlated with the Pelagic (Gülbahar) lower slope/basinal unit, as noted above. Ophiolitic rocks are exposed to the northeast of the Kemaliye Formation type area.

The Late Cretaceous pelagic carbonate deposition (Kızılkandil Formation) of both the Munzur and Köseyahya thrust sheets ended with a hiatus (early Campanian (?); c. 83-78 Ma), commonly marked by iron-oxide accumulation. The likely cause of the hiatus, similar to that in the Malatya metamorphic succession, was flexural uplift related to the regional ophiolite emplacement. The hiatus was followed by mixed siliciclastic-carbonate redeposition during late Campanian-Maastrichtian, forming the Kemaliye Foramtion. Talus, ranging from sand-sized, to blocks (up to many-metre-sized), were shed into the basin, largely derived from the upper levels of the adjacent Mesozoic carbonate platform and/or slope units (e.g. Cenomanian rudist limestone). The likely cause of basin formation was regional-scale downflexure ahead of the advancing thrust load, which was dominantly ophiolitic. The presence of Triassic-Cretaceous clasts suggests that, in places, all levels of the stratigraphy were exposed and eroded. This, in turn, suggests that platform and slope units were imbricated and uplifted, eroded, and then collapsed as debris into the flexural foredeep. Permian limestone is inferred to have existed beneath the Mesozoic platform and/or slope units, as supported by the presence of the large (km-sized) body of Permian limestone, as associated with the Kemaliye Formation in the northeast of the type area (Area 5A; Fig. 13). In addition, the pelagic lithologies (e.g. radiolarian chert, siliceous pelagic limestone) and also alkaline within plate-type basalt were derived from the Pelagic (Gülbahar) unit. Ophiolitic material is also variably present in the form of basalt, diabase, gabbro and/or serpentinite, sourced from the over-riding ophiolitic units. The succession accumulated in relatively deep water (100s m), as suggested by intercalations of pelagic carbonate containing Campanian-Maastrichtian planktic foraminifera.

Slices of the Munzur limestone were emplaced over the Kemaliye Formation in places, complicating the local tectono-stratigraphy. For example, in Area 3B (Nurhak Dağı), a slice of the highest levels of the neritic Munzur platform, complete with its iron-oxide coating (see above), was imbricated beneath the over-riding Köseyahya thrust sheet. Since the Mesozoic limestones (Munzur and Köseyahya) now structurally overlie the Kemaliye Formation it can be inferred that the Malatya-Keban metamorphics were exhumed, eroded to form clastic material (Kemaliye Formation), and later over-ridden by the regional limestone thrust sheet in this area.

The Kemaliye Formation above the Munzur and Köseyahya platform/slope successions is comparable with the widespread late Cretaceous syn-tectonic Yavça Formation (and facies equivalents) that intervene between platform carbonates, below and ophiolitic rock, above throughout the Taurides, for example in the Aladağ Unit (Maastrichtian Zekeriya Formation) and in the Bolkar Dağ Unit (late Campanian-Maastrichtian Söğüt Formation). These units unconformably overlie units of different age and facies in different areas and are generally interpreted as olistostromes or sedimentary melanges related to regional ophiolite emplacement (Özgül, 1997; Andrew and Robertson, 2002; Parlak and Robertson, 2004; Mackintosh and Robertson, 2012; Bedi and Yusufoğlu, 2018). In summary, the Kemaliye Formation in its type area (Area 5A) is a composite unit which formed above the Malatya (Keban) metamorphics during or after their exhumation. In contrast, the Kemaliye Formation as mapped regionally above the Tauride platform units is am intact succession, interpreted as a foredeep related to ophiolite obduction.

8. Volcanic-sedimentary melange

Definitions: Melanges comprise disorganised blocks of single, or multiple lithologies, with or without a matrix, and may be either sedimentary or tectonic origin, or both (see Raymond, 1984). Volcanic-sedimentary melange is a variety of melange in which the blocks are mainly made up of volcanic and sedimentary rocks, unrelated to ophiolites. Volcanic-sedimentary melange can shed light on both oceanic and emplacement processes.

Volcanic-sedimentary melange is well represented in the northeast of the region studied (Hekimhan area) (Fig. 2), where it is made up of short (10s of m), dismembered sequences of basalt, pelagic limestone and radiolarite (e.g. Yeşildere Melange). A local section comprises pillow basalt (80 m) with intercalations of ribbon radiolarite (c. 20 m), then alternations of radiolarite and pelagic limestone, followed by siliceous pelagic limestone (9 m). Radiolarite from the upper part of this interval was dated as Late Albian-Early Cenomanian (see Table 1). In the Dağlıca area (Area 2), short sections of basaltic lavas (<10s m) are interbedded with, and overlain by Middle Oxfordian-Early Tithonian radiolarian sediments (Robertson et al., 2013b). Geochemical data for the basalts from both areas indicate mid-ocean-ridge, to enriched intra-plate settings, although some samples have a subduction-related influence (Robertson et al., 2013b; Robertson et al., in press a). A similar range of basaltic compositions has been identified within meta-volcanic-sedimentary melange farther west, including the Anatolides (Afyon zone) (Robertson et al., 2009; in press b).

The volcanic-sedimentary melange was sourced from oceanic crust, including MOR-type basalt, 'seamounts' and subduction-influenced crust, within an oceanic basin that existed at least from Late Jurassic-Late Cretaceous. The melange was accreted related to subduction, and was emplaced onto the Tauride platform together with the other allochthonous units.

9. Ophiolite-related units

Definitions: Ophiolites represent relatively coherent bodies of oceanic lithosphere, although commonly incomplete. Dismembered ophiolites are tectonically dissected. Ophiolitic melange has component lithologies derived from an ophiolite and directly associated deep-sea sediments. Ophiolite-related melange, in contrast, includes a mixture of ophiolitic rocks and other unrelated lithologies (e.g. neritic limestone). These three types of melange all occur within the eastern Taurides, related to sea-floor spreading and ophiolite emplacement.

9. 1. Ophiolite-related melange and ophiolitic melange

Ophiolite-related melange and ophiolitic melange are well exposed north of Elbistan (Area 2, Dağlıca), where they are intergradational and structurally interleaved. Within the ophiolite-related melange, ophiolitic blocks/slices are embedded in a matrix of sheared mudrock. The ophiolitic melange is mainly sheared harzburgite but other ophiolitic lithologies are present including gabbro and diabase dykes (locally cut by plagiogranite veins), as exposed east of Elbistan (Area 5) (see Supplementary Fig. 5). In this area, dismembered ophiolitic rocks of the Dağlıca ophiolite (see below) are spatially associated with short (up to 10s of m), deformed successions of ophiolite-derived, matrix-supported conglomerates. In places, these clastic rocks occur above the Kemaliye Formation. The Kemaliye Formation, as related to the Munzur and Köseyahya thrust sheets, does not usually contain ophiolitic material (in contrast to the type area, above the Keban metamorphics). However, locally in Area 2 (Dağlica), the highest levels of the intact Kemaliye Formation contain ophiolitic debris (Fig. 19 log 4), suggesting a link with the tectonically associated ophiolitic rocks (Dağlıca ophiolite). However, no undeformed contact could be observed. The debris-flow deposits are crudely stratified (Fig. 20f), showing both normal and reverse grading. The clasts are mostly angular to subrounded and are dispersed randomly though a poorly sorted sand-granule-grade matrix (Fig. 20g). Most parts of an ophiolite pseudostratigraphy are represented as clasts, including gabbro (Fig. 20h) and basalt (Fig. 20i); siliceous pelagic carbonate is mostly preserved as diagenetic replacement chert (Fig. 20j).

Another excellent example of ophiolite-related melange, here termed the Divriği melange, is exposed in the northeast of the region (Area 5B) (Figs. 2, 23). This melange is located between the Munzur thrust sheet, below and the Divriği ophiolite, above (Aktimur, 1988; Özgül and Turşucu, 1984; Öztürk and Öztunalı, 1993). This unit is otherwise known as the Yeşiltaşyayla ophiolitic melange (Yılmaz and Yılmaz, 2004), the Refahiye ophiolite (Atabey and Aktimur, 1997), and the Eriç melange (Özer et al., 2004). The Divriği melange has undergone low-grade metamorphism and is cut by Eocene granites (Boztuğ et al., 2007; Kuşcu et al., 2013). The smaller Güneş ophiolite is exposed in the same area (Yılmaz, 2001).

The Divriği melange, up to several 100 m thick, directly overlies the Munzur thrust sheet in its type area, the Munzur Dağları (Aktimur et al., 1998; Fig. 24a, b; see also Supplementary Fig. 4). The highest stratigraphical levels of the Munzur thrust sheet are well dated to the east of our study area. In this area (Ayıkayası Dağı), Cenomanian-aged, rudist-bearing neritic limestones are overlain by a thin (4 m) interval of thin-bedded, reddish siliceous pelagic carbonate of Turonian-Campanian age (Özer et al., 2004). This interval can be correlated, broadly with the latest Cretaceous pelagic cover of the platform carbonates in the Elbistan area (Kızılkandil Formation). Where well exposed in our area, north of Divriği, well-bedded, unmetamorphosed neritic limestones of the Munzur thrust sheet dip regularly westwards and are over-ridden by ophiolite-related melange, with a low-angle thrust contact (Fig. 24b). The highest exposed levels of the Munzur succession (5 km SSE of Divriği) are locally dated as Middle Jurassic, using benthic foraminifera (Fig. 18d, e; see also Supplementary Table 1), suggesting that the Cretaceous part of the original succession is now absent. Dark neritic limestones in the lower levels of the succession in the Divriği area are dated as Middle Triassic, based on benthic foraminifera (Fig. 18c). Similar platform lithologies are now present as blocks in the overlying ophiolite-related melange.

The Divriği melange overlies the succession in the Munzur thrust sheet. In places, neritic limestones are unconformably overlain by mudrocks that are similar to the matrix of the melange (Figs. 23, 24a-c). In places, the contact is faulted (see Supplementary Fig. 4). The lower part of the melange includes a neritic limestone block that was dated as Aptian-Albian, based on benthic foraminifera (Fig. 18f-i; see also Supplementary Table 1), similar to the age of the underlying intact platform succession. The mid to upper levels of the melange are dominated by elongate slices and blocks of recrystallised limestone, up to 100s m long and 10s m thick, set in a sheared shaly matrix (Figs. 24a-c, 25a). Benthic foraminifera within a packstone block gave an Aptian-Albian age (Fig. 18j-q), again suggesting that the missing interval at the top of the Munzur platform succession is represented by blocks in the melange. Other blocks include poorly sorted breccia-conglomerate, indicating a mass-flow (slope-related) setting, prior to emplacement into the melange. Some of the clasts are well-rounded suggesting exposure and reworking prior to redeposition, as in the Kemaliye Formation (see above). The blocks and terrigenous matrix are interspersed with anastomosing strands of highly sheared serpentinite, mostly harzburgitic (Figs. 24a-b; 25b; see Supplementary Fig. 4). In places, serpentinite melange reaches to within c. 80 (structural thickness) of the tectonic contact with the intact Munzur thrust sheet below. The melange as a whole has experienced polyphase deformation, with evidence of both southerly and northerly fold vergences (Fig. 25c, d).

Several additional areas provide supporting evidence. For example, an extensive outcrop of ophiolitic melange southeast of Divriği is dominated by sheared harzburgitic serpentinite, without limestone blocks (Fig. 25e, f). Similar serpentinite melange also occurs extensively, e.g. c. 70 km southwest of Divriği (around Kangal), where it overlies neritic limestones of the Munzur thrust sheet (locally dated as Jurassic; see Supplementary Table 1). In addition, melange outcrops to the west of Divriği (Fig. 2) have been summarised elsewhere (e.g. Büyük Yılanlı Dağ) (Robertson et al., 2013b; see also Özgül et al., 1981; Özgül and Turşucu, 1984; Aktimur et al., 1988; Atabey et al., 1994). These include several types of melange associated with the Pınarbaşı ophiolite in the northeast of the region studied (i.e. Kireçlikyayla melange of Yılmaz et al., 1991, 1993; Pınarbaşı melange of Atabey and Aktimur, 1997).

9.2. Ophiolites and related clastic deposits

Whereas, melanges are widely distributed throughout the eastern Taurides, coherent ophiolites are restricted to four main bodies, the Divriği (also Güneş), Hekimhan, Pınarbaşı and Kuluncak ophiolites, mainly in the north of the region studied (Fig. 2). Here we pay particular attention to the dismembered Dağlıca ophiolite and its associated debris-flow units (Area 2) which shed light on emplacement processes.

In the northeast, the Divriği (Sivas) ophiolite (Area 5B), dated at 93-94 Ma by zircon U-Pb, is partially dismembered and lacks extrusives rocks (Parlak et al., 2006, 2017). A locally exposed metamorphic sole (Fig. 24a, bii), dated at 93-94 Ma by Ar-Ar (Parlak et al., 2017), includes amphibolite, with subordinate, greenschist, marble and metachert, all cut by post-metamorphic diabase/microgabbro dykes. The protoliths of the amphibolite are within-plate basalts (seamount-type) and island-arc-type basalts, whereas the protoliths of the dykes are within-plate basalts (Parlak et al., 2006). Listwaenite is widespread in the Divriği (Sivas) ophiolite (Uçurum, 2000).

Farther southwest (c. 40 km), the dismembered Kuluncak-Hekimhan (Malatya) ophiolite (Fig. 2) comprises variably altered mantle harzburgite (tectonites), cut by isolated basaltic dykes, together with ultramafic cumulates (mainly dunite, wehrlite and pyroxenite), mafic cumulates (olivine-gabbro and normal gabbro), isotropic gabbro, diorite and quartz diorite, a sheeted dyke complex, plagiogranite and extrusive rocks. The basaltic extrusive rocks are associated with radiolarite, chert, pelagic limestone and hemipelagic mudstone (Metin et al., 2013; Camuzcuoğlu et al., 2017). Listwaenite again occurs (Uçurum, 2000). In the northeast, the Pınarbaşı ophiolite, dated as 93-94 Ma by zircon U-Pb (Parlak et al., 2017) (Fig. 2) exposes mantle tectonites, cut by isolated basaltic dykes, together with ultramafic to mafic cumulates, all above an amphibolitic sole (90-93 Ma by zircon U-Pb) (Parlak et al., 2017). These sole rocks are chemically similar to those of the Divriği ophiolite (Vergili and Parlak, 2005).

In addition, the dismembered Dağlıca ophiolite (Fig. 7; sections a, d, e) is restricted to thrust slices and blocks (up to km to km-sized). The lithologies were previously termed the Dağlıca complex (Kozlu et al., 1990; Perinçek and Kozlu, 1984), and the Dağlıca ophiolite (Robertson et al., 2013b). The lithologies include basalt, diabase, diabase dykes in harzburgite, gabbro, gabbro pegmatite, harzburgite, pyroxenite, wehrlite and dunite (see Supplementary Fig. 5). The metamorphic sole is represented by rare blocks of amphibolite-greenschist within adjacent ophiolite-related melange. The basaltic rocks of the Dağlıca ophiolite are chemically indicative of a supra-subduction zone origin (Robertson et al., 2006).

9.3. Interpretation of the ophiolites, melanges and related mass-flow units

The ophiolites formed in a Late Cretaceous (c. 92-93 Ma), supra-subduction zone setting (Parlak et al., 2013, 2019). They represent different parts of a regional-scale thrust sheet of oceanic lithosphere, with a metamorphic sole that is only now locally preserved. The presence of all of the units of a complete ophiolite, taken regionally, suggests that a typical supra-subduction zone ophiolite initially formed with all of the expected lithological units; however, this was variably dismembered during emplacement.

During emplacement, related to flexural loading by advancing oceanic lithosphere, the Mesozoic carbonate platforms (Munzur and Köseyahya) subsided to create the regional-scale foredeep mentioned above (Kemaliye Formation; see above). In proximal (northerly) areas, represented by the Divriği melange, the upper stratigraphic (Cretaceous) levels of the Munzur platform were partly removed. Most likely, they were detached, bulldozed ahead and collapsed as debris-flows and blocks into the northern part of the regional foredeep. During southward emplacement, serpentinite derived from the over-riding ophiolite harzburgite was tectonically incorporated into the foredeep.

During emplacement, the East Tauride ophiolites were variably dismembered. The Dağlıca ophiolite was strongly dismembered to form thrust sheets and broken formation, and also underwent mass-wasting to form ophiolite-derived debris flows. Ophiolitic material was initially sand-sized (within the Kemaliye Formation), then became clast/block sized (i.e. more proximal) and culminated in the emplacement of large ophiolitic blocks and thrust sheets. Gravity emplacement was therefore an important process for the melange units. Ophiolite-related melange covered all parts of the region (including south of Elbistan; Area 4). However, the ordered ophiolites are restricted to the north of the region, closest to their inferred origin and there is no field evidence that they were emplaced southwards over the entire region.

10. Latest Cretaceous-Paleogene cover sediments

Cover sediments provide important constraints on the nature of the substratum, the timing of emplacement and the tectonic conditions soon afterwards. The Divriği ophiolite is unconformably overlain by conglomerates, sandstone, mudstone, marl, limestone and volcaniclastic sediments, dated as Campanian-Maastrichtian (Yılmaz and Yılmaz, 2004; Bilgiç et al., 2008a, b). Approximately 50 km farther west (Tecer Dağı and Büyük Yılanlı Dağ), ophiolitic rocks, similar to the Divriği ophiolite (Kavak et al., 2017), are unconformably overlain by conglomeratic facies (Tecer Formation) (İnan and İnan, 1988), passing upwards into Late Maastrichtian shallow-marine, mixed carbonate-clastic facies (Atabey and Aktimur, 1997; İnan and İnan, 1988; Robertson et al., 2013b). Both the Kuluncak and Hekimhan ophiolites (and related melange units) are unconformably overlain by ophiolite-derived conglomerates, passing upwards into Late Maastrichtian shallow-water carbonates, including rudist limestones (Booth et al., 2013; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018). In addition, the Pınarbaşı ophiolite is unconformably overlain by non-marine clastics and minor carbonates, of inferred Palaeocene age (Erkan et al., 1978).

The widespread deposition of latest Cretaceous, typically late Maastrichtian, cover sediments show that, after short-lived emergence and erosion, the emplaced continental margin and ophiolitic units, were rapidly transgressed by non-marine to shallow-marine sediments, and that this was followed by a return to relatively stable tectonic conditions. The clast composition reflects the nearby units beneath, typically ophiolitic rocks. The timing of regional ophiolite emplacement is constrained as coeval with the syn-tectonic Kemaliye Formation (late Campanian-late Maastrichtian) but prior to the transgressive sediments regionally (probably late Maastrichtian). The emplacement of the allochthonous units therefore took place during a relatively short period of time (c. 75-70 Ma).

11. Structural relationships

11.1. Outcrop-scale structures

To shed additional light on the tectonic emplacement, bedding and fold data (fold axial planes and fold hinges) were measured throughout the study area and plotted on stereonets according to sub-area and tectono-stratigraphic unit (see also Supplementary Fig. 6).

Bedding in the Malatya and/or Keban metamorphics (Areas 1 and 5A) is generally orientated NE-SW (see supplementary Fig. 7). Fold axial planes mainly plot in the northern and southern quadrants, consistent with dominantly E-W folding with variably dipping axial planes (c. 10-80^{o}) (Fig. 26ai-aii).

Structural measurement from the allochthonous Tauride units are relatively variable. North of Elbistan (Area 2), the bedding strike is regionally c. E-W. Bedding orientations are variable in all units, with a slight NW-SE trend, consistent with large-scale symmetrical folding (see Supplementary Fig. 7). Fold axial planes are broadly east-west and commonly west-dipping (Fig. 26bi). Many fold hinges trend c. E-W, with axial planes dipping both N and S at moderate angles, suggesting refolding (Fig. 26bii). A local swing in fold hinge direction (south to west) in the relatively autochthonous Gürün outcrop (see Supplementary Fig. 8) could represent refolding (or possibly local block rotation). Farther east (Area 3A; E of Elbistan), the bedding is more NW-SE. Fold axial planes and fold hinges are broadly east-west, mainly at moderate angles (Fig. 26ci-ii; see Supplementary Fig. 9). In the Kemaliye area in the northeast (Area 5A), bedding data from both the Malatya Metamorphics and the Kemaliye Formation have a slight NW-SE strike, mainly at moderately angles (see Supplementary Fig. 10). Fold axial planes (mostly in the Keban metamorphics) mainly dip southwest at variable angles. Fold hinges have a dominant NW-SE trend. Opposing NW vs. SE directions hint at re-folding (Fig. 26 di-dii).

The relatively coherent data set from the Malatya Metamorphics (Fig. 26 ai-aii) is consistent with N-S compression (without preferred vergence). The fold data from Area 2 (Dağlıca) are consistent with two-phase emplacement along c. E-W axes (with opposing directions). The more NW-SE fold trend in the Kemaliye area farther northeast (Area 5A), mainly in the Malatya (Keban) Metamorphics, represent a different compression direction or possibly bulk rotation.

11.2. Inter-relations of regional tectono-stratigraphic units

The mutual relations are mainly indicated by a combination of sedimentary, metamorphic, igneous and structural evidence.

11.2.1. Relation of the Malatya metamorphics to the Göksun ophiolite: sedimentary evidence

In the south, the Malatya Metamorphics (Bodrum nappe) are thrust over the post-emplacement sedimentary cover of the Göksun ophiolite (Harami Formation), shedding light on its timing of emplacement. South of Afşin (Area 1), the Göksun ophiolite is unconformably overlain by conglomerate, sandstone, sandy/shaly limestone and marl (un-named unit of Perinçek and Kozlu, 1984) that is correlated with the Harami Formation in its type area (Elazığ) (Perinçek and Kozlu, 1984; Robertson et al., 2007; Bedi et al., 2009). The succession south of Afşin begins with polymictic conglomerates with schist and marble, radiolarite, pelagic limestone, chert, ophiolitic rocks (including diabase and basalt), and fines upwards into sandstone, limestone and microconglomerates with clasts of similar composition (Yılmaz et al., 1987; Bedi et al., 2009; this study). Thin sections include monocrystalline (plutonic) quartz, polycrystalline (metamorphic) quartz, sericitic schist, marble, micritic limestone, biotite and muscovite, in generally decreasing order of abundance (Fig. 6k, l). The matrix is biomicrite with a mixture of planktic and benthic foraminifera. The succession is dated as latest Cretaceous using planktic and benthic foraminifera, and also calcareous nannofossils (Perinçek and Kozlu, 1984; Yılmaz et al., 1987, 1993; Robertson et al., 2007; Bedi et al., 2009). The basal conglomerates include pelagic limestone pebbles of Santonian age, similar to the Kızılkandil Formation of the Munzur and also the Köseyahya successions (Bedi et al., 2009). During this work, samples of calcarenite yielded Late Campanian-Maastrichtian ages (see Supplementary Table 1). Samples from the upper part of the formation (Sarıkaya member) have been dated as late Maastrichtian based on planktic foraminifera and nannofossils (Bedi et al., 2009), of which the key taxa are *Gansserina gansseri* (72.35-66 Ma, latest Campanian-Maastrichtian) and *Globotruncanita angulata* (66.04-72.05 Ma, top Maastrichtian).

The post-emplacement sedimentary cover of the Göksun ophiolite accumulated in a shelf sea of moderate water depth (>10s m), with clastic sediment supply both from the Munzur and/or Köseyahya platform units and also from already exhumed Malatya metamorphic rocks. The Malatya metamorphic thrust sheet was, therefore, tectonically juxtaposed with the underlying Göksun ophiolite during the latest Cretaceous.

11.2.2. Post-exhumation imbrication of the Malatya Metamorphics: sedimentary and structural evidence

SW of Elbistan (Area 4), the Neritic-pelagic (Köseyahya) thrust sheet is thrust southwards over the Malatya Metamorphics (Fig. 9, section A). However, elsewhere the contact is steeply dipping and is likely to be a strike-slip fault (Fig. 9, section A). In this area, near Kalaycık (Fig. 9 section A; locality E), Triassic Malatya metamorphic rocks (exposed on Medetsizdağı) are underlain by a small slice (>40 m thick) of unmetamorphosed debris-flow deposits that include gabbro, basalt, pelagic limestone (with volcanic debris) and radiolarite. This facies is similar to the Kemaliye Formation, as exposed c. 12 km to the NE (near Sokullu; Fig. 9 map). A sample from a block of pelagic limestone contains Campanian-Maastrichtian planktic foraminifera, as in the Kemaliye Formation (Fig. 21a-d). However, an additional sample includes Globigerinidae (Fig. 21e, f) and also Rotaliidae, indicating a post-Cretaceous (Cenozoic) age. Two other samples contain a rich Middle Palaeocene (Selandian) planktic foraminiferal assemblage (see Supplementary Table 1). Relatively deep-water pelagic conditions therefore existed during the Palaeogene, followed by reworking of pelagic carbonates within debris-flow deposits. Elsewhere (e.g. west of Afşin), the Malatya Metamorphics are internally imbricated with Eocene shelf-depth Nummulitic limestones (Robertson et al., 2006; Fig. 4 a). The inter-slicing took place during Mid-Late Eocene regional deformation (see below). However, the distance of Eocene thrust transport is likely to have been limited (a few kms at most) because the Göksun ophiolite and the Malatya Metamorphics are mutually intruded by the 88-82 Ma Baskil Granitoids, without major thrust dislocation of the contact relations (Karaoğlan et al., 2012, 2016; Bedi and Yusufoğlu, 2018).

11.2.3. Contact relations between the Munzur and Köseyahya thrust sheets: sedimentary and structural evidence

The Munzur thrust sheet is subdivided into the main, lower thrust sheet that encompasses the entire succession and the much thinner, internally disrupted, upper thrust sheets (mainly Cretaceous), as exposed in the north, in Area 2 (Dağlıca) (Figs. 7; Fig. 20c-e). The upper and lower thrust sheets are separated by the Kemaliye Formation, which has widespread inclusions of the dismembered Dağlıca ophiolite, related melange (Fig. 7) and, locally, of the Pelagic (Gülbahar) unit (Fig. 7f). In places, limestones of upper thrust sheet directly overlie the southern margin of the Gürün autochthon (Fig. 7c).

NE of Elbistan (Area 3A), the Munzur thrust sheet is thrust southwards over the Neritic-pelagic (Köseyahya) thrust sheet (Fig. 8 sections a, e). The two thrust sheets are separated by mass-flow units, correlated with the Kemaliye Formation (see Supplementary Fig. 7). Poorly bedded calcarenites form the matrix of debris-flow deposits; these include large foraminifera and calcareous algae of Late Palaeozoic (Carboniferous-Permian) age (see Supplementary Table 1), hinting at derivation from an original but now missing Late Palaeozoic substratum to the Munzur limestones. The imbrication of the two major platform carbonate/slope thrust sheets therefore took place after formation of the latest Cretaceous Kemaliye Formation, probably during the latest Cretaceous.

In the same area, NE of Elbistan (Area 3A), the Neritic-pelagic (Köseyahya) thrust sheet beneath the Munzur thrust sheet is relatively thin (100s m) and highly disrupted. Pelagic limestones of the Neritic-pelagic (Köseyahya) thrust sheet are repeatedly imbricated with the latest Cretaceous Kemaliye Formation (Fig. 8). The Pelagic (Gülbahar) unit that is locally exposed beneath both the Neritic-pelagic (Köseyahya) thrust sheet and the Munzur thrust sheet are both tightly folded and, in places, intensely imbricated, indicating intense compressional deformation during emplacement (see Supplementary Fig. 6). On the other hand, the widespread presence of conjugate fault blocks indicates extension (see Supplementary Fig. 6). One explanation is that the Neritic-pelagic (Köseyahya) sheets were emplaced by gravity sliding into the Kemaliye foredeep, followed by imbrication during regional emplacement into the latest Cretaceous thrust stack.

In the south (south of Elbistan; Area 4), a Munzur thrust sheet is mapped as underlying a Köseyahya thrust sheet (Bedi et al., 2009) (Fig. 9, section A). This points to complex and variable re-imbrication because to the northeast (e.g. Area 3A; Fig. 8) the Munzur thrust sheet regionally overlies the Köseyahya thrust sheet. All of this imbrication and re-imbrication is inferred to be latest Cretaceous in age.

In addition, to the NW of Elbistan (N of Afşin, near İncirli, Area 2), the Malatya Metamorphics are thrust northwards over the Southern allochthon, including the Kemaliye Formation, above a sharp south-dipping contact (Figs. 2; 4l; Supplementary Fig. 2). This indicates an important, but localised, phase of backthrusting after the initial latest Cretaceous emplacement. Northward vergence is also observed within the adjacent Southern allochthon (Perinçek and Kozlu, 1984; Robertson et al., 2013).

11.2.4. Contact relations between the Gürün autochthon and the allochthonous units

Along the southern margin of the Gürün autochthon (Area 2; Dağlıca; Figs. 7, 20k), the relatively autochthonous succession culminates with Middle Eocene (Lutetian) calcareous mudstones, rich in large foraminifera. Interbedded sandstones and debris-flow deposits contain ophiolitic detritus. Several km to the south (Hurman Çayı-Kalesi area) (Fig. 7, marked in red), ophiolitic rocks and Munzur limestones are thrust over an isolated Early-Mid Eocene succession (with no exposed base) (Robertson et al., 2013b). This begins with limestones that are rich in large foraminifera (e.g. *Alveolina* sp., *Assilina* sp.) and passes upwards into argillaceous and silty limestones (Demiroluk Formation of Bedi et al., 2009). This is interpreted as a fragment of an Eocene shelf succession that was later incorporated into the thrust stack. In the west of Area 2 (e.g. NW of Tavla), the Munzur limestones are unconformably overlain by non-marine conglomerates, with well-rounded clasts that include *Nummulites* sp. suggesting a post-Eocene age of accumulation (Early-Mid Miocene(?) (Fig. 7b; 20l). These conglomerates are also incorporated into the thrust stack. Farther east, within the Gürün autochthon (near Akdere), Cenomanian rudist-bearing limestones are unconformably overlain by thick-bedded to massive non-marine conglomerates, of inferred Early-Mid Miocene age (Gövdelidağ Formation of Perinçek and Kozlu, 1984). The conglomerates are in high-angle fault contact with Munzur limestones. Slickensides indicate right-lateral strike-slip displacement (Robertson et al., 2013a). In the far east of Area 2 (near Sarız), a moderate-angle (30-50°) south-dipping thrust (reverse fault) separates the Paleogene Gürün autochthonous succession from the allochthonous units above, pointing to northward displacement (i.e. backthrusting) (Robertson et al., 2013b), which affected the Southern Allochthon as a whole. The outcrop bordering the Gürün autochthon in the south is folded on a large scale along c. E-W axes. The timing of the folding is inferred to be pre-Pliocene, post-dating the inferred Miocene non-marine conglomerates (Yılmaz et al., 1993; Perinçek and Kozlu, l984; Kozlu et al., 1990; Robertson et al., 2013b). In summary, within the Southern allochthon there is evidence of latest Cretaceous southward thrust-stacking, Eocene re-imbrication and Late (?) Miocene back-thrusting, reverse faulting and large-scale folding.

Along the northern margin of the Gürün autochthon (Fig. 2), the relatively autochthonous succession culminates in Middle Eocene shelf facies, similar to those in the south. The Northern allochthon begins with an equivalent of the neritic Munzur thrust sheet, followed upwards by the Pelagic nappe, equivalent to the Neritic-pelagic (Köseyahya) thrust sheet, but more coherent stratigraphically. Overlying units include the Pınarbaşı ophiolite and related melange units in the northwest (Robertson et al., 2013b). The northern allochthon is overlain by Eocene marine clastic sediments. Although mapped as an unconformable relationship (Yılmaz et al., 1997; MTA 2011; Bedi and Yusufağlu, 2018), field observations in the northeast of the area suggest a thrust relationship (Robertson et al., 2013b). In the southwest, near Pınarbaşı, the contact relations are mainly concealed by numerous neotectonic strike-slip faults.

11.3. Effects of neotectonic faulting

Neotectonic displacements need to be back-stripped to interpret the preceding emplacement history in detail.

Previously published fault data, specifically from the generally NE-SW to ENE-WSW-trending Göksu fault lineament of Kozlu et al. (1990) (Tavla-Sarız area; Figs. 2, 7), indicate dominantly right-lateral displacement, with either reverse or normal components (Robertson et al., 2013b). This is surprising because the dominant offset along neotectonic faults in the region is left-lateral (e.g. Duman and Emre, 2013). During this study, additional faults were measured, mainly farther east (e.g. Hurman Kalesi area). Of the new fault data (see Supplementary Fig. 11), there are six NW-SE trending faults, one of which is left-lateral and the remainder right-lateral. Of 10 NE-SW trending faults, seven are dextral, two have no slickenlines to determine movement sense and one is an oblique reverse fault. The new data support significant right-lateral displacement along a generally NE-SW to ENE-WSW-trending lineament, possibly representing more than one phase of movement. The rectilinear right-lateral faulting appears to post-date the inferred Mid-Late Miocene folding and reverse faulting/backthrusting that affects the Southern allochthon and the adjacent Gürün autochthon (see above).

Neotectonic faults are widely mapped further south, in the general Elbistan area, as follows: (1) NW-SE trending faults (Kışlaköy and Hurman Faults), inferred to be normal faults with dextral strike-slip components (strike N35^{o}E; dip 81^{o}SW; (2) NE-SW trending fault (Sarıyatak Fault), a normal fault with a sinistral component (strike N15^{o}E dip 78^{o}SE; lineation plunges 75^{o}S); (3) ENE-WSW faults (Türkören Fault and Afşin-Elbistan Fault), of which four fault planes on the left-lateral Afşin-Elbistan Fault have allowed calculation of principal stress directions (sigma 1 51^{o}/170^{o}; sigma 2 30^{o}/307^{o}; sigma 3 22^{o}/050^{o}). The NE-SW trending fault is inferred to have influenced the Pliocene-Quaternary clastic deposition within the adjacent depocentre that forms part of the overall Afşin-Elbistan basin (Yusufoğlu et al., 2005; Bedi et al., 2009). Regional c. ENE-WSW left-lateral faulting generated overall NW-SE trending fault-controlled depocentres that infilled with Pleistocene sediments. Some of the neotectonic faults in the Elbistan region are reported to be covered by conglomerates suggesting a switching of faults with time and/or a changing stress regime (Bedi et al., 2009).

The region to the west of the Malatya-Ovacık Fault Zone is transected by numerous Plio-Quaternary left-lateral strike-slip faults, including the Afşin-Elbistan Fault and the generally NNE-SSW Sarız and Gürün faults (MTA, 2011). Some of these faults are interpreted to have active left-lateral movements (i.e. Beyyurdu and Gürün faults of Emre et al. (2018); Türkören fault of Bedi et al. (2009)). The left-lateral faults relate to displacements along the regional northern strand of the East Anatolian Fault System (Sürgü–Misis Fault system). The Pliocene-Pleistocene westward tectonic escape of Anatolia (Şengör et al., 1985; Duman and Emre, 2013) was partially accommodated by displacements along these faults.

In the east, the Malatya-Ovacık Fault Zone delimits the western margin of the large Malatya Basin. Early-Middle Miocene NW–SE extension there was followed by Mid-Late Miocene volcanism (11.99±0.49-4.82±0.57) (Yamadağ volcanics) (Kaymakçı et al., 2006; Kürüm et al., 2008). NNW-SSE left-lateral transpression is inferred along the Malatya-Ovacık Fault Zone during Late Miocene-Early Pliocene, coupled with widespread Pliocene volcanism (Ekici et al., 2007). Active left-lateral displacement began during the Late Pliocene, influenced by variable NNE–SSW transpression (Kaymakçı et al., 2006). In summary, most of the neotectonic faults in the region studied have relatively small displacements (several kms) that do not fundamentally change the regional tectono-stratigraphy; however, the Sürgü–Misis Fault and Malatya-Ovacık Fault have tens of km of fault displacement that need to be restored in any tectonic reconstruction.

12. Discussion

Below, we utilise the assembled body of evidence and interpretation to test and develop several alternative tectonic hypotheses for the relationships between the main tectonic units in the region.

12.1. Relation between the Northern and Southern allochthons and the Gürün autochthon

There are three main hypotheses for the emplacement of the northern and southern allochthons in relation to the Gürün autochthon (Fig. 2). All three assume that the allochthonous units cannot have been emplaced over the intact succession of the Gürün autochthon, at least until the Mid-Late Eocene because of its intact stratigraphical succession (Aziz et al., 1982; Perinçek and Kozlu, 1984; Robertson et al., 2013b).

The first hypothesis is that the Southern allochthon was emplaced southwards over the Gürün autochthon after deposition ended in the Early-Mid Eocene (Aziz et al., 1982). This is consistent with the evidence of southward thrusting during the Mid-Late Eocene in the central Taurides (Özgül, 1984, 1997; Monod, 1977; Gutnic et al., 1979; Görür et al., 1998; Demirtaşlı et al., 1984; Andrew and Robertson, 2002; Mackintosh and Robertson, 2012; McPhee et al., 2018b), and also in the western Taurides (De Graciansky, 1972; Poisson, 1977; Şenel et al., 1989; Collins and Robertson, 1997, 1998, 1999; Robertson et al., 2013a; Pourteau et al., 2016). However, a similar interpretation is problematic in the eastern Taurides for three main reasons: (1) Thrust relations: A thrust is not mapped regionally along the northern margin of the Gürün autochthon, between the Eocene succession and the Northern allochthon (MTA, 2011; Bedi and Yusufoğlu, 2018), although as noted above, a thrust contact has been observed locally (Robertson et al., 2016). (2) Regional melange distribution: The Kemaliye Formation, as exposed above the Malatya (Keban) metamorphics in the Nurhak Dağ area (Area 3b), includes clasts and blocks derived from the Malatya and/or Köseyahya thrust sheets, strongly suggesting that allochthon reached quite far south (10s km) of the Gürün autochthon during the latest Cretaceous. In this case, the allochthon cannot have remained to the north of the Gürün autochthon until the Eocene. (3) Cover relations: In the east, the Southern allochthon is locally covered and sealed by late Maastrichtian-Eocene sediments of the Darende Basin (Fig. 2). Along the western margin of the Darende basin (E of the bounding neotectonic Gürün fault) specifically, allochthonous units, correlated with the Dağlıca ophiolite, are unconformably overlain by conglomerates that pass upwards into Maastrichtian marls and limestones, together with lenticular rudist build-ups (Kırankaya Formation). Further north, along the western margin of the Darende basin, Maastrichtian sediments unconformably overlie the Munzur limestone thrust sheet. Also, the Darende basin is transgressive on an equivalent of the Munzur thrust sheet and related ophiolitic melange around its eastern margin (Booth et al., 2013). After a Palaeocene-Early Eocene hiatus, the sedimentary succession passes into Middle Eocene mixed siliciclastic/shallow-marine carbonates, with localised lenticular volcanics, and then into Bartonian-early Priabonian regressive facies (Gürbüz and Gül, 2005; Bedi et al., 2009; Booth et al., 2013). There is no evidence of increasing deformation upwards that could relate to regional overthrusting. Any post-Cretaceous southward emplacement of the Southern allochthon would instead need to entrain the Darende Basin as a whole above an unexposed deeper-level regional-scale thrust. This requirement would probably also apply to the Hekimhan Basin farther northeast (Booth et al., 2014). However, there is no evidence that the Darende and Hekimhan basins are parts of a regional-scale Eocene thrust sheet; e.g. no frontal thrust is exposed to the south. In summary, southward emplacement of the Southern allochthon over the Gürün platform succession during, or after, the Eocene seems unlikely.

The second hypothesis is that the southern and northern allochthons were emplaced from opposite directions during the latest Cretaceous, with the Gürün autochthon in between (van Hinsbergen et al., 2020) (Fig. 27bi-bii). This is problematic for several reasons: (1) The tectono-stratigraphy of both allochthons is very similar and does not indicate different palaeogeographic origins; (2) The northward thrusting of the Malatya Metamorphics that affects the Southern allochthon (e.g. İncirlik area) took place during the Cenozoic because post-Cretaceous sediments are structurally interleaved; (3) The tectono-stratigraphy of the E Tauride allochthons, combined, differs markedly from the South-

Tauride allochthonous units; e.g. in the Adıyaman and Antalya areas (Robertson et al., 2012).

The third hypothesis is that both of the allochthonous units were assembled by southward thrusting during the latest Cretaceous but in separate areas; subsequently the Gürün autochthon and the already emplaced Northern allochthon were displaced northeastwards (> 60 km) along the Güksu fault zone of Kozlu et al. (1990) to their present positions, probably during the Mid-Late Eocene (Robertson et al., 2013b). This hypothesis is consistent with the southwestward lateral passage of the Gürün autochthon into the Geyik Dağ (Tauride platform) (e.g. in the Tufanbeyli-Saimbeyli-Feke-Kozan area) (MTA, 2011). However, there are also problems with the right-lateral strike-slip hypothesis: (1) There is no single clear-cut fault (terrane boundary fault) separating the Gürün autochthon from the Southern allochthon; instead, strike-slip faults transect both the northern part of the Southern allochthon and the southern part of the Gürün autochthon (Robertson et al., 2013b; (2) Right-lateral strike-slip faults of appropriate c. NE-SW orientation are indeed present (Robertson et al., 2013a; Supplementary Fig. 11) but these appear to post-date the northward-directed displacement and folding of probable Mid-Late Miocene age. A possible explanation is that eastward displacement of the Gürün autochthon/northern allochthon, relative to the Southern allochthon, did indeed take place along the Eocene Göksu fault zone of Kozlu et al. (1990) but this lineament was over-ridden and concealed during the later folding and thrusting. The documented right-lateral neotectonic strike-slip faulting along this lineament could have reactivated such a buried lineament. The dextral strike-slip faults were overprinted by the dominantly Plio-Quaternary left-lateral faults affecting the region in this interpretation.

In summary, both the southern and the northern allochthons were emplaced southwards onto the Tauride platform during latest Cretaceous time. The right-lateral ‘terrane displacement’ interpretation is the most promising of the three options and could also help to explain the regional east-directed Gürün curl (see Supplementary Fig. 1). In this case the regional-scale ‘tectonic escape’ buckled the regional tectono-stratigraphy to form the ‘curl’.

12.2. Relation between the Malatya Metamorphics and the Southern allochthon

Malatya Metamorphics encompass a Late Palaeozoic-Late Cretaceous stratigraphy, consistent with a relatively internal part of the Tauride continent. No marginal (slope) units are exposed. Assuming regional in-sequence thrusting, the Triassic-Late Cretaceous successions of the Munzur and Köseyahya thrust sheets appear to represent northerly parts of the Tauride continent that detached from their basement and were emplaced southwards (Fig. 27a-c). During the Late Cretaceous, the more southerly located (Malatya) platform (>75 km wide) was deeply underthrust northwards and metamorphosed under up to amphibolite, or possibly low HP-LT conditions. This was associated with the intrusion of the unmetamorphosed Baskil granitoids (88-82 Ma) (Bozkaya et al., 2007; Bedi et al., 2009; Oberhansli et al., 2012; Rolland et al., 2012; Bedi and Yusufoğlu, 2018) (Fig. 27d).

In the northeast of the region, c. 100 km north of the main Malatya metamorphic outcrop) there is a small outcrop that comprises Late Palaeozoic schist, overlain by Late Permian meta-carbonates, Middle Triassic-Jurassic meta-platform carbonates and Late Cretaceous meta-clastics/carbonates with meta-carbonate blocks (c. 40 km SW of Divriği; Alacahan-Çetinkaya area; M on Fig. 2)) (Atabey and Aktimur, 1997; MTA, 2011; Robertson et al., 2013b; Beyazpirinç and Akçay, 2013). The succession is comparable to the Malatya Metamorphics, including the Late Cretaceous Karaböğürtlen Formation, suggesting that Malatya metamorphic crust may extend far northwards beneath the Mesozoic allochthonous units. However, it is also possible that the above outcrop represents the metamorphosed northern margin of the Munzur platform (otherwise not exposed).

In the northeast of the region (NW of Pınarbaşı), Hınzır Dağı and Korumaz Dağı (E of Kayseri) there is an additional, sizeable outcrop of high-grade metamorphic rocks including schist, gneiss and meta-platform carbonates, ranging in age from Carboniferous to Cretaceous (Özer et al., 1984; Pourteau et al., 2010; MTA, 2011; unpublished data). These rocks may correlate with the HP-LT Tavşanlı zone and/or the Afyon zone of the Anatolides (Oberhansli et al., 2012; Pourteau et al., 2013), although more study is needed to confirm this correlation.

The Malatya Metamorphics exhumed rapidly (Robertson et al., 2013b), at least partially, as indicated by the latest Cretaceous transgressive cover in the Malatya area (Gündüzbey Formation) (Bedi and Yusufoğlu, 2018). The Kemaliye Formation, extending southwards from its type area near Kemaliye (Area 5A) for at least c. 120 km to Nurhak Dağı (Area 3B), includes metamorphic debris from the Malatya Metamorphics and unmetamorphosed material from the Tauride allochthons, indicating that these two units were juxtaposed during the latest Cretaceous. The Kemaliye Formation in its type area accumulated during and/or very soon after exhumation of the Malatya Metamorphics. The basal unconformity is interpreted as an eroded extensional detachment, explaining the presence of high-strain lithologies (e.g. calc-schist; mylonite) near the top of the Malatya metamorphics (Fig. 16i), and also as clasts in the overlying Kemaliye Formation. The Munzur and Köseyahya thrust sheets were later re-activated and thrust farther south over the Kemaliye Formation in the above areas, probably during the Mid-Late Eocene (Figs. 22a).

The exposure of serpentinised harzburgite with small granitic intrusions that is sliced between the Malatya metamorphics and the Kemaliye Formation ENE of Begre (Fig. 22a) is interpreted as a fragment of the Göksun ophiolite and its granitic intrusions, as widely exposed farther south. Compressional deformation (Mid-Late Miocene?) caused the cross-cutting cleavage and cataclasis observed within the siliciclastic matrix of the Kemaliye Formation in the south (Nurhak Dağı; Area 3B; see above). The overall evidence points to complex multiphase displacement involving both the Malatya (Keban) metamorphics and the Munzur-Köseyahya carbonate platform, during Late Cretaceous, Mid-Late Eocene and Mid-Late Miocene (?).

12.3. Reconstruction of the allochthonous Tauride platform

Alternatives are: First, the Neritic-pelagic (Köseyahya) unit represents a basin within the Munzur shelf. Secondly, the Munzur carbonate platform succession passed northwards into the Neritic-pelagic (Köseyahya) platform (i.e. shalf-ramp) and then into the ocean (Fig. 26 a,b) (preferred reconstruction).

The first alternative (intra-platform basin) is hinted by the structural position of the Neritic-pelagic (Köseyahya) succession beneath the main Munzur thrust sheet in the Southern allochthon (Area 4; Fig. 9). However, against this: (1) No marginal facies of an intra-platform basin are exposed; (2) The Neritic-pelagic thrust sheet also occurs above the Munzur thrust sheet in the Northern allochthon suggesting that it restores to the north, regionally (MTA, 2011; Robertson et al., 2013b). In the second, preferred option, initial southward emplacement of the Tauride platform units during the latest Cretaceous (see above) was accompanied by complex out-of-sequence thrusting, explaining why the Neritic-pelagic (Köseyahya) thrust sheet is locally above the main Munzur thrust sheet (e.g. Area 4; Fig. 9). The distal edge of the Neritic-pelagic (Köseyahya) platform is therefore represented by the Pelagic (Gülbahar) unit, with oceanic crust, including inferred seamounts to the north (Fig. 28c,d).

12.4. Ophiolite and melange emplacement; relation to units farther north

The East Tauride SSZ-type ophiolites were emplaced southwards onto the Tauride platform, represented by the Munzur and Neritic-pelagic (Köseyahya) successions, together with passive margin slope units (Pelagic (Gülbahar) unit) and oceanic sediments and igneous rocks (accretionary melanges) (Figs. 28 e; 29 a-c). The driving force in the southward emplacement was the collision of the regional-scale supra-subduction zone Tauride ophiolite with the Tauride passive margin (Robertson et al., 2013b). The inferred tectonic organisation at the end of the Cretaceous is summarised in Figure 30. By the late Maastrichtian, the Malatya metamorphics were partially exhumed and eroded, while the ophiolites were also partially eroded, producing a variable palaeotopography that was smoothed by clastic debris and transgressed by a shallow sea; this deepened in places during the Palaeocene, as indicated by fragmentary pelagic carbonates (Fig. 21e, f).

Alternatives for the source of the ophiolites are:

Option 1: All of the ophiolites, including those overlying the Arabian continent were derived from a single Mesozoic Tethys to the north (Ricou et al., 1984) (Fig. 31 ai-aii), although this is generally discounted nowadays (Robertson and Dixon, l984; Stampfli and Borel, 2002; Sosson et al., 2010; Rolland et al., 2012; van Hinsbergen et al., 2020);

Option 2: The ophiolites in the area studied (e.g. Pınarbaşı, Divriği) and those to the south of the Malatya Metamorphics (Göksun (N Berit), Kömürhan, İspendere) were derived from a single oceanic basin located within Neotethys to the east and northeast (Stampfli et al., 2001; Stampfli and Borel, 2002; Moix et al., 2008; Sosson et al., 2010; Rolland et al., 2012, 2016, 2020; van Hinsbergen et al., 2020; see Fig. 31 bi-bii).

