Gondwana Research 15 (2009) 111–130

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

K-bentonite, black-shale and flysch successions at the Ordovician–Silurian transition, South China: Possible sedimentary responses to the accretion of Cathaysia to the Yangtze Block and its implications for the evolution of Gondwana

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ARTICLE INFO

Article history:
Received 22 November 2007
Received in revised form 4 June 2008
Accepted 18 June 2008
Available online 2 July 2008

Keywords:
Cathaysia Block
Yangtze Block
K-bentonite-bearing black shale
Flysch
Geochemistry
Gondwana
Ordovician–Silurian transition

ABSTRACT

The K-bentonite, black shale and flysch successions at the Ordovician–Silurian transition in South China have been the subject of comprehensive investigations relative to the probable accretion of the Yangtze Block and the questionable Cathaysia Block. First, the geochemical analyses of K-bentonites show that the parent magma originated in syn-collisional, volcanic-arc and within-plate tectonic settings, which produced mainly intermediate-to-felsic series magmas, associated with continuous collision and subduction of paleo-continental blocks/arcs. Further, the regional distribution of K-bentonite thickness indicates that voluminous explosive volcanism was located in the present southeastern shoreline provinces of China. Secondly, northwestwardly migrating, Ordovician–Silurian, transitional flysch successions, and the accompanying diachronous K-bentonite-bearing black-shale interval, as well as the related, overlying, shallowing-upward succession at the interior of the Yangtze Block, developed as an unconformity-bound sequence that mirrors foreland-basin tectophase cycles in the Appalachian basin. The above features suggest that the sequence accumulated in a similar foreland basin, which formed in response to adjacent deformational loading in a northwesterly migrating orogen located to the southeast. Geochemical and paleocurrent data from the turbiditic flyschoid sandstones also support these depositional settings. Accordingly, it seems that all criteria strongly support the presence of an Ordovician–Silurian, subduction-related orogen resulting from collision with a block to the southeast that must have been the original “Cathaysia Block” of Grabau and later workers. The K-bentonite, black-shale and flysch successions can be regarded as distal, foreland responses to the continuous northwestward collision and accretion of the Cathaysia Block to the Yangtze Block. Hence, we prefer to suggest that the suture zone with the *sensu stricto* Cathaysia Block probably developed along previously identified late Early Paleozoic suture relicts in the shoreline provinces of southeast China. On the other hand, although accretion of fragments with Cathaysian affinities to the Yangtze Block may have begun as early as Middle to Late Proterozoic time, the Ordovician–Silurian orogeny described above probably reflects the final phase of accretion between the two blocks. Moreover, when combined with similar peri-Iapetan orogenic events in other areas during the same period, this accretion event may have been part of a major stage of global tectonic reconstruction in the evolution of Gondwana.

1. Introduction

Traditionally, efforts to determine the boundary between two paleocontinents, or that between a continent and a volcanic island-arc that were accreted during related orogenic periods, have been based mainly on the identification of fossil sutures. In such studies, attention is particularly paid to the occurrence of ophiolite suites, mélanges, and syn-collision magmatism, as well as to the relevant metamorphism. Further, paleobiogeographic data and the polar wandering paths of the different blocks also are commonly considered. However, if the collision had occurred long ago, any fossil suture or related evidence would have been deformed and severely superimposed during subsequent orogenic periods (e.g., South China, see Wang et al., 2005; Li and Li, 2007), and it would be extremely difficult to identify and determine the exact accretion scenario.

Then the question arises, is it possible to determine the possible accretion of continents through the sedimentary record in the related stable cratonic areas and in the remains of an adjacent foreland basin?

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doi:10.1016/j.gr.2008.06.004

The answer is, of course, yes. In fact, many people have tried successfully through studies of certain sedimentary sequences in various tectonic settings, such as the well-known K-bentonite clusters from the Americas and Europe (e.g., Huff et al., 1992; Astini et al., 2007), the black/dark shales in North America (e.g., Ettensohn, 1994), and the flysch deposits of the European Alps (e.g., Hsü, 1972; Sinclair, 1997a). Furthermore, some authors have used computer models of various kinds to support the depositional records mentioned above (e.g., Ettensohn, 1994; Sinclair, 1997b; Allen et al., 2001; Ettensohn, 2005). In this study, we would like to introduce an integrated case study of K-bentonite-bearing black shales and flysch successions around the Yangtze Block during the Ordovician–Silurian transition in South China, with the goal of illuminating the long-lived debate about the Cathaysia Block and its evolution.

The "Cathaysian Oldland" or "Cathaysia Block" of Grabau (1924) has been considered to be a significant tectonic unit in southeast China for many years. Although both the definition and extent of this "block" are still debated, this block or small plate is currently situated on the southeast margin of present-day China and is bordered to the northwest by the former Yangtze Block or plate in southeast-central China (Fig. 1). Obviously, determining its relationship to the Yangtze Block and its geologic history has important implications for understanding the tectonic evolution of both South China and East Asia.

