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Ceratolithus acutus Gartner and Bukry 1974 (= *C. armatus* Müller 1974), calcareous nannofossil marker of the marine reflooding that terminated the Messinian salinity crisis: Comment on "*Paratethyan ostracods in the Spanish Lago-Mare: More evidence for interbasinal exchange at high Mediterranean sea level*" by Stoica et al., 2016. Palaeogeogr., Palaeoclimatol., Palaeoecol. 441, 854–870

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ABSTRACT

The calcareous nannofossil *Ceratolithus acutus* (= *C. armatus*) is an important species associated with the final flooding that ended the Messinian Salinity Crisis in the Mediterranean. We emphasize its robust identifying features and stratigraphic value in the global ocean. This species is particularly useful in recognising and constraining the Messinian–Zanclean boundary in the Mediterranean, as evidenced by reports from 75 localities and 20 references in addition to our own papers. Our emphasis is prompted by the assessment of Stoica et al. (2016) that *Ceratolithus acutus* is a "dubious" species with its lowest occurrence an "unreliable" biostratigraphic event. Such assessments by non-specialists, especially when "supported" by selective referencing of the literature warrant an explanation.

1. Introduction

In recent years great advances have been made in understanding the Messinian Salinity Crisis which affected the Mediterranean domain. The integration of preexisting and new datasets has facilitated an unprecedented degree of detail in the chronostratigraphic assessment of the crisis. At this stage, further refinement is achievable only if there is a consistent and rigorous application of analytical best practices as well as a thorough and unbiased integration of all available investigated tools. This Comment deals with one specific aspect of a paper by Stoica et al. (2016) which has wide-ranging implications for the overall understanding of the Messinian Salinity Crisis.

In their paper, Stoica et al. (2016, p. 868) state that: "In the seismic profiles, the Lago-Mare may consequently have been confused with the Pliocene, especially since in some cases unreliable biostratigraphic events (especially the dubious nannofossil *Ceratolithus acutus*) are used to determine the Messinian–Zanclean boundary in the deep Mediterranean basins (Clauzon et al., 2005; Popescu et al., 2015)". Such a bald statement requires clarification as it has important implications for the correct chronostratigraphic interpretation of the Messinian Salinity Crisis.

These authors, without justification, qualify the lowest occurrence of the calcareous nannofossil species *C. acutus* as an "unreliable" biostratigraphic event, even though specialists of calcareous nannoplankton have established and repeated its global reliability to characterize the Messinian–Zanclean boundary (Bukry, 1973a, 1975; Haq et al., 1980; Okada and Bukry, 1980; Perch-Nielsen, 1985; Young, 1998; Raffi et al., 1998, 2006; Anthonissen, 2009; Zeeden et al., 2013).

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In particular, Stoica et al. (2016) consider *C. acutus* as "dubious", but again without justification. This is particularly mystifying because numerous micropalaeontologists have identified this species in the Mediterranean (see Fig. 1 and references therein). On what grounds is *C. acutus* "dubious" and why is its record an "unreliable stratigraphic event"? No explanations are offered by these authors, none of whom is a calcareous nannoplankton specialist. We hope our comment will prompt the authors to offer concrete evidence in support of their skepticism.

To give credence to the supposed unreliability of *C. acutus* as a marker of the Messinian–Zanclean boundary, Stoica et al. (2016) quote two references: Clauzon et al. (2005) and Popescu et al. (2015). This selective choice of references must be set against a plethora of publications where the presence of *C. acutus* has been evidenced in numerous Mediterranean locations (Fig. 1). Unfortunately, Stoica et al. (2016) do not explain their specific predilection. In addition, the reference to Clauzon et al. (2005) is misleading because the paper (1) does not concern the deep Mediterranean basins and (2) contains no record of *C. acutus*, except to mention the findings of Snel et al. (2006b).

