AGE OF THE WILLISON BAY PLUTON AND OVERLYING SEDIMENTS: IMPLICATIONS FOR THE CARNIAN STAGE BOUNDARY

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INTRODUCTION

A nonconformity between the granodioritic Willison Bay pluton and Triassic sediment is well exposed near the south end of Atlin Lake, northwestern British Columbia (NTS 104M/8; Figures 1 and 2). Earliest comprehensive mapping in the region (Christie, 1957) recognized this nonconformity and attributed a possible pre-Permian age to the Willison Bay Pluton on the basis of overlying sediments that contain clasts of the pluton, which in turn are capped by a limestone layer, believed at the time to be of Permian age. Bultman (1979) considered the limestone to be Upper Triassic (Norian or Carnian) in age based upon several fossil collections identified by John Wells (Cornell University) and himself. He correlated the limestone with the Sinwa Formation along southwest structural trend in the Tulsequah area. Subsequent mapping in the Atlin Lake (Mihalynuk *et al.*, 1990, 1996) and Tulsequah regions (Mihalynuk *et al.*, 1994, 1995, 1996) confirmed this correlation and led to the recognition of Carnian fossils within strata between Sinwa Formation and the eroded top of the Willison Bay pluton (Figures 2 and 3).

Bultman obtained K-Ar age determinations on hornblende from two samples of the Willison Bay pluton which gave 180 ±3 and 222 ±5 Ma (recalculated from 175 ±3 and 215 ±5 Ma, using revised decay constants of Steiger and Jäger, 1977). Argon loss during alteration of hornblende in the less fresh sample, probably accounts for the younger age. The older age is consistent with Norian fossils in the overlying strata based on the Norian age limits of Harland *et al.* (1990, 223.4 to 209.5; Figure 3), but is too young to be overlain by Carnian strata, unless the error limits for Carnian stage boundaries are considered (235 $^{+7.5}/_{-12}$ to 223.4 $^{+4}/_{-3}$ Ma; Harland *et al.* 1990, Table 5.4). New data presented here provides better control on the age of the pluton.

Absolute ages for Late Triassic stage boundaries are relatively unconstrained. They are interpolated from bracketing data sets, and as such, have large uncertainties. Imprecise Upper Triassic stage boundaries have been a source of confusion for mineral explorationists working in rocks from this important metallogenic time frame. Conflicting isotopic and biochronologic age determinations are recognized from geological investigations of the Guichon Creek Batholith (McMillan,

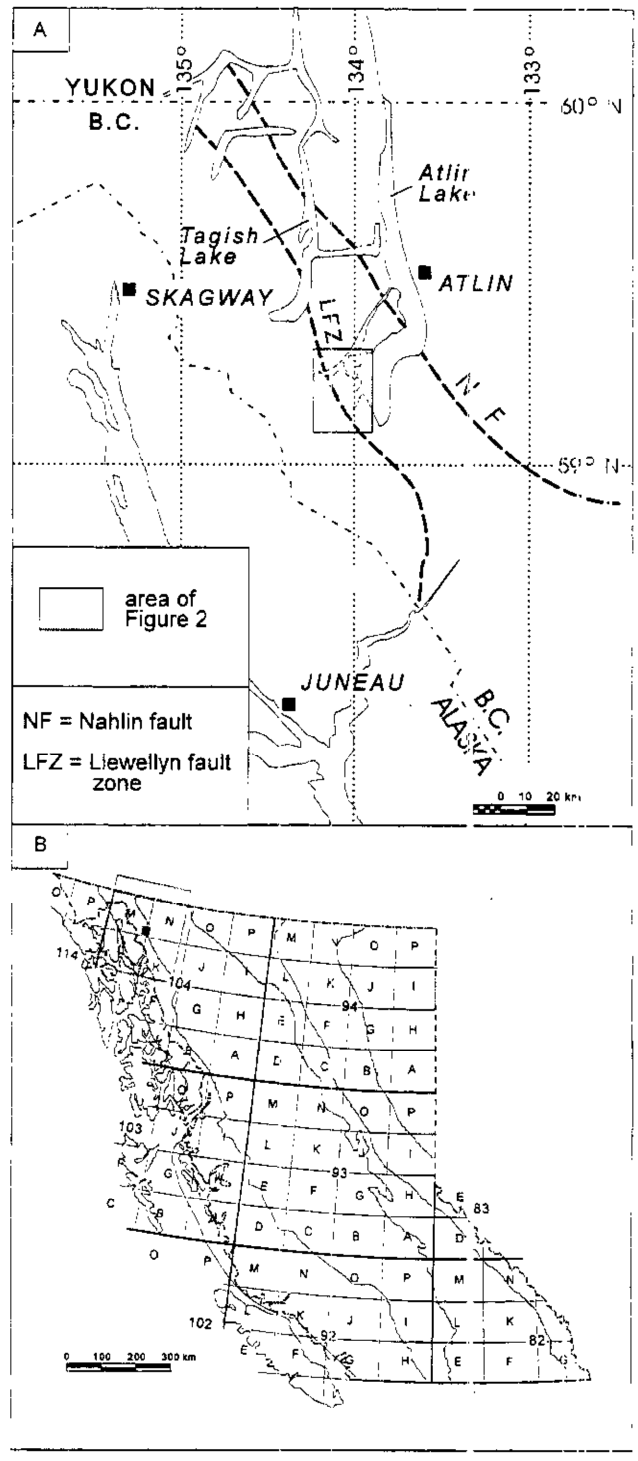

Figure 1. Location of the study area, southern Atlin Lake.

