Preliminary results of detrital zircon geochronology, Wernecke Supergroup, Yukon

F. Furlanetto*[1]*, D.J. Thorkelson
Department of Earth Sciences, Simon Fraser University[2]

W.J. Davis
Geological Survey of Canada[3]

H.D. Gibson
Department of Earth Sciences, Simon Fraser University

R.H. Rainbird
Geological Survey of Canada

D.D. Marshall
Department of Earth Sciences, Simon Fraser University

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ABSTRACT

The Paleoproterozoic Wernecke Supergroup is a >13 km-thick metasedimentary succession exposed in the Wernecke, Ogilvie and Richardson mountains of central and northern Yukon. A program of field and laboratory investigations was initiated in 2007 in order to constrain the provenance, age and environment of deposition of the Wernecke Supergroup, as well as to better constrain the age of subsequent Proterozoic deformation (Racklan orogeny). Clastic and carbonate samples were collected from the Wernecke Supergroup for analysis of detrital and metamorphic minerals, as well as whole rocks, using a range of isotopic methods. Preliminary results from U-Pb analysis of detrital zircons from quartz sandstone beds, using ion probe mass spectrometry, are provided in this report. Patterns of the detrital zircon ages are broadly comparable to other Paleo- to Mesoproterozoic basins in Canada, suggesting a common Laurentian source. The maximum age of the Supergroup of 1.61 ± 0.03 Ga is provided by the age of the youngest detrital grain, which is ~0.1 Ga younger than expected.

RÉSUMÉ

Le Supergroupe de Wernecke du Protérozoïque précoce est une succession métasédimentaire de plus de 13 km d'épaisseur exposée dans les monts Wernecke, Ogilvie et Richardson du centre et du nord du Yukon. Un programme d'étude sur le terrain et en laboratoire a été lancé en 2007 afin de déterminer l'origine, l'âge et le milieu de dépôt du Supergroupe de Wernecke et de préciser l'âge de la déformation protérozoïque subséquente (orogenèse de Racklan). Des échantillons de roches détritiques et carbonatées ont été prélevés dans le Supergroupe de Wernecke aux fins d'analyse des minéraux détritiques et métamorphiques, ainsi que d'analyse de la roche entière, à l'aide d'une gamme de méthodes isotopiques. Les résultats préliminaires de l'analyse U-Pb des zircons détritiques de lits de grès quartzeux, à l'aide de la spectrométrie de masse et d'une sonde ionique, sont présentés dans ce rapport. La distribution des âges des zircons détritiques est dans l'ensemble comparable à celle dans d'autres bassins du Protérozoïque précoce à moyen au Canada, ce qui suggère une origine laurentienne commune. L'âge maximum du Supergroupe de 1,61 ± 0,03 Ga est obtenu d'après l'âge du grain détritique le plus jeune, qui est ~0,1 Ga plus jeune que prévu.

[1]*ffurlane@sfu.ca* [2]*8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6*

[3]*601 Booth Street, Ottawa, Ontario, Canada K1A 0E8*

INTRODUCTION

The Wernecke Supergroup is a Paleoproterozoic metasedimentary succession exposed in the Wernecke, Ogilvie and Richardson mountains, Yukon (Fig. 1). A detailed stratigraphic description of the Wernecke Supergroup and its subdivision into three groups (Fairchild Lake Group, Quartet Group and Gillespie Lake Group) were provided by Delaney (1981, 1985).

The Wernecke Supergroup was weakly deformed and variably metamorphosed during the Racklan orogeny (Thorkelson, 2000; Brideau *et al.*, 2002; Laughton *et al.*, 2005) and then locally invaded by hydrothermal fluids to form numerous breccia zones (Bell and Delaney, 1977; Thorkelson *et al.*, 2001). Despite these events, the Wernecke Supergroup has retained much of its original sedimentary character and composition. The provenance, age of deposition and basinal architecture of the succession, however, remain largely unknown.

To add to the understanding of the geologic evolution of the Wernecke Supergroup, we have undertaken a program of petrological and mineralogical investigations. This paper provides a summary of the fieldwork and the preliminary results of U-Pb analysis of detrital zircons from quartz sandstones. The findings are used to constrain the age of sedimentation and initiate a discussion on the possible sources of the sediments. Forthcoming geochemical and isotopic data will be coupled with the detrital zircon ages to further constrain the location of source terranes, aid in comparison with other Proterozoic basins in North America and abroad, and facilitate critical re-examination of paleocontinental reconstructions.

The study area is located 110 km northeast of the village of Mayo and extends throughout much of NTS map areas 106C/13, 106D/16, and 106E/1 (Fig. 1). The area is remote and mountainous, and access was obtained by helicopter and fixed-wing aircraft.

THE WERNECKE SUPERGROUP

The Wernecke Supergroup is exposed in the Wernecke and Ogilvie mountains, Yukon, and belongs to Sequence A as established by Young *et al.* (1979). It comprises 13 to 14 km of weakly to moderately metamorphosed (upper to lower greenschist grade) siliciclastic and carbonate rocks (Fig. 2). The succession consists of three conformable groups: the Fairchild Lake Group (oldest), the Quartet Group (middle) and Gillespie Lake Group (Delaney, 1981; 1985). Each group consists of stratigraphic units which may be regarded as informally defined formations.

The Fairchild Lake Group is at least 4 km thick and is composed mainly of siltstone, sandstone and minor carbonate. In most locations, the rocks still preserve their original sedimentary textures and mineralogy. Locally, the finer grained rocks have been metamorphosed into slate, phyllite and schist. The Fairchild Lake Group has been subdivided into five formations that, in ascending order, are F-1, F-2, F-3, F-4, F-TR (Delaney, 1981; Fig. 2). Formation F-TR includes beds of carbonate and slate, including a white-weathering dolostone marker bed.