2. Identification of *Ceratolithus armatus* Müller 1974 — *C. acutus* Gartner and Bukry 1974

Ceratolithus armatus was originally described by Müller (1974) from the southwestern Indian Ocean (DSDP Site 242) as follows: "This species has a relatively narrow arch connecting two arms which are distinctly curved. One of them is a little longer than the other. Both arms are distinguished by a row of long teeth. One of these rows is elongated to the apex. The convex side of the curvature is developed deltoid. In polarized light, this species shows a distinct birefringence". Two months later, Gartner and Bukry (1974) described *C. acutus* from the eastern Indian Ocean (DSDP Site 214) as "a robust species with unequal horns and a broad but pronounced apical spine and apical structure". *C. acutus* is highly birefringent in crossed nicols. Specimens are brightest when the horns are at about 45° in crossed nicols and go to extinction when the horns are parallel to the direction of polarization" (Gartner and Bukry, 1975). This description of *C. acutus* is fully accepted by Perch-Nielsen (1985), who specifies that "the species has unequal or almost equal horns and a blunt apical spine terminating in an

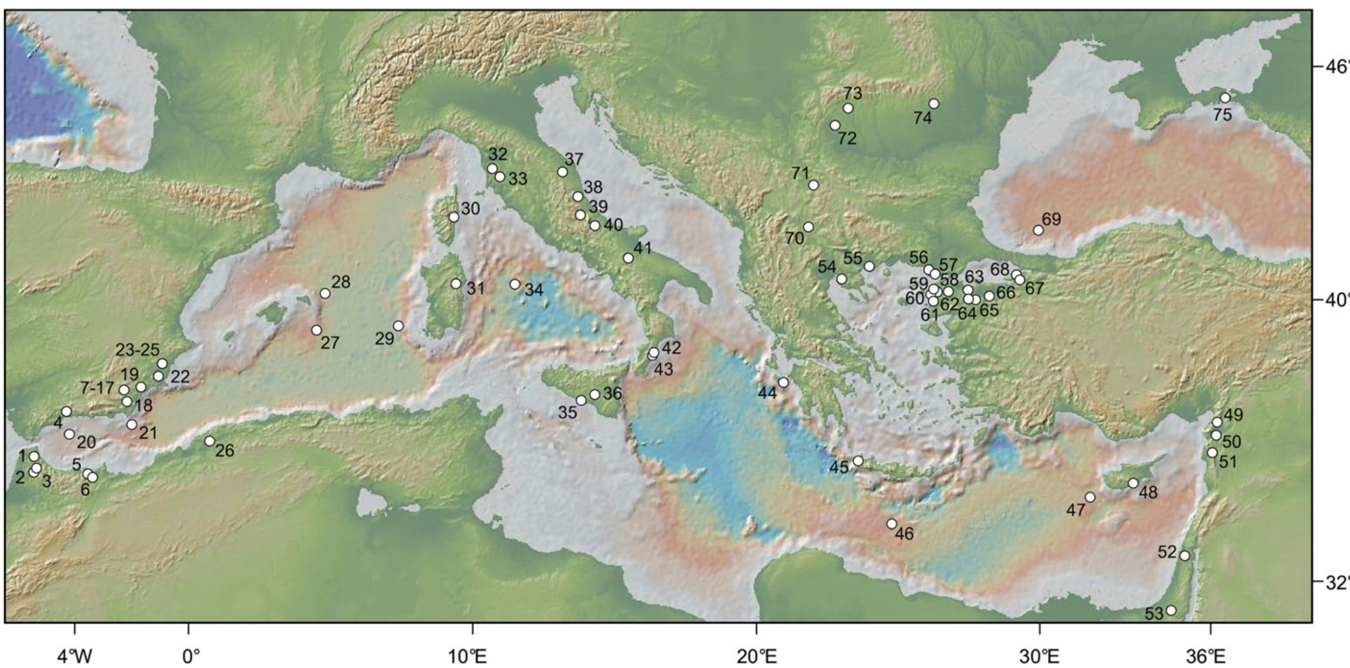

Fig. 1. Localities with *Ceratolithus acutus* in the Mediterranean region *s.l.* 1, Tetouan (Cornée et al., 2014); 2, Ibourouhene, Oued Laou (Cornée et al., 2014); 3, Tirinesse, Oued Laou (Cornée et al., 2014; Do Couto, 2014: data from M.C. Melinte-Dobrinescu); 4, Río Mendelín, Malaga (Do Couto et al., 2014); 5, Aït Abdallah, Boudinar (Cornée et al., 2016); 6, Megzyat, Boudinar (Cornée et al., 2016); 7, Cuesta de Cariatiz, Sorbas (Clauzon et al., 2015); 8, Moras, Sorbas (Clauzon et al., 2015); 9, Cortijo de Hoyo, Sorbas (Clauzon et al., 2015); 10, Cerro de Juan Contrera, Sorbas (Clauzon et al., 2015); 11, Barranco del Infierno, Sorbas (Clauzon et al., 2015); 12, Panorama Viewpoint, Sorbas (Clauzon et al., 2015); 13, Cortijo de Paco el Americano, Sorbas (Clauzon et al., 2015); 14, Hostal Sorbas, Sorbas (Clauzon et al., 2015); 15, Cortijo Marchalien la Gorda, Sorbas (Clauzon et al., 2015); 16, La Cumbre, Sorbas (Clauzon et al., 2015); 17, Torcales del Pocico, Sorbas (Clauzon et al., 2015); 18, Gafares, Níjar Basin (Do Couto et al., 2014); 19, Garapancho, Vera Basin (unpublished data from M.C. Melinte-Dobrinescu); 20, ODP Site 976 (Popescu et al., 2015); 21, ODP Site 978 (Popescu et al., 2015); 22, Cabezzo del Moro, Orihuela (Lancis and Flores, 2007); 23, La Pedrera, Bajo Segura (Soria et al., 2008; Lancis et al., 2015); 24, Dehesa de Pino Hermoso, Bajo Segura (Lancis et al., 2015); 25, Pantano de Elche, Bajo Segura (Lancis et al., 2015); 26, Télégraphe de Sidi Brahim, Chelif (unpublished data from M.H. Mansouri); 27, ODP Site 975 (Di Stefano, 2010); 28, DSDP Site 372 (Müller, 1978); 