Latest Jurassic-earliest Cretaceous (Tithonian-Berriasian) dinoflagellate cysts from the Yanshiping Group of the northern Qinghai-Xizang Plateau (Tibet), western China

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ABSTRACT

Dinoflagellate cysts from the Xiali, Suowa and Xueshan formations (Yanshiping Group) of the Tanggula Mountains, Qinghai-Xizang Plateau, western China were studied. The palynofloras are sparse and poorly-preserved due to high levels of thermal maturation relating to intense tectonic activity. The Xiali, Suowa and the Xueshan formations are interpreted as being of Tithonian to Berriasian (latest Jurassic to earliest Cretaceous) age based on key markers such as *Amphorula delicata*, *Amphorula metaelliptica*,?*Batioladinium* sp., ?*Glossodinium dimorphum*, *Gochteodinia* sp., *Gonyaulacysta* sp. cf. *G. dualis*, ?*Muderongia* sp. and

?*Scriniodinium crystallinum*. The Jurassic-Cretaceous transition probably lies within the upper Suowa Formation. This sparse and low diversity assemblage cannot be easily compared with other floras of the same age. However *Amphorula* is relatively common, and this indicates a connection with the western Tethyan Realm. No endemic Austral or high latitude taxa were encountered. The sizes of the dinoflagellate cysts are markedly smaller than their respective type material. This phenomenon is interpreted as being a result of the loss of volatile components during intense thermal maturation. The dinoflagellate cyst biostratigraphy herein indicates that the narrowing and the closure of the meso-Tethys in western China occurred during the Tithonian and Berriasian.

Key words: dinoflagellate cysts; biostratigraphy; palaeogeography; latest Jurassic-earliest Cretaceous; Qinghai-Xizang Plateau; western China

1. Introduction

The Mesozoic marine palynofloras of the northeast Tethyan Realm are not well-known. For example, the only previous records of Jurassic and Cretaceous dinoflagellate cysts from the Tibetan plateau are brief reports by Mao and Bian (2000) and Cheng and He (2006). This study is on the dinoflagellate cysts of 14 samples from the Xiali, Suowa and Xueshan formations of the Yanshiping Group (Upper Jurassic-Lower Cretaceous) of the northern Qinghai-Xizang plateau, China. This area includes extensive outcrops of marine and non-marine Mesozoic strata which are crucial to the understanding of palaeogeography and tectonics in northeast Tethys (Figures 1, 2). The 14 samples studied herein were collected from the northern slope of the Tanggula Mountains near Wenquan village in Qinghai Province, China (Figures 3, 4). The pollen and spores from these samples were studied by Li and Batten (2004), who invoked an Early Cretaceous (Berriasian-?Barremian) age. By contrast, Cheng and He (2006) studied the marine microplankton from this succession and proposed a Middle-Late Jurassic (Callovian-Tithonian) age. The principal purpose of this contribution is to resolve the stratigraphical anomaly based on the previous age interpretations from the terrestrial and marine palynofloras (Li and Batten, 2004; Cheng and He, 2006 respectively).

Mao and Bian (2000) studied a single sample from the Yanshiping Group (undifferentiated) at the Yanshiping Village of southern Qinghai. It is characterised by abundant *Ctenidodinium combazii*, *Ellipsoidictyum cinctum* and *Lithodinia* spp. This association was interpreted as being of Bathonian to Callovian (Middle Jurassic) age. Cheng and He (2006) studied the Xiali, Suowa and Xueshan formations of the Wenquan village succession. These authors proposed six dinoflagellate cyst zones and concluded that these are Callovian-Tithonian (Middle-Late Jurassic) in age based on *Amphorula dodekovae*, *Amphorula metaelliptica*, *Ctenidodinium*? *schizoblatum*, *Pareodinia ceratophora*, *Scriniodinium crystallinum*, *Tenua wenquanensis* and *Tubotuberella egemenii*. The present authors have identified additional biostratigraphcally significant dinoflagellate cyst taxa that were not documented by earlier researchers from this succession. A revised stratigraphical interpretation is presented.

