DETRITAL ZIRCON AGE ANALYSIS OF THE FOND DU LAC AND HINCKLEY SANDSTONE FORMATIONS OF NORTHERN MINNESOTA

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INTRODUCTION

The Fond du Lac and Hinckley sandstone formations are located in northeastern Minnesota just south of Duluth, MN as seen in Fig. 1 in Craddock et. al., this volume. Morey and Ojakangas (1982) describe the Fond du Lac as an arkose sandstone primarily composed of quartz but containing a sizeable fraction of feldspar. Recorded alluvial paleoflow indicators indicate an easterly current for the Fond du Lac (Morey and Ojakangas, 1982). The Fond du Lac is inferred to lie directly on bedrock and below the Hinckley (Morey and Ojakangas, 1982). The Hinckley is composed of 96 percent quartz and is an orthoquartzite (Tryhorn and Ojakangas, 1972). Paleoflow indicators in the Hinckley indicate a rift-axis normal flow into the rift basin (Ojakangas and Morey, 1982b). These two formations are part of a large sedimentary series filling the Midcontiinent Rift (Ojakangas and Morey, 1982a) after its formation 1.1 Ga (Davis and Green, 1997). Based on paleoflow indicators and proximity Ojakangas and Morey (1982a) have stated that the provenance for the Fond du Lac formation is volcanic and other igneous rocks, and the Hinckley formation may in part represent reworking of the Fond du Lac.

This paper reports LA-ICPMS ages of detrital zircons found in the Fond du Lac and Hinckley formations. These ages reveal the provenance of the material making the Fond du Lac and Hinckley formations. For each formation, the youngest observed age constrains the maximum depositional age to the Neoproterozoic at approximately 1.01 Ga. The Fond du Lac's provenance is largely from the Grenville Province on the eastern margin of Laurentia, but contains sediment from northern Minnesota as well. The Hinckley formation contains grains with ages corresponding to more proximal locations, however some ages are best explained using the Grenville Province. The change in age distribution means the provenance of the Fond du Lac is different from the Hinckley. The origin of the Fond du Lac and Hinckley material is much more complex than previously imagined.

METHODS

Zircons were separated from about 10 Kg of rock collected from the Hinckley and Fond du Lac Formations (Fig. 1, Craddock et. al., this volume) using standard mineral separation techniques. The zircons were dated using a Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) in Jeff Vervoort's laboratory at Washington State University following the procedures outlined in Chang et. al. (2006). Data reduction and presentation was accomplished using Ken Ludwig's program (Isoplot 3.0). Reported ages with discordance greater than 10 percent were not included in data presentation in this paper because sufficient data existed with less than 10 percent discordance. Modes were produced by averaging the ages of zircons present in a bin (within error) that corresponded with

TABLE 1. SUMMARY OF DETRITAL-ZIRCON AGES.

Formation	Sample ID and Coordinates[*]	Major zircon modes[§] (Ma)	Youngest zircon grains[#] (Ma)	Keweenawan (1.09-1.108 Ga)[1] (%)	Grenville (1.18-1.23 Ga)[2] (1.19-1.25 Ga)[3] (1.18-1.35 Ga)[4] (%)	Penokean (1.75-1.875 Ga)[5] (%)	Cratonic >1.9 Ga[6] (%)
Hinckley	KP05-20 0510535, 510689	1115, 1170, 1315, 1445, 1685, 1845, 1905, 2080, 2665, 2715, 3045	1052.9±8.7	7	9 10 22	7	19
Fond du Lac	KP05-22 0554645, 5167692	1085, 1210, 1335, 1665, 1810, 2565, 2895	1010.8±12.1	13	29 30 53	3	2

[*]UTM 15T;[§]Listed in chronologic order, from youngest to oldest. Rounded to nearest 5.;[#]Youngest single zircon age reported with 2 sigma error;[†]Maximum depositional age limited by youngest single zircon age;[1]Davis and Green, 1997;[2]Gower and Krogh, 2002;[3]Rivers, 1997;[4]McLelland et. al., 1996;[5]Van Schmus, 1976; Holm, 2005;[6]All dates later than 1.9 Ga are immediately adjacent to or north of the Mid Continent Rift (Holm, 2005). [1,2,3,4,5,6]Rock forming events and theoretical age boundaries. Reported values indicate percent of total grains that fit within established age bounds of event.

a peak in the relative probability curve. All reported values are rounded to the nearest 5 to communicate that these data are averaged and that each date has its own associated error.

