Reply to the Discussion by Granier of Vincent et al. 2018 (Marine and Petroleum Geology, 91, 639-657)

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Abstract

Granier (2019a) questioned the identification of a number of foraminifer species within the study of Vincent et al. (2018). We dispute his findings and provide supporting evidence for our original identifications. Our biostratigraphic work was carried out to support a strontium isotope stratigraphy study of an Upper Jurassic – Lower Cretaceous carbonate succession in the eastern Pontides, Turkey. This was undertaken to constrain the age and duration of a number of hiatal surfaces that we proposed have geodynamic significance for the Black Sea region. Even if Granier's identifications are correct, they do not impact upon the conclusions of our study. Thus, rather than being a 'disappointing application of [a] geochemical tool', our study illustrates the utility of the powerful strontium isotope stratigraphy approach.

1. Background and general comments

Due to his interest in the biostratigraphy of the Jurassic-Cretaceous boundary (e.g. Granier, 2019b), we were delighted when Bruno Granier contacted us about our recently published study in Marine and Petroleum Geology (Vincent et al., 2018). He expressed a desire to carry out additional research on Dasyclad algae within the succession and we willingly loaned him

the thin section collection that underpinned our research, as well as additional hand specimens where these thin sections were missing. It came as a surprise, therefore, when this 'additional biostratigraphic study' evolved into (1) a polemic on the loss of biostratigraphic expertise, (2) a disparaging of the application of geochemical techniques in the geosciences and (3) an attack on the reputation of the biostratigrapher involved in our original study (Granier, 2019a). We shall briefly comment on the first two of these topics here, before turning to the more substantive third part of Granier's discussion.

(1) Marine and Petroleum Geology would seem to be an odd forum to rail against the loss of biostratigraphic expertise. Nevertheless, to counter his pessimism, we note that after the pioneers mentioned by Granier (e.g. Brönniman, Cushman, Cuvillier), many others have contributed extensively to the systematics and biostratigraphy of the Foraminifera including, for example, the late L. Hottinger, who was awarded a lifetime contribution to foraminiferal studies, and F. Banner who worked extensively on thin sections. There are also contemporary workers, such as R. Schroeder, A. Cherchi, A. Arnaud Vanneau, A., G. Less, E. Özcan, K. Drobne, J. Pignati, J. Hohenegger and many others, who have and are still contributing a vast amount of useful research on this group. Granier and others interested in the current vibrant state of research on the phylogenetic and biostratigraphic importance of the Foraminifera might usefully refer to BouDagher-Fadel (2015, 2018a,b).

(2) Whilst Granier (2019a), on a number of occasions, echoed the sentiments of Vincent et al. (2018) that 'the Sr-derived ages are much more precise than those provided by the foraminiferal ages alone', he went on to state 'but they also locally proved to be not consistent with the micropaleontological data [and are] hence wrong'. This drew him to reflect 'that this reminded him of previous disappointing applications of geochemical data'. These statements are sweeping, unjustified, and cannot be left unchallenged as they imply that the conclusions of our original work should be questioned. His disappointment would appear to be based solely on two Sr-derived ages at the top of our measured section (from samples PT09_21E_30 and 21E_32) that are younger than the one he derived by biostratigraphic means. Three points are worth noting in this regard. (i) We dispute his dismissal of our identification of *Debarina hahounerensis* Fourcade in sample PT09_21E_33, which is consistent with our Sr-derived ages (see section 2). (ii) Even if he is correct, the Sr-derived age for the younger of the two samples (PT09_21E_32) might still be consistent with his age determination because two ages are possible given its Sr value (see section 3). (iii) In any case, we clearly state in our strontium isotope stratigraphy (SIS) results (section 6.2.2 of

2

Vincent et al., 2018) with regard to these two samples that 'its exact age should be treated with caution' and 'the age of this sample should be treated with caution', respectively. Our transparent discussion of the quality and reliably of our data would seem to have been ignored by Granier (2019a) to suit his anti-geochemical bias. From a geochemical standpoint, we are entirely relaxed if the age of the top of the section is reassigned. It would make no material difference to the conclusions of our original study (see section 3).

2. Alleged Foraminifera misidentifications

We thank Granier (2019a) for highlighting our mislabelling of the forms A and B in Figure 7.1. The caption to Figure 7.1A should read *Vercorsella arenata* Arnaud-Vanneau and Figure 7.1B, *Debarina hahounerensis* Fourcade. Granier also pointed out the 'huge discrepancy with the age ascription of …. [sample] PT09_21E_15 [that] is said to be "? Kimmeridgian-Tithonian"' with other data. We were aware of this discrepancy and had taken it into account by adding the note 'maybe reworked' to Table 2 of Vincent et al. (2018), and by not including this biostratigraphic age range to our Figure 4. Lastly, Granier (2019a) highlighted two references to biostratigraphic studies on the Kırcaova section (PT09_21E) in the eastern Pontides (Bucur et al., 2004; Bucur et al., 2000) that we did not cite. Given that Ioan Bucur contributed to the later Koch et al. (2008) paper, which we extensively cited, we felt that this was unnecessary, but we are happy to draw attention to these contributions here.

Granier (2019a) felt that many of the foraminifera illustrated in Figure 7 of Vincent et al. (2018) from section PT09_21 in the eastern Pontides had been misidentified. The original identifications and his reinterpretations, many of which are considered indeterminate, are given in the captions to his figures 1 and 2 as well as in his sections 2.1.1 and 2.1.2. We contest his conclusions and illustrate some of the key diagnostic features that support our original interpretations below. We do this in the same order as in Figure 7 of Vincent et al. (2018) and figures 1 and 2 of Granier (2019a).