2. Geological Background

In the northern Qinghai-Xizang Plateau (northeast Tethys), there are extensive outcrops of marine and non-marine Mesozoic sedimentary rocks. These strata are located north of the Bangong Co-Siling Co Suture (Figure 2). Some preliminary palaeontological studies have been carried out on this succession, however the detailed biostratigraphy has still to be established (Westermann and Wang, 1988). Specifically the age of the youngest unit, the Xueshan Formation, is controversial. Some authors considered it to be Late Jurassic (Wang et al., 1979; Yin, 1988; Bai, 1989; Cheng and He, 2006), and others placed it within the Early Cretaceous (Jiang, 1983; Li and Batten, 2004).

The Mesozoic strata in the northern Qinghai-Xizang Plateau are termed the Yanshiping Group and consist of, in ascending stratigraphical order, the Quem Co, Buqu, Xiali, Suowa and Xueshan formations. The section studied here comprises the Buqu, Xiali, Suowa and Xueshan formations (Figure 4). However, only the Xiali, Suowa and Xueshan formations contain dinoflagellate cysts (Figure 5).

The Xiali Formation comprises 595.6 m of interbedded siltstone and sandstone with subordinate limestone and marl, with bivalves, charophytes, ostracods, plant fragments and pollen/spores (Figure 4). Dinoflagellate cysts are extremely rare (Figure 5).

The overlying Suowa Formation is represented by 838.7 m of rhythmic cycles of limestone, marl, mudstone and siltstone with abundant bivalves and miospores, and smaller proportions of charophytes and ostracods. The lowermost part of the succession has more marl beds. Dinoflagellate cysts are relatively common (Figure 5).

The youngest unit, the Xueshan Formation is around 229 m thick at this locality, with an erosional top. It comprises varicoloured interbeds of mudstone, sandstone and siltstone with bivalves, plant fragments, pollen and spores. The bivalves are largely concentrated in the lowermost beds. This unit is characterised by an increasing level of terrestrial input upsection. Dinoflagellate cysts are relatively common (Figure 5).

3. Material and methods

In this study, 14 samples from near Wenquan village were studied for dinoflagellate cysts (Figures 3, 4). The samples are all mudstones, a few of which are calcareous or silty. They were prepared using standard processing techniques (Wood et al., 1996). Hydrogen peroxide was used following the hydrochloric acid/hydrofluoric acid stages in order to bleach the darkened palynomorphs. Photomicrographs of selected dinoflagellate cyst specimens have been compiled as Plate I. The sample material, organic residues, microscope slides, primary data and figured material are housed in the collections of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, China.

4. The dinoflagellate cyst assemblages

The 14 samples in this study all produced extremely sparse, poorly-preserved palynomorph associations (Plate I). Pollen and spores are the dominant groups; dinoflagellate cysts and other marine microplankton proved to be consistently subordinate. The pollen and spores were previously studied by Li and Batten (2004). The samples are of high thermal maturity because all the palynomorphs are dark brown to black (see also Cheng and He, 2006, fig. 3). The poor preservation means that most of the dinoflagellate cysts are unidentifiable at species level (Figure 5, Plate I).

The most common dinoflagellate cysts are *Batiacasphaera* spp., *Pareodinia* spp. and indeterminate forms (Figure 5). Also present in significantly lower proportions are *Amphorula delicata*, *Amphorula metaelliptica*, *Amphorula* spp., *Meiourogonyaulax* spp., *Mendicodinium* spp. and *Sentusidinium* spp. In addition, rare specimens of ?*Batioladinium* sp., *Cribroperidinium* sp., *Ctenidodinium* sp., *Cyclonephelium* spp., ?*Gochteodinia* sp., ?*Glossodinium dimorphum*, *Gonyaulacysta* sp. cf. *G. dualis*, *Hystrichodinium* spp., ?*Muderongia* sp., ?*Scriniodinium crystallinum*, *Systematophora* spp. and *Tubotuberella* sp. were observed (Figure 5). There are no major differences in the marine palynofloras from the three lithostratigraphical units studied and, perhaps as a reflection of the sparseness of the assemblages, no perceptible diversity trends are evident (Figure 5). The occurrences of *Amphorula delicata*, ?*Batioladinium* sp.,?*Gochteodinia* sp., ?*Glossodinium dimorphum* and ?*Muderongia* sp. are all of stratigraphical significance; these forms were not recorded by Cheng and He (2006).

