Current Research (2002) Newfoundland Department of Mines and Energy
Geological Survey, Report 02-1, pages 169-183

LASER ABLATION ICP-MS GEOCHRONOLOGY AND PROVENANCE OF DETRITAL ZIRCONS FROM THE ROGERSON LAKE CONGLOMERATE, BOTWOOD BELT, NEWFOUNDLAND

J.C. Pollock, D.H.C. Wilton, C.R. van Staal[1] and M.N. Tubrett
Department of Earth Sciences, Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X5

ABSTRACT

Using heavy-mineral fractions, especially zircon, found in clastic sedimentary rocks is an important method in investigating zircon (sediment) provenance and depositional history. Zircon is the mineral of choice for geochronological determinations due to its relative uptake of U vs. Pb at the time of crystallization. The spectra of the U–Pb zircon ages measured will yield information regarding the ages of material in the source region, and can help to identify the direction of detrital transport. In this study, new geochronological data is presented from detrital zircons sampled in the Rogerson Lake Conglomerate, in central Newfoundland.

The new data from the two samples indicate that the age spectra in these Rogerson Lake Conglomerate rocks is dominated by Paleozoic zircons with some Mesoproterozoic input; over 80 percent of the zircons have Paleozoic ages between 550 and 420 Ma; most alternate between 510 to 490 Ma. These ages correspond well with the ages of Exploits arc–back-arc volcanic sequences in the Victoria Lake supergroup that are unconformable beneath the Rogerson Lake Conglomerate. The conglomerate detritus also contains zircon populations that are Ordovician (480 to 440 Ma). The source of these grains is most likely the adjacent rocks of the Notre Dame arc.

A small quantity of zircons from the Laurentian basement were also analyzed. Neoproterozoic age groups (890, 1030 and 1250 Ma) correspond with rocks of the Grenville Orogen, while the middle Mesoproterozoic ages (ca. 1500) are correlated with basement gneisses of the Grenville Orogen, western Newfoundland. The high proportion of Paleozoic zircons relative to Proterozoic grains is presumably the result of Middle Ordovician exhumation of the Notre Dame arc and its subsequent collision and accretion to Laurentia. The LAM-ICP-MS technique represents an appropriate method to rapidly date a large number of detrital zircons for the purpose of sediment provenance studies.

INTRODUCTION

The analysis of heavy-mineral fractions, particularly zircons, in clastic sedimentary rocks is an important method in investigating their sedimentological history and can be used to fingerprint sediment sources and depositional environments. Zircon ($ZrSiO_4$) is a common accessory mineral in most rocks and is a frequently studied component of detrital assemblages because it is extremely resistant to chemical weathering and physical breakdown during transport. Zircon is also a mainstay for geochronological determinations due to its extremely high U/Pb ratio at the time of formation and the ability of the zircon crystal to retain the daughter products of U and Th radioactive decay. The range and frequency of U–Pb ages measured on detrital zircon populations yields information relating to the ages of igneous crustal elements in the source region and the clastic transport pathway. This becomes especially important in sedimentary sequences that lack distinct stratigraphic horizons, individual biostratigraphical marker beds and dateable crosscutting intrusions. Preliminary geochronological data is presented from detrital zircons in the Rogerson Lake Conglomerate in central Newfoundland in order to determine the maximum deposition age and sediment provenance of the conglomerate.

When using heavy-mineral fractions such as zircon for sediment provenance studies, knowledge of the geology and

[1] Continental Geoscience Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A OE8

geochronology of potential source regions is essential. Along the Newfoundland Appalachian margin, crustal growth occurred during two periods that are summarized according to a model of multiple ocean-closing cycles. The North American Atlantic margin comprises two collisional orogens and a modern continental margin. The collisional orogens are the Grenville, which developed along the southeastern margin of Laurentia, ca. 1300 to 900 Ma and led to the formation of the supercontinent Rodinia (Hoffman, 1988). Rifting of this supercontinent to form the Laurentian margin and Iapetus Ocean was initiated between 590 and 500 Ma (van Staal *et al.*, 1998). The subsequent closure of Iapetus (ca. 500 to 300 Ma) and collision of Laurentia and Gondwana led to the development of the Appalachian Orogen. The Atlantic continental margin (250 Ma to present) lies seaward of both the Grenville and Appalachian orogens (Williams *et al.*, 1999).

REGIONAL GEOLOGY

The Newfoundland Appalachians (Figure 1) are characterized by a series of Paleozoic accretionary and collisional events that involved a series of island arcs and back-arc basins with associated microcontinents. The present configuration of these Cambro-Devonian sequences in central and western Newfoundland reflects events during the closure of the Iapetus Ocean, during which outboard terranes were accreted to the Laurentian continental margin. The boundaries between the early accreted terranes are soft structural zones marked by ophiolites and melanges formed through head-on collision. By the Late Silurian, rocks from the opposed Godwanan margin rocks were accreted to the Laurentian margin, although their relative spatial configurations were probably modified by later transcurrent faulting related to oblique convergence.

The Dunnage Zone is separated on the basis of geochemical, metallogenic, geochronological, paleontological and geophysical parameters into two subzones, the Notre Dame and Exploits subzones (Williams *et al.*, 1988). These subzones are separated by an extensive fault system, the Red Indian Line, which is a major tectonic boundary that is traceable across Newfoundland. It has been suggested that the two subzones were developed on opposing sides of the Iapetus Ocean (van Staal *et al.*, 1998) and were not linked until the Llanvirn.

The Victoria Lake supergroup (Evans and Kean, 2002) is a composite and structurally complex collection of volcanic, volcaniclastic and epiclastic rocks having varying ages, geochemical signatures and tectonic environments (Figure 2). The supergroup consists of mafic pillow lava, mafic and felsic pyroclastic rocks, chert greywacke and shale, which formed in a variety of island-arc, rifted-arc, back-arc and mature-arc settings. The Victoria Lake supergroup has been divided into two major volcanic units, viz., the Tally Pond group and Tulks belt (Kean, 1985), which are unconformably overlain by the Rogerson Lake Conglomerate along its southeastern contact, although this contact is generally sheared and faulted.

The Rogerson Lake Conglomerate lies within the middle Paleozoic Botwood Belt of the Newfoundland Appalachians (Figure 1). The Botwood Belt consists of a 300-km-long, up to 55-km-wide northeast-trending sequence of mainly Silurian terrestrial volcanic rocks overlain by fluviatile red, green and grey crossbedded sandstones. Polymictic conglomerates occur along the western margin of the belt. Red beds and volcanic rocks of the Botwood Belt are identical to those of the Cape Ray and Springdale belts (Chorlton *et al.*, 1995). Botwood Belt rocks overlie Lower Paleozoic sequences of the Exploits Subzone of the Dunnage Zone.

The Rogerson Lake Conglomerate is a northeast-trending unit that extends for over 100 km from the Burgeo Road to Sandy Lake. The conglomerate unconformably overlies the Tally Pond Group and is nonconformable on the Crippleback Lake Quartz Monzonite. The unit consists of conglomerate, sandstone, siltstone and shale (Kean and Jayasinghe, 1980). Conglomerate is dominant in the Tally Pond area, and is red to purple, with pebble-sized clasts in a matrix of red sandy material. The matrix consists of quartz, feldspar, muscovite and chlorite having hematite and carbonate cement. The varied clast population includes subrounded to rounded clasts of red siltstone, sandstone, shale, quartz, limestone and granitic rocks; mafic flows and porphyritic rhyolite clasts are abundant. Ilmenite, zircon and tourmaline occur in accessory amounts. Sedimentary structures are rare and grain-size variations between silt and sand layers are sharp and well defined (Kean and Jayasinghe, *op. cit.*).

DETRITAL ZIRCON SAMPLES

Two 10-kg samples of the Rogerson Lake Conglomerate were collected for detrital zircon analysis. These samples were subsequently reduced to about 3 to 4 kg by selecting unweathered portions of rock that are representative of the unit. One sample was from a pebble conglomerate of the Cape Ray Belt that outcrops on the Burgeo Highway, and another sample was collected from the type area in the Botwood Belt, at the south shore of Rogerson Lake (Plate 1). Zircons were extracted at Memorial University using conventional mineral separation techniques (crushing, Wilfley table, heavy liquids) from the least magnetic split obtained with a Frantz isodynamic separator. The zircons were then hand-picked in alcohol under a binocular microscope. About