RESULTS

Fond du Lac Formation

The Fond du Lac formation (KP05-22) yielded 102 concordant grains. The youngest date is 1010.8±12.1 Ma, and the oldest date is 2897.0±3.2 Ma (Table 1). Plotted on a histogram, most of these dates (95 zircons) cluster from 1011 to 1400 Ma (Fig. 1). Major peaks in the relative probability curve occur at 1080 and 1210 Ma. A less significant peak occurs at 1340 Ma. Five zircons with distinct ages of 1645, 1680, 1775, 1810, and 1850 Ma produce modes at 1665 and 1810 Ma. Two very old zircons with ages 2565 and 2897 Ma are present as well.

Hinckley Formation

The Hinckley formation (KP05-20) yielded 136 concordant grains. The youngest date is 1052.9±8.7 Ma, and the oldest date is 3046.5±5.3 Ma (Table 1). A histogram plot shows a wide range of dates from 1052 to 2082 Ma (Fig. 2). A small cluster of dates occurs at 2800 Ma. Major peaks are at modes 1170 and 1445 and lesser peaks at 1115 and 1315 Ma. Important peaks in this later body are at 1685, 1845, 1905, and 2080 Ma. The oldest ages range from 2660 to 3050 Ma and produce modes at 2665 and 2715 Ma. The oldest zircon ages are 2838, 2854, and 3046 Ma.

DISCUSSION

The principle modes for these formations are at 1085, 1170, 1210, 1445, and 1685 Ma. Minor modes are at 1115, 1315, 1335, 1845, 1905, 2080, 2665, and 2715 Ma, and these are from the Hinckley (H) formation except 1335. Single grain modes are at 1665, 1810, 2565, 2895, and 3045, all are from the Fond du Lac (FDL) formation except 3045. The maximum age of either formation is 1010 Ma. The principle mode of 1085(FDL) and the minor mode of 1115(H) are similar in age. The principle modes of 1170(H) and 1210(FDL) are close as well. The two minor modes of 1315(H) and 1335(FDL) are the most similar in age between the two formations. The similarities in modes older than 1335 Ma decrease.

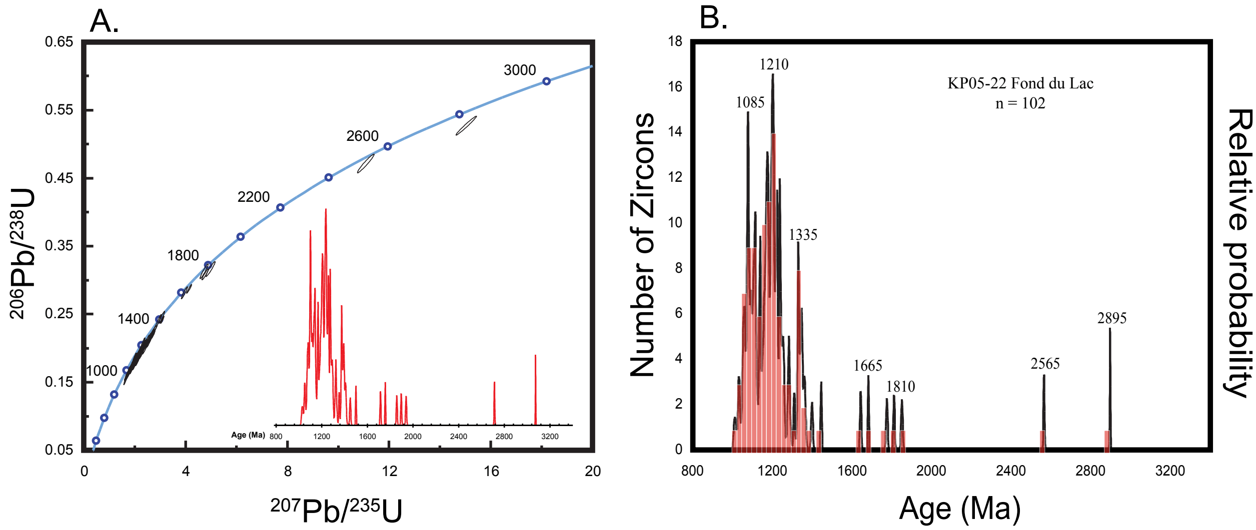

Figure 1. A. Concordia diagram of the 102 zircon dates reported for the Fond du Lac formation. Relative probability plot is inset. B. Histogram and relative probability plot for for the Fond du Lac formation, with modes labeled over respective peaks.