Figures 7.1A, 7.4 and 7.5 – This form, *Vercorsella arenata*, was reinterpreted as indeterminate by Granier (2019a). However, Figure 1 illustrates oblique horizontal sections with less well developed horizontal partitions in later chambers, this being typical of *Vercorsella.*

Figures 7.1B and 7.3 - These figures depicted oblique sections through *Debarina hahounerensis* Fourcade. The diagnostic features of this form are illustrated more fully in

Figure 2. They include the canaliculate walls, possible initial streptospirality and the cribrate aperture. Granier (2019a) dismissed the illustrated forms as being indeterminate.

Figure 7.2 – Granier (2019a) agreed with the identification of *Pseudolituonella* but he named it *Pseudolituonella* sp. instead of recognising the species as *P. gavonensis* Foury as depicted in this figure.

Figures 7.6 and 7.9B – These figures depicted *Praechrysalidina infracretacea* Luperto Sinn. Figure 7.6 is reproduced here (as Figure 3a), along with another example from the same sample (sample PT09_21E_27; Figure 3b). Both show the diagnostic triserial test of this form with an absence of internal pillars. Granier (2019a) dismissed these as being indeterminate.

Figures 7.7, 7.8B and 7.9 – This form, *Andersenolina elongata* (Leupold), was reinterpreted as cf. *Coscinoconus elongatus* (Leupold) by Granier (2019a). This is not the case as the outer wall of *Coscinoconus* is thin (usually much thinner than the spiral septum, and often eroded), imperforate, and lacks the perforated umbilical plate visible in Vincent et al. (2018, Fig. 7.7). Instead, this typically elongated high conical form tends to be parallel sided with the spherical proloculus followed by a tubular, trochospiral second chamber. It is typical of *A. elongata* (see BouDagher-Fadel, 2018a).

Figure 7.8A - This form, *Cuneolina camposaurii* Sartoni and Crescenti, was not seen by Granier (2019a), however, he reinterpreted all *Cuneolina* as belonging to the genus *Scythiolina* spp. (Leupold). The latter resembles *Cuneolina* d'Orbigny in the flattened shape of the test and in the structure of the wall. It differs by possessing a planispiral early stage, by its reduced size, and by the absence of horizontal partitions, which are clearly present in *Cuneolina compausorii*. Therefore, lumping this species with the *Scythiolina* sp. (Leupold) is incorrect.

Figures 7.10 - This form, *Pseudocyclammina lituus* (Yokoyama), was reinterpreted as *Strepocyclammina* gr. *parvula-muluchensis* Hottinger by Granier (2019a). However, Granier is mistaken as the streptospirality of the latter readily distinguishes it from *Pseudocyclammina*. This is illustrated in Figure 4 where, in this oblique cut, the early coils of *Pseudocyclammina lituus* (Yokoyama) are not streptospiral and the rest of the features are typical of this genus.

Figures 7.11 and 7.12 - We have realised that the form in Figure 7.11 was mislabelled as *Pseudocyclammina lituus* (Yokoyama) and should read *Rectocyclammina chouberti* Hottinger. This form was reinterpreted as an indeterminate Lituolid by Granier (2019a). This is not correct. Figure 5 shows an elongate rectilinear test with a broken early stage, thick

septa and a single internally thickened aperture. The septa in the latest part of the test are broken, but the single areal aperture typical of *Rectocyclammina* is clearly seen throughout the test.

Figures 7.13 and 7.14 - This form, *Alveosepta jaccardi* (Schrodt), was reinterpreted as *Strepocyclammina* gr. *parvula-muluchensis* Hottinger by Granier (2019a). However, Granier is mistaken as unlike A*. jaccardi, Streptocyclammina* gr. has a low streptospiral test (not planispiral as seen here in Figure 6) and an empty central zone, lacking pillars/extension of median beams.

Figure 7.15 - This form, *Pseudocyclammina* sp*.*, was also reinterpreted as *Strepocyclammina* gr. *parvula-muluchensis* Hottinger by Granier (2019a). The latter is a heavily agglutinated form and only the streptospirality readily distinguishes it from *Pseudocyclammina*. As is apparent in the original figure, the early coils are not streptospiral, but the section is oblique and randomly cut, and the rest of the features are of a typical *Pseudocyclammina* sp.

Figure 7.16 - This form, *Mesoendothyra* sp., was reinterpreted as a possible gastropod shell by Granier (2019a). Although the form originally illustrated by Vincent et al. (2018) is poorly preserved and is an oblique cut that only partially shows its spires, the partially preserved imperforate outer layer of the wall and the thin inner alveolar layer are characteristic of *Mesoendothyra* (Figure 7).