The Quartet Group is a 4 km-thick succession consisting of pyritic black shale and slate (formation Q-1) and an overlying succession of siltstone and minor fine-grained sandstone (Q-2; Delaney, 1981; Fig. 2).

The Gillespie Lake Group is the uppermost group and consists of an approximately 4 km-thick succession of dolomitized carbonate and subordinate clastic rocks. Stromatolites, algal mats and oolites are locally abundant and suggest a platformal environment. The Gillespie Lake Group was subdivided into seven formations: G-TR, G-2, G-3, G-4, G-5, G-6, and G-7 (Delaney, 1981; Fig. 2). Formation G-TR, which gradationally overlies the Quartet Group, has a striking orange- and grey-banded appearance on mountainsides and consists largely of trough cross-bedded sandstone and orange-weathering dolostone.

Thorkelson (2000) mapped the Wernecke Supergroup in the study area, but used only two divisions within the Fairchild Lake Group, with the upper part corresponding mainly to formation F-TR of Delaney (1981). Thorkelson *(ibid)* mapped the Quartet Group as one unit and the Gillespie Lake Group as two units, with the basal Gillespie Lake Group corresponding mainly to Delaney's formation G-TR.

FIELDWORK 2007

In July, 2007, three weeks of fieldwork were undertaken by F. Furlanetto to collect a representative suite of samples from throughout the Wernecke Supergroup for petrologic, mineralogical, geochemical and isotopic analysis. Fifty-seven samples were taken from clastic and carbonate rocks and were combined with other samples collected during previous and subsequent field work by D. Thorkelson. The stratigraphic position of each sample

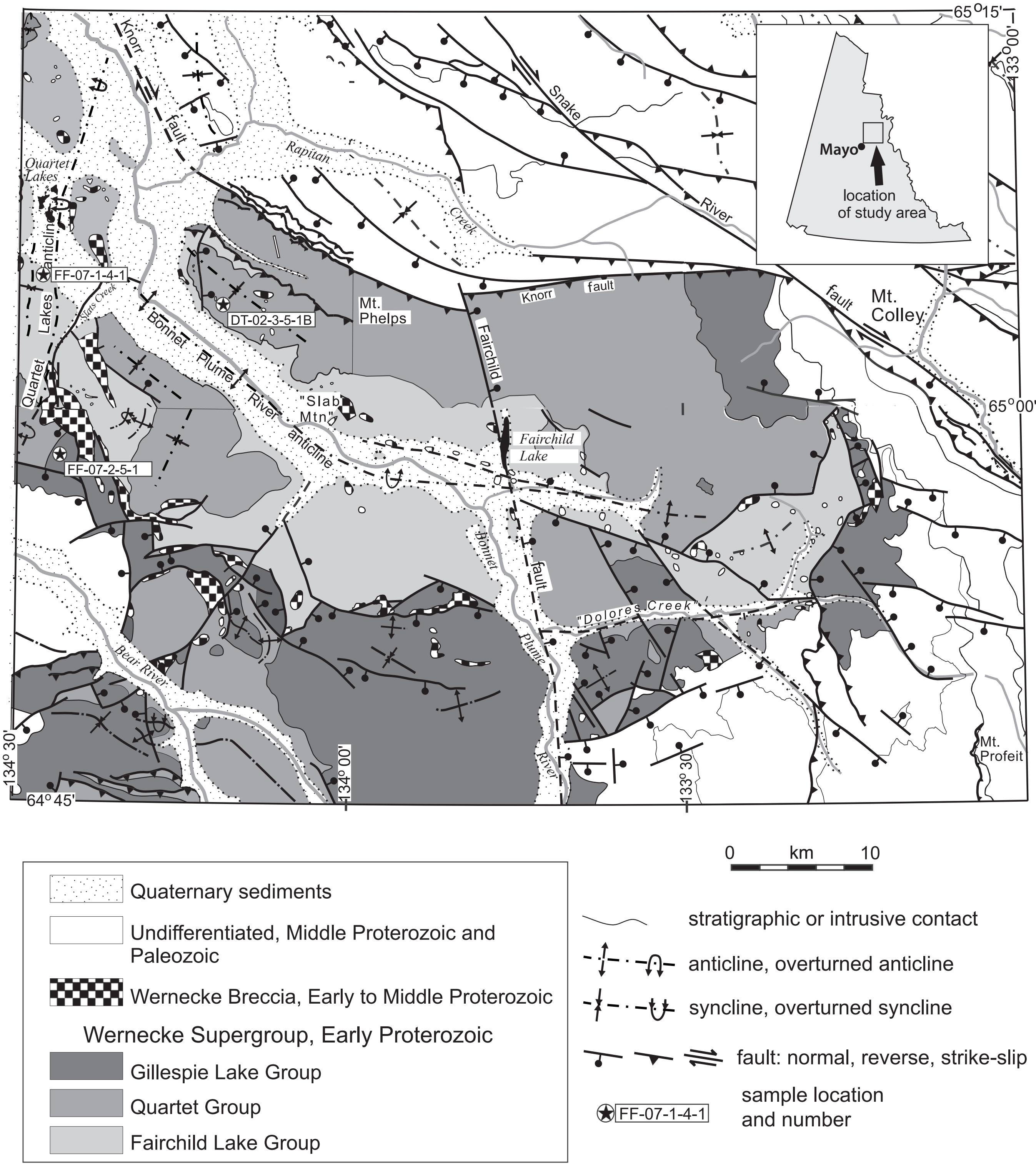


Figure 1. *Simplified geological map of the study area, modified from Thorkelson et al. (2005) showing location of analysed detrital zircon samples. Samples FF-07-4-1-1 and DT-06-3-5-1B are located outside the study area, in NTS 106D/9 and 106L/6 map areas, respectively.*

(using error bars to indicate uncertainty) is shown in Figure 3.

