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THE UPPER TREMADOCIAN (LOWER ORDOVICIAN) GRAPTOLITE *ANCORAGRAPTUS* FROM YIYANG, SOUTH CHINA

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ABSTRACT—Discovery of well-preserved specimens from the Nanba section in Yiyang, Hunan Province, in combination with a literature review, enabled us to re-evaluate and revise the graptolite genus *Ancoragraptus*. This is a genus of biradiate, multiramous anisograptids with horizontal to reclined rhabdosomes and free lower part of the metasicula and slightly isolated autothecal apertures. According to the revised definition, two species are included in *Ancoragraptus*, i.e., *Ancoragraptus bulmani* (Spjeldnæs, 1963) and *Ancoragraptus psigraptoides* Cho, Kim, and Jin, 2009. It is the first time that *A. bulmani* has been reported from China. The occurrences of *Ancoragraptus* reported worldwide are reviewed in the present study and found to be restricted to the lower upper Tremadocian. The restriction of *Ancoragraptus* in stratigraphical distribution makes it a taxon with a high potential for precise biostratigraphical correlation at both regional and global scale.

INTRODUCTION

THE GRAPTOLITE genus *Ancoragraptus* is an anisograptid reported from the upper Tremadocian. Jackson and Lenz (2003) erected this genus and designated *Adelograptus*? *bulmani* Spjeldnæs, 1963 as the type species. In their paper, the diagnosis stated that this is a biradiate anisograptid with horizontal to reclined rhabdosomes, unconcealed distal one half of the metasicula and isograptid-like simple autothecae. Cho et al. (2009) defined *A. psigraptoides* Cho, Kim, and Jin, 2009 based on specimens from the Yeongwol area in South Korea. This species has a narrow funicle and variable number of slender, declined to reclined stipes resulting from branching up to the seventh order, and originating from a biradiate proximal end. Hitherto, *Ancoragraptus* includes these two species. Although erected rather recently, this taxon has already been reported from many localities, e.g., from Oslo in Norway (Spjeldnæs, 1963; Maletz et al., 2010), Yukon in Canada (Jackson and Lenz, 2003; Jackson and Norford, 2004), Yeongwol in Korea (Cho et al., 2009) and Yiyang in South China (this paper). These studies show that the species of *Ancoragraptus* are restricted in the lower upper Tremadocian (late Tremadoc), which indicates this genus may have a high potential for precise biostratigraphical correlation at both regional and global scale.

This paper reviews the occurrences of *Ancoragraptus* reported worldwide and emends the definition of *Ancoragraptus* based on specimens from the Nanba section and some key papers. The new discovery from Nanba has important implications for precise regional and global biostratigraphical correlation during Tremadocian.

GEOLOGICAL SETTING AND MATERIAL

The Nanba section, 30 km southwest of the city of Yiyang in the Hunan Province of South China, is located in the Jiangnan Stratigraphic Region and characterized by slope facies sediments (Feng et al., 2009) (Fig. 1). In the past decade, great progress has been made in our understanding of the taxonomy and biostratigraphy of Tremadocian and Floian graptolites from the Nanba section. The section is well known for its Early Ordovician, notably late Tremadocian, high-resolution graptolite succession (Zhang et al., 2005; Li et al., 2009, 2010, 2012; Li et al., 2007; Feng et al., 2007, 2009, 2010). Micropaleontological studies of chitinozoans and acritarchs have also been carried out, providing precise calibration between different groups of fossils (Wang et al., 2012, 2013).

A large amount of Tremadocian graptolites were collected during fieldwork in 2007 and 2009. The new collections include common *Ancoragraptus bulmani* (Spjeldnæs, 1963) associated with *Adelograptus tenellus* (Linnarsson, 1871), *Kiaerograptus bulmani* (Thomas, 1973) and *Kiaerograptus kutchini* (Jackson and Lenz, 2003). These finds enable us to carry out a comprehensive study on *Ancoragraptus* in the lowermost *Adelograptus tenellus* Biozone of upper Tremadocian. *Ancoragraptus bulmani* recovered in this study has a biradiate rhabdosome with three to four distal stipes and irregular branching intervals. The multiramous trait of *Ancoragraptus*, which had also been observed before by Cho et al. (2009) and Maletz et al. (2010), is no longer in accordance with the generic definition of *Ancoragraptus* given by Jackson and Lentz (2003). Therefore, the diagnosis of *Ancoragraptus* needs considerable revision.

SYSTEMATIC PALEONTOLOGY

Order GRAPTOLOIDEA Lapworth *in* Hopkinson and Lapworth, 1875
Family ANISOGRAPTIDAE Bulman, 1950
Genus ANCORAGRAPTUS Jackson and Lenz, 2003

Type species.—*Adelograptus*? *bulmani* Spjeldnæs, 1963.

