One of the challenges of Archaean geochronology is to find isotopic systems that preserve an indication of a rock's primary age in spite of the effects of later metamorphism. Zircon dating has been used widely with considerable success but not without difficulty, especially in polymetamorphic terrains. Zircons in such cases commonly are found to have lost radiogenic Pb, and despite fractionizing the zircons\textsuperscript{1} or abrading them to remove disturbed portions\textsuperscript{2} it often is not possible to define a pattern of Pb loss from which the original age can confidently be inferred. The refinement of techniques to enable extremely small samples\textsuperscript{3}, or even single crystals\textsuperscript{4}, to be analysed has contributed greatly to solving the problem but even those techniques cannot resolve the micron-scale isotopic heterogeneities within single zircons in which much of their history is recorded. That can only be done by ion microprobe. We present here progress reports on studies of four Archaean rocks, each of which illustrates the power and potential of ion microprobe analysis in solving problems of Archaean geochronology.

\textit{Morton Gneiss.} The gneisses of the Minnesota River Valley have long been recognized to be among the oldest rocks in the United States. However, because their isotopic systems have been disturbed by later metamorphisms and intrusions, there is uncertainty as to their actual age. The gneisses have been the subject of a number of geochronologic studies. Zircon U-Pb analyses by Catanzaro\textsuperscript{5} first showed the great antiquity of the rocks, giving a minimum age of 3250 Ma and an inferred age of 3500 Ma. There have been several zircon U-Pb studies since then\textsuperscript{6,7,8,9} but each, even the single crystal work\textsuperscript{8}, has produced patterns of Pb loss from which the primary age cannot readily be deduced. Interpreted ages range from 3230 Ma\textsuperscript{7,8} to 3590 Ma\textsuperscript{6,9}. The Sm-Nd and Rb-Sr total-rock analyses of McCulloch\textsuperscript{10} support the older value, but other Rb-Sr work\textsuperscript{11} has been interpreted to indicate ages even greater.

We studied a split from sample 673 analysed earlier by Goldich and Wooden\textsuperscript{9}. It came from tonalitic Morton Gneiss 5 km NE of Delhi. The zircons are strongly zoned and at least five stages of growth can be seen, all, or only some of which may be present in any one crystal. A) Unzoned, euhedral, low-U (<500 ppm) cores overgrown by B) strikingly euhedrally zoned, moderate-U (1500 ppm) zircon, broken, then overgrown by C) unzoned, inclusion-rich, high-U (>2000 ppm) zircon, overgrown by D) unzoned or weakly euhedrally zoned low-U (<300 ppm) zircon, rarely overgrown by E) unzoned, moderate-U (800 ppm) euhedral rims. Type D commonly forms whole crystals. Plotted on a Concordia diagram the analyses for zircons type A to D all define, almost within analytical error, a single discordance line, with Concordia intercepts of 3535 ± 45 Ma and 1530 ± 200 Ma. Type E zircon is nearly concordant and unequivocally younger, 2585 ± 10 Ma based on 207\textsuperscript{Pb}/206\textsuperscript{Pb}. The primary age of the bulk of the zircon is therefore probably 3535 ± 45 Ma, and is certainly greater than 3460 Ma. The 2585 ± 10 Ma age of the zircon rims is the same as the age of late intrusives in the Morton area\textsuperscript{9}. It is very likely that the older zircons were also affected at that time so we presently attribute no age significance to the 1530 Ma intercept, except that it shows much of the zircon has suffered Pb loss at or after 1530 Ma. An excess of radiogenic Pb at one analysed spot suggests Pb movement may have occurred recently. Earlier conventional analyses of these zircons\textsuperscript{9} are readily explicable as mixtures of the components that the ion microprobe has identified.
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Gneiss at Watersmeet. The Watersmeet Dome in northern Michigan is a second area in the United States where very early rocks have been identified. There also, later metamorphisms and intrusions have disturbed the older isotopic systems, making the determination of original ages difficult. Indications of Archaean ages were first found at Watersmeet in a Rb-Sr study by Sims and Peterman. Subsequent Rb-Sr work and zircon U-Pb analyses by Peterman and others showed that the gneisses were at least 3410 Ma, and possibly 3500 to 3800 Ma old. As in the case of the Morton Gneiss, the uncertainty in the age was due to the poor definition of the zircon Pb-loss pattern. Sm-Nd analyses confirmed the antiquity of the gneisses at Watersmeet. McCulloch and Wasserburg measured a total-rock model age of 3600 ± 40 Ma on one sample, Futa measured model ages of 3520 ± 70 Ma and 3919 ± 30 Ma (the latter was interpreted as being affected by metamorphism) on others. Recent zircon U-Pb work by Peterman and others has resulted in a revised zircon age estimate of 3562 ± 39 Ma.