In Figure 3, the samples are organized by the four main rock types collected: quartz sandstone, carbonate, shale/phyllite and garnetiferous schist. The sandstone was collected for U-Pb analysis of detrital zircons; the carbonate for C, O and Sr isotopes; the shale/phyllite for Nd isotopes; and the garnetiferous schist for Lu-Hf dating of garnet. The goal of these analytical methods is to establish the provenance and maximum age of the sediments, and in the case of Lu-Hf dating, the age of deformation, which is considered to be Racklan orogeny (Brideau *et al*., 2002; Laughton *et al*., 2005; Thorkelson *et al*., 2005). Results from U-Pb dating of detrital zircons are the first analytical results from this study and are summarized in a subsequent section of this paper. A preliminary study of Nd isotopic composition of whole rock samples was published in Thorkelson *et al*. (2005) and is the only previous isotopic work on the provenance of the Wernecke Supergroup.

Samples collected from the Fairchild Lake Group include fine-grained sandstone, shale and slate, chloritoid ± garnet-bearing schist and phyllite, and carbonate. The fine-grained sandstone is present as massive beds within siltstone and mudstone in the lower to middle Fairchild Lake Group. These are mostly grey to light grey and locally greenish grey-weathered coarse siltstone to very fine sandstone (grey on fresh surfaces), with cross and parallel laminations. The shale and slate are dark grey on the weathered and fresh surfaces. The chlorite-muscovite-chloritoid/garnet-bearing schists and phyllites are light grey-green, light blue, locally rusty, weathered, kink-folded and finely crenulated. Other garnet-bearing rocks sampled for garnet dating are light green to light grey and light brown-weathered siltstones (grey on fresh surfaces), with garnets up to 4 mm in diameter within chlorite-rich domains. The carbonate samples have been collected in two levels in the lower and middle Fairchild Lake Group and are brownish grey, rusty-weathered with even parallel laminations (light grey to white on fresh surfaces). The sample collected from the ’white marker’ in formation F-TR is a light grey to white-weathered dolomitic siltstone and is grey on the fresh surfaces.

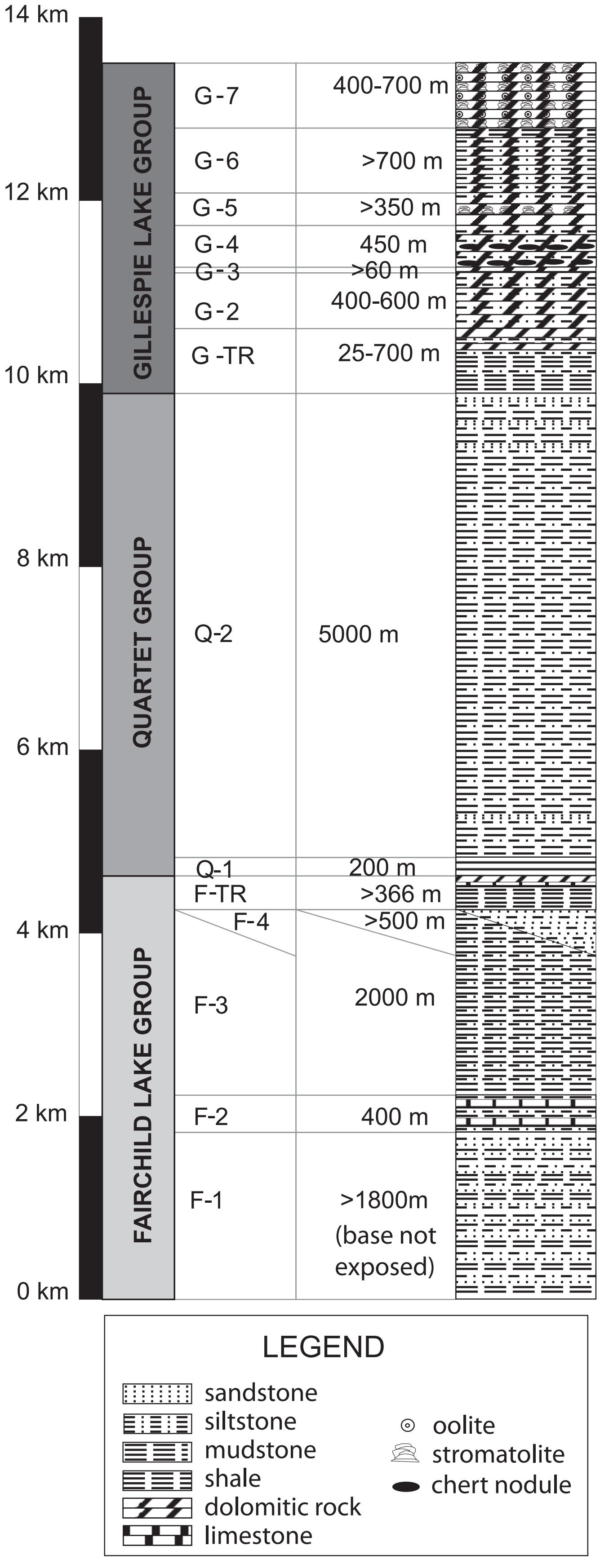


Figure 2. *Simplified stratigraphic column of the Wernecke Supergroup with main lithologies and thicknesses, modified from Delaney (1981).*

The Quartet Group samples are principally siltstone, black shale and slate, and sandstone. Samples from Q-1 are representative of this formation; they include black shale to slate, which are locally pyritic, waxy and rusty-weathered (dark grey to black on fresh surfaces), and are crenulated and kink-folded. Q-2 is characterized mostly by dark grey-weathered shaley siltstone, black shale and, locally, very fine sandstone. The uppermost Q-2, close to the transition with G-TR, is characterized by orange to pink, light green to light grey-weathered siltstone (dark grey on fresh surfaces), with local algal mats, laminations and storm intraclasts. Black shale and sandstone are also present. The sandstone samples collected in the lower part of Q-2 are dark brown and dark grey weathered variably cleaved siltstone to very fine grained sandstone (light grey on fresh surfaces). The sandstone collected from the uppermost Q-2 is from the scoured base of a 60 cm-thick bed of brown to dark grey-weathered coarse siltstone to very fine grained laminated sandstone (light grey on fresh surfaces).