Granier (2019a) also did not recognise some of the forms that we identified and listed in Table 4 of Vincent et al. (2018) from section PT09_17 in the central Pontides. He specifically highlighted the absence of *Pseudocyclammina lituus*, *Actinoporella podolica*, *Triploporella* spp. and *Paleodasyclads* sp. Rather than contest every identification claimed by Granier (2019a) we instead focus on key (mis)identifications, which are the basis of his critique of the dating presented in Vincent et al. (2018). According to Granier (2019a) 'At the locality PT09_17, the classical Jurassic markers such as *Clypeina sulcata* (Alth), *Alveosepta jaccardi* (Schrodt) or *Anchispirocyclina lusitanica* (Egger) have not been found. However, the algal assemblage pleads for a late Kimmeridgian to Tithonian age. BouDagher-Fadel reached almost the same conclusion (Vincent *et al.*, 2018, Table 4), but on the basis of wrong identifications.' Whilst it is true that the classic markers he listed were not found, our identifications are correct and provide robust age control, despite not being picked up by Granier (2019a). These markers were not illustrated in Vincent et al. (2018) but were almost all listed in our Table 4. The presence at locality PT09_17 of *Pseudocyclammina bukowiensis*

5

(Bajocian-Kimmeridgian, Figure 8) and *Pseudocyclammina lituus* (Kimmeridgian – Barremian) in sample PT09_17_04 indicate a Kimmeridgian age (see BouDagher-Fadel, 2018a). Additionally, the combination of *Everticyclammina praekelleri* (Kimmeridgian-Tithonian, Figure 9a) and *Pseudocyclammina lituus* (Kimmeridgian – Barremian, Figure 9b) in overlying sample PT09_17_06 indicate that the succession may also range up into the Tithonian as originally stated. The top of this section is Early Berriasian in age as determined by our SIS data (Vincent et al., 2018). In summary, we conclude that the ages presented in Vincent et al. (2018) are correct, as documented by the foraminiferal forms identified and explained above.

3. Implications

We have plotted the age ranges of the forms Granier (2019a) reported on Figure 10, alongside our original biostratigraphic findings. We have also replotted the age range of the stratigraphy as defined by the SIS data alone. Both foraminiferal studies are broadly compatible with the SIS data. If correct, there are two places where the biostratigraphic data of Granier (2019a) affect our interpretation of the age of the Kırcaova section (PT09_21): at the very base and top of the section (Figure 10).

At the base of the section, Granier (2019a) suggested that the strata are Kimmeridgian in age, in contrast to Vincent et al. (2018) whose biostratigraphic data suggested an age somewhere in the Bathonian to Oxfordian. Both are compatible with the SIS data. An inflection in the marine Sr-isotope curve means that two ages are possible, with the younger Late Oxfordian to Early Kimmeridgian age being more likely.

At the top of the section, sample PT09_21E_32 has a Sr value close to another inflection in the marine Sr-isotope curve making intra-Hauterivian and Late Barremian to earliest Aptian ages possible. In Vincent et al. (2018) we opted for the younger of these ages due to the presence of *Debarina hahounerensis* in an immediately overlying sample that indicates a Late Barremian age. Alternatively, Granier (2019a) identified *Montsalevia* gr. *salevensis* and, although he stated that its LO is unknown, variously inferred 'an Early Hauterivian' and 'a no younger than Hauterivian' age for samples PT09_21E_27-33 based on the presence of this form. This is compatible with the older of the two possible Sr-derived ages for sample PT09_21E_32. However, if correct, this would imply that the Sr values of the underlying sample PT09_21E_30 are erroneous. This is perfectly possible given that, as pointed out

earlier, the Sr values and therefore ages of both samples PT09_21E_30 & 32 need to be treated with caution due to possible diagenetic overprinting.

If the older intra-Hauterivian Sr-derived age for the top of the section were adopted, this would imply that the hiatus associated with erosion surface D is restricted to the Hauterivian rather than to the Late Hauterivian to Early Barremian as originally stated (Figure 10). This is the only occasion where Granier's reinterpretation of foraminiferal species might materially affect the study of Vincent et al. (2018), given that its focus was to constrain the age and duration of the hiatuses within the Berdiga Formation in the eastern Pontides.

When considering the duration of the hiatuses identified in the Kırcaova section, it is also worth noting that Granier (2019a) asserted in his abstract that 'the major stratigraphic gap [erosion surface A] possibly corresponds to the Berriasian' and went further in one of his online highlights by stating that 'the oldest transgressive deposits above the subaerial exposure surface are Valanginian in age, not Berriasian'. However, he presented no biostratigraphic evidence to support these claims. His oldest (Valanginian) biostratigraphic determination is ~120 m above erosion surface A (Figure 10). There is no biostratigraphic control for strata below this. However, our SIS results indicate that at least the latest and possibly all of the Berriasian is present within the incised valley immediately above erosion surface A (Figure 10). We therefore reject Granier's attempts to redefine the duration of this hiatus.

In conclusion, the only occasion where Granier's reinterpretation of foraminiferal species might materially affect the study of Vincent et al. (2018) is in restricting the duration of the hiatus associated with erosion surface D from the Late Hauterivian to Early Barremian to the Hauterivian. Either age range is compatible with the SIS data and the wider conclusions of Vincent et al. (2018). They both fall within a longer interval of widespread discontinuous sedimentation around the Black Sea region in the Early Cretaceous and within a Hauterivian to Early Aptian interval of increased subsidence in the Greater Caucasus Basin (see Figure 9 of Vincent et al., 2018). Vincent et al. (2018) linked these features and postulated that the generation of this, and earlier, hiatuses might be driven by rift flank uplift during episodes of regional extension. Elsewhere around the Black Sea, Late Jurassic and Early Cretaceous hiatus formation is associated with platform carbonate karstification and this led us to speculate that similar reservoir-enhancing features might be developed on the rift shoulders of the intervening Eastern Black Sea.