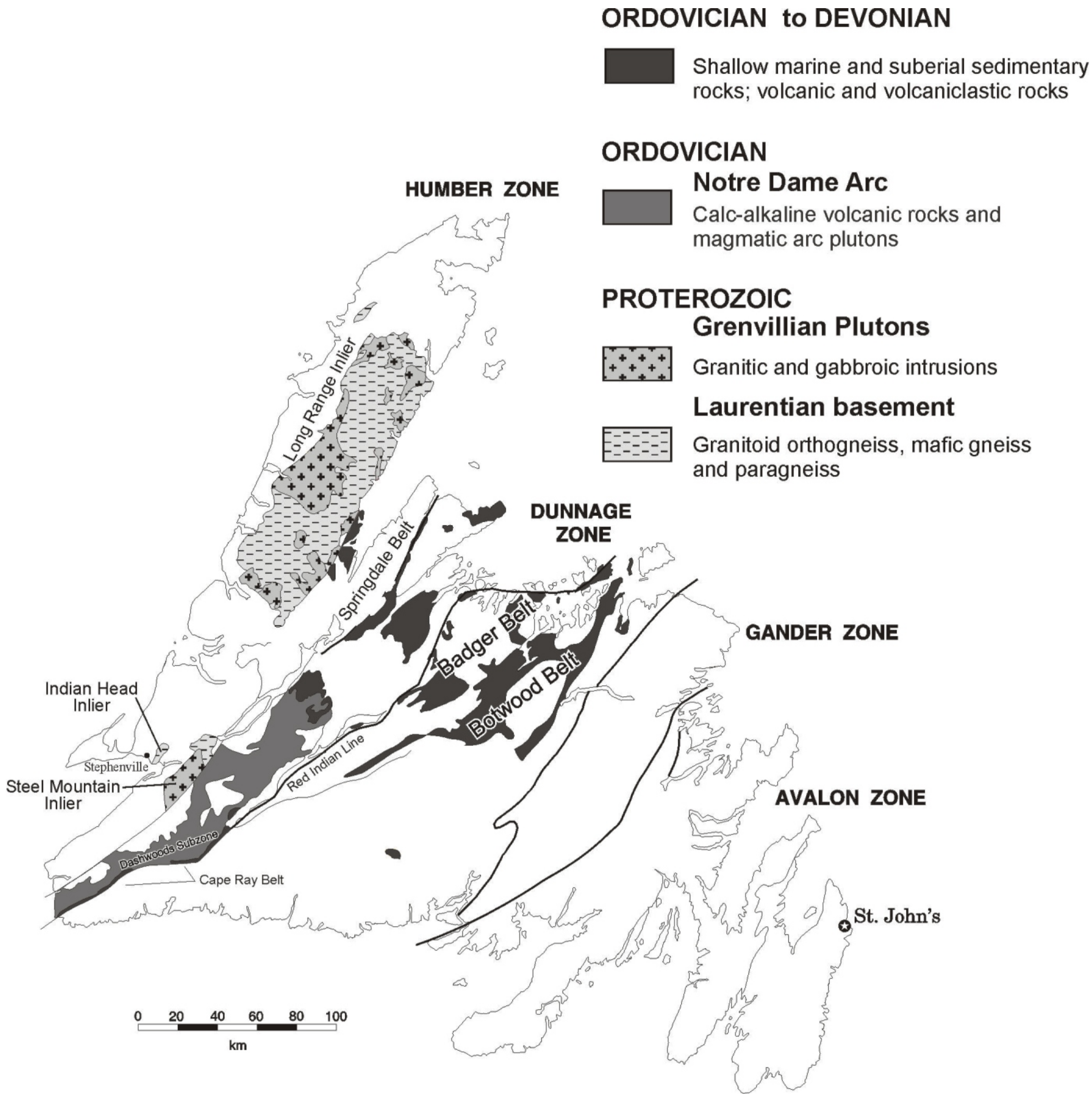

Figure 1. *Location of Proterozoic inliers and middle Paleozoic belts of the Newfoundland Appalachians.*

150 zircons were selected and then separated into populations based on morphology and colour. The Rogerson Lake sample (#71) consisted of a single zircon population (50 zircons) consisting of grains that were clear and colourless having euhedral to subhedral shapes. The sample from the Burgeo Highway (#72) contained two zircon populations containing about 50 grains each, zircons that are euhedral, clear and colourless, and grains that are slightly rounded, clear and slightly reddish in colour (Plate 2). Some of the zircon grains from each of the two samples contain internal cracks and fissures in addition to zircon rims and cores (Plate 3b). The zircons were mounted with epoxy in 2.5 cm diameter grain mounts and polished to expose even surfaces at the cores of the grains for analysis.

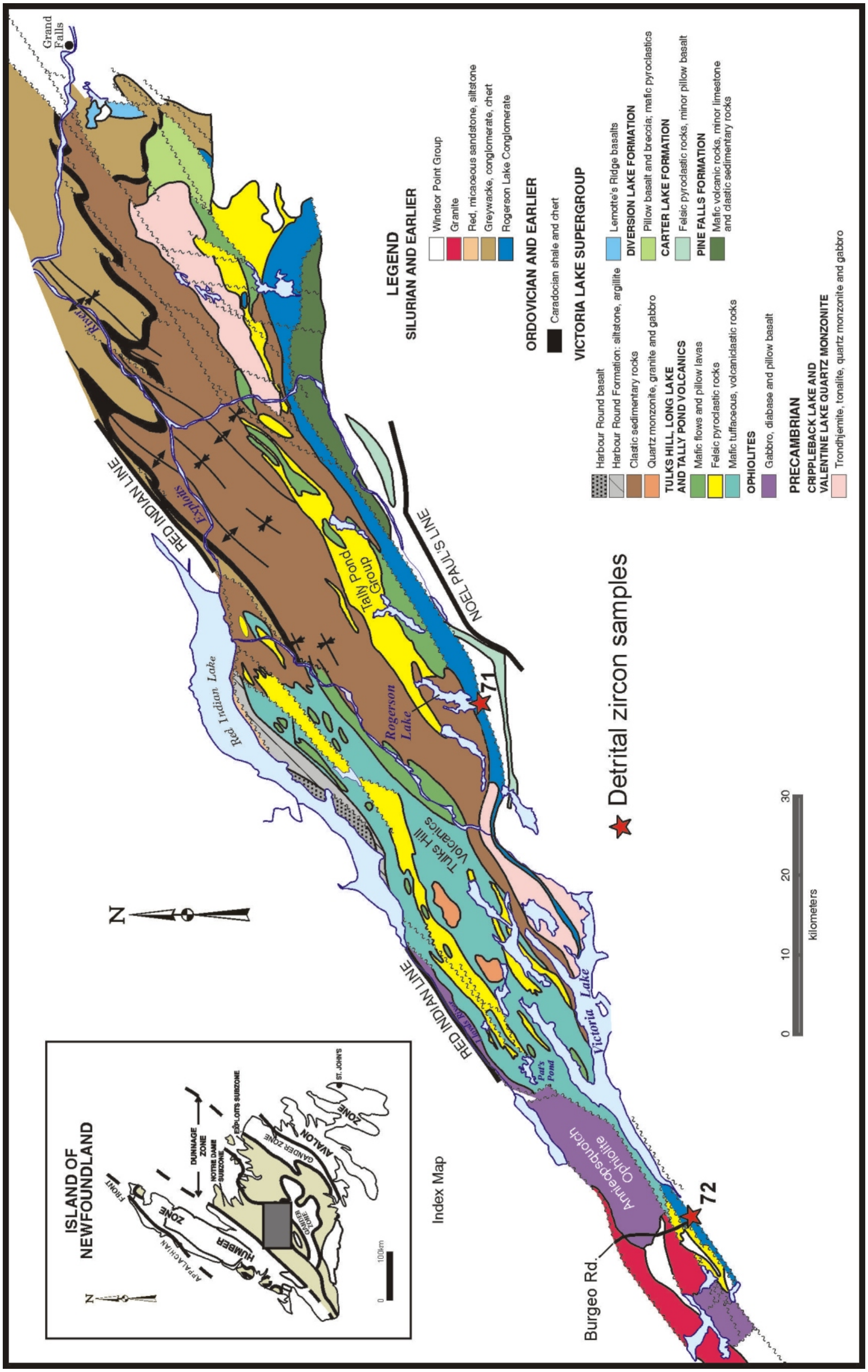

Figure 2. *Geology of the Victoria Lake supergroup and adjoining sequences (after Kean and Evans, 2002).*

Plate 1. *Polymictic Rogerson Lake Conglomerate collected from the type area along the southern shore of Rogerson Lake.*

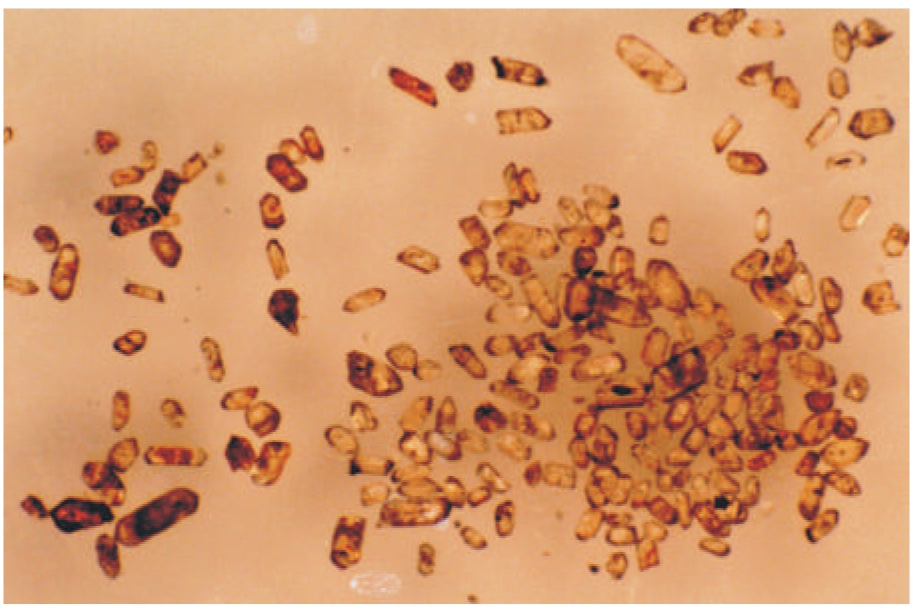

Plate 2. *Photomicrograph of detrital zircons obtained from the Rogerson Lake Conglomerate at Burgeo Road.*

