U-Pb dating of Detrital Zircon from the Fond du Lac and Hinckley Formations of Northern Minnesota

Lee Finley- Blasi,
Senior Integrative Exercise
March 10, 2006

Submitted in partial fulfillment of the requirements for a Bachelor of Arts degree from Carleton College, Northfield, Minnesota.

TABLE OF CONTENTS

INTRODUCTION 1

GEOLOGIC SETTING 2

Figure 1 4,5

ZIRCON GEOCHRONOLOGY 8

Figure 2 10

METHODS 11
Outcrop Description 11
Sample Collection and Processing 12
Data Processing 13
Image Analysis 14

Figure 3 15

Figure 4 16

RESULTS 17
Geochronology 17
Figure 5 18
Figure 6 19
Table 1 20
Figure 7 22
Figure 8 23
Grain Morphology 24
Figure 9 25
Figure 10 26

DISCUSSION 27
Maximum Depositional Age 27
Fond du Lac Histogram 27
Figure 11 29
Hinckley Histogram 31
Recycling 32
Conclusions 33

ACKNOWLEDGEMENTS 33
REFERENCES CITED 34

Appendix 1 38
Appendix 2 45

U-Pb dating of Detrital Zircon from the Fond du Lac and Hinckley Formations of Northern Minnesota

Lee Finley- Blasi, Carleton College Geology Department
Senior Integrative Exercise, Advisor Cameron Davidson
March 10, 2006

Abstract: Laser Ablation Inductively Coupled Plasma Mass Spectrometry is used to determine U-Pb dates for over one hundred detrital zircons from two formations in the Midcontinent Rift of eastern Minnesota. Both the Fond du Lac and Hinckley formations are quartz sandstones with a Neoproterozoic date of formation. The Fond du Lac recorded major zircon modes strongly centered on 1,200 Ma, with the most significant mode at 1210 Ma. Other significant modes are at 1085 and 1335 Ma. These data indicate a supply of zircons in this formation from the Grenville Province, located on the eastern margin of Laurentia. The youngest single zircon date recorded is 1010.8±12.1 Ma, constraining the upper limit of formation age to the Neoproterozoic. The Hinckley displays a large array of zircon ages with significant peaks at 1170 and 1445 Ma. Other peaks include 1315, 1685, 2080, 2665, 2715, and 3045 Ma. The dates represent a cacophony of events spanning all known rocks in central and eastern North America. Significant, specific provenance locations are difficult to constrain, but Grenvillian sources are again likely. The increase in quantities of zircons older than 1.9 Ga means that local Superior Craton and Minnesota rocks provided increased material for the Hinckley formation. Zircon grain form analysis between the Fond du Lac and overlying Hinckley indicate a maturation of grains, agreeing with previous conclusions of a reworking parent connection.

U-Pb dating of Detrital Zircon from the Fond du Lac and Hinckley Formations of Northern Minnesota

Lee Finley- Blasi, Carleton College Geology Department
Senior Integrative Exercise, Advisor Cameron Davidson

Keywords: detrital zircon, Midcontinent Rift, provenance, Fond du Lac, Hinckley, U-Pb geochronology

INTRODUCTION

Extensive research has been done to describe the Keweenawan Supergroup sedimentary formations of the Midcontinent rift after its 1.1 Ga formation (Stauffer, 1927; Hamblin, 1965; Morey and Sims, 1972; Tryhorn and Ojakangas, 1972; Morey, 1977; Ojakangas and Morey, 1982a; Ojakangas and Morey, 1982b). These descriptions provide basic evidence and some discussion of provenance for the quartz-dominant arenites that make up the bulk of the detrital formations (Ojakangas and Morey, 1982a). Previous papers conclude that the quartz sandstones are derived from the proximal Midcontinent Rift formation dated at 1.1Ga (Ojakangas and Morey, 1982a; Morey, 1967), as well as from Archean and Paleoproterozoic rocks from central Minnesota based on paleocurrent indicators, size and shape of grains, and feldspar composition (Morey, 1967; Ojakangas, pers. comm.). Some even suggest a "cannibalistic" provenance, where older less mature sandstone provided quartz and feldspars with overgrowths (Morey, 1967).

Provenance of each formation is of great interest since the information would allow a more complete geochronology of the area. Currently the Keweenawan Supergroup is all that represents the 600 million (Precambrian) years between the Midcontinent Rift (1.1Ga) and the Mt. Simon formation (upper Cambrian).

This project analyzes detrital zircons found in the Fond du Lac and Hinckley Formations of the Midcontinent Rift basin to help constrain the age and the location of source rocks. These dates are compared to major rock forming events throughout North America. Zircon form and size are used to compare characteristics between the Fond du Lac and Hinckley formations, and possible parent reworking connections.

In this paper, I conclude that the primary source of zircons for the Fond du Lac is Grenville related, specifically the Elzevirian event of Southern Ontario, and local Keweenawan volcanics. This conclusion implies a large fluvial east to west sedimentary network between the Grenville front and the Midcontinent Rift. The primary provenance of the Hinckley is less definitive, but more local rocks are contributing to the formation. This research was completed as part of the Keck Consortium REU program in Northern Minnesota in the summer of 2005.

GEOLOGIC SETTING

Approximately 1.1 billion years ago the North American continent (Laurentia) experienced rifting through what is currently Minnesota, Lake Superior, and Michigan (Craddock, 1972). The dates of the rift are associated with volcanics that have produced high precision dates spanning from 1108 to 1086 Ma (Davis and Green, 1997).

Rift related horst and graben structures created basins that have since filled with sediment. The western graben is the current location of approximately 2,000 meters of sediment fill (Ojakangas and Morey, 1982a). Some have termed the entire series “the red clastic series”, as it is typically red and sometimes contains lithic fragments (Stauffer, 1927). Subunits of the series in the two basins are the Fond du Lac and Hinckley and

their laterally associated Bayfield group formations (Fig. 1). The Fond du Lac and Hinckley are in the western basin, and the trend of the basin is rift parallel southwest northeast.

The Hinckley lies directly above the Fond du Lac. Both are primarily quartz in composition, but each possesses unique compositions of feldspars and cementing minerals. Above the Hinckley is the Mt. Simon formation, and below the Fond du Lac is crystalline Precambrian rock (Morey, 1972). Where the Fond du Lac is not deposited directly onto crystalline or volcanic bedrock it overlies the Solor Church formation (Morey, 1972). The nearby Douglas fault is a remnant of the regional extension event creating horst and graben structures. The fault acts as the eastern most boundary of the Fond du Lac Formation, and the western boundary is a nonconformable contact with the Denham and Little Falls Formations (Boerboom, 2001).

The Hinckley Formation is deposited continuously over the western basin and across the Douglas fault and onto the St. Croix horst (Morey, 1972). The Hinckley continues into the eastern basin under the name of Devil's Island sandstone. Ojakangas (1972) interpreted the Fond du Lac depositional environment as a large fluvial network, and the Hinckley depositional environment as a large shallow lacustrine embayment slowly transgressing (Morey and Ojakangas, 1982).

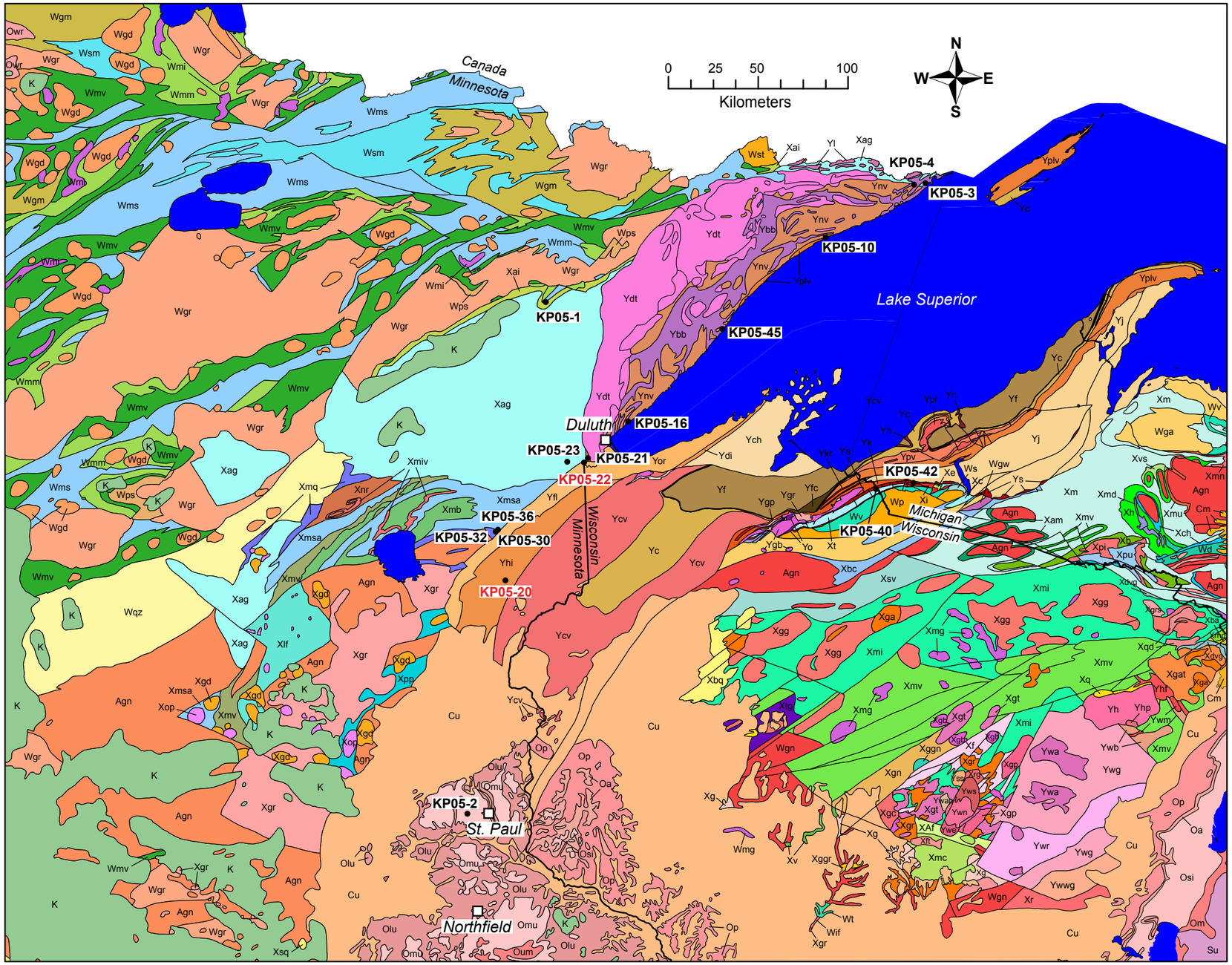

Figure 1. Geologic map of Minnesota and Northern Wisconsin with sample labels at collection locations for all samples taken for the Summer 2005 Northern Minnesota Keck Project. Sample ID's of formations studied in this paper, Fond du Lac (KP05-22) and Hinckley (KP05-20), are highlighted in red. Borders, large bodies of water, and a few important cities are included for orientation. Key to geologic formations is on next page. Modified from Cannon et al. 1999.

Geologic Map Key

Sedimentary and Medisedimentary Rocks

Minnesota

- K — Cretaceous sedimentary rocks
- Owr — Winnipeg and Red River Fms.
- Oum — Upper & Middle Ordovician sed. rocks
- Omu — Middle Ordovician sedimentary rocks
- Olu — Lower Ordovician sedimentary rocks
- Cu — Cambrian undivided

- Yhi — Hinkley Sandstone
- Yfl — Fond du Lac Formation

Wisconisin and U.P. Michigan

- Su — Silurian undivided
- Om — Maquoketa Formation
- Osi — Sinnippee Group
- Oa — Ancell Group
- Op — Prairie du Chien Group
- Cm — Munising Fm
- Cu — Cambrian undivided

- Yj — Jacobsville Sandstone
- Ych — Chequamegon Sandstone
- Ydi — Devils Island Sandstone
- Yor — Orienta sandstone
- Yf — Freda Sandstone
- Yfc — Freda sandstone-cgl member
- Yn — Nonesuch Formation
- Yc — Copper Harbor Conglomerate

Volcanic and Metavolcanic Rocks

Minnesota

- Ypiv — Portage Lake Volcanics
- Ynv — North Shore Volcanic Group
- Ycv — Chengwatana Volcanics

Wisconisin and U.P. Michigan

- Ys — Siemens Creek Volcanics
- Yplr — Portage Lake Vol-rhyolite
- Yplv — Portage Lake Volcanics
- Ypr — Porcupine Volcanics-rhyolite
- Ypv — Porcupine Volcanics
- Yk — Kallander Creek Volcanics
- Ykr — Kallander Creek-rhyolite
- Yh — Hager Rhyolite
- Ycv — Copper Harbor-volcanic member
- Ycv — Chengwatana Volcanics

Plutonic and Metaplutonic Rocks

Minnesota

- Ydt — Duluth Complex
- Ybb — Beaver Bay Complex
- Yl — Logan Intrusions

Wisconisin and U.P. Michigan

- Ygp — granophyre
- Ygr — granite
- Ygb — gabbro
- Yo — olivine gabbro
- Yhp — Hager Quartz Porphyry

- Ywa — WRB-anorthosite
- Ywb — WRB-Belognia Granite
- Ywm — WRB-Peshtigo Mangerite
- Ywr — WRB-Red River Granite
- Ywwg — WRB-Waupaca Granite
- Ywg — WRB-Wolf River Granite
- Yhf — High Falls Granite
- Ywap — WP-aplite
- Ywe — WP-Big Eau Pleine granite
- Ywn — WP-Nine Mile Swamp granite
- Yws — WP-quartz syenite
- Yss — WP-Stettin pluton

- Xsq — Sioux Quartzite
- Xag — Rove, Virginia, Thomson
- Xai — Biwabik, Gunflint, Pokegama
- Xmiv — iron-formation
- Xnr — North Range Group
- Xif — Little Falls Formation
- Xmv — metasedimentary and metavolcanic
- Xmsa — metasedimentary rocks
- Xmq — Trout Lake, Denham

- Xbq — Barron Quartzite
- Xq — quartzite
- Xpu — Paint River Group
- Xc — Copps Formation
- Xt — Tyler Formation
- Xpi — Riverton Iron-Formation
- Xmn — Negaunee Iron-Formation
- Xi — Ironwood Iron-Formation
- Xsv — biotite schist
- Xm — Michigamme Formation
- Xvs — volcanic-sedimentary unit
- Xam — magnetic unit
- Xmmc — Menominee and Chocolay Groups
- Xmsa — Ajibik and Siamo Formations
- Xmu — Menominee Group (Palms)
- Xch — Chocolay Group

- XAf — mylonite

- Xmb — metabasalt

- Xv — volcanic rocks undivided
- Xr — rhyolite
- Xrg — rhyolite
- Xrhd — rhyolite and dacite
- Xmv — Michigamme-volcanic member
- Xmc — Milladore Volcanics
- Xmi — mafic metavolcanic
- Xh — Hemlock Formation
- Xf — felsic volcanic
- Xtg — felsic volcanics
- Xe — Emperor Volcanic Complex
- Xdvg — dacite and graywacke
- Xbc — Blair Creek Formation
- Xmv — bimodal volcanics
- Xba — basaltic breccia
- Xb — Badwater Greenstone

- Xgr — late tectonic intrusions
- Xgd — syntectonic intrusions
- Xop — post tectonic intrusions
- Xpp — Peavy Pond Complex

- Xg — granite
- Xgr — late tectonic intrusions
- Xqd — quartz diorite
- Xgp — porphyritic granite
- Xmd — metadiabase
- Xmg — metagabbro
- Xggn — granitic gneiss
- Xga — granitic rocks
- Xg — granitic rocks undivided
- Xgg — granite and tonalite
- Xgt — granodiorite-tonalite
- Xgn — gneiss-amphibolite
- Xggr — gneissic granite
- Xgb — gabbro
- Xft — foliated tonalite
- Xgr — alkali-fs granite
- Xgrs — Spikehorn Creek Granite
- Xgat — Athelstane Quartz Monzonite
- Xgc — Cherokee Granite

- Wsm — schist-rich migmatite
- Wms — metasedimentary rocks
- Wps — paragneiss

- Wif — iron-formation
- Ws — biotite schist
- Wgw — graywacke

- Wqz — rocks of magnetic quiet zone
- Wmm — mixed metavolcanic rocks
- Wmv — mafic metavolcanic rocks

- Wv — volcanics undivided
- Wt — tuff breccia
- Wd — Dickinson Group

- Wgd — post-tectonic granitic rocks
- Wmi — post-tectonic mafic intrusions
- Wst — Saganaga Tonalite
- Wgr — syntectonic granitic rocks
- Wgm — granite-rich migmatite
- Agn — gneiss and granite

- Wp — Puritan Quartz Monzonite
- Wmg — metagabbro
- Wga — gneiss and amphibolite
- Wgn — gneiss
- Agn — gneiss

Phanerozoic

Mesoproterozoic

Paleoproterozoic

Archean

The Fond du Lac Formation

The Fond du Lac Formation is composed of lenticular sandstone and siltstone with interbedded mudstone and shale (Morey and Ojakangas, 1982). The formation is a poorly sorted arkose sandstone composed of course to fine grain sizes, with a predominance of fine grains (Morey and Ojakangas, 1982). The formation is primarily shades of red, but contains streaks of white, green, and pinkish grey (Morey, 1967). The entire formation is thought to be approximately 2,100 meters thick according to seismic studies (Morey and Ojakangas, 1982). Only 650 meters of the formation has been drilled and only about 100 m. is present in outcrop (Morey and Ojakangas, 1982). The top of the Fond du Lac grades into the Hinckley sandstone, while the bottom of the formation is inferred to lie directly on igneous or metamorphic bedrock (Boerboom, 2001).

A conglomerate with clasts of quartz, highly altered basalt, basalt porphyry, and felsite occurs throughout the Fond du Lac formation (Morey and Ojakangas, 1982). The matrix is composed of angular quartz and feldspar, and pyrite and marcasite are present (Morey and Ojakangas, 1982). A gradational transition from a conglomerate base transitions to a sandstone dominant formation (Morey and Ojakangas, 1982). The clasts are progressively smaller up section, and a red-brown shale conglomerate is common and usually occurs as lenses (Morey and Ojakangas, 1982).

