Natural Resources Canada
Ressources naturelles Canada

New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks, Manitoba and Saskatchewan

N.M. Rayner

Geological Survey of Canada

Current Research 2010-4

2010

Canada

Geological Survey of Canada
Current Research 2010-4

New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks, Manitoba and Saskatchewan

N.M. Rayner

2010

©Her Majesty the Queen in Right of Canada 2010

ISSN 1701-4387
Catalogue No. M44-2010/4E-PDF
ISBN 978-1-100-14590-7
DOI 10.4095/261489

A copy of this publication is also available for reference in depository libraries across Canada through access to the Depository Services Program's Web site at http://dsp-psd.pwgsc.gc.ca

A free digital download of this publication is available from GeoPub:
http://geopub.nrcan.gc.ca/index_e.php

Toll-free (Canada and U.S.A.): 1-888-252-4301

Recommended citation

Rayner, N.M., 2010. New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks, Manitoba and Saskatchewan; Geological Survey of Canada, Current Research 2010-4, 12 p.

Critical review
S. Pehrsson

Author
N.M. Rayner
(Nicole.Rayner@nrcan.gc.ca)
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Correction date:

All requests for permission to reproduce this work, in whole or in part, for purposes of commercial use, resale, or redistribution shall be addressed to: Earth Sciences Sector Copyright Information Officer, Room 644B, 615 Booth Street, Ottawa, Ontario K1A 0E9.
E-mail: ESSCopyright@NRCan.gc.ca

New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks, Manitoba and Saskatchewan

N.M. Rayner

Rayner, N.M., 2010. New U-Pb zircon ages from the Flin Flon Targeted Geoscience Initiative Project 2006–2009: Flin Flon and Hook Lake blocks, Manitoba and Saskatchewan; Geological Survey of Canada, Current Research 2010-4, 12 p.

Abstract: New geochronological results indicate that the predominant age of Flin Flon block volcanism is ca. 1890 Ma. A volcanic breccia within the Millrock member yields a maximum age of 1889 ± 9 Ma. A rhyolite flow at Millrock Hill yields a crystallization age of 1888.9 ± 1.6 Ma. The age of rhyolite at the Flin Flon mine South Main shaft is revised to 1887.1 ± 2.2 Ma. Lapilli tuff at Hilary Lake is dated at 1886 ± 4 Ma. A weakly foliated intermediate dyke is dated at 1872 ± 7 Ma, indicating early deformation. A porphyritic leucocratic granite dyke provides a minimum age for post-Missi folding of 1840 ± 8 Ma north of the Club Lake fault. The maximum age of shearing is constrained by a felsic dyke at 1839 +6/-2 Ma. The western sequence of the Hook Lake block is constrained by a crystallization age of 1891 ± 17 Ma and a minimum age of 1888.1 ± 0.9 Ma. Altered rhyolite from the eastern sequence is dated at 1882.0 ± 1.0 Ma.

Résumé : De nouveaux résultats géochronologiques indiquent que les âges qui témoignent du volcanisme dans le bloc de Flin Flon se situent principalement à environ 1 890 Ma. Une brèche volcanique du membre de Millrock a livré un âge maximal de 1 889 ± 9 Ma. Un âge de cristallisation de 1 888,9 ± 1,6 Ma a été établi pour une coulée rhyolitique du secteur de la colline Millrock. L'âge de la rhyolite au puits South Main de la mine Flin Flon a été révisé et se situe à 1 887,1 ± 2,2 Ma. L'âge du tuf à lapillis au lac Hilary est de 1 886 ± 4 Ma. Une datation indique que l'âge d'un dyke intermédiaire légèrement folié se situe à 1 872 ± 7 Ma, ce qui témoigne d'une déformation précoce. En se basant sur un dyke de granite porphyrique leucocrate, l'âge minimal du plissement postérieur au dépôt du Groupe de Missi est de 1 840 ± 8 Ma au nord de la faille de Club Lake. L'âge maximal du cisaillement est circonscrit à 1 839 +6/-2 Ma par un dyke felsique. L'âge de la séquence occidentale du bloc de Hook Lake est circonscrite par un âge de cristallisation de 1 891 ± 17 Ma et un âge minimal de 1 888,1 ± 0,9 Ma. Une datation établit à 1 882,0 ± 1,0 Ma l'âge de la rhyolite altérée de la séquence orientale.

INTRODUCTION

The Flin Flon Targeted Geoscience Initiative project was designed to aid in the discovery of new base-metal deposits in the Trans-Hudson Orogen in established mining communities of Manitoba and Saskatchewan. An important subcomponent within the project is precise U-Pb geochronology to constrain the stratigraphy, timing of volcanogenic massive-sulphide (VMS) mineralization and deformation history of the Flin Flon camp and adjacent prospective blocks. We report previously unpublished results from ten samples which include igneous crystallization ages for plutonic and volcanic units. These ages underpin the interpretations of a new geological map of the Flin Flon area (Simard et al. 2009, Figure 1). Ages were determined using a combination of the isotope dilution–thermal-ionization mass spectrometry (ID-TIMS) and Sensitive High Resolution Ion Microprobe (SHRIMP) techniques at the Geological Survey of Canada.

All of the VMS deposits mined to date in the Flin Flon area are associated with the 1.9 Ga juvenile Flin Flon arc assemblage (Syme et al. 1999). In the Flin Flon area these rocks have been separated into fault blocks (Fig. 1). The Flin Flon block, which hosts the Flin Flon–Callinan-777 VMS deposits, is bounded to the east by the Channing-Mandy Road faults, and extends beyond the boundaries of the map area to the south and west. The Hook Lake Block, which does not host any known VMS deposits, is bounded to the west by the Cliff Lake Fault, to the east by the Manistikwan Lake Fault.

METHODS

Heavy minerals were separated from the rock samples by standard crushing, grinding and heavy liquid techniques, followed by sorting of the heavy minerals using a Frantz isodynamic separator. Zircons analyzed by ID-TIMS were heavily abraded mechanically (Krogh, 1982) or by the chemical abrasion method (Mattinson, 2005) before being submitted for U-Pb chemistry. Dissolution of zircon in concentrated HF, extraction of U and Pb and mass spectrometry followed the methods described by Parrish et al. (1987). Analytical blanks for Pb were 1 to 3 pg. Results are presented in Table 1.

Prior to SHRIMP analysis, the internal features of the zircons (zoning, structures, alteration, etc.) were characterized with backscattered electrons (BSE) utilizing a Zeiss Evo scanning electron microscope. Detailed SHRIMP analytical procedures and U-Pb calibration details are given in Stern (1997) and Stern and Amelin (2003). The ion-probe results were collected over 5 sessions on 5 separate epoxy mounts with varying instrumental conditions. Specific analytical details for each sample are given in the footnotes of Table 2. An O^- primary beam was used in all analytical sessions with strength ranging from 3.5 to 11 nA. The count rates of ten isotopes of Zr^+, U^+, Th^+, and Pb^+ were sequentially measured over 5 or 6 scans, depending on the sample, with a single electron multiplier. The 1σ external errors of $^{206}Pb/^{238}U$ ratios reported in the data Table incorporate an error between 1.0 and 1.65% in calibrating the standard zircon (Stern and Amelin, 2003). No fractionation correction was applied to the Pb isotope data; common Pb correction utilized the Pb composition of the surface blank (Stern, 1997). Isoplot v. 3.00 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. All ages quoted in the text are given at 2σ. Isotopic ratios in tables 1 and 2 (both ID-TIMS and SHRIMP) are given at the 1σ uncertainty level, however ID-TIMS ages are reported in the tables as 2σ.

RESULTS

Flin Flon block

The stratigraphy of the Flin Flon block volcanic rocks associated with the Flin Flon–Callinan–777 VMS deposits record the infilling of a subsidence basin with localized felsic magmatism and formation of VMS (Flin Flon formation; Bailes and Syme, 1989; Devine, 2003; Syme et al., 1999). The Flin Flon formation can be subdivided into three members from the oldest to the youngest: the Club, the Blue Lagoon, and the Millrock members (Devine et al., 2002). The Millrock member hosts the VMS deposits and includes rhyolitic flows both below (footwall) and above (hanging wall) the VMS deposits. Following VMS deposition and a hiatus in volcanism, there was resurgence in volcanism and subsidence marked by the development of one or more mafic shield volcanoes atop this earlier structure resulting in the deposition of the Hidden and Louis formations. (DeWolfe, 2008; DeWolfe and Gibson, 2005, 2006; Syme et al., 1999).