Diagnosis.—Biradiate anisograptid with horizontal to reclined rhabdosomes, branching dichotomously and irregularly; proximal development of isograptid type; sicula long and slender, erect with the lower part of the metasicula isolated; sicular bitheca present and stipe bithecae occasionally present; autothecae curved, with apertures tended to be slightly isolated in some species.

Occurrence.—In the Oslo region of Norway, first reported by Spjeldnæs (1963), *Ancoragraptus* was associated with *Kiaerograptus kiaeri* (Monsen, 1925) and *Bryograptus ramosus* Brøgger, 1882 in the upper part of the Ceratopyge Shale. According to the latest study by Maletz et al. (2010), the stratigraphical range of *Ancoragraptus* confines it to the *Kiaerograptus kiaeri–Aorograptus victoriae* Biozone in the Oslo region. In Canada, all the reports on *Ancoragraptus* came from the Yukon region and *A. bulmani* was recovered from the lower part of the *Adelograptus* cf. *A. tenellus* Biozone (Jackson and Lenz, 2003; Jackson and

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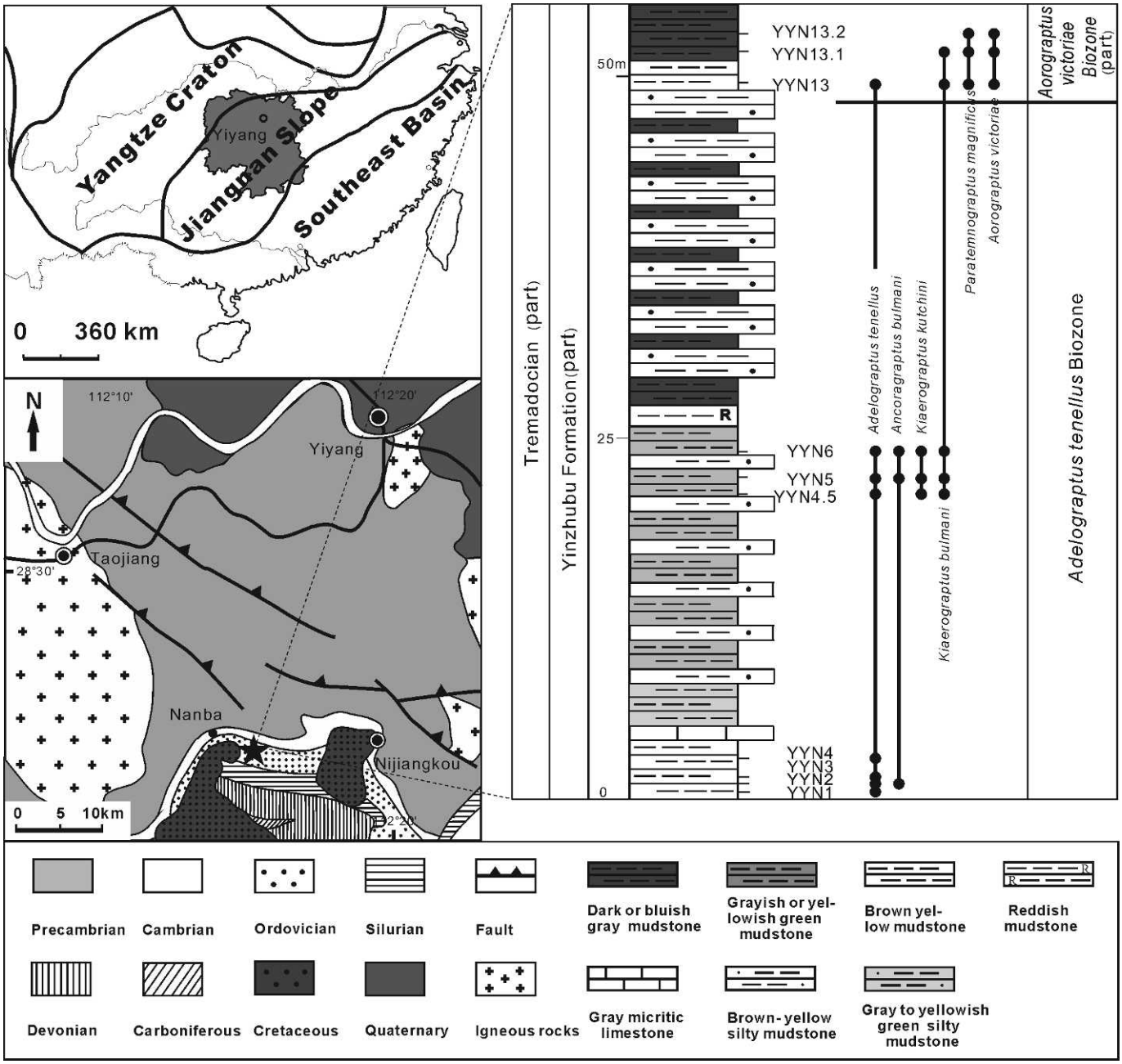

FIGURE 1—Location, biostratigraphy and litho-stratigraphy records of *Ancoragraptus* Jackson and Lenz, 2003 from the Nanba section, Yiyang, Hunan Province, South China. The colors of each rock type represent those on fresh surfaces. Graptolite species ranges according to Feng et al. (2009).