Some workers have suggested that the area of the Cathaysia Block is a folded orogenic belt rather than a cratonic plate (e.g., Hsü et al., 1988, 1990). However, more recent studies have suggested that there was a collision zone at the southeast margin of the Yangtze Block that resulted from the collision of Yangtze and Cathaysia, which began in Middle to Late Proterozoic time (e.g., Chen et al., 1991; Xu et al., 1992; Li et al., 1995; Chen and John, 1998; Zhao and Cawood, 1999; Li et al., 2002; Ye et al., 2007; Wang et al., 2008; Li et al., 2008a,b) and probably lasted through Early Paleozoic time, although the inferred position of the suture is somewhat different in the interpretation of each worker or group (e.g., Wang, 1985; Shui, 1988; Xu et al., 1996; Wang et al., 2005; Fitches and Zhu, 2006). Others, however, do not think that the suture developed until Early Paleozoic time, and they have suggested that the collision occurred at another position to the southeast of the present mainland of China and resulted from collision between a "united Yangtze–Cathaysia plate" and an undetermined cratonic plate (e.g., Rong and Chen, 1987; Chen et al., 1995a; Chen and Mitchell, 1996; Rong et al., 2003; Chen et al., 2004). Moreover, still other authors think that there were several terranes or microcontinents southeast of the Yangtze Block and that even more than three "sutures" or convergence zones may be present in the area (e.g., Guo et al., 1984; Charvet et al., 1996; Wu, 1999; Charvet et al., 1999; Hoe and Rangin, 1999) (see Fig. 1). Metcalfe (e.g., 1996, 2006) has mentioned for years that the "South China Block (including mainly the Yangtze and 'Cathaysia') is a composite terrane" with a complicated history. Obviously, several major problems involving relationships between the Yangtze and Cathaysia blocks must still be considered. These problems include: whether or not the Cathaysia Block existed in southeast China; where the western boundary of Cathaysia was or what the exact definition of the term "Cathaysia Block" is; and what the nature of the accretion process was.

In the following discussion, we would like to examine several new lines of evidence that have a definite bearing on the above questions. One of these centers on the mineralogical and chemical composition and distribution patterns of altered volcanic ash falls, or bentonites. Ordovician–Silurian K-bentonites in Europe and the Americas have proven to be very useful tools for probing the tectonic setting of the parent magmas of the relevant volcanoes in addition to serving as unique chronostratigraphic marker beds for the timing of collisional events (e.g., Huff et al., 1992; Haynes, 1994; Kolata et al., 1996; Huff et al., 1998a,b; Huff et al., 2003; Batchelor et al., 2003; Ramos, 2004; Astini et al., 2007; Zhang et al., 2007).

On the other hand, the huge rhythmic sandy-muddy turbidite successions in marine basins near former plate margins, especially foreland basins, commonly reflect flysch and related deposits that are typically correlated with different sedimentary environments in particular tectonic settings (cf., Bouma, 2004). In addition, not only can the position of these deposits in a sequence provide important interpretive tectonic information (e.g., Ettensohn, 1994; Sinclair, 1997a,b; Allen et al., 2001), but analyses of clastic components, litho-chemical elements from the resulting rocks, and paleocurrent data from the successions can also provide additional information on depositional environments, tectonic settings and source-area characteristics (e.g., Hsü, 1972; Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1988; Bouma, 2004).

Realizing that black- or dark-shale deposition, both in foreland and neighboring intracratonic basins from North America, reflects distinct tectophases of deformational activity in any one Paleozoic orogeny due to rapid, loading-related, lithospheric subsidence and sediment starvation in the resulting basins, Ettensohn (e.g., 1991, 1994, 1998a,b, 2004) proposed a flexural model based on previous studies (e.g., Karner and Watts, 1983; Quinlan and Beaumont, 1984; Beaumont et al., 1988) that accurately predicts associated stratigraphic successions in the resulting foreland basins. According to this model, black-shale deposition and an underlying unconformity, as well as an overlying, shallowing- and coarsening-upward, clastic wedge form a genetic sequence that is interpreted to have resulted from forebulge and foreland-basin migration as a consequence of progressive overthrust loading in an adjacent orogen during active subduction (Ettensohn, 2005). It is noteworthy that other authors have revealed a similar, stratigraphic, flexural-response process in the Swiss Alps (e.g., Sinclair, 1997a,b; Allen et al., 2001), and the recurring success in model application suggests that the flexural model may be reasonably applied in other convergent-margin settings.

Theoretically, an active subduction zone should occur with a trench, a volcanic arc, and a foreland or retro-arc basin in time and space. Although most of these large-scale, tectono-geomorphic features will not be preserved, their presence can be inferred from studies of the preserved sedimentary record in both the foreland and neighboring intracratonic basins. Hence, an integrated study of the K-bentonite, black-shale, and associated flysch deposition within the same stratigraphic framework can be helpful in understanding the likely position and age of a former, deformational orogen and the relevant plate-movement processes that generated it. Here, we would like to introduce such a study based on new stratigraphic and sedimentologic data from South China near the Ordovician–Silurian transition and use it to suggest an interpretation relative to the unresolved problems about relationships between Yangtze and Cathaysia blocks noted above.

2. Geological setting

During early-mid Early Paleozoic time, depositional facies on the Yangtze Block, which includes the present northwestern and central parts of South China, encompassed three different facies belts, the Yangtze region, the Jiangnan (south of Yangtze River) region, and the Hua'nan (South China in the narrow sense) region, which represent platform, slope and basinal environments, respectively (Fig. 1). Some workers prefer to call the first region, in a narrow sense, the "Yangtze Platform," whereas the latter two regions are commonly joined together with the designation, "slope-basin" or "Zhe-Gan-Xiang-Gui Marginal Sea." The distribution of these environments, however, apparently changed during Late Ordovician to Early Silurian time (see Wang, 1985; Yang et al., 1986; Wang and Chen, 1995; Mao and Wang, 1999; Rong et al., 2003; Chen et al., 2004). Although severely deformed, what remains of the so-called Cathaysia Block in a broad sense occurs just southeast of the Yangtze Block, but different viewpoints still prevail about the boundary between the two blocks (see Fig. 1; e.g., Li et al., 1995, 2002; Chen et al., 2004; Fletcher et al., 2004; Wang et al., 2005; Metcalfe, 2006, and references therein).