PQB07-KM157–01–01 (z9500)

A sample of lapilli to block breccia containing abundant quartz eyes and small pinhead, metamorphic garnets was collected for geochronology near the Creighton landfill site. This rhyolite unit occurs within a mafic dyke/sill complex interpreted to be part of the Millrock member of the Flin Flon formation (Fig. 1). It is a composite massive to brecciated body that may either represent a subvolcanic dome or an extrusive flow, although unequivocal volcanic textures demonstrating the latter case are lacking. Five zircons were recovered from the unit (three broken, but simple, euhedral prisms and two fragments), and were analyzed by SHRIMP (Fig. 2a). Replicate analyses on three of the zircon grains yielded a $^{207}Pb/^{206}Pb$ age of 1889 ± 9 Ma (n = 7, mean square of weighted deviates - MSWD = 1.15) which was interpreted to represent the maximum age of the breccia. This date provides a minimum age for the Millrock and underlying Blue Lagoon and Club members. Two of the zircons gave $^{207}Pb/^{206}Pb$ ages of ca. 2.7 Ga and are interpreted as inherited or detrital. Pre-accretionary dates

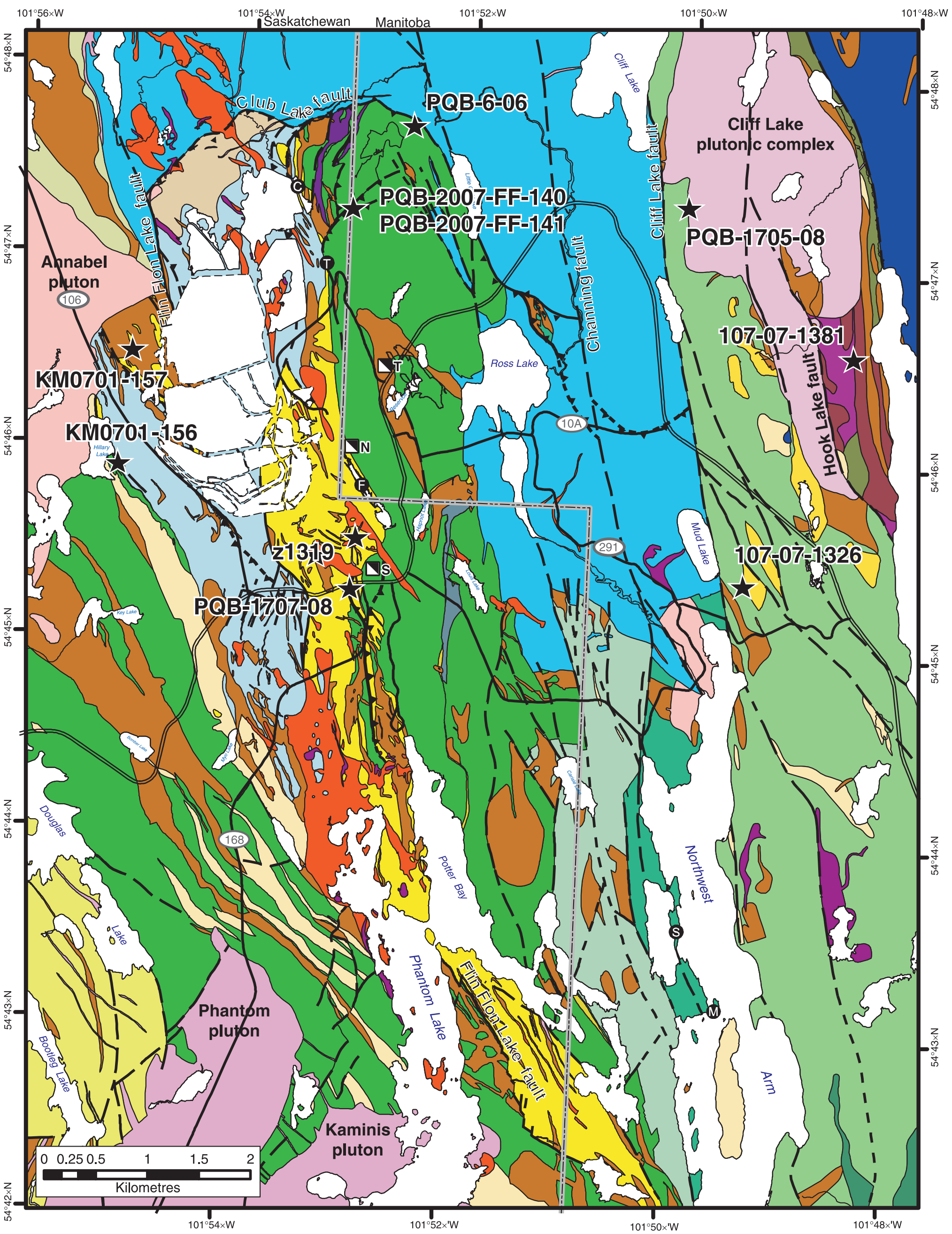


Figure 1. Simplified geological map of the Flin Flon and Hook Lake areas, from Simard et al., 2009. Approximate sample locations are shown.

Table 1. U-Pb TIMS analytical data

Fract.[1]	Description[2]	Wt. µg	U ppm	Pb[3] ppm	$^{206}Pb/^{204}Pb$[4]	Pb[5] pg	Isotopic ratios[6] $^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	±1SE Abs	$^{206}Pb/^{238}U$	±1SE Abs	Corr.[7] Coeff.	$^{207}Pb/^{206}Pb$	±1SE Abs	Ages (Ma)[8] $^{206}Pb/^{238}U$	±2SE	$^{207}Pb/^{235}U$	±2SE	$^{207}Pb/^{206}Pb$	±2SE	% Disc
PQB-1707-08 (z9736; NAD 83, UTM 14, 314482E 6071319N)																					
Z1A (1)	Eu, St, fIn, Frac	2	260	85	3408	3	0.09	5.025	0.006	0.3156	0.0003	0.91982	0.11548	0.00006	1768.1	2.8	1823.5	2	1887.4	1.8	7.22
Z1B (1)	Eu, St, fIn, Frac	2	293	97	1340	7	0.10	5.057	0.007	0.318	0.0003	0.84273	0.11535	0.0001	1780	3	1829	2.5	1885.3	3	6.39
Z1C (1)	Eu, St, fIn, Frac	3	111	38	2199	3	0.08	5.295	0.007	0.3326	0.0003	0.84991	0.11546	0.00008	1851.1	3.3	1868.1	2.3	1887.1	2.5	2.19
Z1D (2)	Eu, St, fIn, Frac	3	95	33	2349	2	0.07	5.388	0.007	0.3382	0.0003	0.89376	0.11553	0.00007	1878.1	3.2	1882.9	2.2	1888.2	2.1	0.61
Z1E (2)	Eu, St, fIn, Frac	4	67	23	1836	3	0.07	5.407	0.007	0.3391	0.0003	0.89161	0.11563	0.00007	1882.5	3.1	1886	2.2	1889.8	2.3	0.44
NW Rhyolite dome at South Main (z1319; NAD 83, UTM zone 14, 314692E 6071765N)																					
Z1A (1)	Eu, St, fIn, Frac	1	344	123	1274	6	0.09	5.4838	0.0081	0.34453	0.00035	0.86019	0.11544	0.00009	1908.4	3.4	1898.1	2.5	1886.8	2.8	-1.3
Z1B (1)	Eu, St, fIn, Frac	1	301	106	811	8	0.09	5.3887	0.0098	0.33854	0.00036	0.76144	0.11544	0.00014	1879.6	3.4	1883.1	3.1	1886.8	4.4	0.4
Z1E (1)	Eu, St, fIn, Frac	1	128	44	339	5	0.07	5.4210	0.0180	0.33950	0.00070	0.62368	0.11581	0.00030	1884.3	7.2	1888.2	5.6	1892.5	9.2	0.5
Z1F (multi)	Eu, St, fIn, Frac	2	200	65	328	9	0.09	4.9700	0.0200	0.31220	0.00090	0.56311	0.11544	0.00038	1751.6	8.8	1814.2	6.7	1886.8	11.9	8.2
PQB-2007-FF-140 (z9435; NAD 83, UTM zone14, 314409E 6075108N)																					
Z1A (1)	Eu, Pr, Clr, Co, fIn	12	143	48	32694	1	0.09	5.0600	0.0057	0.32707	0.00029	0.94151	0.11221	0.00005	1824.1	2.8	1829.4	1.9	1835.4	1.5	0.7
Z1B (1)	Eu, Pr, Clr, Co, fIn	11	114	38	21823	1	0.08	5.0571	0.0057	0.32708	0.00028	0.94253	0.11214	0.00005	1824.2	2.8	1828.9	1.9	1834.3	1.5	0.6
Z1C (2)	Eu, Pr, Clr, Co, fIn	9	176	60	30462	1	0.09	5.1121	0.0058	0.32988	0.00029	0.94259	0.11239	0.00005	1837.8	2.8	1838.1	1.9	1838.5	1.5	0.0
Z1D (7)	Eu, Pr, Clr, Co, fIn	7	209	71	8531	4	0.08	5.0886	0.0058	0.32836	0.00029	0.93807	0.11239	0.00005	1830.5	2.8	1834.2	1.9	1838.5	1.6	0.5
PQB-1705-08 (z9738; NAD 83, UTM zone 14 317739E 6075166N)																					
C1Z1 (1)	Eu, Pr, Clr, Co, rIn	7	80	28	5466	2	0.09	5.3960	0.0070	0.33910	0.00030	0.90161	0.11541	0.00007	1882.3	3.0	1884.2	2.1	1886.3	2.1	0.2
C2Z1 (5)	Eu, Pr, Clr, Co, rIn	20	49	17	15403	1	0.07	5.4020	0.0060	0.33900	0.00030	0.9433	0.11556	0.00005	1882.0	2.9	1885.2	1.9	1888.7	1.5	0.4
C3Z2 (1)	Eu, St, Clr, Co, rIn	5	35	12	3277	1	0.06	5.4140	0.0070	0.33970	0.00040	0.91261	0.11557	0.00006	1885.5	3.4	1887	2.2	1888.8	2.0	0.2
Z2B (5)	Eu, St, Clr, Co, rIn	19	53	18	6236	3	0.06	5.4020	0.0060	0.33910	0.00030	0.93648	0.11552	0.00005	1882.5	2.9	1885.1	2	1888.0	1.6	0.3
107-07-1381 (z9550; NAD 83, UTM zone 14 319457E 6073495N)																					
Z1A (9)	Eu, St, fIn, Clr, Co	9	89	31	8692	2	0.09	5.3310	0.0060	0.33570	0.00030	0.93882	0.11516	0.00005	1866.1	2.9	1873.9	2	1882.4	1.6	1.0
Z1B (10)	Eu, St, fIn, Clr, Co	9	126	44	12357	2	0.09	5.3410	0.0060	0.33660	0.00030	0.93524	0.11508	0.00005	1870.5	2.9	1875.5	1.9	1881.1	1.6	0.7
Z1C (12)	Eu, St, fIn, Clr, Co	9	60	21	675	18	0.10	5.3150	0.0110	0.33510	0.00030	0.73516	0.11502	0.00018	1863.1	3.2	1871.2	3.7	1880.3	5.7	1.1
Z1E (1)	Eu, St, fIn, Clr, Co	6	80	28	2440	4	0.08	5.3710	0.0070	0.33820	0.00030	0.90579	0.11519	0.00006	1877.9	3.0	1880.2	2.1	1882.8	2.0	0.3