The 1085(FDL) and 1115(H) modes are close to the established age of the Midcontinent Rift at 1.1 Ga (Davis and Green, 1997), and may derive from rift related rhyolite volcanics. An alternative explanation for these dates is the main orogenic event of the Grenville Orogen at roughly 1.1 Ga (Tollo et. al., 2004). The 1170(H) and 1210(FDL) modes are close to the age of the Elzevirian event (1.2 Ga) associated with the part of the Grenville province located in southern Ontario and northern New York State (McLelland et. al., 1996; Gower and Krogh, 2002; Rivers, 1997).

The 1315(H) and 1335(FDL) are possibly from the Grenville province as well, but come from associate Grenville events in the southeast U.S. (McLelland et. al., 1996; Gaudette et. al., 1981). However, they could alternately be derived from the granite rhyolite complex that lies to the north of the Grenville Orogen (Rivers, 1997; Goodge, 2004). All minor modes and single grain modes are from the following: the Granite-Rhyolite Complex (1.3-1.5 Ga) (Van Schmus et. al., 1996; Holm, 2005), the Mazatzal (approx. 1.65 Ga) and Yavapai (1.8-1.7 Ga) Events (Van Schmus, 1976; Holm, 2005), the Penokean

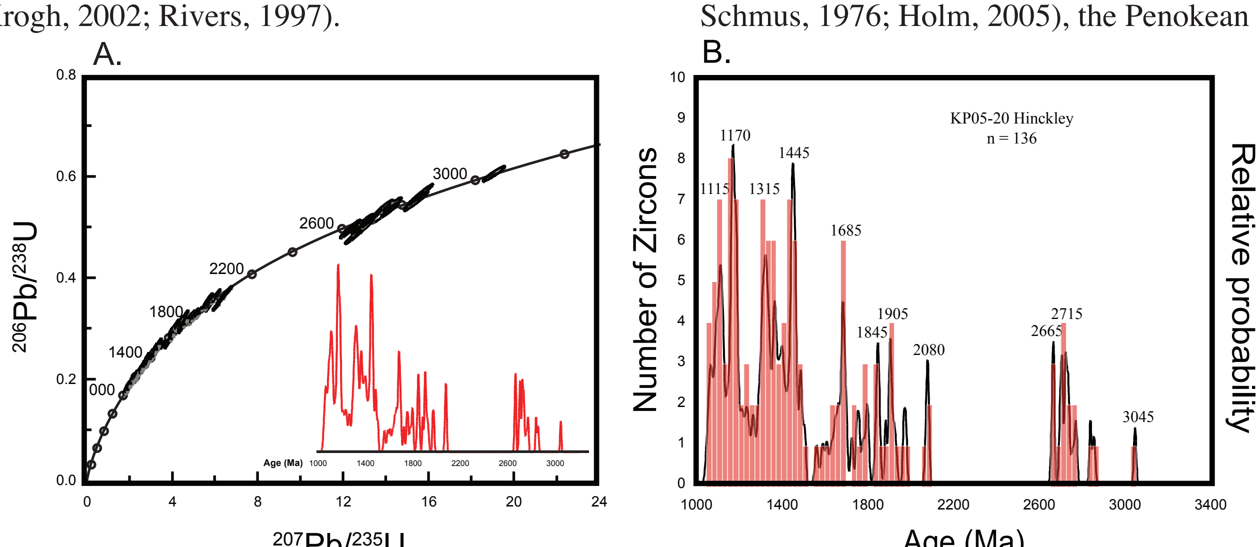

Figure 2. A. Concordia diagram of the 136 zircon dates reported for the Hinckley formation. Relative probability plot is inset. B. Histogram and relative probability plot for the Hinckley formation, with modes labeled over respective peaks.

Event (1875-1835Ma) with associated 1750, 1775, and 1800 Ma events (Holm, 2005), and Minnesota and Superior Craton rocks (>1.9 Ga) (Holm, 2005).

Similarities in modes between the formations suggest some type of relationship between the two formations. These relationships could be that their respective sedimentary delivery systems were somewhat alike or the earlier formation provided material for the other. It is likely that the earlier formation provided material for the younger (Morey, 1967; Tryhorn and Ojakangas, 1972).

The main difference between the Fond du Lac and Hinckley histograms is the large quantity of older dates present in the Hinckley histogram. Hinckley zircon composition expresses a larger variety of sources and an increase supply from older sources that are more proximal to, and north of, the rift. Fond du Lac provenance is more restricted but suggests an intricate transport system that carried material across half of the North American continent (Rainbird, 1992). Recorded paleoflow indicators are too limited spatially to account for such large transport networks, and local variation in such a large system could account for recorded flow directions (Ojakangas and Morey, 1982).

