3.96 Ga gneisses from the Slave province, Northwest Territories, Canada

S. A. Bowring
Department of Earth and Planetary Sciences, Washington University, Campus Box 1169, St. Louis, Missouri 63130-4899
I. S. Williams, W. Compston
Research School of Earth Sciences, Australian National University, G.P.O. Box 4, Canberra, ACT 2601, Australia

ABSTRACT

Ion microprobe U-Pb analyses of zircons have identified the Acasta gneisses, from the westernmost Slave province, Canada, as the oldest known intact terrestrial rocks. Zircons from two samples indicate that the tonalitic to granitic protoliths of the gneisses crystallized at 3962 ±3 Ma, confirming earlier indications, from conventional zircon and Nd analyses, of the rock's antiquity. The U-Pb analyses indicate that in addition to recent Pb loss, the zircons underwent an early episode of Pb loss and that new zircons crystallized ca. 3.6 Ga. The gneisses were derived from a source that had a long-lived enrichment in light REE, possibly from even older rocks that may be present in the Slave province.

INTRODUCTION

Early Archean rocks were discovered in the westernmost Slave province in the course of isotopic dating (Bowring and Van Schmus, 1984) and regional geologic mapping (St-Onge et al., 1988) of the Early Proterozoic Wopmay orogen by members of the Geological Survey of Canada and Bowring. Further isotopic work by Bowring et al. (1989) on an assemblage of gneisses, informally termed the Acasta gneisses, has provided evidence that some of the rocks may be very old indeed, having Nd_{CHUR} model ages up to 4.1 Ga and containing zircons with a minimum age of 3.84 Ga. The zircons had been analyzed as single- and multiple-grain samples by standard isotope dilution techniques; however, the data indicated that the zircons have a complex history involving multiple Pb-loss events or inheritance or both. In the present study, the within-grain analytical capacity of the SHRIMP ion microprobe has been applied to zircons from two Acasta gneiss samples, including the sample reported by Bowring et al. (1989) that indicated the greatest age. Our goal was to distinguish and date accurately the magmatic and possible metamorphic grains and to determine whether measurably older components might be present as inherited zircon.

SLAVE PROVINCE

The Slave province is an Archean granite-supracrustal terrane at the northwestern corner of the Canadian Shield (Fig. 1). The supracrustal rocks (the Yellowknife Supergroup) are predominantly metaturbidites but also include mafic to felsic metavolcanic rocks. U-Pb zircon dating suggests that most of the metavolcanic rocks were erupted ca. 2.65 Ga and then intruded by ca. 2.6 Ga granitic to dioritic plutons (e.g., van Breemen and Henderson, 1988).

Pre-Yellowknife Supergroup granites and gneisses, as well as numerous remnants of supra-

