U-Pb Isotopic Ages from Volcanic Rocks near Ootsa Lake and Francois Lake, West-Central British Columbia

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KEYWORDS: U-Pb zircon isotopic age, Ootsa Lake, Francois Lake, Ootsa Lake Group, Kasalka Group, Late Cretaceous magmatism

INTRODUCTION

Uranium-lead isotopic dates have been determined for porphyritic dacites previously assigned to the Eocene Ootsa Lake Group by Massey *et al.* (2005). Two rock samples were collected for U-Pb geochronology from isolated exposures in central Stikine terrane between Ootsa Lake and Francois Lake during a Quaternary geology and till geochemistry program conducted in Nadina River map area (NTS 093E/15) in 2009 (Ferbey, 2010; Figure 1). The new dates indicate that they are Late Cretaceous and are provisionally included as late volcanic components of the Kasalka Group, a continental margin, magmatic-arc sequence that extends across central Stikine terrane. Regionally, Late Cretaceous magmatic-arc rocks in central Stikine terrane are an important source for porphyry style Cu-Mo mineralization, and currently the focus of exploration for volcanic-hosted, bulk tonnage gold-silver-base metal mineralization.

GENERAL GEOLOGY

The Nadina River map area is centrally located within the Stikine terrane, on the southern flank of the Skeena Arch. The Stikine terrane comprises subduction-related island-arc magmatic rocks that were emplaced from Carboniferous through Early Jurassic time. The Jurassic arc components belong to the Hazelton Group and include volcanic and sedimentary rocks associated with a few widely spaced, coeval plutons that together define the Skeena Arch. The Skeena Arch in Late Jurassic time was a broad highland region underlain by Hazelton Group and older arc strata that effectively formed much of the south and southeast margin for Late Jurassic to Early Cretaceous marine deltaic and slope clastic facies deposited in the Bowser Basin. In contrast to these clastic deposits from the Bowser Lake Group north of the arch, Early Cretaceous marine clastic and rare volcanic deposits of the Skeena Group succeeded by Late Cretaceous and Eocene continental volcanic arc sequences of the Kasalka, Ootsa and Endako groups overlap the southern flank of the Skeena Arch.

The bedrock geology of Nadina Lake area was first mapped by Hedley (1935) and subsequently during regional mapping surveys of the Whitesail Lake map sheet (NTS 093E) by Duffell (1959) and Woodsworth (1980). The oldest rocks, the Hazelton Group, composed of feldspathic sandstone containing Middle Jurassic macrofossils, underlie the area adjacent to Tahtsa Reach and west of Shelford Hills (Woodsworth, 1980; Diakow and Mihalynuk, 1987; Figure 1). According to Woodsworth (1980), rhyolite and andesite flows and fragmental deposits assigned to the Late Cretaceous Kasalka Group underlie the central portion of Nadina Lake map area, at Shelford Hills. In subdued topography east and southeast of Shelford Hills between Francois and Ootsa lakes, Woodsworth (1980) recognized isolated occurrences of felsic volcanic rocks which he designated as latest Cretaceous to Eocene (unit uKEv) comprising part of either the Kasalka Group or Ootsa Lake Group. In this area, bedrock is generally scarce and limited to small, isolated outcrops surrounded by near-continuous cover composed of till and glaciofluvial sediments deposited during the Late Wisconsinan Fraser glaciation (Ferbey, 2010).

ANALYTICAL TECHNIQUE

Samples collected for U-Pb zircon isotopic age determinations were prepared and analyzed by Apatite to Zircon Inc. (Viola, Idaho). Analytical results determined by laser ablation inductively-coupled-plasma mass spectrometry (LA-ICP-MS) are presented in Tables 1 and 2 for samples 10TFE060 and 10TFE061, respectively.