[1] Z=zircon fraction; number in brackets refers to the number of grains in the analysis.
[2] Zircon descriptions: Co=Colorless, Br=brown, Clr=Clear, fIn=Few Inclusions, nIn=numerous inclusions, rIn=Rare Inclusions, Eu=E uhedral, Sh=Subhedral, Pr=Prismatic, St=Stubby Prism, Frac=Fractured
[3] Radiogenic Pb
[4] Measured ratio, corrected for spike and fractionation
[5] Total common Pb in analysis corrected for fractionation and spike
[6] Corrected for blank Pb and U and common Pb, errors quoted are 1 sigma absolute; procedural blank values for this study were 0.1 pg U and 1-3 pg Pb;
Pb blank isotopic composition is based on the analysis of procedural blanks; corrections for common Pb were made using Stacey and Kramers (1975) compositions.
[7] Correlation coefficient
[8] Corrected for blank and common Pb, errors quoted are 2 sigma in Ma
The error on the calibration of the GSC ^{205}Pb-^{233}U-^{235}U spike utilized in this study is 0.22% (2σ).

Table 2. U-Pb SHRIMP analytical data

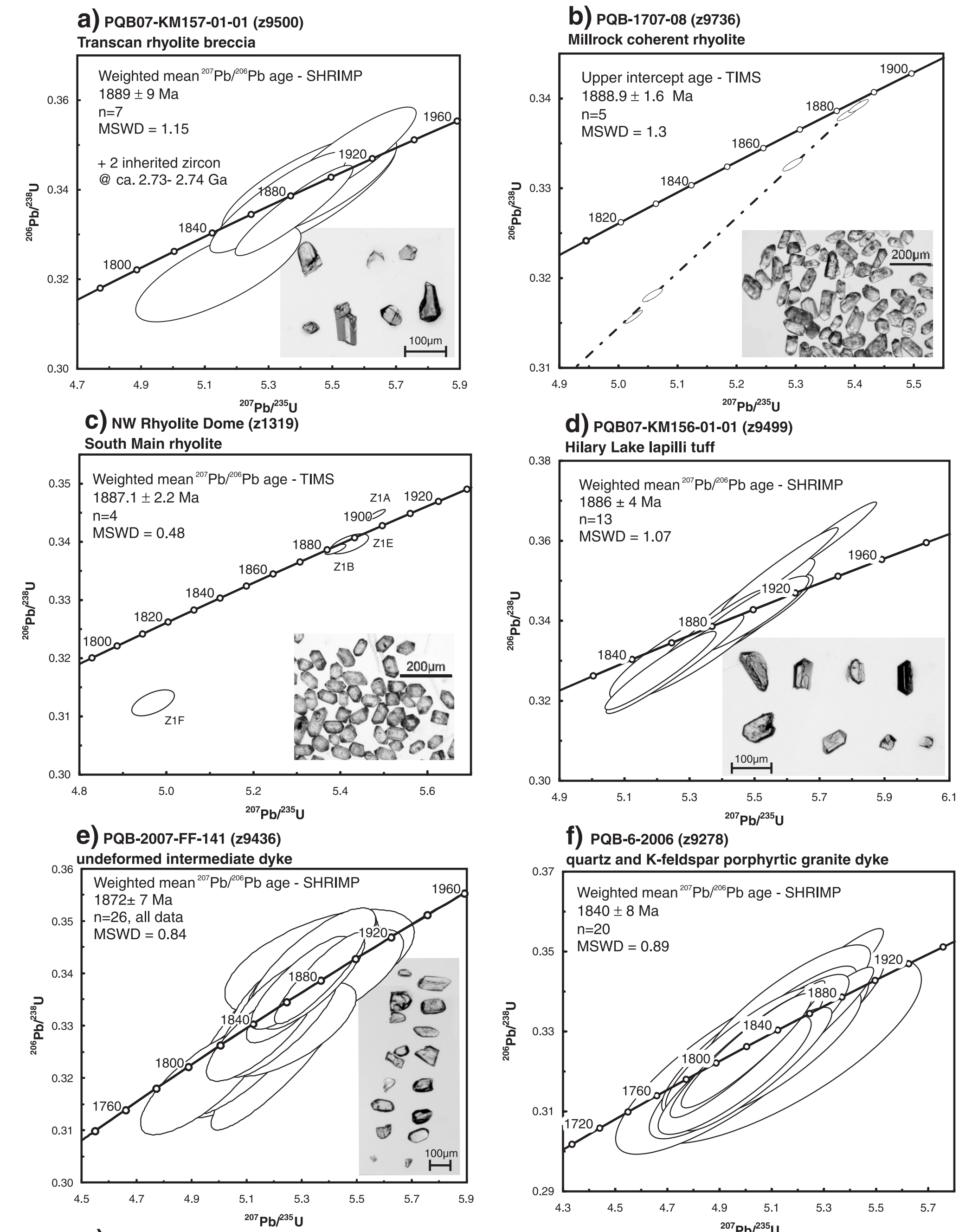
Spot name	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208*}Pb/^{206*}Pb	± ^{208}Pb/^{206}Pb	^{207*}Pb/^{235}U	± ^{207}Pb/^{235}U	^{206*}Pb/^{238}U	± ^{206}Pb/^{238}U	Corr Coeff	^{207*}Pb/^{206*}Pb	± ^{207}Pb/^{206}Pb	Apparent Ages (Ma) ^{206}Pb/^{238}U	± ^{206}Pb/^{238}U	^{207}Pb/^{235}U	± ^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	Disc. (%)
PQB07-KM157-01-01 (z9500; NAD 83, UTM zone 14, 312435E, 6073455N)																								
9500-1.1	89	11	0.13	30	0	0.000008	0.000084	0.00014	0.0388	0.0052	5.430	0.112	0.3407	0.0048	0.7662	0.1156	0.0015	1890	23	1890	18	1889	24	-0.1
9500-1.2	99	14	0.15	31	2	0.000080	0.000050	0.00139	0.0302	0.0045	5.145	0.106	0.3215	0.0044	0.7517	0.1161	0.0016	1797	22	1843	18	1896	25	5.2
9500-5.1	330	92	0.29	113	1	0.000009	0.000051	0.00016	0.0648	0.0031	5.471	0.094	0.3387	0.0047	0.8699	0.1172	0.0010	1881	23	1896	15	1913	15	1.7
9500-5.2	304	81	0.27	108	2	0.000020	0.000034	0.00035	0.0686	0.0033	5.556	0.086	0.3478	0.0044	0.8758	0.1158	0.0009	1924	21	1909	13	1893	14	-1.7
9500-5.3	350	90	0.27	119	4	0.000038	0.000016	0.00065	0.0611	0.0044	5.333	0.087	0.3373	0.0046	0.8877	0.1147	0.0009	1873	22	1874	14	1875	14	0.1
9500-6.1	726	297	0.42	262	4	0.000019	0.000013	0.00033	0.1036	0.0057	5.462	0.076	0.3443	0.0045	0.9660	0.1151	0.0004	1908	21	1895	12	1881	7	-1.4
9500-6.2	381	108	0.29	131	2	0.000015	0.000027	0.00025	0.0718	0.0038	5.382	0.075	0.3355	0.0041	0.9233	0.1164	0.0006	1865	20	1882	12	1901	10	1.9
9500-2.1	79	57	0.75	49	0	0.000010	0.000010	0.00017	0.1777	0.0097	13.678	0.206	0.5272	0.0069	0.9206	0.1882	0.0011	2730	29	2728	14	2726	10	-0.1
9500-3.1	51	28	0.57	31	0	0.000004	0.000080	0.00007	0.1491	0.0071	13.599	0.266	0.5186	0.0074	0.8004	0.1902	0.0023	2693	31	2722	19	2744	20	1.8
PQB07-KM156-01-01 (z9499; NAD 83, UTM zone14, 312544E 6072112N)																								
9499-1.1	722	319	0.46	254	7	0.000033	0.000029	0.00057	0.1081	0.0048	5.304	0.089	0.3341	0.0049	0.9195	0.1151	0.0008	1858	24	1870	14	1882	12	1.3
9499-1.2	924	449	0.50	357	1	0.000004	0.000009	0.00007	0.1331	0.0025	5.711	0.068	0.3599	0.0040	0.9728	0.1151	0.0003	1981	19	1933	10	1881	5	-5.3
9499-2.1	284	78	0.29	97	1	0.000010	0.000010	0.00017	0.0667	0.0031	5.411	0.077	0.3376	0.0039	0.8726	0.1163	0.0008	1875	19	1887	12	1899	13	1.3
9499-2.1.2	253	67	0.27	86	2	0.000024	0.000024	0.00042	0.0717	0.0051	5.296	0.098	0.3329	0.0050	0.8802	0.1154	0.0010	1852	24	1868	16	1886	16	1.8
9499-4.1	381	120	0.32	135	1	0.000010	0.000010	0.00017	0.0852	0.0024	5.489	0.079	0.3417	0.0041	0.8930	0.1165	0.0008	1895	20	1899	12	1904	12	0.5
9499-4.1.2	315	92	0.30	108	2	0.000018	0.000013	0.00032	0.0878	0.0029	5.325	0.087	0.3324	0.0047	0.9171	0.1162	0.0008	1850	23	1873	14	1898	12	2.6
9499-3.1	322	73	0.23	112	1	0.000010	0.000010	0.00017	0.0580	0.0020	5.500	0.077	0.3455	0.0042	0.9132	0.1155	0.0007	1913	20	1901	12	1887	10	-1.4
9499-3.1.2	288	63	0.23	99	1	0.000010	0.000010	0.00017	0.0601	0.0022	5.406	0.079	0.3387	0.0046	0.9627	0.1158	0.0005	1880	22	1886	13	1892	7	0.6
9499-5.1	1066	533	0.52	406	3	0.000010	0.000014	0.00017	0.1418	0.0024	5.580	0.074	0.3527	0.0044	0.9710	0.1148	0.0004	1947	21	1913	11	1876	6	-3.8