5. Discussion

5.1. Dinoflagellate cyst biostratigraphy and palaeobiology

The majority of the dinoflagellate cyst taxa recognised in these samples have relatively long ranges within the Late Jurassic to Early Cretaceous (Figure 5). These include the genera *Batiacasphaera*, *Cyclonephelium*, *Cribroperidinium*, *Ctenidodinium*, *Hystrichodinium*, *Meiorogonyaulax*, *Mendicodinium*, *Pareodinia*, *Systematophora* and *Tubotuberella* (e.g. Zotto et al., 1987; Riding and Thomas, 1992; Williams et al., 1993; Stover et al., 1996; Riding and Fensome, 2002). The associations are too sparse and poorly-preserved to allow definitive, high-resolution (i.e. chronozone or substage) biostratigraphical assessments.

Amphorula is the most biostratigraphically significant genus recognised in this study. It has been reported from Bulgaria, offshore Canada, Denmark, southeast France and the southwest North Atlantic (Dodekova, 1969; 1994; van Helden, 1986; Zotto et al, 1987; Monteil, 1990; 1992). The total range of this genus is late Oxfordian to Berriasian. *Amphorula delicata* and *Amphorula metaelliptica* are particularly diagnostic of the Jurassic-Cretaceous transition (van Helden, 1986, fig. 3; Monteil, 1990, tables 4, 5; Monteil, 1992, Table 1). For example, the first appearance of *Amphorula metaelliptica* is latest Tithonian in the Tethyan Realm (Monteil, 1992, Table 1). In the material studied herein, the inceptions of *Amphorula delicata*, *Amphorula metaelliptica* and *Amphorula* spp. are all in sample 3406 (Figure 5, Plate I, 8, 11, 12, 15, 16). This indicates that this horizon is close to the Jurassic-Cretaceous boundary.

There are other records which are entirely consistent with this interpretation. For example ?*Gochteodinia* sp. was observed in samples 3498 and 3601 (Figure 5). The inception of *Gochteodinia* is late Tithonian (Davey, 1979; Riding and Thomas, 1992; Poulsen, 1996; Herngreen et al., 2000). Single specimens of ?*Muderongia* were recorded from samples 2103 and 3501 in the Suowa Formation (Figure 5; Plate I, 6). The range base of *Muderongia* is early Tithonian (Riding et al., 2000) and most species of this genus are typical of the Early Cretaceous (Helby, 1987; Monteil, 1991). Therefore the age of sample 2103 is consistent with the Tithonian. *Systematophora* is present in samples 2204 and 3408 (Figure 5). This chorate genus is typical of the Oxfordian to Tithonian interval, but ranges into the Cretaceous (Brenner, 1988; Riding and Thomas, 1992).

Certain taxa are present which are characteristic of the Late Jurassic based largely on records from the Boreal Realm. These include *Gonyaulacysta* sp. cf. *G. dualis* (sample 3805), ?*Glossodinium dimorphum* (sample 3501) and ?*Scriniodinium crystallinum* (sample 3502). *Gonyaulacysta dualis* is typical of the late Oxfordian to the Kimmeridgian of the Northern Hemisphere (Brideaux and Fisher, 1976, fig. 13). *Glossodinium dimorphum* ranges from the mid Oxfordian to the late Tithonian in northwest Europe (Davey, 1979; Woollam and Riding, 1983; Riding and Thomas, 1992; Riding et al., 1999). The distinctive species *Scriniodinium crystallinum* is highly characteristic of the early Oxfordian to Tithonian (Riding and Fensome, 2002); however it ranges into the earliest Cretaceous (Berriasian) in the Southern Hemisphere (Helby et al., 1987, fig. 21). However, the specimen from sample 3805 identified as ?*Scriniodinium crystallinum* (Plate I, 18) exhibits some similarities to *Gonyaulacysta ceratophora*, *Gonyaulacysta fenestrata* and *Gonyualacysta jurassica*. All these taxa range into the Tithonian and Early Cretaceous in the Southern Hemisphere (Davey, 1987; Riding and Helby, 2001a,b; Riding, 2005). Therefore, the occurrence of ?*Scriniodinium crystallinum* and *Systematophora* spp. (Figure 5) is consistent with an earliest Cretaceous age. The occurrences of ?*Glossodinium dimorphum* in sample 3501 and *Gonyaulacysta* sp. cf. *G. dualis* in sample 3805 may represent Late Jurassic reworking.