In one such scenario (Maffione et al., 2017), oceanic lithosphere was generated by intra-oceanic SSZ-spreading, followed by generally southwestward roll-back and c. 90^{o} anticlockwise rotation of the subducting oceanic plate. Collision with continental blocks emplaced ophiolites both southwards (i.e. Southern allochthon) and also northwards (i.e.

Göksun (N Berit), Kömürhan, İspendere) onto the Malatya metamorphic crust. The metamorphism relates to attempted bidirectional subduction during ophiolite emplacement (Fig. 30). An Inner Tauride basin (rift or small ocean) did not exist or, if present, sutured prior to overthrusting by the late Cretaceous ophiolites (Poisson et al., 1996; Hinsbergen et al., 2016).

In another, related scenario, the ophiolites were emplaced generally towards the south-west, over a single Anatolide-Tauride-S Armenian continent (i.e. without an Inner Tauride ocean) during the late Cretaceous (c. 75 Ma), all derived from the northern Neotethys. The ophiolites of the northern Neotethys (İzmir-Ankara-Erzincan suture zone) correlate with those of the Lesser Caucasus in Armenian and Georgia to the east, representing remnants of an enormous (700 km long x 1-200 km wide) slab of oceanic lithosphere that was emplaced onto continental crust during latest Cretaceous time (Sosson et al., 2010; Rolland et al., 2012, 2016, 2020; Rolland, 2017; Hässig et al., 2013a, b). Metamorphic soles of all of the ophiolites are similar in age (to within 10 Ma) suggesting that the ophiolites were emplaced together. Subduction of the ocean was either northwards, away from the continent (Sosson et al., 2010; Rolland et al., 2012, 2020), or southwards, towards the continent (Hässig et al., 2015). Southward obduction was facilitated by Cretaceous within-plate magmatism, documented in the Lesser Caucasus; this rendered the ophiolitic lithosphere relatively hot and mobile at the time of emplacement (Hässig et al., 2016). Syn-post emplacement extensional core-complex development thinned the oceanic lithosphere and facilitated southward emplacement of ophiolites and related continental margin units in this interpretation (Rolland et al., 2020).

The above option (in its variants) is also problematic: (1) The allochthonous Tauride units restore as a Permian-Triassic to Late Cretaceous rift/passive margin to an oceanic basin further north. The emplacement of the continental margin, oceanic crust (melange) and ophiolitic units are intimately related, coeval, and cannot be separated into a sutured Inner Tauride Basin and overthrust ophiolites (relevant to the Maffione et al., 2017 model); (2) the ophiolites in the E Taurides (e.g. Pınarbaşı and Divriği) are Late Cretaceous (Parlak et al., 2013), whereas ophiolites further north within the Ankara-Erzincan suture zone (northern Neotethys) are Early- Late Jurassic (Dilek and Thy, 2006; Robertson et al., 2013c; Çelik et al., 2013; Hässig et al., 2013). Both ophiolites formed in a supra-subduction setting, apparently related to northward subduction and cannot be treated as a single ophiolite of the similar age and tectonic setting (cf. Rolland et al., 2020); (3) Regional mapping (Bedi and Yusufoğlu, 2018) and our structural data (Fig. 26) are consistent with generally N to S emplacement of the allochthonous Tauride units (in present coordinates) during the latest Cretaceous (e.g. Area 2), without evidence of thrust sheets traversing the area obliquely, as suggested by hypothesis two (cf. van Hinsbergen et al., 2016; Maffione et al., 2017); (4) Evidence was not observed in our present field area to support emplacement of the Late Cretaceous ophiolites by core complex-related gravity sliding (Hässig et al., 2016; Rolland et al., 2020). Instead, the field evidence suggests that the ophiolites were relatively intact when emplaced but were thinned in response to later multi-phase deformation and erosion.

Option 3. The Tauride and Pontide-Lesser Caucasus ophiolites represent different supra-subduction spreading events, which both culminated in Late Cretaceous regional ophiolite emplacement (Parlak et al., 2012; Robertson et al., 2013c) (Fig. 31ci, cii). During the Triassic, sea-floor spreading created oceanic lithosphere to the north of the Tauride-Anatolide continental block. The Kırşehir continental unit represents a rifted continental fragment with oceanic lithosphere potentially to the south and the north (e.g. Görür, et al., 1984; Robertson et al., 2012; Barrier et al., 2018). The Jurassic Pontide-Lesser Caucasus ophiolite formed in the Early-Mid Jurassic when oceanic lithosphere to the north of the Kırşehir continental unit started to subduct northwards (Dilek and Thy, 2006; Robertson et al., 2013c; Topuz et al., 2013a). During the Late Cretaceous, plate convergence triggered the genesis of the Late Cretaceous Tauride ophiolites above a N-dipping subduction zone. To the west and east of the Kırşehir continental unit Jurassic and Cretaceous oceanic crust were effectively contiguous with no exposed intervening suture. The Tauride ophiolites were obducted by regional trench-passive margin collision during the latest Cretaceous, which emplaced the Late Cretaceous ophiolites and related melanges throughout the eastern, central and western Taurides as a whole (Görür et al., 1984; Andrew and Robertson, 2002; Clark and Robertson, 2002; Okay et al., 2001; Kadıoğlu et al., 2006; Nairn et al., 2013, Robertson et al., 2013c; Lefebvre et al., 2013b; Darin et al., 2018; Scleiffarth et al., 2018; Legeay et al., 2019). The leading of the colliding Tauride passive margin, represented by the Anatolide crustal block, subducted and underwent HP-LT metamorphism (Pourteau et al., 2010, 2013). Uncertainties with the above option include: i) The absence of an exposed suture between the E Taurides and Pontide ophiolites, although one may exist subsurface; ii) The lack of definitive evidence that Late Cretaceous ophiolites farther west (i.e. Pozantı-

Karsantı and Alihoca ophiolites) originated to the south of the Kırşehir crustal block. In summary, the evidence discussed in this paper is consistent with, but not definitive of, ophiolite emplacement from an Inner Tauride ocean that was located to the south of the Mid-Late Jurassic oceanic crust that characterises the İzmir-Ankara-Erzincan suture zone.

14.5. Malatya metamorphics: relation to adjacent crustal units

There are three main options:

A first option is that the Malatya metamorphics directly correlate with the Afyon zone (Anatolides). The Afyon zone (Bolkar nappe) is restored to a northerly position relative to the unmetamorphosed Aladağ nappe (Özgül, 1984; Pourteau et al., 2010, 2013; Mackintosh and Robertson, 2012). By extension, the Munzur-Köseyahya platform originated as the southward extension of the Malatya carbonate platform. Problems, however, with this are: (1) The Malatya metamorphics are cut by the c. 88-82 Ma Baskil granitoids, which are attributed to northward subduction from an oceanic basin to the south (Berit ocean), suggesting a relatively southerly location (Rızaoğlu et al., 2006, 2009; Karaoğlan et al., 2012, 2016) (Fig. 30); (2) In contrast, the Afyon zone lacks comparable intrusives suggesting a different palaeogeographic setting; (3) Option 1 implies northward deep-level underthrusting of the Malatya platform, followed by exhumation, large-scale out-of-sequence southward thrusting to place the metamorphics in their present structural order beneath the allochthonous Tauride platform units (van Hinsbergen et al., 2020). However, there is no obvious evidence of such regional-scale re-thrusting during either the latest Cretaceous or the Eocene regional tectonic events (e.g. metamorphic klippen or foredeeps with metamorphic detritus are absent). Regional southward emplacement of the northerly ophiolites (Göksun (N Berit), Kömürhan, İspendere) over the entire Tauride platform, followed by re-imbrication beneath, as proposed by van Hinsbergen et al. (2020), is also problematic. The base of the tectonic contact between the Malatya metamorphics and the Göksun ophiolite beneath is cut and sealed by the 83-81 Ma (Santonian-Campanian) Esence granites (Karaoğlan et al., 2016), whereas the northerly ophiolites were emplaced southwards only after deposition of the Albian-Santonian Kızılkandil Formation and the overlying late Campanian-late Maastrichtian Kemaliye Formation (based on nannofossil dating).

A second option is that the Afyon zone and the Malatya metamorphics do indeed correlate laterally but that the Munzur-Köseyahya platform units represent a separate platform that was located to the northeast of the Geyik Dağ (Tauride autochthon). The main problem with this interpretation is the absence of any preserved platform-slope facies (e.g., deep-water slope facies and radiolarites) that could indicate the presence of a rifted margin to the Malatya platform in the north (Perinçek and Kozlu, l984; Kozlu et al., 1990; Bedi et al., 2009; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018). Also, there is no evidence of a southern rifted margin to the Munzur-Köseyahya platform in the south, which would be expected in this alternative. However, it is possible that such margin units existed but are not exposed.

A third option is that the present regional-scale tectono-stratigraphy retains the latest Cretaceous emplacement organisation. In this case, the Malatya and Afyon units, despite undergoing similar metamorphism, did not form a continuous litho-tectonic unit. The Afyon zone originated further northwest, whereas the Malatya metamorphic originated further southeast (possibly offset by a c. N-S transform). The Munzur-Köseyahya platform formed a separate crustal block to the northeast. The Malatya metamorphics originated by collapse of the putative basin between the separate Malatya and Munzur Köseyahya platforms (see above). Such a basin might have formed during Triassic rifting. Collapse of the inferred intra-platform basin might have been driven by compression between two N-dipping subduction zones (Berit/Göksun in the S; Inner Tauride in the N).

In the absence of field evidence of major tectonic re-ordering as required in options 1 and 2, we favour option 3, which implies major palaeogeographic changes between the central and eastern Taurides. It seems likely that the central Tauride platform (Geyik Dağ) narrowed eastwards (Fig. 30), close to the future position of the neotectonic Sürgü-Misis fault zone. To the west, the southern part of the Tauride platform (Geyik Dağ) was not covered by the late Cretaceous south-moving allochthons. In contrast, farther east part of the Tauride platform represented by the Malatya metamorphics, underthrust/subducted northwards beneath more northerly Tauride crust (Munzur-Köseyahya platfors) (Fig. 30cii).

Restoring the reported c. 29 km left-lateral offset along the neotectonic Malatya-Ovacık Fault Zone (Westaway and Arger, 2001) still leaves the type outcrop of the Munzur platform in the Munzur Dağları (Fig. 2) c. 80 km to the north of its counterpart within the Southern allochthon (Munzur thrust sheets). The Tauride (Munzur) platform could, therefore, have stepped northwards towards the northeast, bounded by one or more c. N-S transcurrent faults. However, it is unclear whether this would be entirely a Mesozoic palaeogeographic feature or if it could relate to latest Cretaceous-Eocene (pre-Neogene) tectonics. In either case, pre-existing faults are likely to have been re-activated to form many of the major neotectonic faults seen today. In the absence of continuous exposure, or subsurface evidence (e.g., borehole or seismic reflection) it is, therefore, uncertain as to whether or not the South Armenian platform in the Lesser Caucasus simply represents the eastward extension of the Tauride continent. Previously, the two platform exposures were inferred to be parts of a single large continental unit mainly because of similar late Cretaceous ophiolite emplacement in both areas (Sosson et al., 2010; Rolland et al., 2012). However, an origin as two separate platforms is not precluded.

The Malatya and Bitlis-Pütürge metamorphic units (Fig. 1) have also been considered to represent, respectively westerly and more easterly segments of a single southerly active margin of the Tauride continent, with the Southern Neotethys to the south (Barrier et al., 2018). However, the Malatya and Bitlis-Pütürge continental units are separated by the Late Cretaceous supra-subduction Göksun (N Berit), Kömürhan, İspendere and Yüksekova ophiolites, interpreted as an intervening ocean basin (Robertson et al., 2006, 2012; Rolland et al., 2012; Candan et al., 2014; Çetinkaplan et al., 2016; Barrier et al., 2018). The available evidence is consistent with the existence of a southerly oceanic basin (Berit, or Göksun ocean) that subducted northwards beneath the Malatya-Tauride platform during latest Cretaceous (Fig. 30). The ophiolites (Göksun, İspendere and Kömürhan), dated at c. 87-85 Ma, formed above a subduction zone and include immature arc volcanics (Parlak et al., 2009). The volcanics of the above ophiolites can also be broadly correlated with the Late Cretaceous Yüksekova complex (dated at c. 83-75 Ma) (Karaoğlan et al., 2013), which is traditionally interpreted as an immature oceanic arc (e.g. Ural et al., 2015 and references).

As noted above, the Göksun SSZ-type lithosphere was emplaced beneath the Malatya Metamorphic crust, where both were intruded by subduction-related granitic rocks (88-82 Ma Baskil intrusives) (Karaoğlan et al., 2016: Parlak, 2006; Rızaoğlu et al., 2009). The Baskil intrusives include shoshonitic compositions (dated at 74–72 Ma), suggestive of collisional and/or post-collisional settings (Ertürk et al., 2018; Kuşcu et al., 2013; Sar et al., 2019). This is consistent with the collision of the Bitlis-Pütürge continental units to the south with the Tauride continent to the north (Malatya Metamorphics) thereby closing the Berit ocean. In many reconstructions, some oceanic crust (Southern Neotethys) existed between the Bitlis-Pütürge continental units and the Arabian continent. The initial closure of this ocean basin and collision with Arabia may have occurred during the Mid-Late Eocene, but the main collision took place during the Mid-Late Miocene (Aktaş and Robertson, 1984; Yılmaz, 1993; Robertson et al., 2012a; Rolland et al., 2012, 2020; Barrier et al., 2018; van Hinsbergen et al., 2020).

Conclusions

-The well-exposed eastern Taurides provide important insights into Tethyan palaeogeography and tectonic development, including the unusual Gürün curl structure.

-The region is restored as part of the northern rifted margin of the Tauride continent.

-Rifting took place during the Triassic, separating a shallow-water carbonate platform to the south from a deep-water proximal to distal slope and ocean basin to the north (Inner Tauride ocean).

-The regional Tauride carbonate platform (Geyik Dağ) is proposed to have narrowed and become more palaeogeographically varied towards the eastwards, mainly represented, in the E Taurides, by the Malatya Metamorphics and the unmetamorphosed Munzur and Köseyahya platform units.

-The restored northern part of the shallow-water combined Munzur-Köseyahya platform subsided during the Mid-Jurassic to form a gently sloping, deeper-water ramp near, or beneath, the carbonate compensation depth.

-The Munzur-Köseyahya platform slope was covered by pelagic carbonate during the Late Cretaceous, probably related to regional tectonic subsidence (rather than global sea-level rise).

-Dismembered deep-sea sedimentary and volcanic units exposed over a wide area are restored as the former Triassic-Cretaceous deep-water passive margin slope/base of slope of the Mesozoic carbonate platform (Pelagic (Gülbahar) unit).

-Oceanic lithosphere formed above a subduction zone in the ocean (Inner Tauride ocean), generally to the north (Pınarbaşı, Dağlıca, Hekimhan, Kuluncak and Divriği (and Güneş) ophiolites), with associated formation of ophiolite metamorphic sole (although only locally preserved).

-Local, fragmentary successions of mainly within-plate-type basalts and radiolarian cherts/pelagic limestones are interpreted as accreted/emplaced Jurassic-Cretaceous oceanic seamounts.

- Associated with emplacement of the Late Cretaceous ophiolites, the Tauride passive margin underwent flexural loading and collapse to form a foredeep (late Campanian-Maastrichtian). Talus in the form of gravity flows, blocks and disrupted sheets was shed into the basin, mainly from the platform/slope units, and the advancing ophiolites/accretionary melanges.

-During the latest Cretaceous (late Campanian-late Maastrichtian), the SSZ ophiolites were emplaced generally southwards onto the Tauride platform, in some areas as relatively intact sheets (c. 6 km thick) (e.g. Pınarbaşı ophiolite), but elsewhere as dismembered units, melanges and ophiolite-related debris flows (i.e. Dağlıca ophiolite and melange).

-During its late Cretaceous southward tectonic transport, the allochthonous carbonate platform was locally re-thrust, in places putting the restored southerly neritic carbonate platform (Munzur thrust sheet) over the more northerly-derived deeper water facies (Köseyahya thrust sheet).

-Mixing of clastic debris (Kemaliye Formation) that derived from both the over-riding Tauride allochthons and the Malatya Metamorphics shows that both were tectonically juxtaposed (in close proximity) during the latest Cretaceous regional emplacement.

-The Malatya Metamorphics were at least partially exhumed by the late Maastrichtian as they are covered and sealed by latest Cretaceous sediments, that include metamorphic and granitoid debris.

-The Malatya Metamorphics were tectonically juxtaposed with the Göksun (and related ophiolites) to the south during the latest Cretaceous. Both are cut and sealed by the 88-82 Ma Baskil granitoids. The latest Cretaceous marine sedimentary cover of the Göksun ophiolite includes detritus from both the metamorphics and the unmetamorphosed Tauride units, pointing to rapid exhumation.

- Following Eocene shelf-depth deposition, folding and re-thrusting took place widely during the Mid-Late Eocene. However, the co-intrusion of the Güksun ophiolite and Malatya Metamorphics by the Late Cretaceous granites (Baskil granites) shows that these two regional-scale crustal units were not displaced a large distance relative to each other (i.e. >several km) after the latest Cretaceous.

-Allochthonous units were first juxtaposed with the relatively autochthonous Gürün platform succession (as presently exposed) during Mid-Late Eocene. In the absence of clear evidence that the allochthonous Tauride units to the north (Northern allochthon) were emplaced southwards over the autochthonous Gürün platform during this time, an alternative is that the Southern allochthon and the Gürün platform/Northern allochthon were brought together by >60 km of right-lateral transport during Mid-Late Eocene (i.e. as a result of collision-related 'tectonic escape').

-The Mid-Late Eocene deformation (folding and thrusting) is explained by thick-skinned deformation, driven by suturing of the İzmir-Ankara-Erzincan ocean (northern Neotethys).

- Mid-Late Miocene folding and thrusting (northwards in several areas) is explained by suturing of the Southern Neotethys and collision with Arabia.

-The available evidence is mainly consistent with the former existence of an Inner Tauride ocean, comprising Late Cretaceous supra-subduction zone oceanic crust, that was separate from more northerly supra-subduction zone oceanic crust, of Mid-Late Jurassic age, within the İzmir-Ankara-Erzincan suture zone farther north.

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Figure captions

Fig. 1. Outline map of Turkey showing the main tectonic units and the study area (main data source, MTA 2012).

Fig. 2. Simplified geological map and cross-section of part of central eastern Anatolia, simplified from MTA 1:100,000 and 1:250,000 geological maps of Turkey (MTA, 2011). The area studied is divided into 5 sub-areas, as indicated: Area 1-NE, i.e. mainly NW of Elbistan, including the Afşin area; Area 2-Dağlıca area, farther NW of Elbistan; Area 3A-East of Elbistan, 3B-farther east, near Nurhak Dağı; Area 4-S-mainly south of Elbistan; Area 5A-Kemaliye area, 5B Divriği area (both in the far NE). Additional geological units mentioned in the text: AE Afşin-Elbistan basin; DB Darende basin; GO Göksun ophiolite; GF Göksu Fault; SGF Sürgü-Misis Fault*;* İO İspendere ophiolite; KO Kömürhan ophiolite; KU Kuluncak ophiolite. Additional locations and settlements mentioned in the text: B Büyük Yılanlı Dağ; K Kangal (off map in central N, as indicated); N Nurhak Dağı; S Saimbeyli (just off map in SW); Y Yeşildere.

Fig. 3. Stratigraphical columns showing the age and lithologies of the main geological units discussed in this paper. See text for explanation and data sources.

Fig. 4. Field photographs of key features of the Malatya metamorphics in the area north and west of Elbistan (Area 1). a, Eocene shelf limestones (Seske Fm.) above Malatya Metamorphics; in places the two units are intersliced, Kepez Mah. (in foreground); GPS 37S 0303484/4230790; b, Foliated amphibolite; Late Palaeozoic; 0.5 km S of Türkören; c, Normal-graded debris-flow deposit with carbonate clasts in a coarse calcarenite matrix; recrystallised to micaceous marble; Late Palaeozoic; near Kepez, W of Afşin; GPS 37S 0303518/4229825; d, Isoclinally folded limestone with replacement chert, Late Permian; Saldılek Tepe, NE of Afşin; GPS 37S 0322749/4239163; e, Thin-bedded micritic limestone and dolomite (stromatolitic); Late Triassic; west of Afşin GPS 37S 0303484/4230790; f,

Network of tension cracks infilled with pink micrite (recrystallised); within upper c. 50 m of mapped Late Permian meta-limestone succession; beneath the Karaböğürtlen Formation; GPS 37S 0329702/4236079; g, Debris-flow deposit composed of platy limestone clasts, recrystallised to marble; several m above mapped normal contact with Late Permian meta-limestone; Karaböğürtlen Formation; GPS 37S 0329013/4236061; h, Debris-flow deposit with flattened clasts in a calcareous mudstone matrix; recrystallised to marble; Karaböğürtlen Formation; GPS 37S 0328678/4235639; i, Foliated pebbly conglomerate; clasts mainly sub-rounded; mostly siliceous calc-schist; Malatya metamorphic unit; near Kamalak köy, SSW of İncirli; Karaböğürtlen Formation (GPS 37S 0304287/4250123); j, Blocks of recrystallised limestone (marble), interbedded with carbonate-rock debris-flow deposits and phyllite (Karaböğürtlen Formation); represents the leading edge of the Malatya metamorphic unit (backthrust to N); c. 1 km SE of İncirli (GPS 37S 0307627/4251659); k, Recrystallised limestone (marble) with reworked Megalodont bivalves (Karaböğürtlen Formation); NW of Afşin, GPS 37S 0322629/0239403; l, Kemaliye Formation (foreground), with serpentinite above (Dağlıca ophiolite); overthrust (northwards) by the Malatya Metamorphics (Karaböğürtlen Formation); NW of İncirli.

Fig. 5. Part of the northeast outcrop of the Malatya Metamorphics (Area 1; NW of Elbistan; Fig. 2). Simplified geological map; note the relation of the Late Cretaceous syn-tectonic Karaböğürtlen Formation to the underlying units; modified from Bedi et al. (2009). Logs: 1, Late Palaeozoic succession including meta-basic extrusive rocks (west of Afşin); 2, Triassic siliciclastic-carbonate facies; 3, Late Cretaceous Karaböğürtlen Formation with carbonate and siliciclastic intercalations. Rock-relations diagrams: a, Latest Cretaceous sedimentary cover of the Göksun ophiolite (Harami Fm.), overthrust by the Malatya Metamorphics; 3 km SE of Afşin; b, Jurassic-Cretaceous (?) succession, unconformably overlain by the Late Cretaceous Karaböğürtlen Formation; 6 km E of Afşin; c, Permian succession unconformably overlain by Late Cretaceous Karaböğürtlen Formation; NE of Körkuyu.

Fig. 6. Photomicrographs of sandstone of the Late Cretaceous Karaböğürtlen and Kemaliye formations. Stratigraphy: a-b Karaböğürtlen Formation (Malatya Metamorphics); c-g Kemaliye Formation above the Malatya (Keban) Metamorphics (Areas 1 & 5A); h-i Kemaliye

Formation related to the Munzur limestones; j, Kemaliye Formation beneath the Köseyahya thrust sheet; k-l Maastrichtian cover of the Göksun ophiolite. Composition: a, Rounded grains of monocrystalline quartz and polycrystalline quartz (quartzite) in a recrystallised calcareous matrix; crossed polars; c. 10 km W of Elbistan; GPS 37S 0330991/4230104); b, Note the large rounded, then fragmented quartz grain, with cracks infilled by calcite spar, suggesting high-strain deformation; location as a; c, Poorly sorted sandstone with common monocrystalline quartz, polycrystalline quartz and muscovite in a quartz-rich, granular calcareous matrix; crossed polars; Area 3B (Nurhak Dağı, near Beğre); GPS 37S 0393334/4227050; d, Poorly sorted sandstones with abundant grains of neritic limestone (partly recrystallised), polycrystalline quartz and muscovite (deformed); crossed polars; location as c; e, Poorly sorted sandstones including grains of neritic limestone (partly recrystallised) and basalt (relatively fresh and chloritised); plane-polarised light; location as c; f, Granitic grain from conglomeratic lens; crossed polars; location as c; g, Large alkali feldspar crystal (upper right), together with monocrystalline quartz, other feldspar and microcrystalline quartz in a calcareous and quartz-rich matrix; crossed polars; location as c; h, Sub-rounded clast of fine-grained meta-siltstone (central), together with muscovite (large lath), polycrystalline quartz (left, central), and bioclastic limestone (e.g., upper left); crossed polars; location as c; i, Sub-rounded grains of dark chert (veined and recrystallised) and partly recrystallised siltstone in a quartz- and carbonate-rich matrix; crossed polars; location as c; j, Micaceous sandstone with common monocrystalline quartz, polycrystalline quartz and muscovite, cemented by sparry calcite; near Bakış, east of Elbistan; GPS 37S 0361782/4222559; k, Bioclastic limestone with common bivalve shell fragments, planktic foraminifera and a dark, bituminous schistose grain; cover of the Göksun ophiolite; SW slope of Aktaş Tepe; plane-polarised light; GPS 37S 0318668/4232060; l, Bioclastic limestone, including large grain of relatively well-rounded microcrystalline quartz; crossed polars; same sample as k. Key to letters: B Bioclastic carbonate, BA Basalt, BI Bivalve, C Carbonate (calcite), CH Chert, F Feldspar (alkaline), G Granitic lithoclast, Mq Monocrystalline quartz, M Muscovite, N Neritic limestone, PL Planktic foraminifer, Pq Polycrystalline quartz, S Siltstone, SH Schistose lithoclast.

Fig. 7. Outline geological map and local sections (a-f) of Area (Dağlıca). Based on mapping by Perinçek and Kozlu (1984), Bedi et al. (2013), Robertson et al. (2013b) and this study. The

location of the rock-relations diagrams and the logs (roman numerals Va,b,c, VI, VIII and IX; see Fig. 11 for I-IV) are indicated. a, The lower Munzur thrust sheet is overlain by the Kemaliye Formation and the dismembered Dağlıca ophiolite. The Kırmızı Kandil Formation and the Kemaliye Formation are exposed above the upper Munzur thrust sheet; NW of İncirli; b, Munzur thrust sheet in the north, unconformably overlain by conglomerates (Miocene?), with well-rounded clasts including Eocene nummulitic limestone; NW of Tavla; c, Relatively autochthonous succession (Gürün autochthon), overthrust by a Munzur thrust sheet; near Dallıkavak; d, Lower Munzur thrust sheet, overthrust by the dismembered Dağlıca ophiolite and by an upper Munzur thrust sheet; e, Blocks of the Dağlıca ophiolite within ophiolite-derived debris flows, overthrust by an upper Munzur thrust sheet; Tatlar area; f, Lower Munzur thrust sheet including the Kırmızı Kandil Formation and the Kemaliye Formation; near Elmalı.

Fig. 8. Outline geological map (simplified from Bedi et al., 2009) and local rock-relations diagrams in Area 3A (E of Elbistan). Note: Rock-relations diagrams a-d are located north of the map area (see top right). a, Lower Munzur thrust sheet overlain by the Kırmızı Kandil Formation and the Kemaliye Formation and Pelagic (Gülbahar) unit limestone and chert; near Erikli (c. 20 km NW of the map area); b, Lower Munzur thrust sheet, overlain by the Kırmızı Kandil Formation and the Kemaliye Formation (with blocks of neritic limestone), overthrust by upper Munzur thrust sheet; Gökçek area; 10 km WNW of the map area; c, Contact relations with the Darende basin to the east. Mesozoic Tauride units are locally emplaced eastwards over the basin margin, which is tilted and overturned near the base. Note: in places (off this section) an intact unconformity is exposed between the emplaced Mesozoic allochthonous units and Maastrichtian sediments of the intact Darende basin succession (see text); N of Dağdamı; 12 km N of map area; d, Lower Munzur thrust sheet, overlain by the Kırmızı Kandil Fm. and then the Kemaliye Fm. (with blocks of neritic limestone); 2 km NE of Kapaklı; 7 km N of map area; e, Kemaliye Formation enclosing blocks of Pelagic (Gülbahar) unit lithologies, overthrust by the lower Munzur thrust sheet. The Munzur thrust sheet is mapped as being thrust (SW) over the Köseyahya thrust sheet; 3.5 km E of Türkören (Yumru Tepe); f, Lower Munzur thrust sheet, with the Kırmızı Kandil and Kemaliye formations above (with block of limestone), overthrust by the Köseyahya thrust sheet. Note the Fe-rich crust at the top of the Kırmızı Kandil Formation; NW of Şerefli.

Fig. 9. Outline geological map (simplified from Bedi et al., 2009) and local rock-relations diagrams in Area 4 (S of Elbistan). A-A' Malatya Metamorphics in steep fault contact with the Kemaliye Formation (as mapped by Bedi et al. (2009)), overlain by the Kemaliye Formation including blocks of limestone and radiolarite; in turn overthrust by a Munzur thrust sheet and then by ophiolite-related melange with blocks of ophiolitic rocks and limestone; finally overthrust by a Köseyahya thrust sheet; B-B' folded Köseyahya thrust sheet, emplaced over the Malatya metamorphic succession. The syncline (truncated) formed prior to thrust emplacement.

Fig. 10. Field photographs showing key sedimentary features of the Munzur and Köseyahya thrust sheets. a-h Munzur thrust sheet; i-l Köseyahya thrust sheet. a, Oncolite (algal) within Late Triassic micritic limestone; upper part removed by dissolution along a stylolite; E of Elbistan; GPS 37S 0346331/4227793; b, Thin interbed of intraformational sedimentary breccia (near a); c, Thin, intra-formational slump sheet composed of pelagic micrite (also near a; d, U. Cretaceous rudist limestone; lower Munzur thrust sheet; Kaşanlı area; GPS 37S 0325809/4257928; e, Late Cretaceous limestone of upper Munzur thrust sheet, with Kemaliye Formation beneath (shale with limestone blocks) and ultramafic mafic ophiolitic lithologies above, Hurman kalesi; GPS 37S 0310858/4260897; f, Upper Cretaceous pelagic limestone (Kırmızı Kandil Fm., Kapaklı area; GPS 37S 0361390 / 4257247; loc. 4.4; g, Fe-Mn crust at the contact between Late Cretaceous pelagic limestone below and the Kemaliye Formation above, recording a hiatus; near İncirli; GPS 37S 0305831/4252443; i, Ammonite in red bioclastic limestone (Late Triassic), Köseyahya thrust sheet, near Sarıkaya Tepe; E of Elbistan; GPS 37S 0362757/4228355; j, Crinoidal bioclastic limestone (Late Triassic); Köseyahya thrust sheet; loc. as i; k, White crinoidal limestone with diagenetic chert lenticles (Late Triassic); Köseyahya thrust sheet; loc. As j; l, Bioturbated pelagic limestone (Early Cretaceous), between Özbek and Gücük (E of Elbistan); GPS 37S 036516/4229889.

Fig. 11. Measured sedimentary logs (roman numerals) of Permian-Cretaceous facies of the Pelagic (Gülbahar) unit; see Fig. 8 for I-IV and Fig. 7 for V-IX, and the text for explanation.

Fig. 12. Field photographs of the pelagic (Gülbahar) unit in Area 2 (Dağlıca). a, Sandstone and shale (Triassic), overthrust by thick-bedded limestone of the Köseyahya thrust sheet; Bakış area; GPS 37S 036782/4222559; b, Calcareous mudrock, with thin limestone interbeds; note the small load casts in redeposited limestone; small slice (c. 10 m thick), below Köseyahya thrust sheet; Triassic; Aşağıgücük köy; GPS 37S 0362059/4222332; c, Radiolarian chert and pelagic limestone (centre, pink), depositionally intercalated with pelagic carbonate, with minor replacement chert (grey); Late Jurassic-Early Cretaceous; Ayrancı Tepe; 2 km S of Büyük Tatlı; GPS 37S 0324740/4263734; d, Regularly bedded calciturbidites, largely replaced by quartzitic chert; location near c; e, Calciturbidite, mainly replaced by quartzitic chert; Late Jurassic-Early Cretaceous; Kayseri (near Hurman kalesi); GPS 37S 0302827/4266442; f, Well-cemented debris-flow deposit with angular clasts of chert (red) and pelagic carbonate. The chert mainly formed by replacement of pelagic carbonate, location near c; g, Debris-flow deposit made of sub-rounded clasts of pelagic carbonate in a calcarenite matrix, rich in redeposited ooids; gravity emplaced before completely lithified; Late Jurassic-Early Cretaceous; SE of Büyük Tatlı; GPS 37S 0325527/4262472; h, Debris-flow deposit composed of angular to sub-rounded clasts of white pelagic limestone and red radiolarite; the well-cemented nature is typical of the pelagic succession in contrast to the Kemaliye Fm.; Late Jurassic-Early Cretaceous; near Yumru Tepe, E of Elbistan; GPS 37S 036620/423774; i, Debris-flow deposit made up of angular to sub-rounded clasts of pelagic limestone and redeposited calcarenite in a coarse calcarenite (oolitic) matrix; Late Jurassic-Early Cretaceous; near Topaktaş (Kırkısrak area); GPS 37S 0298744/4262995.

Fig. 13. Outline geological map of Area 5A, Kemaliye and Area 5B, Divriği. See text for explanation and data sources.

Fig. 14. Geological map of the type, Kemaliye area including the Kemaliye Formation (Area 5A), simplified from 1:100,000 geological maps of Turkey (Bilgiç, 2008b, c), with additional information from this study.

Fig. 15. Local cross-sections of the Kemaliye Formation in its type area (5A). a, East of Keban Lake; b, West of Keban Lake (farther southeast). See Fig. 13 for location and the text for explanation.

Fig. 16. Field photograph Kemaliye Formation and related units in the type area (5A) (a-f) and in Area 3B (Nurhak Dağı) (g-l). a, View southwest over the Late Cretaceous Kemaliye Formation, with lenticular blocks, mainly limestone conglomerate in a matrix of shale and sandstone; S of Kemaliye town; b, Calc-mylonite locally exposed near the contact between the Malatya Metamorphics and the Kemaliye Formation (E of Keban Lake); c, Stratiform debris-flow deposits with sub-rounded to well-rounded clasts, mainly neritic limestone, in a coarse-grained sandy matrix; Kemaliye Formation, lower part; d, Debris-flow deposits with mainly angular clasts of micaschist in a coarse-grained sandy matrix; Kemaliye Formation, lower part, near Yuva; e, Lenticular debris-flow conglomerate, dominated by well-rounded, varicoloured clasts of red radiolarian chert in a coarse-grained sandy matrix; Kemaliye Formation, lower part; near Beğre (Area 3B); f, Mainly sub-angular clasts of neritic limestone (calcite-veined) in a coarse-grained sandy matrix; Kemaliye Formation, upper part; near Beğre (Area 3B); g, Serpentinite cut by small granitic intrusions (foreground), overthrust by a thin unit of the Kemaliye Formation, and then by the Köseyahya thrust sheet (pale; main mountain above), near Beğre; h, Calc-mylonite in the uppermost levels of the Malatya Metamorphics, near Beğre; i, Isoclinally folded calc-schist in the uppermost levels of the Malatya Metamorphics, later brecciated, near Beğre; j, Isoclinally folded calc-schist in the uppermost levels of the Malatya Metamorphics, cut by small granitic intrusions (centre-right); fold limb is 5 m across in the foreground, near Beğre; k, Granitic intrusions (by pen) and greenish serpentinite (upper), mutually brecciated, indicating high-strain deformation after intrusion, near Beğre; l, Iron-rich crust at the top of the platform succession, below the Kemaliye Fm., marking a hiatus.

Fig. 17. Sedimentary log of the lower part of the Kemaliye Formation in its type, Kemaliye area (5A). See text for explanation.

Fig. 18. Photomicrographs of key age-diagnostic benthic microfossils. a: *Neoendothyra* sp.; sample ET12.37; Triassic; Dark limestone block in Kemaliye Formation, Area 5A, near Yuva,

GPS 37S 0456773/4345128; b: *Meandrospira* sp., sample ET12.37, as above, Triassic; c: *Thaumatoporella parvovesiculifera* (Tp), *Bosniella fontainei* (Bf), *Siphovalvulina variabilis* (Sv), *Glomospira sp*. (Gl), sample ET12.57; Middle Triassic; Bioclastic limestone from Munzur thrust sheet, Area 5B, c. 8 km SSE of Divriği, Area 5B, GPS 37S 0426455/4351186; d: *Siphovalvulina variabilis*, sample ET12.58 (location as c); Jurassic; e: *Bosniella fontainei*, sample ET12.57, Middle Jurassic (location c, d); f-g: *Nezzazata isabellae*, sample ET12.54, Aptian-Albian, limestone block in lower part of ophiolite-related melange, Area 5B (Divriği), GPS 37S 0425452/4367406; h, i: *Mayncina bulgarica* (Laug et al., 1980), sample ET12.54; Aptian-Albian (location as f-g); j-l: *Parakoskinolina* sp., sample ET12.56; Aptian-Albian; limestone block in mid part of the ophiolite-related melange, Area 5B (Divriği), GPS 37S 0425280/436641; m-o: *Akcaya minuta*, sample ET12.56; Aptian-Albian (location j-o); p: *Nezzazatinella* sp., sample ET12. 56; Aptian-Albian (location as j-p); q: *Vercorsella* sp., sample ET12. 56, Aptian-Albian (location as j-q). Scale bars= 0.2 mm.

Fig. 19. Measured sedimentary logs of the Late Cretaceous Kemaliye Formation in Area 2 (Dağlıca); see the text for explanation. Logs 1-5 in Area 3A (E of Elbistan) and farther north; Log 1. Near Köseyahya; Log 2, 6 km N of map in Fig. 8; Log 3, 5 km WSW of log 2; Log 4, 7 km NE of log 2; Logs 5 and 6 in Area 2 (Dağlıca), see Fig. 7.

Fig. 20. Field photographs in Area 2 (Dağlıca), particularly the Kemaliye Formation. a, Pebbly debris-flow, with mostly well-rounded clasts of meta-sandstone (quartzite), with some micaschist (centre left); Kemaliye Formation; 1 km N of İncirli GPS 37S 0308706/4255621; b, Debris-flow dominated by sub-rounded clasts of limestone (some with rudist debris) in a pebbly matrix; Kemaliye Formation; c. 1 km N of İncirli, GPS 37S 0303828/4254761; c, Cenomanian rudist-bearing limestone (part of a block) within shale and sandstone; Kemaliye Formation; near Hurman kalesi, GPS 37S 0311635/4261660; d, Blocks of neritic limestone with rudist bivalves in highly deformed Kemaliye Formation; near Hurman kalesi, GPS 0307401/4259103; e, Mudrocks of the Kemaliye Formation, interspersed with blocks of Mesozoic neritic limestone; overthrust by the upper Munzur thrust sheet; Hurman kalesi area, GPS 37S 0314553/4260250; f, Crudely stratified, ophiolite-derived debris-flow units, including clasts of basalt, diabase, gabbro, pelagic limestone and radiolarian chert, associated with the Dağlıca ophiolite; near Kaşanlı köy, GPS 37S 0326709/4257612; g,

Matrix-supported debris-flow unit with clasts of gabbro (lower left), diabase and basalt; associated with the Dağlıca ophiolite; same locality as f; h, Ophiolite-derived debris flow, locally dominated by basalt centre right); associated with the Dağlıca ophiolite; 1.5 km W of Kırkısrak, GPS 37S 0294299/4259724; i, as d, e with angular clast of pink pelagic limestone, with red 'replacement' chert; j, Debris-flow conglomerate made up of ophiolitic clasts including gabbro, diabase and basalt; associated with the Dağlıca ophiolite; İncirli area, GPS 37S 030015/425603); k, Late Cretaceous-Eocene succession of the relatively autochthonous Gürün platform, overthrust by Mesozoic Munzur limestone; 2 km NE of Dallıkavak, GPS 37S 0293001/4261378; l, Clast-supported conglomerate including well-rounded clasts of Eocene Nummulitic limestone; probably Miocene; 1.5 km NW Çağsak, GPS 37S 0286787/4257672.

Fig. 21. Photomicrographs of key age-diagnostic planktic microfossils. a, Globotruncana cf. G. mariei Banner & Blow, 1960, sample M.13.35; Kemaliye Formation; Campanian-Maastrichtian, near Kapaklı, Area 3A, NE of Elbistan, GPS 37S 0361390/4259247; b, Globigerinelloides sp., sample M.13.35, Campanian-Maastrichtian (same location); c, Globotruncana linneiana (D'Orbigny, 1839), sample M13.4, pelagic limestone block in Kemaliye Formation, Campanian-Maastrichtian, Odunluk Tepe; Area 3A, E of Elbistan; GPS 37S 0366666/4225559; Archaeoglobigerina cretacea (D'Orbigny, 1840), Campanian-Maastrichtian (same location); e, f: Globigerinidae, sample M13.60, Cenozoic. Pelagic limestone block in debris-flow deposit, near İğde köyü (SE of Elbistan), GPS 37S 0335066/4223251. Scale bars= 0.2 mm.

Fig. 22. Structural relationships in Area 3B (Nurhak Dağı); a, Meta-carbonate rocks of the Malatya Metamorphics, structurally overlain by serpentinised harzburgite which is cut by small granitic intrusions, and in then overthrust by a thin unit of the Kemaliye Formation, with the Köseyahya thrust sheet above; near Beğre;
b, Malatya Metamorphics, structurally overlain by serpentinised harzburgite, then by the Kemaliye Formation, with the Köseyahya thrust sheet above, c. 10 km north-east of a. The blocks in the Kemaliye Formation include Triassic red crinoidal limestone, similar to that in the Köseyahya thrust sheet, in a matrix of terrigenous sandstone and mudrock.

Fig. 23. Simplified geological map of part of Area 5B, Divriği (simplified from MTA 1:100,000 geological maps of Turkey (Bilgiç, 2008a, b, c). Note the locations of the representative sections shown in Fig 25. See text for explanation and data sources.

Fig. 24. Summary of the stratigraphy and structural relations in part of Area 5B, Divriği. a, Stratigraphic column; b, Rock-relations (bi in the north; b-ii in the south). See the text for explanation and data sources.

Fig. 25. Field photographs of Divriği ophiolite-related melange in Area 5B. a, Elongate blocks of thick-bedded neritic limestone set in a matrix of serpentinite and sandstone/shale; c. 6 km NW of Divriği); b, Elongate blocks of Mesozoic neritic limestone embedded in sheared serpentinite; c. 6 km NW of Divriği); c, Part of a large block of thick-bedded neritic limestone, deformed into a SW-verging fold; c. 6 km NW of Divriği); d, Large block of Mesozoic neritic limestone in the Divriği melange, deformed into a N-verging fold; c. 3 km NW of Divriği); e, Serpentinite melange with a strongly sheared steeply dipping fabric; c. 7 km SE of Divriği; f, Large exposure of serpentinite melange, dominated by mantle harzburgite; c. 10 km SE of Divriği.

Fig. 26. Summary of fold data (axial planes and hinges) collected during this study, plotted as poles; equal-area lower hemisphere projection; N= number of measurements; ai-aiv, Fold axial planes; bi-biv Fold hinges. Individual plots: ai-bi Malatya Metamorphics (Area 1. W of Elbistan); aii-bii Allochthonous Tauride units (Area 2, Dağlıca); aiii-biii Allochthonous Tauride units (Area 3A, E of Elbistan); aiv-biv Combined units: Malatya (Keban) metamorphics and Kemaliye Formation (Area 1) (Kemaliye area). See Supplementary Figs. 7-10 for plots of all data, including bedding.

Fig. 27. Geological development of the central and northern parts of the Tauride continent. a, Late Triassic extensional faulting establishes the contiguous neritic Munzur platform, the Neritic-pelagic Köseyahya platform and the Pelagic (Gülbahar) unit; b, Mid-Late Jurassic. N-dipping ramp develops redepositing mainly oolitic facies into deeper water; c, Late Cretaceous (Cenomanian). Rudist bivalve reefs develop on proximal (Munzur) platform

while deeper-water slope conditions persist farther north; d, Campanian-Maastrichtian. The southern part of the Tauride continent (Malatya platform) detaches and is deeply underthrust northwards; ophiolite is emplaced southwards over the northern edge of the Tauride continent which collapsed in advance to form a foredeep.

Fig. 28. Geological development of the Tauride continent in the E Taurides. a, Carboniferous; includes rift-related volcanism; b, Mid-Late Triassic continental rifting; c, Mid-Late Jurassic passive margin subsidence; d, Late Cretaceous (Cenomanian, c. 90 Ma); northward subduction of oceanic crust; e, Late Cretaceous (Campanian-Maastrichtian); collision and crustal imbrication of the Tauride continent. Note: it is uncertain whether the Malatya and Munzur-Köseyahya units were either contiguous or separate platforms. See text for discussion.

Fig. 29. Stages in the latest Cretaceous (late Campanian-Maastrichtian), southward emplacement of oceanic crust and passive continental margin units in the E Taurides. a, Flexural foredeep is imbricated during compressional emplacement; b, With further emplacement, the relatively distal neritic-pelagic (Köseyahya) platform detaches and is thrust over the more proximal neritic (Munzur) platform; c, With further convergence, part of the neritic (Munzur) platform is locally re-thrust over the neritic-pelagic platform unit.

Fig. 30. Rock-relations diagram showing the inferred tectono-stratigraphy of the E Taurides following latest Cretaceous emplacement/exhumation, restored to beneath the latest Cretaceous transgressive shallow-marine sedimentary cover (south of the Gürün autochthon). From the structural base upwards: Malatya (Tauride) continental unit; Late Cretaceous Göksun (Berit) ophiolite; partially exhumed Malatya Metamorphics (both of the latter are stitched by the Late Cretaceous Baskil granitoids); debris-flows (‘olistostromes’) (e.g. Kemaliye Formation type area), with slices and blocks of the pelagic (Gülbahar) unit and finally supra-subduction zone ophiolites and their metamorphic sole. Note: variable internal deformation of the Munzur, Köseyahya and ophiolitic thrust sheets is not shown.

Fig. 31. Alternative tectonic models for the eastern Taurides. ai-aii, Assumes one ocean to the north and one continent to the south. The allochthonous units are emplaced by complex out-of-sequence thrusting (based on Ricou et al., 1984); bi-bii. Assumes a single Mesozoic Neotethys. The Late Cretaceous ophiolites form above a subduction zone to the E-NE that rotates and rolls-back, emplacing segments over the N and S margins of the Tauride continent and over Arabia/N Africa. The Bitlis and Pütürge metamorphism relates to attempted southward subduction. An Inner Tauride basin is assumed between the Tauride continent and a combined Kırşehir-Tavşanlı crustal block in the north, but this basin is not the source of the ophiolites (based on van Hinsbergen et al., 2020); ci-cii. (preferred model). This assumes several microcontinents and small Mesozoic ocean basins. The Bitlis and Pütürge continental units represent rifted fragments with ocean crust on either side. Supra-subduction zone oceanic crust in the northerly basin (Berit ocean) subducts northwards resulting in arc magmatism that intrudes the continental block to the north (Malatya metamorphic unit). An Inner Tauride ocean was potentially the source of Late Cretaceous supra-subduction zone ophiolites in the north. Supra-subduction zones are emplaced separately, southwards onto the Arabian margin. Uncertain is whether the Tauride platform links with the South Armenian platform at depth as there is no continuous surface exposure. See text for discussion.

Late Palaeozoic-Neogene sedimentary and tectonic development of the Tauride continent and adjacent Tethyan ocean basins in eastern Turkey: new data and integrated interpretation

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Abstract

The eastern Taurus exemplifies continental rifting, passive margin development, Late Cretaceous melange genesis and ophiolite emplacement. Following Triassic rifting, a carbonate platform developed near sea level in the south (Munzur unit), whereas its northern extension (Neritic-pelagic unit) subsided into deep water during Late Jurassic-Late Cretaceous. Triassic-Cretaceous deep-water sediments and volcanics restore as distal deep-water slope/base of slope units. Jurassic-Cretaceous basic volcanics, interbedded with pelagic sediments, represent emplaced oceanic seamounts. Supra-subduction zone ophiolites formed to the north (c. 93 Ma), probably within an Inner Tauride ocean, and were emplaced southwards by trench-margin collision during latest Cretaceous (c. 75-66 Ma). The margin underwent flexural uplift/erosion and then subsidence/foredeep-infill. Part of the Tauride continent in the south (Malatya Metamorphics) deeply underthrust/subducted northwards, then exhumed rapidly by the late Maastrichtian (c. 65 Ma). To the south, oceanic lithosphere (e.g. Göksun ophiolite) was thrust northward beneath Tauride (Malatya) crust from a more southerly oceanic basin (Berit ocean), and intruded by Late Cretaceous subduction-related granitic rocks (88-82 Ma). Allochthonous units were assembled during the latest Cretaceous, followed by thick-skinned folding/thrusting, generally southwards, related to regional collision tectonics during Mid-Late Eocene. Part of the unmetamorphosed Tauride platform and its over-riding Late Cretaceous allochthon were apparently displaced >60 km northeastwards. Mid-Late Miocene regional collision drove variable folding and re-thrusting, in places northwards. Regional comparisons suggest that the Tauride carbonate platform (Geyik Dağ) narrowed eastwards, such that the palaeogeography of the E Taurides differed from farther west, influencing the late Mesozoic-Cenozoic structural development.