ANALYTICAL METHODS

The U–Pb method followed is that described by Kosler *et al.* (*in press*). Laser Ablation Microprobe-Inductively Coupled Plasma-Mass Spectrometry (LAM-ICP-MS) analyses were performed in the Department of Earth Sciences at Memorial Univeristy, using a VG PlasmaQuad 2 S+ mass spectrometer coupled to an in-house custom-built Q switched Nd:YAG ultraviolet laser operating with a wavelength of 266 nm. Zircons were ablated using a laser repetition rate of 10Hz and a laser energy of 0.8 mJ/pulse. The laser beam was focussed 100 µm above the sample surface and reduced to a diameter of 10 to 20 µm by masking with a white Teflon® aperture. The sample cell was mounted on a computer driven motorized stage on the microscope. The computer-driven stage was moved beneath the stationary laser to produce a rectangular pit of variable length, usually in the range of 20 to 40 µm, in order to match zircon crystal size (Plate 4). The depth of the pit varied from ca. 10 to 50 µm depending on line/pit length and ablation time.

Using He as a carrier gas, the ablated sample material was transported, via acid-washed plastic tubing, from the sample cell to the ICP-MS. Data was acquired to allow measurement of the U/Pb and Pb isotopic ratios in detrital zircons, as well as the isotopic ratios in the Tl/Bi/Np tracer solution that was nebulized simultaneously with the laser ablated solid sample. The tracer solution contained natural Tl (^{205}Tl/^{203}Tl=2.3871), ^{209}Bi and ^{237}Np at concentrations of approximately 10 ppb for each isotope.

Typical time-resolved data acquisitions consisted of ca. 60 s measurements of the He gas blank and tracer solution signals just before the start of ablation, as well the U and Pb zircon ablation signal, along with the simultaneous Tl/Bi/Np solution signal were acquired for another 180 to 200 s. The data were acquired in peak jumping-pulse counting mode with 1 point measured per peak using PQVision v. 4.30 software. In total 11 masses were measured, 201 (flyback), 203 (Tl), 204 (Pb), 205 (Tl), 206 (Pb), 207 (Pb), 209 (Bi), 237 (Np) and 238 (U) and oxides of Np (^{237}Np^{16}O = 254) and U (^{238}U^{16}O = 254) were monitored to correct for oxide formation. Quadrupole settling time was 1 ms for all masses and the dwell time was 8.3 ms for all masses except for mass 207 where it was 24.9 ms. Over the 240 seconds of measurement approximately 1600 data

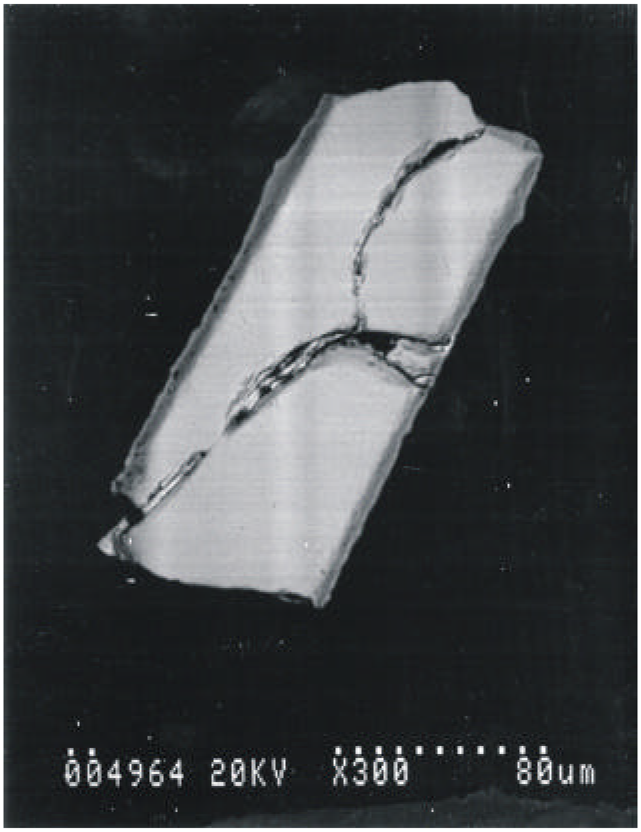

Plate 3. *Scanning electrom micrograph of detrital zircons of the Rogerson Lake Conglomerate showing a) internal cracks and fissures; and b) complex rim and core zoning.*

acquisition cycles (sweeps) were collected (Kosler *et al.*, 2001).

DATA REDUCTION

The raw data were corrected for electron multiplier dead time (20 ns) and downloaded to a computer for offline processing using an in-house spreadsheet-utility program. The $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ratios were calculated and blank corrected for each analysis. The natural $^{238}U/^{235}U$ ratio of 137.88 was used to calculate the ^{235}U since it was not acquired with other isotopes due to its low natural abundance. Aspiration of the tracer solution allowed for a real-time instrument mass bias correction using the known isotopic ratios of the tracer solution measured while the sample was ablated; this technique is largely independent of matrix effects that can variably influence measured isotopic ratios and hence the resulting ages (Kosler *et al., in press*). The amount of common Pb present in zircons analysed in this study was insignificant relative to the content of radiogenic Pb and accordingly, no common Pb correction was applied to the data. Accuracy and reproducibility of U–Pb analysis in the Memorial University laboratory are routinely monitored by measurments of natural in-house zircon standards of known TIMS U–Pb age. For this study, zircon 02123 that is 295 ± 1 Ma (Ketchum *et al.*, 2001) was utilized. The average mass bias corrected $^{206}Pb/^{238}U$ value for the zircon standard 02123 (N = 55), taken over the 3 days of this study, was 0.04697. This value is in excellent agreement with the accepted value of 0.046818 (Ketchum *et al.*, 2001). Final ages and concordia diagrams were produced using the Isoplot/Ex macro (Ludwig, 1999) in conjunction with the LAMdate Excel spreadsheet program (Kosler *et al., in press*).

U–Pb RESULTS

SAMPLE 71 – SOUTH SHORE OF ROGERSON LAKE

The U–Pb data for detrital zircons from the Rogerson Lake Conglomerate at Rogerson Lake are listed in Table 1 and plotted on a concordia diagram in Figure 3. The 31 grains analyzed from the sample are split into two groups that are well separated in frequency and age. The data show one major cluster of 30 analyses (a1-a13 and a15-a31) that produced $^{206}Pb/^{238}U$ ages between 407 and 552 Ma (Figure 4). These zircons varied from 1 to almost 80 percent discor-