Samples 3807 and 3902 from the uppermost part of the Xueshan Formation produced particularly sparse dinoflagellate cyst assemblages (Figure 5). Sample 3807 produced a single specimen of ?*Batioladinium* sp. (Plate I, 9). *Batioladinium* is characteristic of the Jurassic-Cretaceous transition and ranges into the Barremian

(Davey, 1982; Heilmann-Clausen, 1987; Bint and Marshall, 1988; Riding and Helby, 2001b). The presence of ?*Batioladinium* sp. in sample 3807, in the absence of other possible Jurassic markers such as ?*Glossodinium dimorphum* and *Gonyaulacysta* sp. cf. *G. dualis*, means that samples 3807 and 3902 are probably of Berriasian age (Figure 5).

Therefore, despite the poor-preservation and sparse nature of the dinoflagellate cyst associations from the Xiali, Suowa and Xueshan formations, the occurrences of *Amphorula delicata*, *Amphorula metaelliptica*, *Amphorula* sp., ?*Batioladinium* sp., ?*Gochteodinia* sp. and ?*Muderongia* sp. is indicative of a latest Jurassic to earliest Cretaceous (Tithonian-Berriasian) age (Figure 5). The Jurassic-Cretaceous boundary is probably within the middle to upper part of the Suowa Formation. The interpretations herein refine the Berriasian to ?Barremian age based on pollen and spores of Li and Batten (2004). By contrast, the conclusions herein do not support the Jurassic age interpretations for the Xueshan Formation of Wang et al. (1979), Yin (1988) and Bai (1989).

It is difficult to compare this low diversity, sparse dinoflagellate cyst association with coeval high diversity floras. For example, no endemic Arctic or Austral species were observed. It should be noted that the occurrence of *Gonyaulacysta* sp. cf. *G. dualis* does not necessarily indicate a connection to the high northerly latitudes because of its rarity and the uncertainty of the identification. *Gonyaulacysta dualis* was described from the late Oxfordian to Kimmeridgian of arctic Canada (Brideaux and Fisher, 1976, fig. 13). However, the relative prominence of *Amphorula* strongly suggests a direct connection with the western Tethyan area. This genus is reported in significant proportions from Bulgaria, southeast France and the southwest North Atlantic (Dodekova, 1969; 1994; Zotto et al, 1987; Monteil, 1990; 1992).

5.2. Marginal palynology

It is clear that the palynomorphs recovered in this study have been affected by thermal effects related to tectonic activity. Many specimens are too poorly-preserved to identify, in many cases even to generic level (Figure 5, Plate I). Traverse (1972) termed this situation, where the palynomorphs have been brought close to virtual total destruction by thermal effects, 'marginal palynology.' In highly tectonised areas, marginal palynology can help to elucidate the geological history. Riding (1984) represents another example of study on highly thermally-altered Mesozoic dinoflagellate cysts. In this study, significant conclusions on stratigraphy and tectonic history can be made on the basis of this material despite the poor preservation and low diversity. It is possible that these factors were influenced by palaeoenvironmental conditions. Hence future studies with more detailed sampling strategies should be undertaken.

It was noted that the size of the dinoflagellate cysts in this study are significantly smaller than their respective type material. Thermally unaltered specimens of *Amphorula metaelliptica, Gonyaulacysta dualis, Glossodinium dimorphum* and *Scriniodinium crystallinum* are consistently larger than their possible counterparts in this study. For example, the width of the type material of *Amphorula metaelliptica* is 50-75 µm (Monteil, 1990, p. 603). The width of this species in this study is 39-45 µm. These size differences can be greater than this, for example ?*Glossodinium dimorphum* and *Gonyaulacysta* sp. cf. *G. dualis*. In this study the lengths are 38 μm and 54 μm respectively. In the type material, these dimensions are markedly larger, 94-135 μm and 93-135 μm respectively (Brideaux and Fisher 1976; Ioannides et al. 1977). This phenomenon is best explained by the material studied herein being markedly reduced in size during the intense thermal maturation that these strata have undergone. It seems likely that the loss of the most volatile components in the sporopollenin during heating causes significant size decreases in palynomorphs.