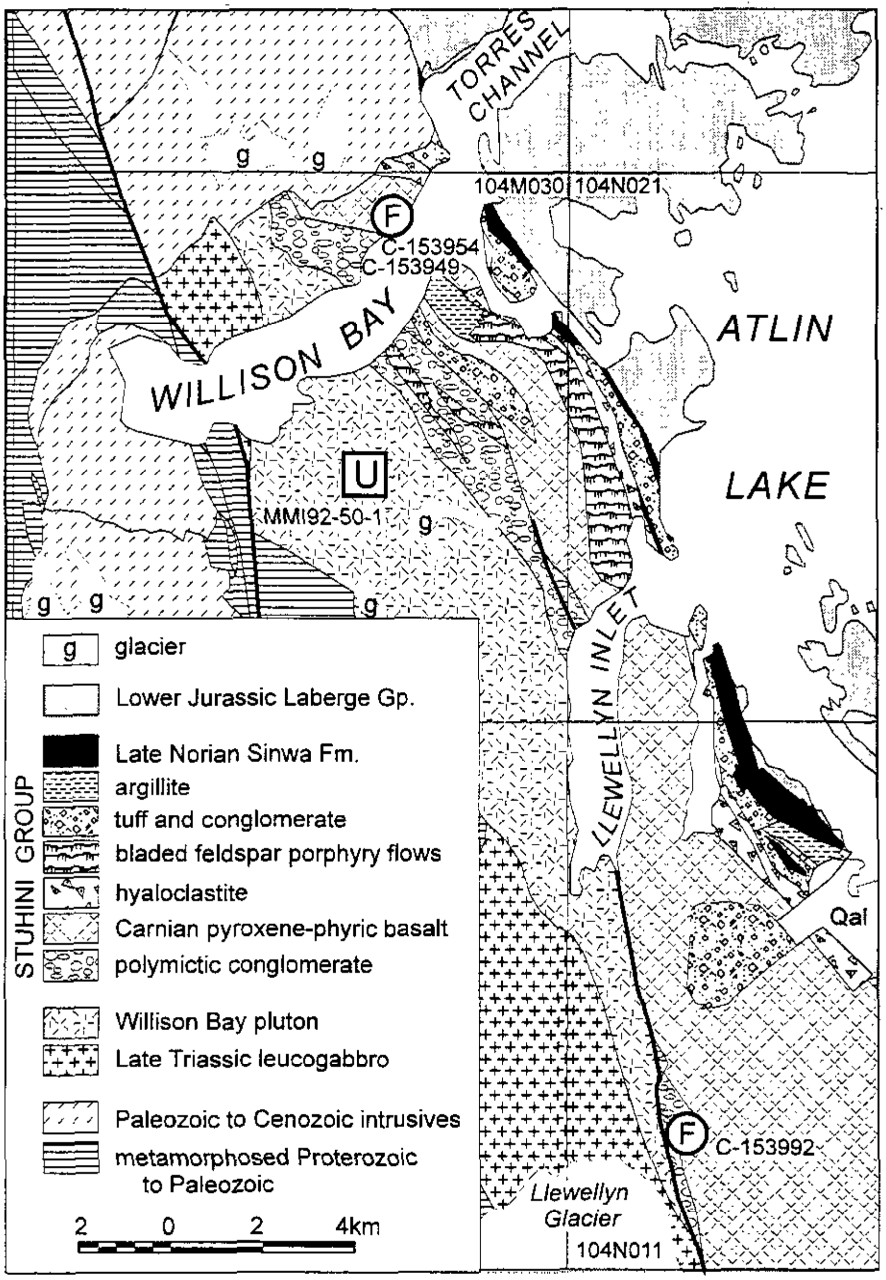

Figure 2. Generalized geology of area around Willison Bay (from Mihalynuk *et al.*, 1996) and location of fossil localities and U-Pb geochron sample site.

1976); Lost Horse intrusions of Copper Mountain (Preto, 1979); and plutons of the Missezula Lake area (Preto, 1972). Thus, it is important to establish precise age determinations for all Upper Triassic magmatic rocks with corresponding biostratigraphic age control, such as is the case for the Willison Bay pluton.