Quartz grains average about 77 percent of composition, and feldspars make up about 18 percent of the rock (Morey and Ojakangas, 1982). Grains are angular to subrounded in morphology (Morey and Ojakangas, 1982). Multiple cycles of deposition are inferred from the presence of abraded overgrowths (sericitized feldspar) on feldspar cores (Morey and Ojakangas, 1982). The sedimentary lithic fragments present are hypothesized to be older red-beds (Morey and Ojakangas, 1982). The calcite and

hematite cement of the formation makes up about 10 percent of the total rock (Morey and Ojakangas, 1982), explaining the red color of the outcrop.

Sedimentary structures seen in the formation are medium to large scale U shape cross-bedding (Morey and Ojakangas, 1982). The structures strongly indicate an eastward current direction in the fluvial system. Alluvial processes are concluded based on the presence of: mud cracks, rain imprints, channel cuts of underlying strata, upward gradation in grain size, cut-and-fill structures, and rapid lateral changes in thickness and lithology (Morey and Ojakangas, 1982).

The Hinckley Formation

The Hinckley formation is a medium to very thickly bedded, fine to coarse grained, pale red/light pink/brownish gray, texturally mature, quartz sandstone in Minnesota (Morey, 1972). The formation is greater than 500 feet thick in east-central Minnesota and thins southward to less than 50 feet (Morey, 1972). Some mudstone lamellae are present (Morey, 1972). The grain shape is typically moderately well rounded and beds exhibit poor to moderate sorting (Morey and Ojakangas, 1982). The Hinckley overlies the Solar Church formation on the St. Croix horst, but is over the Fond du Lac in the graben west of the horst (Morey and Ojakangas, 1982).

The Hinckley is a mineralogically mature arenite, composed of 96 percent quartz, 0-10% percent feldspar, and 2 percent felsic volcanic/metamorphic rock fragments and chert (Morey and Ojakangas, 1982). The development of the Hinckley is proposed to be a shallow water lacustrine environment reworking the Fond du Lac sands (Morey and Ojakangas, 1982).

Ojakangas and Morey (1982) explained the variability in paleocurrent indicators

throughout the formation by stating that all flow was directed towards the axis of the rift. Therefore, the basin was receiving detritus from all surrounding areas (Morey and Ojakangas, 1982).

ZIRCON GEOCHRONOLOGY

Zircon is a resistant mineral that preferentially occurs in igneous rocks of intermediate to high silicon content (Hoskin and Schaltegger, 2003), and is extremely stable in chemically diverse environments (Finch, 2003). Because of its refractive nature, Zircon is found in nearly all sedimentary deposits. Also because of this, extracting the chemical constituents of zircon grains has historically been a laborious process. The first step toward a reasonable result from a practical method of analysis came in 1955 when Clair Patterson and George Tilton, and their Isotope Dilution Thermal Ionization Mass Spectrometer (ID-TIMS), produced accurate dates from milligram quantities of sample (Davis et al. 2003). The LA-ICPMS method used in this study is relatively recent and represents the most time efficient method of acquiring large quantities of reasonably accurate data, essential for provenance analysis (Fedo et al. 2003).

Zircon is used in geochronology because of its affinity for Uranium (U) and Thorium (Th). The two elements are nearly always incorporated into the crystal structure of Zircon ($ZrSiO_4$) in trace amounts. The radiogenic nature of Uranium causes the element to decay through a distinct series of daughter elements. The series is termed the Uranium decay series and its final product is lead (Pb). Depending on the type of uranium present, either ^{238}U or ^{235}U, the end product of the decay series will be either Pb^{206} or Pb^{207} (Fig. 2).

Many naturally occurring processes affect the production and decay of decay-chain constituents. These include phase change, partial melting, crystallization, partitioning, dissolution, adsorption, degassing, oxidation, reduction, and complexation (Bourdon et al. 2003). When processes such as these occur they cause disequilibrium between the parent and daughter. Disequilibrium in the system is termed a fractionation, and can cause problems in reporting ratios between parent and daughter amounts. These ratios are what allow geochronologists to accurately age date a sample of zircon.

Fractionation of samples should become apparent when results are viewed on a concordance diagram, where the two daughter:parent ratios are plotted against each other. The Concordia is the locus of compositions for which the two U-Pb decay systems give the same age (Davis et al. 2003). The two ratios act as a self-check because they should both yield the same age and both should be available from zircon composition analysis. Zircon crystal structure does not provide a good place for lead to reside, and some is inevitably lost. This loss should be taken into account in determining accuracy of results. This skews the results slightly, but is good because no original lead is incorporated into the zircon.

The duration of uranium series half-lives is on the same order of magnitude for studying very old events in earth's history. Uranium 235 has a half-life from 0.7 Ga, and Uranium 238 has a half-life of 4.46 Ga. The relatively short half-life of ^{235}U means that not much is left after 4.4 billion years of earth history. The scarcity of ^{235}U leads to measurement uncertainty and increased error in reported data. The end product of ^{235}U is ^{207}Pb and because most of the ^{235}U is gone from decay, significant quantities of ^{207}Pb are present. The ability to measure Pb^{207} well, allows the hypothetical productivity curve of

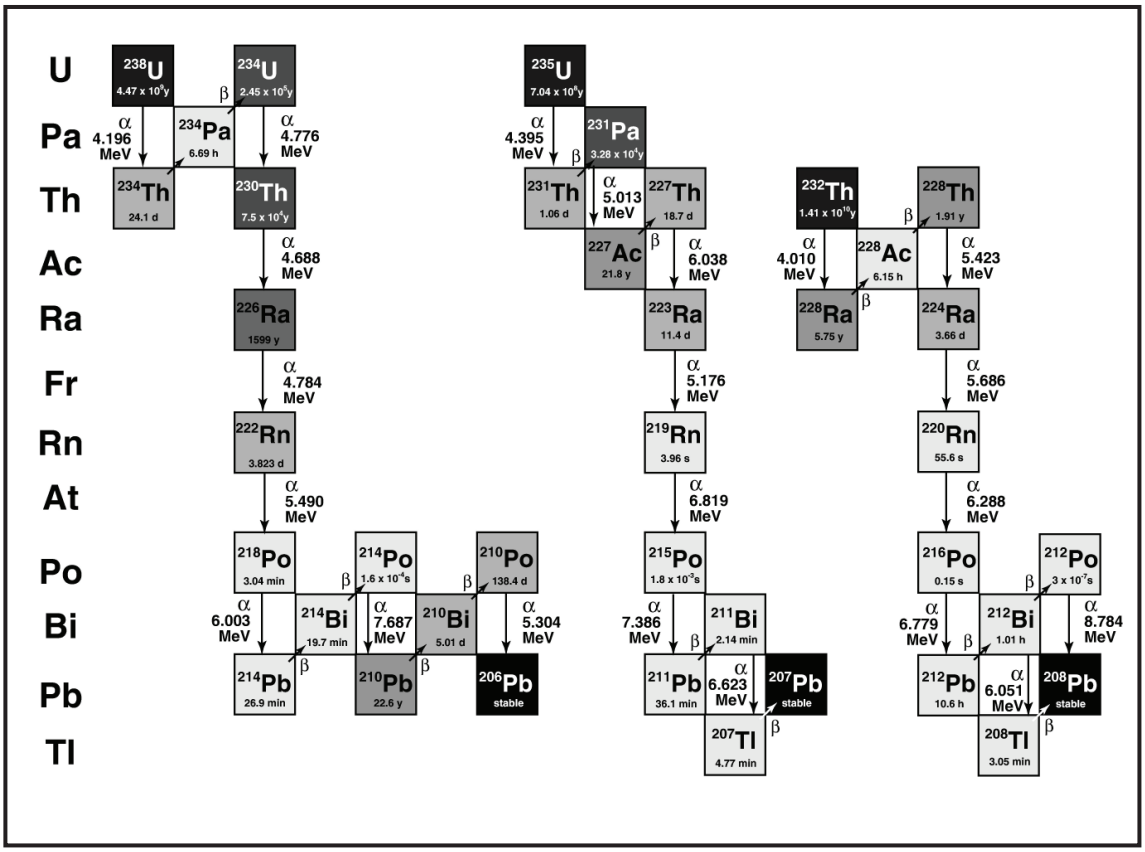

Figure 2. Schematic drawing of the 238U, 235U and 232Th decay chains. The gray-scale reflects half-life, with darker grays for longer half-lives. From Bourdon et al. 2003

^{207}Pb over time to withstand educated scrutiny. For this reason, the presentation of U-Pb ratios is compared to a hypothetical $^{206}Pb/^{207}Pb$ curve.

The most important application of detrital zircon is dating Precambrian basins. No biostratigraphy exists to determine the age of deposition, so cross-cutting and position relationships are important in determining the age of the formation. Zircon dating of the detritus provides a maximum age of deposition, while other relationships may provide minimum age of deposition. Together, detrital zircon dates and relationships can provide formation deposition bounding ages.

METHODS

Outcrop Description

Fond du Lac

The area near Jay Cook State Park and Thompson, MN provided the sample location for the Fond du Lac formation (Fig. 1). At this location, the Fond du Lac is a well-cemented deep red/purple formation with white bands scattered throughout. Outcrop thickness is about 4 meters thick and is continuous. The beds are fairly regular with the largest at about half a meter and the thinnest around a few centimeters. All beds dip generally to the east, but the dip is less than 5 degrees. Very small clay lenses are present. No lithic fragments are present at this location.

Hinckley

We sampled an outcrop along the Kettle River just south of Sandstone, MN (Fig. 1). Large cross-beds are seen in the light pink formation composed of fine to coarse-grained sand. Bedding ranges from one meter thick to as thin as a few centimeters. The middle part of the outcrop contains large well-rounded clasts, and small cavities full of a

clay like material. The outcrop is well sorted as a whole, but one subunit is high in concentration of 2 to 5 centimeter size clasts. The rock is not well cemented. A paleocurrent measurement from crossbedding at the sample area indicates a southerly current.

Sample Collection and Processing

Samples were taken from the Fond du Lac and Hinckley formations using rock hammers and collection bags. 20 to 30 kilograms of each was obtained in order to insure sufficient zircon quantities. Samples were chosen carefully in order to avoid contamination and to improve odds of finding zircons. Weathered surfaces were removed and larger grained samples were preferred.

At Macalester College in St. Paul, Minnesota the rocks were crushed and reduced. First broken into small bits by a Chipmunk Jaw Crusher, the sample was then ground down to sand size bits by a Disc Mill. The grains were split into heavy and light minerals using a Wilfley table, and a Franz Magnetic Separator in free fall mode was then used to pull out all magnetic minerals from the heavy mineral split. The remaining mineral grains were subject to heavy liquid separation with methylene iodide (specific gravity: 3.32). A final mineral separation was performed using a Barrier Franz Magnetic Separator. Zircons from the final split were hand picked and mounted onto a puck, polished, and imaged with Cathodoluminescence. The images were collected to aid in choosing zircons to analyze.

The zircons were then dated using the Laser Ablation – Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) at Washington State University, following the procedures outlined in Chang et al. (submitted). The instrument is a New Wave UP-213

laser ablation system, with a frequency of 10 Hz, connected to a ThermoFinnigan Element2 single collector double focusing magnetic sector ICP-MS. The margin of the grain was targeted when possible, and sample area on each grain was approximately 30 μm in diameter. Helium and argon gas transported ablated material to the ICPMS. The order for ablation and analysis was as such: 6-second warm-up, then an 8 second delay, and finally 35 seconds of rapid scanning laser ablation. Zircon standards FC-1 (1100 Ma) and Pexie (564±4 Ma) were used throughout the session to make sure fractionation was stable and variance in $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ was near 1% (Chang et al., submitted). All samples in this study were dated during a two-week period from Jan. 3 to Jan. 17 2006, when all samples from the Minnesota Keck project were analyzed.

Data Processing

Data reduction and presentation was accomplished Isoplot 3.0 (Ludwig, 2003. In this paper, all dates are reported with 2σ errors, unless otherwise stated, and all data is plotted with 2σ error. The histogram plot is created by specifying the amount of bins to be represented in a certain span of time. In this study, each bin spans a 25 Million year period, allowing us to view a wide range of dates, while still communicating zircon age density well.

The uncertainty of the age is not taken into account in the histogram plot. To account for the uncertainty of the date a relative probability plot is created that roughly follows the contours of the histogram peaks. Dates with larger uncertainty cause the curve to be shorter than dates with well-defined ages. The final curve incorporates all of the dates and associated uncertainties to produce a unique curve describing a set of peaks. These peaks can then be used to describe the amount and relative importance of the

different modes present in the histogram. In this study the $^{207}Pb/^{206}Pb$ dates are used to generate the histograms because of the high precision of these dates.

In a body of zircon ages, the bins with the largest amount of zircon grains present in them represent a mode. Figures produced by Isoplot 3.0 reveal bins of significant zircon age population. To assign specific dates for each mode, the dates within error, corresponding to the bin of interest, are averaged. A mode coincides with a peak in the relative probability plot, and is rounded to nearest 5 Ma. Where a limited number of zircons are present, single distinct ages represent a mode and do not require averaging. The dates of zircons were sorted to see how many reported dates fell within previously defined bounds of rock forming events. The quantities of dates, within error, that fall within the bounds of each event are recorded.

Image Analysis

The program NIH-ImageJ (Rasband, 2006) produces data describing zircon forms recorded in Cathodoluminescence images of mounted samples (Figs. 3 and 4). Our analysis assumes that all samples are arranged such that a c-axis parallel face is seen on all zircons. The longest axis of the grain provides the most information about weathering processes. The primary focus of the image analysis was to record area, surface circumference, long axis, short axis, and circularity of each grain.

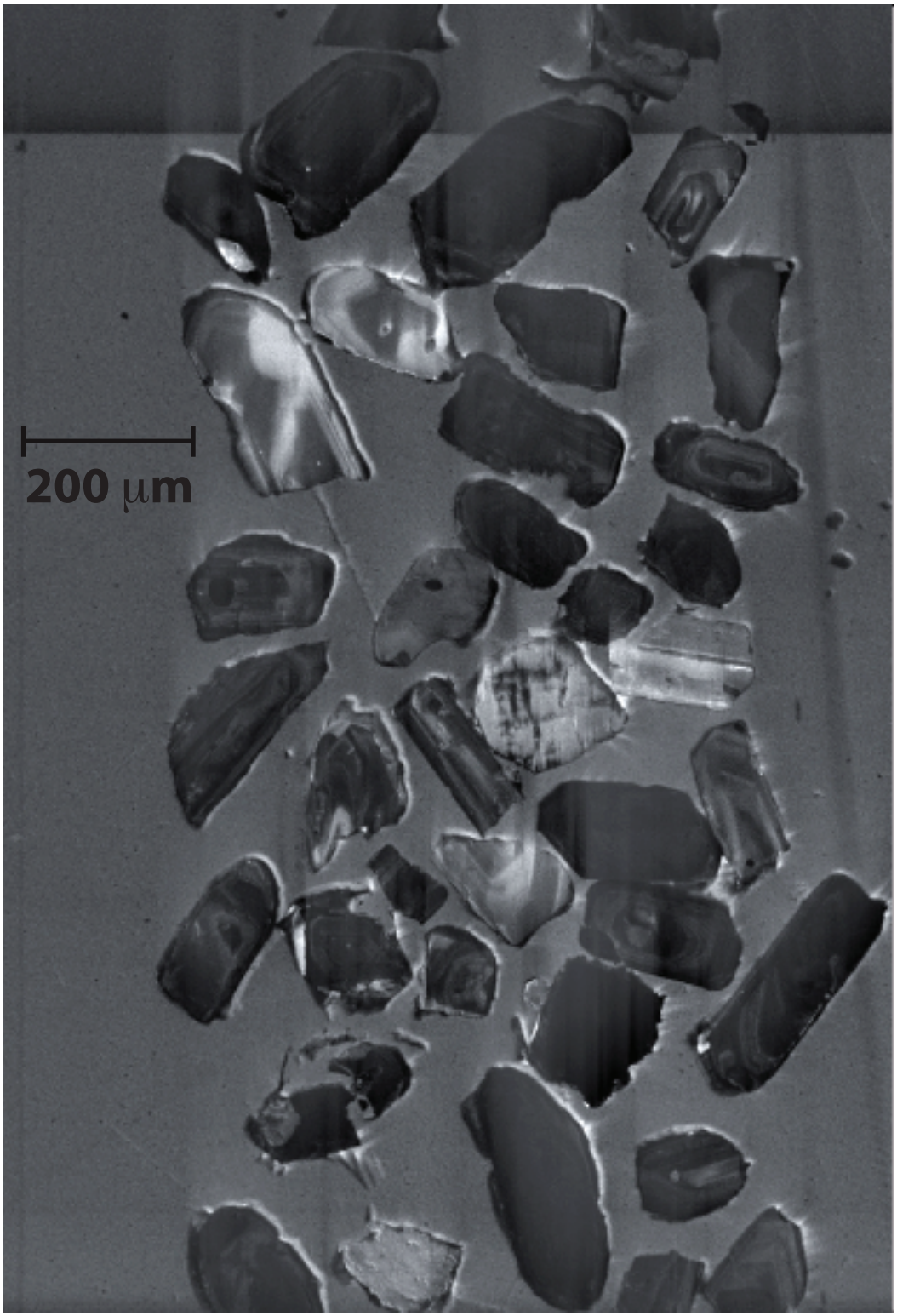

Figure 3. Cathodoluminescence image of zircons from the Fond du Lac Formation. Red circle represents sample area, and is to scale with image.

