Geol. Mag. **152** (2), 2015, pp. 358–366. © Cambridge University Press 2014
doi:10.1017/S0016756814000417

RAPID COMMUNICATION

The earliest species of *Burlingia* Walcott, 1908 (Trilobita) from South China: biostratigraphical and palaeogeographical significance

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(*Received* 26 February 2014; *accepted* 14 July 2014; *first published online* 19 September 2014)

Abstract

Burlingia balangensis sp. nov. from the lower Cambrian of South China represents the earliest species of this genus, and suggests that the genus may have originated in South China. A revision of the genus shows that *B. primitiva* and *B. obscura* can be used in order to indentify the base of the Cambrian Stage 5 when other trilobites are absent because their last appearance datum (LAD) coincides with the first appearance datum (FAD) of *Oryctocephalus indicus*. Available palaeogeographic and palaeoclimatic models suggest five major palaeocurrents during Cambrian times which could control the migration patterns of the *Burlingia* clade from South China to Baltica.

Keywords: Palaeozoic, Gondwana, Guizhou Province, palaeogeography, biostratigraphy.

1. Introduction

Burlingia Walcott, 1908 is a proparian, poorly mineralized trilobite belonging to the Family Burlingiidae Walcott, 1908. Whittington (1994) described and discussed the systematic position of this family as well as their life habits. It is probably monophyletic and contains the genera *Burlingia* and *Schmalenseeia*, but its relationship with other trilobite groups is unclear (Ebbestad & Budd, 2002).

This work is focused on *Burlingia*, which, because it is cosmopolitan, was probably planktonic (Jago, 1972; Whittington, 1994), mainly occurring in marginal platform or outer shelf facies from Canada (Walcott, 1908; Rasetti, 1951), the USA (Robison & Babcock, 2011), Sweden (Westergård, 1936; Whittington, 1994), Siberia (Soloviev, 1969), South China (Zhang *et al.* 1980; Yuan *et al.* 2002) and Norway (Ebbestad & Budd, 2002). It has a stratigraphical range from the upper part of the Cambrian Series 2, Stage 4 to the Cambrian Series 3, Drumian Stage, thus crossing an important geological interval (i.e. the lower–middle Cambrian boundary). The aim of this paper is to describe a new species of *Burlingia* from the traditional lower Cambrian of Guizhou Province (South China) and review the stratigraphical, palaeogeographical and biostratigraphical significance of this genus.

2. Geological setting

The described specimens of *Burlingia balangensis* sp. nov. are from the Cambrian of SE Guizhou Province, South China (Fig. 1a) where rocks are well exposed and documented (Yin & Lee, 1978; Lin *et al.* 2005; Zhao *et al.* 2005*a*, 2012; Yang *et al.* 2010; Yuan *et al.* 2011) as representing (1) the shallow-water Yangtze Platform, (2) deeper water Jiangnan Basin and (3) transitional Jiangnan Slope Belt.

The specimens were collected from the transitional Jiangnan Slope Belt near the locality of Balang in the east of Guizhou Province. Here, the following formations in ascending order are the Tsinghsutung and Wuxun formations (both *c*. 123 to 250 m thick) of the Cambrian Series 2 and the Kaili Formation, which crosses the Cambrian Series 2 – Series 3 boundary (Zhao *et al.* 2005*b*, 2012; Yang *et al.* 2010). Our specimens came from a level 30 m below the Kaili Formation (Fig. 1b), although the lithology here is unlike that of the Tsinghsutung or Wuxun formations studied previously in the transitional Jiangnan Slope Belt (see Yang *et al.* 2010). The Tsinghsutung Formation is mainly developed in the Yangtze Platform, although the facies may be found also in the transitional Jiangnan Slope Belt (Yang *et al.* 2010), where the Wuxun Formation is mainly developed. The type section of the Tsinghsutung Formation is located near Tsinghsutung village, Meitan County, northern Guizhou Province. This formation is about 208 m thick and is mainly composed of grey to dark grey thick-bedded to massive limestone, grey thick-bedded dolomitic limestone, calcareous dolomite and grey thin- to thick-bedded dolomite and argillaceous dolomite. The endemic benthic trilobite fauna contains the genera *Redlichia*, *Hoffetella*, *Antagmus*, *Kunmingaspis*, *Paraperiomma*, *Eoptychoparia* and *Poulsenia* (Zhang *et al.* 1980). The type section of the Wuxun Formation is at Wuxun village, Nangao town, Danzhai County, southwestern Kaili City, southern Guizhou Province. This formation is 122 m thick and is mainly composed of green-grey to yellow-green sandy shale, calcareous shale intercalated with thin-bedded argillaceous limestone, dark grey thin- to medium-bedded limestone and dolomitic limestone in the upper part. The formation contains pelagic or planktonic trilobite forms such as *Protoryctocephalus* and *Arthricocephalus* (Zhang *et al.* 1979). At Balang, rocks containing *Burlingia balangensis* sp. nov. are mainly composed of grey to dark grey thin-bedded limestone, intercalated with grey-yellowish silty shale and mudstone, grey thin-bedded argillaceous limestone and grey