The samples collected from the Gillespie Lake Group are sandstone, carbonate and black shales. The three samples collected for detrital zircon analysis are from the only horizon containing sandstone, near the base of the

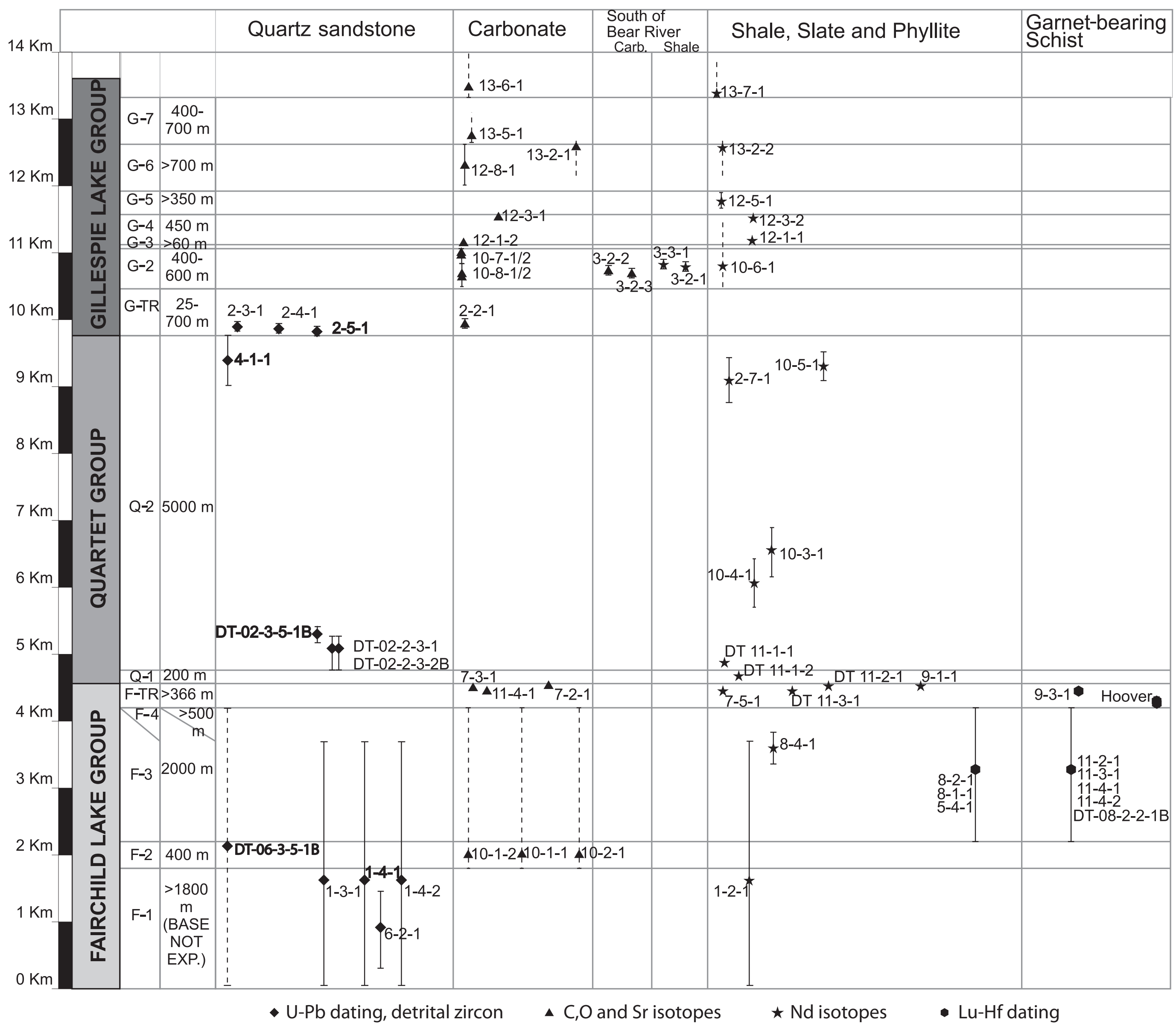


Figure 3. *Sample distribution according to stratigraphic unit, rock type and method of investigation. Samples in bold were analysed for this study.*

Gillespie Lake Group. These are massive brown to orange, yellow and grey-weathered dolomitic siltstone to very fine grained sandstone (grey on fresh surfaces), and are locally laminated. The carbonate and shale samples collected are fairly homogeneously distributed throughout the entire Gillespie Lake Group. The carbonate samples weather light brown, orange-grey and orange-yellow, and are grey on fresh surfaces. They include algal mats and locally contain diagenetic chert beds and nodules. Stromatolites and oolites are found in the middle to upper part of the succession. Some rocks show parallel laminations and others display storm textures and contain intraclasts.

Four samples, which include two carbonates and two shales of the Gillespie Lake Group, were collected from exposures south of Bear River and do not belong to any of the formations identified by Delaney (1981). These units were described by Thorkelson (2000) as mudstone, shale and dolomitic siltstone and interpreted as facies equivalents of the lower part of the Gillespie Lake Group described by Delaney (1981). The samples are shown in Figure 3 as possible equivalents of Delaney's (1981) formation G-2.

One carbonate and one shale sample were collected from strata which apparently sit above G-7, the highest formation of the Gillespie Lake Group defined by Delaney (1981) (Fig. 3). The lower of the two samples comes from a 250 m-thick succession of shale and the upper sample comes from an overlying succession of orange-weathering dolostone (see Fig. 11 of Thorkelson, 2000).