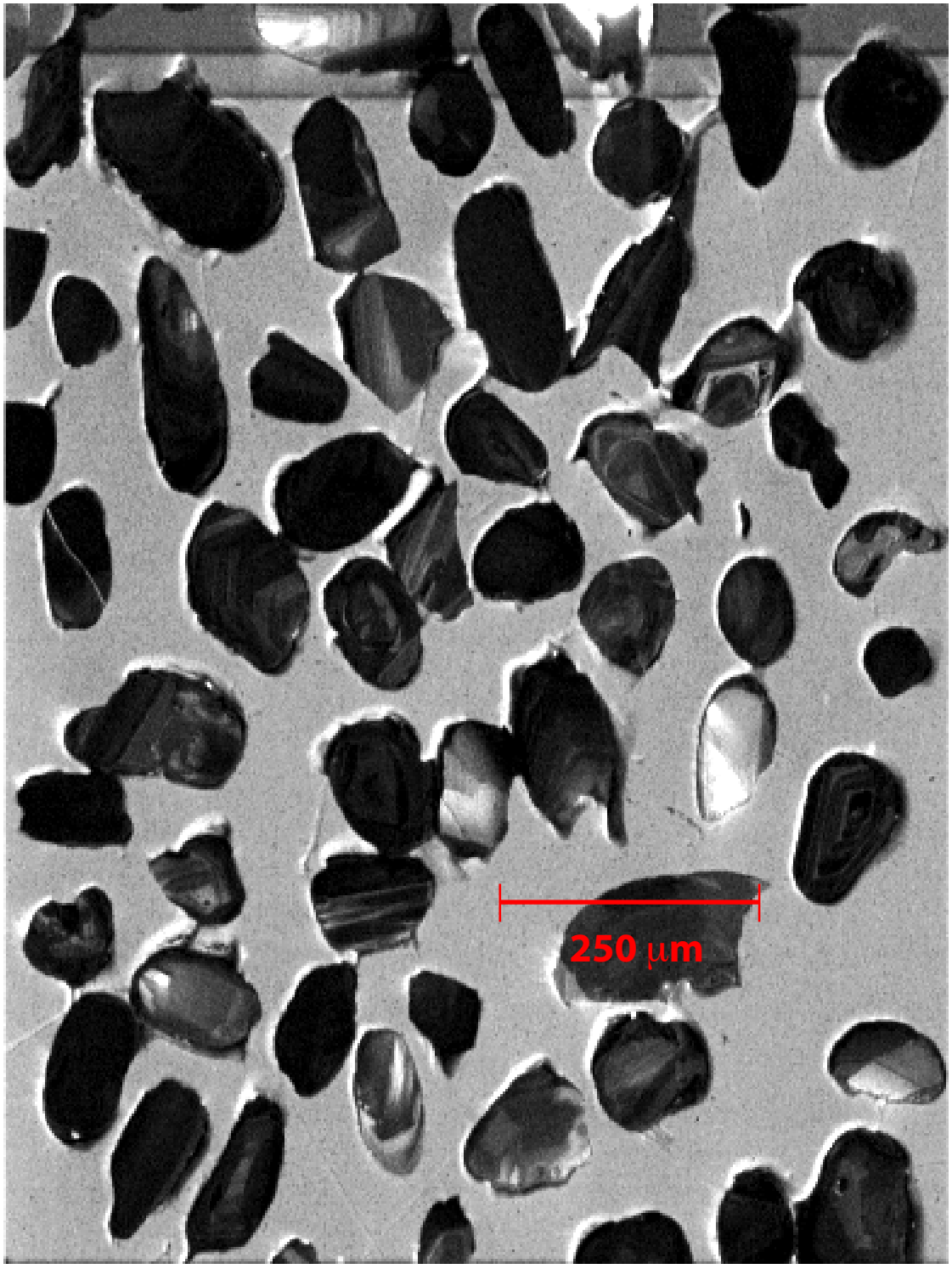

Figure 4. Cathodoluminescence image of Hinckley Formation zircons. Red circle represents sample area from ablating laser and is to scale with image.

RESULTS

Geochronology

Fond du Lac

Fond du Lac histogram analysis (Fig. 5) produced one body of zircon ages and several single grains with older dates. The single body of zircon ages represents dates ranging from 1011 to 1400 Ma. The youngest date reported is 1010.8±12.1 Ma. The oldest date reported is 2897.0±3.2 Ma. A total of 102 grains are chosen, out of a possible 120, for these results. The 102 grains represent the ages recorded with less than 10 percent discordance (Fig. 6).

Major relative probability peaks in the 1011 to 1400 Ma body of zircons are at 1080 and 1210 Ma with a significant peak also present at 1340 Ma. Out of 16 bins in this date range, all have at least one zircon grain present. The maximum number of grains in a single bin is 14. Ninety-five zircon ages are represented in this range (93% of the total).

Five zircons with distinct ages of 1645, 1680, 1775, 1810, and 1850 Ma are closely grouped and produce modes at 1665 and 1810 Ma. Two very old zircons with ages 2565 and 2897 are well constrained and significant. All age data for the Fond du Lac is summarized in Table 1.

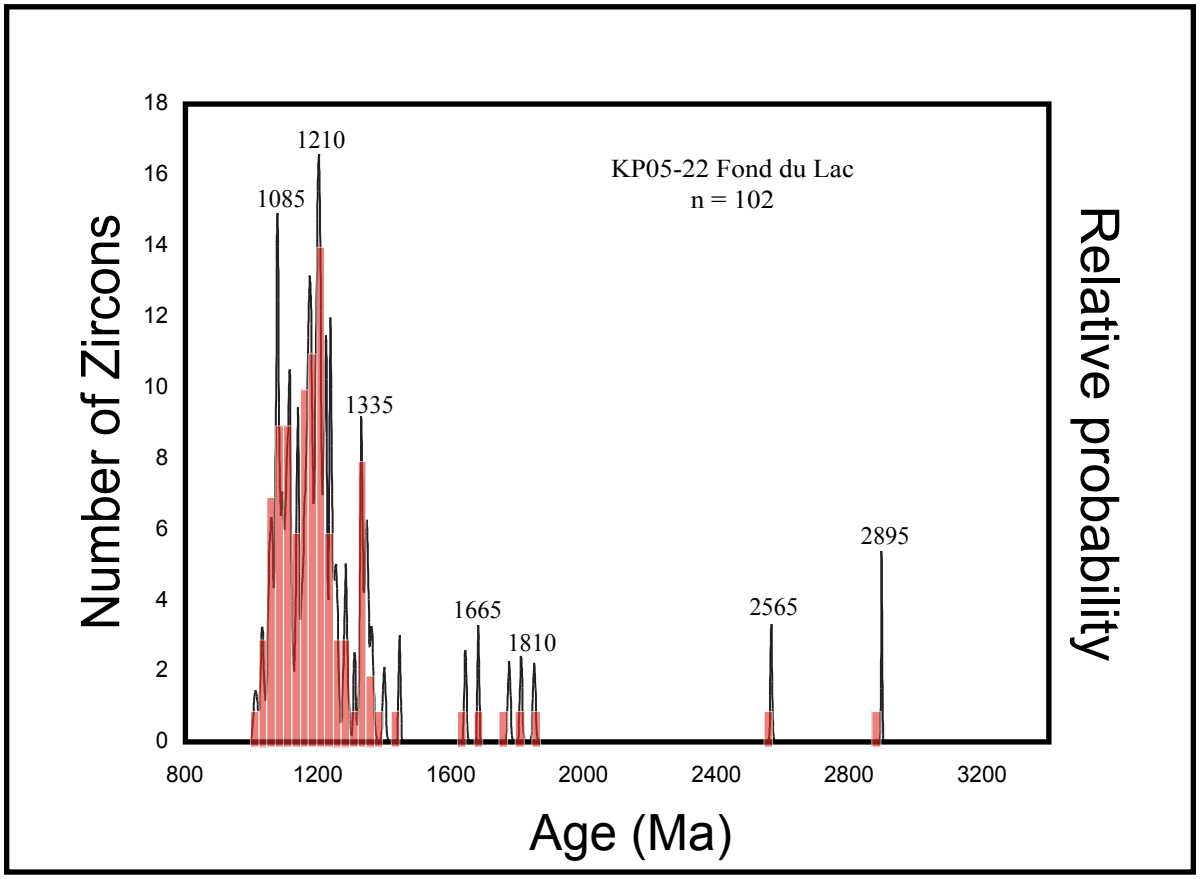

Figure 5. Histogram and relative probability plot of 102 zircon ages reported for the Fond du Lac Formation. Major modes (in Ma) are labeled over respective peaks.

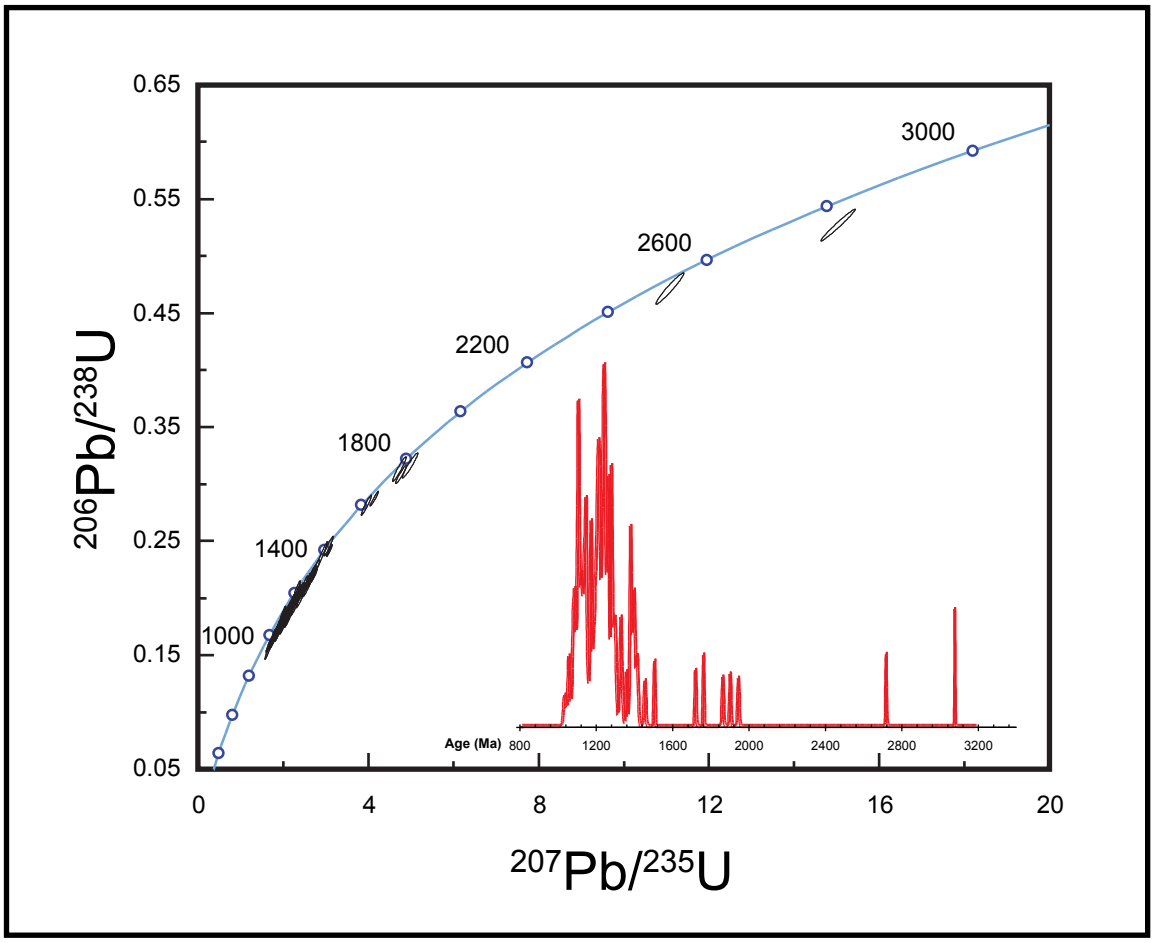

Figure 6. Diagram showing concordia U-Pb analysis of detrital zircon with accompanying relative probability plot for the Fond du Lac Formation.

TABLE 1. SUMMARY OF DETRITAL-ZIRCON AGES.

Formation	Sample ID and Coordinates*	Major zircon modes§ (Ma)	Youngest zircon grains# (Ma)	Maximum depositional age†	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, 5106489	1115, 1170, 1315, 1445, 1685, 1845, 1905, 2080, 2665, 2715, 3045	1052.9±8.7	Neoproterozoic	7	9 10 22	7	19
Fond du Lac	KP05-22 0554645, 5167692	1085, 1210, 1335, 1665, 1810, 2565, 2895	1010.8±12.1	Neoproterozoic	13	29 30 53	3	2

*UTM 15T, NAD 27
§Listed in chronologic order, from youngest to oldest. Rounded to nearest 5 Ma.
#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).
Complete zircon age data is listed in Appendix 1.

Hinckley

The Hinckley formation histogram (Fig. 7) displays a large body of zircon dates spanning from 1052 Ma to 2082 Ma as well as a small cluster of older dates around 2800 Ma and the oldest zircon age of 3046.5±5.3 Ma. The youngest age recorded is 1052.9±8.7 Ma. 135 individual zircon grain ages, from an original 154, are represented on this histogram. The 135 Hinckley detrital zircon ages with less than 10 percent discordance are reported in Figure 8, with an inset of the Relative Probability curve produced by Isoplot.

Major peaks within the 1052 to 1505 Ma large body of zircon dates are at modes 1170 and 1445 Ma and lesser peaks at 1115 and 1315 Ma. This is described as a large body of zircon density because 19 consecutive bins contain at least one zircon, and out of the 19 bins only one bin on the margin has just one zircon grain. Eighty-six grain ages are represented in this date range.

The large body of zircon population decreases in size after approximately 1540 Ma, when no dates are present. The zircon populations frequently become one per bin, and only fill 10 out of 18 bins over a 600 Ma period. However, a few important peaks still emerge in this older body at 1685, 1845, 1905, and 2080 Ma. Thirty-four zircon grains are presented in this age range.

The oldest ages range from 2660 to 3050 Ma and bins have at most 4 grains. Modes of zircons in this group are at 2665 and 2715 Ma. Individual zircons with unique ages are at 2838, 2854, and 3046. Fifteen grains are present in this date range. All modes and age data for the Hinckley are listed in Table1.

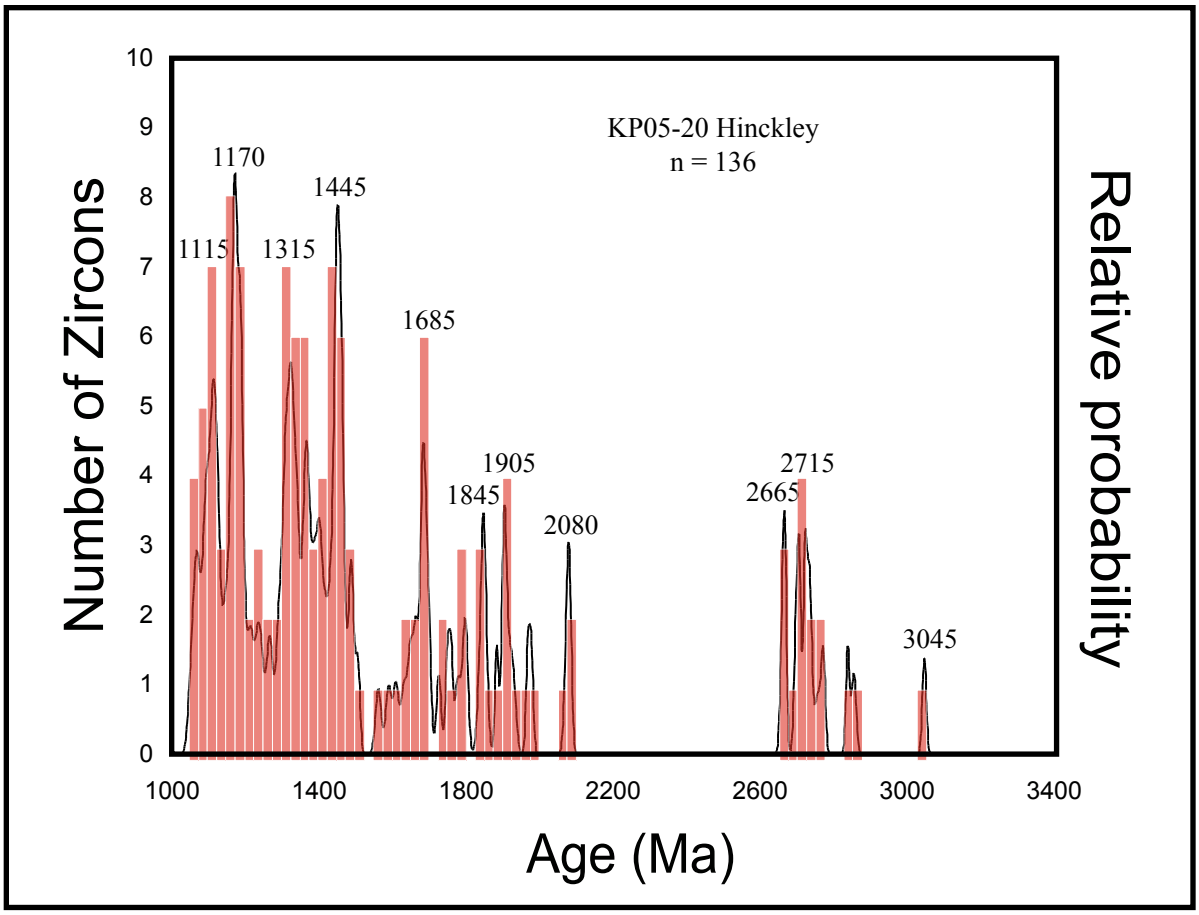

Figure 7. Histogram and relative probability plot of 135 zircon ages reported for the Hinckley Formation. Major modes (in Ma) are labeled over respective peaks.

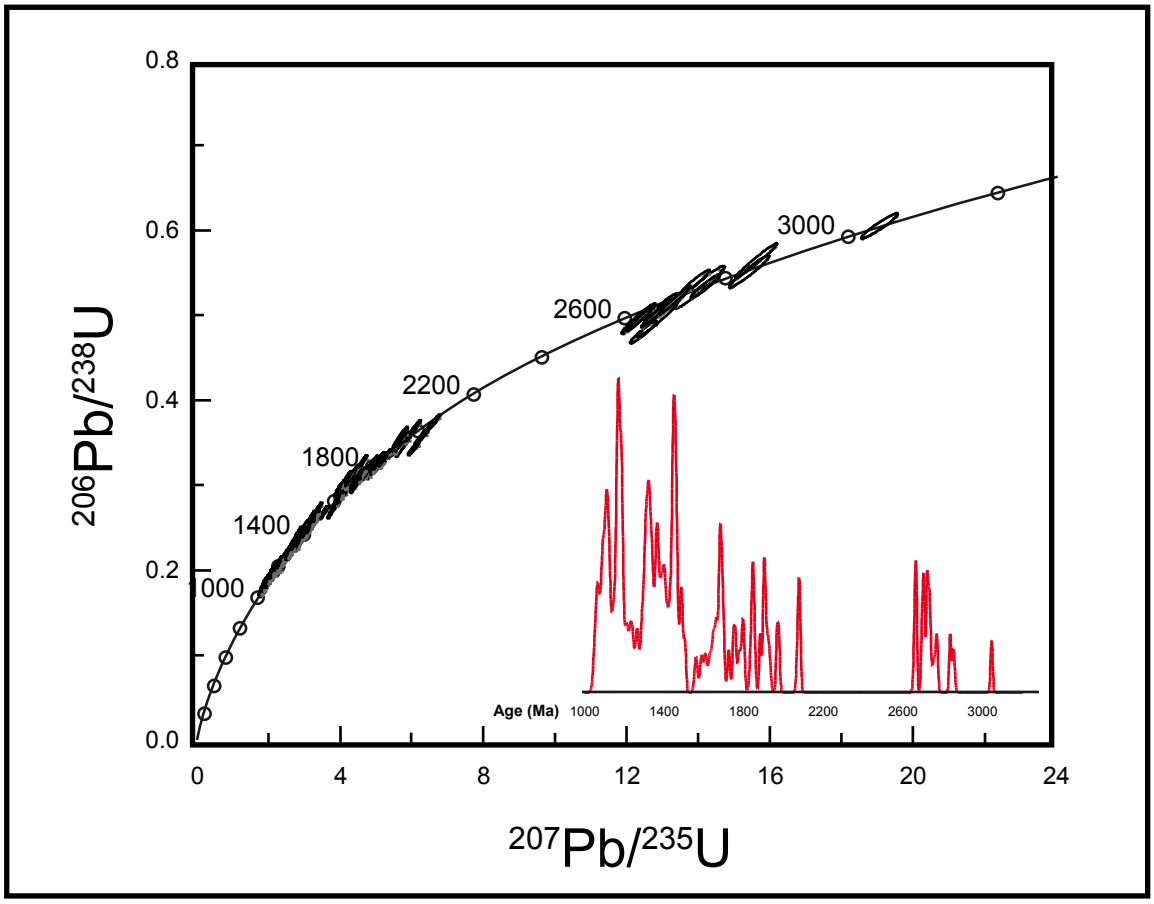

Figure 8. Hinckley Formation concordia U-Pb diagram displaying zircon ages and associated uncertainties. Hinckley relative probability plot is inset.