29, DSDP Site 134 (Popescu et al., 2015); 30, Casabianda, Aleria (Popescu et al., 2009); 31, Onifai, Orosei (unpublished data from M.C. Melinte-Dobrinescu); 32, Cava Serredi, Livorno (Popescu et al., 2009); 33, San Ippolito, Pomarance (unpublished data from M.C. Melinte-Dobrinescu); 34, DSDP Site 132 (Bukry, 1973b); 35, Capo Rossello, Agrigento (Cita and Gartner, 1973; Rio et al., 1976; Ellis and Lohman, 1979); 36, Pasquasia, Caltanissetta (Rio et al., 1976); 37, Maccarone, Apiro (Popescu et al., 2007, 2008); 38, Civitella del Tronto (Brozzetti et al. in press; unpublished data from M.C. Melinte-Dobrinescu); 39, San Nicolao, Maiella Mountain (Crescenti et al., 2002); 40, Fonte dei Pulcini, Maiella Mountain (unpublished data from M.C. Melinte-Dobrinescu); 41, Lacedonia (unpublished data from M.C. Melinte-Dobrinescu); 42, Guardavalle bridge (unpublished data from M.C. Melinte-Dobrinescu); 43, Caulonia (unpublished data from M.C. Melinte-Dobrinescu); 44, Kalamaki, Zakynthos (Karakitsios et al., 2016); 45, Platanos, Crete (Keupp and Bellas, 2000); 46, ODP Site 969 (Castradori, 1998); 47, Site DSDP 375 (Ellis and Lohman, 1979); 48, Psematismenos, Cyprus (unpublished data from M.C. Melinte-Dobrinescu); 49, Kıcı (unpublished data from M.C. Melinte-Dobrinescu); 50, Toprakhisar (unpublished data from M.C. Melinte-Dobrinescu); 51, Ghmam, Lattaquié (unpublished data from M.C. Melinte-Dobrinescu); 52, Nesher Quarry, Haifa (Zilberman et al., 2010); 53, Borehole SH13, Beer Sheva (unpublished data from M.C. Melinte-Dobrinescu); 54, Trilophos (Suc et al., 2015); 55, Akropotamos (Snel et al., 2006a); 56, Enez (Melinte-Dobrinescu et al., 2009); 57, Yaylaköy (Melinte-Dobrinescu et al., 2009); 58, Kilitbahir (Melinte-Dobrinescu et al., 2009) and Melekhanim (unpublished data from M.C. Melinte-Dobrinescu); 59, Sonok and Nuriyamut Abidaal (Karakaş, 2013: data from M.C. Melinte-Dobrinescu); 60, Seddülbahir (Melinte-Dobrinescu et al., 2009); 61, Intepe (Melinte-Dobrinescu et al., 2009); 62, Umurbey (unpublished data from M.C. Melinte-Dobrinescu); 63, Misakça (unpublished data from M.C. Melinte-Dobrinescu); 64, Muratlar (unpublished data from M.C. Melinte-Dobrinescu); 65, Haciveliobasi (unpublished data from M.C. Melinte-Dobrinescu); 66, Muradiye (unpublished data from M.C. Melinte-Dobrinescu); 67, Soguçak (unpublished data from M.C. Melinte-Dobrinescu); 68, Samanh and Koruköy (unpublished data from M.C. Melinte-Dobrinescu); 69, DSDP Site 380 (Popescu et al., 2010, 2016); 70, Batinci, Skopje (Bache et al., 2012; Suc et al., 2015); 71, Gabrovačka Reka, Niš (Bache et al., 2012; Suc et al., 2015); 72, Hinova (Suc et al., 2011, 2015); 73, Ticleni (Drivaliari et al., 1999); 74, Valea Vacii (Snel et al., 2006b); 75, Kertch – Taman (Semenenko and Olejnik, 1995). The map has been elaborated using GeoMapApp©System developed by Ryan et al. (2009).