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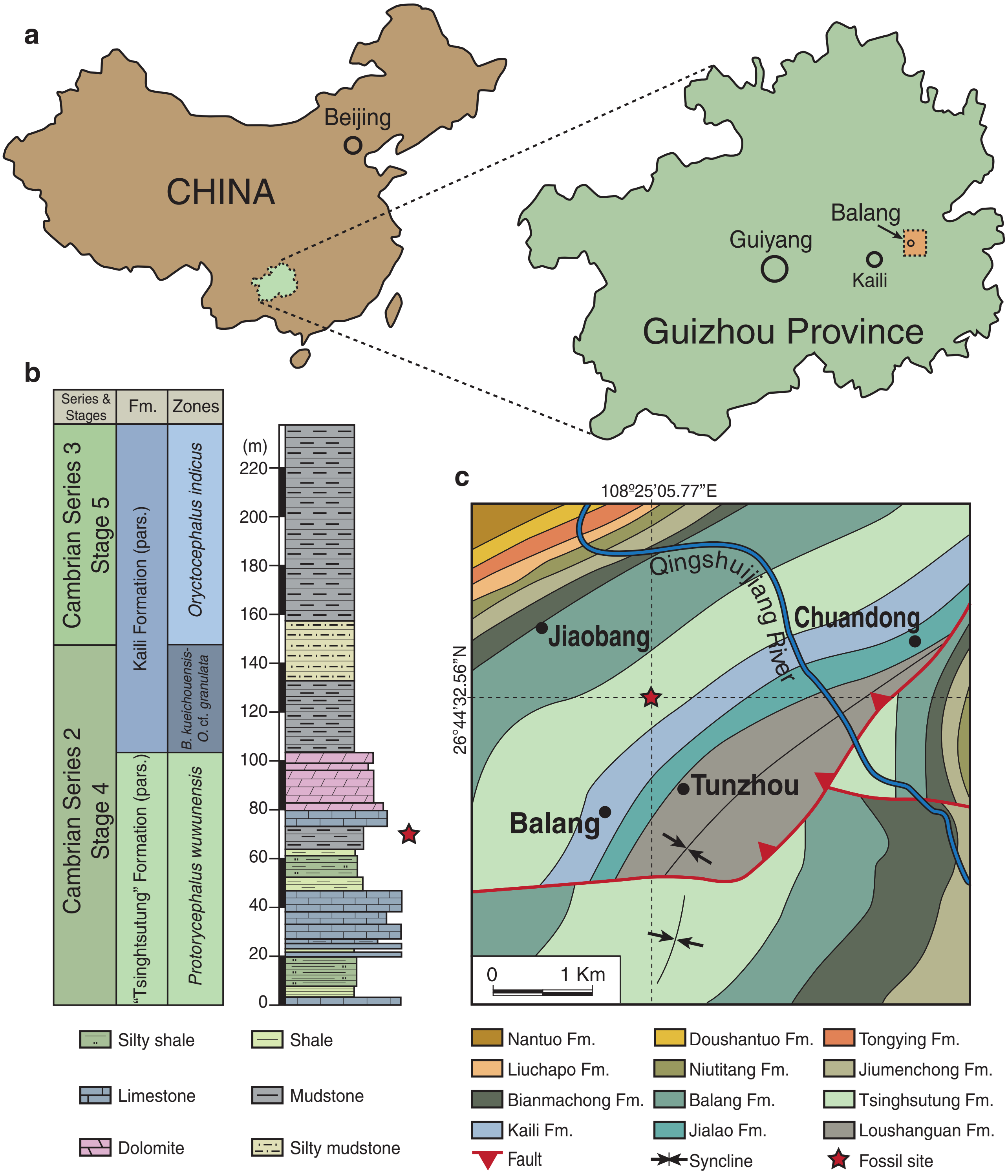

Figure 1. (Colour online) (a–c) Geological setting. (a) Map of China showing Guizhou Province and the Balang locality. (b) Stratigraphic column of the upper part of the 'Tsinghsutung' Formation and the lower part of the Kaili Formation of the Malipo section showing the location of *Burlingia balangensis* sp. nov. (c) Geological map of the Balang area indicating the location where the specimens were collected.

thin- to medium-bedded dolomite in the upper part. These may belong to the Tsinghsutung Formation but further work is necessary before we can confirm this and we use the preliminary term 'Tsinghsutung' Formation for this facies. What does seem clear is that the Balang rocks do not belong to the Wuxun Formation.

The trilobite assemblage of the 'Tsinghsutung' Formation contains a mixed fauna belonging to the *Arthricocephalus jishouensis – Changaspis plana* Zone in the lower part and the *Protoryctocephalus wuxunensis* Zone in the upper part containing *Ovatoryctocara* sp., *O.* aff. *angusta* Tchernysheva, 1962, *Protoryctocephalus wuxunensis* Zhou *in* Lu *et al.* 1974, *P. arcticus* Geyer & Peel, 2011, *Feilongshania* sp., *Duyunaspis* sp., *Changaspis* sp., *Nangaops danzhaiensis* (Zhou *in* Lu *et al.* 1974), *Redlichia takooensis* Lu, 1950, *Olenoides* sp., *Dinesus* sp. and *Burlingia balangensis* sp. nov.