Grain Morphology

Fond du Lac

Fond du Lac zircon grain shape analysis of 216 individual grains reveals area, circularity, and ellipticity distributions as reported in Figures 9 and 10. The average area of zircon grains is 17331.0 μm^2 with a standard deviation of 8018.0 μm^2. The maximum and minimum grain sizes are 66,981.0 μm^2 and 2,347.0 μm^2 respectively. Average circularity of grains is 0.68 with a standard deviation of 0.087; a perfect circle would have a value of 1. The maximum and minimum circularity values are 0.84 and 0.36 respectively. Average ellipticity of grains is 1.66 with a standard deviation of 0.49. Again a circular grain would have a value of 1. Maximum and minimum ellipticity values are 4.26 and 1.05 respectively.

Hinckley

Hinckley zircon grain form analysis of 296 individual grains reveals area, circularity, and ellipticity as reported in Figures 9 and 10. The average area of zircon grains is 12,582.0 μm^2 with a standard deviation of 6,270.0 μm^2. The maximum and minimum grain sizes are 45, 388.0 μm^2 and 2219.0 μm^2 respectively. Average circularity of grains is 0.757 with a standard deviation of 0.078; a perfect circle would have a value of 1. The maximum and minimum circularity values are 0.89 and 0.03 respectively. Average ellipticity of grains is 1.64 with a standard deviation of 0.43; a circular grain would have a value of 1. Maximum and minimum ellipticity values are 3.16 and 1.64 respectively.

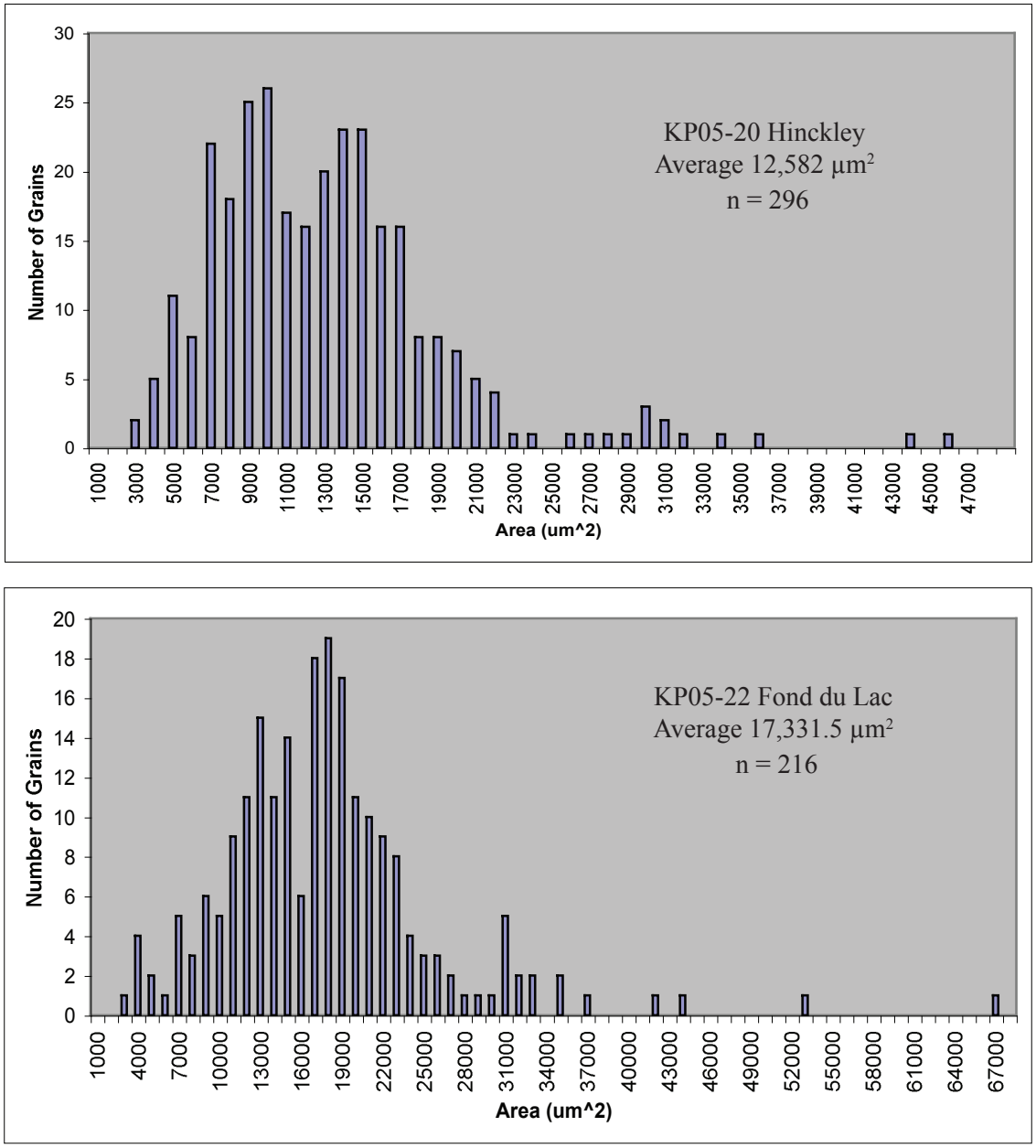

Figure 9. Comparison between area histograms for the Hinckey and Fond du Lac zircons sampled in this study. Possibly a bimodal distribution in each. There is a decrease in average area from the Fond du Lac to the Hinckley.

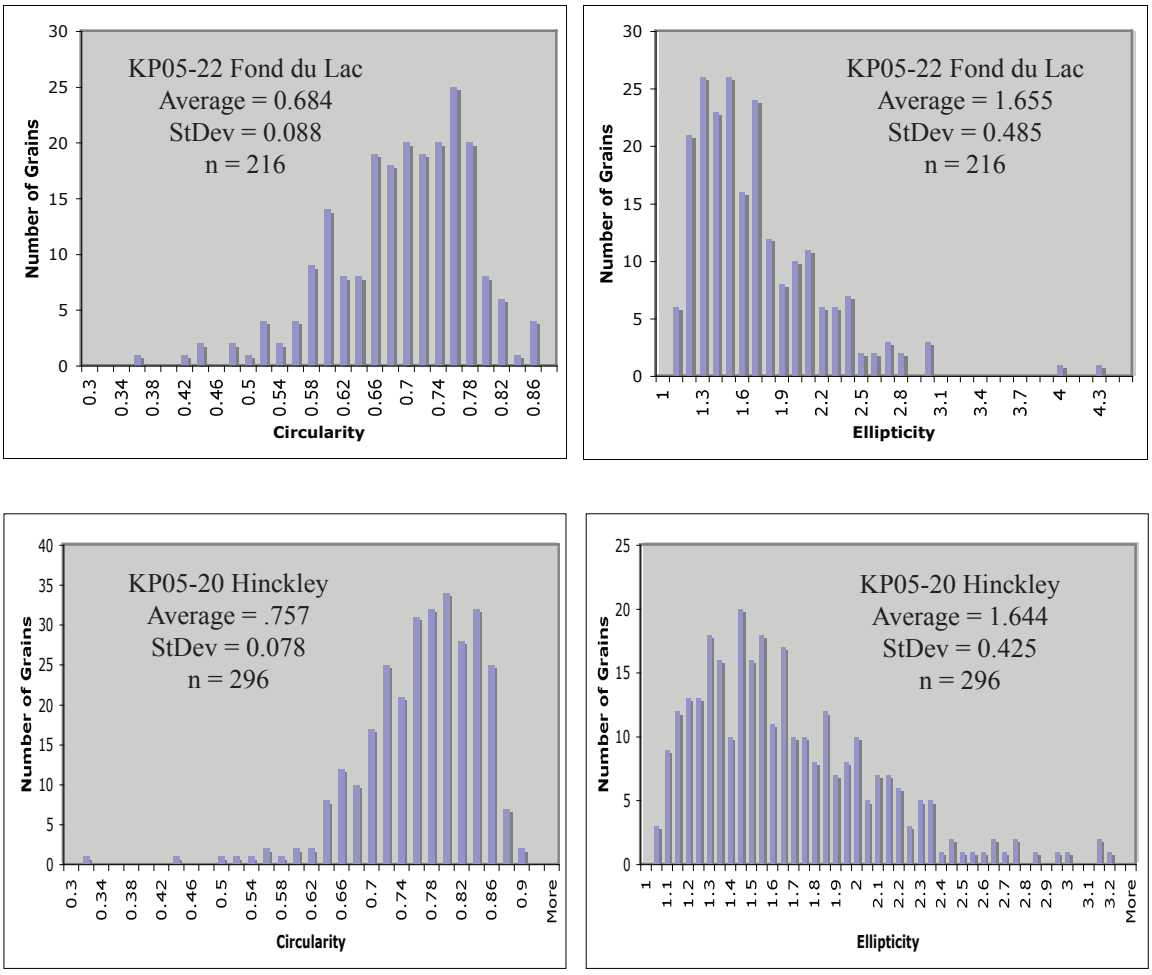

Figure 10. Histogam plots of circularity and ellipticity for the Hinckley and Fond du lac Formations. Data is from ImageJ analysis of zircon shape and size. An increase in average circularity from Fond du Lac to Hinckley is shown as well as a decrease in average ellipticity.

DISCUSSION

Maximum Depositional Age

The youngest grain reported is from the Fond du Lac formation giving a maximum depositional age for the formation at 1010.8±12.1 Ma, and from the law of superposition this date also provides a maximum depositional age for the Hinckley formation.

Fond du Lac Histogram

Even though a large body of ages is present, two specific and very well correlative modes stand out in the body. The first mode, chronologically, is at 1085 Ma and is extremely close to dated events associated with the Midcontinent Rift dates (Davis and Green, 1997). The significant amount of grains from this period present, combined with nine ages that fit into the age bounds of the rift strongly support local provenance for the Fond du Lac Formation. The proximal relationship in space between the Midcontinent Rift and the Fond du Lac Formation illustrates assumed provenance (Ojakangas and Morey, 1982).

The presence of 1,100 Ma dates found from the Fond du Lac formation suggests local provenance, but certainly does not rule out other provenance. Other 1.1 Ga dates in the rock record of North America come from the eastern margin of Laurentia in the Grenville Province (Tollo et al. 2004).

A large mode at 1210 Ma requires a large distinct source. The nearest possibility lies approximately 1,500 km to the east and requires an extremely large and unique sedimentary system to transport large quantities of material the long distance.

The Grenville Event is often defined by the 1.1 Ga Ottawan orogen that spans from Labrador, Canada to the border of Mexico and Texas (Tollo et al. 2004), as seen in

Figure 11. However, the entire Grenville event is also described as lasting 250 Ma years and incorporates several sub-events (Moore and Thompson, 1980). The Grenville orogeny is currently discussed in terms of a sequence of rock forming events that occurred around a general time, and each event may be recorded in the rock record (Moore and Thompson, 1980; McLelland et al. 1996; Rivers, 1997; Gower and Krogh, 2002; Tollo et al. 2004).

The Elzevirian event in southern Quebec and northern New York State is discussed by McLelland et al. (1996), Gower et al. (2002), and Rivers (1997), and is assigned ages of approximately 1,200 Ma, and ranges of: 1,180-1,350, 1,180-1,230, and 1,180-1,250 Ma respectively. Such ranges could include the next histogram peak at 1337 Ma. The latest conclusion by Gower (2002) is that no physical rocks of the northern Grenville Province represent an event at 1,200 Ma. That is, no rocks with dates from this time are reliably recorded (Tollo et al. 2004). What geochronologists do agree on is that there is a change during this time, and rocks pre and post Elzevirian Orogenisis can be dated to constrain the event (Gower and Krogh, 2002). It should be noted that further south, along the Grenville Front, rocks of ~1.25 Ga age are found using Sm-Nd dating methods (Aleinikoff et al. 2004; Bream et al. 2004).

This paper concludes that, the rock geochronologists are unable to account for in the Elziverian event, is completely eroded, and now occurs as sediment in various basins. One of these basins is the Midcontinent Rift. With at least 30 grain ages fitting in the bounds of the Grenville and a major mode corresponding to an established event, the Fond du Lac clearly has a provenance connection with the Eastern margin of Laurentia. A theoretical network of sedimentation that linked the two regions during Fond du Lac

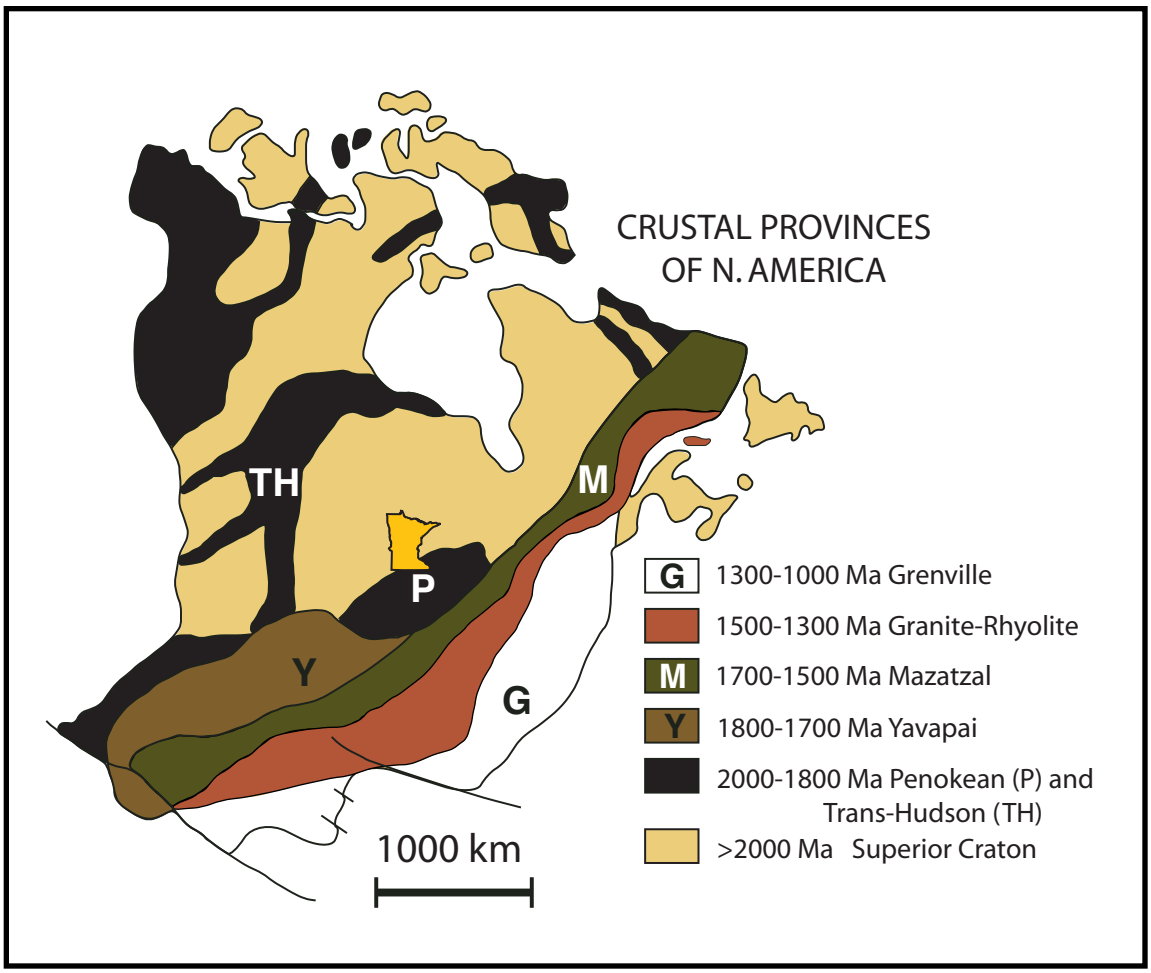

Figure 11. Zircon source rock age and general distribution in North America (Laurentia). Outline of Minnesota is for reference point and is not to scale. Orogens: P - Penokean; TH - Trans-Hudson; Y - Yavapai; M - Mazatzal; G - Grenville. Modified from Holm et al. 2005.

deposition, as supported by Rainbird (1992) and first suggested by Young (1979), would explain these results. The network was likely a vast fluvial system running off of the newly formed mountains of the Grenville Orogeny toward the basin created by the Rift and possibly further (Rainbird, 1992). Santos and others (2002) presents further support for this type of system based on detrital zircon dates from the Middle Run Formation of Ohio.

The less represented modes of 1665 and 1810 Ma (Fig. 5) appear to correspond with the Mazatzal and Penokean orogenies. The Penokean event, 1875-1835 Ma (Van Schmus, 1976), has been described by Holm (2005) to be succeeded by a series of plutons in east-central Minnesota recording dates circa 1750, 1775, and 1800 Ma, close to the 1810 Ma peak. While the Mazatzal accretionary event has been described as 1650 to 1630 Ma in duration (Rainbird, 1992).