9499-5.1.2	955	458	0.50	347	3	0.000011	0.000007	0.00019	0.1348	0.0048	5.369	0.067	0.3382	0.0039	0.9656	0.1151	0.0004	1878	19	1880	11	1882	6	0.2
9499-6.1	421	134	0.33	147	1	0.000010	0.000021	0.00018	0.0744	0.0022	5.486	0.075	0.3416	0.0040	0.9062	0.1165	0.0007	1894	19	1898	12	1903	10	0.5
9499-6.1.2	355	112	0.33	121	0	0.000003	0.000012	0.00005	0.0877	0.0029	5.257	0.086	0.3293	0.0050	0.9612	0.1158	0.0005	1835	24	1862	14	1892	8	3
9499-7.1	691	280	0.42	238	1	0.000004	0.000008	0.00006	0.1068	0.0030	5.213	0.070	0.3277	0.0040	0.9470	0.1154	0.0005	1827	19	1855	11	1885	8	3.1
Notes (*see* Stern, 1997): Analytical details: mount IP472, 17 µm spot size, primary beam intensity 4.0 nA, 6 scans Error in ^{206}Pb/^{238}U calibration 1.1%																								
PQB-2007-FF-141 (z9436; NAD 83, UTM zone 14, 314361E 6075175N)																								
9436-3.1	151	40	0.28	52	0	0.000010	0.000010	0.00017	0.0729	0.0054	5.294	0.074	0.3381	0.0037	0.8455	0.1136	0.0009	1878	18	1868	12	1857	14	-1.1
9436-3.1.2	143	39	0.28	49	0	0.000010	0.000010	0.00017	0.0755	0.0062	5.257	0.093	0.3333	0.0046	0.8443	0.1144	0.0011	1854	22	1862	15	1870	17	0.9
9436-3.2	145	32	0.23	48	0	0.000010	0.000010	0.00017	0.0582	0.0046	5.259	0.098	0.3292	0.0037	0.6896	0.1159	0.0016	1834	18	1862	16	1894	25	3.1
9436-3.2.2	130	29	0.23	43	0	0.000010	0.000010	0.00017	0.0664	0.0031	5.121	0.095	0.3245	0.0047	0.8531	0.1145	0.0011	1812	23	1840	16	1872	18	3.2
9436-5.1	138	42	0.31	48	0	0.000010	0.000010	0.00017	0.0913	0.0064	5.260	0.104	0.3324	0.0041	0.7123	0.1148	0.0016	1850	20	1862	17	1876	26	1.4
9436-5.1.2	114	34	0.31	40	0	0.000010	0.000010	0.00017	0.0848	0.0032	5.311	0.109	0.3372	0.0055	0.8620	0.1142	0.0012	1873	27	1871	18	1868	19	-0.3
9436-6.1	195	65	0.34	69	3	0.000061	0.000085	0.00106	0.1035	0.0056	5.430	0.098	0.3392	0.0038	0.7024	0.1161	0.0015	1883	18	1890	16	1897	24	0.7
9436-6.1.2	155	52	0.35	54	0	0.000010	0.000040	0.00017	0.0937	0.0040	5.320	0.103	0.3384	0.0054	0.8843	0.1140	0.0010	1879	26	1872	17	1865	16	-0.8
9436-8.1	114	32	0.29	39	0	0.000010	0.000010	0.00017	0.0806	0.0031	5.310	0.101	0.3360	0.0038	0.6841	0.1146	0.0016	1868	18	1870	16	1874	26	0.3
9436-8.1.2	89	23	0.26	31	0	0.000010	0.000010	0.00017	0.0768	0.0033	5.336	0.108	0.3359	0.0054	0.8553	0.1152	0.0012	1867	26	1875	18	1883	19	0.9
9436-9.1	113	33	0.30	40	0	0.000010	0.000010	0.00017	0.0909	0.0055	5.366	0.109	0.3393	0.0038	0.6452	0.1147	0.0018	1883	18	1879	18	1875	29	-0.5
9436-9.1.2	102	29	0.30	35	0	0.000010	0.000010	0.00017	0.0838	0.0041	5.192	0.113	0.3337	0.0061	0.8985	0.1128	0.0011	1856	30	1851	19	1846	18	-0.6
9436-9.2	147	45	0.32	50	1	0.000032	0.000045	0.00055	0.0937	0.0043	5.147	0.080	0.3284	0.0037	0.8044	0.1137	0.0011	1830	18	1844	13	1859	17	1.6
9436-9.2.2	133	41	0.32	44	0	0.000010	0.000010	0.00017	0.0844	0.0059	5.206	0.098	0.3224	0.0051	0.9036	0.1171	0.0010	1801	25	1854	16	1913	15	5.8
9436-10.1	146	28	0.20	50	0	0.000010	0.000010	0.00017	0.0548	0.0023	5.339	0.094	0.3419	0.0043	0.7980	0.1133	0.0012	1896	21	1875	15	1852	19	-2.4
9436-10.1.2	126	24	0.20	42	0	0.000010	0.000010	0.00017	0.0566	0.0023	5.233	0.094	0.3289	0.0052	0.9236	0.1154	0.0008	1833	25	1858	15	1886	13	2.8
9436-10.2	239	71	0.31	84	1	0.000010	0.000010	0.00017	0.0882	0.0027	5.364	0.067	0.3391	0.0036	0.9018	0.1147	0.0006	1882	17	1879	11	1876	10	-0.3
9436-10.2.2	202	60	0.31	71	1	0.000010	0.000010	0.00017	0.0934	0.0034	5.296	0.102	0.3368	0.0059	0.9428	0.1140	0.0007	1871	28	1868	17	1865	12	-0.4
9436-11.1	121	38	0.32	42	0	0.000010	0.000010	0.00017	0.0883	0.0054	5.282	0.076	0.3357	0.0037	0.8423	0.1141	0.0009	1866	18	1866	12	1866	14	0
9436-11.1.2	103	32	0.32	35	0	0.000010	0.000010	0.00017	0.0868	0.0033	5.198	0.106	0.3278	0.0054	0.8653	0.1150	0.0012	1828	26	1852	18	1880	19	2.8
9436-12.1	443	183	0.43	159	2	0.000016	0.000015	0.00028	0.1206	0.0021	5.344	0.076	0.3382	0.0037	0.8401	0.1146	0.0009	1878	18	1876	12	1874	14	-0.2
9436-14.1	221	51	0.24	74	3	0.000045	0.000040	0.00078	0.0680	0.0028	5.228	0.081	0.3298	0.0040	0.8499	0.1150	0.0009	1837	19	1857	13	1879	15	2.2

Table 2. (cont.)