Key words: E Anatolia, Tethys, palaeogeography, tectonics, ophiolites, melange, deep-sea sediments

1. Introduction

The geological development of Tethys within and around Anatolia remains of current interest, with several alternative tectonic models being recently proposed (Moix et al., 2008; Robertson et al., 2012, 2013a; Rolland et al., 2012, 2020; Maffione et al., 2017; Parlak et al., 2019; Hinsbergen et al., 2020). In addition to ophiolites, continental margin units and melanges need to be taken into account. The Taurides represent a key part of Anatolia (Fig. 1), where ophiolites were emplaced onto a regional-scale carbonate platform during latest Cretaceous time (Juteau, l980; Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Ricou et al.,1984; Dilek and Moores, 1990; Robertson, 2002; Parlak, 2016; Barrier et al., 2018). There have been several attempts to explain the emplacement of the ophiolites and related continental margin units as a whole in the western Taurides (Hayward and Robertson, 1982; Woodcock and Robertson, l982; Yılmaz and Maxwell, l984; Şenel, l984; Marcoux et al., 1989; Collins and Robertson, 1998), in the central Taurides (Demirtaşlı et al., 1984; Özgül, l997; Dilek and Whitney, l997; Andrew and Robertson, 2002; Parlak and Robertson, 2004; McPhee et al., 2018a), and also in the eastern Taurides (Yılmaz, 1993; Yılmaz et al., 1993, Robertson et al., 2006, 2007, Robertson et al., 2013a b; Rolland et al., 2012, 2020).

The ophiolites, melanges and related continental units of the İzmir-Ankara-Erzincan (northern Neotethyan) suture zone in the Eastern Turkey have also received a considerable amount of attention in recent years (e.g., Yılmaz et al., 1997; Okay and Şahintürk, 1997; Rice et al., 2009; Ustaömer and Robertson, 2010, 2013; Robertson et al., 2013c; Topuz et al., 2013a, b; Rolland et al., 2012, 2020; Hässig et al., 2013, 2017). However, there have been few integrated studies that focus on the carbonate platforms, slope/basin facies and the related melange units in the Eastern Taurides (Fig. 2). These units are located in a critical position between the Arabian Platform (African plate) to the south and the Pontides (Eurasian plate) to the north. The eastern Tauride region has some distinctive features, notably an extraordinary NE-verging fold-like structure, up to 200 km long x 250 km wide (MTA, 2011), termed the Gürün curl after a town in the core of this structure (Lefebvre et al., 2013a) (Fig. 2; Supplementary Fig. 1). Is this a primary palaeogeographic feature, or related to tectonic emplacement, or to some combination of both?

A synthesis of the Tethyan geology of the Eastern Taurides is given here, utilising a combination of new data and also the available literature on this region (Perinçek and Kozlu, 1984; Robertson et al., 2013b; Bedi et al., 2004, 2005; Bedi and Yusufoğlu, 2018). The region studied includes a Late Palaeozoic-Mesozoic metamorphosed carbonate platform, an unmetamorphosed carbonate platform and deeper-water marginal units, several types of melange, and also Late Cretaceous ophiolites with their metamorphic soles. Latest Cretaceous-Miocene cover successions help to constrain the distribution and timing of tectonic events, especially the exhumation of the metamorphic rocks. The assembled information will be used to test alternative tectonic models for the wider region (Kozlu et al., 1990; Robertson et al., 2013a, b; Barrier et al., 2018; van Hinsbergen et al., 2020; Rolland et al., 2012, 2020). We will demonstrate that the geology of eastern Anatolia represents a unique combination of palaeogeographic and tectonic features. The palaeogeography differs significantly from that of the central and western Taurides. Also, the Late Cretaceous ophiolites and related melange units differ significantly from Jurassic counterparts farther north in the E Pontide-Lesser Caucasus region.

In this paper, we use the time scale of Cohen et al. (2020).

2. Regional tectono-stratigraphy

We utilise a modified version of the tectono-stratigraphy based on mapping by the Turkish Petroleum Company (TPAO) (Perinçek and Kozlu, 1984), including changes and additions based on mapping by the Maden Tektik ve Arama (MTA) (Bedi et al., 2009; Bedi and Yusufoğlu, 2018), related studies (Robertson et al., 2013b) and this work.

Moving northwards, the Arabian platform is tectonically overlain by a Miocene imbricate thrust belt, with, to the north of this, the Bitlis and Pütürge allochthonous continental units (Yılmaz, 1993; Yılmaz et al., 1993; Yazgan, 1984) (Fig. 1). These units are tectonically overlain by Late Cretaceous ophiolitic rocks, variously known as the Göksun (Berit), Kömürhan, İspendere or Yüksekova ophiolites. Our study effectively begins in the south with the Late Palaeozoic-Mesozoic Malatya Metamorphics (including the Keban and Binboğa metamorphic rocks; see below). To the north, these metamorphic rocks are over-ridden by allochthonous, unmetamorphosed Tauride carbonate platform, melanges and ophiolitic units. The allochthonous outcrop in the west of the region is split into two parts, termed the Northern and the Southern allochthon (Robertson et al., 2013b). Both the Northern and the Southern allochthon include emplaced thrust sheets of Mesozoic carbonate platform, slope and deeper-water facies, melanges and ophiolitic rocks. The relationships between the two allochthonous assemblages is debatable as they are separated by a relatively autochthonous Tauride platform succession, termed the Gürün autochthon (Kozlu et al., 1990; Atabey, 1993; Atabey et al., 1994, 1997; Robertson et al., 2013b) (Fig. 2).

The Mesozoic-Paleogene units within our study area are unconformably overlain by two geographically and temporarily distinct types of sedimentary basin. The first is represented by latest Cretaceous-latest Eocene basins, including the Darende, Hekimhan and Malatya basins; the second comprises Neogene-Recent sediments (Salyan Formation) and volcanics (Kepezdağ volcanics), notably within the Afşin-Elbistan basin, the Pınarbaşı-Kangal basin and the upper part of the large Malatya basin (Fig. 2). The area is dissected by through-going neotectonic faults, principally the westward-curving Sürgü-Misis Fault (Duman and Emre, 2013), and also three main NNE-SSW-trending faults, the Sarız, Gürün and Malatya-Ovacık faults. Of the latter, by far the largest is the Malatya-Ovacık fault, which is estimated to have accommodated 29 km of left-lateral movement (Fig. 2) (Westaway and Arger, 2001; Kaymakçı et al., 2006; Sancar et al., 2019). In addition, part of the area is transected by lesser known, c. SSW-NNE to SW-NE trending faults (Göksu faults of Kozlu et al., 1990) that are important because they straddle the contact between the Gürün autochthon and the Southern allochthon (Robertson et al., 2013b)

To facilitate description and interpretation, we subdivide our study region into 5 sub-areas (Fig. 2). *Area 1,* NW of Elbistan (Afşin); *Area 2,* Dağlıca; *Area 3,* E of Elbistan (subdivided into *Area 3A* in the west and *Area 3B* (Nurhak Dağı) in the east; *Area 4,* S of Elbistan, and finally, Divriği-Kemaliye in the north-east (subdivided into *Area 5A*, Kemaliye and *Area 5B,* Divriği farther north).

3. Tauride carbonate platform

To the SW of our study area (Tufanbeyli-Saimbeyli-Sarız) (Fig. 2), the autochthonous Tauride platform succession encompasses Precambrian sediments (Emirgazi Formation), Cambrian shelf siliciclastics (Feke Quartzites) and mixed carbonate-siliciclastic sediments (Çal Tepe Formation), which are overlain by Ordovician mainly argillaceous and silty shelf sediments (Seydişehir, Bedivan and Halit Yaylası formations) including some glacial deposits. Fine-grained siliciclastic sediments with calcareous intervals (e.g. Nautiloid limestones) dominate the Silurian (Puşçu Tepe Shale and Yukarı Yayla formations). The Devonian is mainly shelf carbonates, with minor basaltic volcanics, including a reef-bearing horizon (Şafak Tepe Formation). The lower interval (Alitepesi Formation) and the upper interval (Gümüşali and Naltaş formations) are relatively quartz rich. Above a quartz-rich base, the Permian is dominated by algal carbonates (Yığılı Tepe Formation) (Özgül et al., 1973; Metin et al., 1986; Kozlu and Göncüoğlu, 1997; Özgül and Kozlu, 2002; Göncüoğlu et al., 2004; Bedi and Usta, 2006; Bedi et al., 2017).

The Palaeozoic succession accumulated on a continental platform, punctuated by unconformities that were probably tectonically influenced; i.e. at the Precambrian-Cambrian boundary (?), the Early-Late Ordovician boundary, the Silurian-Devonian boundary, the Early-Middle Devonian boundary and the Carboniferous-Permian boundary. There was an increased sedimentation rate during the late Carboniferous (Göncüoğlu et al., 2004). This represents a period of enhanced tectonic subsidence that may relate to Variscan collisional orogeny farther west, in the Aegean-Balkan region.

The Mesozoic succession is dominated by shelf carbonates, with stratigraphic breaks that are likely to have been tectonically controlled; i.e. during the Middle Triassic, the Early-Mid Jurassic, the Late Cretaceous (Turonian-Santonian(?)), and the Early Eocene (Kozlu et al., 1990). Devonian to Permian, and locally also Triassic, siliciclastic and carbonate rocks crop out in the northwest of the Gürün autochthon, where they are unconformably overlain by Early Jurassic to Late Cretaceous shelf carbonates. The Cretaceous carbonates pass upwards into Cenozoic facies without a structural break (Özgül et al., 1973). The succession continues with deeper-water (but still shelf-depth) hemipelagic carbonates, siltstones, mudrocks and sparse sandstones, dated as Maastrichtian-Middle Eocene (Lutetian) (Aziz et al., 1982; Perinçek and Kozlu, 1984; Yılmaz et al., 1991, 1994; Atabey, 1995; Robertson et al., 2013b). Locally, Eocene or older sediments in the Gürün autochthon are unconformably overlain by Miocene sediments (e.g. non-marine conglomerates), and also by Plio-Quaternary volcanics and sediments (Perinçek and Kozlu, 1984; MTA, 2011). There is no evidence of any major structural break or suture zone within, or between, the outcrops that extend northeastwards from the Saimbeyli-Tufanbeyli-Sarız region to the Gürün autochthon (MTA, 2011). This whole crustal unit can, therefore, be correlated with the relatively autochthonous Tauride carbonate platform in the central Taurides (Geyik Dağ).

The Jurassic-Cretaceous carbonates accumulated on a gently subsiding shelf, followed by accelerated subsidence that was probably tectonically controlled during the latest Cretaceous and Palaeocene-Early Eocene. There is no evidence of emplacement of any allochthonous units over the Gürün autochthon, at least until the Mid-Late Eocene (Perinçek and Kozlu, l984; Kozlu et al., 1990; Robertson et al., 2013b); this observation is critical to any tectonic reconstruction.

4. Malatya metamorphics

The regionally extensive Late Palaeozoic (Devonian?) to Late Cretaceous Malatya Metamorphics (Figs. 2, 3) are widely exposed in the south of the study area (Karaman et al., 1993; Yılmaz et al., 1991, 1994; MTA, 2011; Bedi and Yusufoğlu, 2018). The outcrops are variously referred to as the Malatya Metamorphics in the type area (S of Elbistan), the Binboğa Metamorphics (NW of the Sürgü-Misis Fault; i.e. west of Afşin) and the Keban Metamorphics (east of the Malatya-Ovacık Fault) (Perinçek and Kozlu, 1984; Bedi et al., 2005, Bedi and Usta, 2006; Kaya, 2016). The Keban Metamorphics have been locally dated (south of Keban Lake) as 73.8±0.3Ma (Campanian) based on ^{40}Ar/^{39}Ar dating of muscovite within fluorite-bearing marble (Rolland et al., 2012). However, it is unclear whether this age is representative of the Malatya Metamorphics as a whole (see below).

The outcrop to the east of the Malatya-Ovacık Fault was recently remapped as three different units, separated by thrusts (Bedi and Yusufoğlu 2018). The first unit, termed the Bodrum nappe (named after a type area in the western Taurides) is a metamorphosed Middle Devonian to Late Cretaceous succession (Fig. 3). The mineral assemblages in this unit (Bodrum nappe) are mainly suggestive of greenschist facies metamorphism (Perinçek and Kozlu, 1984). Local intercalations of basic metavolcanics rock (west of Afşin) are indicative of amphibolite facies conditions (Robertson et al., in press b). However, reported occurrences of glaucophane (Bedi et al., 2009) hint at high pressure-low temperature (HP-LT) metamorphism. The second, structurally overlying, unit is a metamorphosed Carboniferous to Late Cretaceous succession that is exposed SW of Malatya. This is correlated with the Yahyalı nappe, which has its type area further west, near Yahyalı. The Yahyalı nappe in its type area has undergone HP-LT metamorphism, based on the occurrence of carpholite

(Pourteau et al., 2010). Structurally above comes as third unit with a Late Devonian to Late Cretaceous succession, which is correlated with the Aladağ (Hadim) nappe in the central Taurides (Bedi and Yusufoğlu 2018).

The thrust sheets, as summarised above, are intruded by Late Cretaceous arc-type granitoid rocks (Baskil Granitoids). These are mainly I-type, calc-alkaline hornblende-biotite granodiorites and 'normal' granites, with both mantle and crustal-derived chemical features. The granitoid rocks are dated, radiometrically, as 88-82 Ma (Santonian-Campanian) (Parlak, 2006; Yazgan and Chessex, 1991; Rızaoğlu et al., 2009; Karaoğlan et al., 2016). The Malatya Metamorphics are structurally underlain, directly, by the relatively intact Göksun ophiolite (Parlak, 2006; Parlak et al., 2004, 2020), also known in this area as the Berit meta-ophiolite (Genç et al., 1993; Yılmaz et al., 1987; Yılmaz, 1993), the North Berit ophiolite (Robertson et al., 2006), and the Kömürhan ophiolite (Bedi et al., 2005, 2009).

The Malatya Metamorphics (Bodrum nappe) are unconformably overlain by Middle Palaeocene to Middle Eocene shallow-water calcareous sediments (Seske Formation), as exposed near, and to the west of Afşin (Perinçek and Kozlu, l984; Yılmaz et al., 1991, 1994; Robertson et al., 2006) (Fig. 4a). The succession begins with conglomerate, with clasts including schist and marble and then passes upwards into shallow-water limestones, commonly rich in large foraminifera (e.g. *Alveolina* sp.) and ooids (see below).

The protoliths of the Malatya Metamorphics (Bodrum nappe) within our main study area, namely the Binboğa Mountains west of Afşin (Area 1) and the Doğanşehir and Kemaliye areas farther east (Areas 3B, 5A) (Fig. 2), are dated with variable precision, mainly using benthic foraminifera and some small gastropods (Bedi et al., 2005, 2009). The overall succession (Fig. 3) begins with mixed meta-clastic and meta-carbonate rocks (Yoncayolu Formation) that are dated as Middle Devonian-mid Carboniferous. Meta-volcanic rocks (Fig. 4b) and meta-rudites (Fig. 4c) are intercalated in places (Fig. 5 logs 1, 2). Within the Keban metamorphics farther east, basic meta-dykes cut the Late Palaeozoic succession; also, foliated meta-diabase occurs within the upper part of the early Carboniferous (?) succession (Kaya, 2016). Overlying meta-limestones and meta-dolomitic carbonates (Çayderesi Formation) (Fig. 4d) contain a relatively rich, well-dated Late Permian fauna and flora. Above a meta-bauxite, representing a hiatus, calc-schist and meta-carbonate alternations

(Alıçlı Formation) are dated as Early-Mid(?) Triassic (Özgül et al., 1981). Meta-carbonates, commonly dolomitic, of Mid-Triassic to Early Jurassic age, follow above this (Kayaköy Formation) (Figs. 5 log 2, 4e). The succession passes upwards into shelf carbonates, with common nodular chert of diagenetic replacement origin (Ulu Formation), dated as Mid-Jurassic and Early Cretaceous. There is then a prominent unconformity, followed by meta-siliceous limestone, meta-mudrock and meta-conglomerate, termed the Karaböğürtlen Formation (Bedi et al., 2005, 2009). This unit is named after a Late Cretaceous chaotic 'blocky flysch' in the western Taurides (Denizli-Burdur area) (Özgül et al., 1981; Şenel et al., 1989).

4.1. Late Cretaceous syn-tectonic sediments

The succession in the Malatya Metamorphics (Bodrum nappe) extends through the Cretaceous in the form of mainly siliceous meta-limestones, meta-mudrocks and subordinate meta-conglomerates (Bedi and Yusufoğlu, 2018). Within Area 1 (east of Afşin), the meta-carbonates are mapped as locally ending in the Triassic (e.g. at Ballık Tepe), or in the Late Permian (e.g. at Abaz Tepe) (Fig. 5 section b) (Bedi et al., 2009). In several sections, the platform carbonate succession ends with an unconformity, marked by fissuring with red iron-oxide infills (Fig. 4f) and an iron-rich layer (up to several cm thick). An intact succession of mixed meta-carbonate and meta-siliciclastic rocks follows above this, with subordinate metadebris-flow deposits (Figs. 4g-i; 5 log 3), representing the Karaböğürtlen Formation. Clasts and blocks of Jurassic-Cretaceous meta-neritic limestone are present, and also, rarely, clasts of metabasalt. The matrix includes abundant monocrystalline and polycrystalline quartz, muscovite, carbonate and, locally, basaltic detritus (Fig. 6a-c). A Late Cretaceous (Cenomanian age) is inferred, at least for the lower part of this formation, based on local occurrences of rudist bivalves (Fig. 4k). Similar metamorphosed rudists occur in the Menderes Massif (Özer, 1998).

Thick-bedded meta-debris-flow deposits (calcirudites) are well exposed in a key section, c. 16 km north of Afşin (3 km S of Tanır) (Fig. 2; also Supplementary Fig. 2), where they include abundant deformed and fragmented recrystallised rudist bivalves. The meta-limestones pass into a thin (1m) interval of green meta-chert, formed by diagenetic replacement of carbonate, followed by reddish-brown meta-conglomerate (several m thick), with abundant rounded pebbles (<10 cm in size) of red radiolarian meta-chert and also meta-limestone (recrystallised), set in a sandy matrix. After further meta-limestone conglomerate, with rounded clasts (<10 cm in size), there is a return to thick-bedded detrital meta-carbonates before the section ends. This section is important as it indicates that relatively deep-water facies (radiolarian cherts) were redeposited onto the Malatya carbonate platform during the Late Cretaceous (see below).

In another key section, c. 20 km to the NW (near İncirli), where the Malatya Metamorphics (Bodrum nappe) are thrust northwards over the Southern allochthon (see below), the Karaböğürtlen Formation (up to 300 m thick) comprises lenses (up to >100 m long by 20 m thick) of medium-thick bedded meta-limestone (marble), alternating with sheared and folded meta-mudrock (phyllite.) Both the blocks and the matrix have undergone similar metamorphism. Near the thrust contact there are marble blocks (tens of cm-to m-sized) within sheared matrix-supported conglomerates (Fig. 4j). This section confirms that the Karaböğürtlen Formation includes meta-debris-flow (‘olistostromes’) related to Late Cretaceous tectonic instability.

4.2. Interpretation of the Malatya Metamorphics

During Middle Devonian to Carboniferous, the Malatya Metamorphics (Bodrum nappe) accumulated on a mixed carbonate-clastic-depositing shelf, punctuated by tectonic instability, basaltic volcanism and localised mass-flow deposition. Marine transgression characterised the Late Permian, followed by rift-related tectonic instability and subsidence during the Early-Mid Triassic. A relatively stable, gently subsiding carbonate platform developed during the Late Triassic-Cretaceous, deepening during the Early Cretaceous, as suggested by increased chert content. The rudist reefs signify shallowing during the Cenomanian. The carbonate platform was uplifted and variably eroded, in places down to the Late Permian, resulting in a regional unconformity that was capped by metalliferous oxides during a hiatus in deposition. The unconformity was then covered by a Late Cretaceous (but poorly dated), mixed carbonate-siliciclastic succession, including local debris flow-deposits. The siliciclastic detritus, largely derived from metamorphic and plutonic igneous rocks, was probably recycled from the underlying Malatya succession. The well-rounded nature of many of the pebbles, especially meta-chert (Fig. 6a, b) is indicative or reworking in a high-energy shallow-marine or fluvial setting prior to redeposition as debris flows. The pebbly conglomerates with red chert (near Tanır) show that deep-sea material, typical of the Southern allochthon to the north, was redeposited into the subsided Malatya platform.

The Late Cretaceous Karaböğürtlen Formation is interpreted as the proximal (southerly) part of a regional-scale, flexurally-controlled foredeep related to Late Cretaceous emplacement of continental margin and ophiolitic rocks. However, ophiolitic material is absent from the Karaböğürtlen Formation, in contrast to structurally higher units (see Discussion).

The timing of metamorphism of the Malatya Metamorphics is stratigraphically constrained as postdating the youngest deposition (Late Cretaceous (?) Karaböğürtlen Formation) but predating the Eocene sedimentary cover (Seske Formation) (Özgül et al., 1981; Perinçek and Kozlu, 1984; Kozlu et al., 1990; Robertson et al., 2006; Bedi et al., 2009). East of the Malatya-Ovacık Fault, the Keban metamorphics are locally dated radiometrically as 73.8±0.3Ma (Campanian) (Rolland et al., 2012). In this area the metamorphics are unconformably overlain by latest Cretaceous sediments, known as the Gündüzbey Formation, which correlates with the regional Harami Formation (Erdoğan, 1975). The Gündüzbey Formation begins with polymictic conglomerates, followed by sandstone-shale-conglomerate alternations (generally Santonian-Campanian in age) and then shelf carbonates (Campanian-Maastrichtian) (Bedi and Yusufoğlu, 2018). Along the eastern margin of the Malatya basin, the late Cretaceous sediments are unconformably overlain, directly, by Eocene conglomerates, limestones and turbidites (Yeşilyurt Formation) (Bedi et al., 2017; Bedi and Yusufoğlu, 2018). The 88-82 Ma (Santonian-Campanian) Baskil Granitoids that cut the Malatya Metamorphics are inferred to have taken 6–10 Ma to cool below 300 °C, based on ^{39}Ar–^{40}Ar dating of amphibole, biotite and K-feldspar (Karaoğlan et al., 2016).

The Malatya metamorphics as a whole are intruded by the Baskil granites (unmetamorphosed). The long period of time (6-10 Ma) taken to cool below 300^{o} suggests that the granites were intruded into crust with a high heat flow, presumably related to arc magmatism. The U-Pb age (88-83 Ma) of the granitoid intrusions is significantly older than the reported age of metamorphism (73.8±0.3Ma) (Rolland et al., 2012). However, the fluorite-bearing marble that was dated by these authors could represent a late-stage metasomatic event. The Malatya Metamorphics including the granite-bearing units were tectonically imbricated after intrusion (e.g. E of Doğanşehir) (Bedi and Yusufoğlu, 2018), probably during the Eocene.

5. Late Triassic-Late Cretaceous unmetamorphosed platform carbonates

5.1. Neritic thrust sheets

The mainly neritic Munzur thrust sheet (Fig. 2) is equivalent to the Munzur nappe of Özgül et al. (1981) and Bedi et al. (2004, 2009), to the Andırın Limestone of Perinçek and Kozlu (1984) and to the Neritic nappe of Robertson et al. (2013b). Similar successions are exposed in both the Northern allochthon and the Southern allochthon, respectively, to the north and the south of the Gürün autochthon (Fig. 2). South of the Gürün autochthon, in Area 2 (Dağlıca), the Munzur thrust sheet comprises two main units; first, an extensive, relatively intact, lower Munzur thrust sheet, and secondly a thinner, internally disrupted upper Munzur thrust sheet (transitional to broken formation). The succession in the lower Munzur thrust sheet is widely exposed in Area 2 (Dağlıca) (Fig. 7 sections a-f), in Area 3A (E of Elbistan) (Fig. 8 sections a-e) and in Area 4 (S of Elbistan (Fig. 9). The Munzur thrust sheets are entirely Mesozoic, with no preserved Late Palaeozoic substratum, in contrast to the Malatya Metamorphics (Bodrum nappe). The complete Late Triassic to Late Cretaceous succession is exposed in the lower Munzur thrust sheet (Bedi et al., 2004, 2009; Bedi and Yusufoğlu, 2018), whereas Cretaceous facies are commonly exposed in the more localised upper Munzur thrust sheet, mainly in Area 2 (Fig. 7) and Area 3A (Fig. 8). During this study, bioclastic limestones in the upper Munzur thrust sheet were dated as late Barremian-early Aptian (near Küçük Tatlar) (see Supplementary table 1). Higher stratigraphic levels are rich in Cenomanian rudist bivalves.

Taking the Munzur thrust sheets together, the succession begins with Norian thick-bedded neritic limestone, rich in calcareous algae (Fig. 10a) and Megalodonts, with local evidence of intraformational reworking and tectonic instability (Fig. 10b, c). Above an unconformity, the Early Jurassic begins with a conglomerate, overlain by pinkish nodular micritic limestone, up to 40 m thick, rich in crinoids, algae, ammonites and gastropods. The Middle Jurassic to Early Cretaceous interval is neritic, commonly oolitic and/or rich in benthic foraminifera. The neritic succession typically culminates in a Cenomanian interval rich in rudist bivalves (Fig. 10d), as well-exposed in the upper Munzur thrust sheet in Area 2 (Dağlıca) (Fig. 10e).

The neritic limestones are covered by Albian-Santonian pinkish pelagic carbonates, with sparse thin-bedded bioclastic calcarenites, known as the Kızılkandil Formation (equivalent to the Kırmızı Kandil Formation of Perinçek and Kozlu 1984) (Fig. 10 f). In places (e.g. Küçük tepe-Gerdekes yayla), rudist-bearing neritic limestones are reported to grade laterally and vertically into *Globotruncana*-bearing pelagic limestones (Bedi et al., 2009). The pelagic carbonates include thin (several cm) interbeds of fine to medium-grained, neritic-derived calciturbidites; locally (e.g. near Erikli) these include redeposited Late Jurassic-Early Cretaceous benthic foraminifera (see Supplementary Table 1). The succession ends with an unconformity, which is covered by a ferruginous oxide crust in some sections (Fig. 10g); this is overlain by latest Cretaceous syn-emplacement facies (Kemaliye Formation; see below).

In one area (e.g. E of Tavla), a small thrust sheet is dominated by limestone breccia-conglomerate (mass-flow accumulations) and calciturbidites (c. 150 m thick) (Fig. 10h). This unit is tentatively interpreted as proximal platform-slope facies.

For the Late Triassic, there is widespread evidence of tectonic instability related to regional rifting. The Jurassic-Cenomanian succession accumulated on the inner part of a gently subsiding carbonate platform (Yılmaz, 1994), mainly influenced by global sea-level change. The Albian-Santonian pelagic carbonates (Kızılkandil Formation) accumulated during a time of overall relatively high global sea level (Miller et al., 2005). However, the presence of interbedded bioclastic calciturbidites points to sub-aqueous erosion that was probably triggered by contemporaneous tectonic instability. There was then a hiatus (up to c. 8 Ma), allowing local precipitation of ferruginous oxide from seawater, before syn-emplacement facies (Kemaliye Formation) began to accumulate. The hiatus is likely to be coeval with the break in deposition that affected the adjacent Malatya Metamorphics, and is interpreted to represent the southward passage of an emplacement-related flexural bulge (see below).

5.2. Late Triassic-Late Cretaceous Neritic-pelagic (Köseyahya) thrust sheet

The traditional Munzur nappe (Perinçek and Kozlu, 1984) is made up of two separate regional-scale thrust units. The first comprises the Munzur thrust sheets, which are neritic throughout Late Triassic-Cenomanian, as summarised above. The second is the Köseyahya thrust sheet, as defined near Köseyahya, to the south of the Gürün autochthon (Bedi et al., 2005, 2009) (Fig. 8). A similar succession, termed the Neritic-pelagic nappe is exposed to the north of the Gürün autochthon (Robertson et al., 2013b). The successions in both areas can be correlated and are here referred to as the Neritic-pelagic (Köseyahya) thrust sheet.

The most complete succession (Fig. 3) through the Neritic-pelagic (Köseyahya) thrust sheet is exposed in the type area, near Köseyahya (Area 3A, near log lll) (Fig. 8 sections a, e, f) (Bedi et al., 2009), with an additional outcrop in Area 4, south of Elbistan (Fig. 9 sections a, b) and Area 4B, Nurhak Dağı). The type section is located 750 m south of Köseyahya (near Burmakaya Tepe) (Tekin and Bedi, 2007a, b; Dumitrica et al., 2013). There, the succession begins in the Middle Carnian, as dated by radiolarians, with alternations of fine-grained sandstone, calcareous siltstone, marl, mudstone and micritic limestones. Volcaniclastic interbeds and chert of diagenetic replacement origin are also present, mainly in the higher levels. The succession continues with Late Carnian pink to red calcilutites (4.6 m thick), rich in ammonoids, crinoids, conodonts and pelagic bivalves (*Halobia* sp.) ('Hallstatt limestone') (Fig. 10i, j) (Bedi et al., 2016). Medium to thick-bedded Norian white limestones above ('Dachstein limestones') (Fig. 10k) include abundant Megalodonts and benthic foraminifera (Tekin and Bedi, 2007a, b). Above a discontinuity, the Early Jurassic is made up of relatively thin, stratigraphically condensed (c. 20 m), nodular, ammonite-rich micritic limestone ('Ammonitco Rosso'). The Mid-Late Jurassic is dominated by redeposited limestones (calciturbidites), with pelagic carbonate interbeds that are commonly silicified. The redeposited limestones are rich in neritic grains, especially ooids and are extensively silicified. Radiolarian chert increases in abundance during the Tithonian-Cenomanian interval. The Early Cretaceous (Tithonian-Berriasian) is dated using calpionellids within pelagic interbeds (Area 3A, E of Elbistan) (Fig. 10l) (see Supplementary table 1).

The upper part of the succession (Özbey Formation), where exposed, is depositionally overlain by pinkish pelagic carbonates with radiolarian chert intercalations. The pinkish pelagic carbonates are similar to those of the Munzur thrust sheets (see above) and have been given the same name (Kızılkandil Formation), although only those in the Neritic-pelagic (Köseyahya) thrust sheet are siliceous. The type section (near Kızılkandil mezrası), c. 40-50 m thick, depositionally overlies a layer of redeposited oolitic limestone (Özbey Formation). In a nearby succession, the Kızılkandil Formation unconformably overlies older neritic facies (Demirlitepe Formation), and includes both planktic foraminifera of Turonian-Santonian age and also radiolarians of Turonian-Santonian age. Another section, which is faulted against Late Triassic neritic facies (Ortakandil Tepe), contains Turonian planktic foraminifera and radiolarians; a further section (Han tepe-Toklu tepe) contains Turonian-Santonian radiolarians (Bedi et al., 2009).

The Kızılkandil Formation has been variously dated as Turonian-early Campanian (Perinçek and Kozlu, 1984), Coniacian-Campanian (Pehlivan et al., 1991), or Albian-Santonian, using a combination of nannofossils, radiolarians and planktic foraminifera (Bedi et al., 2009). The shortest-ranging planktic foraminifera, determined by Dr. A. Hakyemez, are *Rotalipora ticinensis*, *Rotalipora apenninica* (upper Albian), *Helvetoglobotruncana helvetica* (lower-middle Turonian) and *Dicarinella asymetrica* (Santonian) (Robaszynski and Caron, 1995). Radiolaria range from Albian-Santonian (Bedi et al., 2009). The pelagic limestones are unconformably overlain by the syn-emplacement Kemaliye Formation (see below).

The succession in the Neritic-pelagic (Köseyahya) thrust sheet began to accumulate during the Carnian on a submerged shelf, in the form of stratigraphically condensed, hemipelagic limestones and siliceous sediments, which are variably rich in ammonites, crinoids, foraminifera, calcareous algae and radiolarians. Condensed ammonite-rich, red pelagic carbonate deposition persisted during the Early Jurassic. During the Late Jurassic, the carbonate platform developed into a gently sloping carbonate ramp on which redeposited ooid-rich facies accumulated. The probable source was the adjacent shallow-water Munzur carbonate platform. The greatly increased abundance of chert in the Tithonian-Albian interval points to further deepening. This probably resulted from tectonic subsidence because global sea-level rise is not inferred during this time interval (Haq, 2014). Where the pelagic limestones (Kızılkandil Formation) overlie older parts of the succession (Demirlitepe Formation), tectonically induced uplift and submarine erosion are inferred. The pelagic carbonates accumulated during the mid-Late Cretaceous (Albian-Santonian), as in the Munzur thrust-sheet succession. The sea floor was already deep, favouring continuing radiolarian deposition. The appearance of pelagic carbonate probably represents increased planktic productivity (Bosellini and Winterer, 1975).

The Late Cretaceous pelagic carbonates in both the Munzur and Köseyahya successions are similar to those overlying the Tauride carbonate platform elsewhere, including the Bey Dağları (Poisson, 1977, 1984) and the Geyik Dağ (Sarı and Özer, 2002; Sarı et al., 2004). In the Geyik Dağ (central Taurides), Cenomanian rudist-rich facies are overlain by pelagic carbonates that accumulated until the Eocene (Solak et al., 2017, 2019), similar to the Gürün autochthon (Fig. 2).

6. Late Permian-Late Cretaceous Pelagic (Gülbahar) unit

Widely distributed, dismembered Late Permian to Late Cretaceous deep-water successions, including both pelagic and coarser-grained redeposited facies, and also basaltic rocks were previously included within the Dağlıca Complex ('flysch with blocks'), together with dismembered ophiolitic rocks (Kozlu et al., 1990; Perinçek and Kozlu, 1984). However, more recent mapping and stratigraphical studies indicate the presence of an originally intact Triassic to Late Cretaceous deep-water platform-margin succession. This has been named the Gülbahar Nappe (Bedi et al., 2009, 2018), based on a proposed correlation with comparable deep-sea successions including basaltic volcanics in the western Taurides (Şenel et al., 1989; Collins and Robertson, 1998; Sayıt et al., 2015). The deep-sea platform-margin succession in the Eastern Taurides has also been termed, informally, as the Pelagic nappe, in contrast to the traditional Munzur thrust-sheet neritic succession (Robertson et al., 2013b).

No complete succession of the Pelagic (Gülbahar) unit is known in any one section, although an overall stratigraphy can be pieced together (Fig. 3). Local sections show considerable facies variation and may represent combinations of lateral variation and/or proximal-distal changes. The most intact sequences are mainly located to the south of the Gürün autochthon in Area 2 (e.g. Büyük Tatlı), whereas, within the Northern allochthon, the Pelagic unit is mainly represented by blocks of Mesozoic deep-water facies within melange (Robertson et al., 2013b).

During the present study, local sequences of the Pelagic (Gülbahar) unit were studied in Areas 2-4 (Figs. 7-9). Relatively intact and continuous sequences (up to c. 80 m thick) are exposed between the lower and the upper Munzur thrust sheets in Area 2 (Dağlıca) (Fig. 7; e.g. near Tatlar, specifically Büyük Tatlı), although these are too small and localised to show effectively on regional-scale maps. Up to tens of m-thick sequences are widely exposed beneath the Köseyahya thrust sheets in Area 3A (E of Elbistan) (Fig. 8), and also occur beneath both the Munzur and Köseyahya thrust sheets in Area 4 (south of Elbistan) (Fig. 9). In addition, variable-sized, isolated blocks of similar lithologies are strewn through the late Cretaceous syn-tectonic Kemaliye Formation, as exposed in each of the above areas (see below).

The oldest known lithologies in the Pelagic (Gülbahar) unit are Late Permian siltstones, marls, siliceous limestones and thin-bedded limestones, including fusilinids and benthic foraminifera (Bedi et al., 2009) (Fig. 11, logs II, III; see Fig. 8 for locations). There are also short, highly deformed intervals of Triassic sandstone and shale (Fig. 12a, b). Jurassic-Cretaceous facies are mainly non-calcareous radiolarites and radiolarian mudstones, interbedded with pelagic carbonates (Fig. 12c), variably silicified calciturbidites (Fig. 12 d, e) and carbonate debris flow-deposits, variably rich in chert clasts (Fig. 12 f-i). The redeposited limestones are rich in redeposited ooids, oolitic limestone, pisoliths, benthic foraminifera (with oolitic coatings) and calcareous algae. Reworked pelagic limestone, radiolarian chert, monocrystalline quartz and muscovite are also present.

Variably preserved radiolarians, identified during this study (see Table 1), yielded the following Late Triassic to Late Cretaceous ages for local sections or blocks: Late Norian (block in serpentinite, near Yoksullu mezra (Area 4; Fig. 11, log I); Middle Jurassic (Bajocian), near Büyük Tatlı (Area 2) and near Yoksullu mezra; Late Oxfordian near Yoksullu mezra; Late Oxfordian-Tithonian near Kayseri (Area 2, log VII) and near Topaktaş (Area 2, log Vlll); Kimmeridgian-early Tithonian near Büyük Tatlı and near Yuksullu mezra; Late Tithonian-Berriasian near Büyük Tatlı); Late Valanginian-Hauterivian (block in debris-flow deposit) near Kabaktepe; Early Albian at Kırandere (near İncelik köy; Area 2); Aptian at Kırandere; and Late Albian-Cenomanian also at Kırandere. In addition, redeposited benthic foraminifera are dated more generally as Late Jurassic-Early Cretaceous (at Kaşanlı, Küçük Tatlı and Büyük Tatlı, all in Area 2 (see Supplementary Table 1).

An overall deep-marine, lower slope to base of-slope setting is inferred for the Pelagic (Gülbahar) unit. Late Permian pelagic carbonates with relatively fine-grained siliciclastic turbidites were followed by Early to Middle Triassic hemipelagic mudrocks, fine-grained sandstone turbidites and thin-bedded hemipelagic carbonates. Middle to Late Triassic hemipelagic limestones (Halobia limestones), radiolarian sediments, calciturbidites, quartzose sandstone/siltstone turbidites and, locally redeposited conglomerates, followed above this. The Jurassic-Early Cretaceous encompassed non-calcareous radiolarian muds, variably silicified calciturbidites and also debris-flow deposits with reworked neritic clasts (e.g. oolitic limestone) and/or pelagic clasts (radiolarite; pelagic limestone). Deposition locally culminated in large-scale gravity collapse of slope facies, leading to redeposition, with clasts of neritic/pelagic limestone and radiolarite in a matrix of lithoclastic debris-flow deposits, sandstone turbidites, ophiolite-derived debris-flow deposits, calciturbidites and muds. The ophiolite-bearing mass-flow units represent a depositional-tectonic link between the passive margin slope lithologies and the emplacement-related mass-flow units which are located higher in the tectono-stratigraphy (see below).

In places (e.g. Dağlıca, Area 2), short, highly deformed sequences of basalt, volcaniclastic sandstone and/or hyaloclastite are interbedded with Middle-Late Triassic deep-water calcareous and siliceous facies (Kozlu et al., 1990; Bedi et al., 2009; Robertson et al., 2013b). Chemically, the basalts are of enriched, alkaline, within-plate type (Robertson et al., 2013b). A sample of radiolarian chert from Area 2 (Bakış) gave a Norian (Late Triassic) age (Fig. 11 log ll; see Table 1). In addition, in Area 5A (Kemaliye) (Fig. 2) basaltic lavas of the Pelagic (Gülbahar) unit are interbedded with Late Triassic pelagic limestones (dated) and radiolarian cherts (see Supplementary Table 1).

The Pelagic (Gülbahar) unit accumulated adjacent to the Munzur and Köseyahya thrust sheet successions, taken together. The Permian siliciclastic material is likely to have been derived from an original, but now tectonically detached, substratum of the carbonate platform units. The Triassic records subsidence, localised alkaline basaltic volcanism (rift-related), terrigenous sand/silt gravity input, hemipelagic carbonate deposition (periplatform ooze) and radiolarian accumulation in a fertile sea. The Jurassic-Cretaceous was characterised by 'background' radiolarian and siliceous pelagic carbonate deposition (diagenetically altered to chert), beneath (or near) the carbonate compensation depth (CCD). The calciturbidites and carbonate debris-flow deposits accumulated on an unstable slope, derived from the adjacent carbonate platform. The Late Cretaceous is characterised by pelagic limestone, marl and chert that accumulated above the CCD, with *Globotrunca* sp., as in the adjacent carbonate platform units (equivalent to the Kızılkandil Formation). The presence of ophiolite-derived debris-flows within a sequence affected by slumping and soft-sediment deposition suggests that the distal platform slope over-steepened and collapsed related to ophiolite emplacement.

7. Late Cretaceous emplacement-related Kemaliye Formation

In different areas, the Malatya Metamorphics and both the Munzur and Köseyahya platform units are depositionally overlain by Late Cretaceous syn-tectonic lithologies that provide key information concerning the nature and timing of both tectonic emplacement and exhumation in the region. In general, the lithologies form coherent to highly disrupted successions, which are characterised by matrix-supported conglomerates, blocks, or dismembered thrust sheets, all set within an argillaceous and/or sandy matrix. The syn-tectonic units occur at two different structural levels in the regional thrust stack. The higher-level unit overlies the Munzur/Köseyahya platform units, whereas the lower-level unit overlies the Malatya (Keban) metamorphics.

In the northeast of the region studied, near Kemaliye (Figs. 13, 14 Area 5A), meta-carbonate rocks (Kaletepesi limestone) that are correlated with the lower part of the Keban metamorphics (Bilgiç, 2008b, c) are mapped as being unconformably overlain by 'olistostromes', named the Kemaliye Formation, after the town in this area (Figs. 13, 14) (Özgül et al., 1981; Özgül and Turşucu, 1984; Perinçek and Kozlu, 1984; Bilgiç, 2008b, c). The formation has been inferred to be Late Senonian (Özgül et al., 1981), or more specifically Late Campanian-Early Maastrichtian (Bilgiç, 2008b, c), based on the youngest datable fossiliferous material (i.e. *Globotruncana*-bearing pelagic limestone). In general, the succession has been described as beginning with localised conglomerates, with clasts of dark grey limestone, chert and diabase, passing into sandstone, with common basic igneous rock and limestone grains, and also interbeds of sandstone and marl (Perinçek and Kozlu, 1984). In its type area, the Kemaliye Formation is locally overlain, unconformably, by Early Eocene lithologies (Subaşı formation) (Bilgiç, 2008b, c). The Kemaliye Formation appears to correlate with the latest Cretaceous Gündüzbey Formation, to the south of Malatya.

The term, Kemaliye Formation was later adopted for all of the Late Cretaceous unmetamorphosed syn-tectonic facies in the region, including those associated with the allochthonous Munzur and Köseyahya successions (Bedi and Yusufoğlu, 2018). However, this is problematic for several reasons: (1) The underlying units differ strongly in different areas (i.e. Malatya (Keban) Metamorphics in the type area, versus Munzur-Köseyahya unmetamorphosed carbonate platform elsewhere); (2) The Kemaliye Formation in its type area includes lithologies (e.g. basalt-pelagic limestone-radiolarite) that are assigned to the Pelagic (Gülbahar) unit elsewhere (i.e. it is a composite unit); (3) The Kemaliye Formation, as previously mapped, is, in part, tectonically assembled rather than an intact sedimentary succession.

Although we retain the general name, Kemaliye Formation here for consistency with previous work, the occurrences in three different tectono-stratigraphic settings are discussed separately below. These are: (1) Unconformably overlying the Malatya (Keban) Metamorphics in Area 5A (Kemaliye) (Figs. 15a, 16a); (2) Unconformably overlying the Munzur and/or the Köseyahya thrust sheets, and also underlying the Munzur and Köseyahya thrust sheets where no basement is exposed. Consideration of these two main contrasting settings allows a more refined interpretation in terms of syn- versus post-emplacement tectonics.

7.1. Late Cretaceous Kemaliye Formation overlying the Malatya (Keban) Metamorphics

An unconformity is mapped between the Kemaliye Formation and the Malatya (Keban) Metamorphics west of Keban Lake (Bilgiç, 2008b, c) (Fig. 14). The meta-carbonate rocks near the contact are in places converted to calc-mylonite, indicating high-strain conditions (Fig. 16b). In some areas, the lower part of the formation is dominated by crudely bedded debris-flow conglomerates (Fig. 15a; 16c), as logged locally (Fig. 17). These contain abundant clasts of metamorphic rocks (Fig. 16d), together with radiolarian chert (Fig. 16e), deformed limestone (Fig. 16f), granite (locally), coral and large bivalves (rudists). Above this, much of the outcrop is dominated by blocks and dismembered thrust sheets (Fig. 16a). Many of the blocks are well-bedded, commonly dark, organic-rich limestones (typically 10s of m in size). Short, intact sequences of well-bedded limestones are intercalated with limestone conglomerates (calcirudites) that locally include well-rounded clasts and rudist debris of probable Cenomanian age. Neritic limestones of Triassic-Cretaceous age, chert (undated) and Late Cretaceous pelagic limestones are also present. A neritic limestone block (near Yuva; Fig. 14) is dated as Triassic based on benthic foraminifera (Fig. 18a, b; see also Supplementary Table 1). In one area, slices and/or large blocks of basaltic lava are exposed above the contact with the metamorphics (Fig. 15b). The lavas are interbedded with pelagic limestones that contain a typical Triassic fauna, including *Halobia* sp. and radiolarians (see

Supplementary Table 1). Although mapped as Kemaliye Formation (Bilgiç, 2008b, c) this volcanogenic unit belongs to the Pelagic (Gülbahar) unit (see above).

The matrix of the Kemaliye Formation in the type area is extremely heterogeneous, including variable abundances of monocrystalline quartz, polycrystalline quartz, plagioclase (altered), muscovite, biotite, epidote, clinopyroxene, hornblende, chlorite (including blue chlorite), zircon, apatite and opaque grains, in generally decreasing order of abundance. Lithoclasts are mainly micaschist, quartzite, chert, neritic limestone, basalt (with orientated microphenocrysts), altered basic volcanic glass (palagonite), felsic volcanics (recrystallised), dacite (with plagioclase phenocrysts), granite, bioclastic carbonate, marble, dolomite, sandstone (with parallel-orientated muscovite laths), siltstone (locally iron-rich), shale (partly recrystallised), serpentinite, gabbro, diabase, phyllite, phyllonite and mylonite (Fig. 6d-g). Bioclasts include micritic grains with shell fragments, pellets, benthic foraminifera, algal grains (pisoliths) and/or oolitic limestone (with clear, plutonic quartz cores). The matrix is either calcareous (partly recrystallised), or siliciclastic (with fine quartz and muscovite). Most grains are angular although a few are well-rounded. Some samples have a calcite spar cement.

In the northeast, where the Kemaliye Formation is mainly covered by younger volcanics (Fig. 14; NE of Yaka), small exposures of debris-flow deposits include clasts and blocks of altered lava, serpentinite and platy grey-pink Triassic pelagic limestone (see Supplementary Table 1). Farther northeast again, towards Ovacık (Fig. 13), the formation includes a large (c. 5 km-long) tabular body of Permian limestone that is tectonically overlain by serpentinised ultramafic rocks (Bilgiç, 2008b, c; MTA, 2011).

7.2. Kemaliye Formation associated with the Munzur and Köseyahya thrust sheets

Previous authors reported that the Munzur limestones, including the Late Cretaceous pelagic limestones (Kızılkandil Formation), pass unconformably upwards into syn-tectonic calcareous siltstones and sandstones, followed by an incoming of limestone blocks. This unit was termed the Binboğa Formation by Perincek and Kozlu (1984), named after the Binboğa Mountains 20 km west of Afşin. However, the term Binboğa Formation was later applied to the entire Early Triassic-Early Cretaceous succession of the Munzur thrust sheet (Kozlu et al., 1990), complicating the use of this name. The latest Cretaceous syn-tectonic interval was later correlated with the Kemaliye Formation (Bedi et al., 2009; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018), although, as noted above, this unit differs strongly from the type Kemaliye area.

Planktic foraminifera from the Kemaliye Formation above the Munzur limestones (Bedi et al., 2009) are long-ranging throughout Campanian-Maastrichtian. The shortest-ranged taxon is *Globotruncana dupeublei*, whose first occurrence (base) is within the *Gansserina gansseri* Zone (71.75-72.97 Ma; late Campanian-early Maastrichtian), whereas the last occurrence (top) is within the *Abatomphalus mayaroensis* Zone (67.30-69.18Ma; top of Maastrichtian stage) (microtax.org/pforams/index.php). In addition, nannoplankton data support a late Campanian-late Maastrichtian age for the Kemaliye Formation within the Munzur and Köseyahya thrust sheets (Bedi et al., 2009).

During this study, six sections of the Kemaliye Formation within the main Munzur thrust sheet were logged in Area 2 (Dağlıca), where they show considerable facies variation (Fig. 19 logs 1-6). The formation is typically dominated by alternations of calcareous mudstone-siltstone-sandstone (Fig. 19 logs 1, 2, 4). In places, sandstone, limestone conglomerates (calcirudites) and limestone breccias appear near the base of the succession (Fig. 19; logs 3, 5, 6; Fig. 20a, b). During this study, intervals of pinkish pelagic limestone were dated as Campanian-Maastrichtian (near Kapaklı; see Supplementary Table 1). Benthic foraminifera within a limestone block, near Kaşanlı, yielded an Early Cretaceous age (Supplementary Table 1). Other blocks are rich in rudist bivalves (Fig. 20c, d).