3. Material and methods

Our material of *Burlingia balangensis* sp. nov. consists of 14 variously articulated (i.e. nearly complete) specimens (NIGP147820–NIGP147833) preserved as internal and external moulds. The internal moulds and latex casts were examined directly under a Leica M165C stereomicroscope and were coated with ammonium chloride sublimate prior to being photographed with a Nikon D300 camera. Length, width and angular measurements of the specimens were made using ImageJ (Abràmoff, Margalhães & Ram, 2004).

4. Systematic palaeontology

We follow the morphological terminology of Whittington & Kelly (1997). The burlingiid specimens are housed in the Palaeontological Collections, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing, China (NIGP).

Order Uncertain
Family BURLINGIIDAE Walcott, 1908
Genus *Burlingia* Walcott, 1908

Type species. *Burlingia hectori* Walcott, 1908 from the Stephen Formation, *Bathyuriscus–Elrathina* Zone (Cambrian Series 3), Mt Stephen in British Columbia, Canada.

Occurrence. From Cambrian Series 2 (Stage 4) to Cambrian Series 3 (Drumian Stage), British Columbia, (Canada), USA, Sweden, Norway, northern Siberia (Russia) and Guizhou Province (South China).

Remarks. Whittington (1994) revised the family Burlingiidae and provided new diagnoses for its two contained genera *Burlingia* and *Schmalenseeia*. Ebbestad & Budd (2002) assigned the species *Schmalenseeia jagoi* Whittington, 1994 to *Burlingia* without the need to emend Whittington's diagnosis and we agree with this. However, our new material indicates reasons for emending the diagnosis (e.g. shorter palpebral lobe or thorax with 10 or 12 thoracic segments).

Diagnosis (emended). Glabella tapering slightly forward, rounded anteriorly, with or without median occipital node; occipital and glabellar furrows either absent, or in rare specimens SO, S1 and S2 present as shallow lateral depressions. Palpebral lobe more than 23 % of glabellar length. Thorax between 10 and 16 segments, which has the short axis poorly defined.

Burlingia balangensis sp. nov.
Figures 2, 3

Material, locality and horizon. The holotype is a complete exoskeleton, NIGP147820 (Fig. 2b); in addition there are 13 paratypes (specimens, NIGP147821–NIGP147833). This new species belongs to the *Protoryctocephalus wuxunensis* Zone of the upper part of the 'Tsinghsutung' Formation at the Malipo section, about 250 m northwest of the Miaobanpo section, near Balang village, Jianhe County, Guizhou (Zhao *et al.* 2012) (Fig. 1b, c).

Etymology. The new species takes the name from the village of Balang (Jianhe County, Guizhou Province), where the specimens were collected.

Diagnosis. A species of *Burlingia* with a short preglabellar field (*c.* 20 % of cephalon length), pyriform glabella, short occipital ring (*c.* 15 % of cephalon length), short palpebral lobe (*c.* 20 % of glabellar length) and small posteromedian invagination in the pygidium.

Description. Exoskeleton broadly oval to elongated oval in outline, well rounded anteriorly. Size small, average length 4.7 mm, the holotype being 5.7 mm. Axial furrow very shallow. Cephalon semicircular, moderately long (*c.* 42 % of total length), three times wider than long; posterior margin nearly straight. Glabella wide (*c.* 22 % of cephalon length and *c.* 30 % of cranidial width) and long (*c.* 80 % of cephalon length, included occipital ring), slightly pyriform in shape, rounded anteriorly, with glabellar furrows absent. Occipital ring short (*c.* 15 % of cephalon length), some specimens with a small occipital node, occipital furrow shallow. Anterior border very narrow (sag.), slightly convex; shallow and narrow anterior border furrow. Preglabellar field relatively short (*c.* 20 % of the cephalic length) and flat. Lack of fixigenae field; posterolateral projection very wide (*c.* 50 % of cephalic length, *c.* 95 % glabella width). Palpebral lobe moderately short (*c.* 23 % of glabellar length), crescent-shaped in outline, in contact with the glabella at about cephalic mid-length bounded by the proparian facial sutures. Anterior branch of suture divergent from palpebral lobes at an angle of about 49 degrees to sagittal line; posterior branches divergent at an angle of about 76 degrees to sagittal line. Two specimens (NIGP147820 and NIGP147821) show a broken glabella and a small hypostome (*c.* 0.5 mm long, *c.* 0.4 mm wide). Thorax with 10 to 12 segments, wide pleural furrow, well-defined anterior and posterior pleural band, pleural segments slightly curving progressively backwards, and last two to three segments narrowing and curved more strongly backwards. Pleural segments gently curved backwards, with a very short pointed pleural spine. Pygidium small, semi-trapezoidal in outline, with a small posteromedian invagination.