Laser Ablation Inductively-Coupled-Plasma Mass Spectrometry

Zircons were extracted using standard mineral-separation techniques at the laboratories of Apatite to Zircon Inc. Zircons (both standards and unknowns) were then mounted in 1 cm^2 epoxy wafers, and ground down to expose internal grain surfaces prior to final polishing. Wafers were etched in 5.5M HNO_3 for 20 seconds at 21°C to thoroughly clean the surface of the grains prior to

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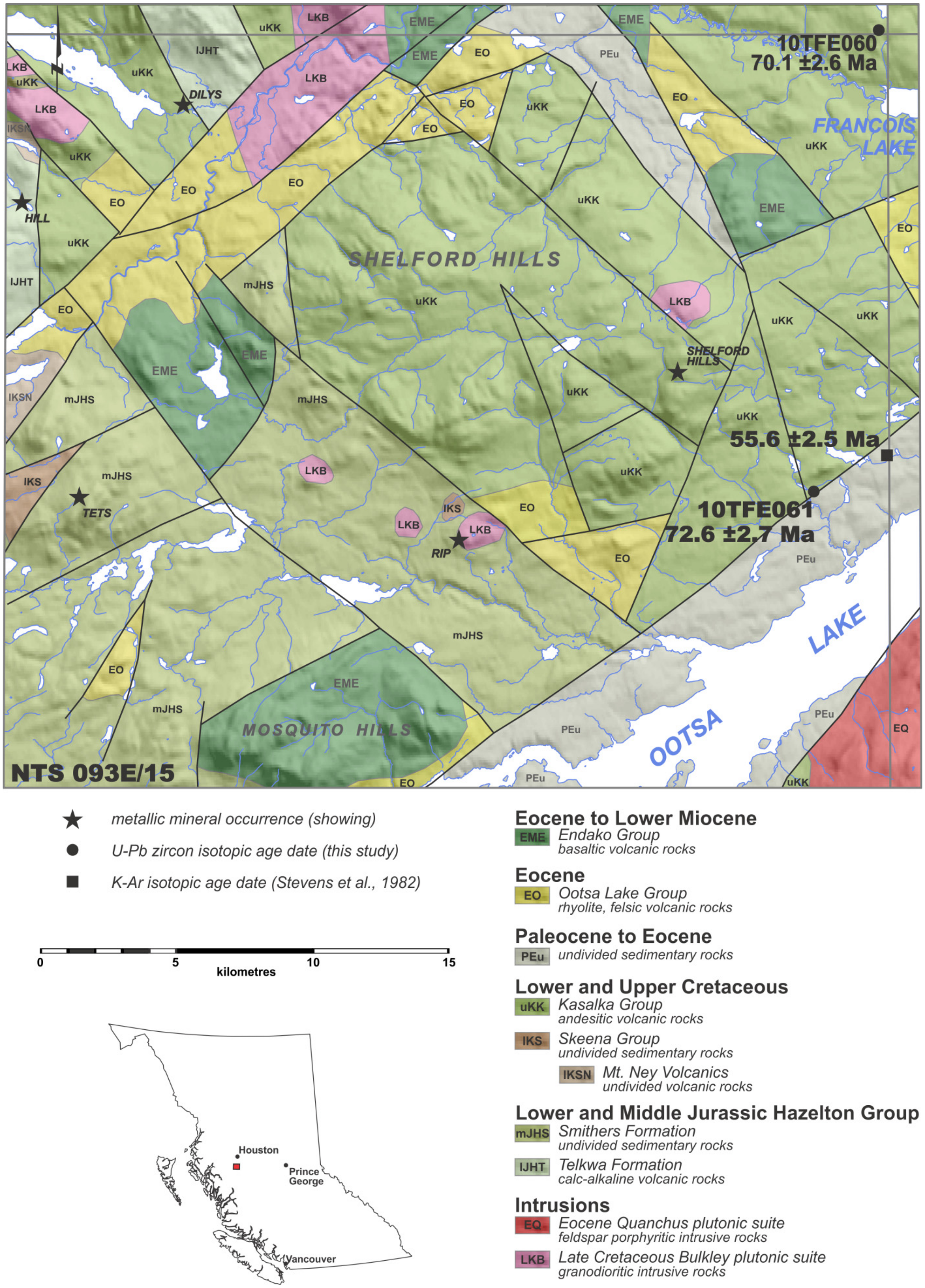

Figure 1. Bedrock geology of NTS 093E/15 (Nadina River) and adjacent areas to the north and east (modified from Massey *et al.*, 2005). Shown in black dots are sample locations for U-Pb zircon isotopic age determinations.

