ION MICROPROBE ZIRCON GEOCHRONOLOGY OF THE UIVAK GNEISSES: IMPLICATIONS FOR THE EVOLUTION OF EARLY TERRESTRIAL CRUST IN THE NORTH ATLANTIC CRATON. Kenneth D. Collerson, Research School of Earth Sciences, Australian National University, P.O. Box 4, Canberra, A.C.T. 2600, Australia.

Introduction. Geochronological studies of high-grade metamorphic rocks from Labrador and Greenland using conventional Rb-Sr, Pb-Pb, U-Pb, Sm-Nd and Lu-Hf isotopic techniques [1-13] have provided important information concerning: (1) the distribution of early terrestrial crust in the North Atlantic Craton (NAC), (2) the isotopic character of the mantle from which this crust was derived, and (3) the response of early crustal areas to subsequent metamorphic events. Nevertheless, interpretations of such isotopic data, in particular the discrimination between protolith and metamorphic ages, as well as the significance (in terms of crustal residence times) of initial $^{87}Sr/^{86}Sr$ (I_{Sr}) values are commonly equivocal. The Sm-Nd and Lu-Hf isotopic systems have provided a potentially useful additional constraint for rationalizing these interpretations. This is because the REE's are generally considered to be less prone to metamorphic disturbance than Rb and Sr. Unfortunately, "cogenetic" suites of high-grade gneisses commonly exhibit little variation in degree of REE fractionation, hence they exhibit limited ranges in Sm/Nd and Lu/Hf. As a result, isochrons are generally of poor quality and both petrogenetic and geochronological conclusions are commonly strongly model dependent.

Although greater accuracy can now be achieved with conventional U-Pb zircon dating techniques [14,15], zircons from polymetamorphic rocks commonly exhibit extremely complex growth and compositional relationships that are impossible to resolve with these methods. Recent developments at the Australian National University in high resolution ion microprobe instrumentation (SHRIMP) and analytical techniques have provided a means of overcoming many of the limitations inherent in conventional U-Pb zircon analysis. In this abstract, ion microprobe U-Pb results for zircons from three Uivak I gneisses and one specimen of Uivak II gneiss, from the Saglek-Hebron area of Northern Labrador are reported. These results are compared with interpretations based on published conventional U-Pb zircon results and with conclusions about crustal evolution in the NAC derived from Rb-Sr, Sm-Nd and Pb-Pb isotopic studies.

Geological Background. Detailed accounts of the geology of the Archaean gneiss complex in Northern Labrador are given in [8,16,17]. The Uivak gneisses, a composite group of orthogneisses, have been subdivided on the basis of field relationships into two groups. The most abundant of these, the Uivak I suite, are dominantly fine-to-medium grained tonalitic and trondhjemitic gneisses with layering on scales ranging in width up to c. 100 cm. The layering is commonly accentuated by several generations of concordant to slightly discordant Na- and K-feldspar-rich pegmatite veins. Mineral assemblages in the Uivak I gneisses include quartz-oligoclase-microcline (or orthoclase) biotite ± hornblende. Accessory phases are dominated by sphene, apatite and zircon. The Uivak II suite of K-feldspar-bearing augen gneisses contains a higher modal content of biotite and iron-rich amphibole. The presence of layered Uivak I gneiss xenoliths in outcrops of relatively undeformed Uivak II gneiss demonstrates that the deformations responsible for the formation of composite layering in the Uivak I gneisses occurred prior to the emplacement of the K-feldspar megacrystic granitic and granodioritic protoliths of the augen gneisses. Both members of the Uivak gneiss suite contain inclusions of older supracrustal rocks (the Nulliak assemblage). These range in size up to c. 2 x 0.25 km and are dominated by amphibolites of ultrabasic and basic composition as well as banded iron formation.

UIVAK ION PROBE ZIRCON RESULTS

Collerson, K.D.

Previous geochronological studies of the Uivak gneisses have yielded Rb-Sr, Sm-Nd, and Pb-Pb ages of 3714 +400/-291 Ma (I_{Sr} 0.69938 -334/+252; ε_{Sr} -11.8 ± 18), 3612 +379/-279 Ma (I_{Nd} 0.50722 -22/+16; ε_{Nd} +1.7) and 3572 ± 318 Ma ($^{238}U/^{204}Pb$ μ_1 = 7.79), respectively [10]. The isochron data for all 3 methods are relatively poorly correlated and hence exhibit large uncertainties; reflecting the combined influence of source heterogeneity as well as open system behaviour during later metamorphic disturbances. If Nulliak assemblage mafic rocks are the source of the tonalitic protoliths of the Uivak I gneisses, then it is valid to regress them with Sm-Nd data for the Uivak I gneisses, which gives 3665 ± 104 Ma (I_{Nd} 0.50719 ∓ 8; ε_{Nd} +2.48 ∓ 1.10). The positive ε_{Nd} value indicates that the Uivak I gneisses were derived from depleted mantle. The involvement of depleted mantle beneath the NAC in the formation of the precursors of the early Archaean tonalites is interpreted as reflecting the formation of still older continental crust.