																		Apparent Ages (Ma)						
Spot name	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb* (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	$\pm\frac{^{204}Pb}{^{206}Pb}$	f(206)^{204}	$\frac{^{208*}Pb}{^{206*}Pb}$	$\pm\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207*}Pb}{^{235}U}$	$\pm\frac{^{207}Pb}{^{235}U}$	$\frac{^{206*}Pb}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	Corr Coeff	$\frac{^{207*}Pb}{^{206*}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\pm\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	Disc. (%)
9436-15.1	66	13	0.20	21	0	0.000010	0.000010	0.00017	0.0514	0.0038	5.100	0.113	0.3229	0.0044	0.7001	0.1146	0.0018	1804	21	1836	19	1873	29	3.7
9436-16.1	101	20	0.20	34	2	0.000056	0.000049	0.00097	0.0585	0.0046	5.308	0.111	0.3370	0.0044	0.7084	0.1143	0.0017	1872	21	1870	18	1868	27	-0.2
9436-16.2	89	21	0.24	31	1	0.000027	0.000079	0.00046	0.0653	0.0044	5.365	0.141	0.3420	0.0042	0.5700	0.1138	0.0025	1896	20	1879	23	1861	40	-1.9
9436-17.1	194	61	0.33	64	2	0.000039	0.000041	0.00068	0.0849	0.0033	4.931	0.090	0.3189	0.0041	0.7792	0.1122	0.0013	1784	20	1808	16	1835	21	2.7
Notes (*see* Stern, 1997):																								
Analytical details: mount IP467, 17µm spot size, primary beam intensity 3.5 nA, 6 scans																								
Error in ^{206}Pb/^{238}U calibration 1.0%																								
PQB-6-2006 (z9278; NAD 83, UTM zone 14; 315136E 6076009N)																								
9278-26.1	121	36	0.31	41	5	0.000141	0.000069	0.00244	0.0835	0.0033	4.995	0.124	0.3254	0.0065	0.8647	0.1113	0.0014	1816	32	1818	21	1821	23	0.3
9278-35.1	120	48	0.42	43	0	0.000010	0.000010	0.00017	0.1232	0.0043	5.157	0.131	0.3356	0.0066	0.8440	0.1115	0.0015	1865	32	1845	22	1823	25	-2.3
9278-22.1	135	30	0.23	44	0	0.000010	0.000010	0.00017	0.0670	0.0023	4.979	0.110	0.3239	0.0064	0.9308	0.1115	0.0009	1809	31	1816	19	1824	15	0.8
9278-16.1	176	42	0.24	58	0	0.000009	0.000050	0.00016	0.0693	0.0025	4.994	0.127	0.3246	0.0072	0.9193	0.1116	0.0011	1812	35	1818	22	1825	18	0.7
9278-25.1	331	84	0.26	110	1	0.000010	0.000010	0.00017	0.0751	0.0014	5.003	0.102	0.3252	0.0059	0.9258	0.1116	0.0009	1815	29	1820	17	1825	14	0.6
9278-12.1	121	45	0.39	41	0	0.000010	0.000010	0.00017	0.1098	0.0030	5.024	0.142	0.3265	0.0072	0.8484	0.1116	0.0017	1821	35	1823	24	1826	28	0.3
9278-2.1	116	18	0.16	37	3	0.000091	0.000137	0.00158	0.0455	0.0056	4.946	0.183	0.3209	0.0089	0.8215	0.1118	0.0024	1794	43	1810	32	1828	39	1.9
9278-21.1	312	64	0.21	103	1	0.000010	0.000010	0.00017	0.0628	0.0012	5.051	0.103	0.3274	0.0062	0.9669	0.1119	0.0006	1826	30	1828	17	1830	10	0.2
9278-17.1	105	32	0.32	36	0	0.000010	0.000010	0.00017	0.0933	0.0023	5.145	0.157	0.3329	0.0094	0.9592	0.1121	0.0010	1853	45	1844	26	1833	16	-1
9278-24.1	183	67	0.38	63	2	0.000042	0.000025	0.00072	0.1133	0.0027	5.110	0.128	0.3298	0.0068	0.8820	0.1124	0.0013	1837	33	1838	22	1839	22	0.1
9278-28.1	145	53	0.37	50	1	0.000028	0.000065	0.00048	0.1096	0.0035	5.088	0.125	0.3281	0.0066	0.8792	0.1125	0.0013	1829	32	1834	21	1840	22	0.6
9278-8.1	135	51	0.39	46	1	0.000039	0.000041	0.00068	0.1152	0.0056	4.956	0.120	0.3191	0.0061	0.8563	0.1127	0.0014	1785	30	1812	21	1843	23	3.1
9278-13.1	111	38	0.35	38	0	0.000010	0.000010	0.00017	0.1089	0.0041	5.018	0.159	0.3230	0.0082	0.8619	0.1127	0.0018	1805	40	1822	27	1843	30	2.1
9278-11.1	120	40	0.34	41	0	0.000010	0.000010	0.00017	0.1020	0.0024	5.070	0.124	0.3262	0.0071	0.9347	0.1128	0.0010	1820	35	1831	21	1844	16	1.3
9278-20.1	190	59	0.32	65	2	0.000036	0.000057	0.00062	0.0944	0.0027	5.198	0.135	0.3316	0.0071	0.8780	0.1137	0.0014	1846	34	1852	22	1859	23	0.7
9278-5.1	146	46	0.33	50	0	0.000010	0.000010	0.00017	0.0967	0.0031	5.146	0.133	0.3272	0.0068	0.8731	0.1141	0.0014	1825	33	1844	22	1865	23	2.2
9278-29.1	144	44	0.32	48	1	0.000025	0.000052	0.00044	0.0960	0.0027	5.042	0.117	0.3206	0.0063	0.9038	0.1141	0.0011	1793	31	1826	20	1865	18	3.9
9278-15.1	237	71	0.31	80	1	0.000011	0.000034	0.00019	0.0932	0.0022	5.116	0.133	0.3244	0.0066	0.8473	0.1144	0.0016	1811	32	1839	22	1870	25	3.2
9278-36.1	132	47	0.37	46	0	0.000010	0.000010	0.00017	0.1054	0.0023	5.192	0.121	0.3290	0.0070	0.9505	0.1145	0.0008	1834	34	1851	20	1871	13	2
9278-10.1	60	23	0.40	21	1	0.000064	0.000184	0.00111	0.1140	0.0080	5.134	0.220	0.3252	0.0095	0.7645	0.1145	0.0032	1815	47	1842	37	1872	51	3
107-07-1326 (z9549; NAD 83, UTM zone 14 318342E 6071314N)																								
9549-2.1	47	16	0.34	17	0	0.000010	0.000010	0.00017	0.1038	0.0038	5.382	0.110	0.3341	0.0055	0.8705	0.1168	0.0012	1858	27	1882	18	1908	18	2.6
9549-2.1.2	50	17	0.35	18	0	0.000010	0.000010	0.00017	0.1032	0.0038	5.276	0.122	0.3314	0.0053	0.7702	0.1155	0.0017	1845	26	1865	20	1887	27	2.3
9549-1.1	144	81	0.58	52	1	0.000019	0.000043	0.00032	0.1721	0.0035	5.136	0.099	0.3274	0.0046	0.7997	0.1138	0.0013	1826	22	1842	17	1861	21	1.9
9549-1.1.2	149	85	0.59	53	2	0.000043	0.000031	0.00075	0.1778	0.0078	5.167	0.102	0.3234	0.0050	0.8479	0.1159	0.0012	1806	24	1847	17	1893	19	4.6
9549-3.1	65	18	0.29	22	0	0.000010	0.000010	0.00017	0.0812	0.0038	5.317	0.127	0.3377	0.0053	0.7375	0.1142	0.0019	1875	25	1872	21	1867	30	-0.4
9549-3.1.2	66	18	0.29	22	3	0.000176	0.000098	0.00305	0.0790	0.0047	5.235	0.118	0.3311	0.0043	0.6641	0.1147	0.0020	1844	21	1858	19	1875	31	1.6
9549-3.2	100	57	0.59	32	1	0.000058	0.000091	0.00100	0.1663	0.0057	4.644	0.130	0.2842	0.0058	0.8026	0.1185	0.0020	1613	29	1757	24	1934	30	16.6
9549-4.1	186	118	0.65	70	1	0.000022	0.000043	0.00037	0.2013	0.0070	5.366	0.101	0.3286	0.0048	0.8386	0.1184	0.0012	1832	23	1879	16	1933	19	5.2
9549-4.2	74	25	0.36	24	2	0.000120	0.000079	0.00208	0.1092	0.0052	4.882	0.137	0.3051	0.0057	0.7488	0.1161	0.0022	1716	28	1799	24	1896	34	9.5
9549-6.1	339	192	0.59	127	2	0.000024	0.000025	0.00041	0.1640	0.0022	5.382	0.069	0.3398	0.0036	0.8968	0.1149	0.0007	1886	18	1882	11	1878	10	-0.4