Norford, 2004). In Argentina, some specimens that were identified as *Ancoragraptus* cf. *bulmani* coexisted with *Aorograptus victoriae* in the upper member of the Coquena Formation. A tentative *Aorograptus victoriae–Kiaerograptus* Biozone was suggested in bio-stratigraphic scheme by Zeballo et al. (2008). In the Yeongwol area of South Korea where regional Tremadocian graptolite biozones have not been established yet, *Ancoragraptus* was found in association with *Psigraptus jacksoni* Richards and Stait, 1984. The latter is the index fossil of the regional lowermost upper Tremadocian graptolite biozone (an interval coeval to the *Adelograptus tenellus* Biozone). From this overview, it is clear that *Ancoragraptus* has a biostratigraphical range from the *Adelograptus tenellus* Biozone to the *Aorograptus victoriae* Biozone (Fig. 2).

Remarks.—*Adelograptus*? *bulmani* reported from Oslo, Norway, is preserved in pyrite in partial or full relief, and reveals important details of proximal development (Spjeldnæs, 1963). The first two autothecae originate high upon the metasicula and diverge from it about half way down, leaving the lower part of the metasicula free. The two primary stipes are horizontal to slightly reclined. Autothecae are simple and some of them have almost leptograptoid apertures which tend to be slightly isolated. Because of the great similarity with species which were then assigned to *Adelograptus* Bulman, 1941, Spjeldnæs (1963) attributed his new species *bulmani* to *Adelograptus*, but used open nomenclature. Jackson and Lenz (2003) first recorded *An. bulmani* outside Norway and suggested that it differs from any other existent genera and thus erected a new genus to accommodate the species. They called their new genus *Ancoragraptus*, and designated *Adelograptus*? *bulmani* as the type

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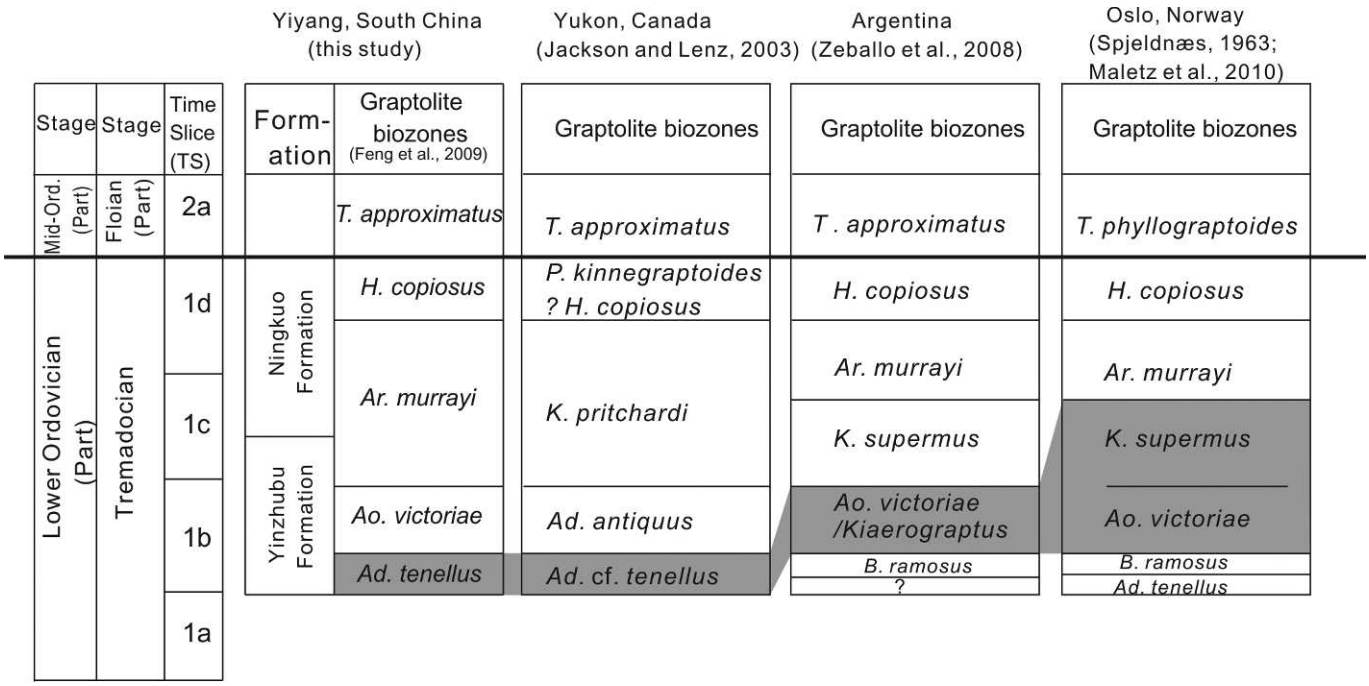