Remarks. In general outline of the exoskeleton the new species is very similar to *Burlingia multisegmenta* Zhao *et al. in* Yuan *et al.* 2002 from the Kaili Formation (see Yuan *et al.* 2002, pp. 131, 255, pl. 39, figs 5, 6). It differs from the latter in having a narrower glabella and axis of the thoracic region (tr.), a shorter preglabellar field (sag.), the anterior branch of the facial sutures less divergent, 10 to 12 thoracic segments rather than 16 thoracic segments in the latter and a semi-trapezoidal pygidium. The new species is also very similar to *Burlingia obscura* Soloviev, 1969 from northern Siberia (Soloviev, 1969, pp. 10, 11, pl. 1, figs 1–7; pl. 2, fig. 3), but the latter has a narrower glabella (tr.), narrower occipital ring (sag.) as well as narrower axial rings in the thoracic region (tr.), a wider pleural region and the posterior branch of the facial sutures almost horizontal with an angle of about 90 degrees to the sagittal line. *B. balangensis* sp. nov. is also similar to *B jagoi*, but the latter differs in the shape of the glabella, the lack of invagination of the posterior border of the pygidium, a wider preglabellar area and a shorter occipital ring (sag.).

5. Stratigraphical distribution of the *Burlingia* species

Together with the present new species, nine are now known belonging to *Burlingia* for which the stratigraphical occurrence in ascending order is shown in Figure 4 and discussed below.

(1) *Burlingia balangensis* sp. nov. comes from the *Protoryctocephalus wuxunensis* Zone (Cambrian Series 2, Stage 4) of southern China.

(2) *Burlingia obscura* Soloviev, 1969 comes from the *Oryctocephalops frischenfeldi – Schistocephalus* Zone of