Ages greater than 1.9 Ga can reasonably be assumed to come from rocks immediately adjacent to or north of the Midcontinent Rift (Fig. 11). The oldest dates of 2565 and 2897 Ma indicate a provenance in the Superior Craton to the north of the Midcontinent Rift. The reported 2565 age is slightly younger than the average age of the Morton block, 2603±1 Ma reported by Schmitz et al. (2006). However, the 2897 Ma date does not seem to fit with reported ages of nearby superior craton rocks (Bickford et al. 2006; Schmitz et al. 2006).

Hinckley Histogram

The histogram for the Hinckley Formation displays a virtually continuous body of ages spanning a billion year period. The Eastern Grenville Province produced rocks spanning much of this time period, from Labradorian, Pinwarian, Elzevirian, and Grenville events (Gower and Krogh, 2002). However, much of the ages present from 1.5 to 1.9 Ga could have been locally derived from the Wolf River Batholith, the Penokean orogeny, Mazatzal and Yavapai events, and the eastern granite-rhyolite province (Van Schmus, 1975; Holm, 2005; Van Schmus, 1996;).

Modes at 1120 Ma and at 1170 Ma are present and could indicate a provenance like that of the Fond du Lac, however, the relative probability peaks are not as large and the dates do not match exactly. The smaller size of the peaks might indicate less input from this part of the Grenville Province. The decrease in peak size may be created by a general reduction in zircon population due to weathering and grain pulverization from recycling of an older formation's zircons.

The mode at 1310 Ma is best explained by rock forming events of the Grenville orogen that date specifically from this time period (Gaudette et al. 1981). However, an alternative would be volcanic and plutonic events from the granite rhyolite belt to the southeast (Rivers, 1997; Goodge, 2004). The belt contains rocks ranging in age from 1300 Ma to 1500 Ma and can be seen in figure 11.

The mode at 1445 Ma fits within the bounds determined by Van Schmus and others (1996) for the formation of the eastern granite-rhyolite province. Their date of 1470±30 Ma would include this peak and is a likely source for rocks of this period. Not many alternatives exist for rocks of this age, and other possibilities move further to the east and into the Grenville Province.

Modes of 1685, 1845, 1905, and 2080 Ma fall in an area of little detailed research, but still fit into Mazatzal, Penokean, and Superior craton ages. Perhaps with further studies of the Penokean, Yavapai, Mazatzal, and the granite-rhyolite provinces these could better match specific source areas. For this study, it is sufficient to say that these dates all come from locations close to the Midcontinent Rift. Older dates all indicate provenance from the superior province to the east and north of the Midcontinent Rift.

Recycling

Recycling relationships between the Hinckley and Fond du Lac Formations must be taken seriously as many geologists suggest this is the best way to produce a pure quartz sandstone such as the Hinckley (Wirth, pers. comm.; Tryhorn and Ojakangas, 1982). Zircon grain morphology supports the evolution of Fond du Lac type grains to Hinckley type grains through processes of maturation. More mature grains are assumed to be less angular and well rounded, with a decrease in average grain size as the grains are broken up over time. Both features are seen when comparing the two formations (Figs. 9 and 10). The recycling of older formations, with no input of new zircons, would preserve the peaks and distribution of the older formation. This would hold true unless winnowing removed zircons of specific size and shape. No drastic difference in grain morphology is seen between the Fond du Lac and Hinckley formations.

Relative Probability peaks of the Hinckley roughly coincide with the peaks of the Fond du Lac until 1500 Ma. In the Hinckley, we see more zircon dates in the 1500 to 2100 Ma range than in the Fond du Lac, as well as very old grains (2600 to 3100 Ma). The change in zircon population from the Fond du Lac to the Hinckley suggests new zircon ages were introduced in the area as the basin evolved and filled.

Conclusions

There are 5 important conclusions of this paper: (1) The maximum age of deposition for the Fond du Lac and Hinckley formations is 1010.8±12.1 Ma. (2) The provenance of the first sediments in the Midcontinent Rift are in part from rocks of the Elzevirian event associated with the Grenville Province. (3) A sedimentary network connected the eastern margin of Laurentia with the center of the North American continent, spanning approximately 1,500 kilometers and navigating pre-existing mountain forming events between source area and final depositional location. (4) Between the deposition of the Fond du Lac and the deposition of the Hinckley the sedimentalogical framework of the rift basin changed such that more locally derived sediment was being transported to the basin during Hinckley deposition. (5) The previous inferences that the Hinckley Formation represents recycled Fond du Lac Formation are in no way refuted. The information presented here supports the connection with evolution of grain morphology. It is important to note that the conclusions of this paper indicate a more complex provenance for the Hinckley formation than previously thought.

ACKNOWLEDGEMENTS

This paper could not have been produced without the help of Professors Karl Wirth and John Craddock of Macalester College, and Cameron Davidson of Carleton College. Jeff Vervoort deserves a large “Thank you” for allowing us to use his lab at Washington State University. The hard work and determination of eight other undergraduate students is also greatly appreciated. All of us were united through the generosity and power of the Keck Consortium. The Carleton Geology department provided full support, as usual, and I am amazed at what they have done with a fellow such as myself. My mother and

stepfather are amazing and their support was wonderful to have. Again, I thank all these people.

REFERENCES CITED

Aleinikoff, J. N., Horton Jr., J. W., Drake Jr., A. A., Wintsch, R. P., Fannin, C. M., and Yi, K., 2004, Deciphering multiple Mesoproterozoic and Paleozoic events recorded in zircon and titanite from the Baltimore Gneiss, Maryland: SEM imaging, SHRIMP U-Pb geochronology, and EMP analysis, Proterozoic Tectonic Evolution of the Grenville Orogen in North America Memoir: Boulder, Geological Society of America, Inc.

Bickford, M. E., Wooden, J. L., and Bauer, R. L., 2006, SHRIMP study of zircons from Early Archean rocks in the Minnesota River Valley: Implications for the tectonic history of the Superior Province: Geological Society of America Bulletin, v. 118, no. 1/2, p. 94-108.

Boerboom, T. J., 2001, Bedrock Geologic Map and Sections: State of Minnesota, Department of Natural Resources, Regents of the University of Minnesota, scale 1:100,000.

Bourdon, B., Turner, S., Henderson, G. M., and Lundstrom, C. C., 2003, Introduction to U-series Geochemistry, *in* Bourdon, B., Henderson, G. M., Lundstrom, C. C., and Turner, S., eds., Uranium-Series Geochemistry: Reviews in Mineralogy & Geochemistry, Geochemical Society and Mineralogical Society of America, p. 1-21.

Bream, B. R., Hatcher Jr., R. D., Miller, C. F., and Fullager, P. D., 2004, Detrital zircon ages and Nd isotopic data from the southern Appalachian crystalline core, Georgia, South Carolina, North Carolina, and Tennessee: New provenance constraints for part of the Laurentia margin, Proterozoic Tectonic Evolution of the Grenville Orogen in North America Memoir: Boulder, Geological Society of America, Inc., 820 p.

Craddock, C., 1972, Keweenawan Geology of East-Central and Southeastern Minnesota, Geology of Minnesota: A Centennial Volume, Minnesota Geological Survey, p. 416

Cannon, W.F., Kress, T.H., Sutphin, D.M., Morey, G.B., Meints, J., and Barber-Delach, R., 1999, Deposits of the Lake Superior region: U.S. Geological Survey Open-File Report 97-0455

Chang, Z., Vervoort, J. D., McClelland, W. C., and Knaack, C., submitted, 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.

Davis, D. W., Williams, I. S., and Thomas, E. K., 2003, Historical Developement of Zircon Geochronology, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., Zircon:

Reviews in Mineralogy & Geochemistry, Mineralogical Society of America and Geochemical Society, p. 145-181.

Fedo, C. M., Sircombe, K. N., and Rainbird, R. H., 2003, Detrital Zircon Analysis of the Sedimentary Record, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., Zircon: Reviews in Mineralogy & Geochemistry, Mineralogical Society of America and Geochemical Society, p. 277-303.

Finch, R. J., and Hanchar, J. M., 2003, Structure and Chemistry of Zircon and Zircon-group Minerals, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., Zircon: Reviews in Mineralogy & Geochemistry, Mineralogical Society of America and Geochemical Society, p. 1-25.

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.

Hamblin, W. K., 1965, Basement Control of Keweenawan and Cambrian sedimentation in Lake Superior region: American Association of Petroleum Geologists Bulletin, v. 49, no. 7, p. 950-958.

Hanchar, J. M., and Hoskin, P. W. O., 2003, Zircon, Reviews in Mineralogy and Geochemistry: Washington, D.C., The Mineralogical Society of America, 500 p.

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.

Hoskin, P. W. O., and Schaltegger, U., 2003, The Composition of Zircon and Igneous and Metamorphic Petrogenesis, *in* Hanchar, J. M., and Hoskin, P. W. O., eds., Zircon: Reviews in Mineralogy & Geochemistry, Mineralogical Society of America and Geochemistry Society, p. 27-62.

Ludwig, K. R., 2003, Isoplot 3.00 A Geochronological Toolkit for Microsoft Excel: Special Publication No. 4, p. 70.

McLelland, J., Daly, S., Mclelland, J.M., 1996, The Grenville Orogenic Cycle (ca. 1350-1000 Ma): And Adirondack perspective: Tectonophysics, v. 265, no. 1-2, p. 1-28.

Moore, J. M., and Thompson, P., 1980, The Flinton Group: A late Precambrian metasedimentary sequence in the Grenville Province of eastern Ontario: Canadian Journal of Earth Sciences, v. 17, p. 1685-1707.

Morey, G.B., 1967, Stratigraphy and Petrology of the Type Fond du Lac Formation Duluth, Minnesota: Report of Investigations – Minnesota Geological Survey, St. Paul, MN, 35 pp.

Morey, G. B., and Sims, P. K., 1972, Petrology of Keweenawan Sandstones in the Subsurface of Southeastern Minnesota, Geology of Minnesota: A Centennial Volume, Minnesota Geological Survey, p. 632.

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.

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.

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.

Rainbird, R. H., Jefferson, C. W., and Young, G. M., 1996, The early Neoproterozoic sedimentary Succession B of northwestern Laurentia: Correlations and paleogeographic significance: Geological Society of America Bulletin, v. 108, no. 4, p. 454-470.

Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2006.

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

Santos, J. O. S., Hartmann, L. A., McNaughton, N. J., Easton, R. M., Rea, R. G., and Potter, P. E., 2002, Sensitive high resolution ion microprobe (SHRIMP) detrital zircon geochronology provides new evidence for hidden Neoproterozoic foreland basin to the Grenville Orogen in the eastern Midwest, U.S.A.: Canadian Journal of Earth Sciences, v. 39, no. 10, p. 1505-1515.

Schmitz, M. D., Bowring, S. A., Southwick, D. L., Boerboom, T. J., and Wirth, K. R., 2006, High-precision U-Pb geochronology in the Minnesota River Valley subprovince and its bearing on the Neoarchean to Paleoproterozoic evolution of the southern Superior Province: Geological Society of America Bulletin, v. 118, no. 1/2, p. 82-93.

Stauffer, C. R., 1927, Age of the red clastic series of Minnesota: Geological Society of America Bulletin, v. 38, p. 469-478.

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, W. R., Medaris Jr., L. G., and Banks, P. O., 1975, Geology and Age of the Wolf River Batholith, Wisconsin: Geological Society of America Bulletin, v. 86, p. 907-914.

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.

APPENDIX 1:

Fond du Lac Zircon Age Data

< 10% discordant

sample name	207/235 age	2 sigma abs err	206/238 age	2 sigma abs err	207/206 age	2 sigma abs err
05KP22_001a	1125.2	13.8	1126.6	20.1	1139.6	10.2
05KP22_002a	1304.7	16.1	1299.7	24.7	1329.7	11.2
05KP22_003a	2818.9	20.7	2730.4	47.7	2897.0	6.4
05KP22_004a	1097.4	13.5	1097.7	19.6	1114.1	9.7
05KP22_005a	1130.2	16.7	1120.3	24.1	1166.4	13.9
05KP22_006a	1101.5	12.4	1123.1	18.5	1076.7	8.7
05KP22_007a	1123.9	15.8	1141.1	23.3	1107.9	12.4
05KP22_008a	1180.1	16.4	1184.3	23.9	1189.7	15.2
05KP22_009a	1225.9	15.2	1203.2	22.6	1283.0	11.0
05KP22_010a	1215.8	19.9	1249.0	30.1	1174.5	17.4
05KP22_011a	1319.9	16.5	1324.7	25.8	1328.8	10.8
05KP22_012a	1175.8	17.2	1168.8	24.3	1196.9	17.4
05KP22_013a	1162.1	12.7	1173.4	18.0	1149.5	12.1
05KP22_014a	1661.0	15.8	1650.7	26.2	1681.9	10.5
05KP22_015a	1088.1	13.2	1096.6	18.3	1079.6	12.7
05KP22_016a	1092.1	14.6	1091.8	20.2	1101.1	14.5
05KP22_017a	1428.4	14.3	1422.7	21.9	1444.7	11.6
05KP22_018a	1181.4	21.2	1192.8	30.9	1168.8	20.2
05KP22_019a	1073.0	13.7	1057.4	18.3	1113.0	15.3
05KP22_021a	1215.2	16.8	1227.9	24.3	1200.8	16.5
05KP22_023a	991.0	18.0	982.9	22.5	1010.8	24.2
05KP22_024a	1157.8	19.2	1150.7	25.6	1172.8	22.1
05KP22_025a	1079.9	15.4	1060.0	19.7	1121.8	16.9
05KP22_026a	1028.3	22.9	1027.5	29.6	1031.6	30.2
05KP22_027a	1201.0	16.6	1198.3	22.1	1207.5	18.6
05KP22_028a	1330.0	19.5	1310.8	26.5	1362.7	22.3
05KP22_029a	1257.1	16.0	1246.4	21.6	1277.0	16.6
05KP22_030a	1778.9	19.1	1753.1	30.6	1810.8	14.4
05KP22_032a	1111.7	16.2	1132.3	21.2	1073.1	19.7
05KP22_034a	1347.1	17.5	1349.7	24.7	1344.6	17.8
05KP22_035a	1056.1	20.1	1042.4	26.1	1086.4	24.6
05KP22_036a	1148.2	17.3	1159.8	24.4	1133.6	15.8
05KP22_037a	1130.9	17.2	1121.4	23.8	1156.6	15.8
05KP22_038a	1113.5	16.9	1083.0	22.8	1180.7	15.2
05KP22_039a	1815.8	25.0	1791.6	43.3	1850.4	15.6
05KP22_040a	1144.2	21.1	1151.3	29.5	1138.1	22.3
05KP22_041a	1162.7	17.5	1158.8	24.7	1177.2	15.3
05KP22_042a	1058.4	18.4	1066.4	24.6	1049.5	21.0
05KP22_043a	1091.2	17.8	1102.3	24.4	1076.6	18.5
05KP22_044a	1075.9	16.9	1065.2	22.8	1105.1	16.2
05KP22_045a	1067.8	17.8	1069.7	24.1	1071.4	18.4
05KP22_046a	1134.0	16.3	1123.9	22.5	1157.6	16.3
05KP22_047a	1160.2	14.4	1156.2	20.3	1171.9	12.7
05KP22_048a	1047.3	18.2	1033.3	24.1	1080.7	20.7
05KP22_049a	1184.6	15.7	1175.3	22.2	1205.6	14.6
05KP22_050a	1773.0	24.0	1774.5	41.9	1775.0	15.2

05KP22_051a	1161.9	17.0	1155.6	23.7	1177.7	16.9
05KP22_052a	1302.9	16.2	1277.7	23.5	1348.5	13.9
05KP22_053a	1423.3	22.0	1442.5	34.9	1398.6	16.4
05KP22_054a	1202.5	15.4	1186.3	21.7	1235.8	14.2
05KP22_055a	2531.7	22.7	2495.1	47.8	2564.7	10.5
05KP22_057a 1	1034.5	17.3	1013.8	21.7	1080.0	22.1
05KP22_058a	1153.2	20.8	1127.6	28.1	1194.3	20.6
05KP22_059a	1231.2	22.1	1219.5	31.0	1244.3	20.6
05KP22_061a	1260.7	23.2	1240.7	32.9	1287.7	21.3
05KP22_064a	1267.3	23.4	1268.3	33.6	1258.1	21.8
05KP22_065a	1196.0	23.3	1161.3	32.0	1252.1	22.4
05KP22_067a	1178.6	23.7	1161.5	32.7	1202.7	24.0
05KP22_068a	1147.3	22.5	1107.1	30.3	1216.8	21.8
05KP22_069a	1323.1	24.3	1307.1	35.5	1341.9	20.9
05KP22_070a	1126.7	21.6	1102.7	29.3	1165.7	20.3
05KP22_071a	1217.1	21.3	1202.6	30.9	1241.9	17.2
05KP22_072a	1217.0	23.1	1227.3	33.7	1197.7	22.3
05KP22_073a	1082.5	21.3	1053.2	29.2	1140.7	19.7
05KP22_074a	1144.5	21.3	1113.3	29.8	1203.0	18.2
05KP22_075a	1186.1	24.2	1164.9	35.1	1223.9	19.5
05KP22_076a	1081.2	23.0	1064.3	31.7	1114.4	22.6
05KP22_077a	1140.9	21.6	1108.8	30.2	1201.5	18.4
05KP22_078a	1071.2	19.9	1050.2	27.4	1113.0	17.6
05KP22_079a	1024.8	19.7	1009.6	26.7	1056.3	18.9
05KP22_080a	1296.7	30.4	1268.8	45.7	1341.9	24.2
05KP22_082a	1176.8	23.3	1154.6	32.8	1216.7	22.4
05KP22_083a	1244.8	26.8	1208.9	39.7	1325.3	16.5
05KP22_084a	1155.0	25.8	1149.6	37.8	1183.5	18.6
05KP22_085a	1113.6	25.4	1081.1	36.0	1195.9	18.3
05KP22_089a	1136.7	26.1	1133.4	38.2	1161.2	18.7
05KP22_091a	1305.4	25.9	1299.4	40.1	1333.3	14.3
05KP22_093a	1148.0	25.1	1119.1	36.0	1221.2	17.4
05KP22_094a	983.8	23.9	957.6	32.4	1061.2	18.3
05KP22_095a	988.7	16.3	976.8	21.9	1030.9	16.8
05KP22_096a	1023.7	14.0	1013.6	18.8	1060.9	15.0
05KP22_101a	1064.6	17.0	1034.7	23.4	1136.6	14.8
05KP22_102a	1365.4	41.6	1375.9	68.5	1359.0	18.5
05KP22_104a	1017.2	15.5	996.0	21.3	1073.3	13.5
05KP22_105a	1028.5	16.5	1003.3	22.6	1092.9	14.4
05KP22_106a	1029.9	18.8	1024.3	26.2	1052.3	16.9
05KP22_108a	1058.6	18.5	1047.3	25.7	1092.3	18.5
05KP22_109a	1201.7	18.7	1205.5	27.7	1205.0	15.4
05KP22_110a	1172.8	21.5	1144.3	30.7	1235.9	19.3
05KP22_111a	1240.8	22.0	1239.4	33.0	1253.4	17.8
05KP22_112a	1107.5	23.8	1126.5	34.2	1088.2	24.5
05KP22_113a	1219.9	16.0	1232.1	23.9	1216.0	13.3
05KP22_114a	1207.3	15.2	1208.2	22.6	1223.2	11.2
05KP22_116a	1623.3	20.4	1620.8	34.4	1643.0	13.4
05KP22_117a	1178.6	25.9	1180.6	36.2	1192.6	31.1
05KP22_118a	1200.2	15.5	1196.6	22.9	1224.1	12.3
05KP22_119a	1078.6	17.8	1076.0	24.5	1101.6	19.6
05KP22_120a	1213.8	15.7	1210.9	23.4	1236.3	11.4