Table 1. Laser ablation inductively-coupled-plasma mass spectrometry U-Pb data for sample 10TFE060.

	Isotopic Ratios				Age (Ma)	
analysis	$^{207}Pb/^{235}U$	±2σ error	$^{206}Pb/^{238}U$	±2σ error	$^{206}Pb/^{238}U$	±2σ error
115706_002	0.0738	0.0025	0.0108	0.0005	69.08	3.10
115706_004	0.0758	0.0025	0.0105	0.0005	67.16	3.04
115706_006	0.0810	0.0025	0.0109	0.0005	70.01	3.16
115706_009	0.0794	0.0025	0.0112	0.0005	71.77	3.25
115706_010	0.0739	0.0025	0.0112	0.0005	71.55	3.19
115706_011	0.0720	0.0025	0.0104	0.0005	66.51	3.09
115706_012	0.0774	0.0025	0.0107	0.0005	68.76	3.09
115706_017	0.0737	0.0025	0.0108	0.0005	69.17	3.12
115706_019	0.0728	0.0025	0.0106	0.0005	68.07	3.04
115706_020	0.0754	0.0025	0.0106	0.0005	67.94	3.05
115706_025	0.0789	0.0025	0.0116	0.0005	74.22	3.34
115706_027	0.0734	0.0025	0.0107	0.0005	68.87	3.08
115706_029	0.0752	0.0025	0.0112	0.0005	71.58	3.23
115706_032	0.0735	0.0025	0.0108	0.0005	69.31	3.13
115706_034	0.0716	0.0025	0.0104	0.0005	66.40	2.97
115706_035	0.0730	0.0025	0.0106	0.0005	68.11	3.06
115706_036	0.0741	0.0025	0.0107	0.0005	68.71	3.07
115706_037	0.2553	0.0025	0.0140	0.0039	89.44	25.08
115706_039	0.1281	0.0025	0.0085	0.0024	54.42	15.31
115706_041	0.0725	0.0025	0.0107	0.0005	68.70	3.16
115706_043	0.0739	0.0025	0.0108	0.0005	69.20	3.11
115706_045	0.0751	0.0025	0.0109	0.0005	70.02	3.15
115706_046	0.0750	0.0025	0.0109	0.0005	69.71	3.22
115706_047	0.0859	0.0025	0.0111	0.0005	71.20	3.41
115706_048	0.0743	0.0025	0.0108	0.0005	69.07	3.13
115706_050	0.0774	0.0025	0.0110	0.0005	70.62	3.17
115706_051	0.0752	0.0025	0.0111	0.0005	71.07	3.17
115706_054	0.0749	0.0025	0.0107	0.0005	68.92	3.09
115706_058	0.0765	0.0025	0.0107	0.0005	68.66	3.08
115706_062	0.0736	0.0025	0.0109	0.0005	69.59	3.11
115706_064	0.0737	0.0025	0.0109	0.0005	69.57	3.14
115706_065	0.1077	0.0025	0.0118	0.0005	75.81	3.53
115706_066	0.0778	0.0025	0.0107	0.0005	68.92	3.10
115706_067	0.0823	0.0025	0.0113	0.0005	72.72	3.28
115706_069	0.0768	0.0025	0.0115	0.0005	73.65	3.30
115706_073	0.0721	0.0025	0.0108	0.0005	69.23	3.11
115706_075	0.0716	0.0025	0.0104	0.0005	66.75	2.99
115706_078	0.0796	0.0025	0.0111	0.0005	71.00	3.22
115706_082	0.0811	0.0025	0.0117	0.0006	75.25	3.59
115706_084	0.0756	0.0025	0.0113	0.0005	72.24	3.23
115706_086	0.1306	0.0025	0.0119	0.0006	76.06	3.78
115706_087	0.0799	0.0025	0.0111	0.0005	71.22	3.21
115706_088	0.0747	0.0025	0.0109	0.0005	70.07	3.15
115706_090	0.0728	0.0025	0.0109	0.0005	70.11	3.13
115706_091	0.0764	0.0025	0.0115	0.0005	73.86	3.32
115706_094	0.0731	0.0025	0.0111	0.0005	71.16	3.19
115706_095	0.0728	0.0025	0.0111	0.0005	71.02	3.25
115706_096	0.0724	0.0025	0.0108	0.0005	69.09	3.10
115706_098	0.0770	0.0025	0.0114	0.0005	72.77	3.52
115706_099	0.0750	0.0025	0.0107	0.0005	68.41	3.06
115706_100	0.0732	0.0025	0.0109	0.0005	70.19	3.14
115706_103	0.0761	0.0025	0.0110	0.0005	70.58	3.17
115706_105	0.0770	0.0025	0.0110	0.0005	70.82	3.16
115706_110	0.0843	0.0025	0.0114	0.0005	72.98	3.25

