N86-28553

EARLY ARCHEAN TONALITE GNEISS IN THE UPPER PENINSULA OF MICHIGAN; Zell E. Peterman, R. E. Zartman, and P. K. Sims, U.S. Geological Survey, MS 963 Box 26046 DFC, Denver, CO 80225

REGIONAL SETTING.--Early Archean[1] gneisses are exposed in the core of a structural dome near Watersmeet in the upper peninsula of Michigan (Fig. 1). These gneisses are part of an extensive gneiss terrane in the Lake Superior region [1] that lies immediately south of a Late Archean greenstone-granite terrane (the Wawa Volcanic Belt of Canadian usage). Other occurrences of such old rocks in this region are Early Archean gneisses in southeastern Minnesota [2] and Middle Archean gneisses [3] in central Wisconsin. The two terranes are joined along a fundamental structural feature called the Great Lakes tectonic zone [4] that extends from west-central Minnesota to and possibly beyond the Grenville Front in Canada. This feature exerted a sustained influence on the structural evolution of the region through the Early Proterozoic with the gneiss terrane generally exhibiting greater mobility than the greenstone-granite terrane during the Penokean orogeny at 1.8 to 1.9 Ga.

GEOLOGY.--The gneiss dome near Watersmeet (Fig. 2) contains a diversity of rock types and tectonic overprints that record a remarkably long interval spanning nearly two billion years of earth history. Isotopic dating [5,6] and field studies [7] have elucidated much of this protracted geologic record. The oldest unit is a tonalitic augen gneiss which is overlain by a succession of well-layered biotite gneiss and schist. Both of these units are Early Archean. These Early Archean gneisses were overlapped by Late Archean volcanic and sedimentary rocks that formed during the development of the volcanic belt immediately to the north. The Late Archean units are amphibolite and interlayered biotite and biotite-hornblende gneiss. All of the gneisses are cut by leucogranite dikes that were emplaced after the gneisses were folded. Collectively, the Early and Late Archean rocks formed the basement on which a thick succession of sedimentary and volcanic rocks of the Early Proterozoic Marquette Range Supergroup were deposited. Reactivation of the Archean basement during the Penokean orogeny led to the development of gneiss domes that rose diapirically to penetrate the overlying supracrustal rocks.

GEOCHRONOLOGY.-- The isotopic systems in the Archean rocks were strongly disturbed during the episode of ductile deformation that resulted in the formation of the gneiss domes. Rb-Sr whole-rock systems were open over a scale of several meters suggesting the presence of fluids. Mineral (Pl-Mi-Bi) data yield good isochrons of about 1,750 Ma, and metamorphically reconstituted zircon from biotite gniess in a ductile-brittle shear zone gives concordant U-Pb ages of 1,757 Ma [5,6].

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[1]DNAG Precambrian classification [8]. Intervals are: Late Proterozozic, 570-900 Ma; Middle Proterozoic, 900-1600 Ma; Early Proterozoic, 1600-2500 Ma; Late Archean, 2500-3000 Ma; Middle Archean, 3000-3400 Ma; and Early Archean, 3400-3800(?).

U-Pb zircon systematics [5,6] for Archean rocks in the Watersmeet dome are shown in Figure 3. The array for the Early Archean gneisses is comprised of data for size and magnetic fractions of zircon from two samples of augen gniess and one sample of biotite gneiss. Zircons from all three samples are very similar in shape, crystal face development, zoning, and color. This array, with some excessive scatter, defines a chord with intercepts at 3560±40 Ma and 1250±90 Ma. Three fractions of zircon from a biotite gneiss in the Late Archean amphibolite sequence give an upper intercept of 2640 Ma but a much younger lower intercept of about 630 Ma. Size fractions of zircon from a leucogranite dike suggest an emplacement age of about 2590 Ma. The concordant zircon from biotite gneiss in a zone of very high strain in the dome is shown at 1,760 Ma.

The lower intercept age of 1250 Ma for the Early Archean chord doesn't correspond well to any known event in the region, Keweenawan igneous activity and rifting at about 1100 Ma being the closest in time. This anomaly and the much younger lower intercepts shown by the Late Archean zircons has led us to suggest that the disposition of points for the Early Archean zircons is the result of multiple episodes of lead loss in a fairly systematic fashion [6]. Episodic loss of lead at 2.7, 1.8, and 0.5 Ga could produce a trajectory on a concordia diagram which would be nearly linear over the interval represented by actual data points. Subsequent ion microprobe analyses by Williams and others [9] of one of the least discordant zircon fractions (Fig. 3) has shown additional complexities in the discordance pattern. They found domains within grains that yielded nearly concordant results and extended the age to 3650 Ma. They also found overgrowths that had formed at 2600 Ma when the Early Archean gneisses and overlying Late Archean supracrustals were deformed, metamorphosed, and intruded by granite. In this particular sample, no evidence was found for the Early Proterozoic event suggesting that its effect on the U-Pb zircon systems was restricted to zones of exceptionally high strain such as that which produced the concordant 1760-Ma zircon.