05KP22_120a	1213.8	15.7	1210.9	23.4	1236.3	11.4
05KP22_121a	1150.6	21.3	1135.5	29.7	1196.6	23.0
05KP22_122a	1287.6	19.1	1285.0	29.2	1309.2	13.8
05KP22_123a	1164.3	20.3	1168.3	29.5	1174.5	19.3

> 10 % discordant

sample name	207/235 age	2 sigma abs err	206/238 age	2 sigma abs err	207/206 age	2 sigma abs err
05KP22_088a	1118.2	26.6	1082.3	37.1	1206.9	22.2
05KP22_098a	1013.0	13.6	981.6	18.1	1097.0	12.9
05KP22_056a	1108.4	17.8	1065.7	23.9	1197.2	17.0
05KP22_103a	1004.6	15.2	970.0	20.6	1091.2	12.3
05KP22_090a	1172.2	25.6	1126.8	36.5	1275.0	17.8
05KP22_092a	1072.5	28.7	1024.7	38.4	1189.4	28.9
05KP22_100a	1017.0	12.9	967.5	17.0	1140.6	10.9
05KP22_086a	1153.1	26.3	1083.0	36.3	1305.3	20.0
05KP22_097a	969.9	13.0	917.0	16.6	1107.3	12.8
05KP22_087a	976.1	28.5	922.7	37.6	1116.9	23.3
05KP22_022a	986.9	21.9	921.9	25.1	1142.6	35.0
05KP22_099a	1042.9	14.0	965.0	18.1	1225.2	12.5

207/206 only

05KP22_031a	1242.0	169.4	1160.1	268.0	1388.6	34.0
05KP22_066a	836.3	21.4	613.4	20.4	1478.8	23.2
05KP22_115a	818.1	26.5	579.8	25.9	1553.3	14.4

Culls

05KP22_020a	1686.0	23.9	1139.6	22.8	2461.0	30.0
05KP22_060a	#VALUE!	#VALUE!	#VALUE!	#VALUE!	5915.5	987.4
05KP22_062a	#VALUE!	#VALUE!	#VALUE!	#VALUE!	3850.5	26.5
05KP22_063a	#VALUE!	#VALUE!	#VALUE!	#VALUE!	662.8	#NUM!

Hinckley Zircon Age Data

< 10% discordant

sample name	207/235 age	2 sigma abs err	206/238 age	2 sigma abs err	207/206 age	2 sigma abs err
05KP20_001a	1743.6	26.2	1798.0	48.6	1679.1	12.5
05KP20_001b	1723.7	20.1	1757.2	36.0	1683.3	12.2
05KP20_002a	1378.6	23.2	1374.3	37.5	1385.3	12.8
05KP20_003a	1370.2	21.4	1376.2	34.1	1360.9	15.3
05KP20_004a	1066.9	20.0	1073.7	28.8	1052.9	17.3
05KP20_005a	1931.5	24.4	1959.8	46.3	1901.2	13.7
05KP20_006a	1171.4	19.9	1173.5	29.9	1167.5	14.4
05KP20_007a	1667.1	24.4	1713.6	43.4	1609.0	14.8
05KP20_008a	1092.8	21.9	1100.6	31.3	1077.3	21.8
05KP20_009a	1156.7	21.0	1138.3	30.5	1191.4	17.0
05KP20_010a	1474.8	23.0	1493.6	37.3	1447.9	15.6
05KP20_011a	1657.7	24.4	1679.3	41.8	1630.5	15.5
05KP20_012a	2843.0	27.6	2826.4	63.1	2854.7	12.7
05KP20_013a	1394.4	24.6	1407.8	39.4	1374.0	15.8
05KP20_015a	1495.3	24.0	1532.5	39.9	1443.0	16.0
05KP20_016a	1472.4	23.7	1459.9	38.1	1490.3	14.5
05KP20_017a	1632.5	22.3	1666.5	37.9	1588.8	15.3
05KP20_018a	1146.2	21.9	1156.0	32.1	1127.6	16.9
05KP20_019a	1385.5	22.0	1400.3	34.5	1362.8	16.6
05KP20_020a	1261.2	24.4	1235.1	36.3	1305.9	17.9
05KP20_021a	2753.6	37.7	2749.1	85.4	2756.8	17.4
05KP20_023a	1426.9	24.8	1430.7	39.3	1421.1	17.2
05KP20_024a	1428.1	23.2	1409.1	35.3	1456.5	19.5
05KP20_025a	1368.5	23.4	1391.3	36.8	1333.2	16.8
05KP20_026a	1127.4	21.7	1135.8	31.0	1111.2	19.4
05KP20_027a	1213.8	21.8	1219.5	32.0	1203.5	18.4
05KP20_028a	1358.4	25.0	1389.2	39.2	1310.3	19.3
05KP20_029a	1354.4	35.6	1369.1	56.2	1331.2	26.5
05KP20_030a	1443.0	23.0	1439.5	36.1	1448.1	18.2
05KP20_031a	1322.1	24.2	1326.4	36.6	1315.1	21.0
05KP20_032a	1161.2	11.5	1147.8	15.4	1186.4	12.1
05KP20_033a	1389.6	16.1	1381.3	24.2	1402.4	13.6
05KP20_035a	1206.1	13.6	1160.7	18.3	1288.2	13.9
05KP20_036a	1084.8	12.9	1047.2	16.5	1161.0	15.0
05KP20_037a	2059.7	20.4	2036.9	38.0	2082.7	11.6
05KP20_038a	1429.0	11.7	1416.9	16.5	1447.1	12.0
05KP20_039a	1103.9	11.5	1102.0	15.0	1107.6	13.6
05KP20_040a	1044.8	12.5	1033.9	15.9	1067.6	15.9
05KP20_041a	2744.6	22.8	2772.8	50.1	2724.0	11.6
05KP20_042a	1081.5	14.3	1077.4	18.4	1089.8	17.2
05KP20_043a	1646.9	18.6	1620.3	29.5	1680.9	13.8
05KP20_044a	1155.5	14.8	1139.2	19.8	1186.3	15.7
05KP20_045a	2621.1	20.3	2567.1	41.2	2663.0	11.7
05KP20_046a	1307.8	16.5	1306.6	23.4	1309.7	16.5
05KP20_047a	2669.9	21.2	2633.1	44.1	2697.9	11.8
05KP20_048a	1718.2	18.0	1733.5	29.8	1699.5	13.2
05KP20_049a	1222.8	15.2	1227.7	21.1	1214.1	15.1

05KP20_050a	1166.1	14.4	1169.3	19.5	1160.2	15.0
05KP20_051a	1070.6	17.8	1072.0	23.4	1067.5	21.1
05KP20_052a	2018.2	20.9	1965.2	36.4	2072.9	13.5
05KP20_053a	1753.1	19.2	1733.0	31.0	1777.0	14.4
05KP20_054a	1084.2	18.5	1093.8	23.9	1065.0	24.7
05KP20_055a	1815.8	28.1	1788.1	48.2	1847.7	19.1
05KP20_056a	1278.6	19.6	1253.7	27.3	1320.7	19.8
05KP20_057a	1835.8	20.9	1833.3	35.1	1838.6	15.4
05KP20_058a	1188.3	22.0	1195.2	30.8	1175.7	23.2
05KP20_059a	1459.6	19.6	1497.1	30.3	1405.5	16.9
05KP20_060a	1672.3	18.0	1659.1	28.1	1688.8	14.6
05KP20_063a	2684.5	22.2	2661.0	46.1	2702.2	12.9
05KP20_064a	1169.3	16.1	1168.5	21.7	1170.7	17.1
05KP20_065a	1109.5	24.0	1106.1	34.4	1116.1	21.9
05KP20_066a	1177.7	18.1	1183.2	27.2	1167.6	12.3
05KP20_067a	1264.0	20.3	1260.6	30.7	1269.6	16.0
05KP20_068a	1425.5	20.5	1422.0	33.0	1430.7	11.8
05KP20_069a	1073.9	19.9	1065.0	28.2	1091.8	16.9
05KP20_070a	1941.5	23.2	1907.9	43.1	1977.5	10.4
05KP20_072a	1983.7	23.5	1998.8	45.2	1968.0	10.2
05KP20_073a	2855.2	28.3	2879.6	67.6	2838.1	9.7
05KP20_075a	1472.9	23.5	1467.4	38.1	1480.7	16.1
05KP20_076a	1483.5	20.5	1468.2	33.4	1505.4	11.5
05KP20_077a	1919.9	31.1	1922.5	58.8	1917.1	14.5
05KP20_078a	2764.0	21.2	2753.6	46.6	2771.6	10.9
05KP20_079a	1916.8	22.4	1905.8	39.8	1928.6	15.6
05KP20_080a	1106.5	13.7	1102.0	18.4	1115.3	14.8
05KP20_081a	1460.3	16.6	1461.8	25.5	1458.0	14.5
05KP20_082a	1111.5	16.5	1104.6	22.3	1124.9	18.8
05KP20_083a	1317.5	16.0	1314.2	23.5	1322.7	14.2
05KP20_085a	3046.3	20.6	3046.0	47.9	3046.5	10.6
05KP20_087a	1474.7	14.8	1465.8	22.5	1487.5	12.3
05KP20_088a	1313.3	16.7	1324.3	24.2	1295.3	17.6
05KP20_089a	1218.0	21.5	1213.5	31.0	1225.8	21.0
05KP20_090a	1165.7	14.1	1163.8	19.2	1169.2	16.0
05KP20_091a	1723.6	15.3	1749.6	24.7	1692.0	13.4
05KP20_093a	1410.8	21.8	1434.6	34.2	1374.9	19.0
05KP20_094a	2642.1	22.3	2524.1	46.0	2733.8	12.2
05KP20_095a	1792.5	17.1	1786.9	28.6	1798.9	13.3
05KP20_096a	1541.7	17.7	1527.7	27.3	1561.0	15.8
05KP20_097a	1471.8	15.4	1476.9	23.5	1464.4	13.6
05KP20_098a	1162.4	13.2	1149.5	17.7	1186.2	14.3
05KP20_099a	1925.9	16.0	1943.4	27.9	1907.1	11.4
05KP20_101a	1985.0	16.9	1896.7	28.9	2078.3	11.4
05KP20_102a	1791.4	30.8	1788.4	54.7	1794.8	16.3
05KP20_103a	1472.0	27.7	1487.9	45.1	1449.2	17.6
05KP20_104a	1154.0	24.7	1143.2	35.7	1174.3	18.5
05KP20_105a	1449.5	27.3	1446.4	43.9	1454.1	15.8
05KP20_106a	1119.2	23.7	1105.9	33.9	1145.2	17.1
05KP20_107a	1060.6	23.6	1043.6	32.8	1095.9	18.5
05KP20_108a	1317.3	26.7	1321.1	41.1	1311.0	18.8

05KP20_109a	1165.1	24.1	1159.0	35.2	1176.5	16.6
05KP20_110a	1147.4	24.0	1127.1	34.5	1185.9	16.2
05KP20_111a	1473.2	27.7	1483.6	45.3	1458.4	16.4
05KP20_112a	1625.6	21.7	1608.3	35.1	1648.0	14.6
05KP20_113a	1203.1	19.7	1186.0	28.0	1233.9	15.8
05KP20_114a	1370.3	21.1	1353.7	31.6	1396.3	16.2
05KP20_116a	2635.1	25.5	2601.1	54.1	2661.3	12.6
05KP20_117a	1703.8	28.3	1742.8	48.7	1656.1	20.1
05KP20_118a	1354.8	21.0	1330.7	31.2	1392.9	16.5
05KP20_119a	1321.0	20.7	1305.0	30.5	1346.9	16.8
05KP20_120a	1340.3	20.9	1327.1	31.0	1361.5	16.4
05KP20_122a	1449.1	20.9	1440.5	32.2	1461.7	15.0
05KP20_123a	1396.1	22.9	1365.2	35.6	1443.5	14.0
05KP20_125a	1260.7	22.1	1259.7	33.4	1262.1	15.6
05KP20_126a	2671.2	31.9	2587.5	70.1	2735.1	12.5
05KP20_129a	1829.5	26.5	1810.2	47.3	1851.5	13.9
05KP20_131a	1371.5	23.6	1342.4	36.4	1416.9	15.2
05KP20_132a	1310.5	22.3	1291.6	34.0	1341.4	14.2
05KP20_133a	1091.5	20.5	1076.0	29.0	1122.5	15.2
05KP20_134a	1065.0	20.1	1049.9	28.2	1096.1	15.3
05KP20_135a	1724.7	24.5	1723.6	42.8	1725.8	13.0
05KP20_136a	1744.8	22.7	1741.4	40.7	1749.0	10.4
05KP20_137a	1593.9	23.0	1541.0	38.4	1664.5	12.0
05KP20_138a	1083.1	18.8	1069.3	26.9	1111.0	14.7
05KP20_139a	2669.8	25.3	2620.6	56.9	2707.2	8.5
05KP20_140a	1310.0	20.9	1274.7	31.7	1368.2	14.5
05KP20_141a	1869.4	23.7	1840.0	43.3	1902.4	11.2
05KP20_142a	1153.2	18.0	1142.9	26.7	1172.7	10.7
05KP20_143a	1232.5	21.7	1225.7	32.7	1244.3	15.9
05KP20_144a	2704.8	25.2	2682.8	57.5	2721.2	8.8
05KP20_145a	1110.9	18.9	1093.1	27.2	1145.8	14.6
05KP20_146a	1835.8	20.8	1826.1	37.6	1846.8	11.3
05KP20_149a	2635.0	22.7	2592.1	50.2	2668.1	8.6
05KP20_150a	1720.0	19.4	1688.2	33.5	1758.9	10.3
05KP20_151a	1306.9	19.7	1289.6	30.1	1335.4	14.0
05KP20_152a	1292.7	17.7	1273.2	26.9	1325.3	11.9
05KP20_153a	1862.5	19.9	1843.9	36.2	1883.4	9.6

> 10% discordant

sample name	207/235 age	2 sigma abs err	206/238 age	2 sigma abs err	207/206 age	2 sigma abs err
05KP20_034a	962.3	10.0	894.1	11.7	1121.5	11.8
05KP20_062a	2303.5	25.3	1880.2	41.5	2703.5	15.0
05KP20_100a	1207.4	26.8	1103.2	35.5	1399.0	27.8
05KP20_115a	2744.8	25.9	2515.4	53.1	2918.2	12.1
05KP20_121a	1279.0	25.3	1210.3	36.1	1396.3	19.8
05KP20_127a	1071.1	20.7	1021.1	28.1	1174.1	16.7
05KP20_128a	1079.5	36.0	1009.4	50.4	1223.7	19.6
05KP20_147a	1227.5	16.8	1116.0	23.3	1429.2	10.7

05KP20_148a	1026.4	17.4	925.2	22.5	1249.1	13.4

207/206 only

05KP20_071a	974.7	29.2	884.7	38.5	1183.6	13.5
05KP20_074a	880.2	40.0	643.0	42.2	1535.6	11.9
05KP20_084a	2580.0	22.6	2377.3	45.3	2743.2	11.1
05KP20_086a	798.8	36.4	674.9	42.4	1162.2	17.7
05KP20_130a	657.0	26.7	482.4	25.7	1313.9	14.2

Culled

05KP20_014a	-4892.1	#NUM!	-393.7	-51.0	1977.1	16.7
05KP20_061a	640.8	30.2	420.5	25.8	1520.8	14.9
05KP20_124a	1933.2	37.7	1422.9	41.3	2535.0	46.3

APPENDIX 2:

Fond du Lac Grain Analysis

Grain Number	Area (μm$^{2)}$	Perimeter (μm)	Major (μm)	Minor (μm)	Angle (°)	Circularity	Ellipticity
1	12326.61	604.534	258.425	60.732	159.464	0.424	4.255
2	30157.22	801.140	320.732	119.718	129.096	0.590	2.679
3	17952.79	577.495	233.314	97.972	88.512	0.676	2.381
4	17257.26	572.164	214.497	102.438	173.727	0.662	2.094
5	11110.08	434.536	154.823	91.368	101.542	0.739	1.694
6	14117.55	459.105	150.420	119.499	125.797	0.842	1.259
7	11364.50	465.410	172.677	83.797	147.323	0.659	2.061
8	18851.97	552.196	182.237	131.714	135.640	0.777	1.384
9	28067.97	723.661	222.541	160.587	78.953	0.674	1.386
10	21060.76	656.850	236.843	113.220	162.310	0.613	2.092
11	8790.22	378.076	118.654	94.325	43.148	0.773	1.258
12	29096.20	770.194	284.431	130.247	158.430	0.616	2.184
13	17631.74	612.288	243.253	92.288	70.371	0.591	2.636
14	12574.15	509.570	201.826	79.325	104.024	0.609	2.544
15	5147.50	301.096	92.451	70.892	94.460	0.714	1.304
16	12150.48	481.057	141.663	109.206	54.775	0.660	1.297
17	16165.55	575.693	199.730	103.052	50.758	0.613	1.938
19	12278.48	474.825	151.491	103.197	155.713	0.684	1.468
20	34183.93	840.450	329.648	132.033	105.186	0.608	2.497
21	14490.45	525.727	194.315	94.948	57.986	0.659	2.047
23	8352.26	377.590	136.531	77.891	125.287	0.736	1.753
24	12788.89	466.395	162.301	100.328	110.498	0.739	1.618
25	12746.05	466.085	168.258	96.452	121.099	0.737	1.744
26	6130.25	333.114	114.992	67.877	129.461	0.694	1.694
27	52308.63	1011.215	276.929	240.500	73.696	0.643	1.151
28	26496.53	813.482	254.334	132.646	14.213	0.503	1.917
29	13298.78	581.791	197.250	85.843	111.067	0.494	2.298
30	17055.74	570.434	176.082	123.329	173.911	0.659	1.428
31	16920.33	577.611	215.721	99.868	80.284	0.637	2.160
32	17075.31	563.442	223.005	97.491	38.231	0.676	2.287
33	16112.66	560.199	218.680	93.814	173.299	0.645	2.331
34	9359.34	381.101	128.028	93.079	21.003	0.810	1.375
36	14530.65	664.292	206.302	89.679	62.621	0.414	2.300
37	32788.63	857.618	281.656	148.223	161.277	0.560	1.900
38	24651.11	676.427	252.077	124.512	125.998	0.677	2.025
39	12493.75	431.189	141.214	112.649	42.807	0.844	1.254
40	12585.79	460.335	131.629	121.742	133.706	0.746	1.081
41	14031.34	502.522	168.939	105.750	32.898	0.698	1.598
42	66981.03	1387.277	406.245	209.930	137.759	0.437	1.935
43	16036.50	520.360	173.576	117.633	137.950	0.744	1.476
44	18528.26	624.235	173.922	135.641	78.200	0.598	1.282
45	31582.15	724.548	247.623	162.391	43.171	0.756	1.525
46	30449.72	766.584	287.546	134.830	38.142	0.651	2.133
47	11863.27	460.017	153.765	98.233	61.685	0.704	1.565
48	12614.88	461.442	172.868	92.913	132.412	0.744	1.861
49	17437.09	612.538	215.851	102.856	95.204	0.584	2.099
50	16262.88	534.358	189.185	109.451	155.421	0.716	1.728
51	21319.93	643.053	228.195	118.957	170.545	0.648	1.918
52	32431.07	773.151	295.989	139.507	123.226	0.682	2.122
53	20754.51	627.235	239.198	110.475	157.813	0.663	2.165
54	12554.05	482.773	189.482	84.358	163.961	0.677	2.246
55	12999.41	478.823	175.613	94.249	150.407	0.712	1.863
56	10201.39	414.087	139.582	93.055	129.603	0.748	1.500
57	17752.33	536.123	184.153	122.740	14.672	0.776	1.500
58	13936.66	493.016	171.167	103.669	44.014	0.721	1.651
59	7757.22	358.784	116.523	84.763	20.769	0.757	1.375

60	15537.19	508.998	176.155	112.302	6.893	0.754	1.569
61	20102.88	556.418	170.319	150.282	165.981	0.816	1.133
62	20960.79	677.060	252.403	105.736	51.079	0.575	2.387
63	13294.55	532.074	211.059	80.201	127.194	0.590	2.632
64	18145.85	624.381	198.715	116.267	73.676	0.585	1.709
65	14005.95	543.206	205.704	86.692	111.196	0.596	2.373
66	20653.49	602.989	224.046	117.373	168.591	0.714	1.909
67	14173.09	489.358	166.367	108.469	153.127	0.744	1.534
68	4919.54	296.591	110.016	56.935	140.396	0.703	1.932
69	26549.42	755.817	318.156	106.249	53.136	0.584	2.994
70	17388.96	558.238	213.587	103.659	64.544	0.701	2.060
71	18793.26	569.766	208.093	114.989	166.022	0.727	1.810
72	17764.50	572.474	171.631	131.785	123.254	0.681	1.302
73	8705.59	377.426	115.723	95.783	106.040	0.768	1.208
74	19191.54	581.761	166.959	146.356	68.728	0.713	1.141
75	4747.64	280.251	88.617	68.213	131.606	0.760	1.299
76	30837.42	786.431	304.361	129.003	113.359	0.627	2.359
77	9480.99	401.891	132.448	91.142	7.113	0.738	1.453
78	10905.92	422.991	125.445	110.693	15.768	0.766	1.133
79	20832.26	586.081	207.241	127.988	124.848	0.762	1.619
80	11495.14	456.244	157.096	93.166	74.205	0.694	1.686
81	10522.45	432.966	143.151	93.591	169.629	0.705	1.530
82	11517.88	453.786	149.443	98.131	72.535	0.703	1.523
83	17531.77	624.958	258.152	86.469	26.610	0.564	2.985
84	20808.99	557.679	186.405	142.136	96.293	0.841	1.311
85	18462.15	549.420	194.536	120.835	150.069	0.769	1.610
86	14439.14	508.486	172.706	106.449	109.840	0.702	1.622
87	17827.97	631.374	169.762	133.712	153.896	0.562	1.270
88	11275.11	421.123	130.876	109.691	168.118	0.799	1.193
89	19161.92	562.378	184.496	132.240	21.652	0.761	1.395
90	16401.98	526.117	158.777	131.528	11.375	0.745	1.207
91	25602.12	726.424	240.936	135.296	84.438	0.610	1.781
92	19396.23	553.108	166.966	147.911	59.213	0.797	1.129
93	15875.17	577.026	210.960	95.814	91.559	0.599	2.202
94	16279.80	506.636	173.183	119.689	46.575	0.797	1.447
95	20849.19	632.985	243.164	109.169	134.425	0.654	2.227
96	16953.65	523.463	193.888	111.333	48.966	0.778	1.742
97	22441.26	609.458	195.617	146.067	105.512	0.759	1.339
98	15224.60	535.490	188.928	102.603	17.912	0.667	1.841
99	17509.03	531.661	191.753	116.260	130.471	0.778	1.649
100	25540.23	692.543	259.125	125.495	162.517	0.669	2.065
101	10967.80	439.843	141.988	98.351	106.763	0.712	1.444
102	12435.57	448.144	146.156	108.333	72.280	0.778	1.349
103	27939.97	709.473	226.651	156.956	115.614	0.698	1.444
104	36401.19	870.830	354.171	130.862	123.190	0.603	2.706
105	34039.54	805.925	233.358	185.725	60.652	0.659	1.256
106	10009.39	416.187	146.622	86.920	121.811	0.726	1.687
107	17594.71	539.092	183.159	122.311	130.373	0.761	1.497
108	16562.25	524.973	164.110	128.498	116.683	0.755	1.277
109	19881.79	578.675	183.867	137.677	98.736	0.746	1.335
110	18163.31	547.880	158.302	146.090	148.763	0.760	1.084
111	19360.26	590.725	174.256	141.460	129.532	0.697	1.232
112	14128.13	502.497	174.039	103.359	128.497	0.703	1.684
113	21294.02	616.140	214.549	126.369	141.189	0.705	1.698
114	21578.58	670.725	208.386	131.845	113.804	0.603	1.581
116	24235.90	649.655	207.559	148.671	173.489	0.722	1.396
117	11420.03	474.807	159.386	91.228	175.743	0.637	1.747
118	23715.97	629.572	195.220	154.678	47.069	0.752	1.262
119	16259.17	599.294	209.368	98.878	149.476	0.569	2.117

120	22181.55	696.645	260.476	108.426	47.097	0.574	2.402
121	16751.07	499.436	155.011	137.591	18.559	0.844	1.127
122	18914.91	562.559	184.963	130.206	29.725	0.751	1.421
123	18635.64	600.287	183.561	129.263	168.275	0.650	1.420
124	18068.10	657.019	217.803	105.623	156.537	0.526	2.062
125	30447.07	717.654	238.310	162.672	14.887	0.743	1.465
126	15412.36	549.098	165.740	118.400	150.441	0.642	1.400
127	3440.66	276.210	93.940	46.634	164.895	0.567	2.014
128	17216.00	582.935	207.671	105.552	108.758	0.637	1.967
129	25756.03	656.429	218.405	150.151	5.037	0.751	1.455
130	18852.50	644.220	207.594	115.628	57.702	0.571	1.795
131	17972.89	566.862	191.680	119.385	88.755	0.703	1.606
132	14200.60	570.064	188.765	95.784	124.669	0.549	1.971
133	24794.45	671.133	245.527	128.577	179.237	0.692	1.910
134	16550.61	557.046	188.035	112.069	90.999	0.670	1.678
135	21242.18	622.682	199.201	135.775	172.128	0.688	1.467
136	16956.30	607.620	190.745	113.185	106.795	0.577	1.685
137	17137.72	581.115	225.995	96.553	46.378	0.638	2.341
138	13205.69	463.279	145.424	115.620	138.764	0.773	1.258
139	19842.65	620.048	183.824	137.438	178.243	0.649	1.338
140	18160.13	596.659	168.895	136.903	156.010	0.641	1.234
141	9071.07	384.716	111.429	103.650	49.727	0.770	1.075
142	6989.75	337.525	102.641	86.707	91.781	0.771	1.184
143	41815.27	875.360	299.157	177.969	66.769	0.686	1.681
144	19089.46	595.923	209.997	115.742	93.372	0.675	1.814
145	11080.99	456.871	129.645	108.826	75.021	0.667	1.191
146	23978.31	663.379	189.916	160.756	57.138	0.685	1.181
147	6553.92	329.207	105.070	79.420	39.838	0.760	1.323
148	16593.46	526.884	155.898	135.521	153.213	0.751	1.150
149	13766.35	509.661	160.433	109.253	74.646	0.666	1.468
150	14469.29	495.748	147.388	124.996	150.438	0.740	1.179
151	18003.04	570.490	163.750	139.983	71.249	0.695	1.170
152	11098.98	468.538	131.220	107.694	3.419	0.635	1.218
153	22281.52	596.525	212.781	133.328	161.886	0.787	1.596
154	12025.65	502.242	156.669	97.732	107.724	0.599	1.603
155	19362.38	550.771	167.694	147.012	145.339	0.802	1.141
156	10469.03	421.950	119.034	111.981	57.729	0.739	1.063
157	16109.49	586.891	193.205	106.163	65.164	0.588	1.820
158	12600.60	468.697	138.779	115.605	74.279	0.721	1.200
159	21537.32	624.825	201.411	136.150	79.047	0.693	1.479
160	18353.19	569.522	188.672	123.855	110.375	0.711	1.523
161	22575.60	619.049	181.861	158.055	149.421	0.740	1.151
162	13367.54	506.313	166.055	102.497	124.075	0.655	1.620
163	10321.98	419.845	132.939	98.860	174.678	0.736	1.345
164	19980.17	577.160	186.796	136.189	121.278	0.754	1.372
165	17377.32	581.335	225.403	98.160	149.837	0.646	2.296
166	14892.43	527.998	157.334	120.518	90.460	0.671	1.305
167	6569.26	339.668	104.470	80.064	152.181	0.716	1.305
168	7608.07	347.939	108.060	89.643	94.236	0.790	1.205
169	18721.32	678.235	210.980	112.981	66.689	0.511	1.867
170	6543.87	328.957	115.497	72.140	70.517	0.760	1.601
171	15653.55	586.185	146.291	136.240	120.100	0.572	1.074
172	20360.46	617.741	232.793	111.360	84.532	0.670	2.090
173	18144.79	652.224	251.872	91.724	80.614	0.536	2.746
174	3981.75	252.980	84.457	60.027	22.635	0.782	1.407
175	2347.37	207.080	68.481	43.644	155.737	0.688	1.569
176	31791.07	928.172	226.607	178.625	97.499	0.464	1.269
177	14483.57	475.695	158.354	116.454	92.060	0.804	1.360
178	23072.26	620.461	195.935	149.930	137.633	0.753	1.307

179	21072.40	584.304	183.232	146.427	51.835	0.776	1.251
180	19756.96	560.399	188.754	133.270	154.674	0.791	1.416
181	8192.53	433.568	136.418	76.464	0.341	0.548	1.784
182	13031.67	470.449	146.577	113.200	136.036	0.740	1.295
183	14698.84	597.645	151.216	123.764	137.025	0.517	1.222
184	9111.80	416.862	114.008	101.761	80.181	0.659	1.120
185	13439.47	458.782	140.011	122.217	46.333	0.802	1.146
186	13359.07	529.939	167.564	101.509	117.426	0.598	1.651
187	13562.71	523.841	152.407	113.306	142.208	0.621	1.345
188	11125.95	522.240	151.015	93.805	47.991	0.513	1.610
189	3257.12	229.561	79.482	52.177	46.434	0.777	1.523
190	8665.39	431.262	140.985	78.257	160.444	0.585	1.802
191	14253.49	469.524	151.159	120.059	128.810	0.812	1.259
192	17433.39	544.837	176.583	125.702	142.957	0.738	1.405
193	13060.23	508.297	153.852	108.083	88.183	0.635	1.423
194	30640.13	740.190	220.520	176.911	116.376	0.703	1.247
195	17784.60	566.716	154.193	146.855	160.563	0.696	1.050
196	22054.61	637.843	202.607	138.597	80.135	0.681	1.462
197	16550.08	530.584	179.414	117.450	39.744	0.739	1.528
198	20715.90	614.028	177.905	148.260	134.443	0.690	1.200
199	22524.83	664.042	217.694	131.742	4.004	0.642	1.652
200	3262.94	248.501	82.921	50.102	41.434	0.664	1.655
201	16203.64	525.490	153.324	134.559	137.480	0.737	1.139
202	7884.69	463.547	199.597	50.297	41.280	0.461	3.968
203	20748.17	576.205	182.572	144.696	71.833	0.785	1.262
204	10553.12	421.214	139.390	96.396	93.966	0.747	1.446
205	8618.84	548.762	168.086	65.287	139.316	0.360	2.575
206	10588.56	433.805	129.095	104.433	23.490	0.707	1.236
207	21683.84	626.778	198.647	138.984	54.847	0.694	1.429
208	9566.68	395.647	120.555	101.038	132.126	0.768	1.193
209	11360.79	443.294	158.114	91.485	12.331	0.726	1.728
210	23451.50	630.114	214.441	139.243	57.087	0.742	1.540
211	16710.35	550.041	191.850	110.900	85.597	0.694	1.730
212	43332.23	839.957	248.219	222.273	72.188	0.772	1.117
213	12908.43	492.091	154.116	106.644	0.355	0.670	1.445
214	15775.21	505.285	177.600	113.095	60.820	0.776	1.570
215	19756.96	607.809	205.309	122.525	6.208	0.672	1.676
216	18919.14	639.590	203.921	118.127	96.544	0.581	1.726
217	22602.05	660.483	195.163	147.455	154.218	0.651	1.324
218	22708.89	626.559	206.839	139.789	148.922	0.727	1.480
219	21532.56	701.648	284.131	96.491	16.005	0.550	2.945
220	18305.59	526.531	184.011	126.663	120.506	0.830	1.453

n	216		216	216
max	66981.03		0.844	4.255
min	2347.37		0.360	1.050
average	17331.50		0.684	1.655
stdev	8018.61		0.087	0.485

Hinckley Grain Analysis:

Grain Number	Area (μm²)	Perimeter (μm)	Major (μm)	Minor (μm)	Angle (°)	Circularity	Ellipticity
1	12173.37	499.363	197.531	78.467	101.034	0.613	2.517
2	13463.41	476.861	178.082	96.260	57.899	0.744	1.850
3	20337.06	590.425	225.577	114.790	65.726	0.733	1.965
4	27427.87	732.677	248.300	140.646	66.268	0.642	1.765
5	19808.11	574.475	215.972	116.777	58.788	0.754	1.849
6	12552.56	436.124	130.008	122.934	172.191	0.829	1.058
7	14234.04	494.827	188.328	96.233	90.374	0.731	1.957
8	8912.53	380.648	117.953	96.206	86.394	0.773	1.226
9	22678.88	618.623	240.117	120.256	5.244	0.745	1.997
10	13504.94	451.708	139.215	123.514	37.145	0.832	1.127
11	15438.30	534.465	214.487	91.645	104.446	0.679	2.340
12	10940.51	404.116	127.656	109.121	127.792	0.842	1.170
13	14185.02	463.542	160.650	112.424	68.450	0.830	1.429
14	45388.39	844.190	300.728	192.168	115.627	0.800	1.565
15	23715.68	628.164	238.262	126.733	39.699	0.755	1.880
16	16229.35	536.888	200.401	103.112	55.282	0.708	1.944
17	30170.65	769.975	322.488	119.119	79.510	0.640	2.707
18	12960.33	453.407	167.128	98.736	74.266	0.792	1.693
19	20052.50	602.660	240.029	106.369	70.311	0.694	2.257
20	10904.43	456.521	183.668	75.593	91.380	0.657	2.430
21	13564.17	454.173	155.819	110.836	164.228	0.826	1.406
22	15534.97	536.121	168.409	117.451	108.481	0.679	1.434
23	13910.67	509.146	203.538	87.019	69.487	0.674	2.339
24	16637.80	548.204	208.736	101.487	117.634	0.696	2.057
25	7138.46	331.309	97.345	93.369	8.057	0.817	1.043
26	7404.64	330.825	110.026	85.688	83.009	0.850	1.284
27	3574.68	241.247	86.553	52.585	34.169	0.772	1.646
28	12798.31	474.293	185.024	88.072	110.533	0.715	2.101
29	30005.23	741.073	293.905	129.987	101.914	0.687	2.261
30	17036.73	577.038	237.710	91.253	106.488	0.643	2.605
31	16093.87	505.860	168.637	121.511	156.608	0.790	1.388
32	12256.42	465.945	166.076	93.965	136.677	0.709	1.767
33	25621.81	768.546	318.810	102.326	107.159	0.545	3.116
34	9564.01	397.985	142.291	85.580	68.957	0.759	1.663
35	14483.19	477.213	167.393	110.163	131.706	0.799	1.520
36	15722.18	551.705	202.440	98.884	112.718	0.649	2.047
37	15800.47	502.946	176.232	114.155	82.545	0.785	1.544
38	9920.73	395.168	145.648	86.726	41.543	0.798	1.679
39	16776.68	545.436	195.952	109.010	145.198	0.709	1.798
40	11431.34	441.172	148.025	98.327	98.799	0.738	1.505
41	6527.82	317.624	100.557	82.655	99.374	0.813	1.217
42	9535.42	417.303	148.592	81.706	90.946	0.688	1.819
43	14696.27	480.693	164.489	113.758	65.829	0.799	1.446
44	18196.07	521.049	170.700	135.723	53.758	0.842	1.258
45	15224.54	500.364	189.072	102.524	31.759	0.764	1.844
46	17566.36	559.424	221.785	100.846	52.564	0.705	2.199
47	13927.01	464.226	166.000	106.822	35.608	0.812	1.554
48	14779.32	541.789	206.102	91.302	138.209	0.633	2.257
50	13246.25	470.177	138.913	121.411	77.096	0.753	1.144
51	10063.01	389.147	136.433	93.912	18.504	0.835	1.453
52	18149.09	529.183	178.854	129.201	22.198	0.814	1.384
53	16859.73	532.683	188.151	114.092	7.794	0.747	1.649
54	8118.08	348.342	117.458	87.999	88.515	0.841	1.335
55	7356.99	326.641	101.537	92.254	59.516	0.866	1.101
56	14854.89	469.108	147.076	128.599	110.026	0.848	1.144
57	7431.87	371.162	127.998	73.927	96.790	0.678	1.731
58	9269.24	380.897	129.020	91.474	41.372	0.803	1.410