Table 2. Laser ablation inductively-coupled-plasma mass spectrometry U-Pb data for sample 10TFE061.

	Isotopic Ratios				Age (Ma)	
analysis	$^{207}Pb/^{235}U$	±2σ error	$^{206}Pb/^{238}U$	±2σ error	$^{206}Pb/^{238}U$	±2σ error
115707_001	0.0851	0.0031	0.0121	0.0005	77.46	3.52
115707_002	0.0753	0.0025	0.0112	0.0005	71.73	3.23
115707_003	0.0769	0.0026	0.0110	0.0005	70.82	3.20
115707_005	0.0777	0.0025	0.0113	0.0005	72.57	3.26
115707_006	0.0806	0.0026	0.0116	0.0005	74.20	3.36
115707_008	0.0755	0.0024	0.0112	0.0005	71.99	3.26
115707_009	0.0774	0.0026	0.0114	0.0005	73.01	3.32
115707_010	0.0799	0.0030	0.0113	0.0005	72.15	3.32
115707_017	0.0766	0.0025	0.0115	0.0005	73.80	3.32
115707_021	0.0761	0.0027	0.0108	0.0005	69.36	3.12
115707_022	0.0791	0.0026	0.0115	0.0005	73.79	3.33
115707_024	0.0788	0.0027	0.0116	0.0005	74.35	3.35
115707_025	0.0819	0.0031	0.0119	0.0005	76.31	3.53
115707_028	0.0742	0.0028	0.0110	0.0005	70.54	3.22
115707_029	0.0763	0.0026	0.0111	0.0005	71.32	3.18
115707_032	0.0799	0.0025	0.0117	0.0005	75.09	3.36
115707_033	0.0761	0.0025	0.0112	0.0005	71.83	3.23
115707_034	0.0769	0.0025	0.0111	0.0005	71.21	3.18
115707_035	0.0764	0.0025	0.0114	0.0005	73.04	3.29
115707_037	0.0739	0.0023	0.0110	0.0005	70.21	3.14
115707_038	0.0757	0.0026	0.0110	0.0005	70.81	3.18
115707_042	0.0771	0.0025	0.0111	0.0005	70.87	3.18
115707_043	0.1493	0.0568	0.0117	0.0007	75.25	4.57
115707_045	0.0762	0.0025	0.0110	0.0005	70.67	3.16
115707_050	0.0762	0.0024	0.0112	0.0005	71.92	3.21
115707_052	0.0750	0.0023	0.0112	0.0005	71.48	3.18
115707_054	0.0747	0.0024	0.0110	0.0005	70.53	3.15
115707_055	0.0779	0.0024	0.0117	0.0005	74.73	3.35
115707_058	0.0785	0.0027	0.0114	0.0005	73.02	3.35
115707_059	0.0758	0.0024	0.0112	0.0005	72.00	3.22
115707_061	0.1334	0.0197	0.0117	0.0007	75.16	4.61
115707_063	0.0813	0.0059	0.0111	0.0006	71.39	3.91
115707_066	0.0834	0.0109	0.0114	0.0005	73.22	3.35
115707_067	0.0785	0.0027	0.0115	0.0005	73.78	3.31
115707_069	0.0765	0.0024	0.0114	0.0005	73.01	3.26
115707_070	0.0753	0.0023	0.0112	0.0005	71.78	3.22
115707_074	0.0797	0.0027	0.0113	0.0005	72.14	3.24
115707_082	0.0760	0.0025	0.0112	0.0005	71.79	3.21
115707_083	0.0906	0.0057	0.0120	0.0006	76.88	3.79
115707_084	0.0788	0.0025	0.0117	0.0005	74.94	3.34
115707_085	0.0743	0.0025	0.0110	0.0005	70.67	3.21
115707_091	0.0759	0.0026	0.0112	0.0005	72.03	3.26
115707_094	0.0761	0.0024	0.0113	0.0005	72.48	3.24
115707_095	0.0829	0.0037	0.0120	0.0006	77.01	3.56
115707_098	0.0806	0.0025	0.0118	0.0005	75.81	3.42
115707_099	0.0756	0.0056	0.0107	0.0005	68.66	3.27
115707_100	0.0775	0.0025	0.0113	0.0005	72.47	3.24
115707_101	0.0875	0.0037	0.0121	0.0005	77.51	3.52
115707_105	0.0737	0.0025	0.0110	0.0005	70.49	3.17
115707_106	0.0748	0.0036	0.0108	0.0005	69.51	3.20
115707_107	0.0778	0.0026	0.0113	0.0005	72.43	3.24
115707_108	0.0751	0.0024	0.0112	0.0005	71.88	3.22
115707_109	0.0781	0.0025	0.0112	0.0005	72.09	3.21
115707_110	0.0791	0.0030	0.0118	0.0005	75.38	3.52