FIGURE 2—Biostratigraphical occurrences of *Ancoragraptus* Jackson and Lenz, 2003 in main localities around the world, shown in gray. TS=Time Slice, according to Webby et al. (2004).

species. The diagnosis stated that the rhabdosome is small, slightly reclined, with two short, undivided first-order branches, and the sicula symmetrically disposed relative to the first pair of autothecae, leaving the distal one-half of the metasicula free. Specimens recovered from both Oslo region in Norway and Yukon Territory in Canada have undivided first-order branches. It is noteworthy that specimens recovered from Oslo have two horizontal to slightly reclined stipes, while those from Yukon have two more obviously reclined stipes. Studying specimens from both areas, Jackson and Lenz (2003) defined the altitude of stipes in this genus as slightly reclined. *Ancoragraptus psigraptoides* reported from Yeongwol area in Korea is characterized by the declined to reclined stipes, up to seventh order branching and free lower part of metasicula. These characters are of typical *Ancoragraptus*, but the fact that *A. psigraptoides* has multiramous rhabdosomes is in contradiction with the original definition of *Ancoragraptus* by Jackson and Lenz (2003).

With the accumulation of reports concerning *Ancoragraptus* from all the main continents, more and more evidence indicates that species in *Ancoragraptus* are multiramous (i.e., *Ancoragraptus psigraptoides* and *An. bulmani* recovered in the present study are multiramous, while previously reported unbranching *An. bulmani* are juvenile forms without second-order branching). Therefore, the definition of *Ancoragraptus* is in need of revision. Based on specimens from the Nanba section, combined with those reported from elsewhere, we re-define *Ancoragraptus* as a biradiate anisograptid with multiramous, horizontal to reclined rhabdosomes, a long and slender sicula, and isograptid type proximal development. Th1[1] originates high on the metasicula, leaving the lower part of the metasicula free. Bitheca in the proximal end is present, and occasionally can be observed along the stipes. Autothecae have downward curvatures and, in some species, autothecal apertures are slightly isolated.

Being biradiate anisograptid recovered from upper Tremadocian, the revised *Ancoragraptus* is quite different from other contemporaneous biradiate anisograptids e.g., *Adelograptus*, *Kiaerograptus* Spjeldnæs, 1963 and *Psigraptus* Jackson, 1967. *Ancoragraptus* differs from *Adelograptus* in having a longer, free lower part of metasicula, horizontal to reclined stipes, and larger overlapping ratio. It differs from *Kiaerograptus* not only in the proximal development, but in having uncovered lower distal part of metasicula and isolate autothecal apertures as well. Although both *Ancoragraptus* and *Psigraptus* have free lower parts of their metasicula, the latter can be distinguished by its reclined to scandent stipes, strong curvature of the first two autothecae, and isolate autothecal apertures in every single autotheca.

Zhao and Zhang (1985) suggested that *Neoclonograptus gracilis* Zhao and Zhang, 1985 might have evolved into *Muenzigraptus* Zhao and Zhang, 1985 and then into *Psigraptus* through the progressive isolation of proximal autothecal apertures. When discussing the evolutionary relationship of *Chigraptus* Jackson and Lenz, 1999 and *Psigraptus*, Jackson and Lenz (1999) proposed that *Chigraptus* was a transitional stage between *Staurograptus*-like quadriradiate graptolites and bi-radiate graptolites, through the process of primary stipe reduction and autothecal aperture isolation. Recently, Cho et al. (2009) tentatively suggested that *Neoclonograptus gracilis* could have been synonymous with *A. psigraptoides*. They also suggested an evolutionary lineage of *Adelograptus–Ancoragraptus–Psigraptus* based on their gradual stratigraphical appearance within strata in Korea. However, the fact that *Ancoragraptus* appears later than *Psigraptus* in Yukon, Canada (Jackson and Lenz, 2003) does not support the lineage which was suggested by Cho et al. (2009). In the Nanba section, *A. bulmani* is confined within the *Adelograptus tenellus* Biozone, and largely appears at levels YYN5 and YYN6, above the appearance of typical specimens of *Adelograptus* which are confined to levels YYN1 and YYN2. This suggests that evolution may have headed from *Adelograptus* to *Ancoragraptus*.

ANCORAGRAPTUS BULMANI (Spjeldnæs, 1963)
Figures 3.1–3.16, 4.1–4.10

1963 *Adelograptus*? *bulmani* SPJELDNÆS, p. 127, pl. 18, figs. 1–8; text-figs. 3, 4.