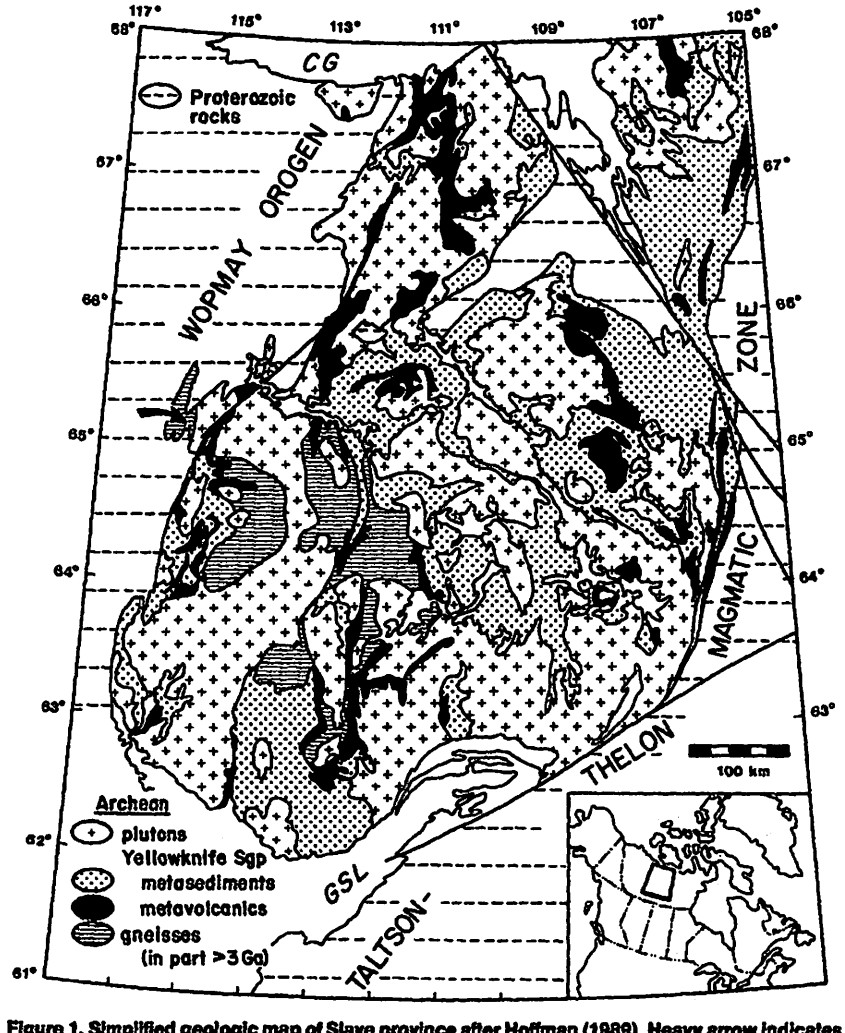

Figure 1. Simplified geologic map of Slave province after Hoffman (1989). Heavy arrow indicates area adjacent to Wopmay orogen in which Acasta gneisses occur.

Note: Additional material for this article is Supplementary Data 8917, available on request from the GSA Documents Secretary (see footnote 1).

crustal rocks whose relation to the older units is uncertain, occur only in the western part of the Slave province (Fig. 1). The older units of the Slave province consist primarily of heterogeneous tonalitic to granitic gneisses for which ages between 2.98 and 3.15 Ga have been measured (Nikic et al., 1980; Frith et al., 1986; Krogh and Gibbins, 1978). Additionally, Dudas (1989) has reported Nd isotopic data that suggest the presence of crust as old as 3.1 Ga in the Slave province.

ACASTA GNEISSES

The Acasta gneisses are exposed in the foreland and metamorphic internal zone of the Wopmay orogen (King, 1986; St-Onge et al., 1988) in a set of Proterozoic structural culminations continuous with the westernmost Slave province (Fig. 1). The gneisses range from pink, massive to foliated granite in the eastern culmination to complexly interlayered tonalitic to granitic gneisses in the western culmination. The samples analyzed in this study come from the structural saddle between the central and western culminations (Fig. 1).

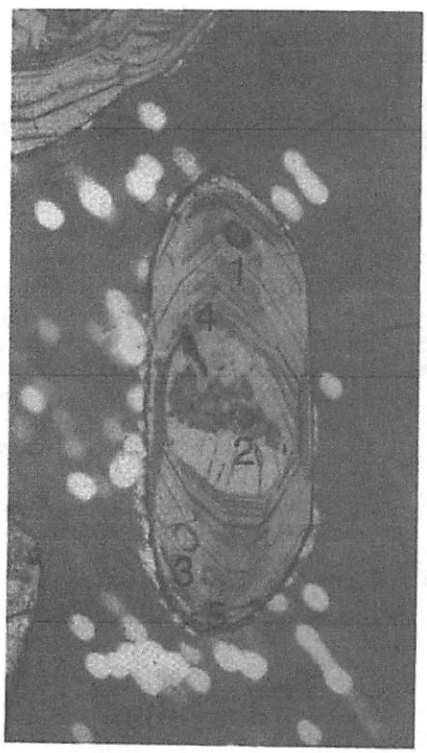

Figure 2. Photomicrograph of BGXM zircon grain 11, reflected light, interference contrast. Polished surface of sectioned crystal has been HF etched to highlight internal structures, and shows structureless core (partly altered) overgrown by finely zoned zircon, overgrown in turn by thin structureless mantle. Oblong, flat-bottomed pits were excavated by ion probe primary beam during analysis. Numbers refer to analyses in Tables 1 and A (see footnote 1). Grain is 0.50 mm long.

ION MICROPROBE ZIRCON DATING

The ability of the ion microprobe SHRIMP to measure isotopic heterogeneities within individual zircon crystals on the scale of a few tens of micrometres has transformed the study of the age and history of polymetamorphic rocks and removed some of the ambiguity involved in the interpretation of conventional single- and multigrain zircon analyses. The methods employed for U-Th-Pb isotopic dating by SHRIMP have been described in detail elsewhere (Compston et al., 1984).