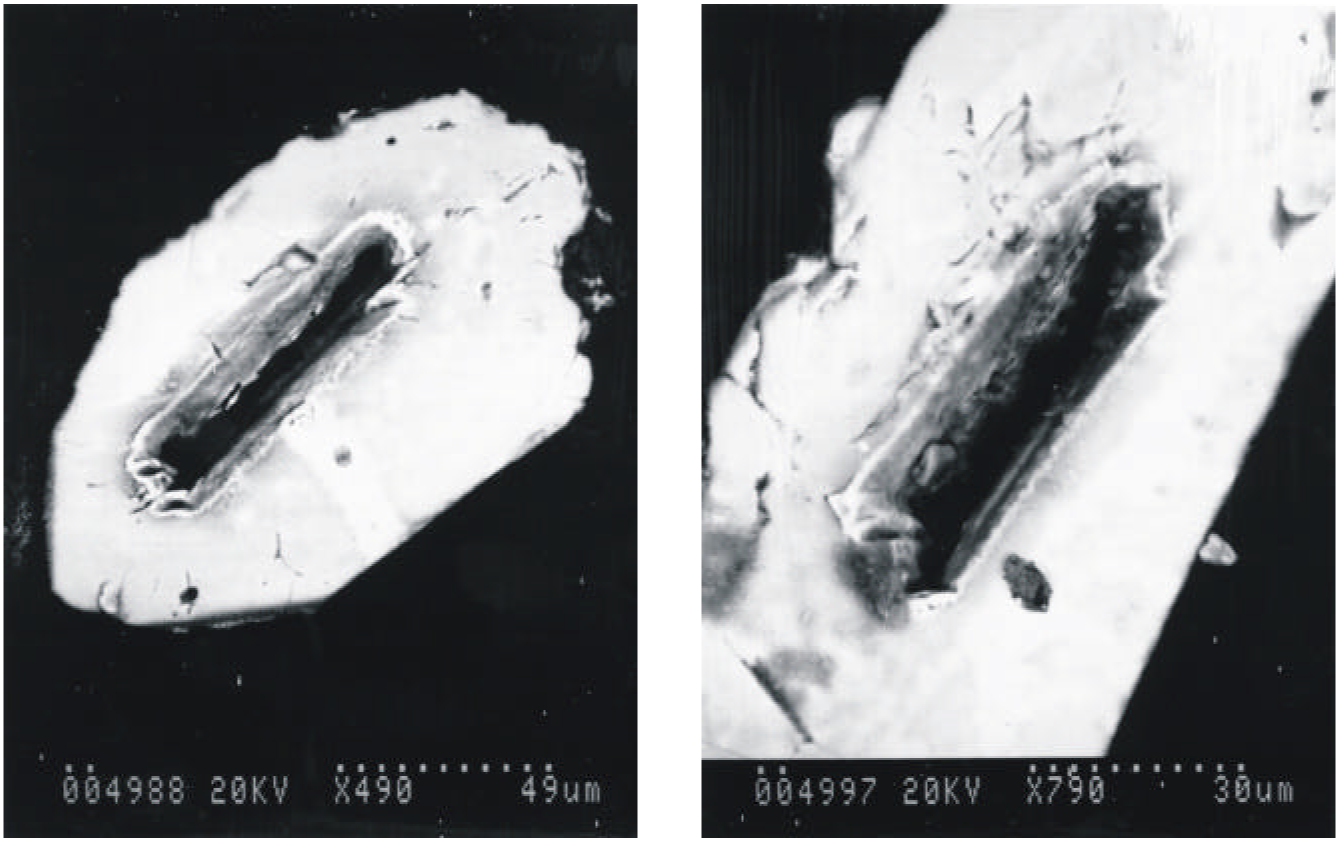

Plate 4. *Scanning electrom micrographs showing line raster-ablation pit in zircon crystal.*

dant and show a concentration of ages at ca. 495 Ma, representing a dominantly Paleozoic zircon source. Although comprising only one grain (a14) that is 23 percent discordant, a minor late Mesoproterozoic component is recognized with a $^{206}Pb/^{238}U$ age of 994 Ma and a $^{207}Pb/^{235}U$ age of 972 Ma. Most of analyses plot either on concordia or slightly above concordia; the negative discordance maybe due to an uncorrected common Pb contamination or an incorrect mass bias correction for some analyses.

SAMPLE 72 –BURGEO HIGHWAY

A total of 80 single detrital zircon grains analyzed from the Burgeo Highway sample include both zircon populations of clear, colourless zircons and clear, red zircons. The data (Table 2) show that no age differences are apparent between detrital zircons of different colour. The distribution of data points in the concordia diagram on Figure 5 and the cumulative probability plot (Figure 6) suggests that the ages of the sample have five maxima. Most of the zircons (70 grains) have $^{206}Pb/^{238}U$ ages between 530 and 419 Ma that vary between 1 to 80 percent discordant. These data show a strong concentration of ages at ca. 500 Ma and a minor concentration of ages in the 480 to 450 Ma range. The second cluster of ages is represented by analyses a1, a2 and a28 with $^{206}Pb/^{238}U$ ages of 759, 698 and 723 Ma, respectively, that are between 6 to 15 percent discordant and bracket the age of the source at ca. 725 Ma.

The presence of Neoproterozoic and late Mesoproterozoic components is indicated by the cluster of zircon analyses at ages of 890 and 1030 Ma. Zircons a18, a43 and a66 are between 4 and 20 percent discordant and have ages between 838 and 915 Ma. Two analyses (a23 and a31) produced ages of 1079 and 1016 Ma that are 27 and 9 percent discordant, respectively. Middle Mesoproterozoic ages of 1240 and 1480 Ma are represented by three analyses (a38, a40, a68). Zircon a68 has a $^{206}Pb/^{238}U$ age of 1244 Ma and a $^{207}Pb/^{235}U$ age of 1233 Ma; the analysis lies close to concordia and is 7 percent discordant. Analyses a38 and a40 produced $^{206}Pb/^{238}U$ ages of 1469 and 1487 Ma and $^{207}Pb/^{235}U$ ages of 1481 and 1514, respectively. These ages are 2 and 8 percent discordant and indicate the age of the zircon component is approximately 1480 Ma.

DISCUSSION

The new data from the two samples of the Rogerson Lake Conglomerate indicate that the age spectra in these rocks is dominated by Paleozoic zircons with minor Meso-

Table 1. Laser ablation U–Pb data and calculated ages for detrital zircons from the Rogerson Lake Conglomerate at Rogerson Lake (Sample 71)

	CONCORDIA COLUMNS							2 σ %	2 σ %	2 σ %			Ages Ma	
Analyses	$^{207}Pb/^{235}U$	$^{207}Pb/^{235}U$ err	$^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$ err	Rho	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ err	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{235}U$ age	1 σ	$^{206}Pb/^{238}U$	1 σ
a1	0.5533	0.0641	0.0866	0.0035	0.95	0.0617	0.0018	23.19	8.08	5.85	447.2	41.9	**535.3**	± 21
a2	0.7905	0.0717	0.0850	0.0031	0.95	0.0766	0.0023	18.14	7.22	5.96	591.5	40.7	**525.7**	± 18
a3	0.5361	0.0371	0.0835	0.0029	0.95	0.0578	0.0014	13.84	6.96	4.83	435.8	24.5	**517.2**	± 17
a4	0.5280	0.0417	0.0775	0.0022	0.95	0.0643	0.0016	15.79	5.73	4.91	430.5	27.7	**481.1**	± 13
a5	0.6039	0.0466	0.0864	0.0031	0.95	0.0652	0.0016	15.43	7.10	4.85	479.7	29.5	**534.1**	± 18
a6	0.5769	0.0243	0.0767	0.0019	0.95	0.0574	0.0008	8.44	4.92	2.72	462.4	15.7	**476.6**	± 11
a7	0.7509	0.1118	0.0895	0.0056	0.95	0.0860	0.0035	29.77	12.57	8.15	568.8	64.8	**552.6**	± 33
a8	0.4984	0.0349	0.0769	0.0024	0.95	0.0547	0.0011	14.00	6.29	4.05	410.6	23.6	**477.3**	± 14
a9	0.6095	0.0308	0.0792	0.0026	0.95	0.0566	0.0010	10.11	6.61	3.46	483.2	19.4	**491.6**	± 15
a10	0.5139	0.0580	0.0749	0.0031	0.95	0.0597	0.0026	22.59	8.19	8.75	421.1	38.9	**465.5**	± 18
a11	0.6297	0.0380	0.0832	0.0024	0.95	0.0585	0.0013	12.08	5.73	4.52	495.9	23.7	**515.2**	± 14
a12	0.6150	0.0334	0.0785	0.0030	0.95	0.0583	0.0009	10.85	7.62	3.07	486.7	21.0	**487.1**	± 18
a13	0.6004	0.0363	0.0800	0.0034	0.90	0.0562	0.0016	12.08	8.52	5.70	477.5	23.0	**495.8**	± 20
a14	1.6061	0.1367	0.1667	0.0075	0.70	0.0844	0.0053	17.03	8.95	12.52	972.6	53.3	**994.0**	± 41
a15	0.5033	0.0640	0.0737	0.0046	0.96	0.0625	0.0043	25.42	12.50	13.76	413.9	43.2	**458.2**	± 28
a16	0.6717	0.0466	0.0883	0.0037	0.95	0.0613	0.0015	13.87	8.32	4.85	521.8	28.3	**545.5**	± 22
a17	0.7935	0.1001	0.0881	0.0043	0.95	0.1017	0.0040	25.23	9.82	7.90	593.2	56.7	**544.2**	± 26
a18	0.5339	0.0394	0.0779	0.0029	0.95	0.0581	0.0014	14.77	7.38	4.83	434.4	26.1	**483.8**	± 17
a19	0.5540	0.0296	0.0818	0.0021	0.95	0.0554	0.0012	10.69	5.22	4.18	447.6	19.3	**506.6**	± 13
a20	0.5481	0.0785	0.0880	0.0050	0.95	0.0617	0.0021	28.65	11.38	6.90	443.8	51.5	**543.8**	± 30
a21	0.6981	0.0465	0.0842	0.0042	0.92	0.0585	0.0017	13.32	9.89	5.65	537.7	27.8	**521.1**	± 25
a22	0.5343	0.0492	0.0772	0.0029	0.95	0.0731	0.0021	18.43	7.61	5.82	434.7	32.6	**479.4**	± 18
a23	0.4447	0.0738	0.0652	0.0059	0.95	0.0591	0.0012	33.18	18.23	4.21	373.5	51.9	**407.2**	± 36
a24	0.4867	0.0371	0.0780	0.0035	0.95	0.0517	0.0016	15.25	8.86	6.21	402.6	25.3	**484.5**	± 21
a25	0.5781	0.0356	0.0745	0.0023	0.95	0.0619	0.0010	12.31	6.30	3.33	463.2	22.9	**463.3**	± 14
a26	0.6654	0.0703	0.0828	0.0041	0.99	0.0737	0.0042	21.12	9.95	11.45	517.9	42.8	**512.9**	± 25
a27	0.6195	0.0796	0.0777	0.0042	0.95	0.0746	0.0030	25.69	10.71	8.02	489.5	49.9	**482.4**	± 25
a28	0.5487	0.0547	0.0743	0.0040	0.60	0.0659	0.0053	19.93	10.65	16.02	444.1	35.8	**462.1**	± 24
a29	0.6024	0.0497	0.0752	0.0027	0.95	0.0636	0.0027	16.51	7.18	8.59	478.7	31.5	**467.3**	± 16
a30	0.6211	0.0396	0.0803	0.0033	0.95	0.0577	0.0009	12.74	8.24	3.26	490.5	24.8	**497.6**	± 20
a31	0.5145	0.0321	0.0758	0.0025	0.83	0.0530	0.0021	12.46	6.67	7.89	421.5	21.5	**471.3**	± 15
a32	0.5905	0.0298	0.0789	0.0024	0.95	0.0584	0.0011	10.11	6.07	3.85	471.2	19.0	**489.5**	± 14