SANDSTONE PETROGRAPHY

Petrographic analysis of the Wernecke Supergroup samples was carried out using transmitted and reflected-light microscopy, as well as a scanning electron microscope (SEM). Most samples are classified as quartz arenite with modest amounts of other minerals including accessory zircon as described below. White mica is present in some samples and appears to reflect metamorphism of detrital clay and feldspar. The quartz grains typically display undulose extinction, sub-grain rotations and local grain-boundary migrations (Fig. 4), consistent with deformation and metamorphism (possibly associated with the Racklan orogeny). SEM observations indicate the presence of xenotime overgrowths (up to 6 microns thick, Fig. 5) on the surface of many zircon grains.

FAIRCHILD LAKE GROUP

In the Fairchild Lake Group quartz sandstone, quartz is the predominant mineral. Minor constituents are fine lamellae of white mica, mainly in the form of chlorite and sericite. Accessory minerals are iron oxides, rutile, and zircon, the latter being 20 microns in average length. Garnet (partially chloritized) is present in sample DT-06-3-5-1B, but it is unclear whether these grains are detrital or metamorphic in origin.

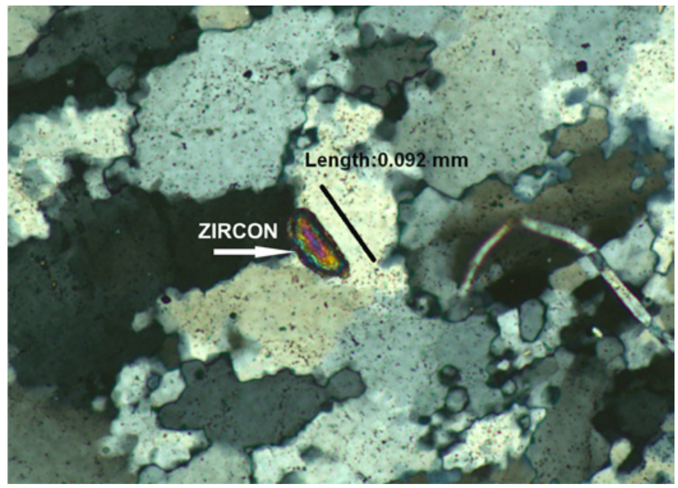


Figure 4. *Photomicrograph of DT-02-3-5-1B quartz sandstone, showing a zircon grain bounded by quartz grains that show evidence for grain-boundary migration. Length of scale bar is 0.092 mm.*

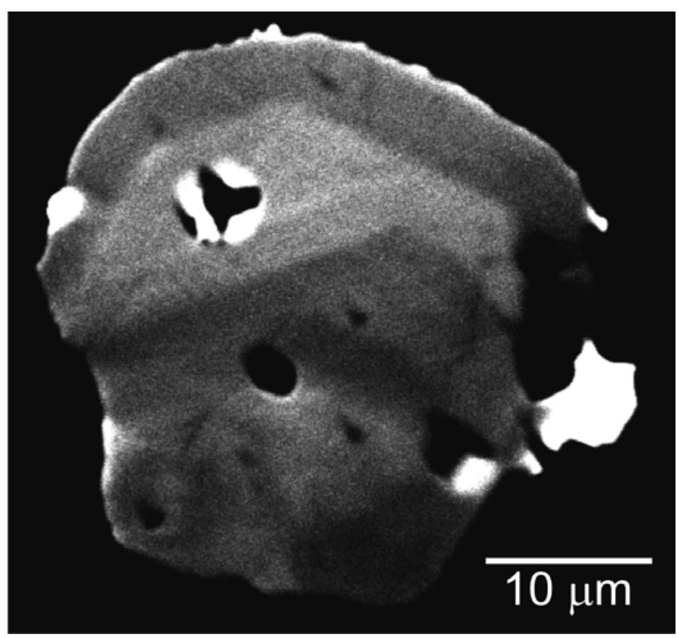


Figure 5. *Backscattered scanning electron microscopic image of zoned zircon with xenotime overgrowth from sample FF-07-4-1-1.*

QUARTET GROUP

The sandstone samples collected in the lower Quartet Group is mainly composed of quartz and white mica, with iron oxides, zircon, and other high relief accessory minerals. The sample from the upper Quartet Group is composed of quartz and carbonate in equal proportions, rare mica, iron oxides, and zircon as accessory minerals.

GILLESPIE LAKE GROUP

The sandstone samples collected in the lower Gillespie Lake Group are mainly composed of quartz and carbonate in equal proportions, minor white mica, iron oxides, and rare zircon as accessory minerals.

DETRITAL ZIRCON STUDY

U-Pb geochronology of detrital zircon from quartz-rich sandstones of the Wernecke Supergroup was conducted to identify the provenance of sediments that fed the Wernecke Basin during the Paleoproterozoic. The study is also designed to establish the maximum age of the sedimentation, which is poorly constrained at present. The results will, in turn, be used for correlating the Wernecke Supergroup with potentially coeval successions in North America and elsewhere in the world in order to refine paleocontinental reconstructions that involved Laurentia at that time.

In this study, we analysed 5 of 12 samples collected in the field, which were selected according to their stratigraphic position, geographic location and zircon abundance observed in thin section. The geographic locations of three of the five samples analysed are shown in Figure 1, and the stratigraphic positions of all five samples is shown in Figure 3. Two samples belong to the Fairchild Lake Group: FF-07-1-4-1 is from the middle Fairchild Lake Group in the Wernecke Mountains and DT-06-3-5-1B (not plotted on Figure 1) is from the Richardson Mountains. Sample DT-02-3-5-1B belongs to the lower Quartet Group; sample FF-07-4-1-1 (not plotted on Figure 1) is from the upper Quartet Group, close to the transition with the Gillespie Lake Group; and, sample FF-07-2-5-1 belongs to the basal Gillespie Lake Group. No samples from the middle and upper Gillespie Lake Group were collected due to the absence of sandstones in that part of the succession.