The Yanshiping Group represents the late history of the meso-Tethys ocean, and the Xueshan Formation recorded the closure of this seaway (SBJGET, 1990; BGMRX, 1993; Sun and Zheng, 1998; Sha et al., 2004). Clearly it is important to derive accurate biostratigraphical ages for such major tectonic events. This study has determined that the closure and narrowing of the meso-Tethys in western China was during the latest Jurassic (Tithonian) and earliest Cretaceous (Berriasian).

The Qinghai-Xizang Plateau of western China was subjected to intense tectonic compression during the Cenozoic. It is this tectonic activity that has resulted in the high geothermal gradients which have baked the Xiali, Suowa and Xueshan formations and the adjacent lithostratigraphical units, leading to the poorly-preserved and sparse nature of the palynomorph assemblages. This study has shown that meaningful biostratigraphical interpretations can be derived from these highly altered palynomorphs. We agree with Traverse (1972) that biostratigraphical interpretations of 'marginal' assemblages in highly tectonised regions can be critical to the establishment of the geological history of these complex areas.

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Appendix 1

This appendix lists all the dinoflagellate cyst taxa below generic level mentioned herein with full author citations. The references for the author citations can be found in Fensome and Williams (2004).

Amphorula delicata van Helden 1986

Amphorula dodekovae Zotto et al. 1987

Amphorula metaelliptica Dodekova 1969

Ctenidodinium combazii Dupin 1968

Ctenidodinium? *schizoblatum* (Norris 1965) Lentin & Williams 1973

Ellipsoidictyum cinctum Klement 1960

Glossodinium dimorphum Ioannides et al. 1977

Gonyaulacysta ceratophora (Cookson & Eisenack 1960) Riding 2005

Gonyaulacysta dualis (Brideaux & Fisher 1976) Stover & Evitt 1978

Gonyaulacysta fenestrata Riding & Helby 2001

Gonyualacysta jurassica (Deflandre 1939) Norris & Sarjeant 1965

Pareodinia ceratophora Deflandre 1947

Scriniodinium crystallinum (Deflandre 1938) Klement 1960

Tenua wenquanensis Cheng and He 2006

Tubotuberella egemenii (Gitmez 1970) Stover & Evitt 1978

Figure captions:

Fig. 1. A palaeogeographical reconstruction for the latest Jurassic. The sample locality at Wenquan village, on the northeast margin of Tethys, is indicated by an asterisk.

Fig. 2. A simplified tectonic map of Indo-China. The sample locality at Wenquan village is indicated by the triangle located to the north of the Bangong Co–Siling Co Suture (BSS). Major Boundary Thrust = MBT; Indus-Yarlung Zangbo Suture = IYS.

Fig. 3. The locality of the Yanshiping Group outcrop studied at Wenquan village, northern Qinghai-Xizang Plateau, western China (triangle). The broad grey line in the southern part of the main map represents the Bangong Co–Siling Co Suture. The area depicted in the main part of the map is the rectangular shaded area on the inset map north of Lhasa.

Fig. 4. A lithostratigraphical log of the Yanshiping Group succession studied at Wenquan village, with the positions of the 14 samples indicated. The top of the Xueshan Formation is erosional.

Fig. 5. A semiquantitative range chart of dinoflagellate cysts and acritarchs in the 14 samples studied. The taxa which are asterisked were not recorded by Cheng and He (2006).

Plate explanation:

Plate I.

A representative selection of dinoflagellate cysts from the Xiali, Suowa and Xueshan formations of Wenquan village, China. The scale bar represents 10 µm. For all the figured specimens, the sample number, slide number and England-Finder coordinate are given. Note the high thermal maturity and the poor state of preservation of this material.

1. *Mendicodinium* sp. Note the epicystal archaeopyle and the smooth autophragm. Maximum width of the hypocyst, 44 µm. Xiali Formation, sample 1803, slide 5, K48/3.

2. *Batiacasphaera* sp. Note the well-developed accessory archaeopyle sutures, and the absence of ornamentation and tabulation. Maximum width of the hypocyst, 49 µm. Suowa Formation, sample 2103, slide 1, J32.