analysis. Grains, and the locations for laser spots on these grains, were selected using transmitted light with an optical microscope at a magnification of 2000x. This approach is preferred over the use of cathodoluminescence (CF) 2-D imaging as it allows for the recognition and characterization of features below the surface of individual grains, including the presence of inclusions and the orientation of fractures which may result in spurious isotopic counts.

Isotopic analyses were performed with a New Wave UP-213 laser ablation system, in conjunction with a ThermoFinnigan Element2 single collector, double-focusing magnetic-sector LA-ICP-MS, in the GeoAnalytical Lab at Washington State University (Pullman, Washington). For all analyses (both standard and unknown), laser-beam diameter was set at 20 µm and the laser frequency was set at 5 Hz yielding ablation pits ~10-15 µm deep. Helium and Ar gas were used to deliver the ablated material into the plasma source of the mass spectrometer. Each analysis of 250 cycles took approximately 30 seconds to complete, and consisted of a 6 second integration on peaks with the laser turned off (for background measurements), followed by a 25 second integration with the laser firing. A delay of up to 30 seconds occurred between analyses in order to purge the previous analysis and prepare for the next.

For each spot, fractionation factor-corrected isotopic ratios and ages were then calculated using data collected during scans 70-250 for each analysis. Errors for the isotopic ratios and ages are based on the fitting errors of the respective isotopes. Up to 181 individual scans, each yielding isotopic ratios and ages, are available for ultimate preferred age calculation. Plotting of analytical results was completed in Isoplot3 v. 3.71 (Ludwig, 2008).

VOLCANIC ROCK SAMPLES AND GEOCHRONOLOGY RESULTS

Two widely spaced bedrock exposures sampled between Francois Lake and Ootsa Lake for U-Pb geochronology during the Quaternary geology program consist of a relatively unaltered lava flow (10TFE060) and an altered lava flow (10TFE061). These samples were analyzed for 37 elements by inductively coupled plasma mass spectrometry (ICP-MS), following an aqua regia digestion. Determinations for copper, molybdenum, lead, zinc, silver, and gold, and pathfinder elements such as arsenic, antimony, and mercury are low in both samples.