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Figures
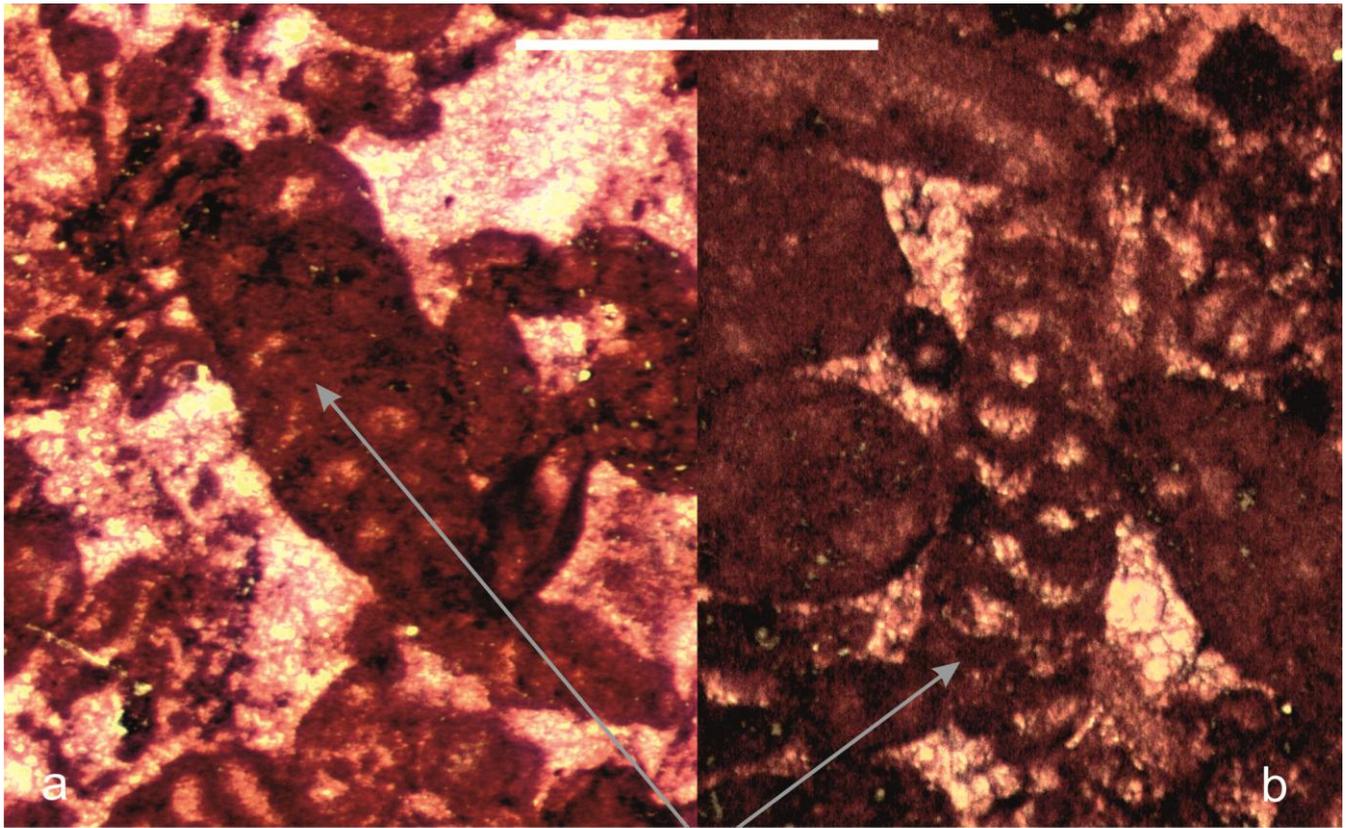
Horizontal partitions less well developed in later chambers

Figure 1. *Vercorsella arenata* Arnaud-Vanneau, sample PT09_21E_33. Scale bar = 1mm. Oblique horizontal sections illustrated by Vincent et al. (2018) as (a) Figure 7.4 and (b) Figure 7.1A. Both specimens lack well-developed horizontal partitions.