Sr isotopic data for eleven large specimens of Uivak II gneiss yields a poorly fitted isochron (MSWD=248) with slope equivalent to an age of 3412 ± 158 Ma (I_{Sr} = 0.69982 ∓ 250). However, whole-rock Pb isotopic results are better correlated (MSWD=13.4) and yield an isochron equivalent to an age of 3703 ± 293 Ma,with a calculated μ_1 value for their source region of 7.65.

Uivak Gneiss Zircon Results. (1) Conventional Data. Previously published conventional U-Pb zircon analyses on both unsorted multi-grain samples of Uivak I and Uivak II gneiss [5] and zircon size-fractions from a single sample of Uivak II gneiss [18] are all highly discordant with $^{207}Pb/^{206}Pb$ ages ranging from 2690 to 3485 Ma. With the exception of three of the Uivak I zircon analyses, which show the effect of recent Pb loss, seven multi-grain samples of Uivak I gneiss zircons are moderately well correlated (MSWD=34) and define a linear trend with a lower intercept of 2600 +67/-80 Ma and an upper intercept with Concordia of 4377 +234/-297 Ma. Data for the Uivak II gneiss zircon size-fractions, when combined with two multi-grain analyses, are extremely well correlated (MSWD=2.0) and define a chord with a lower intercept of 2540 +26/-28 Ma (within error of the Uivak I gneiss zircon result) and an upper intercept of 3950 ± 88 Ma. When regressed alone, the size-fractioned sample yields a Model 1 solution (MSWD=0.1) with significantly larger uncertainties in the upper intercept 3760 +387/-281 Ma and a lower intercept of 2490 +95/-137 Ma. Although these arrays may be the result of a single episode of Pb loss and have genuine age significance, the interpretation of the older Concordia ages must remain equivocal in view of the poly-metamorph history of the gneiss complex.

(2) Ion Microprobe Results. In an attempt to clarify interpretation of the conventional zircon results, zircon populations for three Uivak I gneisses and one Uivak II gneiss were analysed using the ion microprobe (SHRIMP) at the Australian National University [19,20]. Under routine operating conditions, the mass resolution of ≤ 7000 is sufficient to separate all significant spectral interferences, which obviates the necessity for peak stripping [cf. 21]. Methods have also been developed for determining Pb/U and Th/U ratios of unknown zircons to a precision of c. 3%[22]. The majority of the analyses are based on the means of three analyses achieved over a period of c. 45 minutes on the same spot. In most cases, the precision of the mean $^{207}Pb/^{206}Pb$ per spot was typically between 0.5 and 0.8% (1σ), limited principally by ion-counting statistics.

In terms of morphology, the Uivak I gneiss zircons generally exhibit a rounded core up to 100 μm in diameter surrounded by euhedral to subhedral rims that commonly display well preserved growth zones. In contrast to the highly discordant conventional analytical results for the Uivak I zircons, the majority of the cores plot within error of Concordia or define a number of slightly discordant populations with ages between c. 3600 and c. 3920 Ma (Fig. 1). This range is similar to that shown by the $^{207}Pb/^{206}Pb$ ages (Fig. 2).

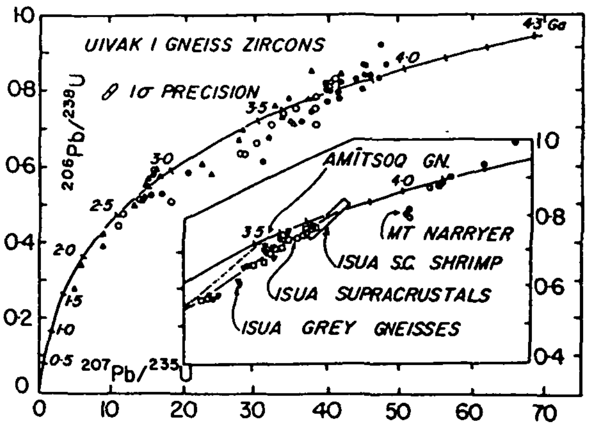

Fig. 1: Concordia diagram showing SHRIMP zircon analyses for three specimens of Uivak I gneiss; KC-78-633D open circles, and KC-78-620A triangles. The 1σ precision limits represent 3% uncertainty in determining Pb/U. The error box shown was calculated for the "old" zircon component. For comparison data are given in the insert from Mt. Narryer [23], the Amîtsoq gneisses [2, 24], the Isua grey gneisses [25] and the Isua supracrustal sequence [27,23].

