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Tectonics and surface effects of the supercontinent Columbia

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ABSTRACT

Assembly of the supercontinent Columbia at about 1.85–1.90 Ga coincided with several events that affected the entire earth. The oldest worldwide network of orogenic belts formed at the same time. Although some granite–granodiorite (GG) suites had formed earlier, the GG suites became common in the 1.8–1.9 Ga orogenic belts. These suites succeeded the older tonalite–trondhjemite–granodiorite (TTG) suites, which were not produced after 1.8 Ga. Changes on the earth's surface at 1.8–1.9 Ga include rapid increase in the concentration of oxygen in the atmosphere and oceans and probably the evolution of eukaryotes. All of these surface changes occurred as Columbia accreted, and the assembly of Columbia may have contributed to the drastic changes in the earth's surface environment as well as to the evolution of primitive life forms.

1. Introduction

The supercontinent Columbia was first proposed in an abstract by Rogers (2000). Two slightly different configurations were then described in articles by Rogers and Santosh (2002), who suggested a maximum packing at 1.6 Ga, and G. Zhao et al. (2002), who suggested a maximum packing at 1.8 Ga. Condie (2002) and G. Zhao et al. (2002) also called attention to the worldwide distribution of orogenic belts with ages of about 1.8 Ga. Hou et al. (in press) proposed a third configuration of Columbia slightly different from the other two.

In the more than five years since Columbia was proposed, the configuration of this supercontinent has been useful for several types of investigations. They include both tectonic and surface processes. In this paper, we synthesize the recent information on Columbia and address the following major aspects: (1) the concept of "maximum packing" of supercontinents, which recognizes that supercontinents break-up in some places at the same time as they are assembled in other regions; (2) new information about the configuration, age, and components of Columbia; (3) new work on the occurrence of Palaeoproterozoic orogenic belts; (5) recent discoveries about the oldest granite–granodiorite magmatic suites developed during subduction; (6) new work on 1.9-Ga granite–granodiorite (GG) suites; and (7) new insights on changes that occurred in the atmosphere and oceans at about the same time as the accretion of Columbia.

Based on this information, we consider a possible relationship between Palaeoproterozoic tectonics and changes in the atmosphere and oceans.

2. Maximum packing of supercontinents

The concept of "maximum packing" of supercontinents recognizes that accretion and dispersion both occur simultaneously in different parts of the same supercontinent. The age of maximum packing is, consequently, the time at which the greatest amount of continental lithosphere is attached to a single landmass. We clarify this process by using the well documented history of Pangea (Fig. 1; Veevers, 1995; further references and summary in Rogers and Santosh, 2004).

Fig. 1 shows the configuration of Pangea during its maximum packing at about 250 Ma (see caption for explanation of method of projection). At this time, the Permian suture between the South China and North China cratons was complete and contained several ultrahigh-pressure (UHP) terranes (Wang et al., 2005; Hacker et al., 2006; Rogers and Bernosky, 2008). Suturing between North China craton and Siberia along the Mongolian fold belt, apparently began in the late Paleozoic but was not completed until the Triassic (Donskaya et al., 2008).

Suturing of the North China and South China blocks to Eurasia may not have been completed before Cimmerian terranes (Fig. 1) began to rift from Gondwana in the late Paleozoic (Ueno, 2003). Whether the terranes rifted as one coherent block or as several separate blocks and accreted to Eurasia as one or several blocks is uncertain. Regardless of the process, it is clear that rifting and accretion were occurring at the

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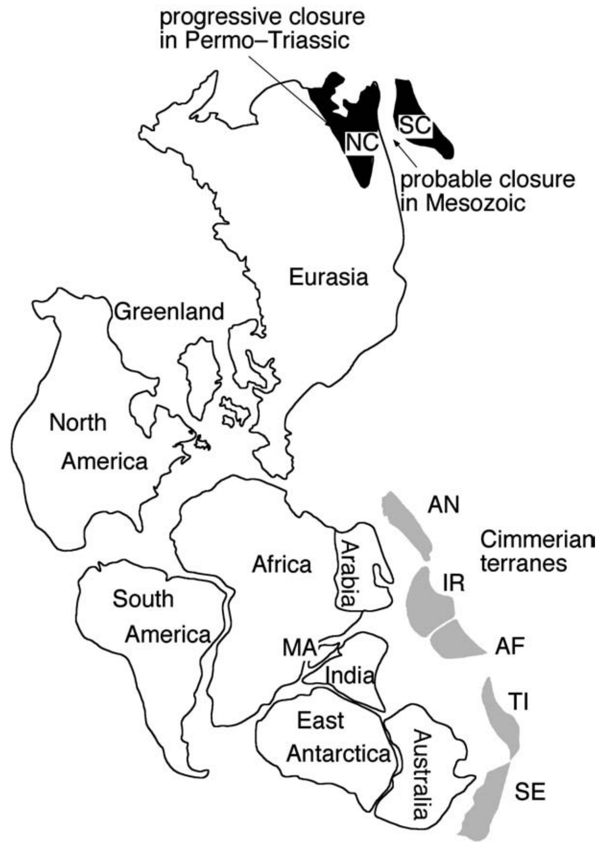

Fig. 1. Pangea as an illustration of the concept of maximum packing at about 250 Ma. Suring of the North China craton (NC) to Eurasia was only partly complete at this time, and the South China block (SC; Cathay and Yangtze cratons) may not have begun to accrete to Eurasia. Cimmerian blocks are: AN, Anatolia; IR, Iran; AF, Afghanistan; TI, Tibet; and SE, Southeast Asia. The Cimmerian blocks may already have separated from the Gondwana part of Pangea in the late Paleozoic.

same time in different parts of Pangea, and the age of maximum packing can only be estimated as 250 Ma.