Aperture cribrate at base of apertural face

Planispiral

Possibly streptospiral

Canaliculate walls
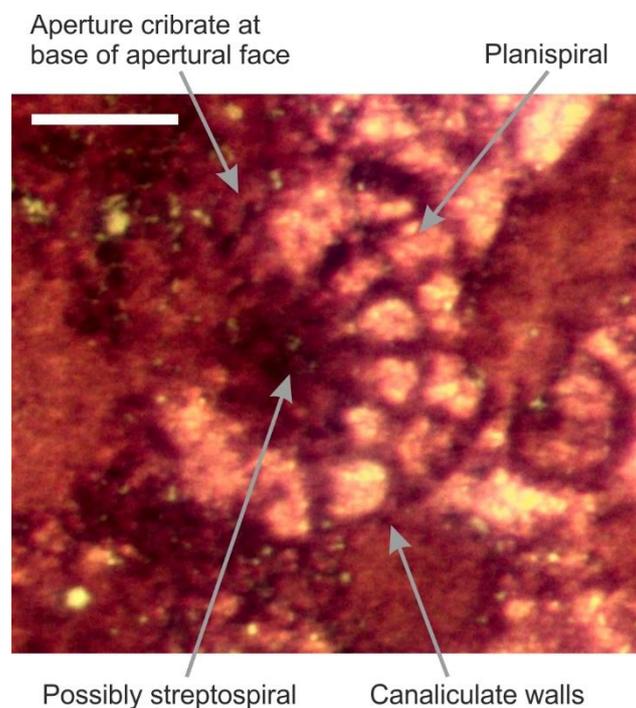
Figure 2. An oblique equatorial section of *Debarina hahounerensis* Fourcade with its key morphological features labelled. This sample, PT09_21E_33, was illustrated by Vincent et al. (2018) as Figure 7.3. Scale bar = 0.15 mm.
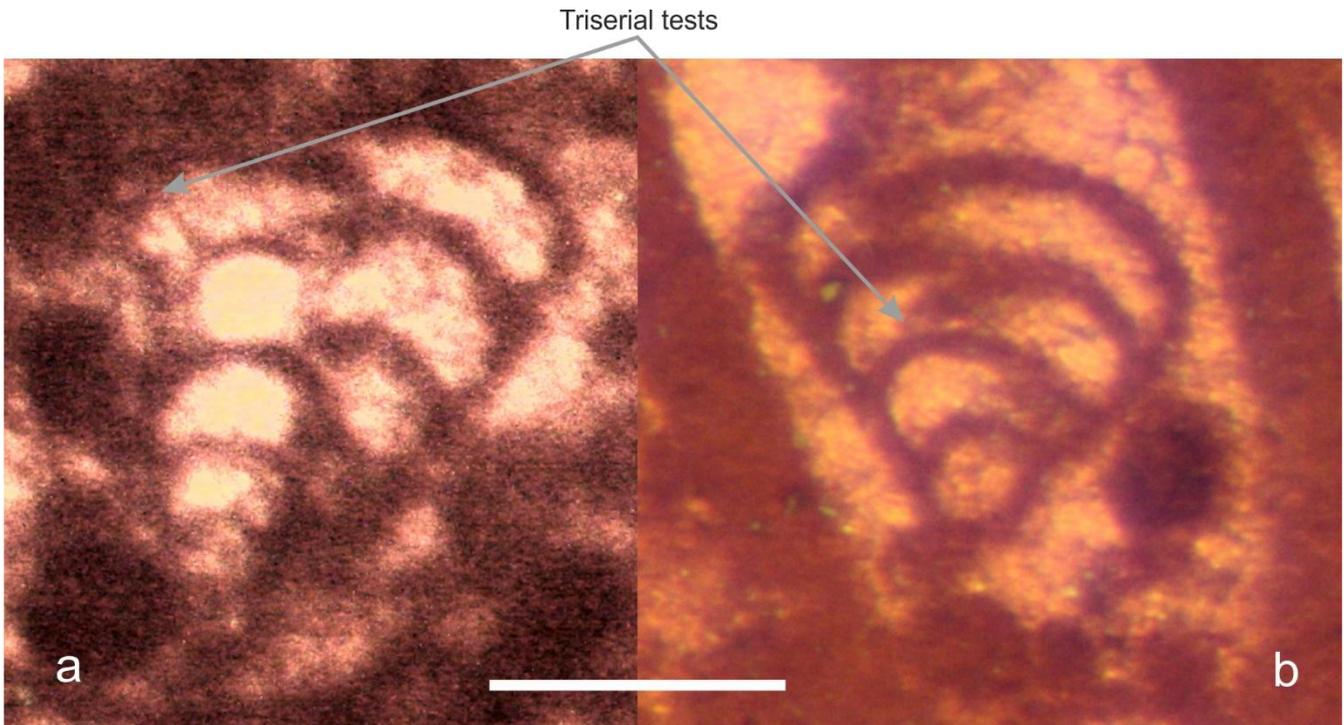
Figure 3. Oblique sections through *Praechrysalidina infracretacea* Luperto Sinni showing the characteristic triserial chambers with no internal pillars; (a) was illustrated by Vincent et al. (2018) as Figure 7.6, (b) is another specimen from the same sample showing the triserial chambers more clearly. Sample PT09_21E_27. Scale bar = 0.5 mm.
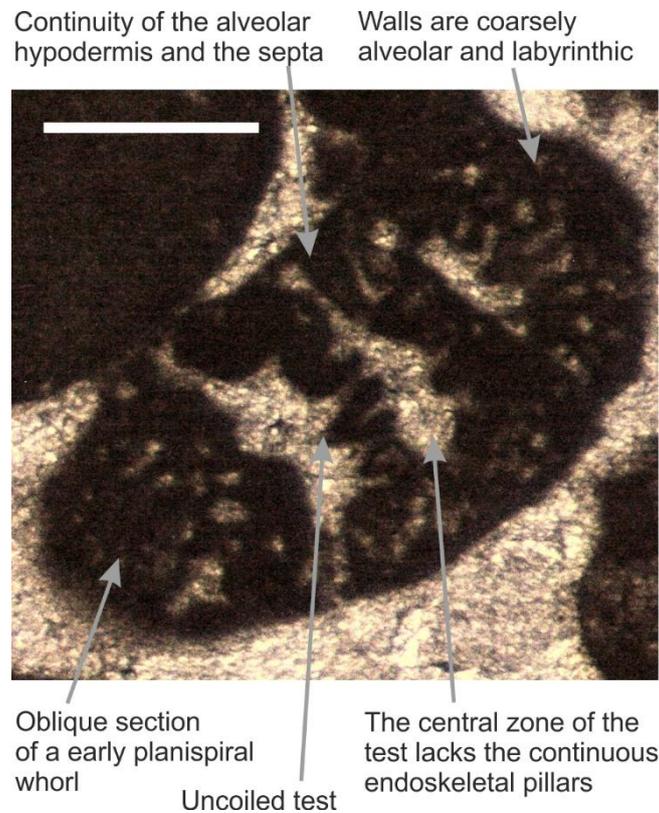
