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Priscoan (4.00–4.03 Ga) orthogneisses from northwestern Canada

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Abstract Ancient crustal rocks provide the only direct evidence for the processes and products of early Earth differentiation. SHRIMP zircon U-Th-Pb dating has identified, amongst the Acasta gneisses of the western Slave Province, Canada, two metatonalites and a metagranodiorite that have igneous ages of 4002 ± 4, 4012 ± 6 and 4031 ± 2 Ga respectively. These are the first identified Priscoan terrestrial rocks. A record of metamorphic events at ~3.75, ~3.6 and ~1.7 Ga also is preserved. These discoveries approximately double, to about 40 km², the area over which ~4.0 Ga gneisses are known to occur. A single older zircon core in one sample suggests that rocks as old as 4.06 Ga might yet be found in the region. As early as 4.03 Ga, terrestrial differentiation was already producing tonalitic magmas, probably by partial melting of pre-existing, less differentiated crust.

Introduction

Continental crust covers about 40% of Earth’s surface and is about 0.4% of Earth’s volume. Archean (2.5–4.0 Ga) continental crust accounts for less than 0.05% of the planet’s mass and less than 15% of the present continental area. Continental crust older than 3.8 Ga is known from only a few localities, and has a total exposure area of a few hundred square kilometres. From a planetary perspective it seems likely that Earth’s first or primary crust was basaltic in composition (Taylor 1992), however most fragments of Archean crust preserved today are neither primary nor basaltic. Thus, the processes operative during the first 600 million years of Earth history must be inferred from much younger rocks.

A major issue in the study of Earth’s evolution is whether the present volume of continental crust is principally the result of gradual crustal accumulation, with only limited amounts of recycling (McCulloch and Bennett 1994), or instead a ‘snapshot’ of an approximately steady-state condition in which formation of new crust is balanced by return of older crust to the mantle (Armstrong 1991; Bowring and Housh 1995). Stated in another way: does the relatively small amount of silicic crust older than 3.8 Ga reflect the amount of crust that formed, or is it all that remains following plate-tectonic recycling and disruption by bolide impacts? The answer to this question has far-reaching implications for a variety of issues that range from explaining the present geochemical organization of the planet, to determining the composition of Archean sea water and the role of continental crust in the emergence of life.

Identification and characterization of the few surviving fragments of ancient crust provides the most direct evidence available of the processes which shaped the early Earth. Continental crustal rocks older than 3.8 Ga are now known or inferred from the Wyoming and Slave Provinces of North America (Bowring et al. 1989; Mueller et al. 1992), northern Labrador (Collerson et al. 1991; Bridgewater and Schiøtte 1991), Greenland (Nutman et al. 1996), China (Song et al. 1996), and Antarctica (Black et al. 1986). In addition, 4.1–4.3 Ga detrital zircons interpreted to have been derived from continental crust have been found in Western Australia (Froude et al. 1983, Compston and Pidgeon 1986). These discoveries show that continental crust older than 3.8 Ga was once far more voluminous and widespread than at present, and that some crustal remnants did
survive the intense meteorite bombardment early in Earth history. Furthermore, because Earth’s history has been dominated by plate tectonics, the dimensions of today’s Archean cratons are unlikely to reflect their original size.

The oldest rocks currently known are the Acasta gneisses (hereafter the Acasta Gneiss Complex) from the Northwest Territories of Canada (Bowring et al. 1989, 1990). In this paper we present new zircon U-Pb isotopic analyses for three samples of tonalitic to granodioritic Acasta gneiss which are significantly older than any previously described, and which together double the known areal extent of ~4.0 Ga rocks. They are the first Priscoan (>4.0 Ga; Harland et al. 1990) terrestrial rocks identified. Stern et al. (1997) have reported dates as old as 4.02 Ga from the same outcrop reported on by Bowring et al. (1989).

**The Acasta Gneiss Complex**

The Acasta Gneiss Complex (AGC) is exposed along the western margin of the Slave craton (Fig. 1) in the northwest corner of the Canadian Shield (Bowring et al. 1989, 1990). It consists of a heterogeneous assemblage of 3.6 to >4.0 Ga foliated to gneissic tonalites, granodiorites and granites, as well as an assortment of amphibolites and ultramafic rocks of as yet unknown age. Detailed mapping, coupled with U-Pb geochronology, has documented a complex history of intrusion and deformation.

Deformation of the complex is highly variable. In areas of high strain, finely banded gneisses consisting of layers of different age and composition are juxtaposed. In local low strain zones, however, the layering is defined by sharp contacts between rock types, and cross-cutting relationships (variably deformed) between primary igneous precursors are preserved. Samples from such low strain domains provide direct evidence for the igneous processes responsible for development of Earth’s oldest known crust.

Samples for the present study were collected from a sequence of broadly layered amphibolitic and tonalitic gneisses preserved in low strain areas where the layering commonly reflects primary intrusive relationships. They are from a zone of ~4.0 Ga gneisses, which mapping has shown to extend at least 10 km south of the original discovery outcrops described by Bowring et al. (1989). Sample SAB91-63 is a gray, weakly foliated tonalitic gneiss, SAB91-37 is a foliated tonalitic gneiss from a zone of amphibolitic and tonalitic gneisses interbanded on a 10 to 45 cm scale, and SAB94-134 is a foliated, gray, granodioritic gneiss containing small (5 x 20 mm) granitic pods or segregations and cut by a dike of 3.6 Ga non-deformed granite.

**Zircon U-Pb geochronology**

Most zircon grains from the Acasta gneisses, having been affected by radiation damage, recrystallization and multiple thermal events, are structurally extremely complex. This is not unusual for zircon from poly-metamorphic Archean terranes (e.g. Black et al. 1986; Pidgeon 1992). Isotope dilution analyses of selected Acasta zircon fragments have yielded $^{207}\text{Pb}/^{206}\text{Pb}$ ages as old as 3.98 Ga (Davidek et al. 1997), but the SHRIMP (Sensitive High Resolution Ion MicroProbe) ion-microprobe, with its high spatial resolution, is a much better means of unraveling the record of the gneisses’ multi-stage thermal history preserved in the micron-scale zonation of individual zircon grains. Zircon was analyzed using both the SHRIMP I and II ion microprobes at the Australian National University. The analytical procedure broadly followed that of Williams and Claesson (1987) and Williams et al. (1996). Reference zircons SL13 (572 Ma) and AS3 (1099 Ma) were used as standards for the measurement of $^{206}\text{Pb}/^{238}\text{U}$. 

![Fig. 1 Simplified geologic map of the type locality of the Acasta gneisses (Pattern free areas are lakes)](image-url)