The zircons studied by ion microprobe were from sample M83, a tonalitic biotite augen gneiss from 7 km NW of Watersmeet. Conventional zircon U-Pb analyses of M83 have been reported by Peterman and others. The ion microprobe analyses show a wide range in Pb/U and Pb isotopic composition in the zircons, even within single crystals. On a Concordia diagram the data do not define a single line. Areas of zircons with the lowest U (<400 ppm) have the highest 207Pb/206Pb and average 15% discordance. All have the same 207Pb/206Pb age, 3625 ± 13 Ma. Areas of zircons with the highest U (>800 ppm) mostly define a line with an upper Concordia intercept of 2645 ± 35 Ma. Analyses of intermediate-U zircon scatter in between. The original age of the gneiss is probably 3625 ± 13 Ma. The zircons are interpreted to have been partially or totally reset at 2645 ± 35 Ma and all the zircons have again lost radiogenic Pb at least as recently as 300 Ma. The 2645 ± 35 Ma Pb loss event corresponds to the time of intrusion of younger dykes and granites in the Watersmeet area. Mixtures of zircons of these compositions account for the scatter observed in the conventional zircon analyses.

Gneiss at Mount Sones. The Napier Complex of Enderby Land, Eastern Antarctica, is a granulite grade terrain that despite having undergone at least three major episodes of deformation and metamorphism still preserves some isotopic evidence of great antiquity. One sample from the Fyfe Hills has been shown by ion microprobe analysis to contain a minor zircon component at least 3800 Ma old. A much greater concentration of old zircon has now been found by ion microprobe in a granodioritic orthogneiss from Mount Sones. The U-Pb systems in the zircons are unusually complex. Most of the grains are brown and markedly zoned, a few are pale and structureless. Analyses of the pale zircons mostly plot near the Concordia at ~2400 Ma, recording the metamorphism at 2456 ± 7 Ma identified by Black and others. The brown zircons show a much greater range in composition which can be related to the three visible stages of crystal growth: A) cores overgrown by B) euhedrally-zoned zircon, overgrown by C) relatively structureless rims. Analyses of type C zircon mostly plot on a short discordance line that intersects the Concordia at ~3000 Ma, recording the granulite facies metamorphism at 3072 ± 34 Ma. The analyses of zircons type A and B are very widely dispersed; some are reversely discordant indicating an excess of radiogenic Pb. They scatter about a line with Concordia intercepts of ~2400 Ma and ~3750 Ma. If the type A zircons are regressed separately, their upper intercept is ~3850 Ma. At one 35 μm spot on a type A zircon a large and variable excess of radiogenic Pb was found. A correlated change in the Pb/U and 207Pb/206Pb indicates that Pb was gained at the spot ~2400 Ma ago, evidently in response to the same metamorphism that in most other zircons caused Pb loss. 207Pb/206Pb ages up to 4200 Ma were
measured on the spot, showing that $^{207}\text{Pb}/^{206}\text{Pb}$ ages measured on very small zircon samples need not necessarily be minimum ages.

Quartzite at Mount Narryer. One of the aims of Archaean geochronology is to determine when the earliest terrestrial crust formed. An ideal place to look for surviving remnants of that crust is in the earliest sediments. Dating zircons in sediments by conventional methods is both difficult and tedious for in most cases the zircon population is a mixture of zircons from many rocks of different ages. The ion microprobe however, with its ability to make rapid analyses of single crystals, is ideally suited to the task. During a reconnaissance survey of zircon in Archaean metasediments from a variety of localities in Western Australia, zircons have been identified that are up to 4200 Ma old\textsuperscript{23}. The old zircons occur in a quartzite at Mount Narryer, 250 km NE of Geraldton. They comprise about 5% of the zircon in the rock, most of the remainder being zircon formed at $\sim$3750 Ma or $\sim$3500 Ma. The analyses of the old zircons are very nearly concordant. The possibility that the measured age is nevertheless an artifact of inherited radiogenic Pb was tested by analysing one crystal seven times. Despite a range of a factor of 1.5 in the U content of different areas of the grain, Pb/U and $^{207}\text{Pb}/^{206}\text{Pb}$ were virtually constant, arguing strongly that excess radiogenic Pb is not present. The existence of the old grains shows that silica-saturated rocks were present on the Earth's surface as early as 4200 Ma and that they were a significant fraction of the surface exposure at the time the original sand was being deposited, probably sometime between 3300 Ma and 3500 Ma. This evidence that some early rocks did survive the pre-3900 Ma meteorite bombardment of the Earth gives hope that intact segments of that crust may yet be found.

References.