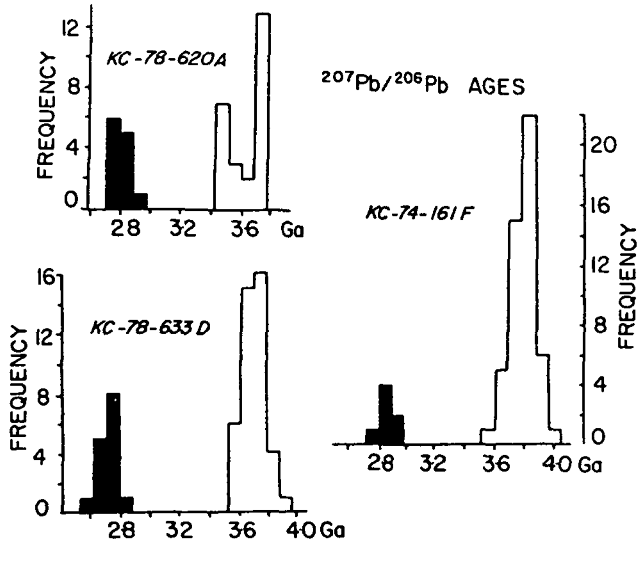

Fig. 2: Histogram showing the range of $^{207}Pb/^{206}Pb$ ages for near concordant Uivak I gneiss zircons. The cores are shown without ornamentation, and the rims with solid ornamentation. The uncertainty in determining $^{207}Pb/^{206}Pb$ ratios is generally better than 0.8%. This is significantly less than the age variation level.

Although most of the old cores contained relatively low amounts of Pb (18-100 ppm), U (less than 100 ppm), and Th (less than 50 ppm), a few cores were observed which contained substantially higher amounts of these elements; up to 1320 ppm Pb, 1380 ppm U, and 212 ppm Th. In a number of grains, cores showed considerable variation in $^{207}Pb/^{206}Pb$ during sputtering, presumably reflecting compositional variation on a scale of c. 25 μm x 3 μm. For example, in one grain from KC-74-161F $^{207}Pb/^{206}Pb$ ages varied from 4008 Ma through 3954 Ma to 3914 Ma. In Figure 1, analyses which lie above Concordia could reflect uncertainty in determining the Pb/U ratio. Alternatively, the reverse discordance may be the result of early gain of radiogenic Pb or loss of U. This feature has also been observed in microprobe analyses of zircons from elsewhere, e.g. Mt Narryer, Figure 1 [23].

The majority of zircon analyses with $^{207}Pb/^{206}Pb$ ages between 3500 and 3000 Ma are relatively discordant (Fig. 1). This is interpreted to be the result of Pb-loss at between c. 3600 - 3800 Ma and c. 2800 Ma, as well as recent Pb-loss. In general, the higher U grains are the most discordant [cf. 24,25]. Rims of zircon typically have significantly higher contents of Pb, U and Th than are generally present in the older core regions. Most plot within error of Concordia at c. 2700 to 2900 Ma. This result is in excellent agreement with previously published estimates for a period of late Archaean regional metamorphism in the NAC [3,8,11,26].

Data for three zircons from the Uivak II gneiss plot close to Concordia on a chord of virtually constant $^{207}Pb/^{206}Pb$ ratio which is equivalent to an age of c. 3350 Ma. A single rim analysis lies within error of Concordia at c. 3000 Ma.

Discussion and Conclusions. Analytical results for zircon cores in the three specimens of Uivak I gneiss described in this paper are significantly older than published conventional U-Pb analyses of zircons from the Amîtsoq grey gneisses, viz. 3595 ± 50 Ma [2] and 3575 ± 50 Ma [24]. Many of the analyses are also older than the c. 3700 Ma zircon population in the Isua grey gneisses [25]. These data are plotted for comparison in Figure 1. The c. 3600 Ma age for the Amîtsoq gneiss zircons is interpreted therefore as a metamorphic age [24,25]. In Figure 1 it is clear that most of the Uivak I gneiss zircon data are broadly within error of conventional [27] as well as SHRIMP [23] results for time of crystallization of zircons from the Isua supracrustal sequence, viz. 3813 +6/-4 Ma. From this, it follows that zircon cores in the Uivak I gneisses may be xenocrystic, representing compositions inherited from a c. 3800 Ma old source which melted to form the plutonic precursors of the Uivak I gneisses. Alternatively, the zircons may have crystallized c. 3800 Ma ago in the plutonic protoliths of the Uivak I gneisses. The low Pb, U and Th content of most of the Uivak I gneiss zircon cores either reflects the relatively basic character of the crustal precursors of the gneisses, or it may be typical of the compositional range of zircon crystallizing from melts of tonalitic and trondhjemitic composition.