After the preliminary petrographic observations described above, the samples were processed using standard techniques of crushing, grinding and heavy mineral separation using a Wilfley table at Simon Fraser University. Frantz magnetic separation and heavy liquid processing were conducted on sample FF-07-2-5-1. Selection of grains according to size, colour and morphology was avoided in order to maintain the integrity of the sample and prevent biasing of age populations.

The zircon grain shapes range from elongate to nearly spherical and from well rounded to nearly euhedral-prismatic crystals. Some grains, however, have irregular shapes probably because they were damaged during sample processing. The grains range from pink to brown, to brownish green, and rarely, colourless. Grain size is quite small, ranging from 40 to 140 microns, with an average of ~60 microns (Fig. 6).

The grains were mounted in a 2 cm-diameter epoxy puck, which was polished to reveal grain centres and then coated with high purity gold. Prior to the analysis, the zircon grains were examined and photographed with a reflected light microscope and with a scanning electron microscope operating in backscatter mode (BSE).

PRELIMINARY RESULTS

The detrital zircon grains were analysed with the Sensitive High Resolution Ion Microprobe (SHRIMP II) at the J.C. Roddick Ion Microprobe Laboratory of the Geological Survey of Canada in Ottawa. Analytical procedures were based on those described by Stern (1997), and the assessment of errors and reduction of data were based on Stern and Amelin (2003). The zircon standard used for the analysis is z6266 Sri Lanka megacryst (weighted mean $^{206}Pb/^{238}U$ age of 559±0.2 Ma). The reduced data were filtered, eliminating those grains characterized by discordances greater than 5%, high common lead, excess

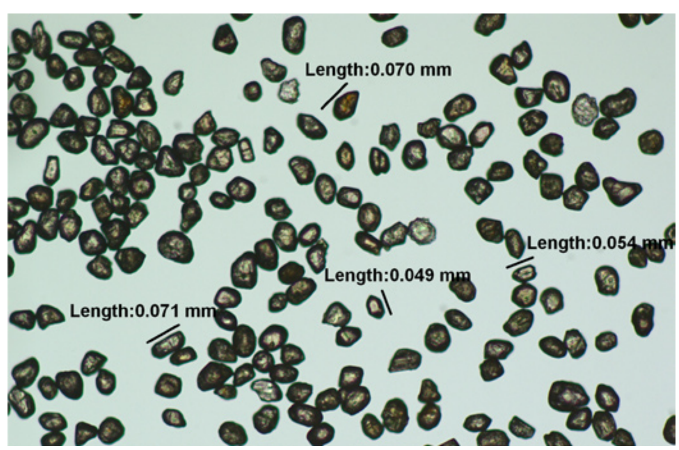


Figure 6. *Photomicrograph of separated detrital zircon grains from sample FF-07-2-5-1.*