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2001 *Kiaerograptus* sp. A. MALETZ AND EGENHOFF, p. 52, fig. 4-I.
2003 *Ancoragraptus bulmani* (Spjeldnæs); JACKSON AND LENZ, p. 141, figs. 6-m, o; 7a-l.
2004 *Ancoragraptus bulmani* (Spjeldnæs); JACKSON AND NORFORD, p. 340, fig. 7-A.
2008 *Ancoragraptus* cf. *A. bulmani*, ZEBALLO ET AL., p. 316, fig. 5-1.
2009 *Kiaerograptus* sp., FENG ET AL., p. 293, text-fig. 5-A.
2010 *Ancoragraptus bulmani* (Spjeldnæs); MALETZ ET AL., p. 64, text-figs. 6C, 6D, 6L, 6M, 9B.

Diagnosis.—Rhabdosome with two long, horizontal to slightly reclined first-order stipes; branching quite late and irregular, resulting in three to four distal stipes; sicula narrowly conical, with parallel-sided metasicula; th1[1] and th1[2] diverge from the sicula high, leaving the lower part of the metasicula free; autothecae similar to leptograptid type, with some autothecal apertures slightly isolated (emended from Spjeldnæs, 1963).

Description.—The sicula is narrowly conical and straight, 1.24–1.71 mm in length and 0.23–0.34 mm in width at the aperture. The nema can be observed in some specimens. The first theca (th1[1]) originates about 0.09–0.20 mm below the apex of the sicula, and turns distinctly outwards after it has grown 0.5–0.62 mm, leaving the ventral portion of the metasicula free for 0.45–0.76 mm and forming an divergence angle of approximately 57–101°.

The proximal development is of the leptograptid-like isograptid type, either dextral or sinistral (Fig. 5.1, 5.2). The second theca (th1[2]) originates from th1[1] and crosses the sicula at an angle of 118–134°, leaving the dorsal wall of the metasicula free for 0.2–0.44 mm. Th1[2] is the dicalycal theca and gives budding to the third (th2[1]) and the fourth (th2[2]) autothecae. The sicula is either symmetrically (Fig. 5.3) or subsymmetrically (Fig. 5.4) disposed relative to the first pair of autothecae, depending on the preserving condition. The proximal end forms a shape of an anchor. The sicular bitheca is small, and closes at the same level where th1[1] diverges from the metasicula. The stipes occasionally bear bitheca (Fig. 4.7).

The first-order stipes are normally horizontal to slightly reclined. Their length is variable, some juvenile ones are about 1.9–3.73 mm long, and each bears two to three autothecae. Others are relatively long and may attain up to 7.34 mm in length, and each bears five to six autothecae before division (Fig. 5.5, 5.6). The stipes are generally slender and have a wide variation in width, from 0.14 to 0.21 mm near their proximal ends, and from 0.37 to 0.54 mm across thecal apertures. The stipes tend to be slightly reclined from th2[1] and th2[2] onwards. The dorsal edges of the stipes are slightly undulating. The autothecae, long and slender, are of leptograptid-like type. Th1[1] and th1[2] are 0.95–1.28 mm and 1.1–1.42 mm in length, respectively. The free ventral walls of the autothecae are somewhat concaved and the autothecal apertures are occasionally slightly isolated, free for 0.08–0.14 mm. The thecal overlapping ratio is around 0.48–0.52. Two thecae repeat distance (2TRD) near the proximal end is 1.9–2.5 mm.

Material.—Thirty-seven (37) specimens from the Nanba section in Yiyang, Hunan Province, South China.

Occurrence.—In the *Adelograptus tenellus* Biozone of the Yizhubu Formation in the Nanba section, Yiyang, Hunan Province, South China. *Ancoragraptus bulmani* is otherwise known from Oslo region of Norway (Spjeldnæs, 1963; Maletz et al., 2010) and Yukon, Canada (Jackson and Lenz, 2003; Jackson and Norford, 2004).

Remarks.—Spjeldnæs (1963) reported small-bodied *A. bulmani* with only two undivided stipes from the Oslo region of Norway. Because most of the specimens show only sicula and several thecae, these specimens were treated as juveniles by Spjeldnæs. Whether this species bears second-order branching or not was uncertain at that time. In addition, based on some branching fragments, he pointed out that if there was any second-order branching, it took place after the fifth thecae. This is confirmed by the new find of *A. bulmani* recovered in the Nanba section. Some specimens display second-order branching after the fifth thecae on one primary stipe (Figs. 3.16, 4.9, 4.10). However, others show that the primary stipes may not branch until more than six autothecae (Fig. 3.14). It is noteworthy that in the same horizon of Oslo, *An. bulmani* is associated with a species of *Adelograptus* which has thinner stipes, a shorter conical sicula and regular second-order branching at its fourth or fifth thecae. This species can be discriminated from *An. bulmani* by its relatively early branching. Jackson and Lenz (2003) reported *An. bulmani* from the *Adelograptus* cf. *tenellus* Biozone in Yukon, Canada. Compared with the type materials from the Oslo region, the specimens from Yukon have more obviously reclined stipes and less obviously isolate autothecal apertures in the first pair of autothecae. The Yukon form is more densely spaced (2TRD near the proximal end: 1.7–1.92 mm) than those from the type area (2TRD near the proximal end: 2.07–2.47 mm) and the Nanba section (2TRD near the proximal end: 1.9–2.5 mm). Furthermore, the Yukon form does not branch until up to the sixth theca on each stipe. This has been confirmed by specimens recovered later from Yukon (Jackson and Norford, 2004), which have two autothecae on each reclined, undivided primary stipe.