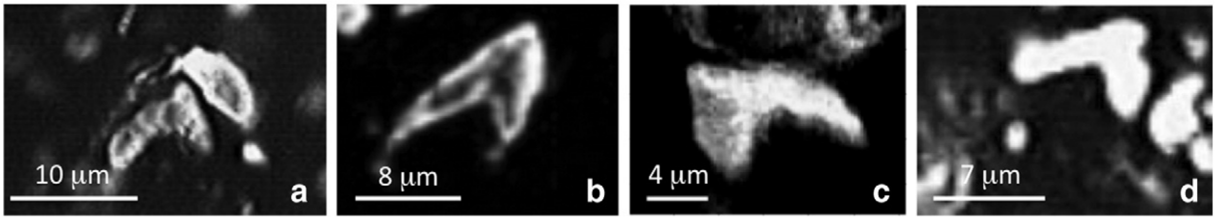

Fig. 2. Photographs in polarized light (crossed nicols) of some specimens of *Ceratolithus acutus* and of a abiogenic debris showing some likeness with *C. acutus*. *C. acutus*: a, Civitella del Tronto (Colombacci Formation at the Crocetta Chapel – site 38 in Fig. 1); b, Orosei (bottomset beds just overlying the Messinian Erosional Surface at Onifai – site 31 in Fig. 1); c, Sorbas Basin (clays overlying the Sorbas Limestone at La Cumbre – site 16 in Fig. 1). Abiogenic debris: d, Sorbas Basin (clays overlying the Sorbas Limestone at La Cumbre – site 16 in Fig. 1).

acute angle". As *C. armatus* and *C. acutus* are very similar, Young (1998) concluded that they are synonyms. Despite *C. armatus* has two months priority, nannofossil workers continued to use both names in a random way, *C. acutus* being preferred in the Mediterranean realm. *C. acutus* has a chronological range from 5.345 to 5.04 Ma (Raffi et al., 2006).