The upper levels of the succession are commonly tectonically disrupted and include neritic and pelagic limestone blocks (Fig. 19 log 6; Fig. 20d, e). Clasts of bioclastic calcarenite yielded reworked Middle-Late Jurassic benthic foraminifera (see Supplementary Table 1). In places, the outcrop is chaotic with limestone blocks strewn through a sheared mudstone-sandstone matrix.

The sandstone interbeds are heterogeneous and include both monocrystalline and polycrystalline quartz, muscovite, neritic carbonate, chert, quartzose siltstone and basalt (Fig. 6h-i). The calcarenites comprise variable mixtures of platform-derived material (e.g. pisoliths, shells, echinoderm debris, ooids), chert (microcrystalline quartz), altered basalt, vesicular volcanic glass (with plagioclase microphenocrysts), serpentinite, microgabbro and dolerite, together with rare monocrystalline quartz, siltstone (terrigenous), phyllite, plagiogranite, amphibolite, muscovite, altered plagioclase and pyroxene. Many grains are well-rounded. Planktic foraminifera (e.g. *Globotrunca* sp.) occur rarely.

Comparable sequences of the Kemaliye Formation are also exposed unconformably overlying the Late Cretaceous pelagic carbonates of the Köseyahya platform/proximal slope succession (Kızılkandil Fm.), as well exposed in Area 3A (E of Elbistan) and Area 4 (S of Elbistan). The succession in Area 3A encompasses interbedded mudstones, siltstones, sandstones and clasts of limestone (Triassic-Cretaceous), chert and serpentinite (Fig. 6j). Overlying debris-flow deposits ('blocky flysch') include clasts and blocks that can be correlated with the platform succession beneath, including micritic, oolitic and pisolitic limestone, and also pelagic limestones (Kızılkandil Formation). Other lithologies can be correlated with the over-riding Pelagic (Gülbahar) unit (e.g. radiolarite and volcanic material). Blocks of pink, chert-bearing pelagic limestone in Area 3A, east of Elbistan (near Odunluk Tepe and Yumru Tepe) are dated as Campanian-Maastrichtian based on planktic foraminifera (see Supplementary Table 1). A chalky debris flow-deposit farther northeast (near Dağdam) includes Late Cretaceous planktic foraminifera (see Supplementary Table 1). Facies equivalents of the Kemaliye Formation are also well exposed south of Elbistan (Area 4), beneath the Köseyahya thrust sheet and/or the Munzur thrust sheet, with no exposed stratigraphic base (Fig. 8). In the southern part of Area 4, pelagic limestone blocks contain Campanian-Maastrichtian planktic foraminifera, as in the Kemaliye Formation generally (Fig. 21a-d). However, a sample from the same local outcrop contains Globigerinidae (Fig. 21e, f), and also Rotaliidae, indicating a post-Cretaceous (Cenozoic) age, and thus that the Kemaliye Formation underwent post-depositional reworking in this area (see below).

The Kemaliye Formation is also exposed farther east, as a narrow c. NE-SW-trending strip in Area 3B, Nurhak Dağı which exhibits some critical additional field relationships (Figs. 2, 16g, 22a, b). The uppermost exposed levels of the Malatya Metamorphics there are represented by well-bedded calc-schists, in places transformed to calc-mylonite (Fig. 16h), or are isoclinally folded (Fig. 16i). Above a low-angle tectonic contact, meta-carbonate rocks are overlain by meta-serpentinite (Fig. 22a, b). Both the calc-schist and the meta-serpentinite are cut by small granitic intrusions (Figs. 22a). The Malatya Metamorphics were isoclinally folded prior to intrusion (Fig. 16j). The contact between the meta-serpentinite and the granitic intrusion is brecciated indicating subsequent brittle deformation (Fig. 16k). Although not dated specifically, these intrusions are likely to form part of the Eocene

Doğanşehir granitoids (MTA, 2011; Kuşcu et al., 2013; Karaoğlan et al., 2012, 2016; Bedi and Yusufoğlu, 2018). The serpentinite is overlain, with a low-angle thrust contact, by a thin facies equivalent of the Kemaliye Formation that includes blocks of Triassic red crinoidal limestone, similar to the Köseyahya platform/slope succession (see above), and also blocks of limestone and limestone breccia set in a sandy matrix (Fig. 22b). Further south (near Beğre), the serpentinite is overthrust by a thin slice of neritic limestone and limestone debris-flow deposits with rudist debris, of probable Cenomanian age, capped by Fe-oxide (Figs. 16l; 22a; see also Supplementary Fig. 3). This unit is interpreted as a small thrust slice of the contact between the Köseyahya platform/slope succession and the overlying Kemaliye Formation.

In thin section, some of the matrix sandstones of the Kemaliye Formation in Area 3B (Nurhak Dağı) have a well-developed shear fabric, in which large quartz grains are fractured and veined, with a calcite spar infill at right angles to the shear fabric. Foliated muscovite is present along shear bands indicating partial recrystallisation. Two phases of deformation are indicated by the presence of extensional calcite veins orientated at right angles to each other. *En echelon* cracks are interpreted as riedel shears.

7.3. Interpretation of the syn-tectonic Kemaliye Formation

The type area of the Kemaliye Formation (near Kemaliye; Area 5A) is a composite unit, dominated by gravity-controlled deposition, mainly by mass-flow processes. The rudist bivalves and *Globotruncana*-bearing limestones within slices and blocks indicate a Late Cretaceous age, although the matrix remains poorly dated. The lower part of the succession includes debris-flow conglomerates (‘olistostromes’), sandstones, shales and exotic blocks that covered the Malatya metamorphic rocks. The metamorphic and local granitic detritus were derived from the subjacent Malatya (or Keban) Metamorphics, confirming that they were exhumed prior to deposition (see Discussion). However, the dominant sources of the exotic material were the over-riding Munzur thrust sheet, the Pelagic (Gülbahar) unit, and ophiolitic rocks (e.g. serpentinite). The limestone conglomerates with well-rounded clasts and rudist debris were sourced from the Munzur platform. The Triassic basalts with Halobia-limestone and radiolarite are correlated with the Pelagic (Gülbahar) lower slope/basinal unit, as noted above. Ophiolitic rocks are exposed to the northeast of the Kemaliye Formation type area.

The Late Cretaceous pelagic carbonate deposition (Kızılkandil Formation) of both the Munzur and Köseyahya thrust sheets ended with a hiatus (early Campanian (?); c. 83-78 Ma), commonly marked by iron-oxide accumulation. The likely cause of the hiatus, similar to that in the Malatya metamorphic succession, was flexural uplift related to the regional ophiolite emplacement. The hiatus was followed by mixed siliciclastic-carbonate redeposition during late Campanian-Maastrichtian, forming the Kemaliye Foramtion. Talus, ranging from sand-sized, to blocks (up to many-metre-sized), were shed into the basin, largely derived from the upper levels of the adjacent Mesozoic carbonate platform and/or slope units (e.g. Cenomanian rudist limestone). The likely cause of basin formation was regional-scale downflexure ahead of the advancing thrust load, which was dominantly ophiolitic. The presence of Triassic-Cretaceous clasts suggests that, in places, all levels of the stratigraphy were exposed and eroded. This, in turn, suggests that platform and slope units were imbricated and uplifted, eroded, and then collapsed as debris into the flexural foredeep. Permian limestone is inferred to have existed beneath the Mesozoic platform and/or slope units, as supported by the presence of the large (km-sized) body of Permian limestone, as associated with the Kemaliye Formation in the northeast of the type area (Area 5A; Fig. 13). In addition, the pelagic lithologies (e.g. radiolarian chert, siliceous pelagic limestone) and also alkaline within plate-type basalt were derived from the Pelagic (Gülbahar) unit. Ophiolitic material is also variably present in the form of basalt, diabase, gabbro and/or serpentinite, sourced from the over-riding ophiolitic units. The succession accumulated in relatively deep water (100s m), as suggested by intercalations of pelagic carbonate containing Campanian-Maastrichtian planktic foraminifera.

Slices of the Munzur limestone were emplaced over the Kemaliye Formation in places, complicating the local tectono-stratigraphy. For example, in Area 3B (Nurhak Dağı), a slice of the highest levels of the neritic Munzur platform, complete with its iron-oxide coating (see above), was imbricated beneath the over-riding Köseyahya thrust sheet. Since the Mesozoic limestones (Munzur and Köseyahya) now structurally overlie the Kemaliye Formation it can be inferred that the Malatya-Keban metamorphics were exhumed, eroded to form clastic material (Kemaliye Formation), and later over-ridden by the regional limestone thrust sheet in this area.

The Kemaliye Formation above the Munzur and Köseyahya platform/slope successions is comparable with the widespread late Cretaceous syn-tectonic Yavça Formation (and facies equivalents) that intervene between platform carbonates, below and ophiolitic rock, above throughout the Taurides, for example in the Aladağ Unit (Maastrichtian Zekeriya Formation) and in the Bolkar Dağ Unit (late Campanian-Maastrichtian Söğüt Formation). These units unconformably overlie units of different age and facies in different areas and are generally interpreted as olistostromes or sedimentary melanges related to regional ophiolite emplacement (Özgül, 1997; Andrew and Robertson, 2002; Parlak and Robertson, 2004; Mackintosh and Robertson, 2012; Bedi and Yusufoğlu, 2018). In summary, the Kemaliye Formation in its type area (Area 5A) is a composite unit which formed above the Malatya (Keban) metamorphics during or after their exhumation. In contrast, the Kemaliye Formation as mapped regionally above the Tauride platform units is am intact succession, interpreted as a foredeep related to ophiolite obduction.

8. Volcanic-sedimentary melange

Definitions: Melanges comprise disorganised blocks of single, or multiple lithologies, with or without a matrix, and may be either sedimentary or tectonic origin, or both (see Raymond, 1984). Volcanic-sedimentary melange is a variety of melange in which the blocks are mainly made up of volcanic and sedimentary rocks, unrelated to ophiolites. Volcanic-sedimentary melange can shed light on both oceanic and emplacement processes.

Volcanic-sedimentary melange is well represented in the northeast of the region studied (Hekimhan area) (Fig. 2), where it is made up of short (10s of m), dismembered sequences of basalt, pelagic limestone and radiolarite (e.g. Yeşildere Melange). A local section comprises pillow basalt (80 m) with intercalations of ribbon radiolarite (c. 20 m), then alternations of radiolarite and pelagic limestone, followed by siliceous pelagic limestone (9 m). Radiolarite from the upper part of this interval was dated as Late Albian-Early Cenomanian (see Table 1). In the Dağlıca area (Area 2), short sections of basaltic lavas (<10s m) are interbedded with, and overlain by Middle Oxfordian-Early Tithonian radiolarian sediments (Robertson et al., 2013b). Geochemical data for the basalts from both areas indicate mid-ocean-ridge, to enriched intra-plate settings, although some samples have a subduction-related influence (Robertson et al., 2013b; Robertson et al., in press a). A similar range of basaltic compositions has been identified within meta-volcanic-sedimentary melange farther west, including the Anatolides (Afyon zone) (Robertson et al., 2009; in press b).

The volcanic-sedimentary melange was sourced from oceanic crust, including MOR-type basalt, 'seamounts' and subduction-influenced crust, within an oceanic basin that existed at least from Late Jurassic-Late Cretaceous. The melange was accreted related to subduction, and was emplaced onto the Tauride platform together with the other allochthonous units.

9. Ophiolite-related units

Definitions: Ophiolites represent relatively coherent bodies of oceanic lithosphere, although commonly incomplete. Dismembered ophiolites are tectonically dissected. Ophiolitic melange has component lithologies derived from an ophiolite and directly associated deep-sea sediments. Ophiolite-related melange, in contrast, includes a mixture of ophiolitic rocks and other unrelated lithologies (e.g. neritic limestone). These three types of melange all occur within the eastern Taurides, related to sea-floor spreading and ophiolite emplacement.

9. 1. Ophiolite-related melange and ophiolitic melange

Ophiolite-related melange and ophiolitic melange are well exposed north of Elbistan (Area 2, Dağlıca), where they are intergradational and structurally interleaved. Within the ophiolite-related melange, ophiolitic blocks/slices are embedded in a matrix of sheared mudrock. The ophiolitic melange is mainly sheared harzburgite but other ophiolitic lithologies are present including gabbro and diabase dykes (locally cut by plagiogranite veins), as exposed east of Elbistan (Area 5) (see Supplementary Fig. 5). In this area, dismembered ophiolitic rocks of the Dağlıca ophiolite (see below) are spatially associated with short (up to 10s of m), deformed successions of ophiolite-derived, matrix-supported conglomerates. In places, these clastic rocks occur above the Kemaliye Formation. The Kemaliye Formation, as related to the Munzur and Köseyahya thrust sheets, does not usually contain ophiolitic material (in contrast to the type area, above the Keban metamorphics). However, locally in Area 2 (Dağlica), the highest levels of the intact Kemaliye Formation contain ophiolitic debris (Fig. 19 log 4), suggesting a link with the tectonically associated ophiolitic rocks (Dağlıca ophiolite). However, no undeformed contact could be observed. The debris-flow deposits are crudely stratified (Fig. 20f), showing both normal and reverse grading. The clasts are mostly angular to subrounded and are dispersed randomly though a poorly sorted sand-granule-grade matrix (Fig. 20g). Most parts of an ophiolite pseudostratigraphy are represented as clasts, including gabbro (Fig. 20h) and basalt (Fig. 20i); siliceous pelagic carbonate is mostly preserved as diagenetic replacement chert (Fig. 20j).

Another excellent example of ophiolite-related melange, here termed the Divriği melange, is exposed in the northeast of the region (Area 5B) (Figs. 2, 23). This melange is located between the Munzur thrust sheet, below and the Divriği ophiolite, above (Aktimur, 1988; Özgül and Turşucu, 1984; Öztürk and Öztunalı, 1993). This unit is otherwise known as the Yeşiltaşyayla ophiolitic melange (Yılmaz and Yılmaz, 2004), the Refahiye ophiolite (Atabey and Aktimur, 1997), and the Eriç melange (Özer et al., 2004). The Divriği melange has undergone low-grade metamorphism and is cut by Eocene granites (Boztuğ et al., 2007; Kuşcu et al., 2013). The smaller Güneş ophiolite is exposed in the same area (Yılmaz, 2001).

The Divriği melange, up to several 100 m thick, directly overlies the Munzur thrust sheet in its type area, the Munzur Dağları (Aktimur et al., 1998; Fig. 24a, b; see also Supplementary Fig. 4). The highest stratigraphical levels of the Munzur thrust sheet are well dated to the east of our study area. In this area (Ayıkayası Dağı), Cenomanian-aged, rudist-bearing neritic limestones are overlain by a thin (4 m) interval of thin-bedded, reddish siliceous pelagic carbonate of Turonian-Campanian age (Özer et al., 2004). This interval can be correlated, broadly with the latest Cretaceous pelagic cover of the platform carbonates in the Elbistan area (Kızılkandil Formation). Where well exposed in our area, north of Divriği, well-bedded, unmetamorphosed neritic limestones of the Munzur thrust sheet dip regularly westwards and are over-ridden by ophiolite-related melange, with a low-angle thrust contact (Fig. 24b). The highest exposed levels of the Munzur succession (5 km SSE of Divriği) are locally dated as Middle Jurassic, using benthic foraminifera (Fig. 18d, e; see also Supplementary Table 1), suggesting that the Cretaceous part of the original succession is now absent. Dark neritic limestones in the lower levels of the succession in the Divriği area are dated as Middle Triassic, based on benthic foraminifera (Fig. 18c). Similar platform lithologies are now present as blocks in the overlying ophiolite-related melange.

The Divriği melange overlies the succession in the Munzur thrust sheet. In places, neritic limestones are unconformably overlain by mudrocks that are similar to the matrix of the melange (Figs. 23, 24a-c). In places, the contact is faulted (see Supplementary Fig. 4). The lower part of the melange includes a neritic limestone block that was dated as Aptian-Albian, based on benthic foraminifera (Fig. 18f-i; see also Supplementary Table 1), similar to the age of the underlying intact platform succession. The mid to upper levels of the melange are dominated by elongate slices and blocks of recrystallised limestone, up to 100s m long and 10s m thick, set in a sheared shaly matrix (Figs. 24a-c, 25a). Benthic foraminifera within a packstone block gave an Aptian-Albian age (Fig. 18j-q), again suggesting that the missing interval at the top of the Munzur platform succession is represented by blocks in the melange. Other blocks include poorly sorted breccia-conglomerate, indicating a mass-flow (slope-related) setting, prior to emplacement into the melange. Some of the clasts are well-rounded suggesting exposure and reworking prior to redeposition, as in the Kemaliye Formation (see above). The blocks and terrigenous matrix are interspersed with anastomosing strands of highly sheared serpentinite, mostly harzburgitic (Figs. 24a-b; 25b; see Supplementary Fig. 4). In places, serpentinite melange reaches to within c. 80 (structural thickness) of the tectonic contact with the intact Munzur thrust sheet below. The melange as a whole has experienced polyphase deformation, with evidence of both southerly and northerly fold vergences (Fig. 25c, d).

Several additional areas provide supporting evidence. For example, an extensive outcrop of ophiolitic melange southeast of Divriği is dominated by sheared harzburgitic serpentinite, without limestone blocks (Fig. 25e, f). Similar serpentinite melange also occurs extensively, e.g. c. 70 km southwest of Divriği (around Kangal), where it overlies neritic limestones of the Munzur thrust sheet (locally dated as Jurassic; see Supplementary Table 1). In addition, melange outcrops to the west of Divriği (Fig. 2) have been summarised elsewhere (e.g. Büyük Yılanlı Dağ) (Robertson et al., 2013b; see also Özgül et al., 1981; Özgül and Turşucu, 1984; Aktimur et al., 1988; Atabey et al., 1994). These include several types of melange associated with the Pınarbaşı ophiolite in the northeast of the region studied (i.e. Kireçlikyayla melange of Yılmaz et al., 1991, 1993; Pınarbaşı melange of Atabey and Aktimur, 1997).

9.2. Ophiolites and related clastic deposits

Whereas, melanges are widely distributed throughout the eastern Taurides, coherent ophiolites are restricted to four main bodies, the Divriği (also Güneş), Hekimhan, Pınarbaşı and Kuluncak ophiolites, mainly in the north of the region studied (Fig. 2). Here we pay particular attention to the dismembered Dağlıca ophiolite and its associated debris-flow units (Area 2) which shed light on emplacement processes.

In the northeast, the Divriği (Sivas) ophiolite (Area 5B), dated at 93-94 Ma by zircon U-Pb, is partially dismembered and lacks extrusives rocks (Parlak et al., 2006, 2017). A locally exposed metamorphic sole (Fig. 24a, bii), dated at 93-94 Ma by Ar-Ar (Parlak et al., 2017), includes amphibolite, with subordinate, greenschist, marble and metachert, all cut by post-metamorphic diabase/microgabbro dykes. The protoliths of the amphibolite are within-plate basalts (seamount-type) and island-arc-type basalts, whereas the protoliths of the dykes are within-plate basalts (Parlak et al., 2006). Listwaenite is widespread in the Divriği (Sivas) ophiolite (Uçurum, 2000).

Farther southwest (c. 40 km), the dismembered Kuluncak-Hekimhan (Malatya) ophiolite (Fig. 2) comprises variably altered mantle harzburgite (tectonites), cut by isolated basaltic dykes, together with ultramafic cumulates (mainly dunite, wehrlite and pyroxenite), mafic cumulates (olivine-gabbro and normal gabbro), isotropic gabbro, diorite and quartz diorite, a sheeted dyke complex, plagiogranite and extrusive rocks. The basaltic extrusive rocks are associated with radiolarite, chert, pelagic limestone and hemipelagic mudstone (Metin et al., 2013; Camuzcuoğlu et al., 2017). Listwaenite again occurs (Uçurum, 2000). In the northeast, the Pınarbaşı ophiolite, dated as 93-94 Ma by zircon U-Pb (Parlak et al., 2017) (Fig. 2) exposes mantle tectonites, cut by isolated basaltic dykes, together with ultramafic to mafic cumulates, all above an amphibolitic sole (90-93 Ma by zircon U-Pb) (Parlak et al., 2017). These sole rocks are chemically similar to those of the Divriği ophiolite (Vergili and Parlak, 2005).

In addition, the dismembered Dağlıca ophiolite (Fig. 7; sections a, d, e) is restricted to thrust slices and blocks (up to km to km-sized). The lithologies were previously termed the Dağlıca complex (Kozlu et al., 1990; Perinçek and Kozlu, 1984), and the Dağlıca ophiolite (Robertson et al., 2013b). The lithologies include basalt, diabase, diabase dykes in harzburgite, gabbro, gabbro pegmatite, harzburgite, pyroxenite, wehrlite and dunite (see Supplementary Fig. 5). The metamorphic sole is represented by rare blocks of amphibolite-greenschist within adjacent ophiolite-related melange. The basaltic rocks of the Dağlıca ophiolite are chemically indicative of a supra-subduction zone origin (Robertson et al., 2006).

9.3. Interpretation of the ophiolites, melanges and related mass-flow units

The ophiolites formed in a Late Cretaceous (c. 92-93 Ma), supra-subduction zone setting (Parlak et al., 2013, 2019). They represent different parts of a regional-scale thrust sheet of oceanic lithosphere, with a metamorphic sole that is only now locally preserved. The presence of all of the units of a complete ophiolite, taken regionally, suggests that a typical supra-subduction zone ophiolite initially formed with all of the expected lithological units; however, this was variably dismembered during emplacement.

During emplacement, related to flexural loading by advancing oceanic lithosphere, the Mesozoic carbonate platforms (Munzur and Köseyahya) subsided to create the regional-scale foredeep mentioned above (Kemaliye Formation; see above). In proximal (northerly) areas, represented by the Divriği melange, the upper stratigraphic (Cretaceous) levels of the Munzur platform were partly removed. Most likely, they were detached, bulldozed ahead and collapsed as debris-flows and blocks into the northern part of the regional foredeep. During southward emplacement, serpentinite derived from the over-riding ophiolite harzburgite was tectonically incorporated into the foredeep.

During emplacement, the East Tauride ophiolites were variably dismembered. The Dağlıca ophiolite was strongly dismembered to form thrust sheets and broken formation, and also underwent mass-wasting to form ophiolite-derived debris flows. Ophiolitic material was initially sand-sized (within the Kemaliye Formation), then became clast/block sized (i.e. more proximal) and culminated in the emplacement of large ophiolitic blocks and thrust sheets. Gravity emplacement was therefore an important process for the melange units. Ophiolite-related melange covered all parts of the region (including south of Elbistan; Area 4). However, the ordered ophiolites are restricted to the north of the region, closest to their inferred origin and there is no field evidence that they were emplaced southwards over the entire region.

10. Latest Cretaceous-Paleogene cover sediments

Cover sediments provide important constraints on the nature of the substratum, the timing of emplacement and the tectonic conditions soon afterwards. The Divriği ophiolite is unconformably overlain by conglomerates, sandstone, mudstone, marl, limestone and volcaniclastic sediments, dated as Campanian-Maastrichtian (Yılmaz and Yılmaz, 2004; Bilgiç et al., 2008a, b). Approximately 50 km farther west (Tecer Dağı and Büyük Yılanlı Dağ), ophiolitic rocks, similar to the Divriği ophiolite (Kavak et al., 2017), are unconformably overlain by conglomeratic facies (Tecer Formation) (İnan and İnan, 1988), passing upwards into Late Maastrichtian shallow-marine, mixed carbonate-clastic facies (Atabey and Aktimur, 1997; İnan and İnan, 1988; Robertson et al., 2013b). Both the Kuluncak and Hekimhan ophiolites (and related melange units) are unconformably overlain by ophiolite-derived conglomerates, passing upwards into Late Maastrichtian shallow-water carbonates, including rudist limestones (Booth et al., 2013; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018). In addition, the Pınarbaşı ophiolite is unconformably overlain by non-marine clastics and minor carbonates, of inferred Palaeocene age (Erkan et al., 1978).

The widespread deposition of latest Cretaceous, typically late Maastrichtian, cover sediments show that, after short-lived emergence and erosion, the emplaced continental margin and ophiolitic units, were rapidly transgressed by non-marine to shallow-marine sediments, and that this was followed by a return to relatively stable tectonic conditions. The clast composition reflects the nearby units beneath, typically ophiolitic rocks. The timing of regional ophiolite emplacement is constrained as coeval with the syn-tectonic Kemaliye Formation (late Campanian-late Maastrichtian) but prior to the transgressive sediments regionally (probably late Maastrichtian). The emplacement of the allochthonous units therefore took place during a relatively short period of time (c. 75-70 Ma).

11. Structural relationships

11.1. Outcrop-scale structures

To shed additional light on the tectonic emplacement, bedding and fold data (fold axial planes and fold hinges) were measured throughout the study area and plotted on stereonets according to sub-area and tectono-stratigraphic unit (see also Supplementary Fig. 6).

Bedding in the Malatya and/or Keban metamorphics (Areas 1 and 5A) is generally orientated NE-SW (see supplementary Fig. 7). Fold axial planes mainly plot in the northern and southern quadrants, consistent with dominantly E-W folding with variably dipping axial planes (c. 10-80^{o}) (Fig. 26ai-aii).

Structural measurement from the allochthonous Tauride units are relatively variable. North of Elbistan (Area 2), the bedding strike is regionally c. E-W. Bedding orientations are variable in all units, with a slight NW-SE trend, consistent with large-scale symmetrical folding (see Supplementary Fig. 7). Fold axial planes are broadly east-west and commonly west-dipping (Fig. 26bi). Many fold hinges trend c. E-W, with axial planes dipping both N and S at moderate angles, suggesting refolding (Fig. 26bii). A local swing in fold hinge direction (south to west) in the relatively autochthonous Gürün outcrop (see Supplementary Fig. 8) could represent refolding (or possibly local block rotation). Farther east (Area 3A; E of Elbistan), the bedding is more NW-SE. Fold axial planes and fold hinges are broadly east-west, mainly at moderate angles (Fig. 26ci-ii; see Supplementary Fig. 9). In the Kemaliye area in the northeast (Area 5A), bedding data from both the Malatya Metamorphics and the Kemaliye Formation have a slight NW-SE strike, mainly at moderately angles (see Supplementary Fig. 10). Fold axial planes (mostly in the Keban metamorphics) mainly dip southwest at variable angles. Fold hinges have a dominant NW-SE trend. Opposing NW vs. SE directions hint at re-folding (Fig. 26 di-dii).

The relatively coherent data set from the Malatya Metamorphics (Fig. 26 ai-aii) is consistent with N-S compression (without preferred vergence). The fold data from Area 2 (Dağlıca) are consistent with two-phase emplacement along c. E-W axes (with opposing directions). The more NW-SE fold trend in the Kemaliye area farther northeast (Area 5A), mainly in the Malatya (Keban) Metamorphics, represent a different compression direction or possibly bulk rotation.

11.2. Inter-relations of regional tectono-stratigraphic units

The mutual relations are mainly indicated by a combination of sedimentary, metamorphic, igneous and structural evidence.

11.2.1. Relation of the Malatya metamorphics to the Göksun ophiolite: sedimentary evidence

In the south, the Malatya Metamorphics (Bodrum nappe) are thrust over the post-emplacement sedimentary cover of the Göksun ophiolite (Harami Formation), shedding light on its timing of emplacement. South of Afşin (Area 1), the Göksun ophiolite is unconformably overlain by conglomerate, sandstone, sandy/shaly limestone and marl (un-named unit of Perinçek and Kozlu, 1984) that is correlated with the Harami Formation in its type area (Elazığ) (Perinçek and Kozlu, 1984; Robertson et al., 2007; Bedi et al., 2009). The succession south of Afşin begins with polymictic conglomerates with schist and marble, radiolarite, pelagic limestone, chert, ophiolitic rocks (including diabase and basalt), and fines upwards into sandstone, limestone and microconglomerates with clasts of similar composition (Yılmaz et al., 1987; Bedi et al., 2009; this study). Thin sections include monocrystalline (plutonic) quartz, polycrystalline (metamorphic) quartz, sericitic schist, marble, micritic limestone, biotite and muscovite, in generally decreasing order of abundance (Fig. 6k, l). The matrix is biomicrite with a mixture of planktic and benthic foraminifera. The succession is dated as latest Cretaceous using planktic and benthic foraminifera, and also calcareous nannofossils (Perinçek and Kozlu, 1984; Yılmaz et al., 1987, 1993; Robertson et al., 2007; Bedi et al., 2009). The basal conglomerates include pelagic limestone pebbles of Santonian age, similar to the Kızılkandil Formation of the Munzur and also the Köseyahya successions (Bedi et al., 2009). During this work, samples of calcarenite yielded Late Campanian-Maastrichtian ages (see Supplementary Table 1). Samples from the upper part of the formation (Sarıkaya member) have been dated as late Maastrichtian based on planktic foraminifera and nannofossils (Bedi et al., 2009), of which the key taxa are *Gansserina gansseri* (72.35-66 Ma, latest Campanian-Maastrichtian) and *Globotruncanita angulata* (66.04-72.05 Ma, top Maastrichtian).

The post-emplacement sedimentary cover of the Göksun ophiolite accumulated in a shelf sea of moderate water depth (>10s m), with clastic sediment supply both from the Munzur and/or Köseyahya platform units and also from already exhumed Malatya metamorphic rocks. The Malatya metamorphic thrust sheet was, therefore, tectonically juxtaposed with the underlying Göksun ophiolite during the latest Cretaceous.

11.2.2. Post-exhumation imbrication of the Malatya Metamorphics: sedimentary and structural evidence

SW of Elbistan (Area 4), the Neritic-pelagic (Köseyahya) thrust sheet is thrust southwards over the Malatya Metamorphics (Fig. 9, section A). However, elsewhere the contact is steeply dipping and is likely to be a strike-slip fault (Fig. 9, section A). In this area, near Kalaycık (Fig. 9 section A; locality E), Triassic Malatya metamorphic rocks (exposed on Medetsizdağı) are underlain by a small slice (>40 m thick) of unmetamorphosed debris-flow deposits that include gabbro, basalt, pelagic limestone (with volcanic debris) and radiolarite. This facies is similar to the Kemaliye Formation, as exposed c. 12 km to the NE (near Sokullu; Fig. 9 map). A sample from a block of pelagic limestone contains Campanian-Maastrichtian planktic foraminifera, as in the Kemaliye Formation (Fig. 21a-d). However, an additional sample includes Globigerinidae (Fig. 21e, f) and also Rotaliidae, indicating a post-Cretaceous (Cenozoic) age. Two other samples contain a rich Middle Palaeocene (Selandian) planktic foraminiferal assemblage (see Supplementary Table 1). Relatively deep-water pelagic conditions therefore existed during the Palaeogene, followed by reworking of pelagic carbonates within debris-flow deposits. Elsewhere (e.g. west of Afşin), the Malatya Metamorphics are internally imbricated with Eocene shelf-depth Nummulitic limestones (Robertson et al., 2006; Fig. 4 a). The inter-slicing took place during Mid-Late Eocene regional deformation (see below). However, the distance of Eocene thrust transport is likely to have been limited (a few kms at most) because the Göksun ophiolite and the Malatya Metamorphics are mutually intruded by the 88-82 Ma Baskil Granitoids, without major thrust dislocation of the contact relations (Karaoğlan et al., 2012, 2016; Bedi and Yusufoğlu, 2018).

11.2.3. Contact relations between the Munzur and Köseyahya thrust sheets: sedimentary and structural evidence

The Munzur thrust sheet is subdivided into the main, lower thrust sheet that encompasses the entire succession and the much thinner, internally disrupted, upper thrust sheets (mainly Cretaceous), as exposed in the north, in Area 2 (Dağlıca) (Figs. 7; Fig. 20c-e). The upper and lower thrust sheets are separated by the Kemaliye Formation, which has widespread inclusions of the dismembered Dağlıca ophiolite, related melange (Fig. 7) and, locally, of the Pelagic (Gülbahar) unit (Fig. 7f). In places, limestones of upper thrust sheet directly overlie the southern margin of the Gürün autochthon (Fig. 7c).

NE of Elbistan (Area 3A), the Munzur thrust sheet is thrust southwards over the Neritic-pelagic (Köseyahya) thrust sheet (Fig. 8 sections a, e). The two thrust sheets are separated by mass-flow units, correlated with the Kemaliye Formation (see Supplementary Fig. 7). Poorly bedded calcarenites form the matrix of debris-flow deposits; these include large foraminifera and calcareous algae of Late Palaeozoic (Carboniferous-Permian) age (see Supplementary Table 1), hinting at derivation from an original but now missing Late Palaeozoic substratum to the Munzur limestones. The imbrication of the two major platform carbonate/slope thrust sheets therefore took place after formation of the latest Cretaceous Kemaliye Formation, probably during the latest Cretaceous.

In the same area, NE of Elbistan (Area 3A), the Neritic-pelagic (Köseyahya) thrust sheet beneath the Munzur thrust sheet is relatively thin (100s m) and highly disrupted. Pelagic limestones of the Neritic-pelagic (Köseyahya) thrust sheet are repeatedly imbricated with the latest Cretaceous Kemaliye Formation (Fig. 8). The Pelagic (Gülbahar) unit that is locally exposed beneath both the Neritic-pelagic (Köseyahya) thrust sheet and the Munzur thrust sheet are both tightly folded and, in places, intensely imbricated, indicating intense compressional deformation during emplacement (see Supplementary Fig. 6). On the other hand, the widespread presence of conjugate fault blocks indicates extension (see Supplementary Fig. 6). One explanation is that the Neritic-pelagic (Köseyahya) sheets were emplaced by gravity sliding into the Kemaliye foredeep, followed by imbrication during regional emplacement into the latest Cretaceous thrust stack.

In the south (south of Elbistan; Area 4), a Munzur thrust sheet is mapped as underlying a Köseyahya thrust sheet (Bedi et al., 2009) (Fig. 9, section A). This points to complex and variable re-imbrication because to the northeast (e.g. Area 3A; Fig. 8) the Munzur thrust sheet regionally overlies the Köseyahya thrust sheet. All of this imbrication and re-imbrication is inferred to be latest Cretaceous in age.

In addition, to the NW of Elbistan (N of Afşin, near İncirli, Area 2), the Malatya Metamorphics are thrust northwards over the Southern allochthon, including the Kemaliye Formation, above a sharp south-dipping contact (Figs. 2; 4l; Supplementary Fig. 2). This indicates an important, but localised, phase of backthrusting after the initial latest Cretaceous emplacement. Northward vergence is also observed within the adjacent Southern allochthon (Perinçek and Kozlu, 1984; Robertson et al., 2013).

11.2.4. Contact relations between the Gürün autochthon and the allochthonous units

Along the southern margin of the Gürün autochthon (Area 2; Dağlıca; Figs. 7, 20k), the relatively autochthonous succession culminates with Middle Eocene (Lutetian) calcareous mudstones, rich in large foraminifera. Interbedded sandstones and debris-flow deposits contain ophiolitic detritus. Several km to the south (Hurman Çayı-Kalesi area) (Fig. 7, marked in red), ophiolitic rocks and Munzur limestones are thrust over an isolated Early-Mid Eocene succession (with no exposed base) (Robertson et al., 2013b). This begins with limestones that are rich in large foraminifera (e.g. *Alveolina* sp., *Assilina* sp.) and passes upwards into argillaceous and silty limestones (Demiroluk Formation of Bedi et al., 2009). This is interpreted as a fragment of an Eocene shelf succession that was later incorporated into the thrust stack. In the west of Area 2 (e.g. NW of Tavla), the Munzur limestones are unconformably overlain by non-marine conglomerates, with well-rounded clasts that include *Nummulites* sp. suggesting a post-Eocene age of accumulation (Early-Mid Miocene(?) (Fig. 7b; 20l). These conglomerates are also incorporated into the thrust stack. Farther east, within the Gürün autochthon (near Akdere), Cenomanian rudist-bearing limestones are unconformably overlain by thick-bedded to massive non-marine conglomerates, of inferred Early-Mid Miocene age (Gövdelidağ Formation of Perinçek and Kozlu, 1984). The conglomerates are in high-angle fault contact with Munzur limestones. Slickensides indicate right-lateral strike-slip displacement (Robertson et al., 2013a). In the far east of Area 2 (near Sarız), a moderate-angle (30-50°) south-dipping thrust (reverse fault) separates the Paleogene Gürün autochthonous succession from the allochthonous units above, pointing to northward displacement (i.e. backthrusting) (Robertson et al., 2013b), which affected the Southern Allochthon as a whole. The outcrop bordering the Gürün autochthon in the south is folded on a large scale along c. E-W axes. The timing of the folding is inferred to be pre-Pliocene, post-dating the inferred Miocene non-marine conglomerates (Yılmaz et al., 1993; Perinçek and Kozlu, l984; Kozlu et al., 1990; Robertson et al., 2013b). In summary, within the Southern allochthon there is evidence of latest Cretaceous southward thrust-stacking, Eocene re-imbrication and Late (?) Miocene back-thrusting, reverse faulting and large-scale folding.

Along the northern margin of the Gürün autochthon (Fig. 2), the relatively autochthonous succession culminates in Middle Eocene shelf facies, similar to those in the south. The Northern allochthon begins with an equivalent of the neritic Munzur thrust sheet, followed upwards by the Pelagic nappe, equivalent to the Neritic-pelagic (Köseyahya) thrust sheet, but more coherent stratigraphically. Overlying units include the Pınarbaşı ophiolite and related melange units in the northwest (Robertson et al., 2013b). The northern allochthon is overlain by Eocene marine clastic sediments. Although mapped as an unconformable relationship (Yılmaz et al., 1997; MTA 2011; Bedi and Yusufağlu, 2018), field observations in the northeast of the area suggest a thrust relationship (Robertson et al., 2013b). In the southwest, near Pınarbaşı, the contact relations are mainly concealed by numerous neotectonic strike-slip faults.

11.3. Effects of neotectonic faulting

Neotectonic displacements need to be back-stripped to interpret the preceding emplacement history in detail.

Previously published fault data, specifically from the generally NE-SW to ENE-WSW-trending Göksu fault lineament of Kozlu et al. (1990) (Tavla-Sarız area; Figs. 2, 7), indicate dominantly right-lateral displacement, with either reverse or normal components (Robertson et al., 2013b). This is surprising because the dominant offset along neotectonic faults in the region is left-lateral (e.g. Duman and Emre, 2013). During this study, additional faults were measured, mainly farther east (e.g. Hurman Kalesi area). Of the new fault data (see Supplementary Fig. 11), there are six NW-SE trending faults, one of which is left-lateral and the remainder right-lateral. Of 10 NE-SW trending faults, seven are dextral, two have no slickenlines to determine movement sense and one is an oblique reverse fault. The new data support significant right-lateral displacement along a generally NE-SW to ENE-WSW-trending lineament, possibly representing more than one phase of movement. The rectilinear right-lateral faulting appears to post-date the inferred Mid-Late Miocene folding and reverse faulting/backthrusting that affects the Southern allochthon and the adjacent Gürün autochthon (see above).

Neotectonic faults are widely mapped further south, in the general Elbistan area, as follows: (1) NW-SE trending faults (Kışlaköy and Hurman Faults), inferred to be normal faults with dextral strike-slip components (strike N35°E; dip 81°SW; (2) NE-SW trending fault (Sarıyatak Fault), a normal fault with a sinistral component (strike N15°E dip 78°SE; lineation plunges 75°S); (3) ENE-WSW faults (Türkören Fault and Afşin-Elbistan Fault), of which four fault planes on the left-lateral Afşin-Elbistan Fault have allowed calculation of principal stress directions (sigma 1 51°/170°; sigma 2 30°/307°; sigma 3 22°/050°). The NE-SW trending fault is inferred to have influenced the Pliocene-Quaternary clastic deposition within the adjacent depocentre that forms part of the overall Afşin-Elbistan basin (Yusufoğlu et al., 2005; Bedi et al., 2009). Regional c. ENE-WSW left-lateral faulting generated overall NW-SE trending fault-controlled depocentres that infilled with Pleistocene sediments. Some of the neotectonic faults in the Elbistan region are reported to be covered by conglomerates suggesting a switching of faults with time and/or a changing stress regime (Bedi et al., 2009).

The region to the west of the Malatya-Ovacık Fault Zone is transected by numerous Plio-Quaternary left-lateral strike-slip faults, including the Afşin-Elbistan Fault and the generally NNE-SSW Sarız and Gürün faults (MTA, 2011). Some of these faults are interpreted to have active left-lateral movements (i.e. Beyyurdu and Gürün faults of Emre et al. (2018); Türkören fault of Bedi et al. (2009)). The left-lateral faults relate to displacements along the regional northern strand of the East Anatolian Fault System (Sürgü–Misis Fault system). The Pliocene-Pleistocene westward tectonic escape of Anatolia (Şengör et al., 1985; Duman and Emre, 2013) was partially accommodated by displacements along these faults.

In the east, the Malatya-Ovacık Fault Zone delimits the western margin of the large Malatya Basin. Early-Middle Miocene NW–SE extension there was followed by Mid-Late Miocene volcanism (11.99±0.49-4.82±0.57) (Yamadağ volcanics) (Kaymakçı et al., 2006; Kürüm et al., 2008). NNW-SSE left-lateral transpression is inferred along the Malatya-Ovacık Fault Zone during Late Miocene-Early Pliocene, coupled with widespread Pliocene volcanism (Ekici et al., 2007). Active left-lateral displacement began during the Late Pliocene, influenced by variable NNE–SSW transpression (Kaymakçı et al., 2006). In summary, most of the neotectonic faults in the region studied have relatively small displacements (several kms) that do not fundamentally change the regional tectono-stratigraphy; however, the Sürgü–Misis Fault and Malatya-Ovacık Fault have tens of km of fault displacement that need to be restored in any tectonic reconstruction.

12. Discussion

Below, we utilise the assembled body of evidence and interpretation to test and develop several alternative tectonic hypotheses for the relationships between the main tectonic units in the region.

12.1. Relation between the Northern and Southern allochthons and the Gürün autochthon

There are three main hypotheses for the emplacement of the northern and southern allochthons in relation to the Gürün autochthon (Fig. 2). All three assume that the allochthonous units cannot have been emplaced over the intact succession of the Gürün autochthon, at least until the Mid-Late Eocene because of its intact stratigraphical succession (Aziz et al., 1982; Perinçek and Kozlu, 1984; Robertson et al., 2013b).

The first hypothesis is that the Southern allochthon was emplaced southwards over the Gürün autochthon after deposition ended in the Early-Mid Eocene (Aziz et al., 1982). This is consistent with the evidence of southward thrusting during the Mid-Late Eocene in the central Taurides (Özgül, 1984, 1997; Monod, 1977; Gutnic et al., 1979; Görür et al., 1998; Demirtaşlı et al., 1984; Andrew and Robertson, 2002; Mackintosh and Robertson, 2012; McPhee et al., 2018b), and also in the western Taurides (De Graciansky, 1972; Poisson, 1977; Şenel et al., 1989; Collins and Robertson, 1997, 1998, 1999; Robertson et al., 2013a; Pourteau et al., 2016). However, a similar interpretation is problematic in the eastern Taurides for three main reasons: (1) Thrust relations: A thrust is not mapped regionally along the northern margin of the Gürün autochthon, between the Eocene succession and the Northern allochthon (MTA, 2011; Bedi and Yusufoğlu, 2018), although as noted above, a thrust contact has been observed locally (Robertson et al., 2016). (2) Regional melange distribution: The Kemaliye Formation, as exposed above the Malatya (Keban) metamorphics in the Nurhak Dağ area (Area 3b), includes clasts and blocks derived from the Malatya and/or Köseyahya thrust sheets, strongly suggesting that allochthon reached quite far south (10s km) of the Gürün autochthon during the latest Cretaceous. In this case, the allochthon cannot have remained to the north of the Gürün autochthon until the Eocene. (3) Cover relations: In the east, the Southern allochthon is locally covered and sealed by late Maastrichtian-Eocene sediments of the Darende Basin (Fig. 2). Along the western margin of the Darende basin (E of the bounding neotectonic Gürün fault) specifically, allochthonous units, correlated with the Dağlıca ophiolite, are unconformably overlain by conglomerates that pass upwards into Maastrichtian marls and limestones, together with lenticular rudist build-ups (Kırankaya Formation). Further north, along the western margin of the Darende basin, Maastrichtian sediments unconformably overlie the Munzur limestone thrust sheet. Also, the Darende basin is transgressive on an equivalent of the Munzur thrust sheet and related ophiolitic melange around its eastern margin (Booth et al., 2013). After a Palaeocene-Early Eocene hiatus, the sedimentary succession passes into Middle Eocene mixed siliciclastic/shallow-marine carbonates, with localised lenticular volcanics, and then into Bartonian-early Priabonian regressive facies (Gürbüz and Gül, 2005; Bedi et al., 2009; Booth et al., 2013). There is no evidence of increasing deformation upwards that could relate to regional overthrusting. Any post-Cretaceous southward emplacement of the Southern allochthon would instead need to entrain the Darende Basin as a whole above an unexposed deeper-level regional-scale thrust. This requirement would probably also apply to the Hekimhan Basin farther northeast (Booth et al., 2014). However, there is no evidence that the Darende and Hekimhan basins are parts of a regional-scale Eocene thrust sheet; e.g. no frontal thrust is exposed to the south. In summary, southward emplacement of the Southern allochthon over the Gürün platform succession during, or after, the Eocene seems unlikely.

The second hypothesis is that the southern and northern allochthons were emplaced from opposite directions during the latest Cretaceous, with the Gürün autochthon in between (van Hinsbergen et al., 2020) (Fig. 27bi-bii). This is problematic for several reasons: (1) The tectono-stratigraphy of both allochthons is very similar and does not indicate different palaeogeographic origins; (2) The northward thrusting of the Malatya Metamorphics that affects the Southern allochthon (e.g. İncirlik area) took place during the Cenozoic because post-Cretaceous sediments are structurally interleaved; (3) The tectono-stratigraphy of the E Tauride allochthons, combined, differs markedly from the South-

Tauride allochthonous units; e.g. in the Adıyaman and Antalya areas (Robertson et al., 2012).

The third hypothesis is that both of the allochthonous units were assembled by southward thrusting during the latest Cretaceous but in separate areas; subsequently the Gürün autochthon and the already emplaced Northern allochthon were displaced northeastwards (> 60 km) along the Güksu fault zone of Kozlu et al. (1990) to their present positions, probably during the Mid-Late Eocene (Robertson et al., 2013b). This hypothesis is consistent with the southwestward lateral passage of the Gürün autochthon into the Geyik Dağ (Tauride platform) (e.g. in the Tufanbeyli-Saimbeyli-Feke-Kozan area) (MTA, 2011). However, there are also problems with the right-lateral strike-slip hypothesis: (1) There is no single clear-cut fault (terrane boundary fault) separating the Gürün autochthon from the Southern allochthon; instead, strike-slip faults transect both the northern part of the Southern allochthon and the southern part of the Gürün autochthon (Robertson et al., 2013b; (2) Right-lateral strike-slip faults of appropriate c. NE-SW orientation are indeed present (Robertson et al., 2013a; Supplementary Fig. 11) but these appear to post-date the northward-directed displacement and folding of probable Mid-Late Miocene age. A possible explanation is that eastward displacement of the Gürün autochthon/northern allochthon, relative to the Southern allochthon, did indeed take place along the Eocene Göksu fault zone of Kozlu et al. (1990) but this lineament was over-ridden and concealed during the later folding and thrusting. The documented right-lateral neotectonic strike-slip faulting along this lineament could have reactivated such a buried lineament. The dextral strike-slip faults were overprinted by the dominantly Plio-Quaternary left-lateral faults affecting the region in this interpretation.

In summary, both the southern and the northern allochthons were emplaced southwards onto the Tauride platform during latest Cretaceous time. The right-lateral ‘terrane displacement’ interpretation is the most promising of the three options and could also help to explain the regional east-directed Gürün curl (see Supplementary Fig. 1). In this case the regional-scale ‘tectonic escape’ buckled the regional tectono-stratigraphy to form the ‘curl’.

12.2. Relation between the Malatya Metamorphics and the Southern allochthon

Malatya Metamorphics encompass a Late Palaeozoic-Late Cretaceous stratigraphy, consistent with a relatively internal part of the Tauride continent. No marginal (slope) units are exposed. Assuming regional in-sequence thrusting, the Triassic-Late Cretaceous successions of the Munzur and Köseyahya thrust sheets appear to represent northerly parts of the Tauride continent that detached from their basement and were emplaced southwards (Fig. 27a-c). During the Late Cretaceous, the more southerly located (Malatya) platform (>75 km wide) was deeply underthrust northwards and metamorphosed under up to amphibolite, or possibly low HP-LT conditions. This was associated with the intrusion of the unmetamorphosed Baskil granitoids (88-82 Ma) (Bozkaya et al., 2007; Bedi et al., 2009; Oberhansli et al., 2012; Rolland et al., 2012; Bedi and Yusufoğlu, 2018) (Fig. 27d).

In the northeast of the region, c. 100 km north of the main Malatya metamorphic outcrop) there is a small outcrop that comprises Late Palaeozoic schist, overlain by Late Permian meta-carbonates, Middle Triassic-Jurassic meta-platform carbonates and Late Cretaceous meta-clastics/carbonates with meta-carbonate blocks (c. 40 km SW of Divriği; Alacahan-Çetinkaya area; M on Fig. 2)) (Atabey and Aktimur, 1997; MTA, 2011; Robertson et al., 2013b; Beyazpirinç and Akçay, 2013). The succession is comparable to the Malatya Metamorphics, including the Late Cretaceous Karaböğürtlen Formation, suggesting that Malatya metamorphic crust may extend far northwards beneath the Mesozoic allochthonous units. However, it is also possible that the above outcrop represents the metamorphosed northern margin of the Munzur platform (otherwise not exposed).