Figure 4. An oblique axial section of *Pseudocyclammina lituus* (Yokoyama), sample PT09_21E_02, illustrated by Vincent et al. (2018) as Figure 7.10. Scale bar = 0.5 mm. Note the rectilinear terminal chambers that is rare in this species but common in *P. vasconica.* However, the later has a smaller test size and a less complexly alveolar wall.
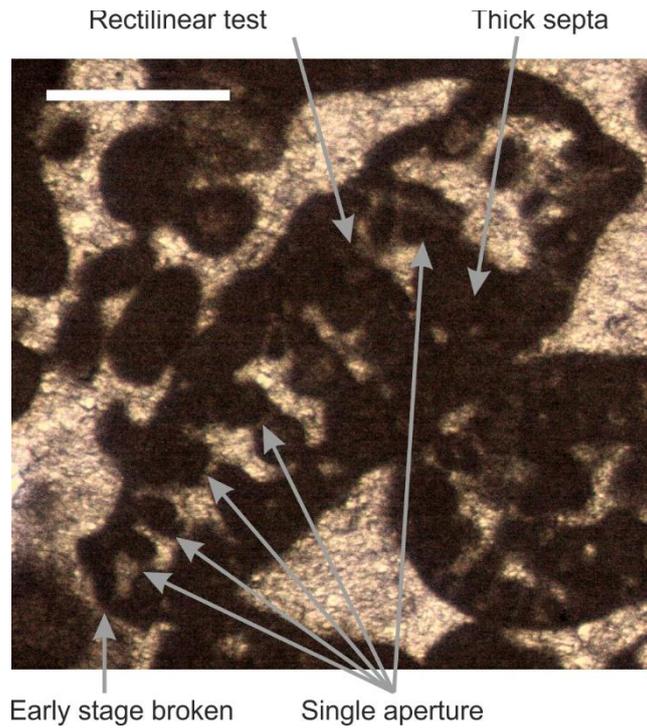
Figure 5. Oblique axial sections of *Rectocyclammina chouberti* Hottinger, sample PT09_21E_02. Scale bar = 0.5 mm. This specimen was illustrated by Vincent of al. (2018) as Figure 7.11.
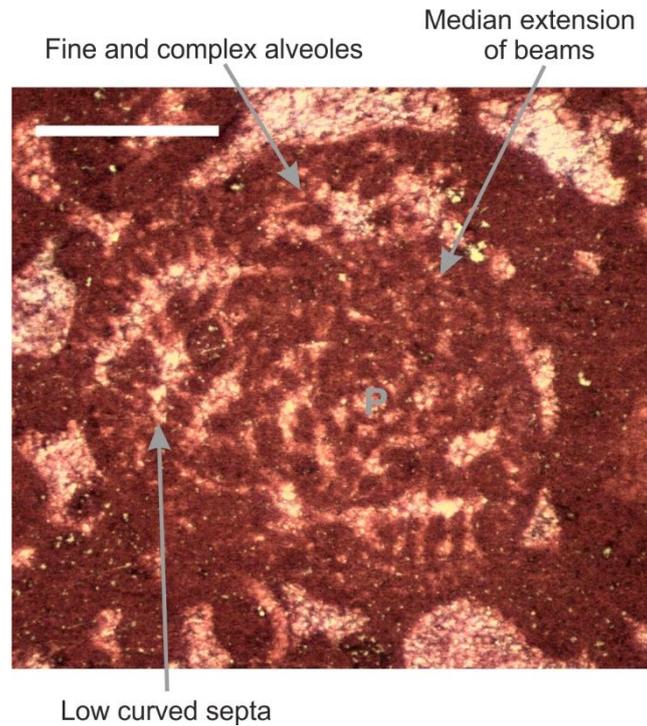
Figure 6. A megalospheric planispiral form of *Alveosepta jaccardi* (Schrodt), sample PT09_21E_02, illustrated by Vincent et al. (2018) as Figure 7.14. Scale bar = 0.5 mm. P = Protoconch.
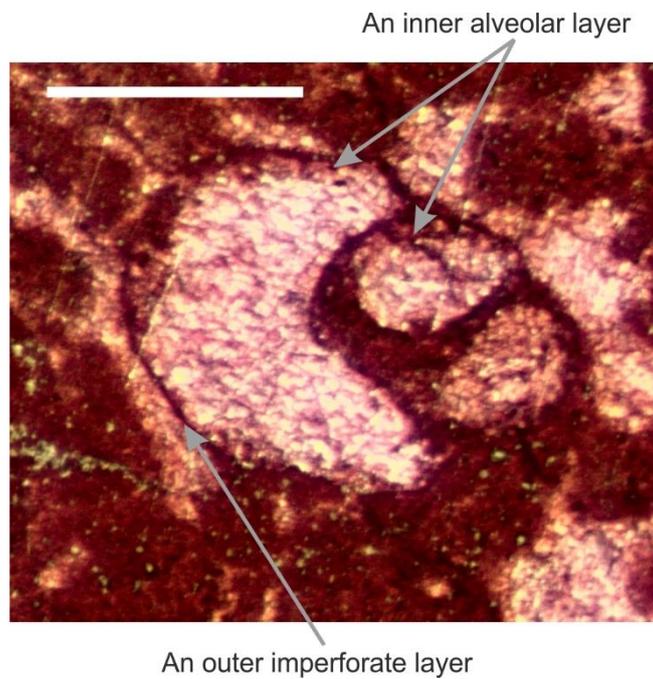
Figure 7. An oblique equatorial section of *Mesoendothyra* sp. with diagenetically altered test, sample PT09_21E_02, illustrated by Vincent et al. (2018) as Figure 7.16. Scale bar = 0.5 mm.
