CRUZIANA YINI YANG, A PERI-GONDWANAN TRILOBITE TRACE WITH NEW RECORDS IN THE ORDOVICIAN OF SOUTH AMERICA AND IBERIA

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INTRODUCTION

Armorican-type sandstones rich in trilobite traces of the Cruziana rugosa group are widely distributed around Gondwana, especially in the Lower Ordovician of south-western Europe (Durand, 1985; Romano, 1991; Neto de Carvalho, 2006 and references therein), north Africa – Middle East (Seilacher, 1970, 1990; El-Khayal and Romano, 1988; Ramos et al., 2006), Avalonia and Eastern Newfoundland (Crimes, 1970, 1975; Fillion and Pickerill, 1990), and in the Lower and Upper Ordovician of the Central Andean basin (a.o. Toro et al., 1990; Mángano et al., 2001; Aceñolaza and Aceñolaza, 2002; Mángano and Buatois, 2003; Aceñolaza and Milana, 2005; Egenhoff et al., 2007). Outside northern and western Gondwana, there are scattered occurrences of the Cruziana rugosa group in the Lower Ordovician of South China (Yang and Fu, 1985) and perhaps in Baltica (Knaust, 2004), but only the former show close resemblance with Gondwanan assemblages.

Here we report some South American and European records of an interesting member of the Chinese association of the Cruziana rugosa group, showing the wide peri-Gondwanan distribution attained by their corresponding, and somewhat-related, trilobite makers.

THE CHINESE RECORD OF CRUZIANA YINI

Yang (in Yang and Fu, 1985) originally described Cruziana yini from the Lower Ordovician quartzose sandstones of the Hongsiya (= Hungshiya, Hongshiyian) Formation in the section of Wuting, eastern Yunnan. The original description provided two figured specimens (Figs. 1 A and B), one of which was later designated as lectotype of the ichnospecies (Fillion and Pickerill, 1990, p. 27), while the other was considered as a compound specimen, transitional to C. rugosa d’Orbigny. In their brief review of C. yini, Fillion and Pickerill (1990) established the main ichnotaxobases to distinguish it as a valid and separate ichnospecies, as well as the criteria to differentiate it from its most closely related form, C. breadstoni Crimes, 1975, not considered by the Chinese author in the original description.
Although most members of the *Cruziana rugosa* group usually reached a wide geographical (and even stratigraphical) distribution through the Lower Paleozoic, *C. yini* was so far apparently restricted to the westernmost part of the Yangtze platform (South China Paleoplate). The stratotypical Hongsiya Formation is a 200-324 m succession of sandstones and shales with quartzose sandstones, where trace fossils are quite common, including *C. rugosa* d’Orbigny, *C. furcifera* d’Orbigny, *C. goldfussi* (Rouault), *Monomorphichnus, Dimorphichnus, Palaeophycus*, etc. (Yin, 1933; Xiong, 1944; Yang and Fu, 1985). Its type section lies in the western suburb of the Kunming city (Kuo, 1941), but the formation was later recognized along the eastern paleo-shore the old Kum-Yunnania Land from the type locality to Puge, in western Sichuan, either conformably overlying the Tangchi Formation (Tremadocian) or unconformably resting (with a 5 m-thick basal conglomerate) over Upper Cambrian rocks (Chen et al., 1995). Li (1991) defined the Hongsiya Formation as a near-shore, Armorican-type sandstone, which has been dated as late Floian by the occurrence in shale intercalations of some graptolites (*Baltograptus deflexus, B. turgidus*), trilobites (*Taihungshania, Symphysurus*) and acritarchs of this age.

**Cruziana yini** from South-America

South American material assignable to *Cruziana yini* comes from three localities in the Eastern Cordillera of northwestern Argentina. The first is situated towards the upper part of the Ordovician sequence in the Chamarra Creek, north of the Los Colorados (Jujuy Province). A single specimen (Fig. 2 B) was collected in this section from a succession of sandstones and shales lying above the Alto del Cóndor Formation, which until very recently was regarded by different authors as an equivalent of the “Sepulturas” Formation (*sensu lato*). However, new records of different fossils in the *Cruziana*-bearing strata favored a different age dating to this unit, which ranges from late Middle Ordovician to early Upper Ordovician, as indicated by some conodonts and by the early fish *Sacabambapis javierii* (Albanesi and Astini, 2003).