Such a clear and precise formal definition of *C. armatus*/*C. acutus* is accompanied by a series of detailed textual and/or photographic descriptions from the Mediterranean records (Rio et al., 1976; Ellis and Lohman, 1979; Castradori, 1998; Keupp and Bellas, 2000; Snel et al., 2006a, b; Melinte-Dobrinescu et al., 2009; Suc et al., 2011; Cornée et al., 2014, 2016; Do Couto et al., 2014; Clauzon et al., 2015; Lancis et al., 2015; Popescu et al., 2016). Some selected photographs from our records of *C. acutus* are shown in Fig. 2a–c. Some risk of confusion could be argued with similarly shaped and sized abiogenic debris being birefringent too in polarized light (crossed nicols). As shown for such a debris in Fig. 2d, the absence of the above mentioned morphological characters guarantees the reliability of records of *C. acutus*/*C. armatus*.

Such a large body of evidence makes the identification of *C. acutus* particularly robust because based on a very careful work. As it is a rare species, an extended search is often needed to find specimens. Therefore, it is difficult to infer much from the presumable absence of this nannofossil.

3. Records of *Ceratolithus acutus* in the Mediterranean

We welcome this opportunity to underscore the chronostratigraphic importance of *Ceratolithus acutus*. This species has been recorded in the Mediterranean and its Late Miocene–Early Pliocene appendage, the Eastern Paratethys, in at least 75 localities (Fig. 1). As demonstrated by several of our extensive field expeditions in various regions such as in southeastern Spain and onland the southern Marmara Sea, relatively frequent records of *C. acutus* can be obtained only by (1) processing a large number of samples and (2) analyzing smear slides in more detail than for routine investigations. Despite the relative scarcity of *C. acutus* (Di Stefano and Sturiale, 2010), its numerous records within the Mediterranean Basin make it an important species.

4. Discussion and conclusion

While only our own papers reporting the occurrence of *Ceratolithus acutus* are questioned by Stoica et al. (2016), twenty other references citing the presence of this species are not met with similar skepticism. This selective referencing of the literature should be accompanied by an explanation.

The stratigraphic value of the calcareous nannofossil record from the Jurassic to present in general and within the Messinian–Zanclean boundary interval especially, is at least equivalent to that of ostracods and/or magnetostratigraphy. To expect strict reproductibility (van Baak et al., 2015) in microfossil content between twin samples is utopian because a rare microfossil may be present in a small part of the sample and absent from the rest, or may simply reflect a chance encounter. Any micropalaeontologist knows that the presence of a species has more robust significance than its absence (Popescu et al., 2016).

A possible explanation for the reluctance to accept the various occurrences of *C. acutus* in the Mediterranean region is because this species has been recorded in several places obviously below the formally defined base of the Zanclean (e.g., for the published localities: Malaga: Do Couto et al., 2014; Sorbas: Clauzon et al., 2015; Apennine foredeep: Popescu et al., 2007, 2008; Brozzetti et al. in press; Zakynthos: Karakitsios et al., 2016, see in particular their Appendix 2). Such occurrences imply that marine reflooding of the Mediterranean Basin closing the Messinian Salinity Crisis occurred significantly before the Zanclean Stage, as also revealed by other evidence (Cavazza and DeCelles, 1998; Cornée et al., 2006; Bache et al., 2012; Brozzetti et al. in press; Crescenti and Raffi, in press). Such a mounting body of evidence bears witness to a more complex sequence of events and contradicts the established belief of Mediterranean reflooding at 5.33 Ma, i.e. at the base of the Zanclean (Van Couvering et al., 2000). This belief is well ingrained in the literature on the Messinian Salinity Crisis and informs the work of many scientists researching this fascinating issue. From a scientific standpoint, there is a little point in continuing to dispute the relevance of *Ceratolithus acutus*, arguing about its supposed unreliability and/or its scarcity.

The intense and rewarding international debate on the causes, process and timing of the Messinian Salinity Crisis deserves to be handled objectively.

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