3. ?*Gochteodinia* sp. Note the relatively small apical horn and the low-relief ornamentation; much of the cyst body is obscured by a fragment of palynodebris. Maximum length of the hypocyst including the apical horn, 33 µm. Suowa Formation, sample 3408, slide C5, S36/4.

4. *Sentusidinium* sp. Note the apical archaeopyle with dense, short and sharp spines (processes). Maximum width of the cyst, 38 µm. Suowa Formation, sample 2701, slide 10, R42/4.

5. ?*Glossodinium dimorphum* Ioannides et al. 1977. Note the reduced antapical structure, and the well-developed sutural crests and cingulum. This specimen was designated questionable status because it lacks a prominent antapical structure, and is considerably smaller than the type material. Maximum length of cyst, 38 µm. Suowa Formation, sample 3501, slide 2, J38/3.

6. *Muderongia* sp. Note the apical archaeopyle, the cavate cyst organisation and the two horns on the hypocyst. Maximum width of the cyst 37 µm. Suowa Formation, sample 2103, slide 5, P48/3.

7. *Tubotuberella* sp. Note the elongate, angular outline and the antapical ‘tube’; the apical area appears to be damaged. Maximum length of the cyst, 43 µm. Suowa Formation, sample 2701, slide 10, S39/4.

8, 12. *Amphorula metaelliptica* Dodekova 1969. Note the relatively long, entire or perforated, arcuate/circular penitabular septa and the apical archaeopyle. 8 - Maximum width of the cyst 39 µm. Suowa Formation, sample 3408, slide C1, N39/3. 12 - Maximum width of the cyst 36 µm. Xueshan Formation, sample 3601, slide 1, L40/2.

9. ?*Batioladinium* sp. Note the apical archaeopyle and the single antapical horn. Maximum length of the cyst 40 µm. Xueshan Formation, sample 3807, slide 4, L42/2.

10. *Ctenidodinium* sp. An isolated hypocyst; note the epicystal archaeopyle and the lack of sutural ornamentation. Maximum width of the cyst 53 µm. Suowa Formation, sample 3408, slide C6, O47/3.

11, 16. *Amphorula* spp. Note the relatively short, closed, subrectangular to semicircular penitabular septa and the apical archaeopyle. Distal extremity of septa denticulate or flaring. 11 - Maximum width of the cyst 39 µm. Suowa Formation, sample 3406, slide C2, R35. 16 - Maximum width of the cyst 45 µm. Suowa Formation, sample 3408, slide C3, G43/3.

13, 14, 17. *Pareodinia* spp. Note the single apical horn and the anterior intercalary archaeopyle. 13 - Maximum length of the cyst 42 µm. Sample 2103, slide 4, U33. 14 - Maximum length of the cyst 46 µm. Sample 2103, slide 2, D36/2. 17 - Maximum length of the cyst 47 µm. Sample 2103, slide 1, J30/3.

18. ?*Scriniodinium crystallinum* (Deflandre 1939) Klement 1960. Note the cavate cyst organisation, the precingular archaeopyle, the prominent cingulum, the short apical horn and the broadly elliptical outline which are characteristic of this species. This specimen was given questionable status because of the major damage to the periphragm. Maximum width of the cyst 53 µm. Suowa Formation, sample 3502, slide C5, N37/2.

15. *Amphorula delicata* van Helden 1986. Note the relatively long, open, perforated, round to semicircular penitabular septa and the apical archaeopyle. Maximum width of the cyst 53 µm. Suowa Formation, sample 3406, slide 2, K42/2.

19. *Gonyaulacysta* sp. cf. *G. dualis* (Brideaux & Fisher 1976) Stover & Evitt 1978. Note the bicavate/circumcavate cyst organisation, the short hypocyst/long epicyst and the low, smooth sutural crests. This specimen is smaller than the type material, and lacks the long apical horn and prominent, occasionally denticulate, sutures of the type material. Maximum length of the cyst 54 µm. Xueshan Formation, sample 3805, slide 2, V38.

20. *Hystrichodinium* sp. Note the relatively short, delicate, distally-pointed processes, some of which may be broken. Maximum length of the cyst (without processes) 41 µm. Suowa Formation, sample 3103, slide 1, J31/2.