In the northeast of the region (NW of Pınarbaşı), Hınzır Dağı and Korumaz Dağı (E of Kayseri) there is an additional, sizeable outcrop of high-grade metamorphic rocks including schist, gneiss and meta-platform carbonates, ranging in age from Carboniferous to Cretaceous (Özer et al., 1984; Pourteau et al., 2010; MTA, 2011; unpublished data). These rocks may correlate with the HP-LT Tavşanlı zone and/or the Afyon zone of the Anatolides (Oberhansli et al., 2012; Pourteau et al., 2013), although more study is needed to confirm this correlation.

The Malatya Metamorphics exhumed rapidly (Robertson et al., 2013b), at least partially, as indicated by the latest Cretaceous transgressive cover in the Malatya area (Gündüzbey Formation) (Bedi and Yusufoğlu, 2018). The Kemaliye Formation, extending southwards from its type area near Kemaliye (Area 5A) for at least c. 120 km to Nurhak Dağı (Area 3B), includes metamorphic debris from the Malatya Metamorphics and unmetamorphosed material from the Tauride allochthons, indicating that these two units were juxtaposed during the latest Cretaceous. The Kemaliye Formation in its type area accumulated during and/or very soon after exhumation of the Malatya Metamorphics. The basal unconformity is interpreted as an eroded extensional detachment, explaining the presence of high-strain lithologies (e.g. calc-schist; mylonite) near the top of the Malatya metamorphics (Fig. 16i), and also as clasts in the overlying Kemaliye Formation. The Munzur and Köseyahya thrust sheets were later re-activated and thrust farther south over the Kemaliye Formation in the above areas, probably during the Mid-Late Eocene (Figs. 22a).

The exposure of serpentinised harzburgite with small granitic intrusions that is sliced between the Malatya metamorphics and the Kemaliye Formation ENE of Begre (Fig. 22a) is interpreted as a fragment of the Göksun ophiolite and its granitic intrusions, as widely exposed farther south. Compressional deformation (Mid-Late Miocene?) caused the cross-cutting cleavage and cataclasis observed within the siliciclastic matrix of the Kemaliye Formation in the south (Nurhak Dağı; Area 3B; see above). The overall evidence points to complex multiphase displacement involving both the Malatya (Keban) metamorphics and the Munzur-Köseyahya carbonate platform, during Late Cretaceous, Mid-Late Eocene and Mid-Late Miocene (?).

12.3. Reconstruction of the allochthonous Tauride platform

Alternatives are: First, the Neritic-pelagic (Köseyahya) unit represents a basin within the Munzur shelf. Secondly, the Munzur carbonate platform succession passed northwards into the Neritic-pelagic (Köseyahya) platform (i.e. shalf-ramp) and then into the ocean (Fig. 26 a,b) (preferred reconstruction).

The first alternative (intra-platform basin) is hinted by the structural position of the Neritic-pelagic (Köseyahya) succession beneath the main Munzur thrust sheet in the Southern allochthon (Area 4; Fig. 9). However, against this: (1) No marginal facies of an intra-platform basin are exposed; (2) The Neritic-pelagic thrust sheet also occurs above the Munzur thrust sheet in the Northern allochthon suggesting that it restores to the north, regionally (MTA, 2011; Robertson et al., 2013b). In the second, preferred option, initial southward emplacement of the Tauride platform units during the latest Cretaceous (see above) was accompanied by complex out-of-sequence thrusting, explaining why the Neritic-pelagic (Köseyahya) thrust sheet is locally above the main Munzur thrust sheet (e.g. Area 4; Fig. 9). The distal edge of the Neritic-pelagic (Köseyahya) platform is therefore represented by the Pelagic (Gülbahar) unit, with oceanic crust, including inferred seamounts to the north (Fig. 28c,d).

12.4. Ophiolite and melange emplacement; relation to units farther north

The East Tauride SSZ-type ophiolites were emplaced southwards onto the Tauride platform, represented by the Munzur and Neritic-pelagic (Köseyahya) successions, together with passive margin slope units (Pelagic (Gülbahar) unit) and oceanic sediments and igneous rocks (accretionary melanges) (Figs. 28 e; 29 a-c). The driving force in the southward emplacement was the collision of the regional-scale supra-subduction zone Tauride ophiolite with the Tauride passive margin (Robertson et al., 2013b). The inferred tectonic organisation at the end of the Cretaceous is summarised in Figure 30. By the late Maastrichtian, the Malatya metamorphics were partially exhumed and eroded, while the ophiolites were also partially eroded, producing a variable palaeotopography that was smoothed by clastic debris and transgressed by a shallow sea; this deepened in places during the Palaeocene, as indicated by fragmentary pelagic carbonates (Fig. 21e, f).

Alternatives for the source of the ophiolites are:

Option 1: All of the ophiolites, including those overlying the Arabian continent were derived from a single Mesozoic Tethys to the north (Ricou et al., 1984) (Fig. 31 ai-aii), although this is generally discounted nowadays (Robertson and Dixon, l984; Stampfli and Borel, 2002; Sosson et al., 2010; Rolland et al., 2012; van Hinsbergen et al., 2020);

Option 2: The ophiolites in the area studied (e.g. Pınarbaşı, Divriği) and those to the south of the Malatya Metamorphics (Göksun (N Berit), Kömürhan, İspendere) were derived from a single oceanic basin located within Neotethys to the east and northeast (Stampfli et al., 2001; Stampfli and Borel, 2002; Moix et al., 2008; Sosson et al., 2010; Rolland et al., 2012, 2016, 2020; van Hinsbergen et al., 2020; see Fig. 31 bi-bii).

In one such scenario (Maffione et al., 2017), oceanic lithosphere was generated by intra-oceanic SSZ-spreading, followed by generally southwestward roll-back and c. 90^{o} anticlockwise rotation of the subducting oceanic plate. Collision with continental blocks emplaced ophiolites both southwards (i.e. Southern allochthon) and also northwards (i.e.

Göksun (N Berit), Kömürhan, İspendere) onto the Malatya metamorphic crust. The metamorphism relates to attempted bidirectional subduction during ophiolite emplacement (Fig. 30). An Inner Tauride basin (rift or small ocean) did not exist or, if present, sutured prior to overthrusting by the late Cretaceous ophiolites (Poisson et al., 1996; Hinsbergen et al., 2016).

In another, related scenario, the ophiolites were emplaced generally towards the south-west, over a single Anatolide-Tauride-S Armenian continent (i.e. without an Inner Tauride ocean) during the late Cretaceous (c. 75 Ma), all derived from the northern Neotethys. The ophiolites of the northern Neotethys (İzmir-Ankara-Erzincan suture zone) correlate with those of the Lesser Caucasus in Armenian and Georgia to the east, representing remnants of an enormous (700 km long x 1-200 km wide) slab of oceanic lithosphere that was emplaced onto continental crust during latest Cretaceous time (Sosson et al., 2010; Rolland et al., 2012, 2016, 2020; Rolland, 2017; Hässig et al., 2013a, b). Metamorphic soles of all of the ophiolites are similar in age (to within 10 Ma) suggesting that the ophiolites were emplaced together. Subduction of the ocean was either northwards, away from the continent (Sosson et al., 2010; Rolland et al., 2012, 2020), or southwards, towards the continent (Hässig et al., 2015). Southward obduction was facilitated by Cretaceous within-plate magmatism, documented in the Lesser Caucasus; this rendered the ophiolitic lithosphere relatively hot and mobile at the time of emplacement (Hässig et al., 2016). Syn-post emplacement extensional core-complex development thinned the oceanic lithosphere and facilitated southward emplacement of ophiolites and related continental margin units in this interpretation (Rolland et al., 2020).

The above option (in its variants) is also problematic: (1) The allochthonous Tauride units restore as a Permian-Triassic to Late Cretaceous rift/passive margin to an oceanic basin further north. The emplacement of the continental margin, oceanic crust (melange) and ophiolitic units are intimately related, coeval, and cannot be separated into a sutured Inner Tauride Basin and overthrust ophiolites (relevant to the Maffione et al., 2017 model); (2) the ophiolites in the E Taurides (e.g. Pınarbaşı and Divriği) are Late Cretaceous (Parlak et al., 2013), whereas ophiolites further north within the Ankara-Erzincan suture zone (northern Neotethys) are Early- Late Jurassic (Dilek and Thy, 2006; Robertson et al., 2013c; Çelik et al., 2013; Hässig et al., 2013). Both ophiolites formed in a supra-subduction setting, apparently related to northward subduction and cannot be treated as a single ophiolite of the similar age and tectonic setting (cf. Rolland et al., 2020); (3) Regional mapping (Bedi and Yusufoğlu, 2018) and our structural data (Fig. 26) are consistent with generally N to S emplacement of the allochthonous Tauride units (in present coordinates) during the latest Cretaceous (e.g. Area 2), without evidence of thrust sheets traversing the area obliquely, as suggested by hypothesis two (cf. van Hinsbergen et al., 2016; Maffione et al., 2017); (4) Evidence was not observed in our present field area to support emplacement of the Late Cretaceous ophiolites by core complex-related gravity sliding (Hässig et al., 2016; Rolland et al., 2020). Instead, the field evidence suggests that the ophiolites were relatively intact when emplaced but were thinned in response to later multi-phase deformation and erosion.

Option 3. The Tauride and Pontide-Lesser Caucasus ophiolites represent different supra-subduction spreading events, which both culminated in Late Cretaceous regional ophiolite emplacement (Parlak et al., 2012; Robertson et al., 2013c) (Fig. 31ci, cii). During the Triassic, sea-floor spreading created oceanic lithosphere to the north of the Tauride-Anatolide continental block. The Kırşehir continental unit represents a rifted continental fragment with oceanic lithosphere potentially to the south and the north (e.g. Görür, et al., 1984; Robertson et al., 2012; Barrier et al., 2018). The Jurassic Pontide-Lesser Caucasus ophiolite formed in the Early-Mid Jurassic when oceanic lithosphere to the north of the Kırşehir continental unit started to subduct northwards (Dilek and Thy, 2006; Robertson et al., 2013c; Topuz et al., 2013a). During the Late Cretaceous, plate convergence triggered the genesis of the Late Cretaceous Tauride ophiolites above a N-dipping subduction zone. To the west and east of the Kırşehir continental unit Jurassic and Cretaceous oceanic crust were effectively contiguous with no exposed intervening suture. The Tauride ophiolites were obducted by regional trench-passive margin collision during the latest Cretaceous, which emplaced the Late Cretaceous ophiolites and related melanges throughout the eastern, central and western Taurides as a whole (Görür et al., 1984; Andrew and Robertson, 2002; Clark and Robertson, 2002; Okay et al., 2001; Kadıoğlu et al., 2006; Nairn et al., 2013, Robertson et al., 2013c; Lefebvre et al., 2013b; Darin et al., 2018; Scleiffarth et al., 2018; Legeay et al., 2019). The leading of the colliding Tauride passive margin, represented by the Anatolide crustal block, subducted and underwent HP-LT metamorphism (Pourteau et al., 2010, 2013). Uncertainties with the above option include: i) The absence of an exposed suture between the E Taurides and Pontide ophiolites, although one may exist subsurface; ii) The lack of definitive evidence that Late Cretaceous ophiolites farther west (i.e. Pozantı-

Karsantı and Alihoca ophiolites) originated to the south of the Kırşehir crustal block. In summary, the evidence discussed in this paper is consistent with, but not definitive of, ophiolite emplacement from an Inner Tauride ocean that was located to the south of the Mid-Late Jurassic oceanic crust that characterises the İzmir-Ankara-Erzincan suture zone.

14.5. Malatya metamorphics: relation to adjacent crustal units

There are three main options:

A first option is that the Malatya metamorphics directly correlate with the Afyon zone (Anatolides). The Afyon zone (Bolkar nappe) is restored to a northerly position relative to the unmetamorphosed Aladağ nappe (Özgül, 1984; Pourteau et al., 2010, 2013; Mackintosh and Robertson, 2012). By extension, the Munzur-Köseyahya platform originated as the southward extension of the Malatya carbonate platform. Problems, however, with this are: (1) The Malatya metamorphics are cut by the c. 88-82 Ma Baskil granitoids, which are attributed to northward subduction from an oceanic basin to the south (Berit ocean), suggesting a relatively southerly location (Rızaoğlu et al., 2006, 2009; Karaoğlan et al., 2012, 2016) (Fig. 30); (2) In contrast, the Afyon zone lacks comparable intrusives suggesting a different palaeogeographic setting; (3) Option 1 implies northward deep-level underthrusting of the Malatya platform, followed by exhumation, large-scale out-of-sequence southward thrusting to place the metamorphics in their present structural order beneath the allochthonous Tauride platform units (van Hinsbergen et al., 2020). However, there is no obvious evidence of such regional-scale re-thrusting during either the latest Cretaceous or the Eocene regional tectonic events (e.g. metamorphic klippen or foredeeps with metamorphic detritus are absent). Regional southward emplacement of the northerly ophiolites (Göksun (N Berit), Kömürhan, İspendere) over the entire Tauride platform, followed by re-imbrication beneath, as proposed by van Hinsbergen et al. (2020), is also problematic. The base of the tectonic contact between the Malatya metamorphics and the Göksun ophiolite beneath is cut and sealed by the 83-81 Ma (Santonian-Campanian) Esence granites (Karaoğlan et al., 2016), whereas the northerly ophiolites were emplaced southwards only after deposition of the Albian-Santonian Kızılkandil Formation and the overlying late Campanian-late Maastrichtian Kemaliye Formation (based on nannofossil dating).

A second option is that the Afyon zone and the Malatya metamorphics do indeed correlate laterally but that the Munzur-Köseyahya platform units represent a separate platform that was located to the northeast of the Geyik Dağ (Tauride autochthon). The main problem with this interpretation is the absence of any preserved platform-slope facies (e.g., deep-water slope facies and radiolarites) that could indicate the presence of a rifted margin to the Malatya platform in the north (Perinçek and Kozlu, l984; Kozlu et al., 1990; Bedi et al., 2009; Robertson et al., 2013b; Bedi and Yusufoğlu, 2018). Also, there is no evidence of a southern rifted margin to the Munzur-Köseyahya platform in the south, which would be expected in this alternative. However, it is possible that such margin units existed but are not exposed.

A third option is that the present regional-scale tectono-stratigraphy retains the latest Cretaceous emplacement organisation. In this case, the Malatya and Afyon units, despite undergoing similar metamorphism, did not form a continuous litho-tectonic unit. The Afyon zone originated further northwest, whereas the Malatya metamorphic originated further southeast (possibly offset by a c. N-S transform). The Munzur-Köseyahya platform formed a separate crustal block to the northeast. The Malatya metamorphics originated by collapse of the putative basin between the separate Malatya and Munzur Köseyahya platforms (see above). Such a basin might have formed during Triassic rifting. Collapse of the inferred intra-platform basin might have been driven by compression between two N-dipping subduction zones (Berit/Göksun in the S; Inner Tauride in the N).

In the absence of field evidence of major tectonic re-ordering as required in options 1 and 2, we favour option 3, which implies major palaeogeographic changes between the central and eastern Taurides. It seems likely that the central Tauride platform (Geyik Dağ) narrowed eastwards (Fig. 30), close to the future position of the neotectonic Sürgü-Misis fault zone. To the west, the southern part of the Tauride platform (Geyik Dağ) was not covered by the late Cretaceous south-moving allochthons. In contrast, farther east part of the Tauride platform represented by the Malatya metamorphics, underthrust/subducted northwards beneath more northerly Tauride crust (Munzur-Köseyahya platfors) (Fig. 30cii).

Restoring the reported c. 29 km left-lateral offset along the neotectonic Malatya-Ovacık Fault Zone (Westaway and Arger, 2001) still leaves the type outcrop of the Munzur platform in the Munzur Dağları (Fig. 2) c. 80 km to the north of its counterpart within the Southern allochthon (Munzur thrust sheets). The Tauride (Munzur) platform could, therefore, have stepped northwards towards the northeast, bounded by one or more c. N-S transcurrent faults. However, it is unclear whether this would be entirely a Mesozoic palaeogeographic feature or if it could relate to latest Cretaceous-Eocene (pre-Neogene) tectonics. In either case, pre-existing faults are likely to have been re-activated to form many of the major neotectonic faults seen today. In the absence of continuous exposure, or subsurface evidence (e.g., borehole or seismic reflection) it is, therefore, uncertain as to whether or not the South Armenian platform in the Lesser Caucasus simply represents the eastward extension of the Tauride continent. Previously, the two platform exposures were inferred to be parts of a single large continental unit mainly because of similar late Cretaceous ophiolite emplacement in both areas (Sosson et al., 2010; Rolland et al., 2012). However, an origin as two separate platforms is not precluded.

The Malatya and Bitlis-Pütürge metamorphic units (Fig. 1) have also been considered to represent, respectively westerly and more easterly segments of a single southerly active margin of the Tauride continent, with the Southern Neotethys to the south (Barrier et al., 2018). However, the Malatya and Bitlis-Pütürge continental units are separated by the Late Cretaceous supra-subduction Göksun (N Berit), Kömürhan, İspendere and Yüksekova ophiolites, interpreted as an intervening ocean basin (Robertson et al., 2006, 2012; Rolland et al., 2012; Candan et al., 2014; Çetinkaplan et al., 2016; Barrier et al., 2018). The available evidence is consistent with the existence of a southerly oceanic basin (Berit, or Göksun ocean) that subducted northwards beneath the Malatya-Tauride platform during latest Cretaceous (Fig. 30). The ophiolites (Göksun, İspendere and Kömürhan), dated at c. 87-85 Ma, formed above a subduction zone and include immature arc volcanics (Parlak et al., 2009). The volcanics of the above ophiolites can also be broadly correlated with the Late Cretaceous Yüksekova complex (dated at c. 83-75 Ma) (Karaoğlan et al., 2013), which is traditionally interpreted as an immature oceanic arc (e.g. Ural et al., 2015 and references).

As noted above, the Göksun SSZ-type lithosphere was emplaced beneath the Malatya Metamorphic crust, where both were intruded by subduction-related granitic rocks (88-82 Ma Baskil intrusives) (Karaoğlan et al., 2016: Parlak, 2006; Rızaoğlu et al., 2009). The Baskil intrusives include shoshonitic compositions (dated at 74–72 Ma), suggestive of collisional and/or post-collisional settings (Ertürk et al., 2018; Kuşcu et al., 2013; Sar et al., 2019). This is consistent with the collision of the Bitlis-Pütürge continental units to the south with the Tauride continent to the north (Malatya Metamorphics) thereby closing the Berit ocean. In many reconstructions, some oceanic crust (Southern Neotethys) existed between the Bitlis-Pütürge continental units and the Arabian continent. The initial closure of this ocean basin and collision with Arabia may have occurred during the Mid-Late Eocene, but the main collision took place during the Mid-Late Miocene (Aktaş and Robertson, 1984; Yılmaz, 1993; Robertson et al., 2012a; Rolland et al., 2012, 2020; Barrier et al., 2018; van Hinsbergen et al., 2020).

Conclusions

-The well-exposed eastern Taurides provide important insights into Tethyan palaeogeography and tectonic development, including the unusual Gürün curl structure.
-The region is restored as part of the northern rifted margin of the Tauride continent.
-Rifting took place during the Triassic, separating a shallow-water carbonate platform to the south from a deep-water proximal to distal slope and ocean basin to the north (Inner Tauride ocean).
-The regional Tauride carbonate platform (Geyik Dağ) is proposed to have narrowed and become more palaeogeographically varied towards the eastwards, mainly represented, in the E Taurides, by the Malatya Metamorphics and the unmetamorphosed Munzur and Köseyahya platform units.
-The restored northern part of the shallow-water combined Munzur-Köseyahya platform subsided during the Mid-Jurassic to form a gently sloping, deeper-water ramp near, or beneath, the carbonate compensation depth.
-The Munzur-Köseyahya platform slope was covered by pelagic carbonate during the Late Cretaceous, probably related to regional tectonic subsidence (rather than global sea-level rise).
-Dismembered deep-sea sedimentary and volcanic units exposed over a wide area are restored as the former Triassic-Cretaceous deep-water passive margin slope/base of slope of the Mesozoic carbonate platform (Pelagic (Gülbahar) unit).
-Oceanic lithosphere formed above a subduction zone in the ocean (Inner Tauride ocean), generally to the north (Pınarbaşı, Dağlıca, Hekimhan, Kuluncak and Divriği (and Güneş) ophiolites), with associated formation of ophiolite metamorphic sole (although only locally preserved).

-Local, fragmentary successions of mainly within-plate-type basalts and radiolarian cherts/pelagic limestones are interpreted as accreted/emplaced Jurassic-Cretaceous oceanic seamounts.

- Associated with emplacement of the Late Cretaceous ophiolites, the Tauride passive margin underwent flexural loading and collapse to form a foredeep (late Campanian-Maastrichtian). Talus in the form of gravity flows, blocks and disrupted sheets was shed into the basin, mainly from the platform/slope units, and the advancing ophiolites/accretionary melanges.

-During the latest Cretaceous (late Campanian-late Maastrichtian), the SSZ ophiolites were emplaced generally southwards onto the Tauride platform, in some areas as relatively intact sheets (c. 6 km thick) (e.g. Pınarbaşı ophiolite), but elsewhere as dismembered units, melanges and ophiolite-related debris flows (i.e. Dağlıca ophiolite and melange).

-During its late Cretaceous southward tectonic transport, the allochthonous carbonate platform was locally re-thrust, in places putting the restored southerly neritic carbonate platform (Munzur thrust sheet) over the more northerly-derived deeper water facies (Köseyahya thrust sheet).

-Mixing of clastic debris (Kemaliye Formation) that derived from both the over-riding Tauride allochthons and the Malatya Metamorphics shows that both were tectonically juxtaposed (in close proximity) during the latest Cretaceous regional emplacement.

-The Malatya Metamorphics were at least partially exhumed by the late Maastrichtian as they are covered and sealed by latest Cretaceous sediments, that include metamorphic and granitoid debris.

-The Malatya Metamorphics were tectonically juxtaposed with the Göksun (and related ophiolites) to the south during the latest Cretaceous. Both are cut and sealed by the 88-82 Ma Baskil granitoids. The latest Cretaceous marine sedimentary cover of the Göksun ophiolite includes detritus from both the metamorphics and the unmetamorphosed Tauride units, pointing to rapid exhumation.

- Following Eocene shelf-depth deposition, folding and re-thrusting took place widely during the Mid-Late Eocene. However, the co-intrusion of the Güksun ophiolite and Malatya Metamorphics by the Late Cretaceous granites (Baskil granites) shows that these two regional-scale crustal units were not displaced a large distance relative to each other (i.e. >several km) after the latest Cretaceous.

-Allochthonous units were first juxtaposed with the relatively autochthonous Gürün platform succession (as presently exposed) during Mid-Late Eocene. In the absence of clear evidence that the allochthonous Tauride units to the north (Northern allochthon) were emplaced southwards over the autochthonous Gürün platform during this time, an alternative is that the Southern allochthon and the Gürün platform/Northern allochthon were brought together by >60 km of right-lateral transport during Mid-Late Eocene (i.e. as a result of collision-related 'tectonic escape').

-The Mid-Late Eocene deformation (folding and thrusting) is explained by thick-skinned deformation, driven by suturing of the İzmir-Ankara-Erzincan ocean (northern Neotethys).

- Mid-Late Miocene folding and thrusting (northwards in several areas) is explained by suturing of the Southern Neotethys and collision with Arabia.

-The available evidence is mainly consistent with the former existence of an Inner Tauride ocean, comprising Late Cretaceous supra-subduction zone oceanic crust, that was separate from more northerly supra-subduction zone oceanic crust, of Mid-Late Jurassic age, within the İzmir-Ankara-Erzincan suture zone farther north.

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Figure captions

Fig. 1. Outline map of Turkey showing the main tectonic units and the study area (main data source, MTA 2012).

Fig. 2. Simplified geological map and cross-section of part of central eastern Anatolia, simplified from MTA 1:100,000 and 1:250,000 geological maps of Turkey (MTA, 2011). The area studied is divided into 5 sub-areas, as indicated: Area 1-NE, i.e. mainly NW of Elbistan, including the Afşin area; Area 2-Dağlıca area, farther NW of Elbistan; Area 3A-East of Elbistan, 3B-farther east, near Nurhak Dağı; Area 4-S-mainly south of Elbistan; Area 5A-Kemaliye area, 5B Divriği area (both in the far NE). Additional geological units mentioned in the text: AE Afşin-Elbistan basin; DB Darende basin; GO Göksun ophiolite; GF Göksu Fault; SGF Sürgü-Misis Fault*;* İO İspendere ophiolite; KO Kömürhan ophiolite; KU Kuluncak ophiolite. Additional locations and settlements mentioned in the text: B Büyük Yılanlı Dağ; K Kangal (off map in central N, as indicated); N Nurhak Dağı; S Saimbeyli (just off map in SW); Y Yeşildere.

Fig. 3. Stratigraphical columns showing the age and lithologies of the main geological units discussed in this paper. See text for explanation and data sources.

Fig. 4. Field photographs of key features of the Malatya metamorphics in the area north and west of Elbistan (Area 1). a, Eocene shelf limestones (Seske Fm.) above Malatya Metamorphics; in places the two units are intersliced, Kepez Mah. (in foreground); GPS 37S 0303484/4230790; b, Foliated amphibolite; Late Palaeozoic; 0.5 km S of Türkören; c, Normal-graded debris-flow deposit with carbonate clasts in a coarse calcarenite matrix; recrystallised to micaceous marble; Late Palaeozoic; near Kepez, W of Afşin; GPS 37S 0303518/4229825; d, Isoclinally folded limestone with replacement chert, Late Permian; Saldılek Tepe, NE of Afşin; GPS 37S 0322749/4239163; e, Thin-bedded micritic limestone

and dolomite (stromatolitic); Late Triassic; west of Afşin GPS 37S 0303484/4230790; f, Network of tension cracks infilled with pink micrite (recrystallised); within upper c. 50 m of mapped Late Permian meta-limestone succession; beneath the Karaböğürtlen Formation; GPS 37S 0329702/4236079; g, Debris-flow deposit composed of platy limestone clasts, recrystallised to marble; several m above mapped normal contact with Late Permian meta-limestone; Karaböğürtlen Formation; GPS 37S 0329013/4236061; h, Debris-flow deposit with flattened clasts in a calcareous mudstone matrix; recrystallised to marble; Karaböğürtlen Formation; GPS 37S 0328678/4235639; i, Foliated pebbly conglomerate; clasts mainly sub-rounded; mostly siliceous calc-schist; Malatya metamorphic unit; near Kamalak köy, SSW of İncirli; Karaböğürtlen Formation (GPS 37S 0304287/4250123); j, Blocks of recrystallised limestone (marble), interbedded with carbonate-rock debris-flow deposits and phyllite (Karaböğürtlen Formation); represents the leading edge of the Malatya metamorphic unit (backthrust to N); c. 1 km SE of İncirli (GPS 37S 0307627/4251659); k, Recrystallised limestone (marble) with reworked Megalodont bivalves (Karaböğürtlen Formation); NW of Afşin, GPS 37S 0322629/0239403; l, Kemaliye Formation (foreground), with serpentinite above (Dağlıca ophiolite); overthrust (northwards) by the Malatya Metamorphics (Karaböğürtlen Formation); NW of İncirli.

Fig. 5. Part of the northeast outcrop of the Malatya Metamorphics (Area 1; NW of Elbistan; Fig. 2). Simplified geological map; note the relation of the Late Cretaceous syn-tectonic Karaböğürtlen Formation to the underlying units; modified from Bedi et al. (2009). Logs: 1, Late Palaeozoic succession including meta-basic extrusive rocks (west of Afşin); 2, Triassic siliciclastic-carbonate facies; 3, Late Cretaceous Karaböğürtlen Formation with carbonate and siliciclastic intercalations. Rock-relations diagrams: a, Latest Cretaceous sedimentary cover of the Göksun ophiolite (Harami Fm.), overthrust by the Malatya Metamorphics; 3 km SE of Afşin; b, Jurassic-Cretaceous (?) succession, unconformably overlain by the Late Cretaceous Karaböğürtlen Formation; 6 km E of Afşin; c, Permian succession unconformably overlain by Late Cretaceous Karaböğürtlen Formation; NE of Körkuyu.

Fig. 6. Photomicrographs of sandstone of the Late Cretaceous Karaböğürtlen and Kemaliye formations. Stratigraphy: a-b Karaböğürtlen Formation (Malatya Metamorphics); c-g

Kemaliye Formation above the Malatya (Keban) Metamorphics (Areas 1 & 5A); h-i Kemaliye Formation related to the Munzur limestones; j, Kemaliye Formation beneath the Köseyahya thrust sheet; k-l Maastrichtian cover of the Göksun ophiolite. Composition: a, Rounded grains of monocrystalline quartz and polycrystalline quartz (quartzite) in a recrystallised calcareous matrix; crossed polars; c. 10 km W of Elbistan; GPS 37S 0330991/4230104); b, Note the large rounded, then fragmented quartz grain, with cracks infilled by calcite spar, suggesting high-strain deformation; location as a; c, Poorly sorted sandstone with common monocrystalline quartz, polycrystalline quartz and muscovite in a quartz-rich, granular calcareous matrix; crossed polars; Area 3B (Nurhak Dağı, near Beğre); GPS 37S 0393334/4227050; d, Poorly sorted sandstones with abundant grains of neritic limestone (partly recrystallised), polycrystalline quartz and muscovite (deformed); crossed polars; location as c; e, Poorly sorted sandstones including grains of neritic limestone (partly recrystallised) and basalt (relatively fresh and chloritised); plane-polarised light; location as c; f, Granitic grain from conglomeratic lens; crossed polars; location as c; g, Large alkali feldspar crystal (upper right), together with monocrystalline quartz, other feldspar and microcrystalline quartz in a calcareous and quartz-rich matrix; crossed polars; location as c; h, Sub-rounded clast of fine-grained meta-siltstone (central), together with muscovite (large lath), polycrystalline quartz (left, central), and bioclastic limestone (e.g., upper left); crossed polars; location as c; i, Sub-rounded grains of dark chert (veined and recrystallised) and partly recrystallised siltstone in a quartz- and carbonate-rich matrix; crossed polars; location as c; j, Micaceous sandstone with common monocrystalline quartz, polycrystalline quartz and muscovite, cemented by sparry calcite; near Bakış, east of Elbistan; GPS 37S 0361782/4222559; k, Bioclastic limestone with common bivalve shell fragments, planktic foraminifera and a dark, bituminous schistose grain; cover of the Göksun ophiolite; SW slope of Aktaş Tepe; plane-polarised light; GPS 37S 0318668/4232060; l, Bioclastic limestone, including large grain of relatively well-rounded microcrystalline quartz; crossed polars; same sample as k. Key to letters: B Bioclastic carbonate, BA Basalt, BI Bivalve, C Carbonate (calcite), CH Chert, F Feldspar (alkaline), G Granitic lithoclast, Mq Monocrystalline quartz, M Muscovite, N Neritic limestone, PL Planktic foraminifer, Pq Polycrystalline quartz, S Siltstone, SH Schistose lithoclast.

Fig. 7. Outline geological map and local sections (a-f) of Area (Dağlıca). Based on mapping by Perinçek and Kozlu (1984), Bedi et al. (2013), Robertson et al. (2013b) and this study. The location of the rock-relations diagrams and the logs (roman numerals Va,b,c, VI, VIII and lX; see Fig. 11 for I-lV) are indicated. a, The lower Munzur thrust sheet is overlain by the Kemaliye Formation and the dismembered Dağlıca ophiolite. The Kırmızı Kandil Formation and the Kemaliye Formation are exposed above the upper Munzur thrust sheet; NW of İncirli; b, Munzur thrust sheet in the north, unconformably overlain by conglomerates (Miocene?), with well-rounded clasts including Eocene nummulitic limestone; NW of Tavla; c, Relatively autochthonous succession (Gürün autochthon), overthrust by a Munzur thrust sheet; near Dallıkavak; d, Lower Munzur thrust sheet, overthrust by the dismembered Dağlıca ophiolite and by an upper Munzur thrust sheet; e, Blocks of the Dağlıca ophiolite within ophiolite-derived debris flows, overthrust by an upper Munzur thrust sheet; Tatlar area; f, Lower Munzur thrust sheet including the Kırmızı Kandil Formation and the Kemaliye Formation; near Elmalı.

Fig. 8. Outline geological map (simplified from Bedi et al., 2009) and local rock-relations diagrams in Area 3A (E of Elbistan). Note: Rock-relations diagrams a-d are located north of the map area (see top right). a, Lower Munzur thrust sheet overlain by the Kırmızı Kandil Formation and the Kemaliye Formation and Pelagic (Gülbahar) unit limestone and chert; near Erikli (c. 20 km NW of the map area); b, Lower Munzur thrust sheet, overlain by the Kırmızı Kandil Formation and the Kemaliye Formation (with blocks of neritic limestone), overthrust by upper Munzur thrust sheet; Gökçek area; 10 km WNW of the map area; c, Contact relations with the Darende basin to the east. Mesozoic Tauride units are locally emplaced eastwards over the basin margin, which is tilted and overturned near the base. Note: in places (off this section) an intact unconformity is exposed between the emplaced Mesozoic allochthonous units and Maastrichtian sediments of the intact Darende basin succession (see text); N of Dağdamı; 12 km N of map area; d, Lower Munzur thrust sheet, overlain by the Kırmızı Kandil Fm. and then the Kemaliye Fm. (with blocks of neritic limestone); 2 km NE of Kapaklı; 7 km N of map area; e, Kemaliye Formation enclosing blocks of Pelagic (Gülbahar) unit lithologies, overthrust by the lower Munzur thrust sheet. The Munzur thrust sheet is mapped as being thrust (SW) over the Köseyahya thrust sheet; 3.5 km E of Türkören (Yumru Tepe); f, Lower Munzur thrust sheet, with the Kırmızı Kandil and

Kemaliye formations above (with block of limestone), overthrust by the Köseyahya thrust sheet. Note the Fe-rich crust at the top of the Kırmızı Kandil Formation; NW of Şerefli.

Fig. 9. Outline geological map (simplified from Bedi et al., 2009) and local rock-relations diagrams in Area 4 (S of Elbistan). A-A' Malatya Metamorphics in steep fault contact with the Kemaliye Formation (as mapped by Bedi et al. (2009)), overlain by the Kemaliye Formation including blocks of limestone and radiolarite; in turn overthrust by a Munzur thrust sheet and then by ophiolite-related melange with blocks of ophiolitic rocks and limestone; finally overthrust by a Köseyahya thrust sheet; B-B' folded Köseyahya thrust sheet, emplaced over the Malatya metamorphic succession. The syncline (truncated) formed prior to thrust emplacement.

Fig. 10. Field photographs showing key sedimentary features of the Munzur and Köseyahya thrust sheets. a-h Munzur thrust sheet; i-l Köseyahya thrust sheet. a, Oncolite (algal) within Late Triassic micritic limestone; upper part removed by dissolution along a stylolite; E of Elbistan; GPS 37S 0346331/4227793; b, Thin interbed of intraformational sedimentary breccia (near a); c, Thin, intra-formational slump sheet composed of pelagic micrite (also near a; d, U. Cretaceous rudist limestone; lower Munzur thrust sheet; Kaşanlı area; GPS 37S 0325809/4257928; e, Late Cretaceous limestone of upper Munzur thrust sheet, with Kemaliye Formation beneath (shale with limestone blocks) and ultramafic mafic ophiolitic lithologies above, Hurman kalesi; GPS 37S 0310858/4260897; f, Upper Cretaceous pelagic limestone (Kırmızı Kandil Fm., Kapaklı area; GPS 37S 0361390 / 4257247; loc. 4.4; g, Fe-Mn crust at the contact between Late Cretaceous pelagic limestone below and the Kemaliye Formation above, recording a hiatus; near İncirli; GPS 37S 0305831/4252443; i, Ammonite in red bioclastic limestone (Late Triassic), Köseyahya thrust sheet, near Sarıkaya Tepe; E of Elbistan; GPS 37S 0362757/4228355; j, Crinoidal bioclastic limestone (Late Triassic); Köseyahya thrust sheet; loc. as i; k, White crinoidal limestone with diagenetic chert lenticles (Late Triassic); Köseyahya thrust sheet; loc. As j; l, Bioturbated pelagic limestone (Early Cretaceous), between Özbek and Gücük (E of Elbistan); GPS 37S 036516/4229889.

Fig. 11. Measured sedimentary logs (roman numerals) of Permian-Cretaceous facies of the Pelagic (Gülbahar) unit; see Fig. 8 for I-IV and Fig. 7 for V-IX, and the text for explanation.

Fig. 12. Field photographs of the pelagic (Gülbahar) unit in Area 2 (Dağlıca). a, Sandstone and shale (Triassic), overthrust by thick-bedded limestone of the Köseyahya thrust sheet; Bakış area; GPS 37S 036782/4222559; b, Calcareous mudrock, with thin limestone interbeds; note the small load casts in redeposited limestone; small slice (c. 10 m thick), below Köseyahya thrust sheet; Triassic; Aşağıgücük köy; GPS 37S 0362059/4222332; c, Radiolarian chert and pelagic limestone (centre, pink), depositionally intercalated with pelagic carbonate, with minor replacement chert (grey); Late Jurassic-Early Cretaceous; Ayrancı Tepe; 2 km S of Büyük Tatlı; GPS 37S 0324740/4263734; d, Regularly bedded calciturbidites, largely replaced by quartzitic chert; location near c; e, Calciturbidite, mainly replaced by quartzitic chert; Late Jurassic-Early Cretaceous; Kayseri (near Hurman kalesi); GPS 37S 0302827/4266442; f, Well-cemented debris-flow deposit with angular clasts of chert (red) and pelagic carbonate. The chert mainly formed by replacement of pelagic carbonate, location near c; g, Debris-flow deposit made of sub-rounded clasts of pelagic carbonate in a calcarenite matrix, rich in redeposited ooids; gravity emplaced before completely lithified; Late Jurassic-Early Cretaceous; SE of Büyük Tatlı; GPS 37S 0325527/4262472; h, Debris-flow deposit composed of angular to sub-rounded clasts of white pelagic limestone and red radiolarite; the well-cemented nature is typical of the pelagic succession in contrast to the Kemaliye Fm.; Late Jurassic-Early Cretaceous; near Yumru Tepe, E of Elbistan; GPS 37S 036620/423774; i, Debris-flow deposit made up of angular to sub-rounded clasts of pelagic limestone and redeposited calcarenite in a coarse calcarenite (oolitic) matrix; Late Jurassic-Early Cretaceous; near Topaktaş (Kırkısrak area); GPS 37S 0298744/4262995.

Fig. 13. Outline geological map of Area 5A, Kemaliye and Area 5B, Divriği. See text for explanation and data sources.

Fig. 14. Geological map of the type, Kemaliye area including the Kemaliye Formation (Area 5A), simplified from 1:100,000 geological maps of Turkey (Bilgiç, 2008b, c), with additional information from this study.

Fig. 15. Local cross-sections of the Kemaliye Formation in its type area (5A). a, East of Keban Lake; b, West of Keban Lake (farther southeast). See Fig. 13 for location and the text for explanation.

Fig. 16. Field photograph Kemaliye Formation and related units in the type area (5A) (a-f) and in Area 3B (Nurhak Dağı) (g-l). a, View southwest over the Late Cretaceous Kemaliye Formation, with lenticular blocks, mainly limestone conglomerate in a matrix of shale and sandstone; S of Kemaliye town; b, Calc-mylonite locally exposed near the contact between the Malatya Metamorphics and the Kemaliye Formation (E of Keban Lake); c, Stratiform debris-flow deposits with sub-rounded to well-rounded clasts, mainly neritic limestone, in a coarse-grained sandy matrix; Kemaliye Formation, lower part; d, Debris-flow deposits with mainly angular clasts of micaschist in a coarse-grained sandy matrix; Kemaliye Formation, lower part, near Yuva; e, Lenticular debris-flow conglomerate, dominated by well-rounded, varicoloured clasts of red radiolarian chert in a coarse-grained sandy matrix; Kemaliye Formation, lower part; near Beğre (Area 3B); f, Mainly sub-angular clasts of neritic limestone (calcite-veined) in a coarse-grained sandy matrix; Kemaliye Formation, upper part; near Beğre (Area 3B); g, Serpentinite cut by small granitic intrusions (foreground), overthrust by a thin unit of the Kemaliye Formation, and then by the Köseyahya thrust sheet (pale; main mountain above), near Beğre; h, Calc-mylonite in the uppermost levels of the Malatya Metamorphics, near Beğre; i, Isoclinally folded calc-schist in the uppermost levels of the Malatya Metamorphics, later brecciated, near Beğre; j, Isoclinally folded calc-schist in the uppermost levels of the Malatya Metamorphics, cut by small granitic intrusions (centre-right); fold limb is 5 m across in the foreground, near Beğre; k, Granitic intrusions (by pen) and greenish serpentinite (upper), mutually brecciated, indicating high-strain deformation after intrusion, near Beğre; l, Iron-rich crust at the top of the platform succession, below the Kemaliye Fm., marking a hiatus.

Fig. 17. Sedimentary log of the lower part of the Kemaliye Formation in its type, Kemaliye area (5A). See text for explanation.

Fig. 18. Photomicrographs of key age-diagnostic benthic microfossils. a: *Neoendothyra* sp.; sample ET12.37; Triassic; Dark limestone block in Kemaliye Formation, Area 5A, near Yuva,

GPS 37S 0456773/4345128; b: *Meandrospira* sp., sample ET12.37, as above, Triassic; c: *Thaumatoporella parvovesiculifera* (Tp), *Bosniella fontainei* (Bf), *Siphovalvulina variabilis* (Sv), *Glomospira sp*. (Gl), sample ET12.57; Middle Triassic; Bioclastic limestone from Munzur thrust sheet, Area 5B, c. 8 km SSE of Divriği, Area 5B, GPS 37S 0426455/4351186; d: *Siphovalvulina variabilis*, sample ET12.58 (location as c); Jurassic; e: *Bosniella fontainei*, sample ET12.57, Middle Jurassic (location c, d); f-g: *Nezzazata isabellae*, sample ET12.54, Aptian-Albian, limestone block in lower part of ophiolite-related melange, Area 5B (Divriği), GPS 37S 0425452/4367406; h, i: *Mayncina bulgarica* (Laug et al., 1980), sample ET12.54; Aptian-Albian (location as f-g); j-l: *Parakoskinolina* sp., sample ET12.56; Aptian-Albian; limestone block in mid part of the ophiolite-related melange, Area 5B (Divriği), GPS 37S 0425280/436641; m-o: *Akcaya minuta*, sample ET12.56; Aptian-Albian (location j-o); p: *Nezzazatinella* sp., sample ET12. 56; Aptian-Albian (location as j-p); q: *Vercorsella* sp., sample ET12. 56, Aptian-Albian (location as j-q). Scale bars= 0.2 mm.

Fig. 19. Measured sedimentary logs of the Late Cretaceous Kemaliye Formation in Area 2 (Dağlıca); see the text for explanation. Logs 1-5 in Area 3A (E of Elbistan) and farther north; Log 1. Near Köseyahya; Log 2, 6 km N of map in Fig. 8; Log 3, 5 km WSW of log 2; Log 4, 7 km NE of log 2; Logs 5 and 6 in Area 2 (Dağlıca), see Fig. 7.

Fig. 20. Field photographs in Area 2 (Dağlıca), particularly the Kemaliye Formation. a, Pebbly debris-flow, with mostly well-rounded clasts of meta-sandstone (quartzite), with some micaschist (centre left); Kemaliye Formation; 1 km N of İncirli GPS 37S 0308706/4255621; b, Debris-flow dominated by sub-rounded clasts of limestone (some with rudist debris) in a pebbly matrix; Kemaliye Formation; c. 1 km N of İncirli, GPS 37S 0303828/4254761; c, Cenomanian rudist-bearing limestone (part of a block) within shale and sandstone; Kemaliye Formation; near Hurman kalesi, GPS 37S 0311635/4261660; d, Blocks of neritic limestone with rudist bivalves in highly deformed Kemaliye Formation; near Hurman kalesi, GPS 0307401/4259103; e, Mudrocks of the Kemaliye Formation, interspersed with blocks of Mesozoic neritic limestone; overthrust by the upper Munzur thrust sheet; Hurman kalesi area, GPS 37S 0314553/4260250; f, Crudely stratified, ophiolite-derived debris-flow units, including clasts of basalt, diabase, gabbro, pelagic limestone and radiolarian chert, associated with the Dağlıca ophiolite; near Kaşanlı köy, GPS 37S 0326709/4257612; g,

Matrix-supported debris-flow unit with clasts of gabbro (lower left), diabase and basalt; associated with the Dağlıca ophiolite; same locality as f; h, Ophiolite-derived debris flow, locally dominated by basalt centre right); associated with the Dağlıca ophiolite; 1.5 km W of Kırkısrak, GPS 37S 0294299/4259724; i, as d, e with angular clast of pink pelagic limestone, with red 'replacement' chert; j, Debris-flow conglomerate made up of ophiolitic clasts including gabbro, diabase and basalt; associated with the Dağlıca ophiolite; İncirli area, GPS 37S 030015/425603); k, Late Cretaceous-Eocene succession of the relatively autochthonous Gürün platform, overthrust by Mesozoic Munzur limestone; 2 km NE of Dallıkavak, GPS 37S 0293001/4261378; l, Clast-supported conglomerate including well-rounded clasts of Eocene Nummulitic limestone; probably Miocene; 1.5 km NW Çağsak, GPS 37S 0286787/4257672.

Fig. 21. Photomicrographs of key age-diagnostic planktic microfossils. a, Globotruncana cf. G. mariei Banner & Blow, 1960, sample M.13.35; Kemaliye Formation; Campanian-Maastrichtian, near Kapaklı, Area 3A, NE of Elbistan, GPS 37S 0361390/4259247; b, Globigerinelloides sp., sample M.13.35, Campanian-Maastrichtian (same location); c, Globotruncana linneiana (D'Orbigny, 1839), sample M13.4, pelagic limestone block in Kemaliye Formation, Campanian-Maastrichtian, Odunluk Tepe; Area 3A, E of Elbistan; GPS 37S 0366666/4225559; Archaeoglobigerina cretacea (D'Orbigny, 1840), Campanian-Maastrichtian (same location); e, f: Globigerinidae, sample M13.60, Cenozoic. Pelagic limestone block in debris-flow deposit, near İğde köyü (SE of Elbistan), GPS 37S 0335066/4223251. Scale bars= 0.2 mm.

Fig. 22. Structural relationships in Area 3B (Nurhak Dağı); a, Meta-carbonate rocks of the Malatya Metamorphics, structurally overlain by serpentinised harzburgite which is cut by small granitic intrusions, and in then overthrust by a thin unit of the Kemaliye Formation, with the Köseyahya thrust sheet above; near Beğre;

b, Malatya Metamorphics, structurally overlain by serpentinised harzburgite, then by the Kemaliye Formation, with the Köseyahya thrust sheet above, c. 10 km north-east of a. The blocks in the Kemaliye Formation include Triassic red crinoidal limestone, similar to that in the Köseyahya thrust sheet, in a matrix of terrigenous sandstone and mudrock.

Fig. 23. Simplified geological map of part of Area 5B, Divriği (simplified from MTA 1:100,000 geological maps of Turkey (Bilgiç, 2008a, b, c). Note the locations of the representative sections shown in Fig 25. See text for explanation and data sources.

Fig. 24. Summary of the stratigraphy and structural relations in part of Area 5B, Divriği. a, Stratigraphic column; b, Rock-relations (bi in the north; b-ii in the south). See the text for explanation and data sources.

Fig. 25. Field photographs of Divriği ophiolite-related melange in Area 5B. a, Elongate blocks of thick-bedded neritic limestone set in a matrix of serpentinite and sandstone/shale; c. 6 km NW of Divriği); b, Elongate blocks of Mesozoic neritic limestone embedded in sheared serpentinite; c. 6 km NW of Divriği); c, Part of a large block of thick-bedded neritic limestone, deformed into a SW-verging fold; c. 6 km NW of Divriği); d, Large block of Mesozoic neritic limestone in the Divriği melange, deformed into a N-verging fold; c. 3 km NW of Divriği); e, Serpentinite melange with a strongly sheared steeply dipping fabric; c. 7 km SE of Divriği; f, Large exposure of serpentinite melange, dominated by mantle harzburgite; c. 10 km SE of Divriği.

Fig. 26. Summary of fold data (axial planes and hinges) collected during this study, plotted as poles; equal-area lower hemisphere projection; N= number of measurements; ai-aiv, Fold axial planes; bi-biv Fold hinges. Individual plots: ai-bi Malatya Metamorphics (Area 1. W of Elbistan); aii-bii Allochthonous Tauride units (Area 2, Dağlıca); aiii-biii Allochthonous Tauride units (Area 3A, E of Elbistan); aiv-biv Combined units: Malatya (Keban) metamorphics and Kemaliye Formation (Area 1) (Kemaliye area). See Supplementary Figs. 7-10 for plots of all data, including bedding.