A careful study on *Bryograptus* Lapworth, 1880 from the NRC section in Norway was carried out by Maletz et al. (2010). In their paper, the specimens (e.g., Maletz et al., 2010, figs. 6C, D, L, M, 9B) with two relatively short primary stipes and isolate lower part of the metasicula were assigned to *An. bulmani*. These specimens have a shorter first pair of autothecae and a more obvious retellum than the type from Oslo. Some other specimens (Maletz et al., 2010. fig. 6A, E, F, J, I), which take second-order branching at the first or second autotheca, were also attributed by Maletz et al. (2010) to *An. bulmani*. These specimens do not match the definition of *An. bulmani*. They are closer to *An. psigraptoides,* which are characterized by a rather early second-order branching. An *Ancoragraptus* species, namely *Ancoragraptus* sp. (Maletz et al., 2010, fig. 9C, D), which without very detailed description, was recovered in association with *An. bulmani*. It branches early at th2[1], being well in accordance with *An. psigraptoides*. We consider *Ancoragraptus* sp. (Maletz et al., 2010) as a possible juvenile form of *An. psigraptoides*. A species reported as *Kiaerograptus* sp. A by Maletz and Egenhoff (2001) was recovered from the *Aorograptus victoriae* Biozone in Norway and resembles *An. bulmani* in rhabdosome shape but differs from the latter in having more robust stipes. This unidentified species is now treated by Maletz et al. (2010) as synonymous with *An. bulmani*.

Another uncertain species of *Kiaerograptus* was reported from the *Adelograptus tenellus* Biozone in the Nanba section (Feng et al., 2009). This species has two horizontal or slightly declined slender stipes, and transitional autothecal morphology between *Kiaerograptus* and *Paradelograptus* Erdtmann, Maletz, and Gutiérrez Marco, 1987. In recent (2009) fieldwork at the Nanba section we collected more such specimens. After a careful restudy on the new collections, we discriminated two types of graptolites formerly identified as *Kiaerograptus* sp. by Feng et al. (2009). One type (Feng et al., 2009, text-fig. 5a) which has curved autothecae and somewhat isolate thecal aperture is typical of *Ancoragraptus*. This form has been assigned to *An. bulmani* in the present study. The second type is tentatively designated as

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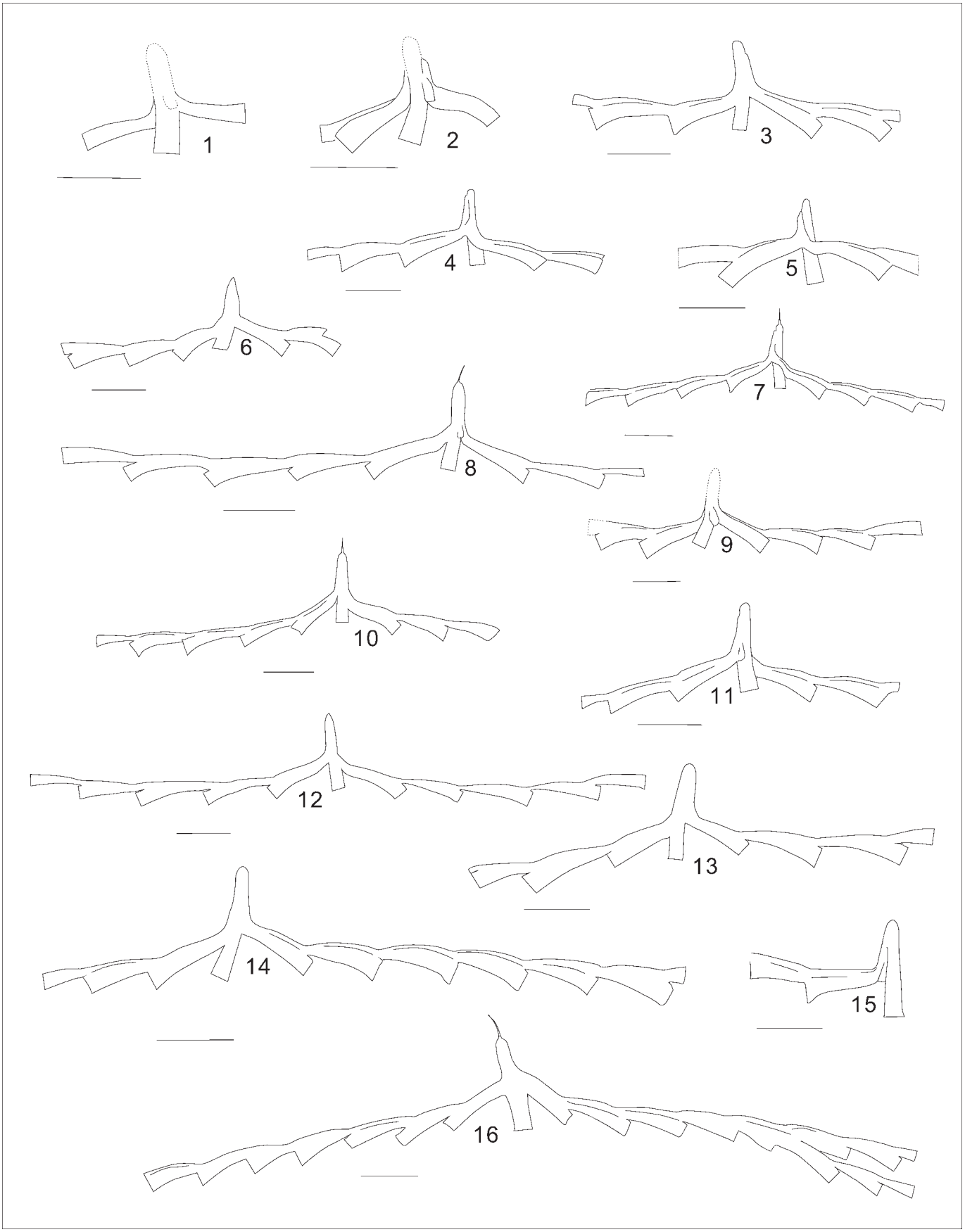