Additional Argentinian material of *C. yini* comes from two different outcrops placed in the Mojotoro Range, northeast and east of the city of Salta, respectively. A first specimen (Fig. 1 C) from the Mojotoro Formation (middle to upper Arenigian) was presented by Mángano et al. (2001) from the Gallinato Creek section, being originally identified as *Cruziana furcifera* d’Orbigny (Mángano et al., 2001, fig. 3 C), and later as *Cruziana rugosa furcifera* (Mángano and Buatois, pl. 1, fig. 10) or again as *C. furcifera* (MacNaughton, 2007, fig. 8.4.B). The second specimen of *C. yini* (Fig. 2 A) comes from the San Bernardo Formation in the northern section of the Cerro San Bernardo, on the foothills of Salta City, being stratigraphically placed in late Tremadocian beds, because of their presence two meters below the FAD of the graptolite *Araneograptus murrayi*.

**Cruziana yini** from Iberia

The Iberian material assigned to this form was primarily recognized in the Portuguese part of the Central Iberian Zone of the Hesperian Massif by Sá (2005, p. 426), who described a specimen of *Cruziana cf. yini* from the fossil locality “Guadramil-6” in the Barreiras Blancas Hills, Bragança area. This sample is also presented here (Fig. 2 C) and comes from the Marão Formation, which is the equivalent to the Armorican Quartzite in the Trás-os-Montes region. Similar material derived from the same unit in the southern flank of the Moncorvo Syncline has been previously described as *C. furcifera* by Rebelo and Romano (1986, pl. 2, fig. 3), but in our opinion is better adscribed to *C. yini* (Fig. 1 E). A third occurrence
of the ichnospecies in Portugal has been indicated by Sá et al. (2007, fig. 3 E) as coming from the Santa Justa Formation (also correlated with the Armorican Quartzite) in the Arouca region (Fig. 2 E).

**Figure 1.** *Cruziana yini* Yang. Images of several specimens previously figured from China (A–B), Argentina (C), Spain (D) and Portugal (E) and discussed in the text. A–B, after Yang and Fu (1985, pl. 1, figs. 6–lectotype- and 5–paralectotype-, respectively). C, after Mángano et al. (2001, fig. 3C), specimen PIL 14629, also refigured by Mángano and Buatois (2003, pl. 1, fig. 10) and MacNaughton (2007, fig. 8.4.B), either identified as *C. furcifera* or as *C. rugosa furcifera*. D, after Crimes and Marcos (1976, pl. 1 a; specimen AMC 6270), described as *C. breadstoni*. E, after Rebelo and Romano (1986, pl. 2, fig. 3; specimen QS), identified as *C. furcifera*. Note that figures are not to scale.

*Cruziana yini* is so far represented in the Spanish part of the Central Iberian Zone by a single occurrence, recorded towards the base of the Armorican Quartzite Formation (= basal “I” unit of San José Lancha et al., 1974) in the Estena River section, within the Cabañeros National Park (Fig. 2 D).

Additional Spanish specimens of *C. yini* are also known from the Cantabrian Zone in the Cabo de Peñas section, Asturian coast. The material was originally described as *Cruziana breadstoni* by Crimes and Marcos (1976, pl. 1a, b; reproduced in part here, Fig. 1 D), and come from two quartzite-shale sequences located approximately 370-440 m below the top of the Barrios Formation, which includes the local equivalent of the Armorican Quartzite. This identification of *C. breadstoni* was taken as indicative of a Tremadocian age for the lower part of the section, in spite of its claimed co-occurrence with typical “Arenigian” traces like *C. rugosa*, *C. goldfussi* and *C. furcifera*, recorded from the same beds. The true *C. breadstoni* have a smaller V-angle than *C. yini* and their scratches are bunched in twos and threes, so that this ichnospecies still belongs to the stratigraphically older *C. semiplicata* group (Upper Cambrian to lower Tremadocian in north Gondwana). To this regard, and according to Mángano and Droser (2004), a significant trilobite turnover event, documented by ichnofossils in shallow-marine siliciclastic deposits of peri-Gondwana, is recorded by the post-Tremadocian replacement of the *C. semiplicata* group by elements of the *C. rugosa* group. Further evidence on the post-Tremadocian age of the beds yielding the Cantabrian specimens of *C. yini* (formerly assigned to *C. breadstoni*) comes also from the stratigraphic review of the same section by Aramburu and García-Ramos (1993). These authors restricted the exposure of the Barrios Formation in the Cabo de Peñas to the Tanes Member (Arenig), which here rests unconformably over the Cambrian to ?basal Tremadocian Oville Formation. The age of the Barrios Formation in the same Fold and Nappes Domain of the Cantabrian Zone was recently refined by Gutiérrez-Alonso et al. (2007), who place the Tremadocian-Floian boundary towards the lower-middle third of the Tanes Member.
According to the original description, and the later review provided by Fillion and Pickerill (1990), the more obvious and distinctive feature of Cruziana yini is the very large V-angle (>160 degrees) reached by the endopodal markings across the lobes. These could correspond to procline-induced scratches running transverse to a median furrow, which is very shallow, becoming remarkably faint in specimens preserved as wide U-shaped burrows. This procline ploughing could generate faint corrugations across the lobes, but without disrupting the course of individual scratches (Figs. 1 B, 2 C and D), unlike in the typical and coarse transverse corrugations of C. rugosa.