59	15017.59	499.480	175.751	108.796	94.104	0.756	1.615
60	15367.50	482.675	168.808	115.910	85.285	0.829	1.456
61	14036.61	463.273	165.149	108.217	177.689	0.822	1.526
62	16053.71	503.195	159.058	128.508	178.320	0.797	1.238
63	17343.07	514.932	184.795	119.494	163.044	0.822	1.546
64	17422.04	552.934	195.525	113.451	86.512	0.716	1.723
65	14892.33	485.326	165.333	114.687	168.994	0.795	1.442
66	35057.16	713.372	215.641	206.993	136.196	0.866	1.042
67	13814.01	495.365	199.146	88.320	56.962	0.707	2.255
68	13003.22	449.326	160.533	103.133	43.057	0.809	1.557
69	10276.09	408.569	130.116	100.556	121.024	0.774	1.294
70	15817.49	547.134	180.253	111.729	56.847	0.664	1.613
71	14233.35	481.445	164.292	110.306	23.680	0.772	1.489
72	18963.96	543.834	197.564	122.217	179.513	0.806	1.617
73	14404.91	486.424	176.598	103.857	80.253	0.765	1.700
74	14606.41	522.319	193.615	96.054	41.535	0.673	2.016
75	13537.62	486.693	135.329	127.369	141.596	0.718	1.062
76	12512.39	445.156	155.309	102.578	144.467	0.793	1.514
77	5836.85	334.375	127.624	58.231	90.938	0.656	2.192
78	12257.79	440.123	149.080	104.690	89.790	0.795	1.424
79	11075.98	403.218	128.451	109.788	78.544	0.856	1.170
80	15631.64	519.351	188.915	105.353	67.864	0.728	1.793
81	14433.50	498.548	194.731	94.373	56.852	0.730	2.063
82	10589.92	403.501	127.937	105.392	101.800	0.817	1.214
83	16639.85	506.032	174.356	121.513	120.904	0.817	1.435
84	6007.04	303.788	108.348	70.591	105.858	0.818	1.535
85	8197.73	360.045	116.237	89.796	64.538	0.795	1.294
86	5947.13	296.221	97.660	77.535	130.904	0.852	1.260
87	19693.74	559.721	183.928	136.329	20.188	0.790	1.349
88	8858.75	403.799	163.688	68.907	91.421	0.683	2.375
89	26935.00	684.567	269.866	127.080	103.070	0.722	2.124
90	16236.15	514.697	180.763	114.363	20.533	0.770	1.581
91	28923.50	683.807	260.855	141.177	45.606	0.777	1.848
92	7340.65	366.846	118.113	79.131	10.267	0.685	1.493
93	12344.92	424.954	132.255	118.847	162.543	0.859	1.113
94	21034.84	739.063	210.166	127.435	12.617	0.484	1.649
95	14173.45	502.546	188.053	95.963	73.903	0.705	1.960
96	12592.72	435.835	127.689	125.567	161.549	0.833	1.017
97	17488.75	511.065	176.458	126.191	155.131	0.841	1.398
98	18907.46	547.335	202.448	118.913	99.433	0.793	1.702
99	29643.06	713.621	265.042	142.403	13.121	0.731	1.861
100	19815.60	564.037	190.329	132.560	84.744	0.783	1.436
101	15579.22	505.031	181.033	109.572	22.505	0.768	1.652
102	18632.43	628.193	265.670	89.297	102.990	0.593	2.975
103	15026.44	476.495	167.032	114.543	62.343	0.832	1.458
104	8178.66	376.132	126.770	82.144	73.926	0.726	1.543
105	14776.60	456.127	141.640	132.831	140.863	0.893	1.066
106	19309.79	539.284	180.811	135.976	86.950	0.834	1.330
107	11105.94	428.323	159.383	88.720	48.849	0.761	1.796
108	12062.41	427.688	147.744	103.952	156.672	0.829	1.421
109	8683.79	371.997	131.329	84.190	88.260	0.789	1.560
110	29425.90	698.555	261.194	143.442	117.027	0.758	1.821
111	9553.80	371.665	116.231	104.656	72.026	0.869	1.111
112	20292.13	544.869	181.832	142.091	29.823	0.859	1.280
113	14475.71	527.967	197.467	93.337	96.694	0.653	2.116
114	33605.09	784.627	314.830	135.906	87.629	0.686	2.317
115	10427.90	422.288	145.844	91.037	146.373	0.735	1.602
116	17492.84	590.190	242.948	91.676	71.468	0.631	2.650
117	13744.57	450.673	155.266	112.711	102.040	0.850	1.378

118	16562.24	545.250	208.556	101.113	97.850	0.700	2.063
119	15349.12	513.496	203.904	95.845	77.391	0.732	2.127
120	8552.40	425.686	155.664	69.954	118.397	0.593	2.225
121	9871.72	395.368	127.092	98.897	44.255	0.794	1.285
122	13319.09	484.463	167.975	100.958	64.632	0.713	1.664
123	16827.05	544.738	199.629	107.323	50.468	0.713	1.860
124	17970.73	530.750	155.572	147.077	117.444	0.802	1.058
125	9104.50	391.799	142.452	81.376	179.150	0.745	1.751
126	12321.78	432.721	133.968	117.107	112.331	0.827	1.144
127	6533.27	321.090	105.519	78.833	160.609	0.796	1.339
128	12799.67	446.386	152.815	106.646	88.761	0.807	1.433
129	7711.66	346.209	110.807	88.612	117.852	0.809	1.250
130	7502.67	368.662	127.583	74.874	113.379	0.694	1.704
131	14548.55	522.030	201.310	92.016	80.885	0.671	2.188
132	5922.62	293.003	94.074	80.159	37.350	0.867	1.174
133	43708.95	816.317	275.634	201.906	87.826	0.824	1.365
134	6437.96	313.171	102.414	80.038	102.787	0.825	1.280
135	6411.41	355.178	115.804	70.492	99.676	0.639	1.643
136	9540.19	400.049	152.652	79.573	102.178	0.749	1.918
137	4371.85	269.217	81.675	68.153	74.218	0.758	1.198
138	4687.04	271.219	94.034	63.463	139.990	0.801	1.482
139	7901.60	345.760	113.427	88.697	76.455	0.831	1.279
140	14982.87	478.359	154.281	123.649	69.765	0.823	1.248
141	9216.83	448.159	192.224	61.050	148.579	0.577	3.149
142	7943.80	373.012	125.801	80.400	81.520	0.717	1.565
143	4941.65	274.368	90.529	69.502	78.051	0.825	1.303
144	8357.71	369.898	130.249	81.700	87.008	0.768	1.594
145	8834.92	375.449	109.170	103.041	72.376	0.788	1.059
146	11915.36	438.389	145.428	104.320	154.660	0.779	1.394
147	3135.59	227.114	80.027	49.887	138.663	0.764	1.604
148	7767.49	337.192	109.536	90.289	98.242	0.858	1.213
149	10032.38	437.403	181.768	70.274	93.719	0.659	2.587
150	12649.22	448.491	156.918	102.636	28.151	0.790	1.529
151	6422.98	314.109	101.992	80.183	129.107	0.818	1.272
152	9715.82	413.002	121.926	101.460	5.865	0.716	1.202
153	13436.86	498.914	190.993	89.576	115.839	0.678	2.132
154	7873.68	341.727	112.498	89.113	108.214	0.847	1.262
156	12069.21	491.595	201.447	76.283	108.833	0.628	2.641
157	11100.49	472.725	180.459	78.320	101.107	0.624	2.304
158	4911.69	283.786	102.499	61.013	91.355	0.766	1.680
159	8397.87	372.797	106.194	100.688	89.355	0.759	1.055
160	9361.83	399.249	150.139	79.392	88.552	0.738	1.891
162	9327.79	385.447	130.907	90.725	96.893	0.789	1.443
163	21179.16	609.026	230.392	117.045	104.415	0.718	1.968
164	3740.10	253.399	97.868	48.658	136.474	0.732	2.011
165	10618.51	420.238	157.515	85.832	57.915	0.756	1.835
166	9404.72	386.931	143.052	83.707	16.528	0.789	1.709
167	21356.16	574.138	199.125	136.555	117.337	0.814	1.458
168	13485.88	456.873	161.072	106.603	116.399	0.812	1.511
169	13875.95	502.360	203.064	87.004	87.717	0.691	2.334
170	11240.05	426.921	152.995	93.541	96.748	0.775	1.636
171	7649.03	353.679	108.168	90.036	129.243	0.768	1.201
172	11416.36	447.061	173.948	83.564	45.234	0.718	2.082
173	9382.93	404.434	145.269	82.238	94.768	0.721	1.766
174	8361.11	348.045	108.169	98.418	23.888	0.867	1.099
175	6525.78	321.173	104.843	79.250	33.723	0.795	1.323
176	5038.99	295.068	111.008	57.796	85.972	0.727	1.921
177	19635.19	564.251	191.078	130.838	167.020	0.775	1.460
178	6119.36	302.020	104.749	74.382	75.361	0.843	1.408

179	9518.40	387.966	125.720	96.398	80.161	0.795	1.304
180	16592.87	520.048	159.288	132.632	111.851	0.771	1.201
181	6375.33	325.040	122.522	66.252	107.164	0.758	1.849
182	12125.72	485.809	185.400	83.274	94.263	0.646	2.226
183	15458.04	484.394	155.770	126.352	149.965	0.828	1.233
184	19863.93	597.523	230.164	109.885	105.795	0.699	2.095
185	9470.07	404.219	156.937	76.831	45.428	0.728	2.043
186	17555.47	518.329	173.067	129.154	0.202	0.821	1.340
187	3539.96	230.497	81.851	55.066	105.535	0.837	1.486
188	4533.87	264.384	96.679	59.710	77.882	0.815	1.619
189	18545.98	544.766	198.572	118.917	171.964	0.785	1.670
190	8715.10	425.271	173.797	63.847	112.935	0.606	2.722
191	11541.62	472.574	178.268	82.434	93.032	0.649	2.163
192	10759.43	399.952	126.967	107.897	69.549	0.845	1.177
193	6762.68	328.741	109.245	78.818	93.393	0.786	1.386
194	21282.64	599.511	214.460	126.354	140.310	0.744	1.697
195	12130.48	471.358	178.103	86.720	105.474	0.686	2.054
196	7480.20	335.859	105.899	89.935	89.277	0.833	1.178
197	12824.86	718.557	219.380	74.433	67.568	0.312	2.947
198	16306.27	558.485	216.692	95.812	104.677	0.657	2.262
199	9989.49	387.166	118.318	107.499	123.047	0.837	1.101
200	14444.39	570.451	241.049	76.296	98.495	0.558	3.159
201	5047.16	277.751	90.711	70.843	109.792	0.822	1.280
202	10750.58	403.736	134.159	102.028	109.415	0.829	1.315
203	9604.18	406.304	135.959	89.942	36.257	0.731	1.512
204	6287.51	322.575	106.744	74.997	145.980	0.759	1.423
205	7127.57	344.227	116.207	78.094	136.860	0.756	1.488
206	4992.02	317.624	118.980	53.421	118.922	0.622	2.227
207	10122.92	406.953	139.342	92.499	138.340	0.768	1.506
208	10800.96	413.520	142.851	96.270	25.145	0.794	1.484
209	7471.35	379.149	132.606	71.738	98.029	0.653	1.848
210	8136.46	377.162	148.684	69.676	95.220	0.719	2.134
211	13306.16	464.826	170.427	99.409	115.994	0.774	1.714
212	8350.90	352.243	109.189	97.379	22.476	0.846	1.121
213	5220.76	310.057	104.419	63.660	29.616	0.682	1.640
214	8800.20	370.581	135.337	82.792	114.578	0.805	1.635
215	8158.92	351.794	115.062	90.284	91.437	0.828	1.274
216	6369.20	309.622	109.687	73.933	98.889	0.835	1.484
217	3325.52	217.462	68.287	62.006	115.246	0.884	1.101
218	15200.72	596.791	189.656	102.049	108.983	0.536	1.858
219	15335.51	499.646	171.178	114.067	177.519	0.772	1.501
220	8020.73	369.145	142.481	71.675	77.489	0.740	1.988
221	12015.43	432.487	146.724	104.268	115.417	0.807	1.407
222	8497.26	394.747	150.097	72.080	85.115	0.685	2.082
223	12108.70	436.256	157.073	98.153	67.854	0.800	1.600
224	6956.70	337.123	118.564	74.707	172.672	0.769	1.587
225	6354.23	333.359	100.348	80.624	101.474	0.719	1.245
226	9768.92	390.597	126.047	98.679	7.695	0.805	1.277
227	20503.16	605.657	208.494	125.209	18.859	0.702	1.665
228	6415.49	316.706	95.994	85.093	61.380	0.804	1.128
229	9419.01	382.733	130.569	91.849	140.743	0.808	1.422
230	7653.12	359.161	133.695	72.884	75.849	0.746	1.834
231	4823.87	283.986	94.450	65.029	105.288	0.752	1.452
232	11069.86	429.821	160.636	87.742	72.957	0.753	1.831
233	10845.89	411.718	122.299	112.915	27.870	0.804	1.083
234	7366.52	330.908	115.859	80.955	163.282	0.845	1.431
235	8062.25	375.829	149.786	68.532	99.991	0.717	2.186
236	11621.27	422.689	140.198	105.542	46.080	0.817	1.328
237	9643.66	418.187	156.934	78.241	65.390	0.693	2.006

238	9099.05	427.619	169.986	68.154	66.602	0.625	2.494
239	19539.89	573.454	205.796	120.892	87.600	0.747	1.702
240	8192.96	365.928	135.003	77.270	93.054	0.769	1.747
241	4058.70	262.216	91.911	56.225	85.801	0.742	1.635
242	16161.95	521.533	173.999	118.265	118.206	0.747	1.471
243	6132.98	327.974	119.504	65.343	92.666	0.716	1.829
244	11168.57	407.417	141.283	100.651	95.912	0.846	1.404
245	11058.97	406.533	141.818	99.287	170.198	0.841	1.428
246	2907.53	222.661	85.113	43.495	88.695	0.737	1.957
247	6543.48	313.288	109.660	75.975	74.561	0.838	1.443
248	5334.44	298.920	114.781	59.174	93.603	0.750	1.940
249	13072.66	484.394	160.428	103.751	37.715	0.700	1.546
250	4777.58	270.052	92.035	66.094	51.904	0.823	1.392
251	16805.95	493.397	159.385	134.254	115.629	0.868	1.187
252	10892.86	419.851	135.156	102.617	97.124	0.777	1.317
253	8516.32	372.832	122.445	88.557	53.475	0.770	1.383
254	11956.89	438.604	136.449	111.573	88.573	0.781	1.223
255	13613.86	469.860	142.040	122.034	17.483	0.775	1.164
256	8447.57	351.912	111.318	96.622	34.919	0.857	1.152
257	13860.98	474.928	163.311	108.066	139.599	0.772	1.511
258	29675.74	661.817	199.309	189.577	70.456	0.851	1.051
259	11019.48	431.657	165.229	84.915	123.372	0.743	1.946
260	16279.72	529.480	201.515	102.861	179.973	0.730	1.959
261	4570.63	337.675	127.879	45.508	99.768	0.504	2.810
262	6186.76	328.575	122.182	64.471	95.006	0.720	1.895
263	13028.41	455.091	140.987	117.658	51.669	0.791	1.198
264	9881.25	401.900	140.298	89.675	125.629	0.769	1.565
265	8574.87	379.764	129.270	84.458	93.733	0.747	1.531
266	10281.54	411.069	144.963	90.305	91.359	0.765	1.605
267	8468.67	376.678	120.179	89.722	32.751	0.750	1.339
268	16231.39	491.332	162.775	126.963	62.671	0.845	1.282
269	9902.35	395.700	144.536	87.232	122.099	0.795	1.657
270	13635.65	458.612	152.253	114.030	134.582	0.815	1.335
271	14528.80	652.662	167.544	110.411	121.820	0.429	1.517
272	13692.83	516.631	206.248	84.531	100.615	0.645	2.440
273	7945.16	355.495	126.251	80.127	82.816	0.790	1.576
274	15221.14	519.634	194.167	99.812	116.436	0.708	1.945
275	31545.79	701.138	242.814	165.416	119.716	0.806	1.468
276	10597.41	397.867	136.334	98.971	63.347	0.841	1.378
277	4099.54	279.104	100.721	51.824	50.370	0.661	1.944
278	2219.28	194.208	70.786	39.919	69.609	0.739	1.773
279	8811.77	394.098	155.137	72.320	93.405	0.713	2.145
280	13634.97	477.144	184.191	94.253	114.817	0.753	1.954
281	11501.46	447.372	167.228	87.570	115.589	0.722	1.910
282	14016.87	460.539	164.886	108.237	84.973	0.830	1.523
283	14266.03	477.061	170.220	106.710	101.039	0.788	1.595
284	9318.26	385.716	123.176	96.320	91.464	0.787	1.279
285	10581.75	396.417	125.943	106.978	125.453	0.846	1.177
286	6908.36	347.361	107.481	81.838	34.181	0.719	1.313
287	14820.17	474.659	154.889	121.827	89.833	0.827	1.271
288	12722.75	460.974	167.878	96.494	74.622	0.752	1.740
289	18174.96	545.084	168.210	137.572	119.522	0.769	1.223
290	6532.58	325.240	105.416	78.902	61.799	0.776	1.336
291	18461.56	558.374	214.983	109.339	49.552	0.744	1.966
292	9632.77	423.552	163.549	74.992	84.305	0.675	2.181
293	6478.12	306.839	98.276	83.929	68.536	0.865	1.171
294	13887.53	501.047	162.444	108.851	57.699	0.695	1.492
295	5748.35	307.572	108.542	67.430	78.699	0.764	1.610
296	20349.31	558.706	173.730	149.137	96.616	0.819	1.165

297	14963.13	478.643	147.277	129.359	121.408	0.821	1.139
298	11048.75	403.936	135.583	103.757	90.385	0.851	1.307
299	6588.41	342.542	123.048	68.174	179.703	0.706	1.805
n	296.00					296.000	296.000
max	45388.39					0.893	3.159
min	2219.28					0.312	1.017
average	12582.52					0.757	1.644
stdev	6270.11					0.078	0.425