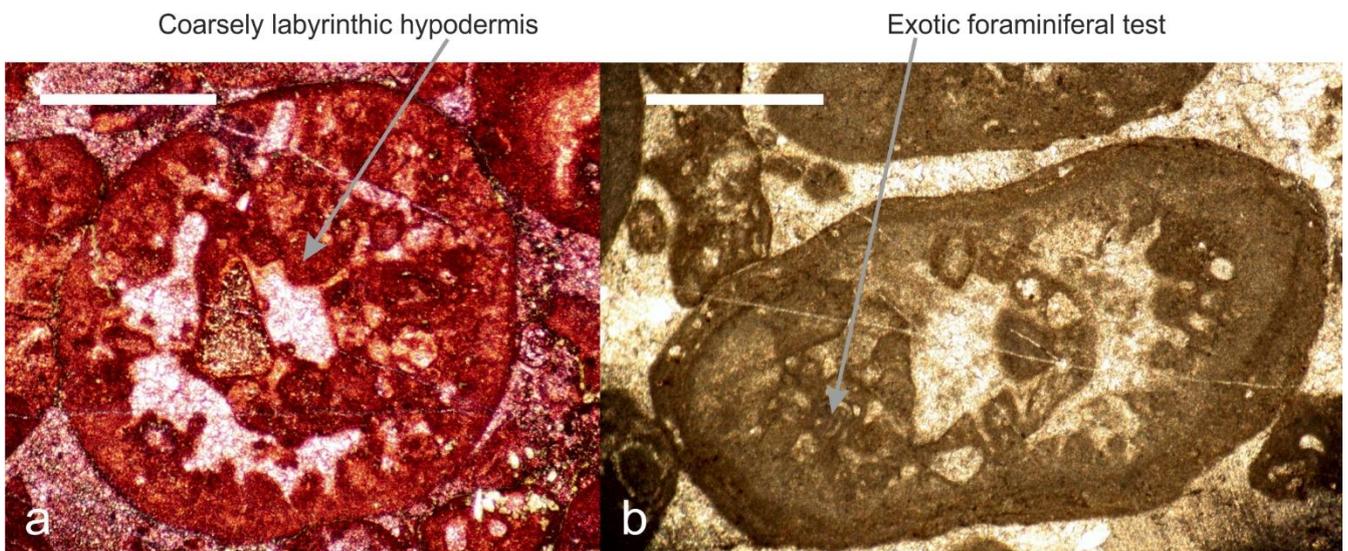
Figure 8. *Pseudocyclammina bukowiensis* (Cushman and Glaz.), sample PT09_17_04, scale bar = 0.5 mm. (a) Oblique equatorial section, (b) oblique axial section. This species has simpler walls but is more heavily labyrinthic and agglutinating than *P. lituus* (Figure 9b). Exotic foraminiferal tests are also illustrated.
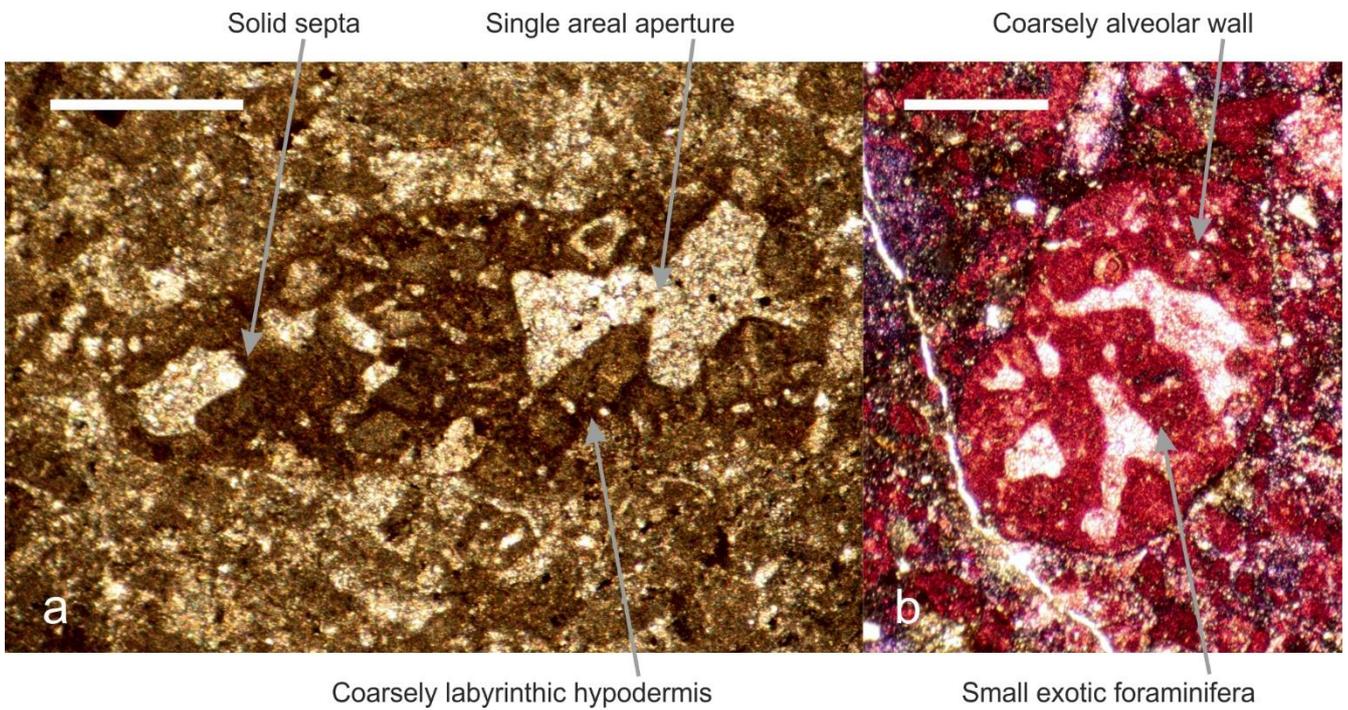
Figure 9. (a) *Everticyclammina praekelleri* Banner and Highton, equatorial section. Note the coarsely labyrinthic hypodermis and the single areal aperture. (b) *Pseudocyclammina lituus* (Yokoyama), oblique equatorial section showing the alveolar wall and continuity of the labyrinthic/alveolar hypodermis and the septa in the rectilinear terminal chambers. Small exotic foraminifera are included in the labyrinthic part of the hypodermis. Sample PT09_17_6, scale bar = 0.5 mm.