The dispersion observed in zircon cores from the Uivak I gneisses between c. 3800 Ma and 3600 Ma is interpreted to be the result of variation in the degree of loss of radiogenic Pb in response to younger periods of metamorphism, together with the effect of recrystallization during such thermal events.

Several virtually concordant low and high U grains have $^{207}Pb/^{206}Pb$ ages that are in excess of 3800 Ma, ranging up to c. 3920 Ma. These provide unequivocal evidence of pre-"Isua" inherited xenocrystic components in the zircons. It is concluded from the range of Pb and U in these xenocrysts that basic as well as LIL element enriched (acid) crustal compositions were present in the source of the protoliths of the Uivak I gneisses. This supports interpretations based on Sm-Nd studies of the Uivak gneisses [10] that they were derived from a depleted source from which earlier crust has been extracted. As none of the ion microprobe data yield ages in excess of 4000 Ma, little geological significance can be ascribed to the value of the upper Concordia intercept defined by the conventional Uivak I gneiss zircon data.

The current interpretation based on field and geochemical evidence is that the protoliths of the Uivak II gneisses were derived by partial melting of pre-existing Uivak I gneiss - Nulliak assemblage crustal components. The involvement of such old source components is supported by previously discussed Pb-Pb whole rock isotopic data and also by conventional U-Pb zircon results. However, the whole rock Sr isotopic data and the zircon ion microprobe data currently available yield significantly younger ages (c. 3350 Ma). This is interpreted to indicate that the megacrystic granite protoliths of the Uivak II gneisses were formed and metamorphosed c. 3350 - 3400 Ma ago, and were contaminated with old crustal unradiogenic Pb [cf. 11]. A second scenario is that the Sr and SHRIMP results currently available were reset by metamorphic recrystallization processes and therefore they date the time of fabric development in the gneisses. Failure to identify an old component, consistent with the interpretation of the conventional zircon data, is interpreted to be a reflection of the small number of analyses currently available.

1. Moorbath, S., O'Nions, R.K., Pankhurts, R.J., Gale, N.H. and McGregor, V.R. (1972) Further rubidium-strontium age determinations in the very early Precambrian rocks of the Godthaab district, West Greenland. Nature Phys. Sci., 240, p. 78-82.
2. Baadsgaard, H. (1973) U-Th-Pb dates on zircons from the early Precambrian Amîtsoq gneisses, Godthaab district, West Greenland. Earth Planet. Sci. Lett., 19, p. 22-28.
3. Baadsgaard, H., Lambert R.St.J. and Krupicka, J. (1976) Mineral isotopic relationships in the polymetamorphic Amîtsoq gneisses, Godthaab District, West Greenland. Geochim. Cosmochim. Acta, 40, p. 513-527.
4. Baadsgaard, H. and McGregor, V.R. (1981) The U-Th-Pb systematics of zircons from the type Nûk gneisses, Godthaabsfjord, West Greenland. Geochim. Cosmochim. Acta, 45, p. 1099-1109.
5. Baadsgaard, H., Collerson, K.D. and Bridgwater, D. (1979) The Archean gneiss complex of northern Labrador. 1. Preliminary U-Th-Pb geochronology. Can. J. Earth Sci., 16, p. 951-961.
6. Hurst, R.W., Bridgwater, D., Collerson, K.D. and Wetherill, G.W. (1975) 3600-m.y. Rb-Sr ages from very early Archean gneisses from Saglek Bay, Labrador. Earth Planet. Sci. Lett., 27, p. 393-403.
7. Cameron, M., Collerson, K.D., Compston, W. and Morton, R. (1981) The statistical analysis and interpretation of imperfectly-fitted Rb-Sr isochrons from polymetamorphic terrains. Geochim. Cosmochim. Acta, 45, p. 1087-1097.
8. Collerson, K.D., Kerr, A. and Compston, W. (1981) Geochronology and evolution of late Archaean gneisses in Northern Labrador: An example of reworked sialic crust. Spec. Publs. Geol. Soc. Aust., 7, p. 205-222.
9. Collerson, K.D. L1983) The Archean gneiss complex of northern Labrador 2. Mineral ages, secondary isochrons and diffusion of strontium during polymetamorphism of the Uivak gneisses. Can. J. Earth Sci., 20. (in press)
10. Collerson, K.D. and McCulloch, M.T. (1982) The origin and evolution of Archaean crust as inferred from Nd, Sr and Pb isotopic studies in Labrador. Fifth Int. Conf. Geochron., Cosmochron. Isotope Geol., Nikko, Japan. Extended Abstracts, p. 61-62.
11. Taylor, P.N., Moorbath, S., Goodwin, R. and Petrykowski, A.C. (1980) Crustal contamination as an indicator of the extent of early Archaean continental crust: Pb isotopic evidence from the late Archaean gneisses of west Greenland. Geochim. Cosmochim. Acta, 44, p. 1437-1453.
12. Pettingill, H.S. and Patchett, P.J. (1981) Lu-Hf total-rock age for the Amîtsoq gneisses, West Greenland. Earth Planet. Sci. Lett., 55, p. 150-156.
13. Hamilton, P.J., O'Nions, R.K., Bridgwater, D. and Nutman, A. (1983) Sm-Nd studies of Archaean metasediments and metavolcanics from West Greenland and their implications for the Earth's early history. Earth Planet. Sci. Lett., 62, p. 263-272.