Notes (*see* Stern, 1997):
Analytical details: mount IP434, 23 µm spot size, primary beam intensity 5.0 nA, 6 scans
Error in ^{206}Pb/^{238}U calibration 1.65%

Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number. Multiple analyses in an individual spot are labelled as x-y.z.z
Uncertainties reported at 1s (absolute) and are calculated by numerical propagation of all known sources of error
f206^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank (4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840)
* refers to radiogenic Pb (corrected for common Pb)
Discordance relative to origin = 100 * (1-(^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb age))
Calibration standard 6266; U = 910 ppm; Age = 559 Ma; ^{206}Pb/^{238}U = 0.09059
Th/U calibration: F = 0.03900*UO + 0.85600



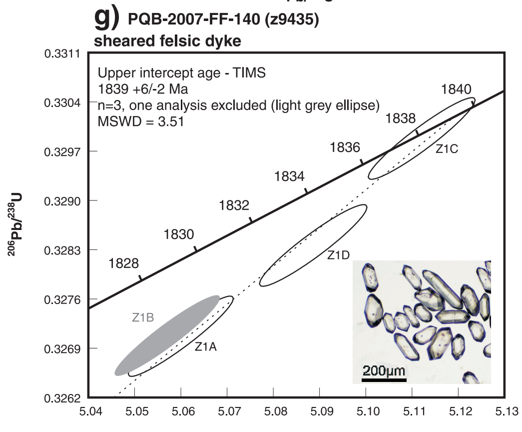


Figure 2. Concordia diagrams of SHRIMP and TIMS results for samples from the Flin Flon area. *See* text for details. Error ellipses plotted at 2σ.

(>1900 Ma) are not common in the Flin Flon area and are restricted to rare, strongly deformed, felsic plutonic rocks, inherited zircon in magmatic rocks and detrital grains in pre- and post-accretion sedimentary rocks (David and Syme, 1994, Stern et al., 1999, Ansdell 1993). The older reported dates range from 2.2 Ga to 3.0 Ga and are thought to represent slivers of continental crust that may have acted as basement to parts of the Amisk collage. This crust was subsequently recycled during accretionary processes to be expressed as detritus in the Flin Flon juvenile arc magmas, which show geochemical and isotopic evidence for a component crustal contamination (Stern et al. 1999; Simard and Creaser, 2007).

PQB-1707–08 (z9736)

A sample of in situ brecciated, coherent, quartz-phyric rhyolite of the Millrock member was collected at Millrock Hill, interpreted to represent the immediate footwall of the mineralized horizon. Approximately 100 zircon grains were recovered; largely poor quality, stubby simple prisms with visible oscillatory zoning in plane-polarized light and numerous fractures. Fractions Z1A-Z1C were chemically abraded following the procedure of Mattinson (2005) at 180°C for 2 hours. Fractions Z1D and Z1E were leached for an additional 4 hours with a noticeable improvement in concordance. Linear regression through the five fractions yield an upper intercept age of 1888.9 ± 1.6 Ma (MSWD = 1.3). This is interpreted as the crystallization age of the rhyolite, which is notably younger than the previous age estimate of the Millrock member; a well constrained age of 1903 +7/-5 Ma age for the Flin Flon 'Mine rhyolite' (Stern et al. 1999).

Northwest rhyolite dome at South Main (z1319)

The northwest rhyolite dome at South Main is one of a pair of massive to brecciated rhyolite bodies situated in the immediate footwall of the Flin Flon mine (Millrock member), at the base of a unit correlated with the Mine rhyolite (Bailes and Syme, 1989, Syme 1997). Lithological descriptions and preliminary geochronological data can be found in Syme et al. 1991 (sample z1319), where the unit was interpreted as a high-level intrusive rock. This sample of rhyolite is one of the rare instances of abundant zircon in Flin Flon felsic volcanic rocks. A second sample of this unit was initially interpreted to have crystallized at 1893 +5/-4 Ma, with some older ca. 1.9 Ga inheritance (sample FF92–2, David et al. 1993). The crystallization age was subsequently reinterpreted as 1903 +15/-12 Ma, coeval with the Mine rhyolite to the north that was dated at 1903 +7/-5 Ma (Stern et al. 1999). Additional fractions of sample z1319 refined the age to 1918 +32/-22 Ma (Stern et al., 1999) and later mapping reclassified it as extrusive (Bray, 2002). The original Syme et al. (1991) sample was reanalyzed owing to the large error and importance of its location in the immediate footwall of the Flin Flon VMS deposit.

Archived zircon separates from sample z1319 were composed of moderate quality stubby, simple prisms with oscillatory zoning visible in plane-polarized light (Fig. 2c, inset). Fractures and inclusions were rare. The zircons were chemically abraded for 2 hours. Single zircon grains that survived abrasion were submitted as individual fractions (Z1A, Z1B, Z1E). In cases where no grains survived intact, a fraction was composed of fragments of multiple zircon grains (Z1F). Where previous mechanically abraded fractions were between 2 and 12% discordant, with most greater than 4% discordant (Stern et al., 1999), three chemically abraded fractions were between −1.3 to 0.5% discordant and a fourth 8.2% discordant but along a chord to the origin. The weighted mean $^{207}Pb/^{206}Pb$ age of these four fractions is 1887.1 ± 2.2 Ma (MSWD = 0.48, Fig. 2c). interpreted as the crystallization age of the rhyolite. It is distinctly younger than the previous, imprecise age constraint on this sample and is identical in age to the Millrock Hill rhyolite described above. The South Main rhyolite, Millrock Hill rhyolite and apparently older Mine rhyolite all occur within the Millrock member and are interpreted to be footwall to the Flin Flon VMS deposits.

PQB07-KM156–01–01 (z9499)

A sample of bedded lapilli tuff was collected near Hilary Lake (Fig. 1) from a laterally continuous felsic volcaniclastic layer sitting conformably on rocks of the Blue Lagoon member and overlain by flows of the Hidden formation. This finely bedded Hilary Lake lapilli tuff is clearly extrusive and it is interpreted to be correlative to the Millrock member of the Flin Flon formation (MacLachlan and Devine, 2007, Simard et al., 2009). A sample of a felsic intrusive unit (Myo unit), collected approximately 2km to the southeast near Myo Lake, cuts across the southern extension of the Hilary Lake tuff and yields an age of 1888.9 ± 1.7 Ma (Bailey, 2006).

As is typical in samples from the Flin Flon area, zircon recovery was poor. Although only 7 zircons were recovered, all were simple euhedral prisms, typical of volcanic zircon (*see* Fig. 2d inset). Due to the low yield, this sample was dated by SHRIMP (Fig. 2d). The weighted mean $^{207}Pb/^{206}Pb$ age of 13 analyses on 7 zircon grains, is 1886 ± 4 Ma (MSWD = 1.07). Uranium concentrations range between 250 and1050 ppm. This is interpreted as the crystallization age of this extrusive felsic unit and constrains the age of the upper Millrock member. This extrusive felsic unit and the overlying flows of the Hidden formation are both cut by an essentially coeval Myo intrusive rock indicating that the emplacement of the overlying Hidden formation occurred very rapidly after the deposition of the Flin Flon formation.

PQB-2007-FF-141 (z9436)

A weakly foliated intermediate dyke cuts a deformed, scoriaceous volcaniclastic layer of the Hidden formation, the hanging wall to the Flin Flon mine sequence (Fig. 1). The sample has poor zircon yield (n = 17, Fig. 2e inset) and therefore was analyzed by SHRIMP. The weighted mean $^{207}Pb/^{206}Pb$ age of 26 analyses of 13 zircons is 1872 ± 7 Ma (MSWD = 0.84, Fig. 2e) and is interpreted as the crystallization age of the dyke. This is the oldest phase documented to intrude the hanging wall and also demonstrates the occurrence of a generation of deformation prior to the deposition of Missi Group rocks in the Flin Flon area, bracketed between 1847 and 1842 Ma (Ansdell 1993, Heaman et al. 1992). The intrusion of the dyke overlaps in within error with the emplacement of the Annabel pluton (1866 Ma, Stern and Lucas, 1994) and the Gants Lake pluton (1876 Ma, Whalen and Hunt, 1994) as one of the earliest successor arc phases.

PQB-6–2006 (z9278)

A quartz and K-feldspar porphyritic leucocratic granite dyke crosscuts a limb of the early Flin Flon creek synform in the Missi sedimentary rocks. The dyke contains a northwest-trending fabric and a younger northeast-trending fabric and it is folded by an open north-south trending fold (LaFrance, pers. comm.). The age of the dyke provides a minimum age of F_1 Missi folding and related tightening of the pre-Missi Hidden Lake syncline to the south and a maximum age for open north-south folding. The crystallization age of the dyke was determined by SHRIMP (Fig. 2f). The weighted mean $^{207}Pb/^{206}Pb$ age from 20 zircon grains is 1840 ± 8 Ma (MSWD = 0.89). This unit has been correlated, on the basis of lithology, with a feldspar-phyric phase of the Boot-Phantom Lake intrusive suite, dated at 1838 ± 2 Ma (Heaman et al. 1992). This recent age determination supports this correlation.