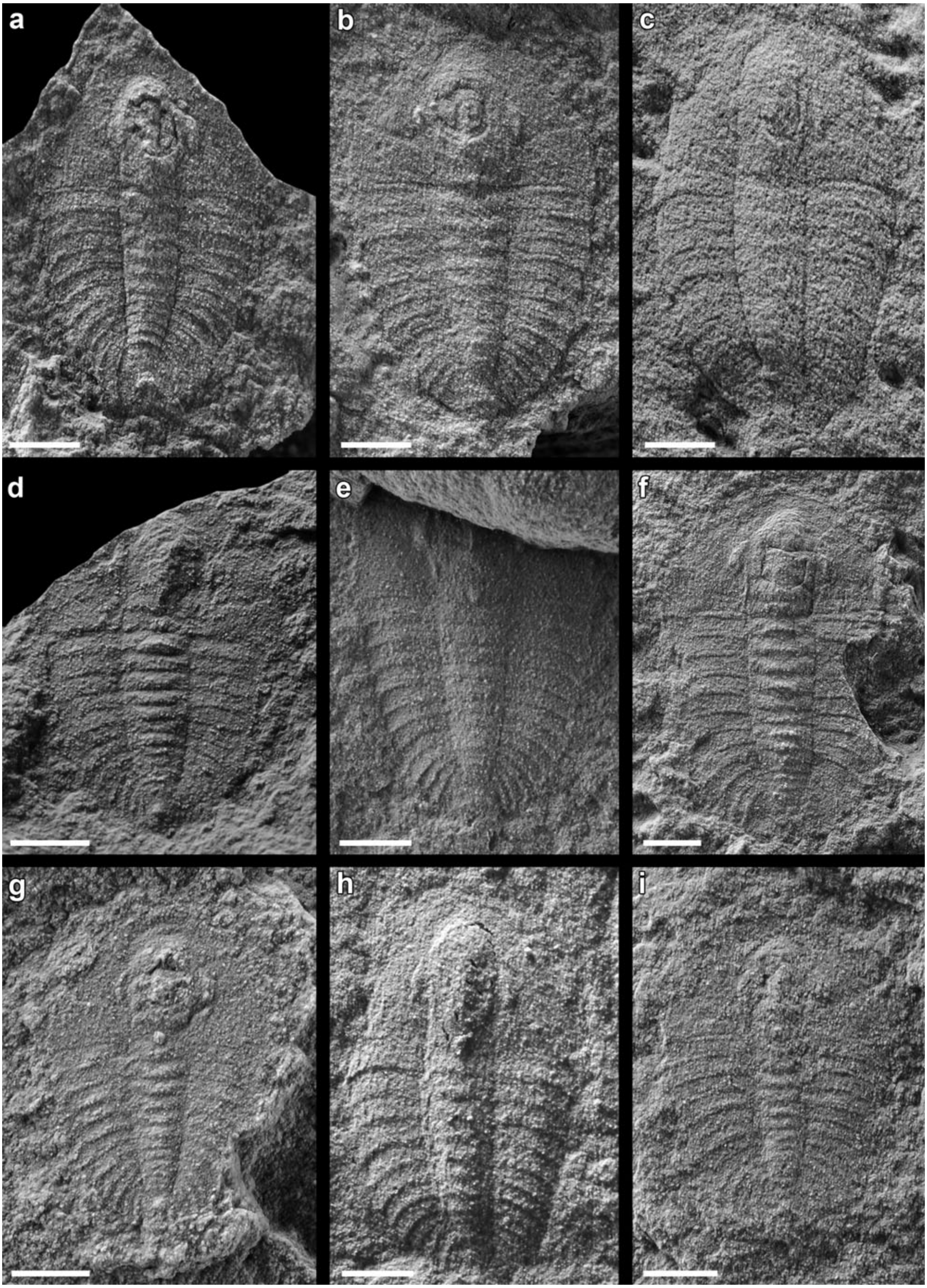

Figure 2. *Burlingia balangensis* sp. nov. *Protoryctocephalus wuxunensis* Zone of the upper part of the 'Tsinghsutung' Formation at the Malipo section, Balang village, Jianhe County, Guizhou. (Scale bar = 1 mm). (a) NIGP147821, internal mould showing the small posteromedian invagination in the pygidium; the glabella is broken and remains of the hypostome are visible. (b) NIGP147820, holotype, internal mould showing the small node in the glabella and wide posterolateral projection of the cranidium; the glabella

Figure 3. Reconstruction of *Burlingia balangensis* sp. nov. *Protoryctocephalus wuxunensis* Zone of the upper part of the 'Tsinghsutung' Formation at the Malipo section, Balang village, Jianhe County, Guizhou.

northern Siberia, Russia. Ebbestad & Budd (2002) correlated this species to the *Eccaparadoxides pinus* Zone, which corresponds to the early Cambrian Series 3, Stage 5. However, *Oryctocephalops frischenfeldi* Lermontova, 1940 is found in the *Bathynotus kueichouensis* – *Ovatoryctocara* cf. *granulata* Zone of South China (see Yuan *et al.* 2002; Sundberg *et al.* 2011), suggesting to us that the *Oryctocephalops frischenfeldi* – *Schistocephalus* Zone should be correlated with the *Bathynotus kueichouensis* – *Ovatoryctocara* cf. *granulata* Zone. This is late Cambrian Series 2, Stage 4 (Zhao & Yuan *in* Yuan *et al.* 2002).

(3) *Burlingia primitiva* Zhao *et al. in* Yuan *et al.* 2002 occurs in the *Bathynotus kueichouensis* – *Ovatoryctocara* cf. *granulata* Zone of southeastern Guizhou, South China. This is late Cambrian Series 2, Stage 4 (Zhao & Yuan *in* Yuan *et al.* 2002).

(4) *Burlingia ovata* Zhou & Yuan *in* Zhang *et al.* 1980 has been reported in the *Bathynotus kueichouensis* – *Ovatoryctocara* cf. *granulata* Zone of the Wiliu–Zangjiayan section. This is late Cambrian Series 2, Stage 4 (Sundberg *et al.* 2011).

(5) *B. multisegmenta* Zhao *et al. in* Yuan *et al.* 2002 and also *B. ovata* come from the *Oryctocephalus indicus* Zone of southeastern Guizhou Province, South China. Ebbestad & Budd (2002) assigned *B. ovata* to the *Eccaparadoxides pinus* Zone, which corresponds to the late Stage 5 below the *Ptychagnostus gibbus* Zone. But this is mistaken and *B. ovata* is slightly older and should be assigned to the early Stage 5 within the *O. indicus* Zone.

(6) *Burlingia hectori* Walcott, 1908 comes from the *Bathyuriscus–Elrathina* Zone of Mt Stephen in British Columbia, Canada, which is correlated with the *Pentagnostus praecurrens* Zone (see Sundberg, 1994, p. 11). This is Cambrian Series 3, Stage 5 (Peng, Babcock & Cooper, 2012).

(7) *Burlingia halgedahlae* Robison & Babcock, 2011 has been found from the middle *Bolaspidella* Zone of the House Range (USA), which is correlated to the *Ptychagnostus punctuosus* Zone (Robison & Babcock, 2011). This is Cambrian Series 3, Drumian Stage (Geyer & Shergold, 2000; Peng, Babcock & Cooper, 2012).

(8) *Burlingia jagoi* (Whittington, 1994) comes from the *Tomagnostus fissus* and *Ptychagnostus atavus* zones to the lower part of the *Ptychagnostus punctuosus* Zone of Sweden and Norway. In addition, the species *B.* cf. *jagoi* (Whittington, 1994) was described from the upper part of the *Ptychagnostus punctuosus* Zone of Norway. Both are within the Cambrian Series 3, Drumian Stage (Geyer & Shergold, 2000; Peng, Babcock & Cooper, 2012).

(9) *Burlingia angusta* Ebbestad & Budd, 2002 comes from the lower part of the *Ptychagnostus punctuosus* Zone of Norway. This is Cambrian Series 3, Drumian Stage.