14. Krogh, T.E. (1982a) Improved accuracy of U-Pb zircon dating by selection of more concordant fractions using a high gradient magnetic separation technique. Geochim. Cosmochim. Acta, 46, p. 631-635.
15. Krogh, T.E. (1982b) Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. Geochim. Cosmochim. Acta, 46, p. 637-649.
16. Bridgwater, D., Collerson, K.D., Hurst, R.W. and Jesseau, C.W. (1975) Field characters of the early Precambrian rocks from Saglek, Coast of Labrador. Geol. Surv. Can. Paper, 75-1, Part A, p. 287-296.
17. Collerson, K.D. and Bridgwater, D. (1979) Metamorphic development of early Archaean tonalitic and trondhjemitic gneisses: Saglek area, Labrador. In Trondhjemites Dactites and Related Rocks. Chap. 7, Elsevier, p. 205-273.
18. Wanless, R.K., Bridgwater, D. and Collerson, K.D. (1979) Zircon age measurements for Uivak II gneisses from the Saglek area, Labrador. Can. J. Earth Sci., 16, p. 962-965.
19. Clement, S.W.J., Compston, W. and Newstead, G. (1977) Design of a large, high resolution ion microprobe. Proc. Int. S.I.M.S. Conf., Meunster, Springer Verlag.
20. Compston, W., Williams, I.S. and Clement, S.W.J. (1982) U-Pb ages within single zircons using a sensitive high mass-resolution ion microprobe. Ann. Conf. Am. Soc. Mass Spectrometry, 30th, Honolulu, p. 593-595.
21. Hinthorne, J.R., Anderson, C.A., Conrad, R.L. and Lovering, J.F. (1979) Single-grain $^{207}Pb/^{206}Pb$ and U/Pb age determination with a 10 μm spatial resolution using the ion microprobe mass analyzer (IMMA). Chem. Geol., 25, p. 271-303.
22. Compston, W., Williams, I.S. and Meyer, C. (1983) U-Pb geochronology of zircons from Breccia 73217 using a sensitive high mass-resolution ion microprobe. J. Geophys. Res. (in press)
23. Froude, D.O., Ireland, T.R., Kinny, P.D., Williams, I.S., Compston, W., Williams, I.R. and Myers, J.S. (1983) Ion microprobe identification of 4100 Ma-old terrestrial zircons. Nature (in press)
24. Pidgeon, R.T. and Kalsbeek, F. (1978) Zircon U-Pb isotopic systems in an augen gneiss and a grey gneiss from the Amîtsoq gneisses of Akilia Island, West Greenland. In Proceedings of the 1978 Archaean Geochemistry Conference, p. 363-365, University of Toronto.
25. Baadsgaard, H. (1983) U-Pb isotope systematics on minerals from the gneiss complex at Isukasia ,West Greenland. Rapp. Grønlands geol. Unders. (in press).
26. Black, L.P., Moorbath, S., Pankhurst, R.J. and Windley, B.F. (1973) $^{207}Pb/^{206}Pb$ whole rock age of the Archean granulite facies metamorphic event in West Greenland. Nature Phys. Sci., 244, p. 50-53.
27. Baadsgaard, H., Nutman, A.P., Bridgwater, D., Rosing, M., McGregor, V.R. and Allaart, J.H. (1983) The zircon geochronology of the Alkilia Association and Isua Supracrustal Belt, West Greenland. Earth Planet. Sci. Lett. (in press).