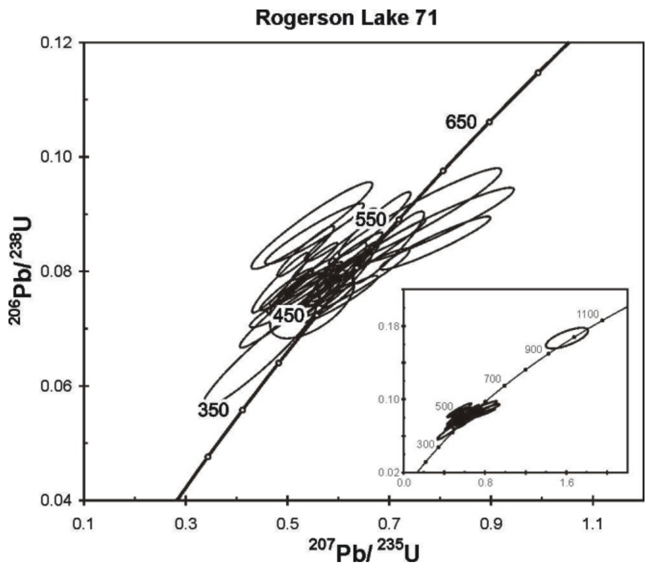

Figure 3. *Concordia diagram showing data points measured on detrital zircons from the Rogerson Lake Conglomerate (Sample 71), Rogerson Lake, for the ca. 500 Ma range. The inset shows a detailed concordia plot for the whole range.*

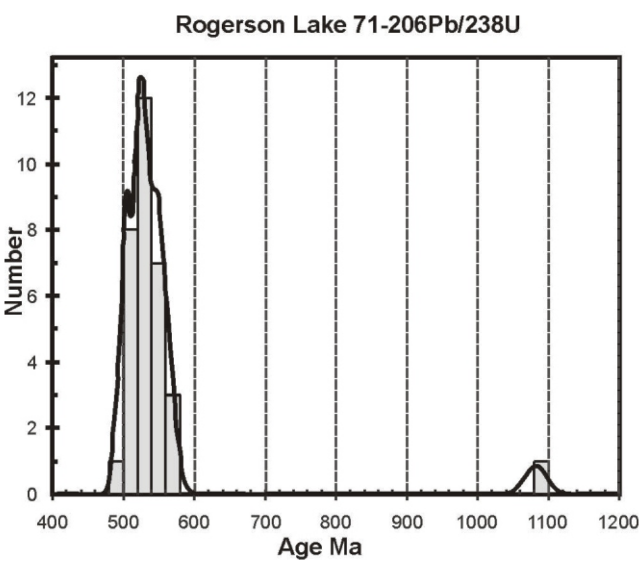

Figure 4. *Cumulative probability plot of detrital zircons from the Rogerson Lake Conglomerate (Sample 71).*

proterozoic input. Both conglomerate samples contain over 80 percent zircons that have Paleozoic ages of between 552 and 419 Ma; however the majority of these grains have an age in the 510 to 490 Ma range. These ages correspond well with the ages of Exploits arc–back-arc volcanic sequences in the Victoria Lake supergroup that are unconformable beneath the Rogerson Lake Conglomerate. Zircons derived from two rhyolite samples of the Tally Pond group have yielded identical U–Pb ages of 513 ± 2 Ma (Dunning *et al.*, 1991) and dating of a subvolcanic porphyry of the Tulks belt yielded a Tremadocian age of 498 +6/-4 Ma (Evans *et al.*, 1990). A coeval quartz monzonite intrusion in the Tulks belt also yielded a Tremadocian age of 495 ± 2 Ma (Evans *et al.*, 1990). Therefore, the volcanic sequences represented by the Victoria Lake supergroup (the Tally Pond group and Tulks belt) represent the major component in the sediment source to the Rogerson Lake Conglomerate.

The Rogerson Lake Conglomerate detritus also contains zircon populations that are Ordovician, approximately 480 to 440 Ma. The source of these grains is most likely the adjacent rocks of the Notre Dame arc. This arc is a collection of Arenig to Llanvirn calc-alkaline volcanic rocks intruded by Lower to Upper Ordovician (488 to 456 Ma) magmatic arc plutons (van Staal *et al.*, 1998), represented by the Dashwoods Subzone. The Dashwoods Subzone is located west of the Cape Ray Belt and consists of medium- to high-grade metamorphic rocks cut by tonalites and granites. The Cape Ray Granite and Cape Ray Tonalite from the Dashwoods Subzone have been dated by U–Pb zircon geochronology and yielded ages of 488 ± 3 Ma and 469 ± 2 Ma, respectively (Dubé *et al.*, 1996). A deformed volcanic rock from the Windsor Point Group yielded a U–Pb zircon age of 453 +5/-4 Ma. The Windowlass Hill Granite, a pretectonic S-type granite, has been dated at 424 ± 2 Ma (Dubé *et al.*, 1996).

The three detrital zircons ages in the ca. 725 Ma range do not correlate with any known rocks in the Laurentian basement or Notre Dame arc sequences. However, these ages may be related to the earliest stages of Iapetan rifting along the Laurentian Margin. Wanless *et al*. (1968) reported an igneous crystallization K–Ar age of 761 ± 100 Ma for mafic dykes of the Long Range Dyke swarm and similar ages (730 Ma) have been reported for mafic dykes in the central and southern Appalachians (Hoffman, 1989). Late Proterozoic intrusive episodes related to the breakup of Laurentia are present in the southwestern and northern Canadian Shield (Kamo *et al.*, 1995). One of these events, the Franklin dyke swarm located in Nunavut, has been dated by U–Pb geochronology at 723 Ma (Heaman *et al.*, 1992). This intrusive dyke event has been considered to be associated with the break-up and rifting along northwestern Laurentia and may, in part, be linked to a series of discrete, large-scale intrusive events, including the Long Range dykes, that span over 200 Ma, culminating in the final breakup of Laurentia (Heaman *et al.*, 1992).

The possibility also exists that the 725 Ma zircons are Avalonian, as similar 760 to 700 Ma ages are found in the Burin Group (763 ± 2 Ma) and Flemish Cap granodiorite (751 Ma). However, due to the absence of additional Aval-

Table 2. Laser ablation U–Pb data and calculated ages for detrital zircons from the Rogerson Lake Conglomerate at Burgeo Road (Sample 72)