6. Biostratigraphical and palaeobiogeographical significance

Burlingia balangensis sp. nov. is the earliest species of the genus and arose at a critical time when there was a faunal change from typical redlichiid assemblages in the late Stage 4 to typical oryctocephalid assemblages in the early Stage 5. *B. balangensis* sp. nov. is associated with other trilobites such as *Feilongshania* sp., *Changaspis* sp., *Duyunaspis* sp., *Redlichia* sp., *Dinesus* sp., *Olenoides* sp. and abundant early oryctocephalid trilobites such as *Protoryctocephalus arcticus* Geyer & Peel, 2011, *Ovatoryctocara* sp. and *O.* aff. *angusta* Tchernysheva, 1962. The occurrence of *B. balangensis* sp. nov. in the Cambrian Series 2, Stage 4, thus likely represents the origin of this family on the east margin of Gondwana. Two other Chinese species, *B. primitiva* and *B. obscura*, also occur in the upper Cambrian Series 2, but these became extinct just before the first appearance datum (FAD) of *Oryctocephalus indicus* (Reed, 1910). Therefore, the last appearance datums (LADs) of these older burlingiids can be used to help constrain the proposed GSSP interval in sections where *Oryctocephalus indicus* is absent.

The global biostratigraphy and palaeobiogeography of the Cambrian Series 2 and 3 suffer both from a relatively low diversity of trilobites and pronounced endemism (Álvaro *et al.* 2003). Moreover, the distribution of trilobites is, from the earliest times, strongly controlled by facies, so that even an accurate interregional correlation is complicated. *Burlingia* has a wide geographical distribution, which helps the interregional correlation and tests the various palaeogeographical models. As a consequence of the orientation of the western margin of Gondwana, being oriented approximately SW–NE in a position on the northern and southern hemispheres (McKerrow, Scotese & Brasier, 1992; Scotese, 2004; Álvaro *et al.* 2013; Torsvik & Cocks, 2013), the tropical zones were affected by the course of major ocean currents transporting cool waters towards the tropics (Fig. 5). South China exhibits

is broken showing a small hypostome and a small posteromedian invagination in the pygidium. (c) NIGP147822, latex cast of and articulated specimen without pygidium. (d) NIGP147823, latex cast of and articulated specimen without pygidium. (e) NIGP147824, latex cast showing the small posteromedian invagination in the pygidium. (f) NIGP147825, latex cast of and articulated specimen showing the occipital node. (g) NIGP147826, internal mould. (g) NIGP147827, internal mould.