PQB-2007-FF-140 (z9435)

A felsic dyke deformed by a north-northwest-trending shear zone was collected to constrain the maximum age of shearing along the west limb of the Hidden Lake syncline. The maximum age of post-Missi Group folding is constrained to be 1840 Ma from sample PQB-6–2006; this sample will test whether shearing and post-Missi Group north-south folding are coeval. This sample had excellent zircon yield and consequently was analyzed by ID-TIMS with single grain and small multigrain (1 to 7 zircon grains), air-abraded fractions. Four fractions gave an upper intercept age of 1839 +6/-2 Ma (Fig. 2g) determined by a regression through 3 of the fractions. The intercept age is in excellent agreement with the $^{207}Pb/^{206}Pb$ age of the most concordant fraction. This is interpreted as the crystallization age and an upper limit on the time of shearing. This age is identical within error to the age of the post-Missi Group felsic dyke PQB-6–2006 (this study) and thus, while not proven, coeval shearing and folding is permissible.

Hook Lake block

The Hook Lake block is composed of two distinct sequences: 1) a western sequence consisting of basaltic flows with smaller amounts of felsic volcanic rocks, accompanied by a stratigraphically overlying sequence of reworked mafic and felsic proximal volcanic rocks, and 2) an eastern sequence of massive to fragmental, quartz- and feldspar-phyric rhyolitic flows in a thick package of heterolithic mafic to mafic-felsic breccia (Kremer and Simard, 2007). The boundary between the two sequences is marked, in places, by the Cliff Lake pluton and, elsewhere, by the Hook Lake Fault. New geochronological results are being used to assess the relationship of the Hook Lake block stratigraphy to the VMS-hosting stratigraphy of the Flin Flon block.

107–07–1326 (z9549)

A sample of buff to white quartz- and feldspar-phyric massive rhyolite was collected east of Mud Lake in the western sequence of Hook Lake block (Fig. 1). The outcrop consists largely of massive, generally ‘unaltered’ rhyolite, which cannot be traced along strike as numerous strike-slip faults have dismembered the stratigraphy. Zircon recovery from this sample was very poor, only six grains were recovered, five of them of sufficient quality for ion-probe analysis (Fig. 3a, inset). The weighted mean $^{207}Pb/^{206}Pb$ age of 10 analyses of these zircons is 1891 ± 17 Ma and was interpreted as the time of crystallization (Fig. 3a).

PQB-1705–08 (z9738)

A sample of quartz diorite, interpreted to be a synvolcanic phase of the complex Cliff Lake pluton. The Cliff Lake pluton is a multiphase body whose components are differentiated in the field by the amount of assimilated host rock xenoliths (Bailes and Syme, 1989). Previous geochronology of this intrusion yielded ages ranging from 1874 to 1894 Ma, with the complexity attributed to sampling a combination of inherited and primary igneous material (Gordon et al. 1990, MacQuarrie, 1980). Stern et al. (1999) reported the most precise age of 1886 ± 1 Ma from a cognate quartz diorite xenolith. Quartz diorite (phase 45b, Bailes and Syme, 1989) is the least contaminated major phase and therefore was recently sampled to determine a precise, early, synvolcanic crystallization age. Abundant, clear, colourless, prismatic to stubby zircons (Fig. 3b, inset) were recovered and chemically abraded for 8 hours (Mattinson, 2005). Two single-grain and two multigrain fractions yield a weighted mean age of 1888.1 ± 0.9 Ma (MSWD = 1.4, Fig. 3b) by ID-TIMS. This age is interpreted as the crystallization age of this phase of the Cliff Lake pluton and is identical, within

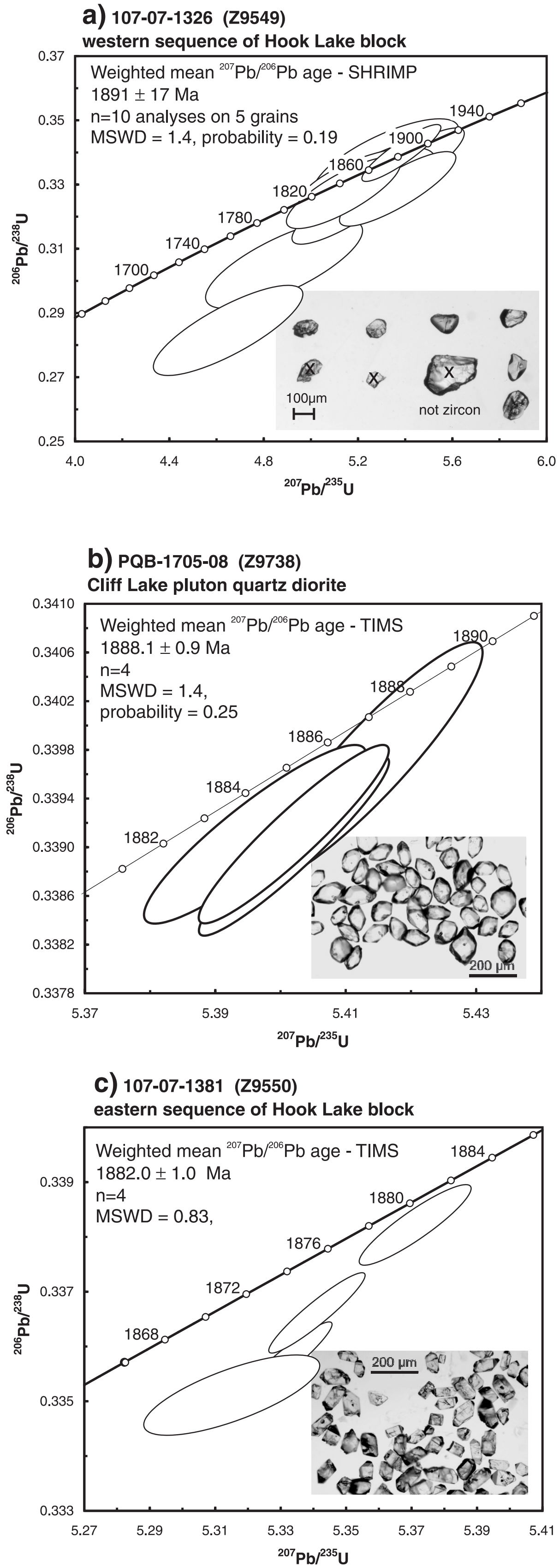


Figure 3. Concordia diagrams of SHRIMP and TIMS results for samples from the Hook Lake area.

error, to the age determined by Stern et al. (1999). While the age of the western sequence of the Hook Lake block is imprecisely constrained, the crosscutting relationship between the quartz diorite and the western sequence would suggest a volcanic package older than 1888 Ma, roughly coeval with the Millrock member in the Flin Flon block.

107–07–1381 (z9550)

A sample of moderately to strongly silicified rhyolite with abundant quartz veining was collected west of Manistikwan Lake (Fig. 1) for comparison with the western sequence and Flin Flon block stratigraphy. Abundant clear, colourless, high quality, prismatic zircons were recovered and mechanically abraded (Fig. 3c, inset). Four multigrain fractions yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1882.0 ± 1.0 Ma (MSWD = 0.83, Fig. 3c) by the ID-TIMS technique, interpreted as the time of crystallization.

Although the large error on the age from the western sequence prevents us from positively correlating the two sequences of the Hook Lake block, the younger age obtained from the eastern sequence clearly demonstrates a significantly different age from the western sequence as well as from dated units in the VMS-hosting Flin Flon block.

CONCLUSIONS

The results presented here address a number of outstanding questions related to the stratigraphy and deformation history of the Flin Flon area in Saskatchewan and Manitoba.

1. The ages of four volcanic units from the Flin Flon block presented in this report suggest that ca. 1890 Ma is the dominant age of volcanism and possibly VMS mineralization in the Flin Flon area. The significance of the1903 Ma age for the Flin Flon Mine rhyolite (Stern et al. 1999) is now unclear.
2. A 1872 Ma folded felsic dyke confirms an early, pre-Missi Group generation of deformation. Post-Missi Group deformation consists of multiple episodes. Two felsic dykes independently indicate that post-Missi folding and shearing occurred after 1840 Ma. These results permit an interpretation of coeval thrusting and shearing.
3. An imprecise age from a rhyolite from the western sequence of the Hook Lake block prevents us from positively correlating it with the Flin Flon block. However, geochemical similarities, as well as a minimum age of 1888 Ma from the crosscutting Cliff Lake pluton, are consistent with coeval volcanism in the two blocks.
4. The younger (1881 Ma) age obtained from the eastern sequence of the Hook Lake block clearly demonstrates that this sequence is distinct from western sequence and the Flin Flon block.