	CONCORDIA COLUMNS							2 σ %	2 σ %	2 σ %	Ages Ma			
Analyses	^{207}Pb/ ^{235}U	^{207}Pb/ ^{235}U err	^{206}Pb/ ^{238}U	^{206}Pb/ ^{238}U err	Rho	^{207}Pb/ ^{206}Pb	^{207}Pb/ ^{206}Pb err	^{207}Pb/ ^{235}U	^{206}Pb/ ^{238}U	^{207}Pb/ ^{206}Pb	^{207}Pb/ ^{235}U age	1 σ	^{206}Pb/ ^{238}U	1 σ
a1	1.1447	0.1027	0.1250	0.0109	0.98	0.0688	0.0014	17.94	17.49	3.95	774.7	48.6	**759.3**	± 63
a2	1.0330	0.0948	0.1144	0.0071	0.95	0.0642	0.0012	18.35	12.38	3.88	720.4	47.3	**698.2**	± 41
a3	0.7613	0.0565	0.0843	0.0025	0.95	0.0777	0.0017	14.85	5.92	4.43	574.7	32.6	**521.5**	± 15
a4	0.8628	0.0447	0.0771	0.0022	0.92	0.0705	0.0020	10.35	5.62	5.59	631.6	24.3	**478.7**	± 13
a5	0.6093	0.0222	0.0757	0.0016	0.95	0.0591	0.0006	7.29	4.15	2.01	483.1	14.0	**470.3**	± 9
a6	0.6565	0.0511	0.0854	0.0035	0.95	0.0618	0.0018	15.57	8.18	5.86	512.5	31.3	**528.4**	± 21
a7	0.5166	0.0654	0.0607	0.0080	0.99	0.0596	0.0010	25.32	26.47	3.23	422.8	43.8	**379.7**	± 49
a8	0.5729	0.0267	0.0786	0.0021	0.95	0.0558	0.0008	9.32	5.25	3.01	459.9	17.2	**487.6**	± 12
a9	0.6075	0.0270	0.0770	0.0017	0.95	0.0584	0.0012	8.90	4.49	4.24	482.0	17.1	**478.4**	± 10
a10	0.5220	0.0323	0.0750	0.0016	0.95	0.0545	0.0007	12.37	4.15	2.75	426.5	21.5	**465.9**	± 9
a11	0.6550	0.0286	0.0804	0.0029	0.95	0.0578	0.0009	8.74	7.24	2.98	511.5	17.6	**498.3**	± 17
a12	0.5774	0.0245	0.0739	0.0022	0.98	0.0561	0.0008	8.47	6.06	2.87	462.8	15.7	**459.4**	± 13
a13	0.6381	0.0319	0.0773	0.0027	0.94	0.0598	0.0013	10.01	6.99	4.23	501.1	19.8	**479.7**	± 16
a14	0.5943	0.0321	0.0816	0.0025	0.95	0.0569	0.0006	10.79	6.05	2.06	473.6	20.4	**505.6**	± 15
a15	0.6126	0.0235	0.0767	0.0024	0.93	0.0565	0.0008	7.68	6.38	2.93	485.2	14.8	**476.7**	± 15
a16	0.6472	0.0273	0.0793	0.0031	0.99	0.0577	0.0004	8.44	7.89	1.47	506.8	16.8	**492.2**	± 19
a17	0.5841	0.0392	0.0744	0.0041	0.99	0.0539	0.0008	13.43	11.03	2.82	467.1	25.1	**462.4**	± 25
a18	1.3917	0.0670	0.1467	0.0060	0.99	0.0668	0.0007	9.63	8.19	2.08	885.4	28.5	**882.7**	± 34
a19	0.7089	0.0395	0.0898	0.0033	0.95	0.0572	0.0009	11.13	7.29	2.99	544.1	23.4	**554.3**	± 19
a20	0.6364	0.0354	0.0812	0.0032	0.95	0.0614	0.0008	11.12	7.81	2.75	500.0	22.0	**503.5**	± 19
a21	0.7832	0.0578	0.0736	0.0036	0.95	0.0755	0.0009	14.75	9.74	2.29	587.3	32.9	**457.5**	± 22
a22	0.5560	0.0362	0.0826	0.0022	0.95	0.0620	0.0013	13.04	5.34	4.31	448.9	23.6	**511.9**	± 13
a23	1.7686	0.0988	0.1824	0.0083	0.97	0.0673	0.0010	11.17	9.10	3.11	1034.0	36.2	**1079.8**	± 45
a24	0.6252	0.0250	0.0786	0.0021	0.95	0.0563	0.0006	8.00	5.34	1.96	493.1	15.6	**487.8**	± 13
a25	0.5838	0.0299	0.0764	0.0028	0.95	0.0554	0.0006	10.25	7.24	2.16	466.9	19.2	**474.6**	± 17
a26	0.7817	0.0281	0.0953	0.0035	0.95	0.0606	0.0007	7.18	7.38	2.36	586.5	16.0	**586.6**	± 21
a27	0.5826	0.0351	0.0766	0.0029	0.95	0.0555	0.0008	12.07	7.65	3.01	466.2	22.6	**475.7**	± 18
a28	1.1473	0.0659	0.1187	0.0048	0.95	0.0671	0.0007	11.48	8.06	2.18	776.0	31.1	**723.3**	± 28
a29	0.7168	0.0252	0.0763	0.0026	0.93	0.0603	0.0008	7.02	6.83	2.51	548.8	14.9	**473.9**	± 16
a30	0.8759	0.0475	0.0940	0.0038	0.95	0.0634	0.0007	10.84	8.00	2.36	638.7	25.7	**578.9**	± 22
a31	1.7175	0.0658	0.1707	0.0059	0.98	0.0699	0.0006	7.66	6.97	1.58	1015.1	24.6	**1016.1**	± 33
a32	0.5988	0.0714	0.0787	0.0057	0.95	0.0587	0.0009	23.85	14.47	2.96	476.4	45.3	**488.2**	± 34
a33	1.0334	0.1046	0.0975	0.0057	0.95	0.1024	0.0041	20.25	11.68	7.96	720.6	52.2	**599.5**	± 33
a34	1.6469	0.1701	0.1680	0.0157	0.99	0.0703	0.0013	20.66	18.64	3.61	988.4	65.3	**1001.2**	± 86
a35	0.6231	0.0351	0.0860	0.0025	0.95	0.0584	0.0010	11.28	5.92	3.47	491.8	22.0	**531.9**	± 15
a36	0.7248	0.0741	0.0994	0.0058	0.95	0.0604	0.0016	20.44	11.71	5.41	553.5	43.6	**610.8**	± 34
a37	0.7203	0.0525	0.0912	0.0043	0.95	0.0601	0.0010	14.57	9.44	3.21	550.8	31.0	**562.8**	± 25
a38	3.4427	0.1799	0.2595	0.0128	0.98	0.0948	0.0010	10.45	9.90	2.15	1514.2	41.1	**1487.0**	± 66
a39	0.5351	0.0244	0.0751	0.0018	0.95	0.0593	0.0009	9.10	4.70	2.99	435.2	16.1	**466.7**	± 11
a40	3.3023	0.2905	0.2560	0.0149	0.95	0.0988	0.0017	17.59	11.68	3.37	1481.6	68.6	**1469.4**	± 77

Table 2. Continued

Analyses	CONCORDIA COLUMNS $^{207}Pb/^{235}U$	$^{207}Pb/^{235}U$ err	$^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$ err	Rho	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ err	2 σ % $^{207}Pb/^{235}U$	2 σ % $^{206}Pb/^{238}U$	2 σ % $^{207}Pb/^{206}Pb$	Ages Ma $^{207}Pb/^{235}U$ age	1 σ	$^{206}Pb/^{238}U$	1 σ
a41	0.7207	0.0485	0.0842	0.0033	0.95	0.0680	0.0010	13.47	7.74	3.02	551.1	28.6	**521.0**	± 19
a42	0.9516	0.0684	0.0818	0.0023	0.95	0.0782	0.0023	14.37	5.71	5.84	678.9	35.6	**507.0**	± 14
a43	1.2001	0.1042	0.1390	0.0073	0.95	0.0682	0.0018	17.37	10.52	5.29	800.6	48.1	**838.9**	± 41
a44	0.5218	0.0426	0.0723	0.0032	0.95	0.0563	0.0009	16.35	8.95	3.21	426.4	28.5	**449.9**	± 19
a45	0.5086	0.0387	0.0806	0.0020	0.95	0.0582	0.0012	15.21	5.05	4.21	417.5	26.0	**499.9**	± 12
a46	0.5573	0.0215	0.0710	0.0022	0.98	0.0561	0.0006	7.73	6.27	2.05	449.8	14.1	**442.1**	± 13
a47	0.5115	0.0828	0.0794	0.0068	0.95	0.0553	0.0011	32.36	17.16	3.83	419.5	55.6	**492.4**	± 41
a48	0.5490	0.0499	0.0726	0.0029	0.95	0.0563	0.0012	18.17	7.99	4.24	444.3	32.7	**451.8**	± 17
a49	0.5450	0.0429	0.0801	0.0021	0.95	0.0626	0.0014	15.76	5.35	4.43	441.7	28.2	**496.9**	± 13
a50	0.5510	0.0291	0.0734	0.0037	0.97	0.0534	0.0007	10.55	10.08	2.54	445.6	19.0	**456.8**	± 22
a51	0.6037	0.0335	0.0838	0.0022	0.95	0.0629	0.0011	11.09	5.25	3.46	479.6	21.2	**518.6**	± 13
a52	0.5776	0.0711	0.0832	0.0033	0.95	0.0689	0.0017	24.61	7.82	4.88	462.9	45.7	**515.4**	± 19
a53	0.6889	0.0324	0.0848	0.0032	0.98	0.0592	0.0007	9.40	7.59	2.35	532.1	19.5	**525.0**	± 19
a54	0.4922	0.0409	0.0712	0.0028	0.95	0.0589	0.0008	16.62	7.80	2.65	406.4	27.8	**443.1**	± 17
a55	0.4138	0.0401	0.0723	0.0028	0.95	0.0546	0.0012	19.36	7.76	4.35	351.6	28.8	**450.0**	± 17
a56	0.4858	0.0382	0.0707	0.0022	0.95	0.0604	0.0015	15.72	6.26	4.99	402.1	26.1	**440.3**	± 13
a57	0.5867	0.0300	0.0782	0.0021	0.95	0.0642	0.0010	10.21	5.43	3.14	468.8	19.2	**485.3**	± 13
a58	0.4812	0.0759	0.0722	0.0034	0.95	0.0614	0.0014	31.53	9.43	4.62	398.9	52.0	**449.5**	± 20
a59	0.4650	0.0323	0.0735	0.0020	0.95	0.0549	0.0009	13.91	5.57	3.14	387.7	22.4	**457.3**	± 12
a60	0.5791	0.0300	0.0727	0.0019	0.95	0.0598	0.0012	10.35	5.19	3.89	463.9	19.3	**452.3**	± 11
a61	0.5175	0.0534	0.0710	0.0038	0.95	0.0584	0.0010	20.65	10.84	3.26	423.5	35.7	**441.9**	± 23
a62	0.4929	0.0385	0.0780	0.0020	0.95	0.0595	0.0012	15.64	5.25	4.04	406.9	26.2	**484.0**	± 12
a63	0.6276	0.0220	0.0789	0.0016	0.95	0.0589	0.0008	7.00	4.15	2.56	494.6	13.7	**489.3**	± 10
a64	0.5330	0.0263	0.0722	0.0023	0.95	0.0560	0.0005	9.88	6.24	1.96	433.8	17.4	**449.5**	± 14
a65	0.6084	0.0129	0.0765	0.0012	0.98	0.0574	0.0004	4.25	3.19	1.31	482.6	8.2	**475.3**	± 7
a66	1.4917	0.1924	0.1525	0.0113	0.95	0.0778	0.0015	25.79	14.79	3.86	927.0	78.4	**915.1**	± 63
a67	0.5167	0.0715	0.0781	0.0052	0.95	0.0514	0.0014	27.68	13.33	5.33	422.9	47.9	**484.6**	± 31
a68	2.3701	0.1155	0.2129	0.0096	0.98	0.0787	0.0008	9.75	9.00	2.03	1233.6	34.8	**1244.2**	± 51
a69	0.5382	0.0643	0.0689	0.0038	0.95	0.0662	0.0011	23.88	11.15	3.46	437.2	42.4	**429.6**	± 23
a70	0.3891	0.0627	0.0755	0.0030	0.95	0.0564	0.0014	32.23	7.82	5.11	333.7	45.8	**469.2**	± 18
a71	0.4912	0.0380	0.0716	0.0024	0.95	0.0592	0.0010	15.49	6.62	3.31	405.7	25.9	**445.5**	± 14
a72	0.7269	0.0402	0.0805	0.0019	0.95	0.0650	0.0011	11.06	4.66	3.51	554.7	23.6	**498.9**	± 11
a73	0.6471	0.0331	0.0783	0.0018	0.95	0.0670	0.0009	10.23	4.55	2.55	506.7	20.4	**485.8**	± 11
a74	0.7195	0.0468	0.0761	0.0022	0.95	0.0666	0.0015	13.01	5.69	4.48	550.4	27.6	**473.1**	± 13
a75	0.5270	0.0475	0.0729	0.0033	0.95	0.0565	0.0007	18.03	9.10	2.39	429.8	31.6	**453.5**	± 20
a76	0.5077	0.0317	0.0790	0.0017	0.95	0.0612	0.0013	12.50	4.23	4.17	416.9	21.4	**490.2**	± 10
a78	0.4785	0.1011	0.0745	0.0095	0.95	0.0514	0.0010	42.27	25.59	3.97	397.0	69.5	**463.0**	± 57
a79	0.4606	0.0454	0.0740	0.0025	0.95	0.0602	0.0011	19.73	6.78	3.55	384.7	31.6	**460.2**	± 15
a80	0.6634	0.0369	0.0770	0.0027	0.95	0.0616	0.0010	11.14	7.13	3.19	516.7	22.5	**478.3**	± 16
a81	0.5500	0.0394	0.0764	0.0023	0.95	0.0572	0.0009	14.32	6.05	3.20	445.0	25.8	**474.6**	± 14
a82	0.5466	0.0766	0.0673	0.0064	0.95	0.0611	0.0012	28.01	19.07	4.07	442.7	50.3	**419.9**	± 39