Some of the South American and Iberian specimens of C. yini have been previously misidentified as C. furcifera because a number of them showed endopodal markings crisscrossing at acute angles (Figs. 1 C to E). However, they lacked the characteristic reticulate scratch pattern on the lobes and the arrangement of successive sets of scratch marks may have occurred separately (Fig. 2 B). Even in the case of accepting the existence of compound specimens of C. furcifera–C. yini, the observed intergradation between other ichnospecies within the C. rugosa group (e.g., Kolb and Wolf, 1979; Mángano et al., 2001) show that the currently observed changes from procline to isocline (C. rugosa → C. furcifera) and isocline to opisthocline (C. furcifera → C. goldfussi) orientations of the tracemarker during excavation conflict with the isocline to procline pattern of critical material of C. yini (Figs. 1 C and D). This morphoethological and constructional variation also serves to justify the ichnotaxonomic separation of Cruziana yini from the remaining members of the C. rugosa group, which may be established either at the ichnospecific or ichnosubspecific level. The latter view was proposed by Seilacher (1996) without much support, other than Mángano and Buatois (2003). Likewise, the attempt by Kolb and Wolf (1979) to synonymize some of the most widespread forms of the C. rugosa group has also met the skepticism of most other authors (a.o., Pickerill et al., 1984; Durand, 1985; Fillion and Pickerill, 1990; Egenhoff et al., 2007).

While the type material of C. yini lacks lateral spine grooves (of pleural or genal origin), indications of such external furrows are observed in some of the Portuguese specimens (Figs. 1 E and 2 E). However, and as already described for other forms like C. goldfussi, C. furcifera, C. rugosa or C. beirensis, the presence/absence of marginal grooves is not truly diagnostic for particular ichnospecies within the C. rugosa group and may be partly due to preservational aspects.

Together with the very large V-angle of endopodal markings and the shallow median furrow, the main character of C. yini is the curved trend of individual scratches, passing from anterior obliquely oriented against the external border of each lobe to being perpendicular to the central furrow posteriorly. Within this arched scratch pattern, some of the endopodal ridges occasionally cross without interruption from one lobe to the other over the faint median furrow, giving the trace an unilobed aspect, very different to the ichnospecies presently included either under Cruziana or Rusophycus.

The repository information of the figured specimens is as follows: PIL, Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán (Argentina); AMC, Alberto Marcos collection, Universidad de Oviedo (Spain); QS, José Rebelo collection, Instituto Nacional de Energia e Geologia, Lisbon (Portugal); GDM, Sá collection, Universidade de Trás-os-Montes e Alto Douro, Vila Real (Portugal).

Figure 2. New material of Cruziana yini from the Ordovician of Argentina (A–B), Portugal (C and E) and Spain (D). A, PIL 14551, Cerro San Bernardo, Salta; B, PIL 14550, Chamarra Creek, Jujuy; C, GDM-VI 42, Guadramil, Bragança; D, field photograph, Navas de Estena, Cabañeros National Park; E, field photograph, Paiva River Valley, Arouca. Scale bars, 2 cm.
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CONCLUDING REMARKS

*Cruziana yini* is a peculiar trilobite trace whose stratigraphical and paleogeographical distribution is notably widened by its occurrences outside China in late Tremadocian to Sandbian strata from South America (Argentina) and Europe (Portugal and Spain).

Such peri-Gondwanan distribution of a trace fossil, originally described from the South China Plate, had also been recognized among the Lower Ordovician trilobites of the same area (Turvey, 2005). In this sense, the paleobiogeographical relationships of the Chinese trilobites point to a tropical or subtropical peri-Gondwanan association of South China with other Asian terranes, but also display faunal connections with north Gondwanan and South American regions.

The age and distribution of *Cruziana yini* agrees with that of the suppossed tracemakers of the ichnospecies included in the *C. rugosa* group, which were possibly related with the feeding and locomotion of asaphid trilobites as already suggested by Bergström (1973) and later authors.

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