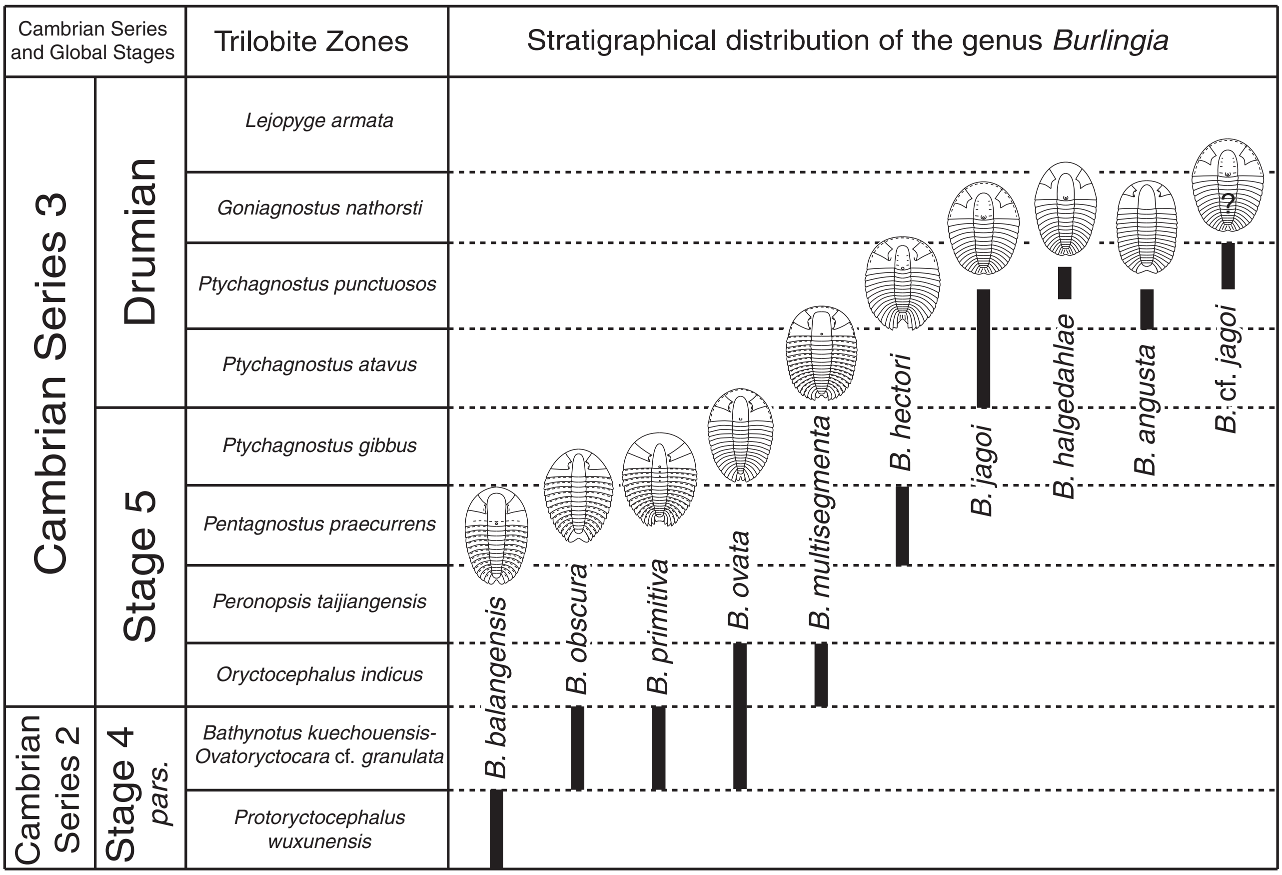

Figure 4. Stratigraphical distribution of species of *Burlingia* (see text for explanation).

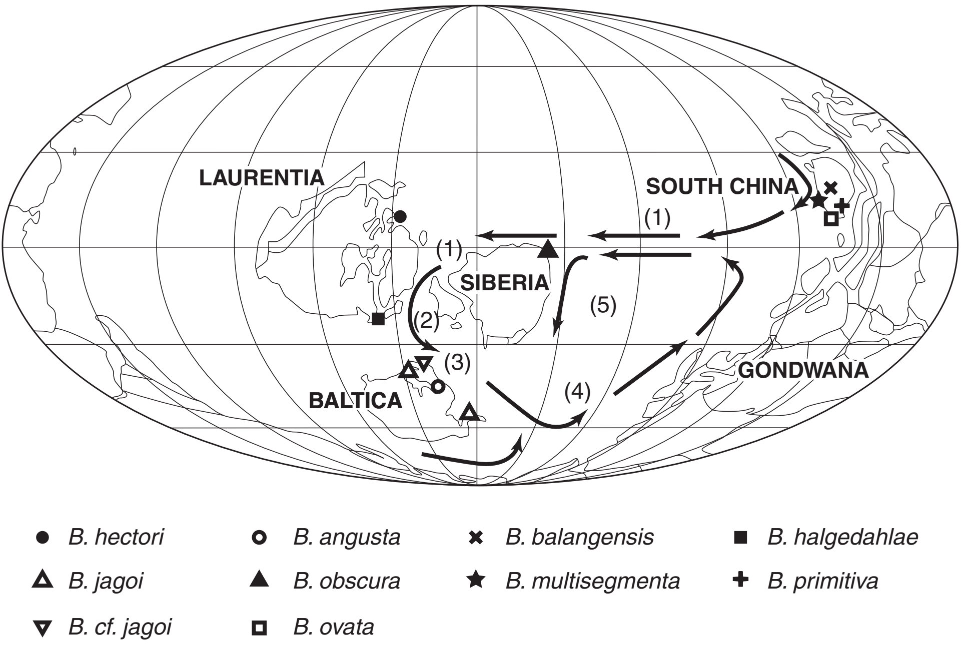

Figure 5. Palaeogeographic reconstruction of the early Cambrian Series 3 after Scotese (2004) with distribution of species of *Burlingia* (see text for explanation).

the highest diversity of *Burlingia* with four species (*B. balangensis*, *B. primitiva*, *B. ovata* and *B. multisegmenta*) from the upper Stage 4 and lower Stage 5. Therefore, these early *Burlingia* species from South China were in an incomparable geographical situation allowing efficient migrations to areas in the southwest. According to the reconstructions by Scotese (2004), Torsvik & Cocks (2013) and Álvaro *et al.* (2013), other palaeocontinents show a different distribution. Thus, Siberia was at lower latitudes just below the equator and between Gondwana and Laurentia allowing equatorial currents to pass towards palaeocontinents in the west (Fig. 5). Laurentia was also in an equatorial position but acting as a barrier that displaced the equatorial currents towards the south. Álvaro *et al.* (2003) suggested different cool and warm water currents associated with the same palaeocontinent distribution. Wilde & Quinby-Hunt (1991) and recently Servais *et al.* (2014) argued that this geographical distribution in connection with the Coriolis effect of winds also influenced and affected the palaeocurrents. The major currents generated by these factors can also be identified with climatic zones, although the currents are connected at zonal boundaries (Wilde & Quinby-Hunt, 1991). Thus, we suggest that this system could allow five major currents: (1) the North Equatorial current, (2) the East Laurentian current, (3) the East Baltica current, (4) the Western Gondwana current and (5) the South Equatorial current, which were affected by the position of the continents and could change slightly during the Cambrian owing to continental drift. Cambrian palaeomagnetic data show that Siberia and Laurentia were closer to Gondwana in the Cambrian Series 2 and moved away towards northern latitudes in the Cambrian Series 3 (Lottes & Rowley, 1990; Torsvik & Renström, 2001). On the other hand, Baltica was closer to Laurentia and away from Gondwana in the Cambrian Series 2 but approached the latter in the Cambrian Series 3 (Torsvik & Renström, 2001; Cocks & Torsvik, 2005). Obviously, all these factors affected faunal migrations during Cambrian times and the *Burlingia* clade is a good example of this. It is noteworthy to observe that the stratigraphical distributions of taxa belonging to *Burlingia* extend from Stage 4 in South China to Stage 5 in Siberia and Laurentia (Canada) and from the Drumian Stage in Laurentia (USA) to the Drumian Stage in Baltica (Norway and Sweden), and this trend is consistent with the major currents suggested above (Fig. 5).