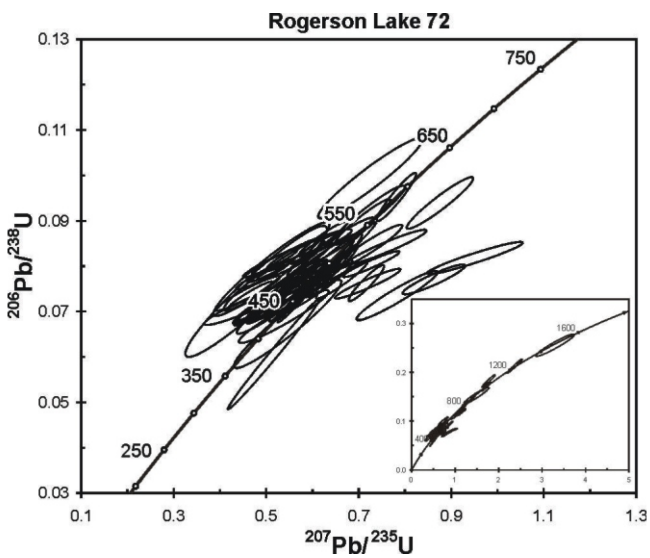

Figure 5. *Concordia diagram for detrital zircons from the Rogerson Lake Conglomerate (Sample 72) at Burgeo Road for the ca. 500 Ma range. The inset displays a concordia diagram for the whole range.*

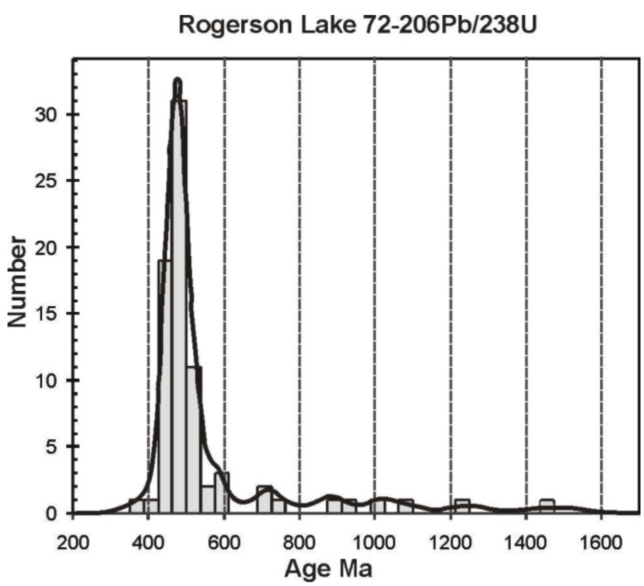

Figure 6. *Cumulative probability plot of detrital zircons from the Rogerson Lake Conglomerate (Sample 72).*

onian ages and the fact that the provenance source indicates a dominantly westward-transportation direction of the zircons, an Avalonian source for detritus in the Rogerson Lake Conglomerate is not contemplated.

The Neoproterozoic (890 Ma) and Mesoproterozoic age groups (1250 and 1030 Ma) correspond with rocks of the Grenville Orogen, whereas the middle Mesoproterozoic ages (ca. 1500) are correlated with basement gneisses of the Grenville Orogen (Owen and Erdmer, 1990). These Laurentian rocks contributed a minor quantity (approximately 10 percent) of the zircons that were analysed in the Rogerson Lake Conglomerate. The Indian Head Inlier of western Newfoundland contains several granitic gneiss units dated in the 900 to 800 Ma range. Samples from the Stephenville area contain hornblende and biotite that yielded an undisturbed ^{40}Ar/^{39}Ar spectra with ages of 880 and 825 Ma, respectively (Dallmeyer, 1978). The K–Ar ages obtained from biotite yield ages that correspond with the ^{40}Ar/^{39}Ar data. A granitic gneiss unit was dated at 830 ± 42 Ma (Lowden, 1961) and a 900 ± 45 Ma age was obtained from biotite in a pegmatite dyke (Lowden *et al.*, 1963).

Correlative rocks of the Indian Head Inlier and the Long Range and Steel Mountain inliers contain similar high-grade quartz feldspar gneisses and granites that are Mesoproterozoic. Basement gneisses of the Long Range Inlier in the area of Western Brook Pond have ages of 1250 Ma (Erdmer, 1986). These rocks were intruded by a belt of granitoid plutons in the Long Range Inlier and the adjacent Grenville Province in southern Labrador and adjacent Quebec. These large plutons yielded U–Pb zircon ages between 1080 and 960 Ma (Gower and Loveridge, 1987; Scharer and Gower, 1988), with a U–Pb zircon age of 1023 +7/-5 Ma obtained from a granitoid intrusion of the Lake Michel intrusive suite (Owen and Erdmer, 1990). A felsic granulite gneiss of the Disappointment Hill complex in the Steel Mountain Inlier yielded an upper intercept U–Pb zircon age 1498 +9/-8 Ma and a foliated gabbro related to Steel Mountain anorthositic rocks has an upper intercept age of 1254 ± 14 Ma (Currie *et al.*, 1992). The ages of Proterozoic zircons in the Rogerson Lake Conglomerate, therefore, correlate within the limits of uncertainty with the ages previously reported for Laurentian rocks of the Grenvillian basement inliers in western Newfoundland.

McNicoll and van Staal (2001) reported U–Pb SHRIMP data for zircons from syntectonic sediments in the Badger Belt along the Red Indian Line. Coarse-grained sandstone samples from the base and top of the Badger group were dominated by Late Cambrian to Ordovician zircons with the amount of Grenville-aged zircons decreasing toward the top of the group. The Rogerson Lake Conglomerate and the Botwood Belt overlie the Badger group and contain a smaller proportion of Grenvillian detrital zircons. The decrease in contribution of Laurentian zircons from the base of the Badger group stratigraphically upwards to the Rogerson Lake Conglomerate is attributed to the collision-induced uplift of the Notre Dame arc that diminished the input of Laurentian basement (McNicoll and van Staal, 2001). Similarly, McNicoll and van Staal (*op. cit.*) attribute the absence of zircons in the 680 to 620 Ma range as evidence for the presence of a seaway separating the Gander margin and Avalonia from the Notre Dame, Victoria and Exploits arc terranes that were accreted to Laurentia.