Fig. 27. Geological development of the central and northern parts of the Tauride continent. a, Late Triassic extensional faulting establishes the contiguous neritic Munzur platform, the Neritic-pelagic Köseyahya platform and the Pelagic (Gülbahar) unit; b, Mid-Late Jurassic. N-dipping ramp develops redepositing mainly oolitic facies into deeper water; c, Late Cretaceous (Cenomanian). Rudist bivalve reefs develop on proximal (Munzur) platform

while deeper-water slope conditions persist farther north; d, Campanian-Maastrichtian. The southern part of the Tauride continent (Malatya platform) detaches and is deeply underthrust northwards; ophiolite is emplaced southwards over the northern edge of the Tauride continent which collapsed in advance to form a foredeep.

Fig. 28. Geological development of the Tauride continent in the E Taurides. a, Carboniferous; includes rift-related volcanism; b, Mid-Late Triassic continental rifting; c, Mid-Late Jurassic passive margin subsidence; d, Late Cretaceous (Cenomanian, c. 90 Ma); northward subduction of oceanic crust; e, Late Cretaceous (Campanian-Maastrichtian); collision and crustal imbrication of the Tauride continent. Note: it is uncertain whether the Malatya and Munzur-Köseyahya units were either contiguous or separate platforms. See text for discussion.

Fig. 29. Stages in the latest Cretaceous (late Campanian-Maastrichtian), southward emplacement of oceanic crust and passive continental margin units in the E Taurides. a, Flexural foredeep is imbricated during compressional emplacement; b, With further emplacement, the relatively distal neritic-pelagic (Köseyahya) platform detaches and is thrust over the more proximal neritic (Munzur) platform; c, With further convergence, part of the neritic (Munzur) platform is locally re-thrust over the neritic-pelagic platform unit.

Fig. 30. Rock-relations diagram showing the inferred tectono-stratigraphy of the E Taurides following latest Cretaceous emplacement/exhumation, restored to beneath the latest Cretaceous transgressive shallow-marine sedimentary cover (south of the Gürün autochthon). From the structural base upwards: Malatya (Tauride) continental unit; Late Cretaceous Göksun (Berit) ophiolite; partially exhumed Malatya Metamorphics (both of the latter are stitched by the Late Cretaceous Baskil granitoids); debris-flows (‘olistostromes’) (e.g. Kemaliye Formation type area), with slices and blocks of the pelagic (Gülbahar) unit and finally supra-subduction zone ophiolites and their metamorphic sole. Note: variable internal deformation of the Munzur, Köseyahya and ophiolitic thrust sheets is not shown.

Fig. 31. Alternative tectonic models for the eastern Taurides. ai-aii, Assumes one ocean to the north and one continent to the south. The allochthonous units are emplaced by complex out-of-sequence thrusting (based on Ricou et al., 1984); bi-bii. Assumes a single Mesozoic Neotethys. The Late Cretaceous ophiolites form above a subduction zone to the E-NE that rotates and rolls-back, emplacing segments over the N and S margins of the Tauride continent and over Arabia/N Africa. The Bitlis and Pütürge metamorphism relates to attempted southward subduction. An Inner Tauride basin is assumed between the Tauride continent and a combined Kırşehir-Tavşanlı crustal block in the north, but this basin is not the source of the ophiolites (based on van Hinsbergen et al., 2020); ci-cii. (preferred model). This assumes several microcontinents and small Mesozoic ocean basins. The Bitlis and Pütürge continental units represent rifted fragments with ocean crust on either side. Supra-subduction zone oceanic crust in the northerly basin (Berit ocean) subducts northwards resulting in arc magmatism that intrudes the continental block to the north (Malatya metamorphic unit). An Inner Tauride ocean was potentially the source of Late Cretaceous supra-subduction zone ophiolites in the north. Supra-subduction zones are emplaced separately, southwards onto the Arabian margin. Uncertain is whether the Tauride platform links with the South Armenian platform at depth as there is no continuous surface exposure. See text for discussion.

Figure 1

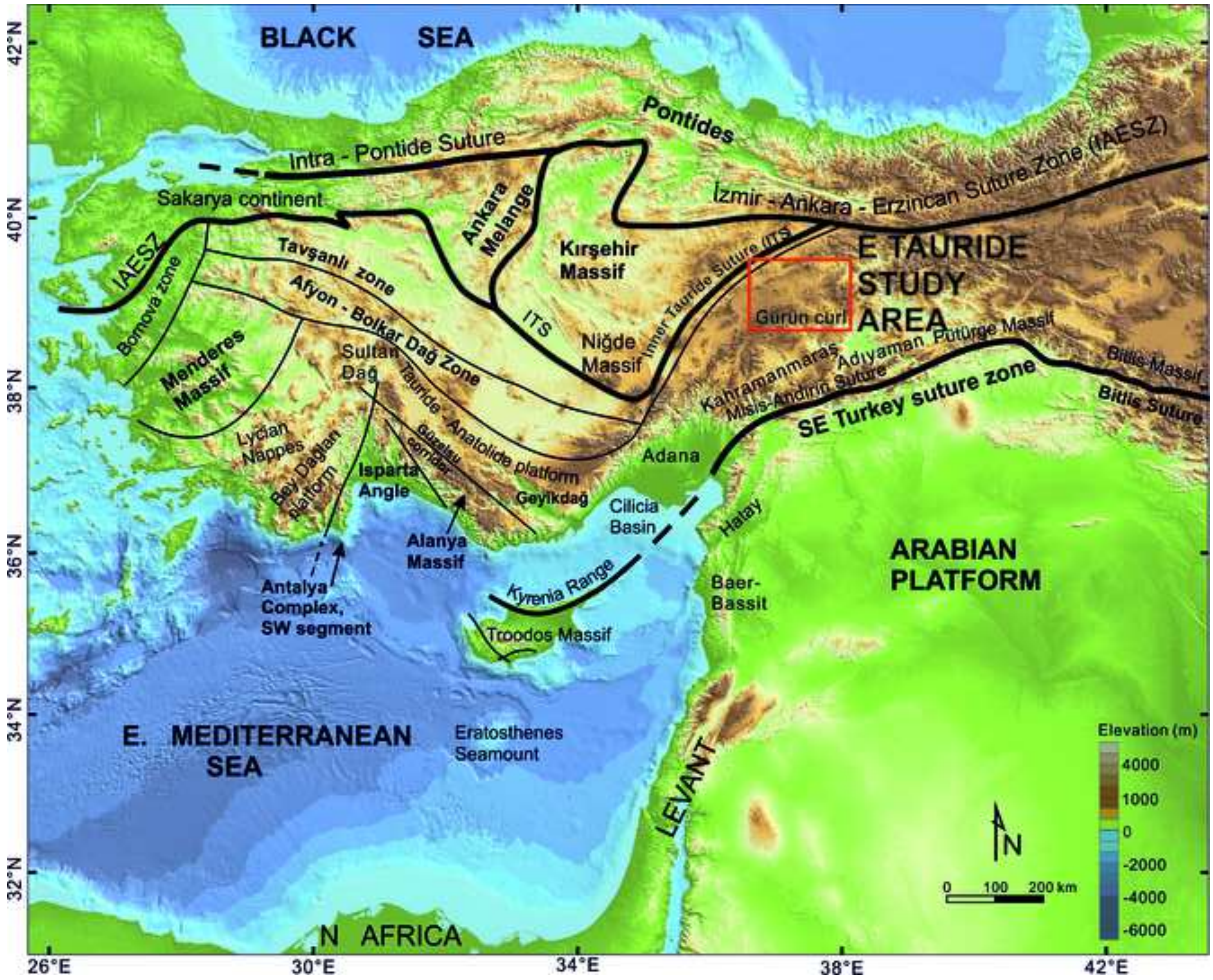

BLACK SEA
Pontides
Intra - Pontide Suture
Sakarya continent
IAESZ
Bornova zone
Menderes Massif
Tavşanlı zone
Afyon - Bolkar Dağ Zone
Ankara Melange
Kırşehir Massif
ITS
Niğde Massif
İzmir - Ankara - Erzincan Suture Zone (IAESZ)
Inner Tauride Suture (ITS
E TAURIDE STUDY AREA
Gürün curl
Pütürge Massif
Adıyaman Suture
Kahramanmaraş
Misis-Andırın Suture
Bitlis Massif
Bitlis Suture
SE Turkey suture zone
Sultan Dağ
Tauride - Anatolide platform
Lycian Nappes
Bey Dağları platform
Isparta Angle
Güzelsu corridor
Geyikdağ
Adana
Cilicia Basin
Hatay
Alanya Massif
Antalya Complex, SW segment
Kyrenia Range
Troodos Massif
Baer-Bassit
ARABIAN PLATFORM
E. MEDITERRANEAN SEA
Eratosthenes Seamount
LEVANT
N AFRICA
N
0 100 200 km
Elevation (m)
4000
1000
0
-2000
-4000
-6000
42°N
40°N
38°N
36°N
34°N
32°N
26°E
30°E
34°E
38°E
42°E

Figure 2

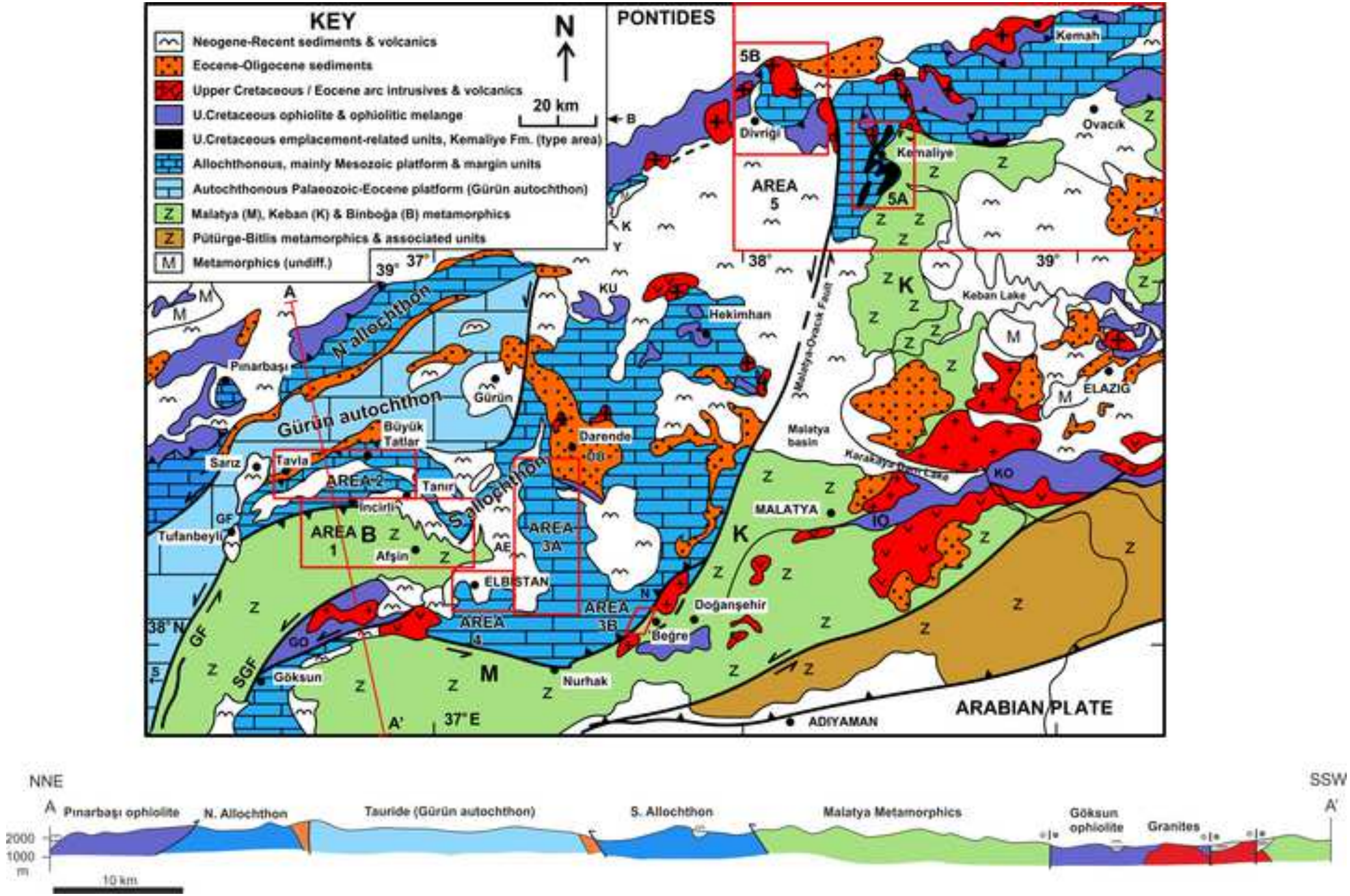

KEY
Neogene-Recent sediments & volcanics
Eocene-Oligocene sediments
Upper Cretaceous / Eocene arc intrusives & volcanics
U.Cretaceous ophiolite & ophiolitic melange
U.Cretaceous emplacement-related units, Kemaliye Fm. (type area)
Allochthonous, mainly Mesozoic platform & margin units
Autochthonous Palaeozoic-Eocene platform (Gürün autochthon)
Malatya (M), Keban (K) & Binboğa (B) metamorphics
Pütürge-Bitlis metamorphics & associated units
Metamorphics (undiff.)
N
20 km
PONTIDES
ARABIAN PLATE
AREA 1
AREA 2
AREA 3A
AREA 3B
AREA 4
AREA 5
5A
5B
Gürün autochthon
N. allochthon
S. allochthon
Malatya-Ovacık Fault
Malatya basin
Keban Lake
Kemah
Ovacık
Divriği
Kemaliye
Hekimhan
ELAZIG
MALATYA
Doğanşehir
Beğre
Nurhak
ADIYAMAN
Darende
Gürün
Pınarbaşı
Sarız
Tavla
Büyük Tatlar
Tanır
İncirli
Afşin
ELBISTAN
Tufanbeyli
Göksun
GF
SGF
39° 37°
38°
39°
38° N
37° E
NNE
SSW
A
A'
Pınarbaşı ophiolite
N. Allochthon
Turide (Gürün autochthon)
S. Allochthon
Malatya Metamorphics
Göksun ophiolite
Granites
2000
1000
m
10 km

Figure 3

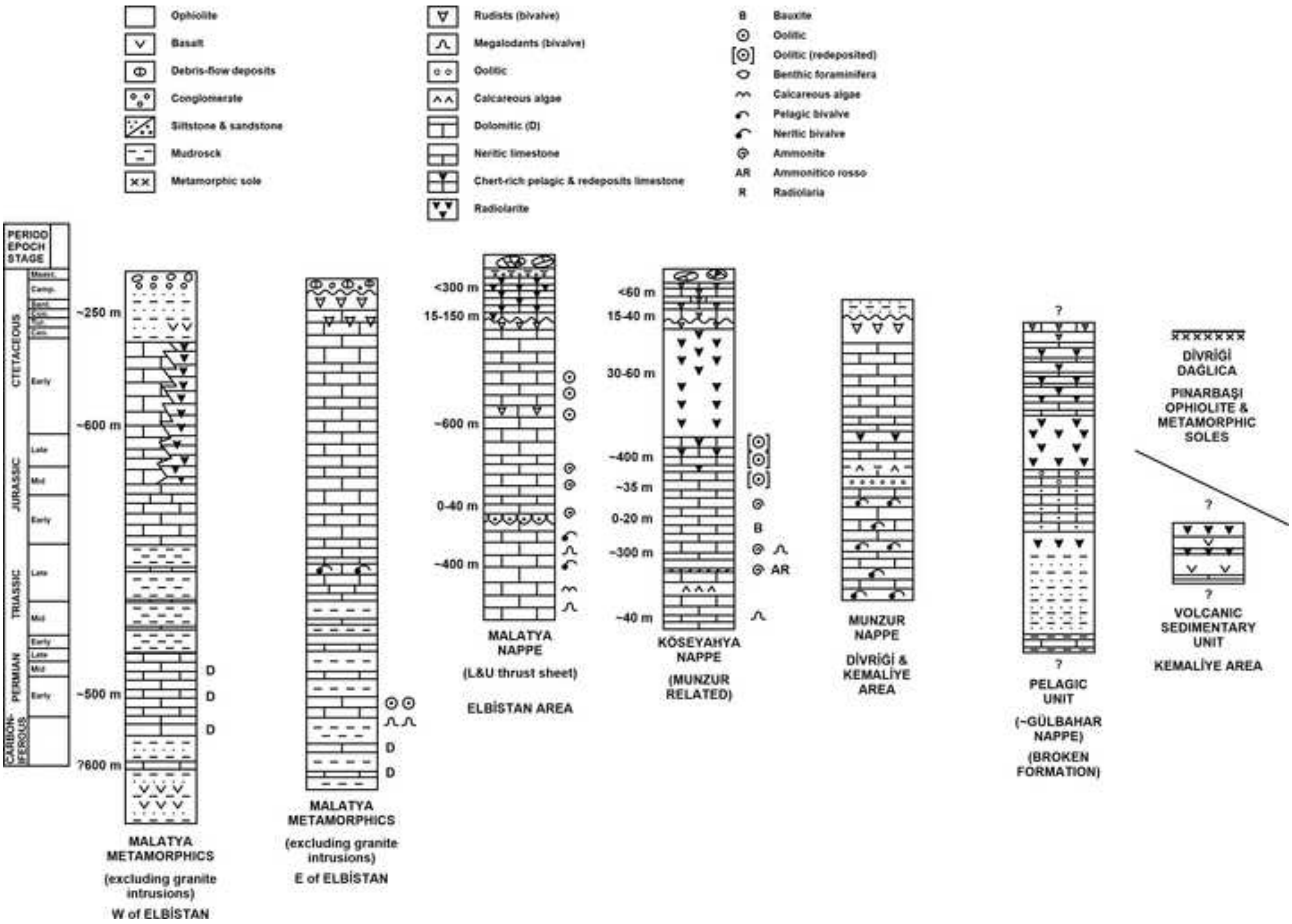

Ophiolite
Basalt
Debris-flow deposits
Conglomerate
Siltstone & sandstone
Mudrosck
Metamorphic sole
Rudists (bivalve)
Megalodants (bivalve)
Oolitic
Calcareous algae
Dolomitic (D)
Neritic limestone
Chert-rich pelagic & redeposits limestone
Radiolarite
B Bauxite
Oolitic
Oolitic (redeposited)
Benthic foraminifera
Calcareous algae
Pelagic bivalve
Neritic bivalve
Ammonite
AR Ammonitico rosso
R Radiolaria
PERIOD EPOCH STAGE
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBON-IFEROUS
Maast.
Camp.
Early
Late
Mid
~250 m
~600 m
~500 m
?600 m
D
MALATYA METAMORPHICS
(excluding granite intrusions)
W of ELBİSTAN
MALATYA METAMORPHICS
(excluding granite intrusions)
E of ELBİSTAN
<300 m
15-150 m
~600 m
0-40 m
~400 m
MALATYA NAPPE
(L&U thrust sheet)
ELBİSTAN AREA
<60 m
15-40 m
30-60 m
~400 m
~35 m
0-20 m
~300 m
~40 m
KÖSEYAHYA NAPPE
(MUNZUR RELATED)
MUNZUR NAPPE
DİVRİĞİ & KEMALİYE AREA
?
PELAGIC UNIT
(~GÜLBAHAR NAPPE)
(BROKEN FORMATION)
DİVRİĞİ DAĞLICA
PINARBAŞI OPHIOLITE & METAMORPHIC SOLES
VOLCANIC SEDIMENTARY UNIT
KEMALİYE AREA

Figure 4

Click here to access/download;Figure;Fig4.jpg

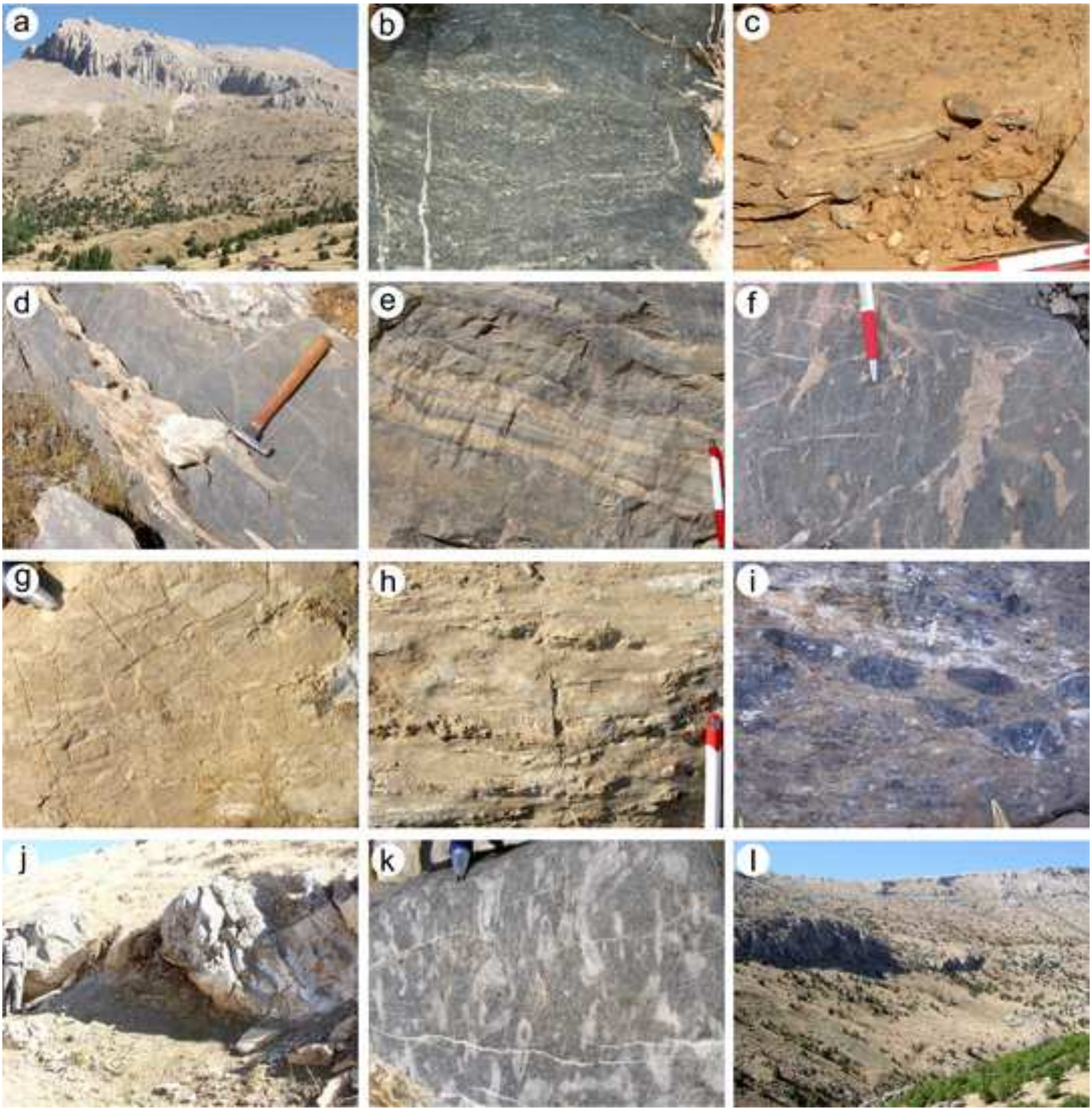
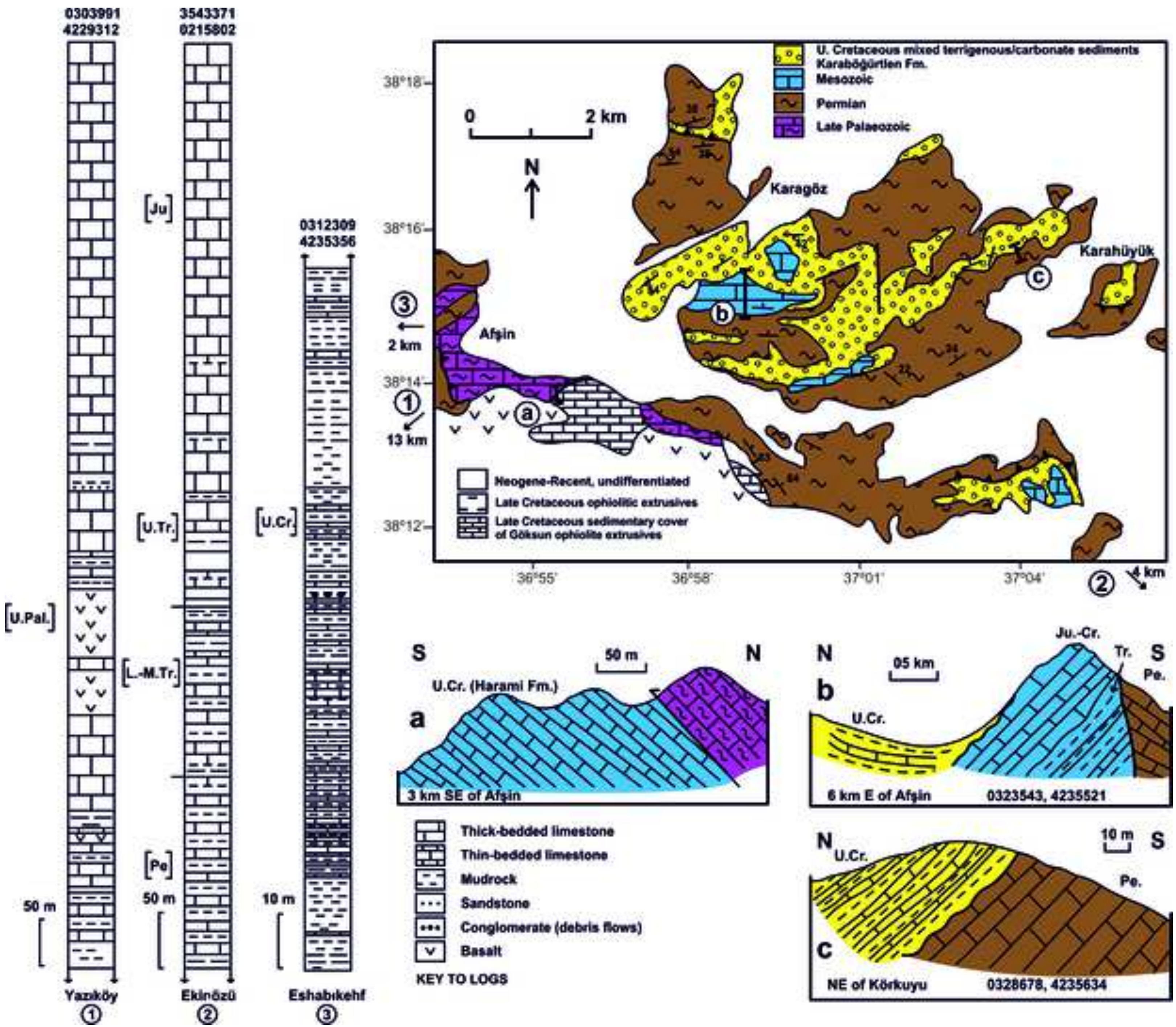


Figure 5



0303991 4229312
3543371 0215802
0312309 4235356
[Ju]
[U.Tr.]
[U.Cr.]
[U.Pal.]
[L.-M.Tr.]
[Pe]
50 m
50 m
10 m
Yazıköy ①
Ekinözü ②
Eshabıkehf ③
38°18'
38°16'
38°14'
38°12'
36°55'
36°58'
37°01'
37°04'
0
2 km
N
③ 2 km
① 13 km
② 4 km
Afşin
Karagöz
Karahüyük
U. Cretaceous mixed terrigenous/carbonate sediments Karaböğürtlen Fm.
Mesozoic
Permian
Late Palaeozoic
Neogene-Recent, undifferentiated
Late Cretaceous ophiolitic extrusives
Late Cretaceous sedimentary cover of Göksun ophiolite extrusives
S
N
50 m
U.Cr. (Harami Fm.)
a
3 km SE of Afşin
b
05 km
U.Cr.
Ju.-Cr.
Tr.
Pe.
6 km E of Afşin
0323543, 4235521
c
10 m
NE of Körkuyu
0328678, 4235634
Thick-bedded limestone
Thin-bedded limestone
Mudrock
Sandstone
Conglomerate (debris flows)
Basalt
KEY TO LOGS

Figure 6

Click here to access/download;Figure;Fig. 6.jpg

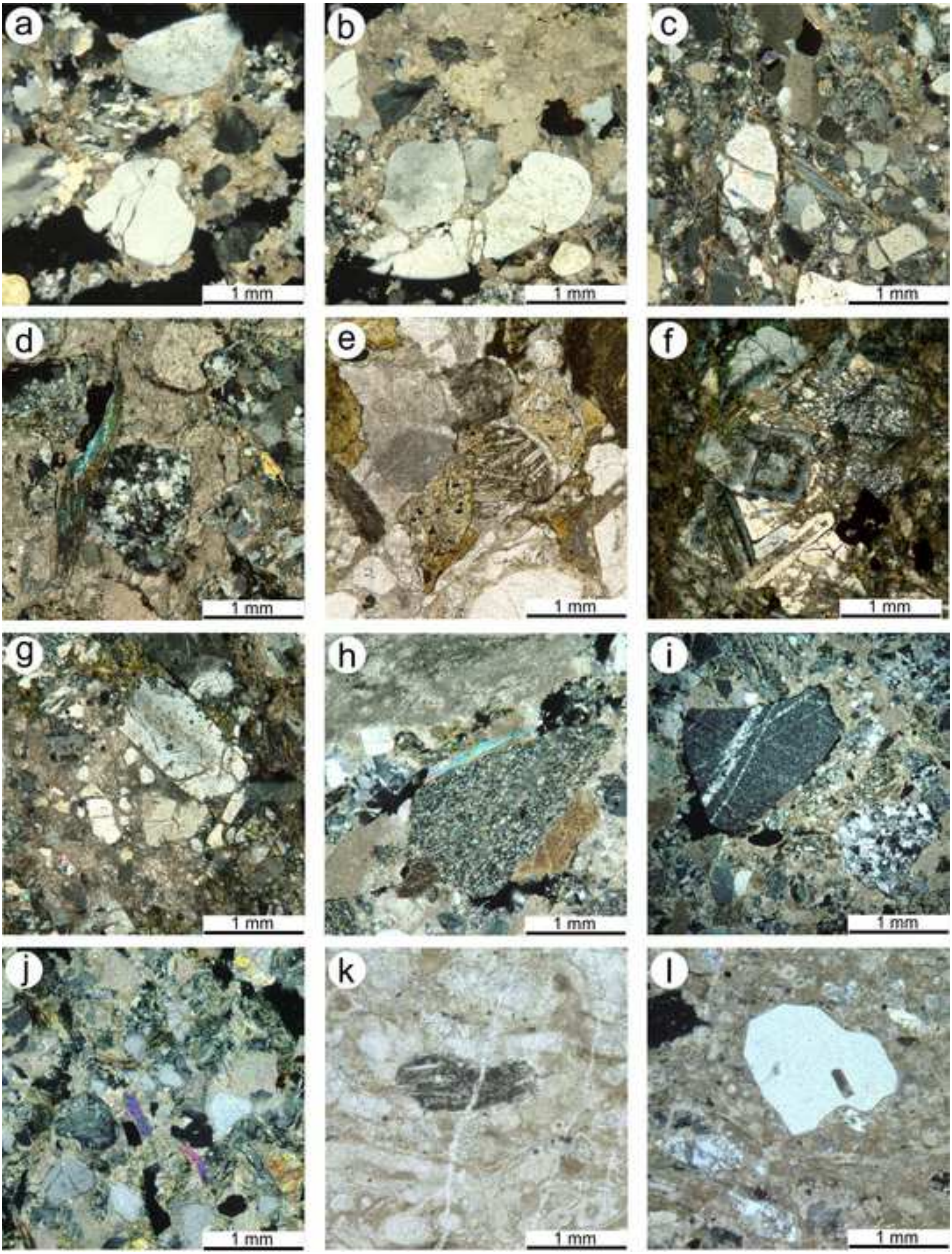
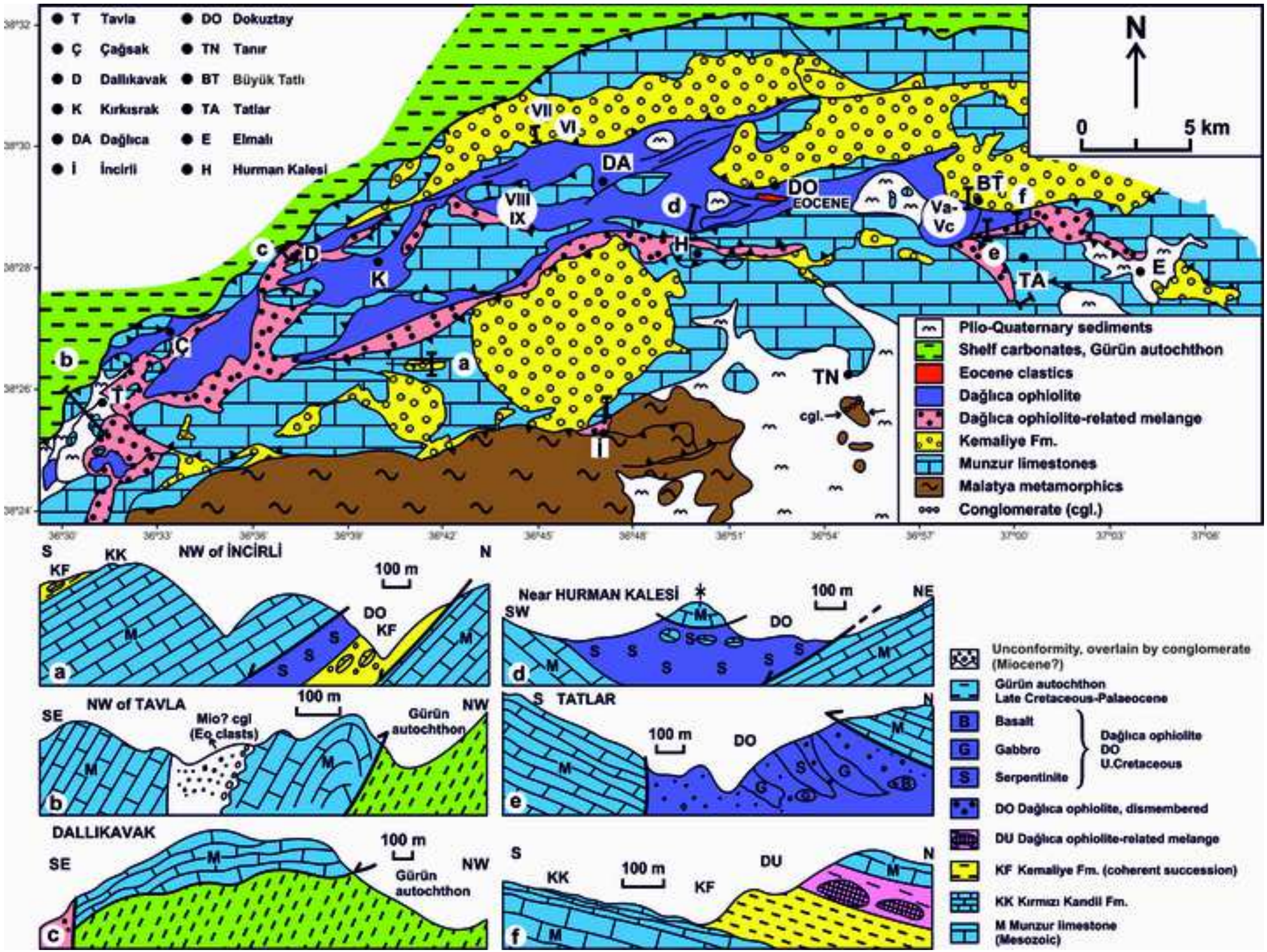


Figure 7



T Tavla
Ç Çağsak
D Dallıkavak
K Kırkısrak
DA Dağlıca
İ İncirli
DO Dokuztay
TN Tanır
BT Büyük Tatlı
TA Tatlar
E Elmalı
H Hurman Kalesi
N
0
5 km
EOCENE
cgl.
Plio-Quaternary sediments
Shelf carbonates, Gürün autochthon
Eocene clastics
Dağlica ophiolite
Dağlica ophiolite-related melange
Kemaliye Fm.
Munzur limestones
Malatya metamorphics
Conglomerate (cgl.)
NW of İNCİRLİ
100 m
Near HURMAN KALESİ
NW of TAVLA
Mio? cgl (Eo clasts)
Gürün autochthon
TATLAR
DALLIKAVAK
Unconformity, overlain by conglomerate (Miocene?)
Gürün autochthon Late Cretaceous-Palaeocene
Basalt
Gabbro
Serpentinite
Dağlica ophiolite DO U.Cretaceous
DO Dağlica ophiolite, dismembered
DU Dağlica ophiolite-related melange
KF Kemaliye Fm. (coherent succession)
KK Kırmızı Kandil Fm.
M Munzur limestone (Mesozoic)

Figure 8

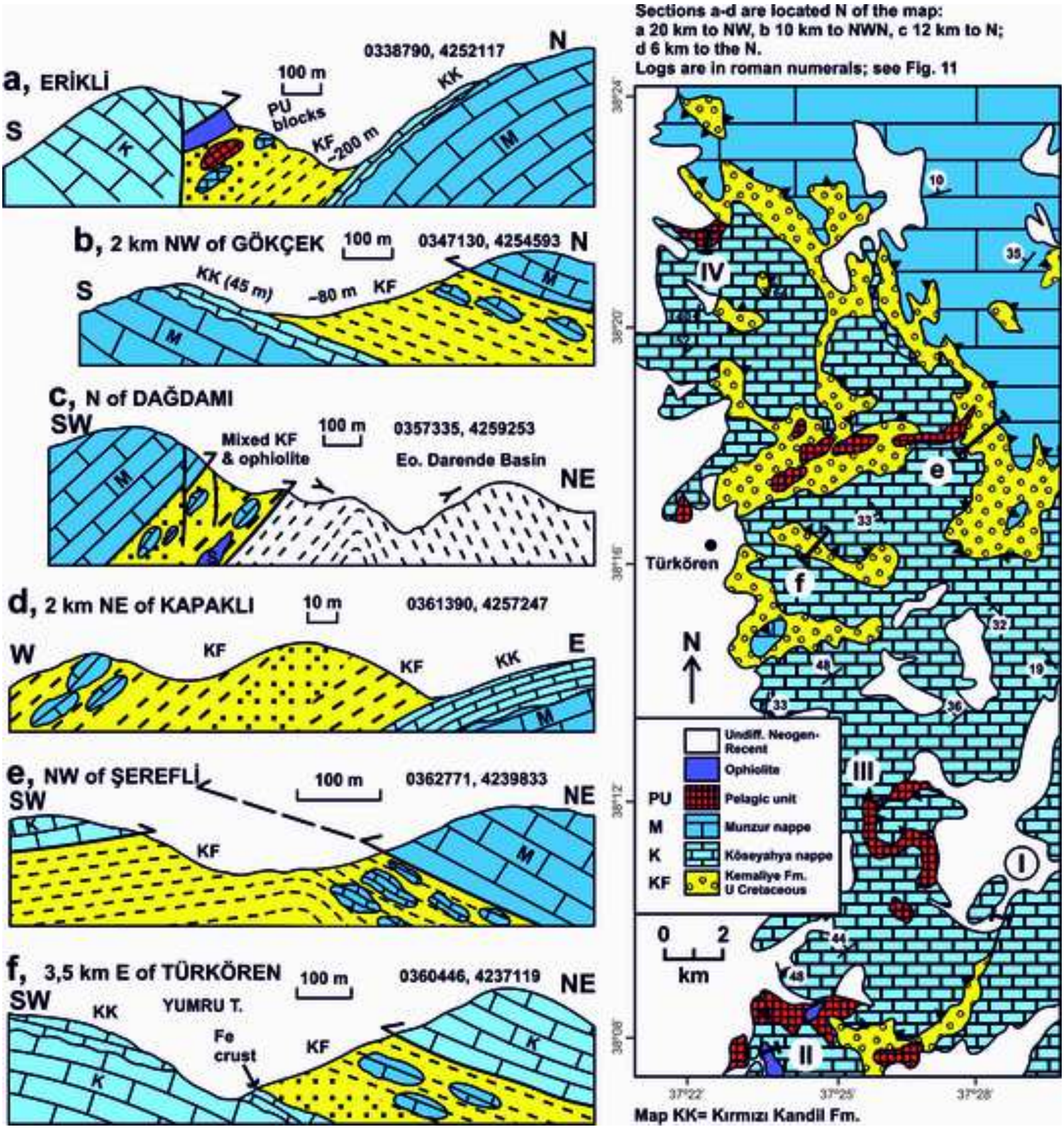

Sections a-d are located N of the map:
a 20 km to NW, b 10 km to NWN, c 12 km to N;
d 6 km to the N.
Logs are in roman numerals; see Fig. 11
a, ERİKLİ
S
N
0338790, 4252117
100 m
PU blocks
KF ~200 m
KK
K
M
b, 2 km NW of GÖKÇEK
100 m
0347130, 4254593
KK (45 m)
~80 m
KF
c, N of DAĞDAMI
SW
NE
Mixed KF & ophiolite
100 m
0357335, 4259253
Eo. Darende Basin
d, 2 km NE of KAPAKLI
10 m
0361390, 4257247
W
E
e, NW of ŞEREFLİ
SW
NE
100 m
0362771, 4239833
f, 3,5 km E of TÜRKÖREN
SW
NE
100 m
0360446, 4237119
YUMRU T.
Fe crust
Türkören
Undiff. Neogen-Recent
Ophiolite
PU Pelagic unit
M Munzur nappe
K Köseyahya nappe
KF Kemaliye Fm. U Cretaceous
0 2 km
Map KK= Kırmızı Kandil Fm.

Figure 9

Click here to access/download;Figure;Fig_9REVAR14,4,21_MOD

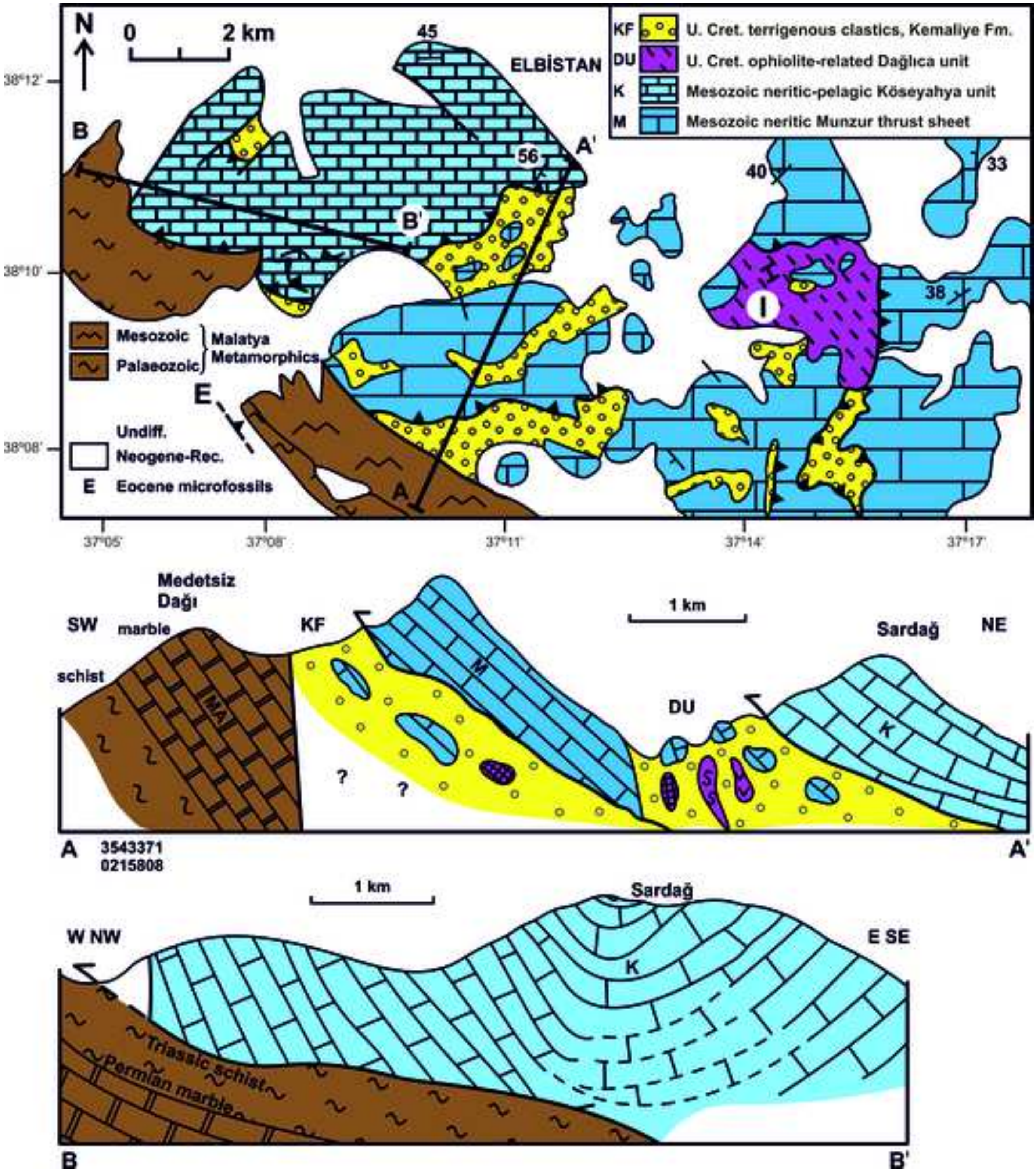


Figure 10

Click here to access/download;Figure;Fig10.jpg

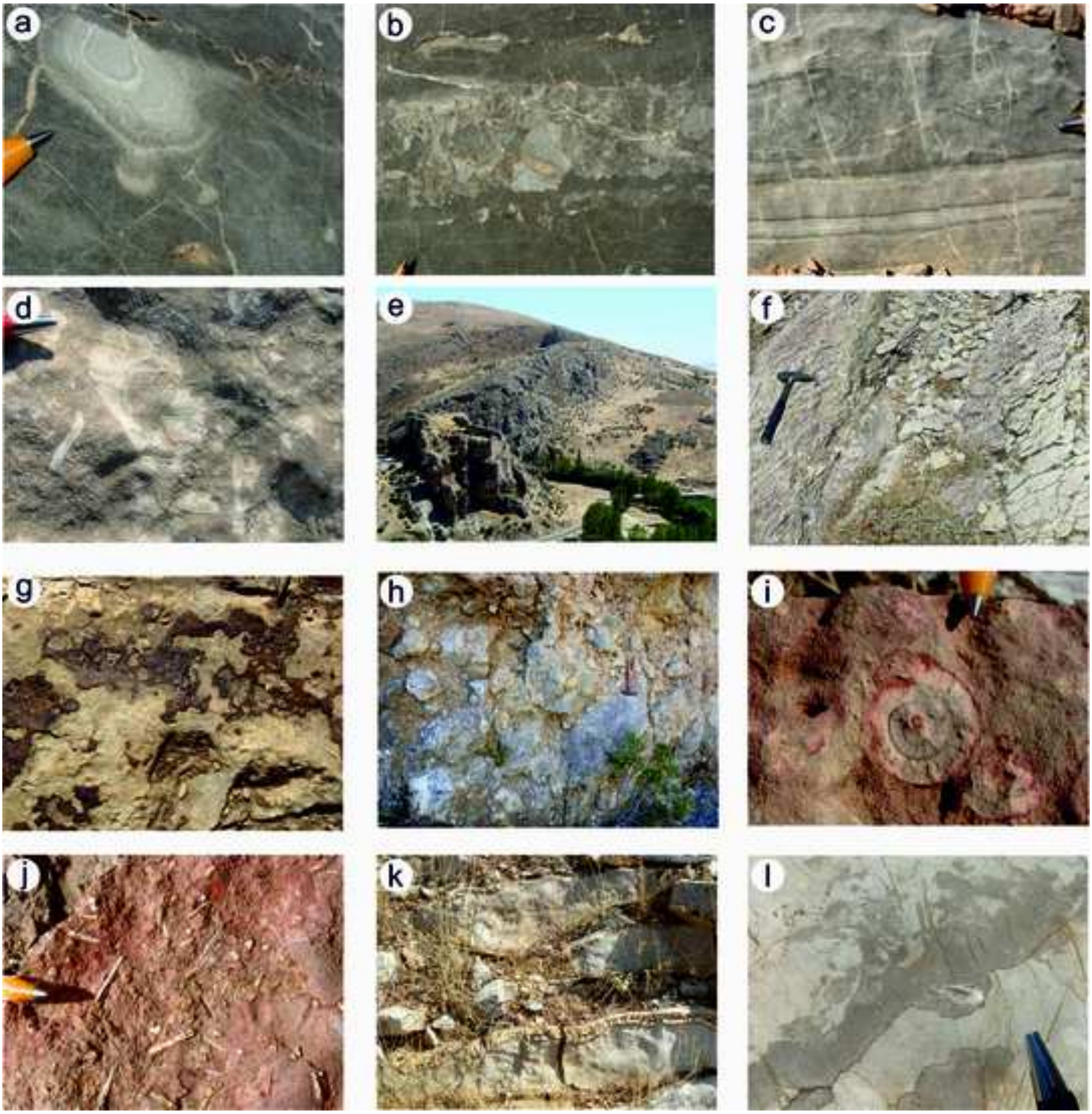
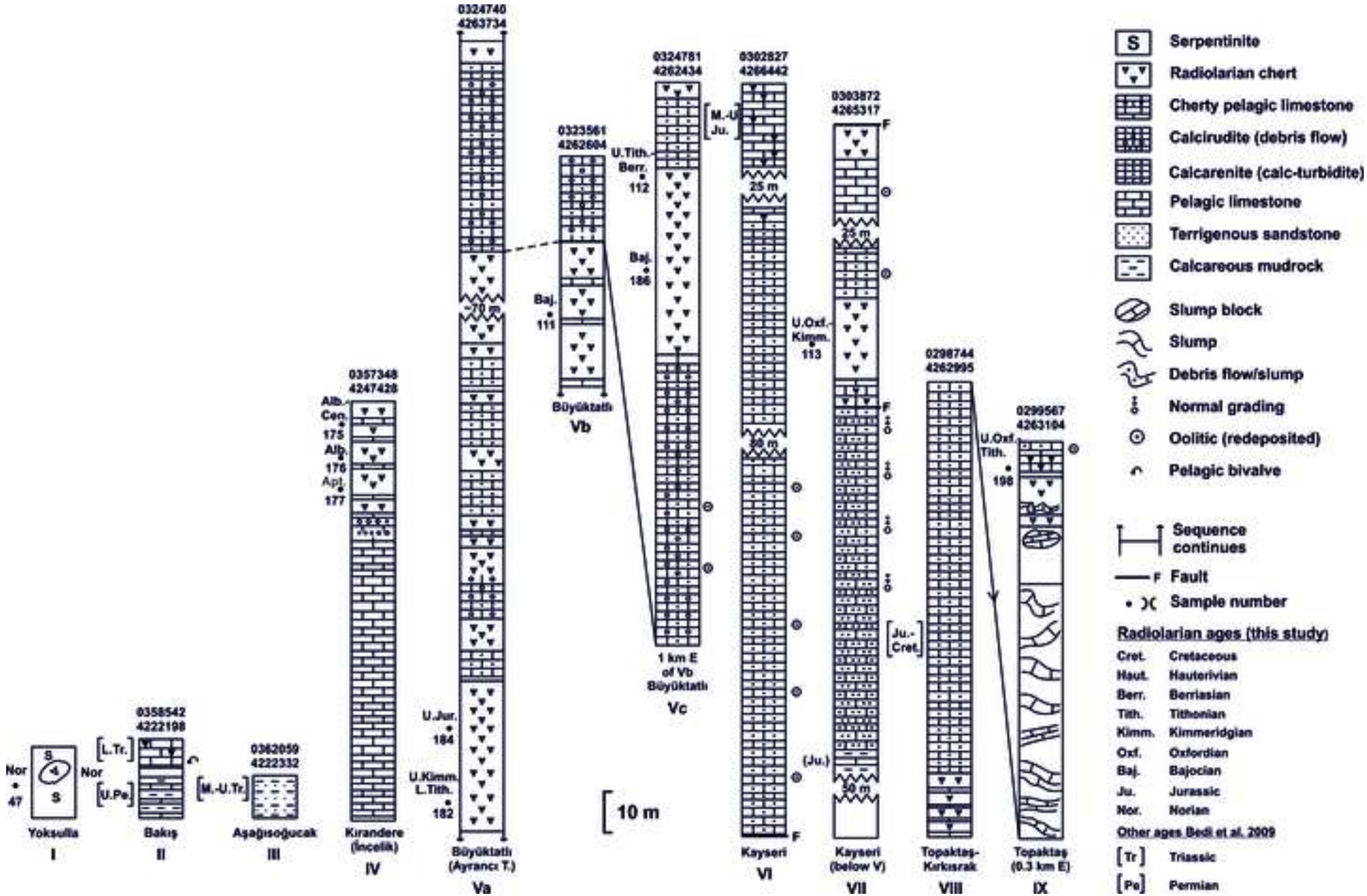