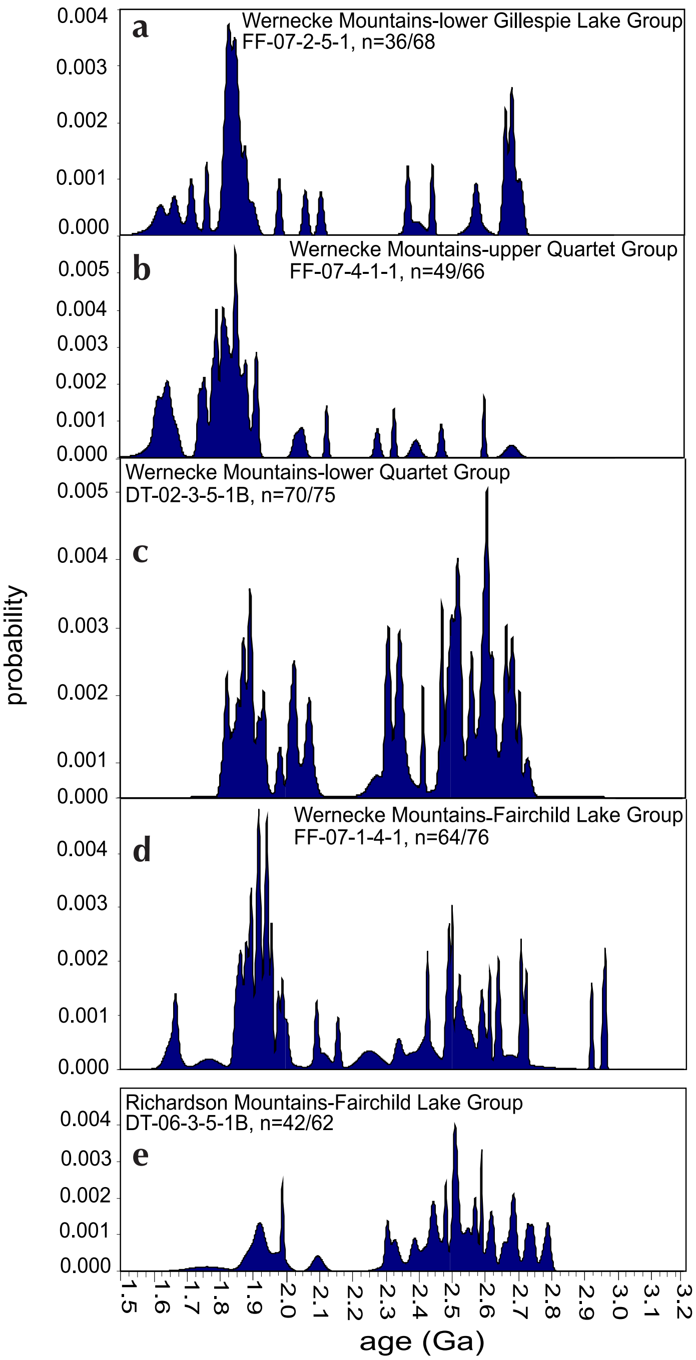


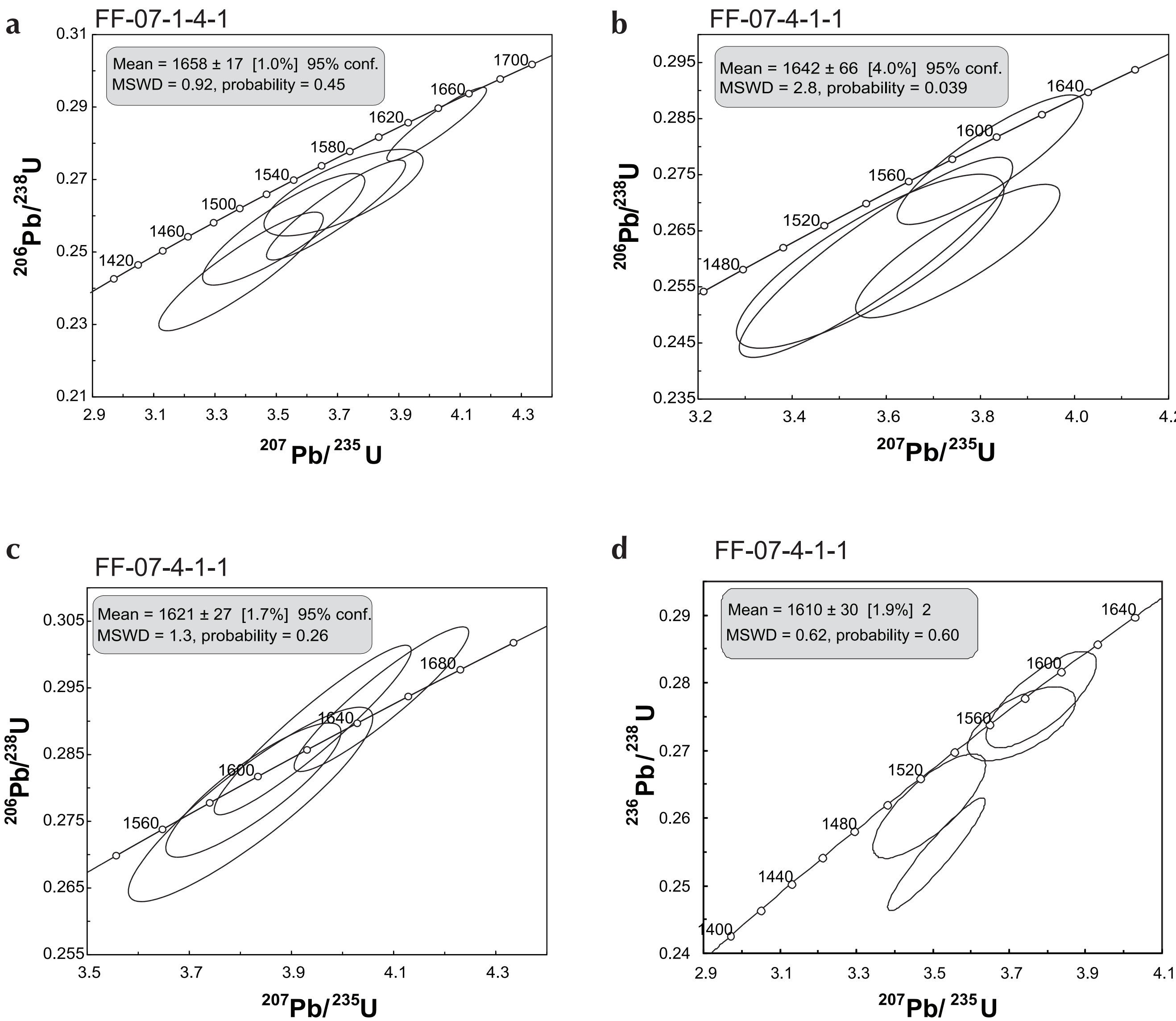
Figure 7. *Probability density distribution diagrams of detrital zircon ages from five samples of the Wernecke Supergroup, arranged according to stratigraphic order. Analyses over 5% discordant were not included. The quotient "n" indicates the number of 95-105% concordant grains over the total number of grains analysed. The graphs were produced using AgeDisplay (Sircombe, 2004).*

uranium, and large errors on the U-Pb ages. The ages are displayed here in probability density distribution diagrams using AgeDisplay (Sircombe 2004; Fig. 7). Multiple analyses were performed on the youngest zircons in order to reproduce the result, improve the precision and assess possible isotopic disturbance within the grains. The ages of those grains are displayed on U-Pb concordia diagrams using ISOPLOT (Ludwig, 2003; Fig. 8). Tables of isotopic data and histograms of zircon populations will be provided in a future paper.