CONCLUSIONS

The zircon age ranges obtained by LAM-ICP-MS provide new insights into the depositional history of the Rogerson Lake Conglomerate. This Silurian sedimentary sequence dominantly consists of detritus derived from the underlying Late Cambrian to Early Ordovician arc volcanic sequences of the Victoria Lake supergroup. The conglomerate also yielded a smaller proportion of Ordovician (480 to 440 Ma) zircons that were in all probability were derived from the calc-alkaline volcanic rocks and associated magmatic arc plutons of the adjacent Notre Dame arc. The presence of a small number of ca. 725 Ma zircons may possibly be attributed to input from igneous intrusions associated with the earliest stages of Iapetan rifting on the Laurentian margin.

The Rogerson Lake Conglomerate also contains a minor zircon population derived from Proterozoic rocks of Laurentian basement. High-grade quartz feldspar basement gneisses and younger granite plutons within Grenville inliers have yielded U–Pb zircon ages ranging from ca. 1500 to 900 Ma. These data suggest that the dominant transport direction for detritus that make up the conglomerate was from west to east and that the conglomerate contains material sampled from a geographically large area presently exposed over 50 000 km^2. The high proportion of Paleozoic zircons relative to Proterozoic grains is presumably the result of Middle Ordovician exhumation of the Notre Dame arc and its subsequent collision and accretion to Laurentia.

This study demonstrates the effectiveness of using LAM-ICP-MS for detrital zircon geochronology. This method, although less precise than conventional TIMS analysis, provides for better spatial resolution and therefore more accurate age dates and is the more efficient and cost effective technique, having the potential to analyse a greater number of zircon grains in a shorter time period. The LAM-ICP-MS technique represents a suitable method for the rapid dating of a large number of detrital zircons for the purpose of sediment provenance studies.

ACKNOWLEDGMENTS

Richard Cox (MUN) is acknowledged for his assistance in mineral separation, for valuable discussion concerning LAM-ICP-MS geochronology and for reviewing an earlier version of this paper. The first author would especially like to thank Richard for introducing him to the particulars of detrital zircon geochronology and for help in operating the laser ablation system and mass spectrometer. Data reduction and processing were performed with the help of Glen Penny (MUN). Derek Newhook and Canadian Helicopters provided helicopter support. This manuscript was reviewed by Lawson Dickson who provided many helpful comments. Many of our ideas pertaining to central Newfoundland geology were developed by the numerous discussions with our colleagues Vicki McNicoll, Neil Rogers, Pablo Valverde-Vacquero and Hank Williams.

REFERENCES

Chorlton, L.B., Williams, H. and Wilton, D.H.C.
1995: Cape Ray Belt. *In* Chapter 4. Geology of the Appalachian-Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, No. 6, pages 397-403.

Currie, K.L., van Breeman, O., Hunt, P.A. and van Berkel, J.T.
1992: The age of high-grade gneisses south of Grand Lake, Newfoundland. Atlantic Geology, Volume 28, no. 2, pages 153-161.

Dallmeyer, R.D.
1978: 40Ar/39Ar incremental release ages of hornblende and biotite from Grenville basement rocks within the Indian Head Range Complex, southwest Newfoundland: their bearing on late Proterozoic-Early Paleozoic thermal history. Canadian Journal of Earth Sciences, Volume 15, pages 1374-1379.

Dubé, B., Dunning, G.R., Lauziere, K. and Roddick, J.C.
1996: New insights into the Appalachian Orogen from geology and geochronology along the Cape Ray fault zone, southwest Newfoundland. Geological Society of America Bulletin, Volume 108, pages 101-116.

Dunning, G.R., Swinden, H.S., Kean, B.F., Evans, D.T.W. and Jenner, G.A.
1991: A Cambrian island arc in Iapetus: geochronology and geochemistry of the Lake Ambrose Volcanic Belt, Newfoundland Appalachians. Geological Magazine, Volume 128, pages 1-17.

Erdmer, P.
1986: Geology of the Long Range Inlier in Sandy Lake map area (12H) western Newfoundland. Geological Survey of Canada, Open File 1310.

Evans, D.T.W. and Kean, B.F.
2002: Paleotectonic setting of the Victoria Lake supergroup and adjoining sequences, central Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey, Open File # 2772.

Evans, D.T.W., Kean, B.F. and Dunning, G.R.
1990: Geological studies, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 131-144.

Gower, C.F. and Loveridge, W.D.
1987: Grenvillian plutonism in the eastern Grenville Province. *In* Ragiogenic Age and Isotope Studies: Report 1: Geological Survey of Canada, Paper 87-2, p. 55-58.

Heaman, L.M., LeCheminant, A.N. and Rainbird, R.H.
1992: Nature and timing of Franklin igneous events, Canada: Implications for a Late Proterozoic mantle plume and the breakup of Laurentia. Earth and Planetary Science Letters, Volume 109, pages 117-131.

Hoffman, P.F.
1988: United plates of America, The birth of a craton: Early Proterozoic assembly and growth of Laurentia. Annual Reviews of Earth and Planetary Sciences, Volume 16, pages 543-603.

1989: Precambrian geology and tectonic history of North America. *In* The Geology of North America-An Overview. *Edited by* A.W. Bally and A.R. Palmer. Geological Society of America, The Geology of North America, Volume A, pages 447-512.

Kamo, S.L., Krogh, T.E. and Kumarapeli, P.S.
1995: Age of the Grenville dyke swarm, Ontario-Quebec: implications for the timing of Iapetan rifting. Canadian Journal of Earth Sciences, Volume 32, pages 273-280.

Kean, B.F.
1985: Metallogeny of the Tally Pond volcanics, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 89-93.

Kean, B.F. and Jayasinghe, N.
1980: Geology of the Lake Ambrose (12A/10)-Noel Paul's Brook (12A/9) map area, central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pages.

Ketchum, J.W.F., Jackson, S.E., Culshaw, N.G. and Barr, S.M.
2001: Depositional and tectonic setting of the Paleoproterozoic Lower Aillik Group, Makkovik Province, Canada: evolution of a passive margin-foredeep sequence based on petrochemistry and U–Pb (TIMS and LAM-ICP-MS) geochronology. Precambrian Research, Volume 105, pages 331-356.

Kosler, J., Fonneland, H., Sylvester, P., Tubrett, M. and Pederson, R.B.
In press: U-Pb dating of detrital zircons for sediment provenance studies - a comparison of laser ablation ICP-MS and SIMS techniques. Chemical Geology.

Kosler, J., Tubrett, M. and Sylvester, P.
2001: Application of Laser Ablation ICP-MS to U-Th-Pb dating of monazite. The Journal of Geostandards and Geoanalysis, Volume 25, No. 2.

Lowden, J.A.
1961: Age determinations by the Geological Survey of Canada: Report 1, isotopic ages. Geological Survey of Canada, Paper 60-17, 51 pages.

Lowden, J.A., Stockwell, C.H., Tipper, H.W. and Wanlesss, R.K.
1963: Age determinations and geological studies (including isotopic ages- Report 3). Geological Survey of Canada, Paper 62-17, 140 pages.

Ludwig, K.R.
1999: Using Isoplot/Ex, Version 2.01: a geochronological toolkit for Microsoft Excel. Berkeley Geochronology Center Special Publication No. 1a, 47 pages.

McNicoll, V.J. and van Staal, C.R.
2001: Accretionary history of the Northern Appalachians: SHRIMP study of Ordovician-Silurian syntectonic sediments in the Canadian Appalachians. Geological Association of Canada – Mineralogical Association of Canada, Abstracts with Programs, Volume 26, page 100.

Owen, J.V. and Erdmer, P.
1990: Middle Proterozoic geology of the Long Range Inlier, Newfoundland: Regional significance and tectonic implications. *In* Middle Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada, Special Paper 38, pages 215-231.

Scharer, U. and Gower, C.F.
1988: Crustal Evolution in eastern Labrador: constraints from precise U-Pb ages. Precambrian Research, Volume 38, pages 405-421.

van Staal, C.R., Dewey, J.F., Mac Niocaill, C. and McKerrow, W.S.
1998: The Cambrian-Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex, west and southwest Pacific-type segment of Iapetus. *In* Lyell: the Past is the Key to the Present. *Edited by* D.J. Blundell and A.C. Scott. Geological Society, London, Special Publication, Volume 143, pages 199-242.

Wanless, R.K., Stevens, R.D., Lachance, G.R. and Edmonds, C.M.
1968: Age determinations and geological studies: K-Ar isotopic ages, Report 8. Geological Survey of Canada, Paper 67-2A, 141 pages.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectono-stratigraphic subdivisons of central Newfoundland. *In* Current Research, Part B. Geological Survey of Canada, Paper 88-1B, pages 91-98.

Williams, H., Dehler, S.A., Grant, A.C. and Oakey, G.N.
1999: Tectonics of Atlantic Canada. Geoscience Canada, Volume 26, no. 2, pages 51-70.