3. New information about the configuration, age, and components of Columbia

Work in several areas supports or refines the proposed configurations and components of Columbia and also the ages of assembly and dispersion.

One major change in understanding the configuration and components of Columbia comes from investigations in the North China craton (NCC), which is also known as the Sino-Korean craton. Rogers and Santosh (2002) did not include the NCC in their configuration of Columbia, but G. Zhao et al. (2002, 2004) placed the NCC adjacent to the west coast of India, and Wilde et al. (2002) also proposed that the NCC became part of a supercontinent at about 1.8 Ga.

The previous work was followed by additional papers that refined ages in the North China craton. Liu et al. (2006) and G. Zhao et al. (2008) presented U/Pb data for zircon and monazite that showed ages of 1.83–1.88 Ga for the Trans-North China orogen. Xia et al. (2006) found that zircons in the Jining complex had been metamorphosed at 1.81 Ga, and Wan et al. (2006) presented SHRIMP zircon ages that demonstrate late Palaeoproterozoic metamorphism in the North China craton.

The identification of the North Hebei orogenic belt with ages in the range of 1.8–1.9 Ga further demonstrates that the North China craton was part of Columbia (Kusky and Li, 2003; Santosh et al., 2006; Santosh et al., 2007a,b; Kusky et al., 2007; Hou et al., 2008; Santosh et al., 2008). Recent U–Pb monazite ages (Santosh et al., 2007a) and SHRIMP zircon data (Santosh et al., 2007b) from ultrahigh-temperature granulite facies rocks along the North Hebei orogenic belt place the timing of collisional tectonics and incorporation of the North China craton into the Columbia assembly at about 1.9–1.85 Ga. Work in the Qilian Mountains along the southwestern border of the NCC also shows accretion of the NCC to Columbia before 1.8 Ga (Kuoan et al., 2007).

Breakup of parts of Columbia may have occurred as early as 1.88 Ga. French et al. (2008) recently discovered a Large Igneous Province (LIP) of basaltic rocks in south-central India and described similar 1.88-Ga basaltic suites in other cratons. Mafic dikes and aulacogens in the NCC from 1.84–1.77 Ga indicated breakup of the NCC part of Columbia (Zhao et al., 2002, 2004; Hou et al., 2006a,b; Peng et al., 2007; Hou et al., 2008, in press). Breaking of the NCC away from Columbia is also shown by Xiong'er rift sequence that began to develop at 1.8 Ga on the southern margin of the North China craton (Zhao et al., 2004).

Srivastava and Rao (2007) described lamprophyric and other alkaline rocks in central India that apparently formed at about 1.6 Ga. Because basaltic and alkaline rocks generally form in extensional environments, these rocks indicate that central India began undergoing extension shortly after 1.9 Ga and was still fragmenting at 1.6 Ga. Srivastava and Rao (2007) also pointed out that similar rocks of 1.6-Ga age occur in western Australia, and hence it is possible that all of Columbia had begun to break apart by 1.6 Ga. Articles in Chetty et al. (2006) show that shearing and rifting continued in southern India through the Neoproterozoic.

These new data confirm that Columbia was mostly assembled by about 1.9–1.85 Ga, prior to the 1.6 Ga age originally suggested by Rogers and Santosh (2002) for the assembly of this supercontinent, and probably even slightly earlier than 1.8 Ga, as originally proposed by G. Zhao et al. (2002). Subsequent extensional collapse in various regions of Columbia has been documented from the emplacement of alkaline and basaltic rocks beginning at about 1.9 Ga.

Fig. 2a, b, and c show three possible configurations of Columbia and the position of the NCC in it. One difference between the configurations is the coherence of the three continental blocks proposed by Rogers (1996). They include: 1) Ur, formed at 3 Ga as an assemblage of the Kaapvaal and Zimbabwe cratons of southern Africa, part of Madagascar, three cratons in India, and the Pilbara craton of western Australia; 2) Arctica, formed at 2.5 Ga and consisting of Siberia, the Canadian shield of North America, and much of Baltica (Gower et al., 1990, used the name Nena for the combined North America and Baltica); and 3) Atlantica formed at 2 Ga and containing much of West Africa and northeastern South America.

Fig. 2a shows a possible location of the NCC attached to the configuration of Columbia originally proposed by Rogers and Santosh (2002). This configuration maintains the coherence of Ur, Arctica, and Atlantica and places eastern India against western North America. The configuration originally proposed by Rogers and Santosh (2002) did not include the NCC, and we include it here by correlating the North Hebei belt of the NCC with the Volhyn belt of Baltica (Claesson et al., 2001). This position also places the southern margin of the NCC (present orientation) against at least two 1.9-Ga belts of Greenland and North America (see below).

Fig. 2b shows the NCC in the position proposed by G. Zhao et al. (2002, 2004). This position is based on a correlation of the Trans-North China Orogen with the Central Indian Tectonic Zone, both of which were active at 1.9–1.8 Ga. This configuration includes the continental blocks Arctica and Atlantica but does not accept the coherence of Ur since its proposed formation at 3 Ga.

Fig. 2c shows the configuration of Columbia proposed by Hou et al. (in press). This configuration is based on the similarity of the North Hebei belt and Wopmay orogen of western Canada as Andean belts along continental margins.