Sample 10TFE060, located about 2 km north on the Parrot Lakes Road from the west end of Francois Lake (Figure 1), is a subdued outcrop 20 metres wide. It is composed of massive, maroon-weathered lava flow containing up to 25 volume percent white plagioclase phenocrysts, 1 to 4 millimetres in diameter, and a trace of biotite within an oxidized groundmass dusted with fine hematite (Figure 2). Major oxide analyses indicate this sample is dacitic in composition (71.04 wt.% SiO_2). Based on a weighted average of 54 $^{206}Pb/^{238}U$ dates, the crystallization age for this dacite is determined to be 72.6 ±2.7 Ma (Figure 3).

Sample 10TFE061, is from an abandoned roadside quarry 75 m wide located just off the Wisteria Main logging road, west of Wisteria on Ootsa Lake (Figure 1). It consists of massive, porphyritic and locally flow-laminated and brecciated lava flows in which primary volcanic textures are intact but replaced by microscopic quartz, clay minerals and finely disseminated and wisps of pyrite (Figure 4). They exhibit pervasive alteration and have weathered to a yellowish off white with a chalky appearance. Major element analyses reflect the secondary mineralogy, evident from a high SiO_2 composition (77.52 wt.% SiO_2) suggestive of rhyolite. Based on a weighted average of 54 $^{206}Pb/^{238}U$ dates, the crystallization age for this volcanic flow is determined to be 70.1 ±2.6 Ma (Figure 5). These dates are considered to be equivalent.

DISCUSSION

The U-Pb ages confirm inclusion of these rocks within a Late Cretaceous volcanic unit originally mapped by Woodsworth (1980). This volcanic unit is exposed locally through thin glacial cover between Francois and Ootsa lakes. Near the southern sample site at Ootsa Lake (sample 10TFE061), it apparently is succeeded by felsic volcanic rocks resembling the Ootsa Lake Group, dated by the K-Ar method on biotite at 55.6 ±2.5 Ma (Stevens *et al.*, 1982).

Volcanic deposits of Late Cretaceous (*ca*. 67.5-75.3 Ma, Campanian to Maastrichtian) age are uncommon, but have been mapped in isolated localities spanning the breadth of Stikine terrane in central British Columbia (Figure 6). They typically occur as relatively thin tuffs, breccias and flows of andesitic to rhyolitic composition and form rare plutonic bodies (Diakow and Levson, 1997; Diakow, 2006). Because of their spatial association with plutons from the Bulkley Intrusive Suite (*ca.* 88-70 Ma) and/or co-magmatic volcanic rocks of the Kasalka Group, they presumably represent a waning stage of continental-margin arc-magmatism manifest as relatively small-volume felsic eruptive centres with areally restricted distribution.

A well-established genetic association exists between biotite-hornblende granodiorite and quartz diorite of the Late Cretaceous Bulkley suite and Cu±Mo±Au porphyry, polymetallic vein and other styles of mineralization across the Skeena Arch (Carter, 1981; MacIntyre 1985, 2006, 2007). Polymetallic Au-Ag-Zn-Pb-Cu vein mineralization at the past-producing Silver Queen mine, located 25 km northwest of the study area, is associated with porphyritic andesites and hypabyssal intrusions that yield *ca.* 77-75 Ma K-Ar dates (Church and Barakso, 1990), suggesting a correlation with the Kasalka Group (Leitch *et al.*, 1990, 1992; Figure 6).

In the Fawnie Range, located 110 km southeast of the study area, a quartz monzonite stock, garnet-sulphide bearing felsic dikes, and volcanic rocks of andesite to

Figure 2. Sample 10TFE060, a maroon-weathered, plagioclase-phyric dacite.