Figure 11



0324740
4263734
0323561
4262604
0324781
4262434
0302827
4266442
0303872
4265317
0298744
4262995
0299567
4263104
0357348
4247428
0358542
4222198
0362059
4222332
U.Tith.-
Berr.
112
Baj.
186
Baj.
111
M.-U.
Ju.
~70 m
25 m
25 m
30 m
30 m
U.Oxf.-
Kimm.
113
U.Oxf.-
Tith.
198
Alb.-
Cen.
175
Alb.
176
Apt.
177
U.Jur.
184
U.Kimm.-
L.Tith.
182
Ju.-
Cret.
(Ju.)
Nor
47
S
S
Nor
L.Tr.
U.Pe.
M.-U.Tr.
F
10 m
Yoksulla
I
Bakış
II
Aşağısoğucak
III
Kırandere
(İncelik)
IV
Büyüktatlı
(Ayrancı T.)
Va
Büyüktatlı
Vb
1 km E
of Vb
Büyüktatlı
Vc
Kayseri
VI
Kayseri
(below V)
VII
Topaktaş-
Kırkısrak
VIII
Topaktaş
(0.3 km E)
IX
S
Serpentinite
Radiolarian chert
Cherty pelagic limestone
Calcirudite (debris flow)
Calcarenite (calc-turbidite)
Pelagic limestone
Terrigenous sandstone
Calcareous mudrock
Slump block
Slump
Debris flow/slump
Normal grading
Oolitic (redeposited)
Pelagic bivalve
Sequence
continues
F Fault
Sample number
Radiolarian ages (this study)
Cret. Cretaceous
Haut. Hauterivian
Berr. Berriasian
Tith. Tithonian
Kimm. Kimmeridgian
Oxf. Oxfordian
Baj. Bajocian
Ju. Jurassic
Nor. Norian
Other ages Bedi et al. 2009
Tr Triassic
Pe Permian

Figure 12

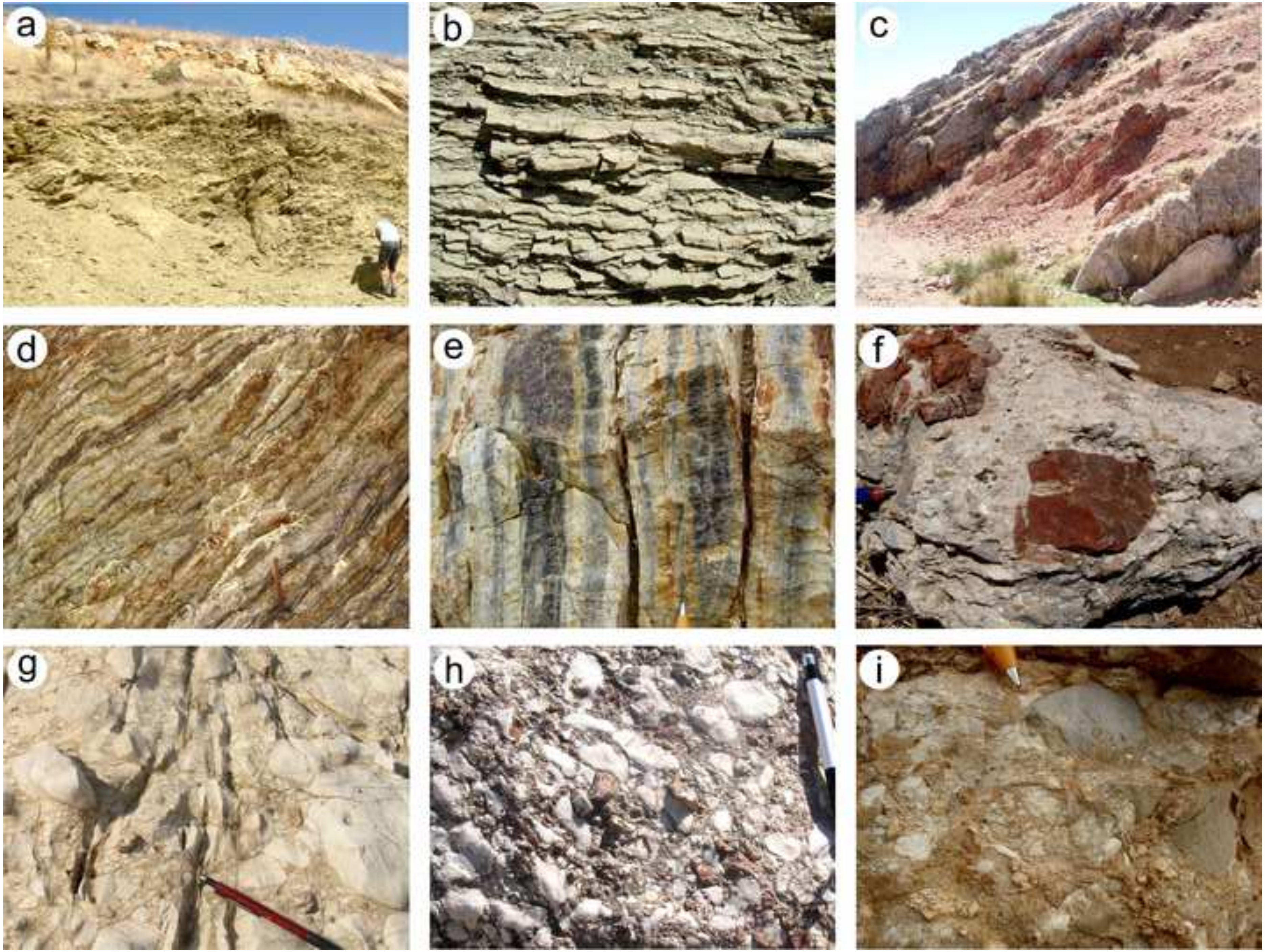
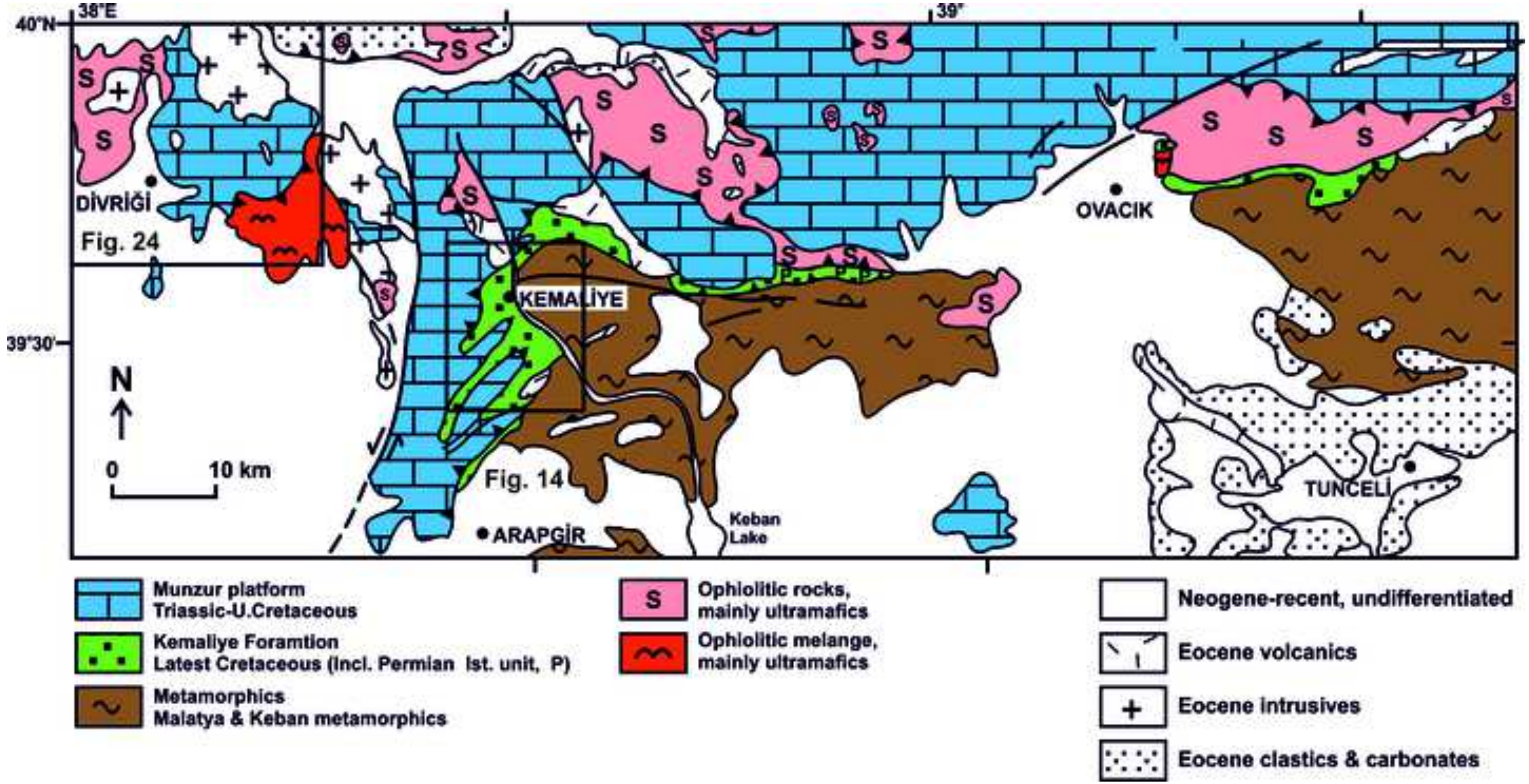


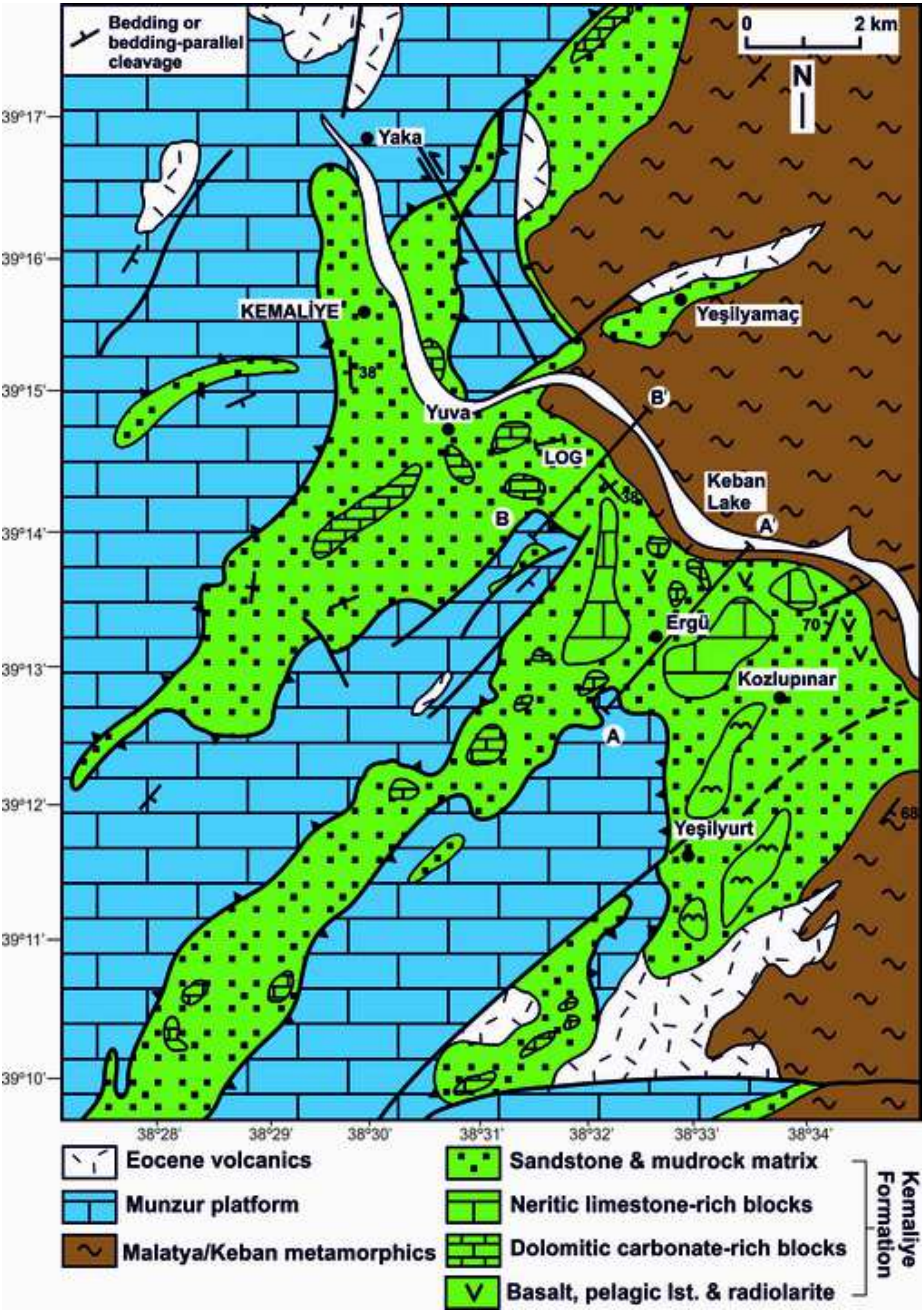
Figure 13



40°N
38°E
39°
39°30'
DIVRIĞI
Fig. 24
KEMALİYE
OVACIK
TUNCELİ
Fig. 14
ARAPGİR
Keban Lake
N
0
10 km
S
Munzur platform Triassic-U.Cretaceous
Kemaliye Foramtion Latest Cretaceous (incl. Permian lst. unit, P)
Metamorphics Malatya & Keban metamorphics
Ophiolitic rocks, mainly ultramafics
Ophiolitic melange, mainly ultramafics
Neogene-recent, undifferentiated
Eocene volcanics
Eocene intrusives
Eocene clastics & carbonates

Figure 14

Click here to access/download;Figure;Fig. 14.ARREV12.1MOD.jpg



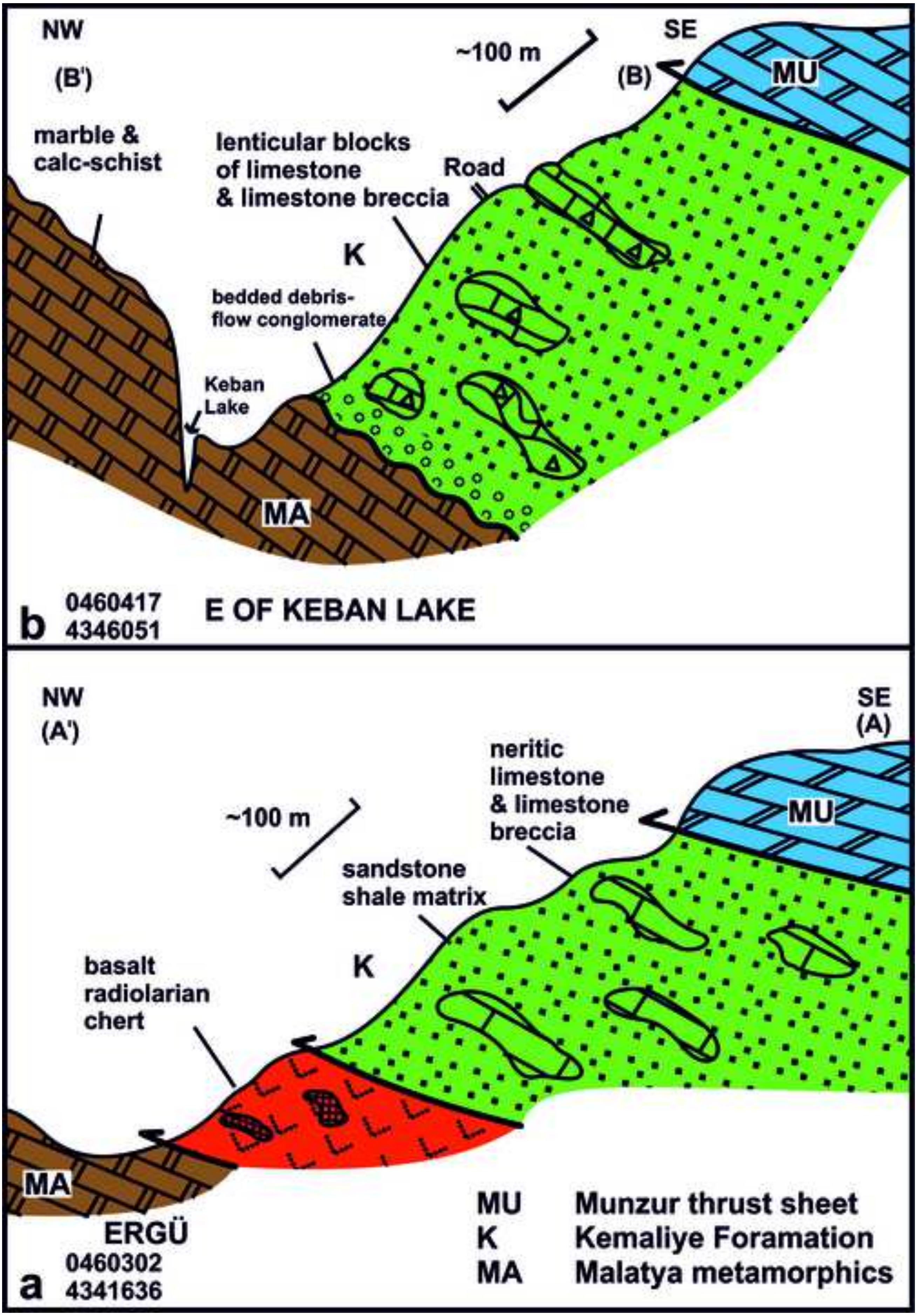

NW
(B')
marble &
calc-schist
lenticular blocks
of limestone
& limestone breccia
Road
~100 m
SE
(B)
MU
K
bedded debris-
flow conglomerate
Keban
Lake
MA
b
0460417
4346051
E OF KEBAN LAKE
NW
(A')
SE
(A)
neritic
limestone
& limestone
breccia
~100 m
MU
sandstone
shale matrix
K
basalt
radiolarian
chert
MA
ERGÜ
a
0460302
4341636
MU Munzur thrust sheet
K Kemaliye Foramation
MA Malatya metamorphics

Figure 16

Click here to access/download;Figure;Fig_16 new.jpg

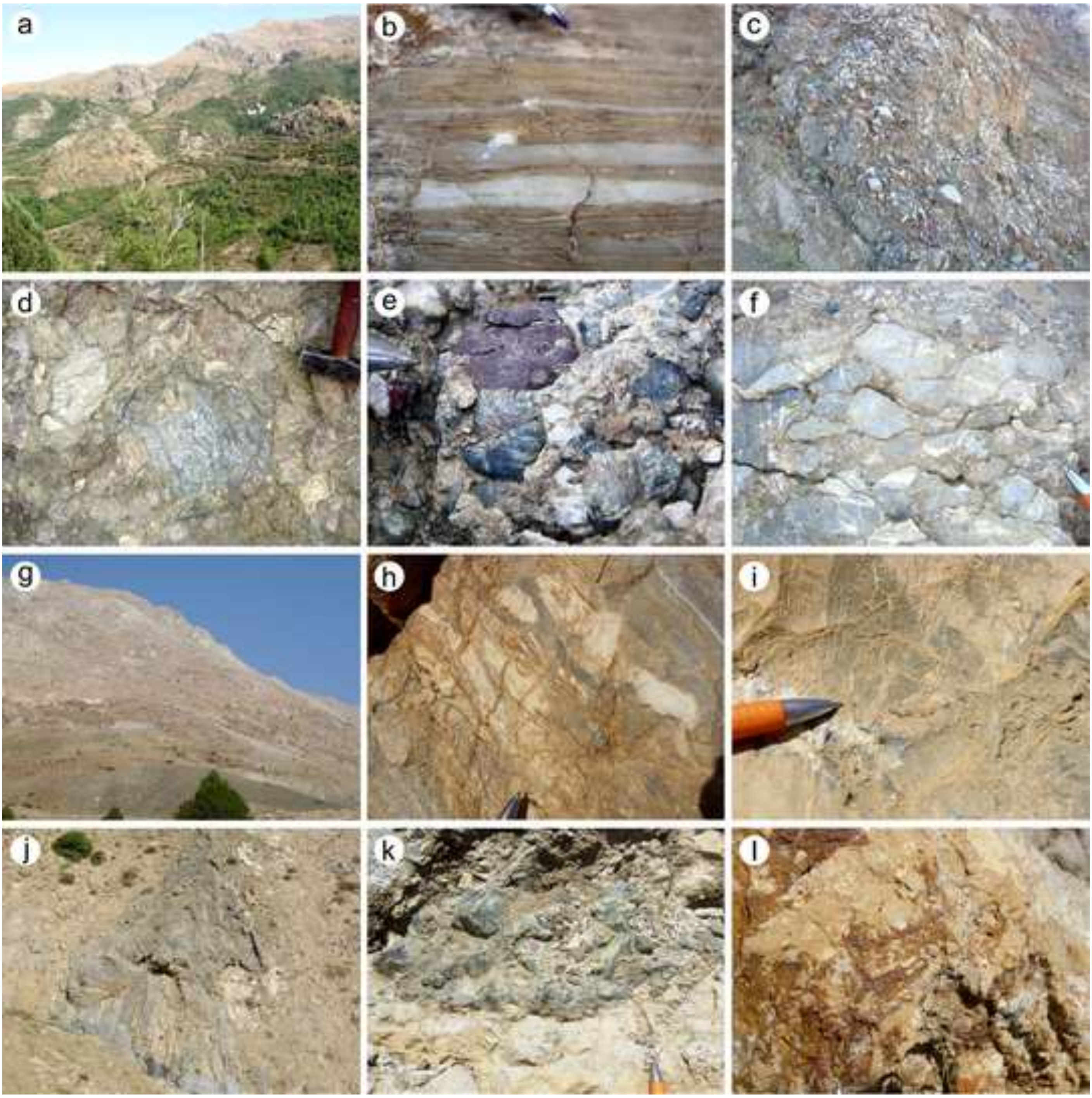


Figure 17

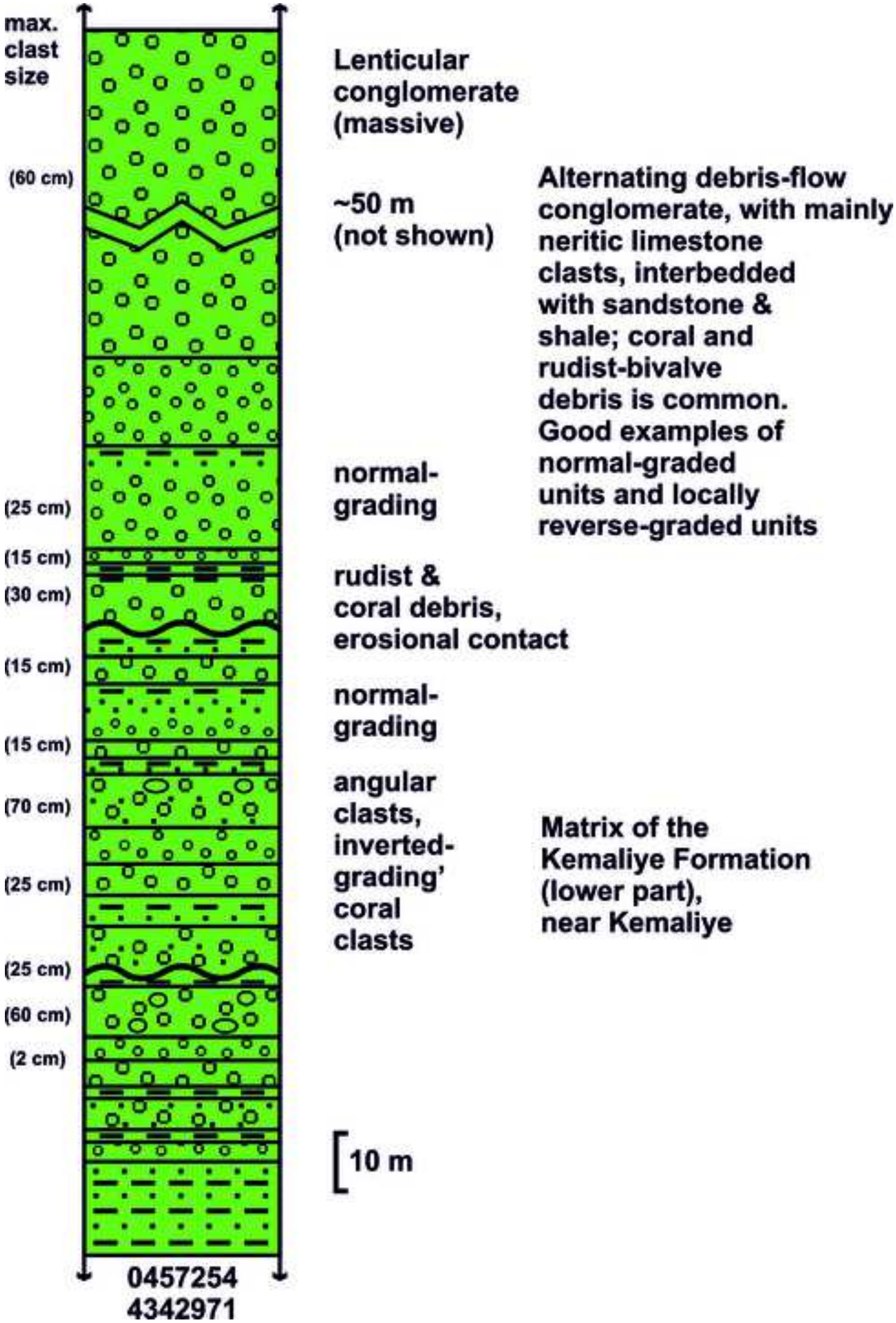

max.
clast
size
(60 cm)
(25 cm)
(15 cm)
(30 cm)
(15 cm)
(15 cm)
(70 cm)
(25 cm)
(25 cm)
(60 cm)
(2 cm)
Lenticular
conglomerate
(massive)
~50 m
(not shown)
Alternating debris-flow
conglomerate, with mainly
neritic limestone
clasts, interbedded
with sandstone &
shale; coral and
rudist-bivalve
debris is common.
Good examples of
normal-graded
units and locally
reverse-graded units
normal-
grading
rudist &
coral debris,
erosional contact
normal-
grading
angular
clasts,
inverted-
grading'
coral
clasts
Matrix of the
Kemaliye Formation
(lower part),
near Kemaliye
10 m
0457254
4342971

Figure 18

Click here to access/download;Figure;Fig. 18..jpg

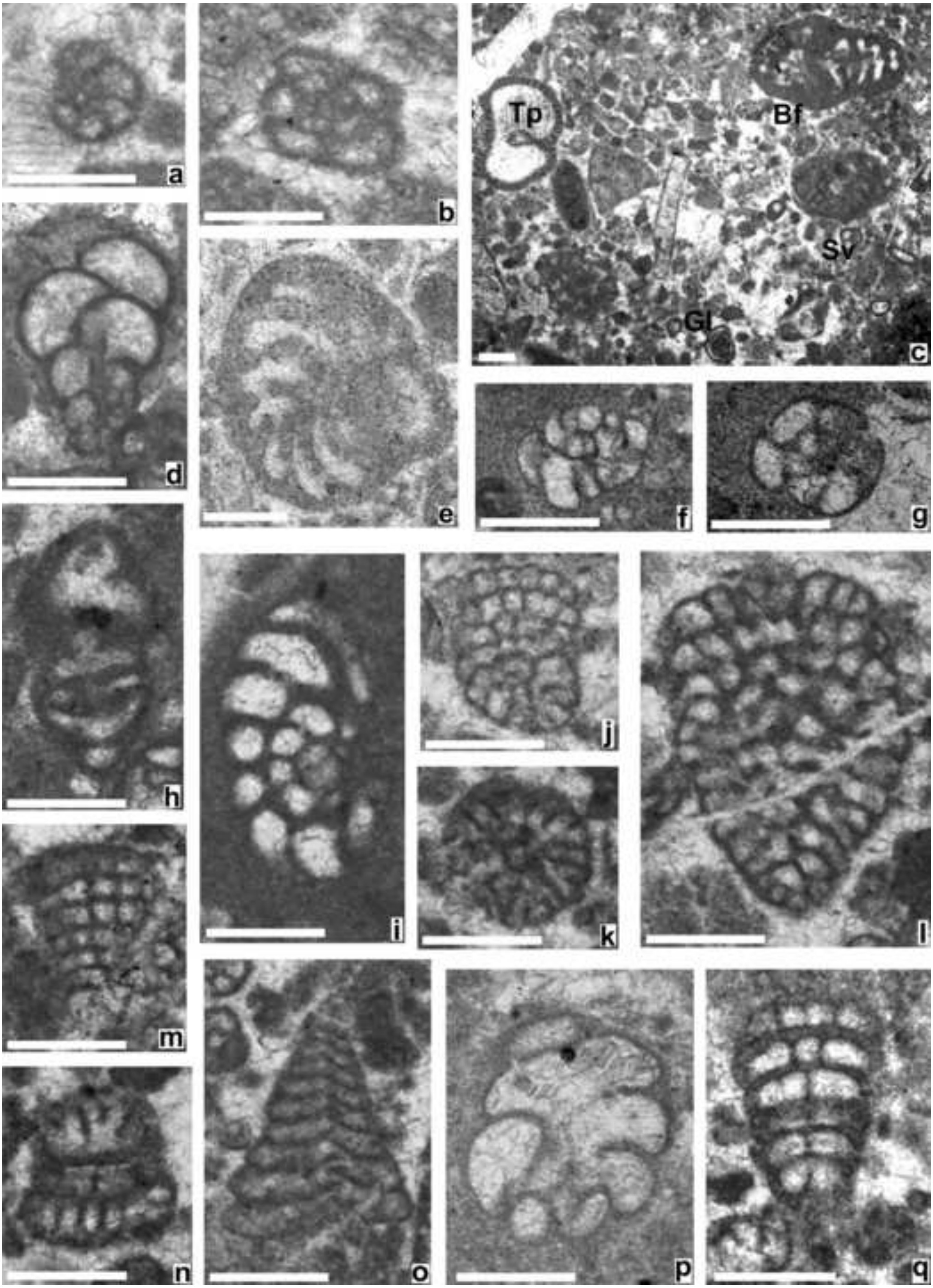
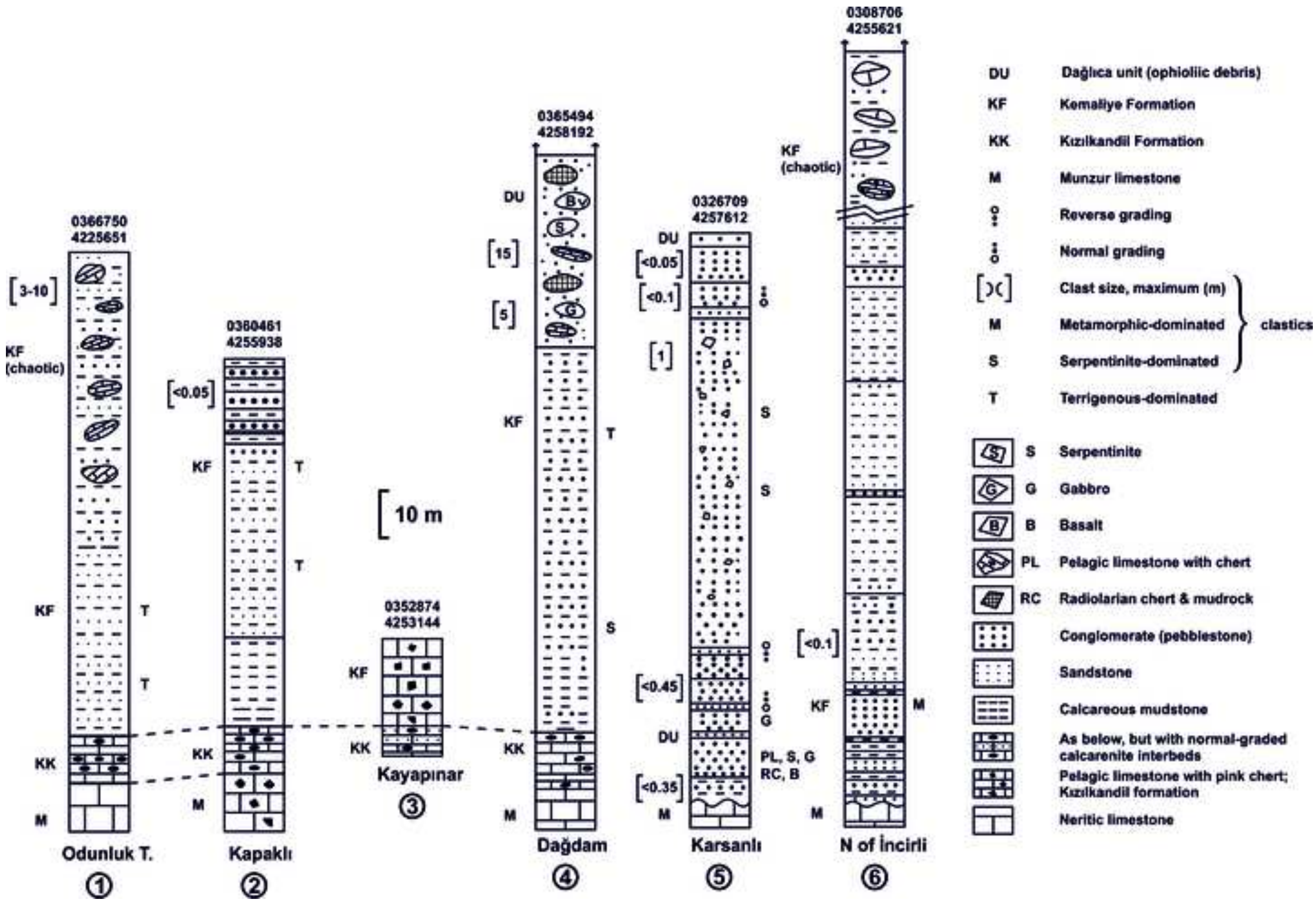


Figure 19



0366750
4225651
[3-10]
KF (chaotic)
KF
T
T
KK
M
Odunluk T.
①
0380461
4255938
[<0.05]
KF
T
T
KK
M
Kapaklı
②
10 m
0352874
4253144
KF
KK
Kayapınar
③
0365494
4258192
DU
[15]
[5]
KF
T
S
KK
M
Dağdam
④
0326709
4257612
DU
[<0.05]
[<0.1]
[1]
S
S
[<0.45]
G
DU
PL, S, G
RC, B
[<0.35]
M
Karsanlı
⑤
0308706
4255621
KF (chaotic)
[<0.1]
KF
M
M
N of İncirli
⑥
DU Dağlıca unit (ophiolitic debris)
KF Kemaliye Formation
KK Kızılkandil Formation
M Munzur limestone
Reverse grading
Normal grading
Clast size, maximum (m)
M Metamorphic-dominated
S Serpentinite-dominated
T Terrigenous-dominated
clastics
S Serpentinite
G Gabbro
B Basalt
PL Pelagic limestone with chert
RC Radiolarian chert & mudrock
Conglomerate (pebblestone)
Sandstone
Calcareous mudstone
As below, but with normal-graded calcarenite interbeds
Pelagic limestone with pink chert; Kızılkandil formation
Neritic limestone

Figure 20 Click here to access/download;Figure;Fig20.jpg

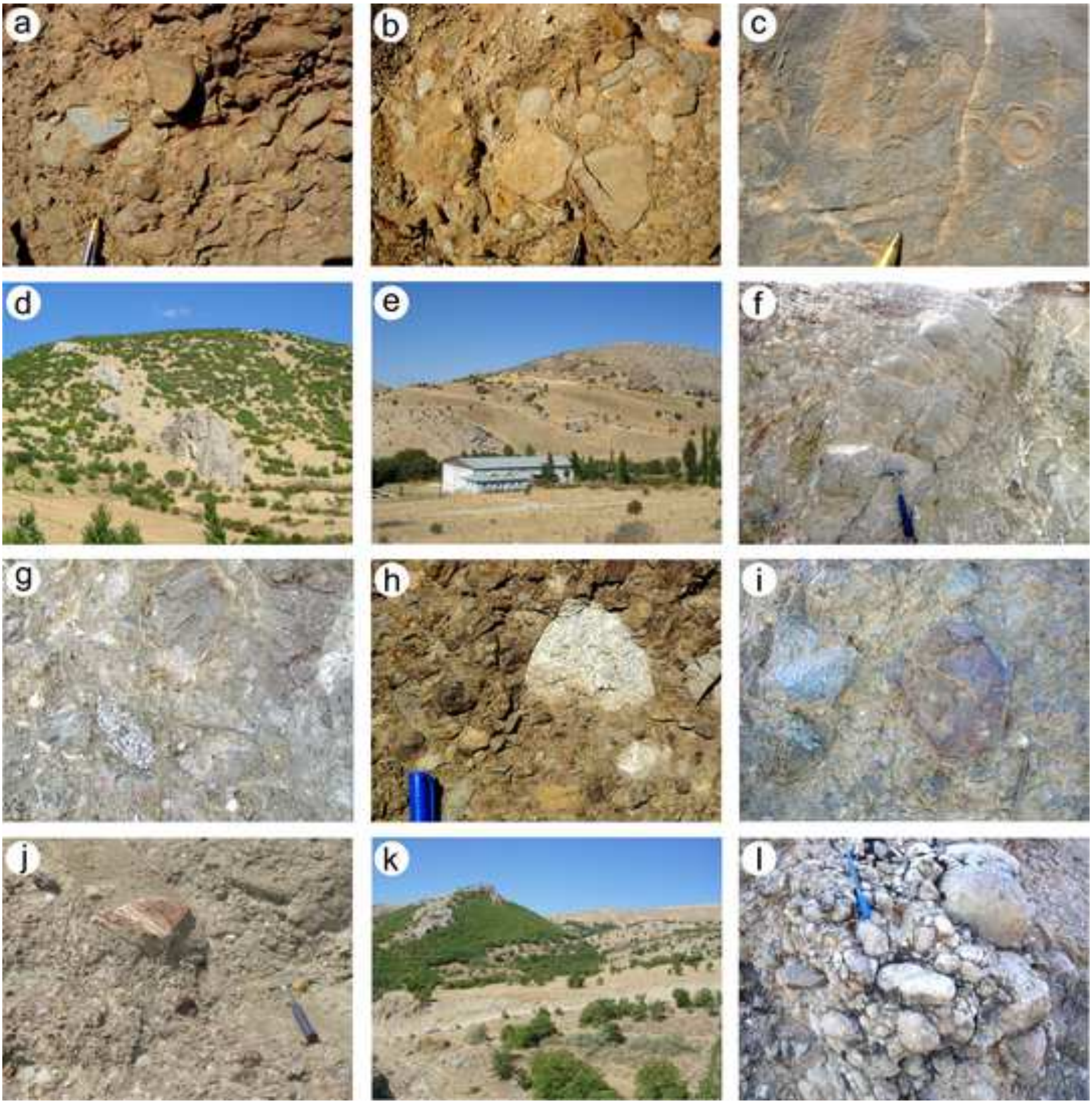


Figure 21

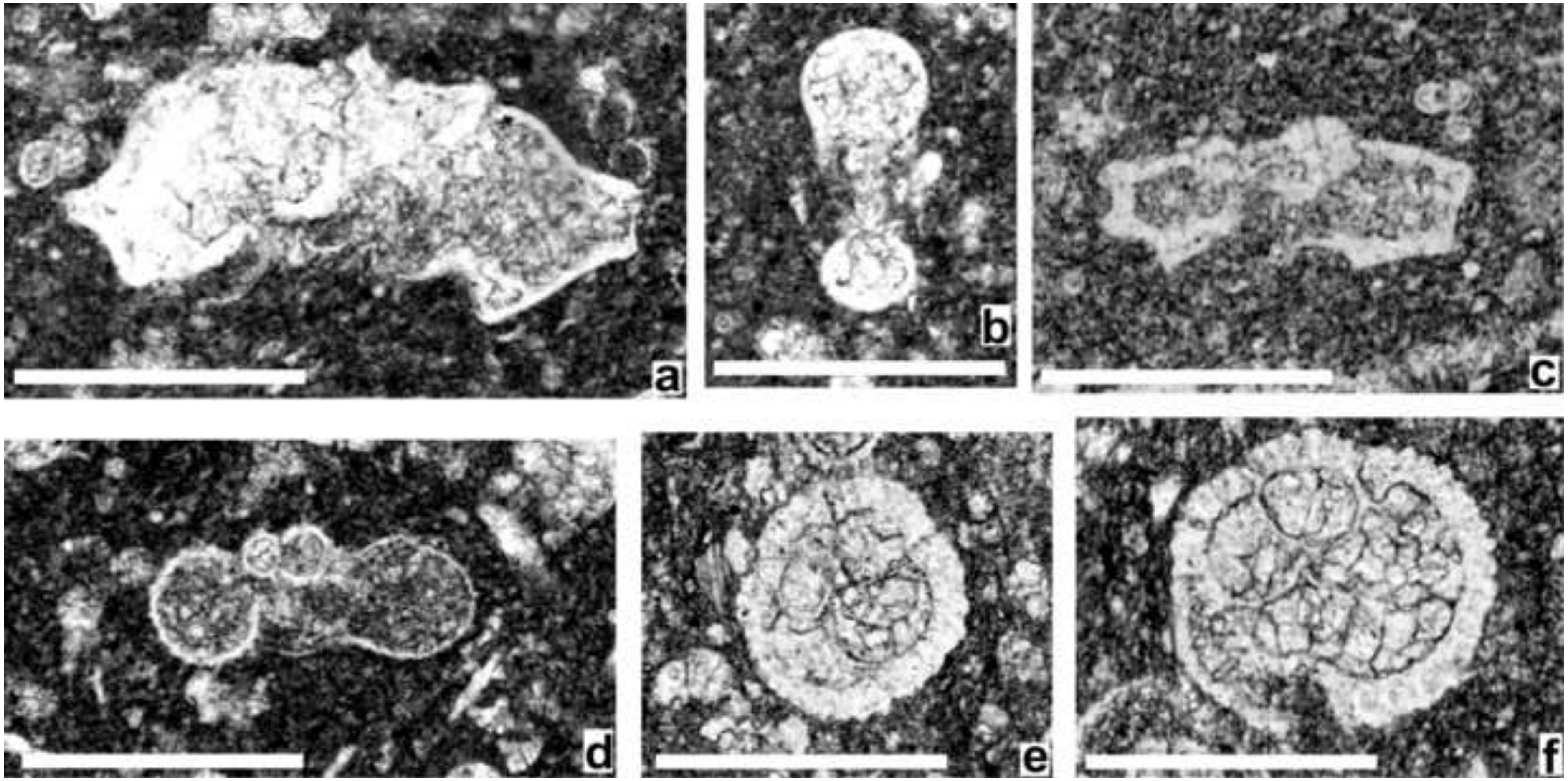
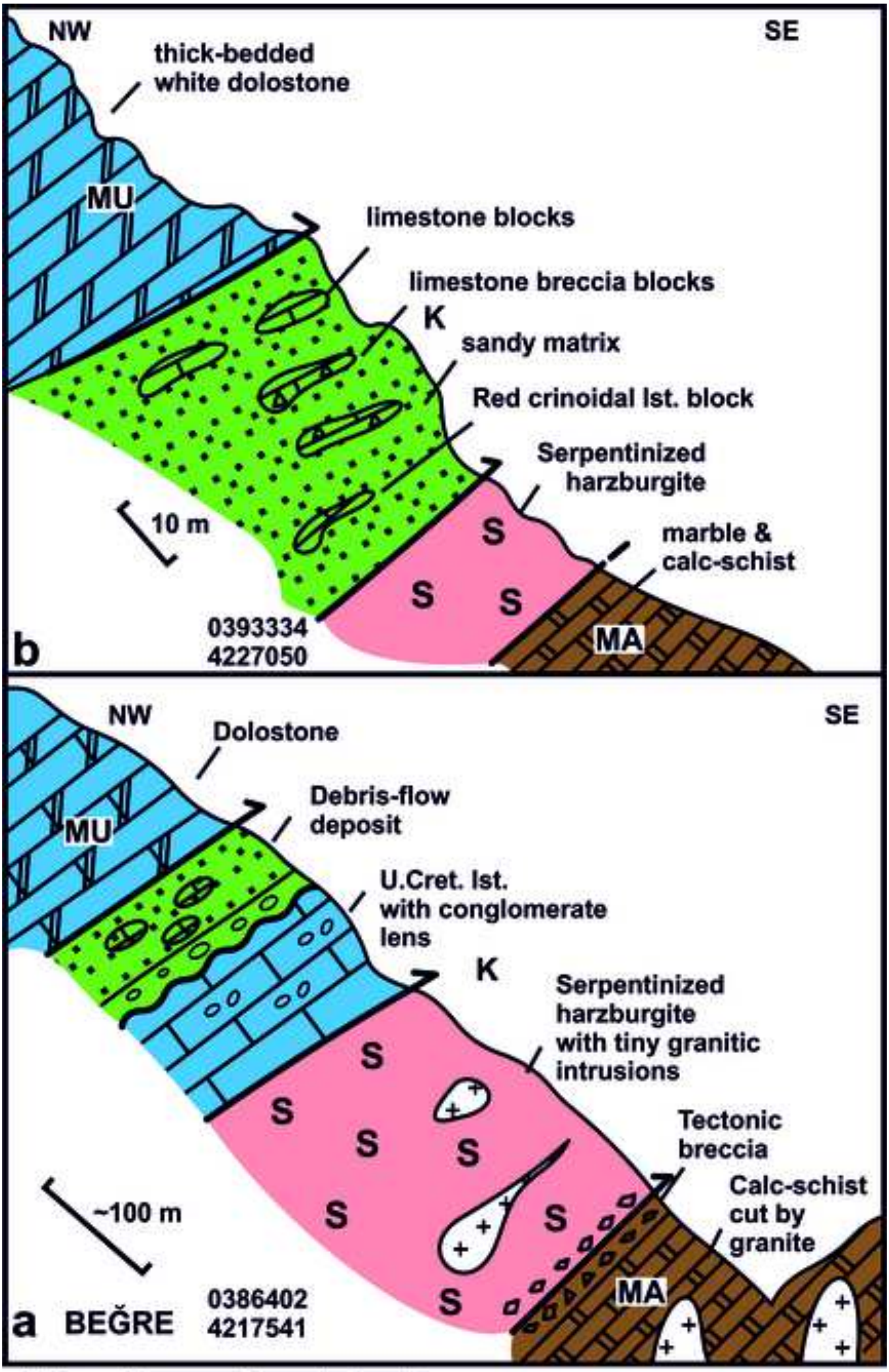
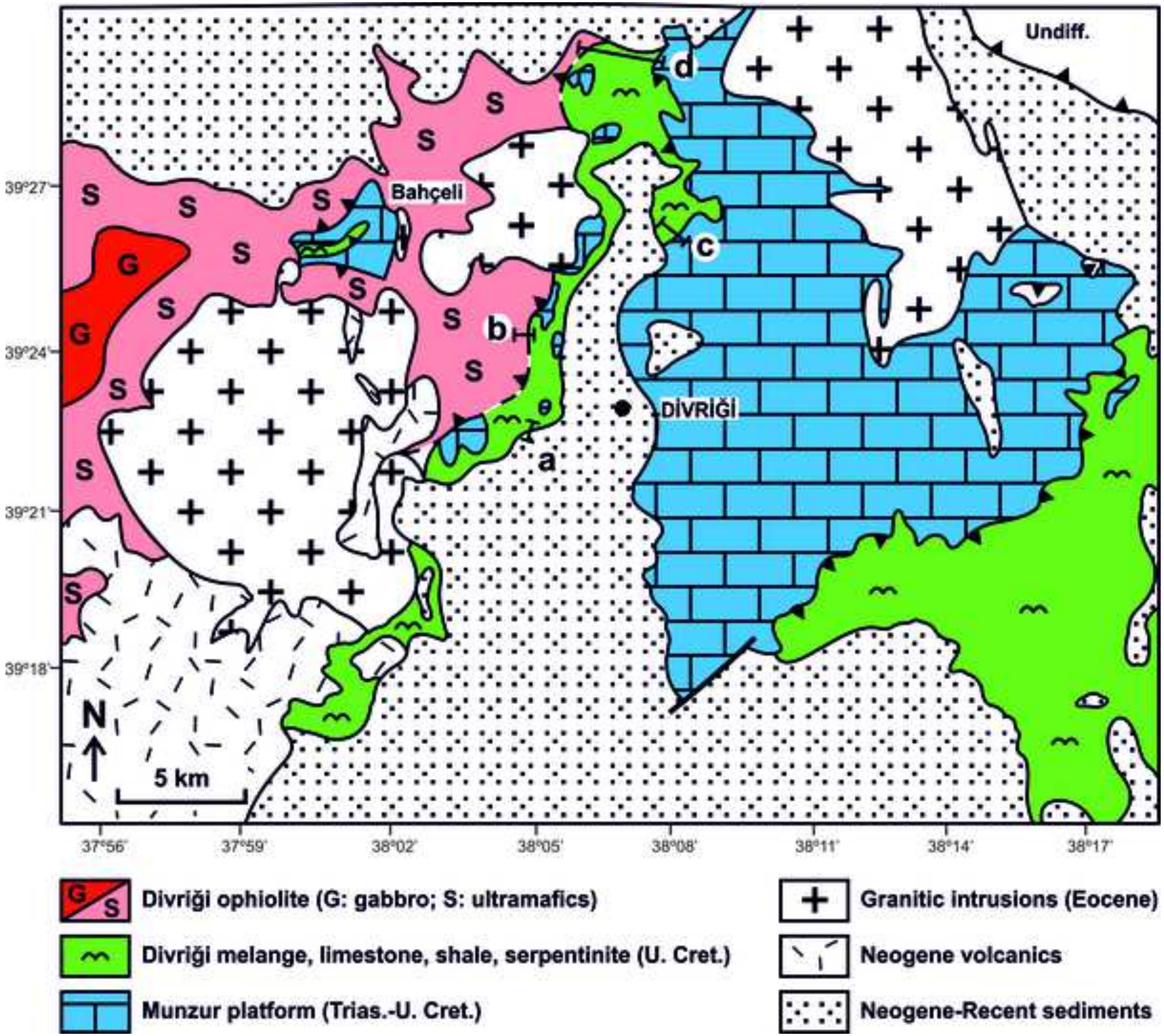