CONCLUSIONS

(1) The age of the sediments deposited in the Midcontinent Rift indicate provenance from rocks of the pre-Grenvillian Elzevirian event. (2) A sedimentary network connected the eastern margin of Laurentia with the center of the North American continent. (3) Between the deposition of the Fond du Lac and the deposition of the Hinckley the sedimentalogical framework of the rift basin changed so that more locally derived sediment was being transported to the basin during Hinckley deposition.

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REFERENCES CITED

Chang, Z., Vervoort, J. D., McClelland, W. C., and Knaack, C., 2006, U-Pb Dating of Zircon by LA-ICPMS: submitted.

Davis, D. W., and Green, J. C., 1997, Geochronology of the North American Midcontinent Rift in western Lake Superior and implications for its geodynamic evolution: Canadian Journal of Earth Sciences, v. 34, no. 4, p. 476-488.

Gaudette, H. E., Vitrac-Michard, A., and Allegre, C. J., 1981, North American Precambrian history recorded in a single sample: high-resolution U-Pb systematics of the Potsdam sandstone detrital zircons, New York State: Earth and Planetary Science Letters, v. 54, p. 248-260.

Goodge, J. W., Williams, I. S., and Myrow, P., 2004, Provenance of Neoproterozoic and lower Paleozoic siliciclastic rocks of the central Ross orogen, Antarctica: Detrital record of rift-, passive-, and active-margin sedimentation: GSA Bulletin, v. 116, no. 9/10, p. 1253-1279.

Gower, C. F., and Krogh, T. E., 2002, A U-Pb geochronological review of the Pre-Labradorian and Labradorian geological history of the eastern Grenville Province: Canadian Journal of Earth Sciences, v. 39, p. 795-829.

Holm, D. K., Van Schmus, W. R., MacNeill, L. C., Boerboom, T. J., Schweitzer, D., and Schneider, D., 2005, U-Pb zircon geochronology of Paleoproterozoic plutons from the northern midcontinent, USA: Evidence for subduction flip and continued convergence after geon 18 Penokean orogenesis: Geological Society of

America Bulletin, v. 117, no. 3/4, p. 259-275.

McLelland, J., Daly, S., McLelland, J.M., 1996, The Grenville orogenic cycle (ca. 1350-1000 Ma); an Adirondack perspective; Tectonophysics, v. 265, no. 1-2, p. 1-28.

Morey, G. B., and Ojakangas, R. W., 1982, Keweenawan sedimentary rocks of eastern Minnesota and northwestern Wisconsin: Geological Society of America Memoir, v. 156, p. 135-146.

Morey, G.B.; 1967, Stratigraphy and Petrology of the Type Fond du Lac Formation Duluth, Minnesota: Report of Investigations - Minnesota Geologic Survey, 35 pp.

Ojakangas, R. W., and Morey, G. B., 1982a, Proterozoic sedimentary rocks: Geological Society of America Memoir, v. 156, p. 83-84.

-, 1982b, Keweenawan sedimentary rocks of the Lake Superior region: A summary: Geological Society of America Memoir, v. 156, p. 157-164.

Rivers, T., 1997, Lithotectonic elements of the Grenville Province; review and tectonic implications: Precambrian Research, v. 86, no. 3-4, p. 117-154.

Rainbird, R. H., Heaman, L. M., and Young, G., 1992, Sampling Laurentia: Detrital Zircon Geochronology Offers Evidence for an Extensive Neoproterozoic River System Originating from the Grenville Orogen: Geology, v. 20, p. 351-354.

Tollo, R. P., Corriveau, L., McClelland, J. M., and Bartholomew, M. J., 2004, Proterozoic tectonic evolution of the Grenville orogen in North America: An introduction, Proterozoic Tectonic Evolution of the Grenville Orogen in North America Memoir: Boulder, The Geological Society of America, Inc., 820 p.

Tryhorn, A. D., and Ojakangas, R. W., 1972, Sedimentation and Geology of Minnesota: A Centennial Volume, Petrology of the Upper Precambrian, Minnesota Geologic Survey, p. 632.

Van Schmus, R., 1976, Early and Middle Proterozoic history of the Great Lakes area, North America: Royal Society of London Philosophical Transactions, v. 280, p. 605-628.

Van Schmus, W. R., Bickford, M. E., and Turek, A., 1996, Proterozoic geology of the east-central Midcontinent basement: Geological Society of America Special Paper, v. 308, p. 7-32.