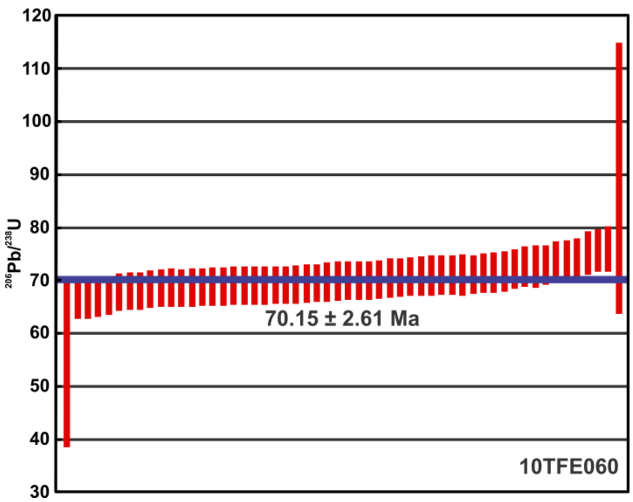

Figure 3. Crystallization age for sample 10TFE060 based on a weighted average of 54 $^{206}Pb/^{238}U$ dates from laser ablation data collected from zircon cores.

Figure 4. Sample 10TFE061, a massive, quartz and clay altered, porphyritic volcanic flow.

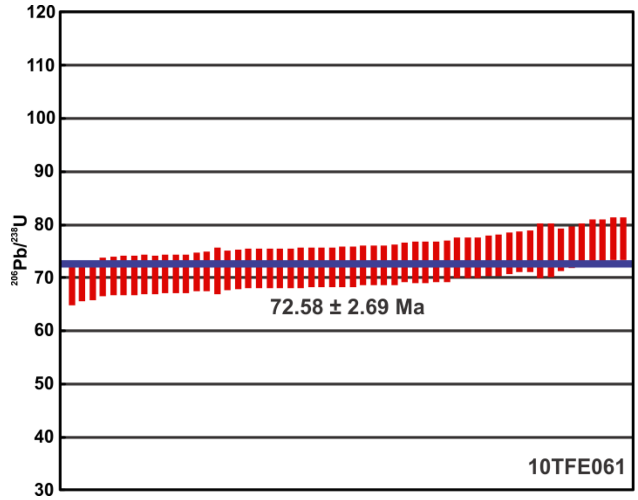

Figure 5. Crystallization age for sample 10TFE061 based on a weighted average of 54 $^{206}Pb/^{238}U$ dates from laser ablation data collected from zircon cores.

rhyolite composition mark the known southeastern extent of Late Cretaceous magmatic rocks, all of which are temporally equivalent to those in the study area (Diakow *et al.*, 1996; Diakow and Levson, 1997; Figure 6). Low grade, disseminated Ag±Zn±Pb±Au mineralization at the Capoose deposit is associated with rhyolite dikes and sills (D. Pawliuk, Silver Quest Resources Ltd., personal communication, 2011). These rocks outside the mineralized zone yield *ca.* 71Ma U-Pb dates (Friedman *et al.*, 2001). The Blackwater-Davidson deposit, 23 km southeast of Capoose, is a low grade disseminated gold deposit with mineralogic features resembling Capoose (*i.e.* garnet-sulphide-felsic rock association). However, this deposit exhibits alteration characteristics associated with low-sulphidation epithermal Au but lacks quartz veining. A recent resource estimate of the Blackwater Davidson deposit, at a cutoff grade of 0.4 g/t Au, indicates 53 million tonnes grading 1.06 g/t Au and 5.6 g/t Ag (Simpson, 2011).

The co-genetic relationship between Late Cretaceous magmatic rocks and precious-metal mineralization at the Capoose and Blackwater-Davidson deposits emphasizes the importance of U-Pb geochronology to discriminate favourable rock successions of similar age for greenfield exploration. New geochronology presented in this paper expands the known distribution of the youngest deposits of the Late Cretaceous Kasalka Group. However, the distribution of this potentially mineralized magmatic tract beyond the Fawnie Range southward, in the Interior Plateau region, remains unknown.