A total of 352 grains were analysed and several age populations with peaks ranging from late Paleoproterozoic to Archean are evident (Fig. 7a-e). Sample FF-07-1-4-1 (Fig. 7d; Fairchild Lake Group) displays age distributions ranging from 1850 to 2000 Ma, 2500 to 2700 Ma and 2900 to 3000 Ma, which are the oldest detrital zircon grains from the Wernecke Supergroup. Minor peaks are present at *ca.* 2100, 2200, 2300 and 2400 Ma. The youngest peak is at *ca.* 1660 Ma. Sample DT-06-3-5-1B (Fig. 7e; Fairchild Lake Group, Richardson Mountains) shows similar age populations with clustering from 1900 to 2000 Ma and 2300 to 2800 Ma, and a minor peak at *ca.* 2100 Ma. Sample DT-02-3-5-1B (Fig. 7c; lower Quartet Group) has three main populations, with ages ranging from 1800 to 1950 Ma, 2300 to 2400 Ma and 2500 to 2750 Ma. Sample FF-07-4-1-1 (Fig. 7b; upper Quartet Group) has a cluster of nine grains, 95 to 105% concordant, from 1600 to 1700 Ma. This sample contains by far the highest number of younger grains compared to the other samples analysed. Replicate analyses of the three youngest grains are within error of each other at 1610±30 Ma, 1621±27 Ma and 1642±66 Ma (Figs. 8b,c,d), and suggest a post-1650 Ma depositional age of the upper Quartet Group. The most prominent grouping in this sample (FF-07-4-1-1) is from 1750 to 1900 Ma, with minor and variable number of grains from 2000 to 2700 Ma. Sample FF-07-2-5-1 (Fig. 7a; lower Gillespie Lake Group) is similar to FF-07-4-1-1 except for a smaller 1600 to 1700 Ma population. A grouping between 1800 to 1900 Ma is the highest, with a minor population from 2000 to 2700 Ma.

GEOLOGICAL SIGNIFICANCE

This new set of data allows us to make some preliminary comparisons between the Wernecke Supergroup and other post-1700 Ma basins in Laurentia. Two possible correlatives with the Wernecke Supergroup are the Athabasca Group and the Muskwa assemblage, given the similar detrital zircon age distributions and also because



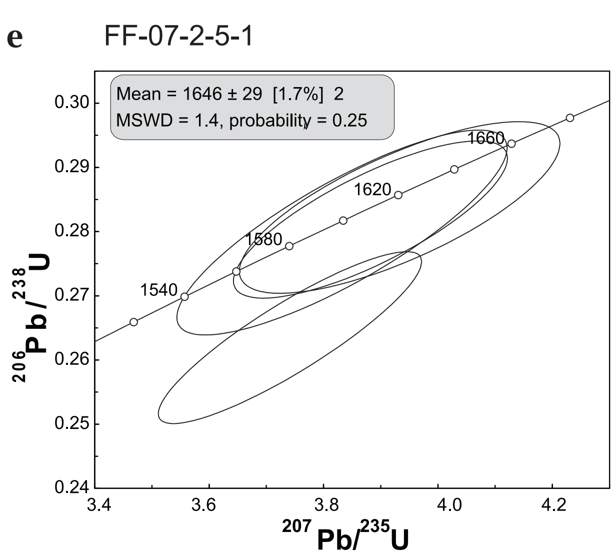


Figure 8. *Concordia diagrams for the five youngest detrital zircon grains. Diagrams were produced using ISOPLOT (Ludwig, 2003). Data point error ellipses are within 2σ.*

all three successions contain detrital zircon grains with ages between 1660 and 1700 Ma. One notable difference between the Wernecke Supergroup and the Athabasca and Muskwa successions is that only the Wernecke succession contains grains younger than 1660 Ma. In three of the five samples from the Wernecke Supergroup, five grains yielded ages between 1610±30 Ma and 1658±17 Ma. The youngest of these ages suggests that the Wernecke Supergroup may be up to 100 Ma younger that previously thought (>1710 Ma; Thorkelson *et al.*, 2001).

Possible sources for the <1700 Ma grains in the Wernecke Supergroup include the Labradorian orogen of eastern Canada (Nunn *et al.*, 1985), or the Yavapai-Mazatzal orogen of the southern United States (Whitmeyer and Karlstrom, 2007). A more local source could be the Narakay Volcanic Complex in the upper Hornby Bay Group of the Northwest Territories, which has been dated at 1663±8 Ma (Bowring and Ross, 1985). It is also possible that some of the grains were derived from another craton having a history of late Paleoproterozoic igneous activity, such as Australia (Solomon and Groves, 1994).

CONCLUSIONS

Zircon was extracted from samples collected from all three groups of the Wernecke Supergroup, spanning approximately 10 km of stratigraphic thickness. U-Pb isotope analysis by ion probe on 352 grains from 5 samples has produced two main results. First, the patterns of age distributions are similar to those of the Athabasca and Muskwa basins, with notable abundances at 1700 and 1900 Ma, and groupings of ages from 2200 to 2800 Ma, with few grains with ages >3000 Ma (Rainbird *et al.*, 2006). Second, three of the five samples show peaks in the 1600 to 1700 Ma range, with the weighted mean ages of the five youngest grains ranging from 1610±30 to 1658±17 Ma. Zircons with ages this young have not been recorded in samples from the Muskwa and are only found in the upper part of the Athabasca basin (Wolverine Point Formation, Rainbird *et al.*, 2006).

The detrital zircon results suggest that the Wernecke basin developed slightly after the Muskwa and could be synchronous with the upper Athabasca basin, but that all three were filled by detritus from similar sources, probably located on Laurentia (Ancestral North America). The youngest set of zircons from the Wernecke Supergroup (1610 to 1660 Ma) may also have been derived from Laurentia, from relatively nearby sources such as the Narakay volcanics of the Northwest Territories or more distal sources such as the Yavapai-Mazatzal orogen in the southern United States or the Labradorian orogen of eastern Canada. Alternatively, these grains may have been derived from another continent with a late Paleoproterozoic history of magmatism, such as Australia.

Previously, the age of the Wernecke basin was considered to be >1710 Ma, based on an interpretation that the 1710 Ma Bonnet Plume River intrusions crosscut the Wernecke Supergroup (Thorkelson *et al.*, 2001). Our new data suggest that the Wernecke Supergroup, which must be younger than its youngest detrital zircon grain (1610±30 Ma), is younger than previously thought, and calls into question the interpretation of emplacement of the Bonnet Plume River intrusions into the Wernecke Supergroup.

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