In order to maximize the number of areas that could be analyzed in the time available, most of the analyses were based on short sets (three scans through the masses of interest) rather than normal sets (seven scans). In these samples, small-scale variations in radiogenic $^{207}Pb/^{206}Pb$ within grains was often encountered. These variations are manifested by the fact that the observed errors in measured radiogenic $^{207}Pb/^{206}Pb$ exceed those expected from counting statistics. Hence, while the data from short sets are generally less precise than those from normal sets, the presence of this variability makes the difference in precision negligible, and the short sets were actually preferred because a smaller volume of zircon was sampled. In these cases, the observed errors have been used in calculating the weighted mean $^{207}Pb/^{206}Pb$ ages. Analytical uncertainties are listed as 1σ and uncertainties in ages as 95% confidence levels unless otherwise stated.

DESCRIPTIONS OF THE ANALYZED SAMPLES

Banded Gneiss BGXM

BGXM is the sample of layered amphibolitic-tonalitic gneiss analyzed by Bowring et al., (1989) for conventional zircon U-Pb, feldspar Pb, and whole-rock Sm-Nd. It is a foliated orthogneiss consisting of tonalitic and amphibolitic layers that alternate on a centimetre scale. The tonalitic layers consist of granoblastic plagioclase and quartz, with relict plagioclase porphyroblasts. Sphene and allanite occur as accessory minerals. The amphibolitic layers consist of hornblende and biotite with variable amounts of plagioclase.

Zircon occurs in both layers as large (up to 1 mm long, ca. 250 μg), euhedral to subhedral, prismatic grains. Several morphological types of zircon are recognizable (Fig. 2), and the analyses made have been identified in terms of the zircon type sampled (Tables 1 and A[1]). The oldest zircon structurally forms rounded cores (C) in other grains and commonly is altered into turbid patches (AC) which appear as a structureless "honeycomb" when etched with HF vapor. Where unaltered, the cores are clear and show no zoning. The cores are overgrown by thick layers of finely euhedrally zoned zircon (Z), which is overgrown in turn by massive, structureless zircon (MO) that also occurs as completely separate, equant grains (M). Alteration similar to that in the cores is common both in the massive overgrowths (AMO) and massive (AM) grains. Volumetrically, zoned zircon dominates the zircon population.

Twenty-six individual grains from BGXM were analyzed in a total of 45 separate areas for this study (Tables 1 and A [see footnote 1]).

SP-405

SP-405 is a leucocratic granitic gneiss sampled about 2 km from BGXM. It was not studied by Bowring et al. (1989). The gneiss is dominated by granoblastic plagioclase, alkali feldspar, and quartz, with larger (10 mm) alkali-feldspar porphyroclasts. Biotite and hornblende make up about 5% of the rock, and anhedral poikilitic garnets (3 mm) are common in some samples.

The zircons from SP-405 are distinctly different from those from BGXM and consist of four principal morphologies. Most of the grains are prismatic and show well-developed fine euhedral zoning. Where the zoning is weak the grains are clear (P), but commonly the zoning is strongly developed and the alteration in many layers makes the grains turbid (TP). A few of the prismatic grains contain structureless cores (C). About 10% of the zircons are approximately equidimensional (E), massive to very weakly zoned, and in most cases surrounded by a very thin zoned mantle. Twenty-seven individual grains from SP-405 were analyzed in a total of 37 separate spots.

ISOTOPIC DATA

The U and Th content of zircons from both samples (Tables 1 and A [see footnote 1]) varies widely, from a few tens to several thousand parts per million. It also varies within grains, partly because overgrowths of different zircon generations have been included (e.g., BGXM 1, 7), but also because the ion probe samples only very small amounts of zircon per analysis (~2 ng), which detects the intrinsic chemical variability of zoned crystals. Despite this, the median U concentration found for BGXM, 666 ppm, is very similar to that obtained by isotope-dilution at 598 ppm (Bowring et al., 1989). Less dispersion was recorded in the latter, but this must be expected in view of the much larger sampling size used for isotope dilution (at least a factor of 10^4 greater). The median value itself is higher than observed in zircons from many other Archean tonalites (e.g., Kinny, 1986). Th/U from both samples is similar and dispersed. Except for a few areas (22.1 in BGXM and 8.4, 3.1, and 6.1 in SP-405), the radiogenic $^{208}Pb/^{206}Pb$ (Table 1) is well correlated with the measured Th/U

[1]Table A, U-Pb Analyses on Zircons from the Acasta Gneiss, GSA Supplementary Data 8917, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.