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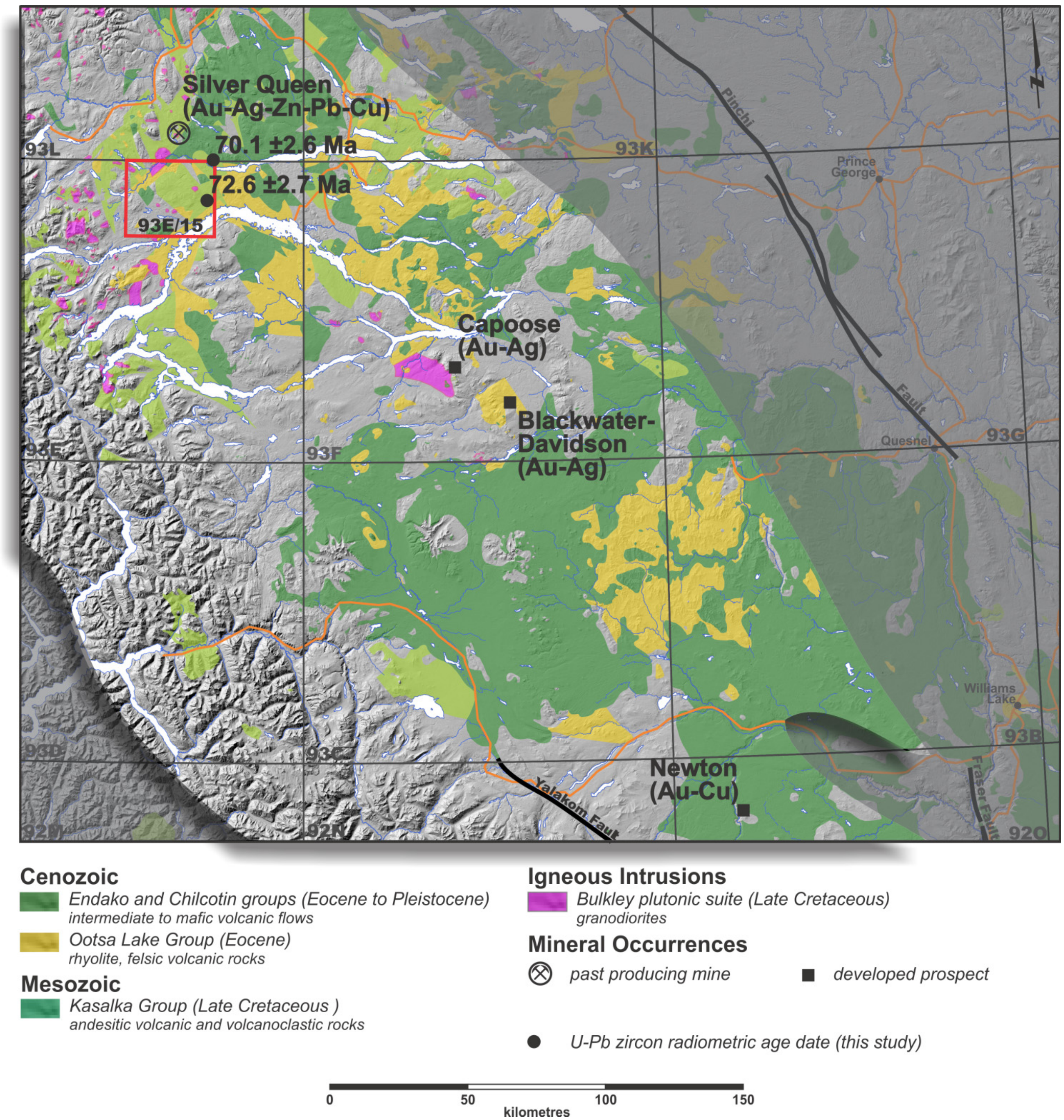

Figure 6. Spatial distribution of Late Cretaceous volcanic rocks within Stikine terrane (highlighted; modified from Massey *et al.*, 2005), showing locations of U-Pb zircon isotopic dates presented in this paper.

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