FIGURE 3—*Ancoragraptus bulmani* (Spjeldnæs, 1963) from the Nanba section, Yiyang, Hunan Province, South China. *1–16, A. bulmani*, YYN2-24-2, YYN2-24-1, YYN6-17, YYN5-270-3, YYN5-24-3, YYN5-66, YYN6-6, YYN5-257, YYN6-100d, YYN5-294, YYN6-12b, YYN5-264-7, YYN5-252, YYN6-23, YYN5-278, YYN5-208b, respectively. Scale bar=1 mm for all specimens.

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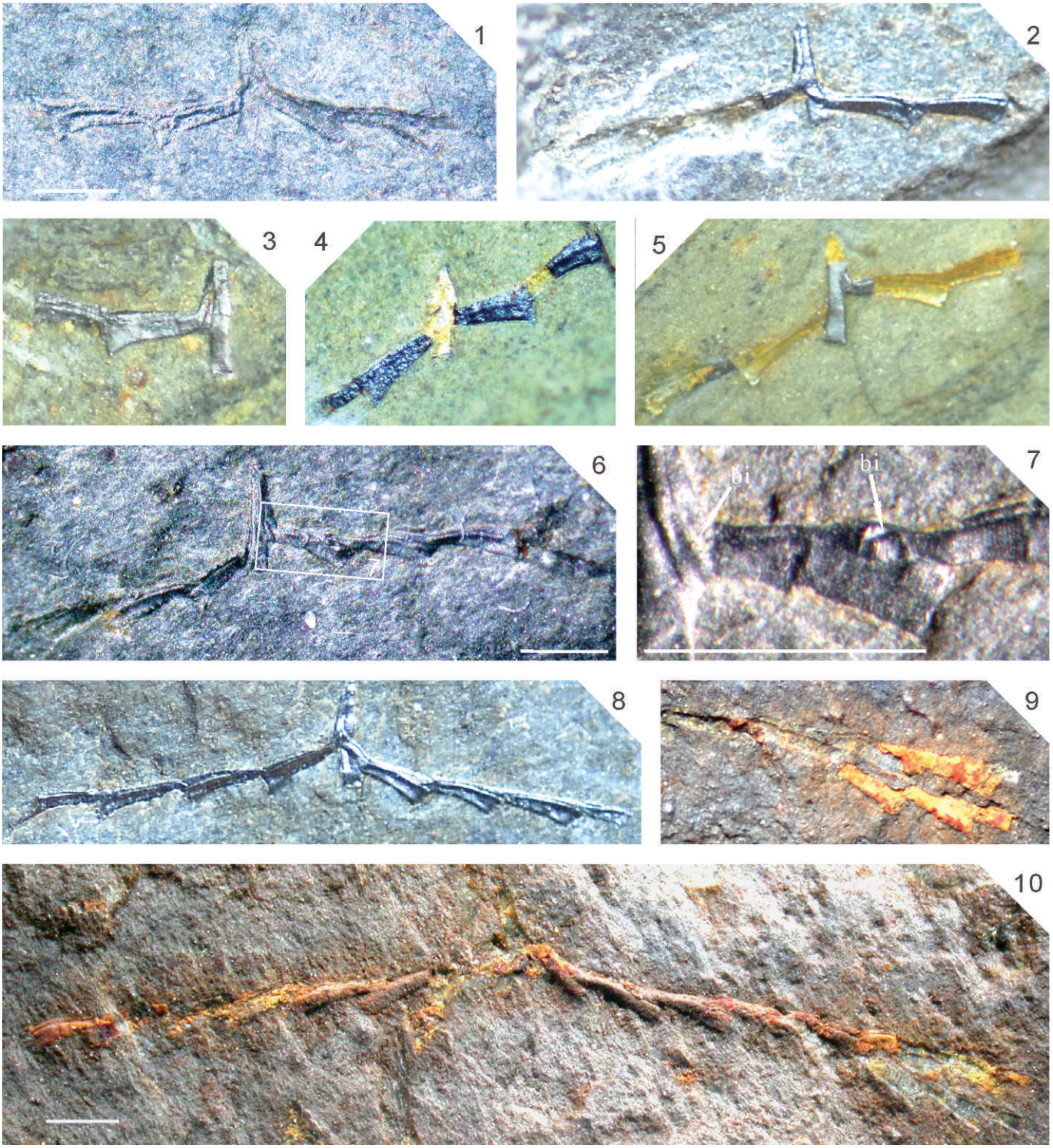