Archean rocks northwest of the dome are part of the Late Archean greenstone-granite terrane (Fig. 2). Zircons from a biotite gneiss in a bimodal gneiss-amphibolite sequence presumed to be interlayered mafic and felsic volcanic rocks are dated at 2750 Ma, somewhat older than the similar 2640-Ma sequence infolded with the Early Archean gneisses in the dome. The Puritan Quartz Monzonite, the principal granite in the greenstone-granite terrane in this area is dated at 2650 Ma by Rb-Sr [10]. Whole-rock samples of Early Proterozoic metagraywackes immediately north of the dome give a Rb-Sr isochron age of 1820±50 Ma. This is a metamorphic age representing resetting attendant with dewatering and recrystallization of the matrix. It is consistent with whole rock and mineral isochrons within the dome that reflect resetting during deformation related to the doming.

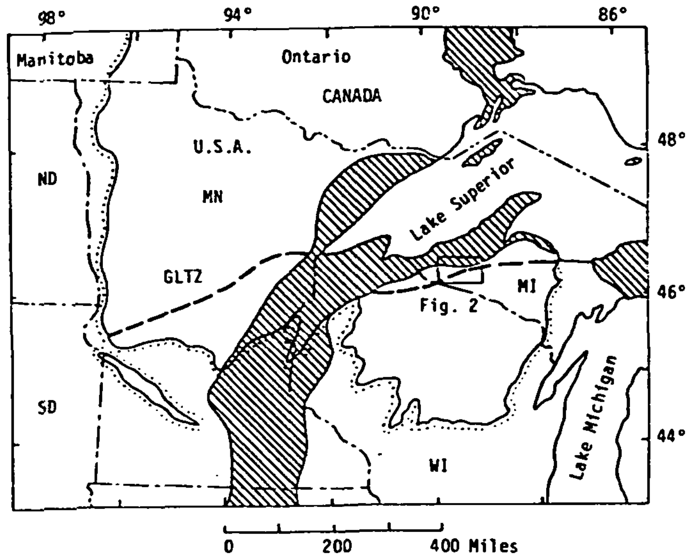

Figure 1.--Index map showing location of Fig. 2. Diagonally ruled area represents 1100 Ma Keweenawan igneous and sedimentary rocks of the midcont. rift system. The line-dot pattern shows the limit of Paleozoic strata. GLTZ is the Great Lakes Tectonic Zone that separates remnants of Early to Middle Archean gneisses on the south from the Late Archean greenstone terrane on the north.

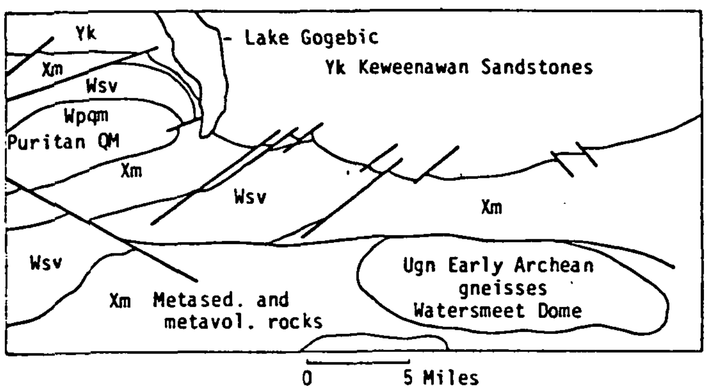

Figure 2.--Simplified geology in the vicinity of the Watersmeet dome. Outcrops of Early Archean gneisses are along northern edge of dome. Wsv refers to Late Archean metased. and metavol. rocks. Other units are defined on the map. The GLTZ lies between the Watersmeet dome and the Puritan Quartz Monzonite.

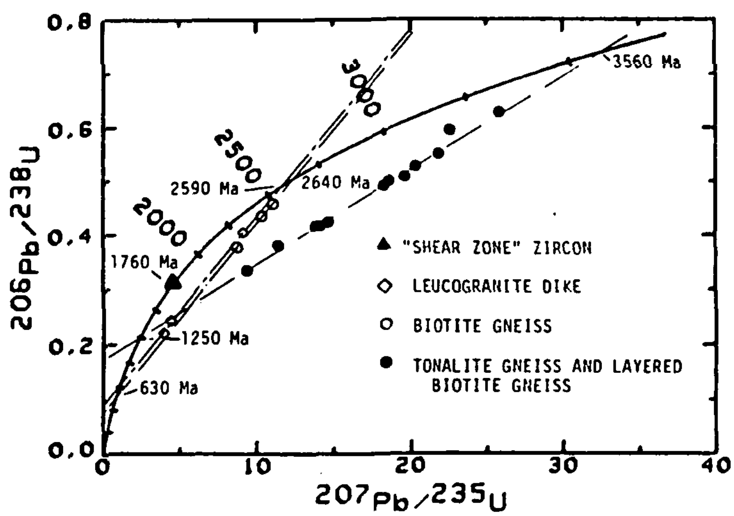

Figure 3.--Concordia diagram for zircons from Early and Late Archean rocks in the Watersmeet dome. Differences in lower intercepts suggest that the Early Archean array is the result of multiple episodes of lead loss and that 3560 Ma is probably a minimum age.

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