The available data suggests that *Burlingia* originated in South China during the late Stage 4. Protaspid as well as meraspid larvae and holaspid specimens of different taxa belonging to this genus could migrate to north of Siberia via the North Equatorial current from South China where *B. obscura* evolved and gave rise to *B. primitiva*, *B. ovata* and *B. multisegmenta* in the Cambrian Series 2 and Series 3 in South China to North Siberia. Further migration following the East Laurentian current from Siberia to British Columbia in Canada in Stage 5 gave rise to *B. hectori* followed by *B halgedahlae* in the Drumian Stage, while the East Baltica current afforded migration of additional species in the early Drumian of Baltica. This is in accordance with the model by Scotese (2004) and Álvaro *et al.* (2013) and the currents involved with additional factors such as open platforms, muddy shelf facies and low temperature gradients.

7. Discussion and conclusions

The present new species *Burlingia balangensis* sp. nov. is the oldest representative of the Family Burlingiidae Walcott, 1908 (Cambrian Series 2, Stage 4). The LAD of *B. primitiva* and *B. obscura* is useful for recognizing the boundary between the Cambrian Series 2 and 3. The geographical distribution of *Burlingia* throughout the late Cambrian Series 2 and early Cambrian Series 3 seems to be controlled by the patterns of major currents suggested by Wilde & Quinby-Hunt (1991), Álvaro *et al.* (2003) and Servais *et al.* (2014). On the palaeo-reconstruction used, Siberia was closer to east Gondwana in the Cambrian Series 2 affording better connection between both palaeocontinents (Lottes & Rowley, 1990; Torsvik & Renström, 2001). Members of the *Burlingia* clade could migrate by using the North Equatorial and East Laurentian currents from China in the Stages 4 and 5 and the East Baltica current to Baltica during the Drumian Stage. This hypothesis shows an allopatric speciation of the *Burlingia* clade, which took around 7 million years from South China to Baltica. Nevertheless, so far *Burlingia* has not been found in Avalonia and the west margin of Gondwana. Other burlingiids such as *Schmalenseeia amphionura* Moberg, 1903 and *S.* cf. *spinulosa* Lazarenko, 1960 have been reported in the lower Guzhangian Stage of Avalonia (Rusthon, 1978), just above the *Erratojincella brachymetopa* Zone. In the absence of records, whether or not *Burlingia* reached the Avalonia palaeocontinent is unclear, but it is not recorded in Avalonia yet. Accordingly, it seems likely that the same niche was taken up by species of *Schmalenseeia* during the early Guzhangian Stage. Alternatively, the lack of *Burlingia* on the marginal platform or in outer shelf facies of the Mediterranean area and Central Europe on the west margin of Gondwana could be explained by two facts: (i) the presence of numerous barren stratigraphical intervals and unconformities (Alvaro *et al.* 2003) and (ii) these areas suffered a widespread coarse-grained terrigenous input associated with a well-documented regressive trend during Stage 5 and the Drumian Stage (see Álvaro & Vizcaïno 1998; Álvaro, Vizcaïno & Vennin, 1999; Álvaro & Vennin, 2001; Álvaro *et al.* 2003) causing loss of the habitat favoured by *Burlingia* and thus its absence in the Mediterranean area and Central Europe.

Acknowledgements. Jin-Liang Yuan is supported by the National key basic Research Program of China (2013CB835000) and the National Natural Science Foundation of China (41362002; 40930211). Jorge Esteve is supported by European Social fund and Ministry of Education Youth and Sport, Czech Republic (Ref. CZ. 1.07/2.3.00/30.0013). This is a contribution to the project CGL2011-24516 from Ministerio de Educación y Ciencia-FEDER-EU (Spain). We are grateful to Isabel Pérez (MEC-FSE, Universidad de Zaragoza, Spain) for her technical support with the figures. Thanks to Javier Álvaro (Centro de Astrobiología, Torrejón de Ardoz, Spain) for his helpful comments in the early stage of this manuscript. We are grateful to two anonymous reviewers for their review and helpful suggestions, which improved this manuscript. David L. Bruton (University of Oslo) kindly corrected the English.

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