ACKNOWLEDGMENTS

The geological underpinning of this report is the careful mapping of the Flin Flon area by Renee-Luce Simard (Manitoba Geological Survey), Kate MacLachlan (Saskatchewan Mines, Energy and Resources), Sally Pehrsson (GSC), Harold Gibson (Laurentian University) and Bruno Lafrance (Laurentian University). Kelly Gilmore at HudBay Minerals is thanked for access to samples and providing supporting documentation. Expert analytical work in the Geological Survey of Canada's Geochronology Laboratories was carried out by Diane Bellerive, Linda Cataldo, Carole Lafontaine and Tom Pestaj. The manuscript benefited from critical reviews by Kate MacLachlan, Renee-Luce Simard, Sally Pehrsson and Paul Kremer.

REFERENCES

Ansdell, K.M., 1993. U-Pb constraints on the timing and provenance of fluvial sedimentary rocks in the Flin Flon and Athapapuskow basins, Flin Flon belt, Trans-Hudson Orogen, Manitoba and Saskatchewan; *in* Radiogenic age and isotopic studies, report 7. Geological Survey of Canada, Paper 93–2, p. 49–57.

Bailes, A.H. and Syme, E.C., 1989. Geology of the Flin Flon–While Lake area. Manitoba Energy and Mines, Geological Report GR87–1, 313 p.

Bailey, K.A., 2006. Emplacement, petrogenesis and volcanic reconstruction of the intrusive and extrusive Myo rhyolite complex, Flin Flon and Creighton, Saskatchewan; M.Sc. thesis, Laurentian University, Sudbury, Ontario, 124 p.

Bray, D., 2002. The geology and geochemistry of the South Main Rhyolite Complex, Flin Flon, Manitoba; B.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 52 p.

David, J. and Syme, E.C., 1994. U-Pb geochronology of the late Neoarchean tonalites in the Flin Flon belt, Trans-Hudson orogen: Surprise at the surface; Canadian Journal of Earth Sciences, v. 31, p. 1785–1790.

David, J., Machado, N., Bailes, A., and Syme, E., 1993. U-Pb geochronology of the Proterozoic Flin Flon Belt – Snow Lake belt: new results; *in* Proceedings, Lithoprobe Trans-Hudson Orogen Transect workshop. Lithoprobe Report 34, p. 84–87.

Devine, C.A., 2003. Origin and emplacement of volcanogenic massive sulphide-hosting, Paleoproterozoic volcaniclastic and effusive rocks within the Flin Flon subsidence structure, Manitoba and Saskatchewan, Canada; M.Sc. thesis, Laurentian University, Sudbury, Ontario, 279 p.

Devine, C.A., Gibson, H.L., Bailes, A.H., MacLachlan, K., Gilmore, K., and Galley, A.G., 2002. Stratigraphy of volcanogenic massive sulphide–hosting volcanic and volcaniclastic rocks of the Flin Flon formation, Flin Flon (NTS 63 K12 and 13), Manitoba and Saskatchewan; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p.9–19.

DeWolfe, Y.M., 2008. Physical volcanology, petrology and tectonic setting of intermediate and mafic volcanic and intrusive rocks in the Flin Flon volcanogenic massive sulfide (VMS) district, Manitoba, Canada: growth of a Paleoproterozoic juvenile arc; Ph.D. thesis, Laurentian University, Sudbury, Ontario, .

DeWolfe, Y.M. and Gibson, H.L., 2005. Physical description of the Bomber, 1920 and Newcor members of the Hidden formation, Flin Flon, Manitoba (NTS 63 K 16SW); *in* Report of Activities 2005, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 7–19.

DeWolfe, Y.M. and Gibson, H.L., 2006. Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 22–34.

Gordon, T.M., Hunt, P.A., Bailes, A.H., and Syme, E.C., 1990. U-Pb ages from the Flin Flon and Kisseynew belts, Manitoba: chronology of crust formation at an Early Proterozoic accretionary margin*; in* The Early Proterozoic Trans-Hudson Orogen of North America, (ed.) J.F. Lewry and M.R. Stauffer; Geological Association of Canada, Special Paper 37, p. 177–199.

Heaman, L.M., Kamo, S.L., Ashton, K.E., Delaney, G.D., Harper, C.T., Reilly, B.A., Sibbald, T.I.I., Slimmon, W.L., and Thomas, D.J., 1992. U-Pb geochronological investigations in the Trans-Hudson Orogen, Saskatchewan; *in* Summary of Investigations 1992, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 92–4, p. 120–123.

Kremer, P.D. and Simard, R.-L., 2007. Geology of the Hook Lake Block, Flin Flon area, Manitoba (part of NTS 63 K/12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 21–32.

Krogh, T.E., 1982. Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique; Geochimica et Cosmochimica Acta, v. 46, p. 637–649. doi:10.1016/0016-7037(82)90165-X

Ludwig, K.R., 2003. User's manual for Isoplot/Ex rev. 3.00: a Geochronological toolkit for Microsoft Excel, Special Publication 4, Berkeley Geochronology Center, Berkeley, 70 p.

MacLachlan, K. and Devine, D., 2007. Stratigraphic evidence for volcanic architecture in the Flin Flon Mining Camp: implications for mineral exploration; *in* Summary of Investigations 2007, Volume 2, Saskatchewan Geological Survey, Saskatchewan Ministry and Energy and Resources, Miscellaneous Report 2007-4.2, CD-ROM, Paper A-1, 29 p.

MacQuarrie, R., 1980. Absolute age of the Flin Flon deposit; Canadian Mining and Metallurgical Bulletin, v. 73, p. 53 (abstract).

Mattinson, J.M., 2005. Zircon U–Pb chemical abrasion ("CA-TIMS") method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages; Chemical Geology, v. 220, p. 47–66. doi:10.1016/j.chemgeo.2005.03.011

Parrish, R.R., Roddick, J.C., Loveridge, W.D., and Sullivan, R.W., 1987. Uranium - lead analytical techniques at the Geochronology Laboratory, Geological Survey of Canada; *in* Radiogenic Age and Isotopic Studies: Report 1; Geological Survey of Canada, Paper 87–02, p. 3–7.

Simard, R.-L. and Creaser, R.A., 2007. Implications of new geological mapping, geochemistry and Sm-Nd isotope data, Flin Flon area, Manitoba (part of NTS 63 K/12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 7–20.

Simard, R.-L., MacLachlan, K., Gibson, H.L., DeWolfe, Y.M., Devine, C., Kremer, P.D., Lafrance, B., Ames, D.E., Syme, E.C., Bailes, A.H., Bailey, K., Price, D., Pehrsson, S., Cole, E., Lewis, D., and Galley, A.G., 2009: Geology of the Flin Flon area, Manitoba and Saskatchewan (part of NTS 63/K12, 13); Manitoba Science, Innovation, Energy and Mines, Manitoba Geological Survey, Geoscientific Map 2009-1, scale 1:10 000 (also Saskatchewan Ministry of Energy and Resources, Geoscience Map 2009-1).

Stacey, J.S. and Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two stage model; Earth and Planetary Science Letters, v. 26, p. 207–221. doi:10.1016/0012-821X(75)90088-6

Stern, R.A., 1997: The GSC Sensitive High Resolution Ion Microprobe (SHRIMP): analytical techniques of zircon U-Th-Pb age determinations and performance evaluation. Radiogenic Age and Isotopic Studies, Report 10, Geological Survey of Canada, Current Research 1997-F, p. 1–31.

Stern, R.A. and Amelin, Y., 2003. Assessment of errors in SIMS zircon U-Pb geochronology using a natural zircon standard and NIST SRM 610 glass; Chemical Geology, v. 197, p. 111–146. doi:10.1016/S0009-2541(02)00320-0

Stern, R.A. and Lucas, S.B., 1994: U-Pb age constraints on the early tectonic history of the Flin Flon accretionary collage, Saskatchewan. *In* Radiogenic age and isotopic studies, report 8. Geological Survey of Canada, Paper 94-F, p. 75–86.

Stern, R.A., Machado, N., Syme, E.C., Lucas, S.B., and David, J., 1999. Chronology of crustal growth and recycling in the Paleoproterozoic Amisk collage (Flin Flon Belt), Trans-Hudson Orogen, Canada; Canadian Journal of Earth Sciences, v. 36, p. 1807–1827. doi:10.1139/cjes-36-11-1807

Syme, E.C. 1997. Geology of the Millrock Hill area, Creighton; Manitoba Energy and Mines, Open File Map OF97–6, scale 1:400.

Syme, E.C., Hunt, P.A., and Gordon, T.M., 1991. Two U-Pb ages from the western Flin Flon belt, Trans-Hudson orogen, Manitoba; *in* Radiogenic age and isotopic studies, report 4, Geological Survey of Canada, Paper 90–2, p.25–34.

Syme, E.C., Lucas, S.B., Bailes, A.H., and Stern, R.A., 1999. Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences, v. 36, p. 1767–1788. doi:10.1139/cjes-36-11-1767

Whalen, J.B. and Hunt, P.A., 1994. Geochronological study of granitoid rocks in the Elbow Lake Sheet (NTS 63 K/15), Manitoba: a portion of the Flin Flon Domain of the Paleoproterozoic Trans-Hudson Orogen; *in* Radiogenic age and isotopic studies, report 8. Geological Survey of Canada, Paper 94-F, p. 87–96.

Geological Survey of Canada Project X91