FIGURE 4—*Ancoragraptus bulmani* (Spjeldnæs, 1963) from the Nanba section, Yiyang, Hunan Province, South China. *1–6, 8*, *A. bulmani*, YYN6-17, YYN5-270-3, YYN5-278, YYN5-299-2, YYN5-270-1, YYN6-19, YYN6-6, respectively; *7,* bithecae details in *6*, YYN6-19; *9*, branching details of *10*, YYN5-208a; *10*, YYN5-208b. All scale bars=1mm. Scale bar in *1* also applies to *2*, *8*, and *9*; scale bar in *6* also applies to *3*, *4*, and *5*.

Kiaerograptus sp. Juvenile *An. bulmani* recovered from the Nanba section usually has two horizontal to slightly reclined stipes, and each stipe has three to five thecae. The juvenile specimens from Nanba section are more similar to the types from Oslo than those from Yukon. Companying with the juveniles, the adult specimens of *An. bulmani* display quite late second-order branching, which happened after the fifth thecae on each primary stipe (Fig. 5.6). Adult specimens of *An. bulmani* show three to four distal stipes, being different from *An. psigraptoides* which obtains up to the seventh-order stipes.

The emended diagnosis allows that *Ancoragraptus* with late second-order branching are included in *An. bulmani*. Other *Ancoragraptus* with early second-order branching are attributed to *An. psigraptoides*.

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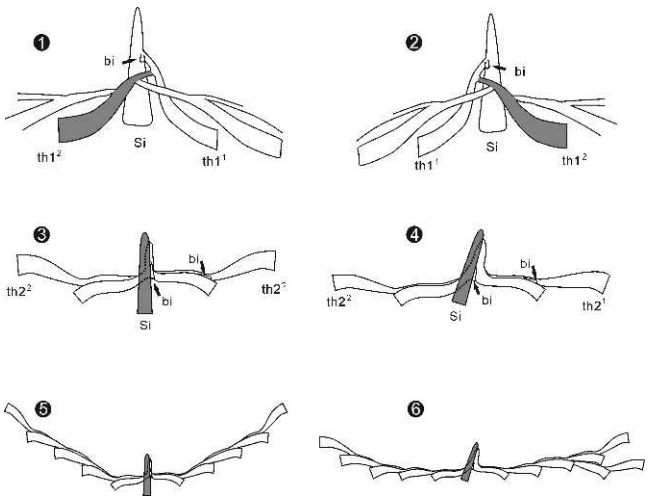

FIGURE 5—Proximal development and stipes diagrams for *An. bulmani* (Spjeldnæs, 1963). *1, 2*, reconstructions of proximal development: *1*, isograptid type, dextral development; *2*, isograptid type, sinistral development; *3*, *4*, proximal stipe attitude diagrams of *An. bulmani* show variations during preservation; *5, 6,* diagrams of mature specimens of *An. bulmani*: *5*, variant with long primary stipes; *6*, variant showing late second-order branching.

CONCLUSIONS

Following a comprehensive restudy of the genus *Ancoragraptus*, based on both literature review and new material recovered from the Yiyang area of South China, the diagnosis of *Ancoragraptus* is emended, and two species are included in the revised genus. The type species, *An. bulmani* is revised and now it represents ancoragraptid with late second-order branching. *Ancoragraptus* is a characteristic genus which only reported in strata of the early late Tremadocian age. It is an important taxon for the recognition of late Tremadocian time interval.

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