Figure 22 Click here to access/download;Figure;Figure 22 mod.jpg

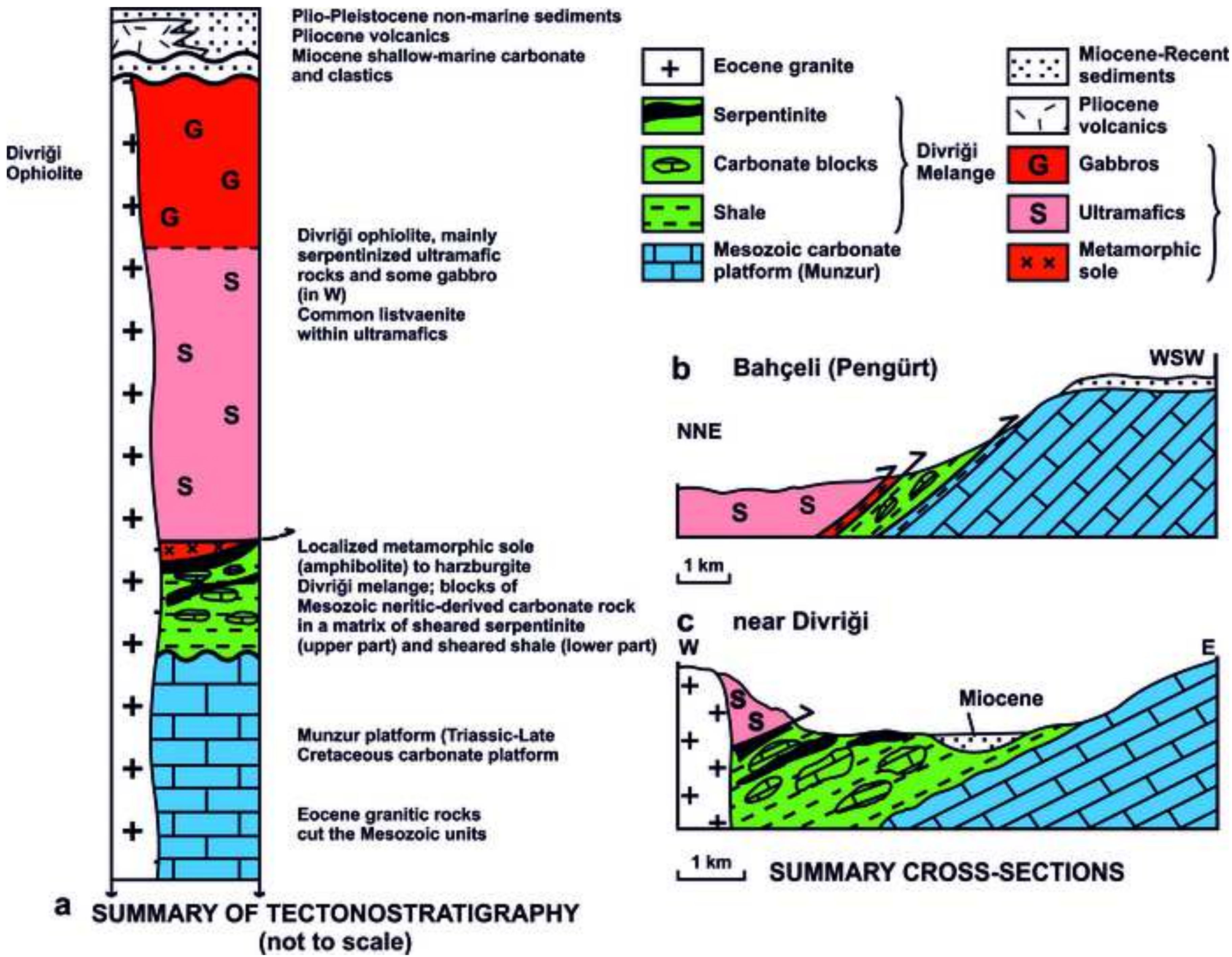


MU Munzur thrust sheet
K Kemaliye Formation
MA Malatya metamorphics



Undiff.
Bahçeli
DİVRİĞİ
a
b
c
d
S
G
5 km
N
39°27'
39°24'
39°21'
39°18'
37°56'
37°59'
38°02'
38°05'
38°08'
38°11'
38°14'
38°17'
Divriği ophiolite (G: gabbro; S: ultramafics)
Divriği melange, limestone, shale, serpentinite (U. Cret.)
Munzur platform (Trias.-U. Cret.)
Granitic intrusions (Eocene)
Neogene volcanics
Neogene-Recent sediments

Figure 24



Divriği Ophiolite
Plio-Pleistocene non-marine sediments
Pliocene volcanics
Miocene shallow-marine carbonate and clastics
Divriği ophiolite, mainly serpentinized ultramafic rocks and some gabbro (in W)
Common listvaenite within ultramafics
Localized metamorphic sole (amphibolite) to harzburgite
Divriği melange; blocks of Mesozoic neritic-derived carbonate rock in a matrix of sheared serpentinite (upper part) and sheared shale (lower part)
Munzur platform (Triassic-Late Cretaceous carbonate platform
Eocene granitic rocks cut the Mesozoic units
a SUMMARY OF TECTONOSTRATIGRAPHY (not to scale)
Eocene granite
Serpentinite
Carbonate blocks
Shale
Divriği Melange
Mesozoic carbonate platform (Munzur)
Miocene-Recent sediments
Pliocene volcanics
Gabbros
Ultramafics
Metamorphic sole
b Bahçeli (Pengürt)
NNE
WSW
1 km
c near Divriği
W
E
Miocene
1 km
SUMMARY CROSS-SECTIONS

Figure 25

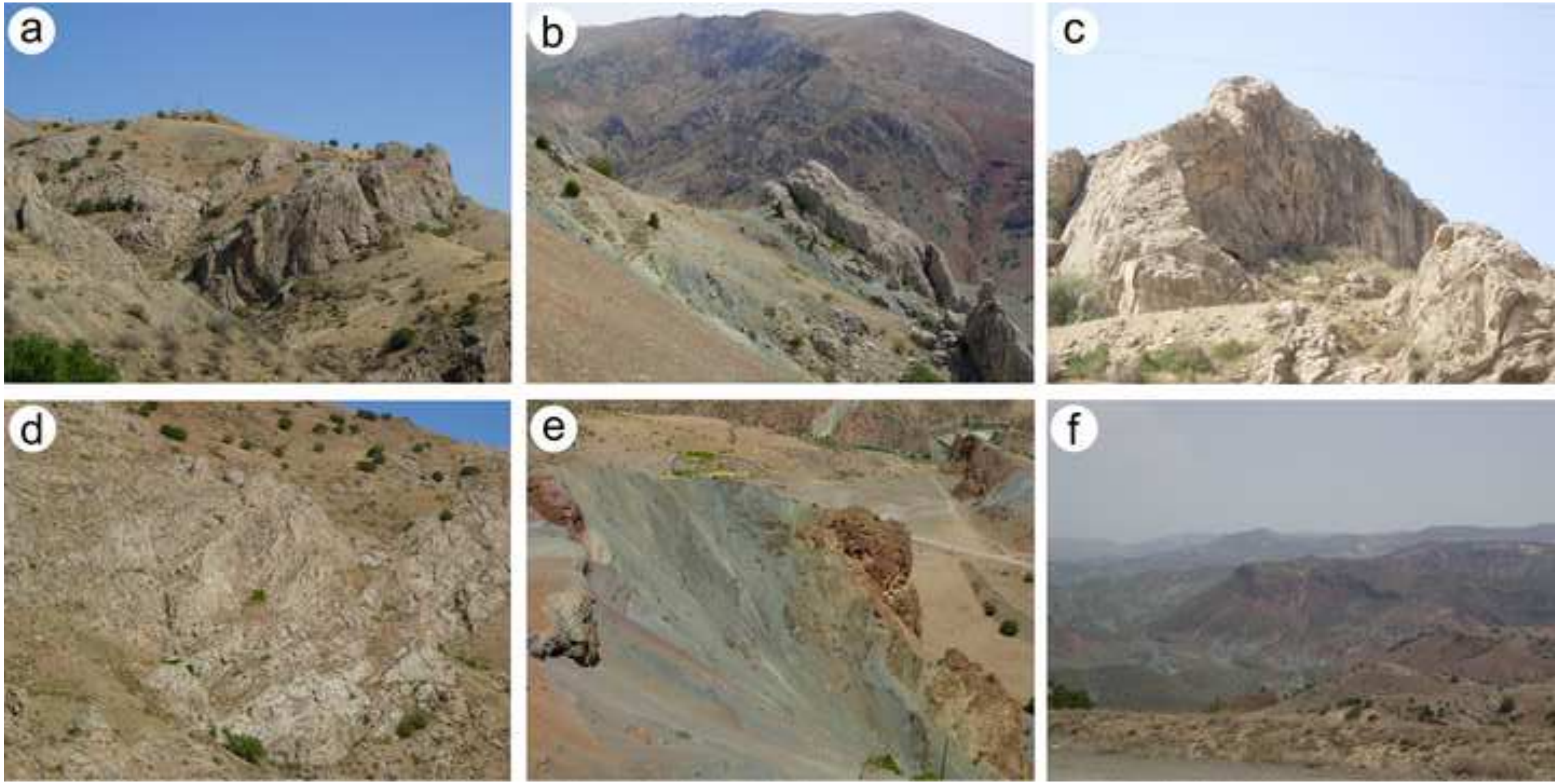
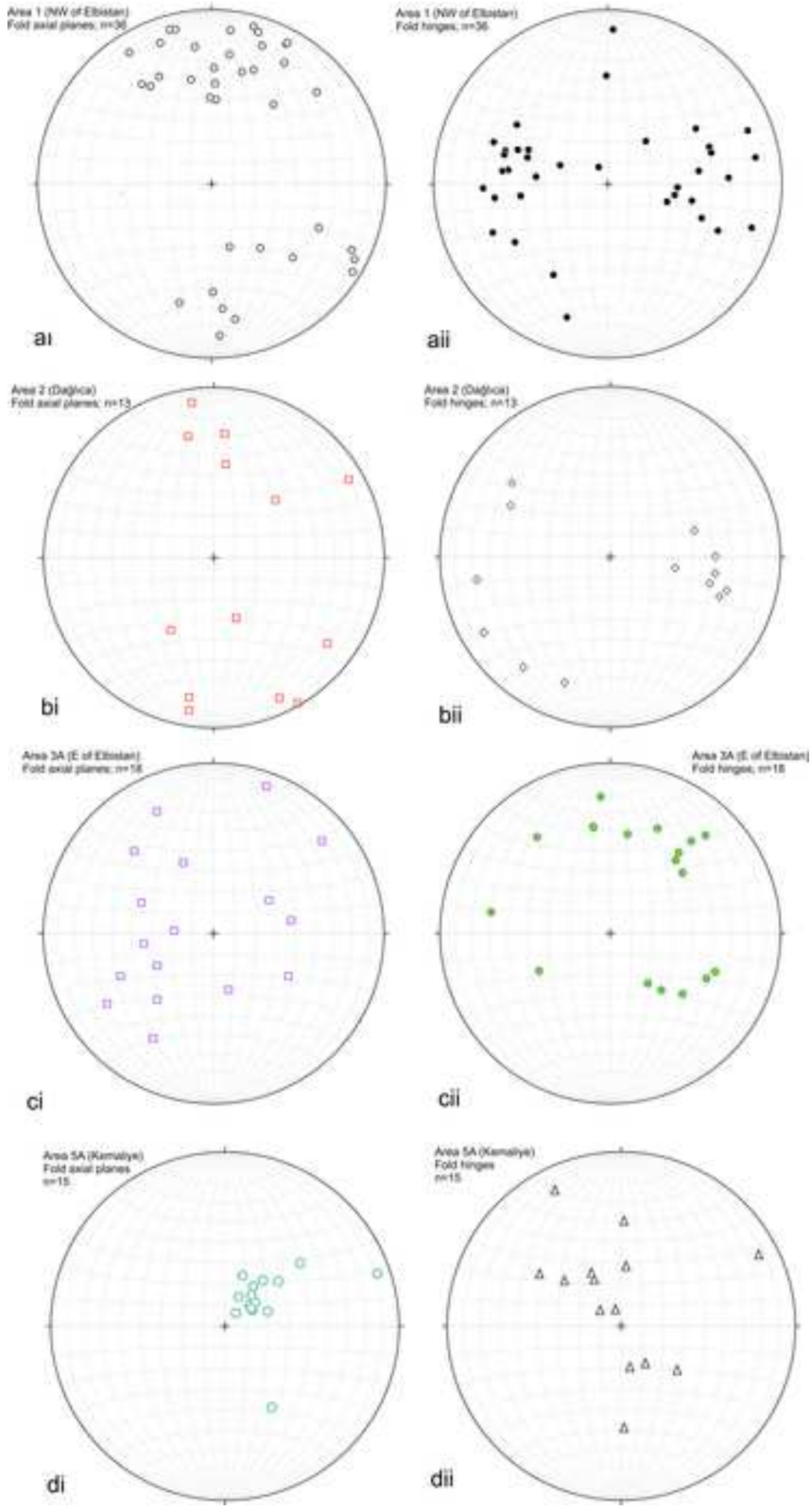


Figure 26



Area 1 (NW of Elbistan)
Fold axial planes: n=36
ai
Area 1 (NW of Elbistan)
Fold hinges: n=36
aii
Area 2 (Dağlıca)
Fold axial planes: n=13
bi
Area 2 (Dağlıca)
Fold hinges: n=13
bii
Area 3A (E of Elbistan)
Fold axial planes: n=18
ci
Area 3A (E of Elbistan)
Fold hinges: n=18
cii
Area 5A (Kemaliye)
Fold axial planes
n=15
di
Area 5A (Kemaliye)
Fold hinges
n=15
dii

Figure 27

[Click here to access/download;Figure;18.5 Fig_27 REVAR12.1.21 2.jpg]

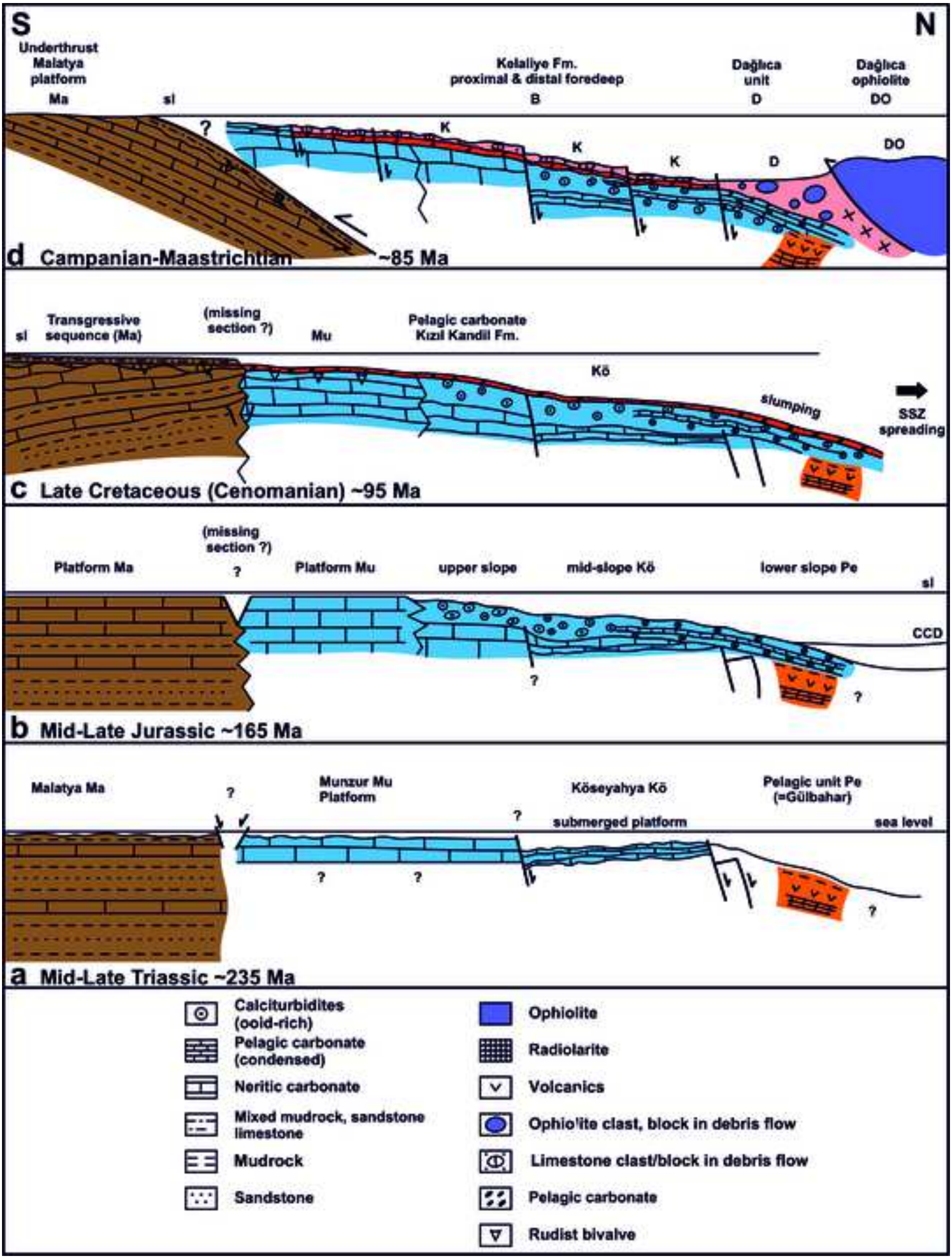


Figure 28

Click here to access/download;Figure;18.5.21 Fig_28 MOD2.jpg

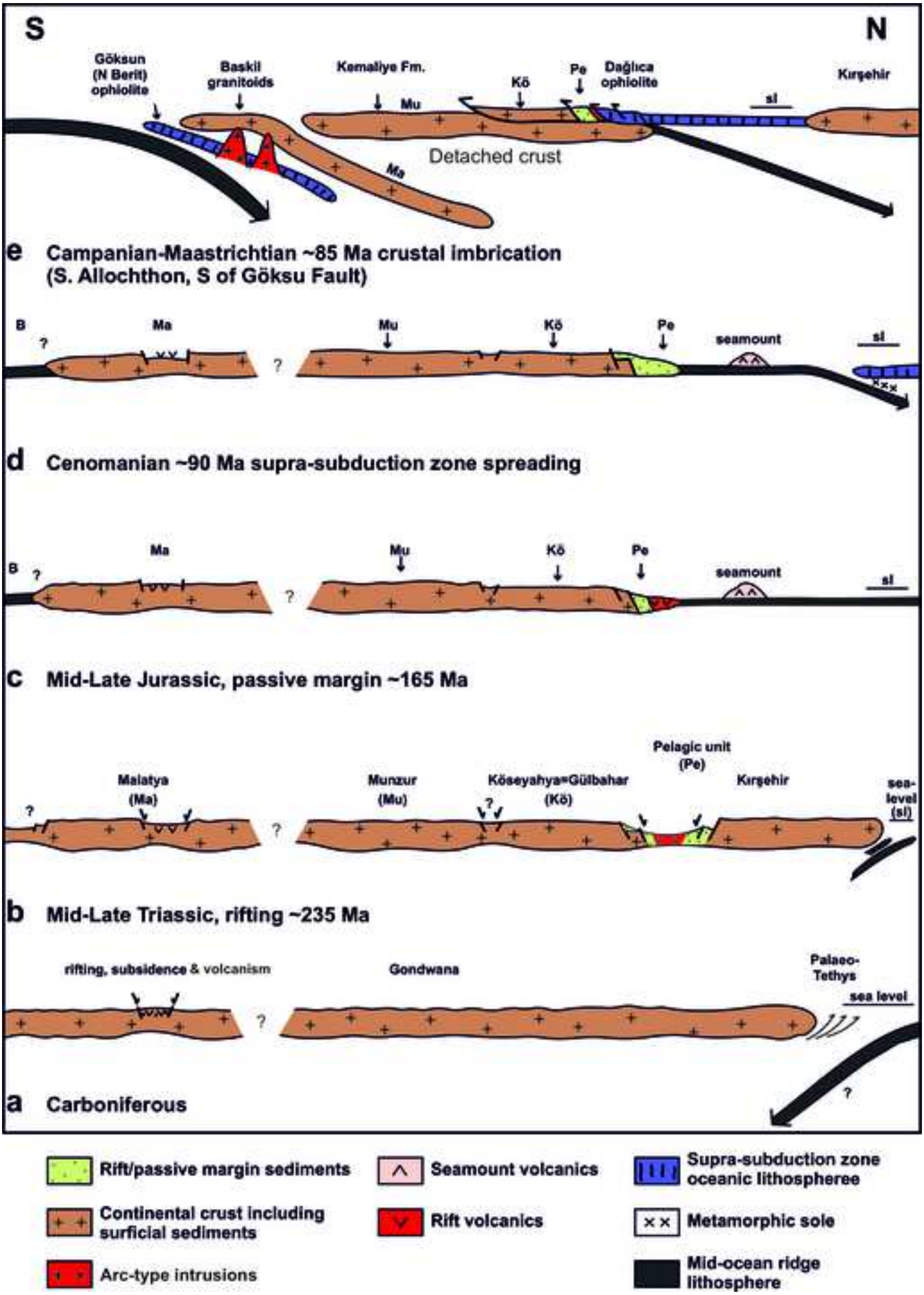
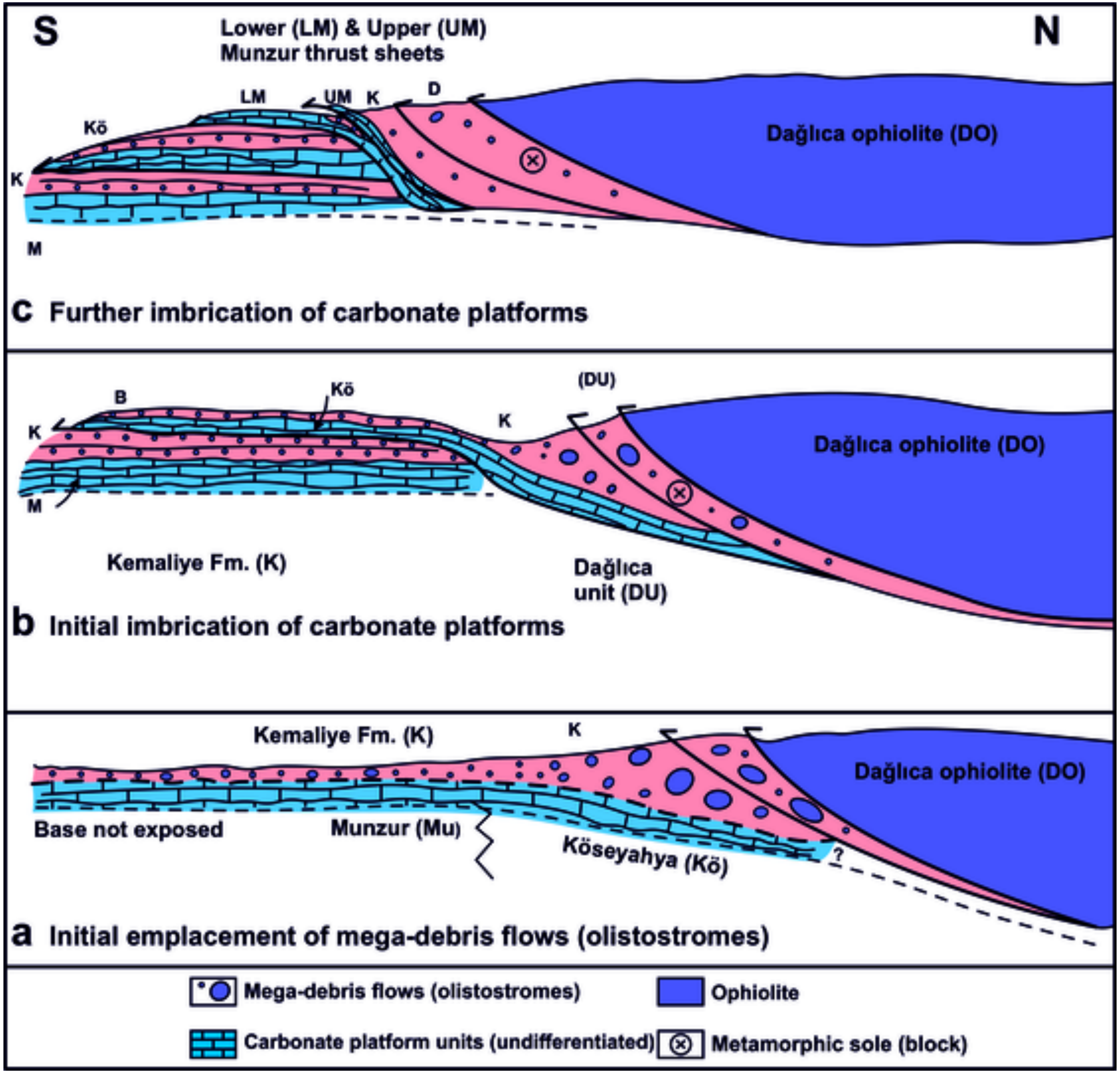
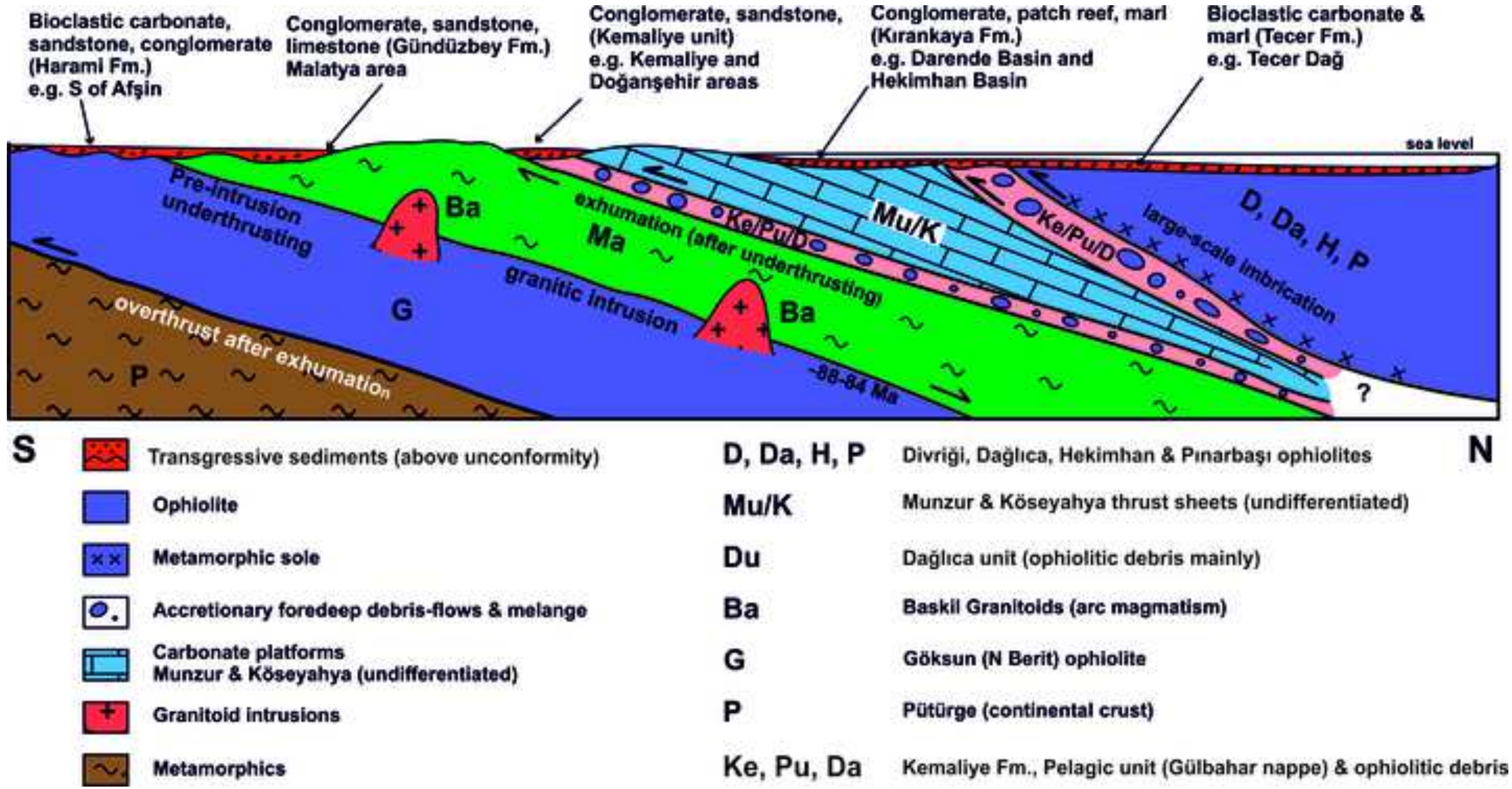


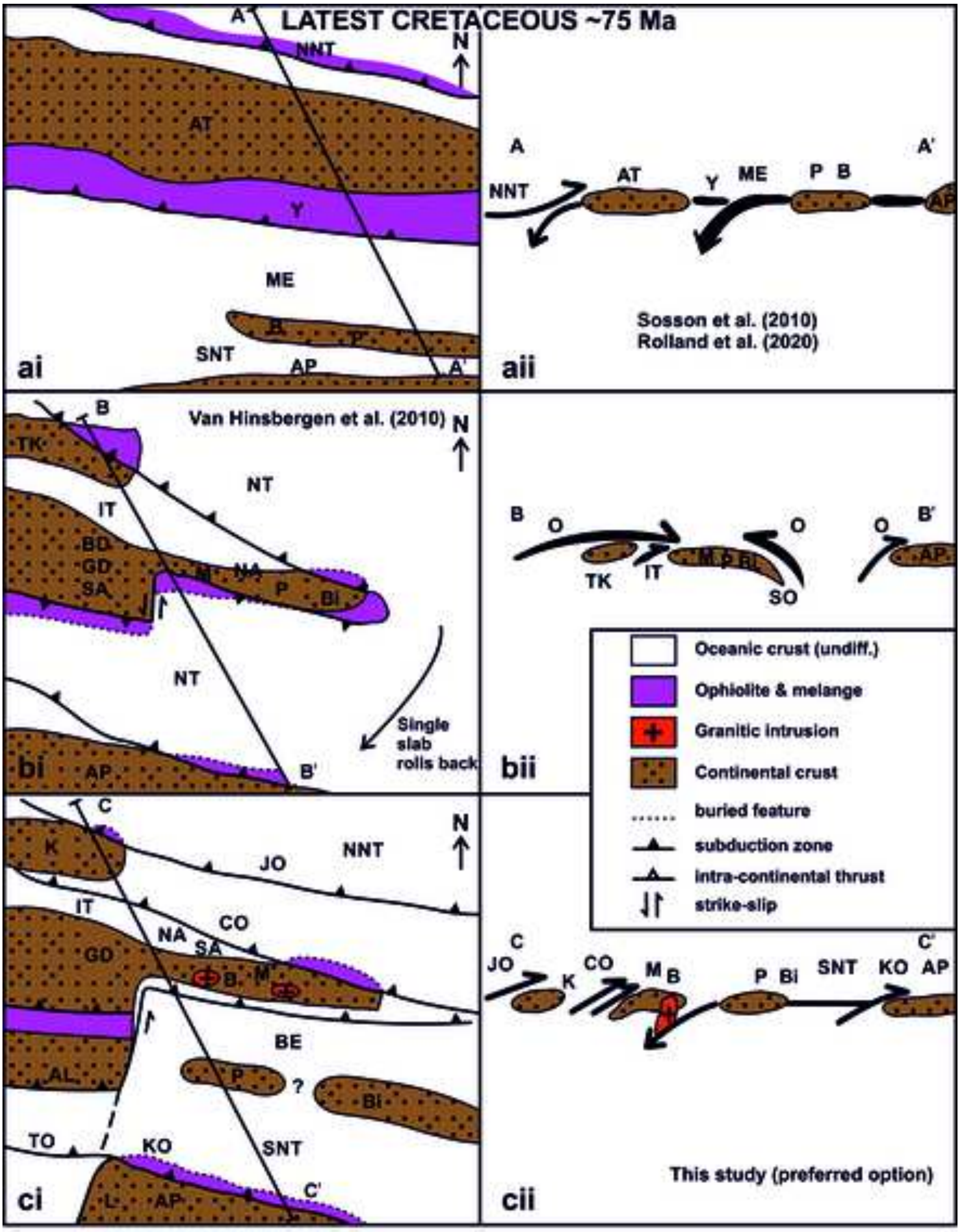
Figure 29


S
N
Lower (LM) & Upper (UM)
Munzur thrust sheets
LM
UM
K
D
Kö
K
M
Dağlıca ophiolite (DO)
c Further imbrication of carbonate platforms
B
Kö
(DU)
K
K
M
Dağlıca ophiolite (DO)
Kemaliye Fm. (K)
Dağlıca
unit (DU)
b Initial imbrication of carbonate platforms
Kemaliye Fm. (K)
K
Dağlıca ophiolite (DO)
Base not exposed
Munzur (Mu)
Köseyahya (Kö)
?
a Initial emplacement of mega-debris flows (olistostromes)
Mega-debris flows (olistostromes)
Ophiolite
Carbonate platform units (undifferentiated)
Metamorphic sole (block)



Bioclastic carbonate, sandstone, conglomerate (Harami Fm.) e.g. S of Afşin
Conglomerate, sandstone, limestone (Gündüzbey Fm.) Malatya area
Conglomerate, sandstone, (Kemaliye unit) e.g. Kemaliye and Doğanşehir areas
Conglomerate, patch reef, marl (Kırankaya Fm.) e.g. Darende Basin and Hekimhan Basin
Bioclastic carbonate & marl (Tecer Fm.) e.g. Tecer Dağ
sea level
Pre-intrusion underthrusting
Ba
G
overthrust after exhumation
P
exhumation (after underthrusting)
Ma
granitic intrusion
Ke/Pu/D
Mu/K
~88-84 Ma
large-scale imbrication
D, Da, H, P
?
S
N
Transgressive sediments (above unconformity)
Ophiolite
Metamorphic sole
Accretionary foredeep debris-flows & melange
Carbonate platforms
Munzur & Köseyahya (undifferentiated)
Granitoid intrusions
Metamorphics
D, Da, H, P
Divriği, Dağlıca, Hekimhan & Pınarbaşı ophiolites
Mu/K
Munzur & Köseyahya thrust sheets (undifferentiated)
Du
Dağlıca unit (ophiolitic debris mainly)
Ba
Baskil Granitoids (arc magmatism)
G
Göksun (N Berit) ophiolite
P
Pütürge (continental crust)
Ke, Pu, Da
Kemaliye Fm., Pelagic unit (Gülbahar nappe) & ophiolitic debris

Figure 31 Click here to access/download;Figure;Fig. 31 rev 30.jpg



AL	Alanya massif	KO	Kızıldağ ophiolite	P	Pütürge massif
AP	Arabian platform	JO	Jurassic ophiolite	SA	Southern allochthon
AT	Anatolide-Tauride block	K	Kırşehir block	SNT	South Neotethys
B	Baskil arc granitoids	L	Levant margin	NNT	North Neotethys
Bi	Bitlis massif	M	Malatya metamorphics	TK	Tavşanlı-Kırşehir block
BE	Berit ocean	ME	Mesogea	TO	Troodos ophiolite
BD	Bolkar Dağ	NA	Northern allochthon (Munzur)	Y	Yüksekova back-arc ocean
CO	Cretaceous ocean	NT	Neotethys		
GD	Geyik Dağ	O	Ophiolite (undiff.)		
IT	Inner Tauride ocean				

Lithology and location	**Radiolarians determined (with comments)**	**Age**
M13-175A Kırandere, near İncelik köy, Area 2. GPS: 0357348 4247428	Radiolarians represented especially by big spherical skeletons probably belonging to *Holocryptocanium barbui* Dumitrica	**Late Albian-Cenomanian**
M13-176A Kırandere, near İncelik köy, Area 2. GPS: 0357348 4247428	Sparse, poorly preserved. *Acaeniotyle diaphorogona* Foreman *Acaeniotyle umbilicata* (Rüst) *Dicerosaturnalis amissus* (Squinabol) (up to end-Aptian *Dictyomitra communis* (Squinabol), Aptian and earlier *Praeconocaryomma* sp. *Xitus spicularius* (Aliev) sensu O'Dogherty (1994)	**Aptian** (based on *Dicerosaturnalis amissus* (Squinabol) and *Dictyomitra communis* (according to O'Dogherty, 1994))
M13-177A Kırandere, near İncelik köy, Area 2 GPS: 0357348 4247428	Sparse, poorly preserved. *Acaeniotyle diaphorogona* Foreman *Acaeniotyle umbilicata* (Rüst) *Dicerosaturnalis amissus* (Squinabol), up to the end of Aptian *Dictyomitra communis* (Squinabol), Aptian and earlier *Praeconocaryomma* sp. *Xitus spicularius* (Aliev) sensu O'Dogherty (1994)	**Early Albian** (based on the first two species and the absence of *Dicerosaturnalis* (see O'Dogherty, 1994)).
M13-17A **Clast in debris flow;** Kabaktepe area; Area 3A, E of Elbistan GPS: 0363392 4240699	Rare, quite well preserved; low-diversity. *Cecrops septemporatus* (Parona) *Pantanellium* sp. *Williriedellum* cf. *carpathicum* Dumitrica (Rare sponge spicules include reniform sclerites)	**Late Valanginian – Hauterivian**
M13-112A 1 km E of Büyük Tatlı; Area 2; 300m from sample 111A GPS: 0325679 4262229	Abundant, diverse, well preserved (mostly silica-filled). *Archaeodictyomitra apiarium* (Rüst) *Archaeodictyomitra excellens* Tan *Archaeodictyomitra minoensis* (Mizutani) *Dicerosaturnalis trizonalis* (Rüst) (primitive forms) *Ditrabs sansalvadorensis* (Pessagno) *Emiluvia chica* Foreman *Emiluvia hopsoni* Pessagno *Hsuum arabicum* Dumitrica *Mirifusus dianae* (Karrer)	**Late Tithonian-Berriasian**

	1. *Tethysetta boesii* (Parona) *Mirifusus odoghertyi* Jud *Pantanellium tredecimporatum* (Rüst) *Triactoma tithonianum* Rüst	
M13-182B Büyük Tatlı; Area 2 GPS: 37 0324740 4263734	Common; some very well preserved. *Acaeniotyle umbilicata* (Rüst) *Archaeodictyomitra excellens* (Tan) *Archaeospongoprunum patricki* Jud *Dicerosaturnalis trizonalis* (Rüst) *Emiluvia chica* Foreman *Emiluvia pentaporata* Steiger & Steiger *Mirifusus dianae* (Karrer) *Pantanellium huazalingoense* Pessagno & McLeod *Praeconosphaera sphaeroconus* (Rüst) *Pyramispongia barmsteinensis* Steiger *Saitoum kapewinteri* Dumitrica & Zügel	**Late Kimmeridgian-early Tithonian**
M13-184A Büyük Tatlı;; Area 2 GPS: 37S 0324740 4263734	Radiolarians rather frequent but poorly preserved, represented especially by archaeodictyomitris and pseudodictyomitrids, most of them as inner casts; very rare Emiluvia and others.	Probably **late Jurassic**
M13-49A Near Yuksullu mezra; Area 4 (S of Elbistan); GPS: 37S 0347339 4225062	Abundant but very poorly preserved, with indistinct superficial ornamentation. (Spumellarians very rare). *Cinguloturris* cf. *carpatica* Dumitrica *Dicerosaturnalis dicranacanthos* (Squinabol) *Praeconosphaera sphaeroconus* (Rüst) *Pseudodictyomitra primitiva* Matsuoka & Yao *Transhsuum brevicostatum* (Ozvoldova)	**Kimmeridgian – early Tithonian**
M13-198A Near **Topaktaş** Tepe; Area 2 GPS: 37S 0299567 4263104	Very rare and very poorly preserved. *Podocapsa amphitreptera* Foreman *Triactoma* sp. *Xitus* sp.	**Late Oxfordian-Tithonian**
M13-193B Kayseri, near Hurman Kalesi; Area 2 GPS: (GPS: 37S 0369890 4333783) 0303387 4265316	Radiolarians common but very poorly preserved. *Emiluvia orea* Baumgartner *Mirifusus dianae* (Karrer)	**Late Oxfordian – Kimmeridgian**
M13-49B Near Yoksullu mezra; Area 4 (S of Elbistan);	Common; generally poorly or moderately preserved. *Emiluvia ordinaria* Ozvoldova *Emiluvia orea* Baumgartner *Parvicingula washitaensis* (Mizutani)	**Late Oxfordian**

GPS: 0347339 4225062	*Podocapsa amphitreptera* (Rüst) *Zhamoidellum ovum* Dumitrica	
M13-186A Büyük Tatlı; area; Area 2 GPS: 37S 0323561 4262607	Common, but poorly or very poorly preserved; some very well preserved including *Praewilliriedellum* sp. and some *Archaeodictyomitra* sp. or *Hsuum* sp. *Eucyrtidiellum unumaense* (Yao) *Cyrtocapsa mastoidea* Yao *Praewilliriedellum cephalospinosum* Kozur *Hexasaturnalis suboblongus* (Yao) *Hexasaturnalis tetraspinus* (Yao	**Bajocian**
M13-111A 1 km E of Büyük Tatlı; Area 2; GPS 37S 0325679 4262229	Common, relatively well preserved to very poorly preserved; sparse assemblage. *Hexasaturnalis hexagonus* (Yao) *Hexasaturnalis suboblongus* (Yao	**Bajocian**
M13-48A Near Yoksullu mezra; Area 4 (S of Elbistan); GPS: 37S 0347339 4225062	Abundant but very poorly preserved. *Acaeniotylopsis variatus triacanthus* Kito & De Wever *Hexasaturnalis suboblongus* (Yao) *Hexasaturnalis tetraspinus* (Yao) *Pantanellium sincerum* Pessagno & Blome	**Bajocian**
M13-47B Block in serpentinite; N of Yuksullu mezra; Area 4 (S of Elbistan); GPS: 37S 0346001 4225266	Very rare, poorly preserved, especially fragments of spines and saturnalids. *Betraccium* cf. *deweveri* Pessagno & Blome, late Norian *Deflandrecyrtium* cf. *nobense* Carter *Praemesosaturnalis* sp. A of Sugiyama (1997)	**Late Norian, *Betraccium deweveri* Zone**
ET-12-61 Yeşildere Melange, Hekimhan area. (GPS: 37S 0369890 4333783)	Radiolarians common but very poorly preserved, corroded. *Dorypyle* ? *anisa* (Squinabol) *Pseudodictyomitra pseudomacrocephala* (Squinabol) *Thanarla veneta* (Squinabol) *Xitus mclaughlini* Pessagno	**Late Albian – early Cenomanian**

Supplementary Fig. 1

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Supplementary Fig. 2

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Supplementary Material
18.5.21 sup fig 2 Tanir_map_sections1 copy.jpg

Supplementary Fig. 3

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Sup Fig. 3 Rev 5.4.jpg

Supplementary Fig. 4

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Sup. Pub Fig. 4REV 5.4.jpg

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6XSSOHPHQWDU\ )LJ

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6XSSOHPHQWDU\ )LJ

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6XSSOHPHQWDU\ )LJ

!!

6XSSOHPHQWDU\ 7DEOH

!!

'HFODUDWLRQ RI ,QWHUHVW 6WDWHPHQW

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/)*" +),+'0"+%1'0)&.+0%2"+%*3+#)*,$(#'+),+(*"'&".'+(*+.145("(*6+'0(.+7%+7"&+0"&"8

&UHGLW $XWKRU 6WDWHPHQW

!"#$%&'()&*+"',&(&#-#.'&
'
/*#'0%#1$2+"3'2(,'4(""%#$'+)&'567689':+;#"&,+.9'<6'=("1(3'(.$'/6'>,&(?-#"6'/*#'
š Œ u] v š] } v • } (o Œ } µ • (} • •] o • Á Œ Œ Œ] } µ Œ Ç < d •
:($%+1("%('2#"#'4(""%#$'+)&';@'=6'A)-%&"%4(6'514+()&'%";)&#$'&+'&*#'0%.(1'-(.),4"%B&6