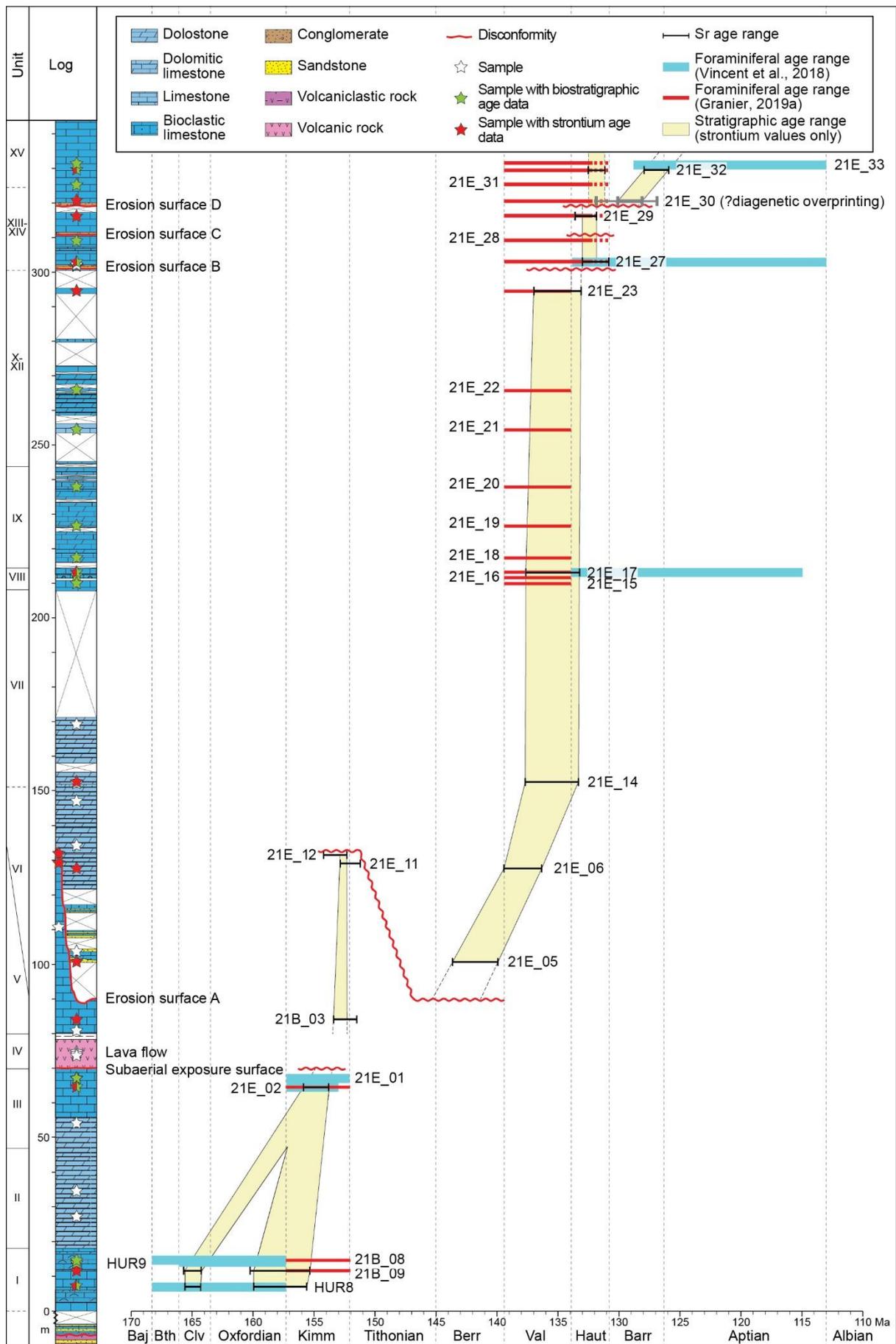
Figure 10. Summary stratigraphy of locality PT09_21 in the Eastern Pontides showing the main facies, the key erosional / subaerially exposed surfaces and the strontium isotope stratigraphy (SIS) age ranges. The SIS age uncertainties include both the analytical error (2σ) and the uncertainty on the seawater curve. This has been

adapted from Figure 4 of Vincent et al. (2018) to include the *in situ* foraminiferal age ranges from the original work (blue) and those from Granier (2019a) (red), and to amend the stratigraphic age range uncertainty so that it is based on the SIS data alone. Note how the age data from both the foraminiferal studies, with the possible exception of sample PT09_21E_30, are compatible with the SIS results. The stage boundaries are from Gradstein et al. (2012). Note, the prefix PT09_ has been omitted from the sample nomenclature for the sake of brevity.