WILLISON BAY PLUTON SETTING

The Willison Bay pluton covers about 42 km^2 and extends from north of Willison Bay to the terminus of the Llewellyn Glacier (Figure 2). Resistant blocky outcrops typical of the pluton (Photo 1) weather grey to tan and are white, pink or tan on fresh surfaces. Some joint surfaces are coated with epidote and chlorite. A weak to moderate foliation may be displayed. Potassium feldspar megacrysts up to 5 centimetres long (normally 2.5 cm, 10%) may be weakly perthitic and commonly contain concentric zones of plagioclase and hornblende inclusions. Fresh, prismatic hornblende comprises up to 4% (3 mm), altered biotite to 3% ($\leq$2 mm), and fine to medium-grained titanite 2% of the rock. Locally, all major mineral phases are phenocrystic. At such localities K-feldspar megacrysts (10 to 15%) occur together with 4 mm tabular plagioclase phenocrysts (up to 60%), and grey quartz eyes (15%) in an aphanitic grey to pink groundmass. Modal mineralogy and X-ray fluorescence

Photo 1. Massive non-porphyritic phase of the Willison Bay pluton at the U-Pb age date sample site. Norm Graham for scale.

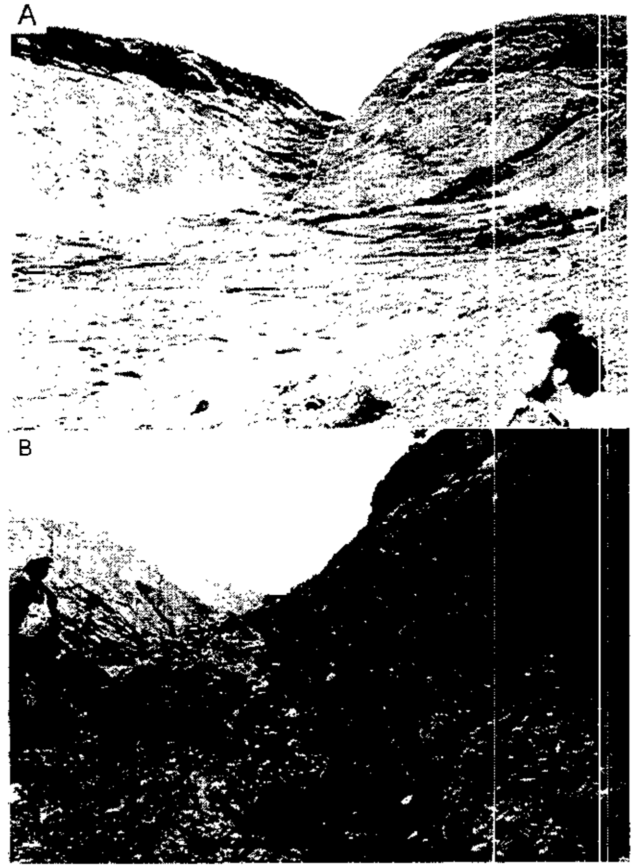

Photo 2. (a) View to the north of the Willison pluton's faulted eastern contact at the terminus of the Llewellyn Glacier. Conglomerate is visible at the far eastern foreground. (b) Close-up of the exposed faulted contact at Llewellyn Inlet. Craig Hart of the Yukon Geoscience Office for scale.

analysis of major oxides indicate that the pluton is a metaluminous calcic granite (Figure 4).

Western and southeastern contacts of the pluton are bounded by the Llewellyn Fault (Photo 2), a long-lived, high-angle crustal scale dip-slip fault, and a subsidiary, coalescing fault to the east. Southwestern pluton contacts are intrusive into greenstone of the Boundary Ranges Metamorphic Suite and foliated, polyphase leucogabbro that is probably comagmatic (Werner, 1978 unpublished; Wilton, 1971; Mihalynuk *et al.*, 1996 and unpublished). The pluton also intrudes leucogabbro on its northwestern margin. At its northern extremity, the Willison Bay Pluton is cut by the post-kinematic Cathedral Pluton of probable Late Cretaceous age. Contacts on the northwestern margin of the Willison Bay pluton are nonconformable with local, minor, syn-(?) and post-depositional fault disruption. A sample for U-Pb age determination was collected from central Willison Pluton where it crops out on the alpine plateau south of Willison Bay (NTS 104M/1, UTM 553200E 6567000N, Zone 8V; Photo 1).

U-Pb age determination

Six zircon fractions from sample MM 92-50-1 have been analyzed. Complete U-Pb analytical procedures employed at the UBC Geochronology are reported in Mortensen *et al.* (1995). Raw data are presented in Table 1, and the analyses are plotted on a concordia diagram in Figure 5. Five of the six samples lie on or near concordia along a chord which passes through zero and has an upper intercept age of 216 ±4 Ma. The sixth fraction, which consisted of unabraided fine non-magnetic zircons, appears to have lost lead. None of the fractions appear to contain significant amounts of inherited zircon, although fractions B and C may contain minor xenocrystic zircon. The linear array formed by fractions A, B and C suggests some degree of lead loss.

A best age estimate for this rock is 215.6 ±4 Ma, as defined by the correlated errors regression (Ludwig, 1980) that is forced through zero and all fractions. Support of this age is given by the mean $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages for the two concordant fractions F and G

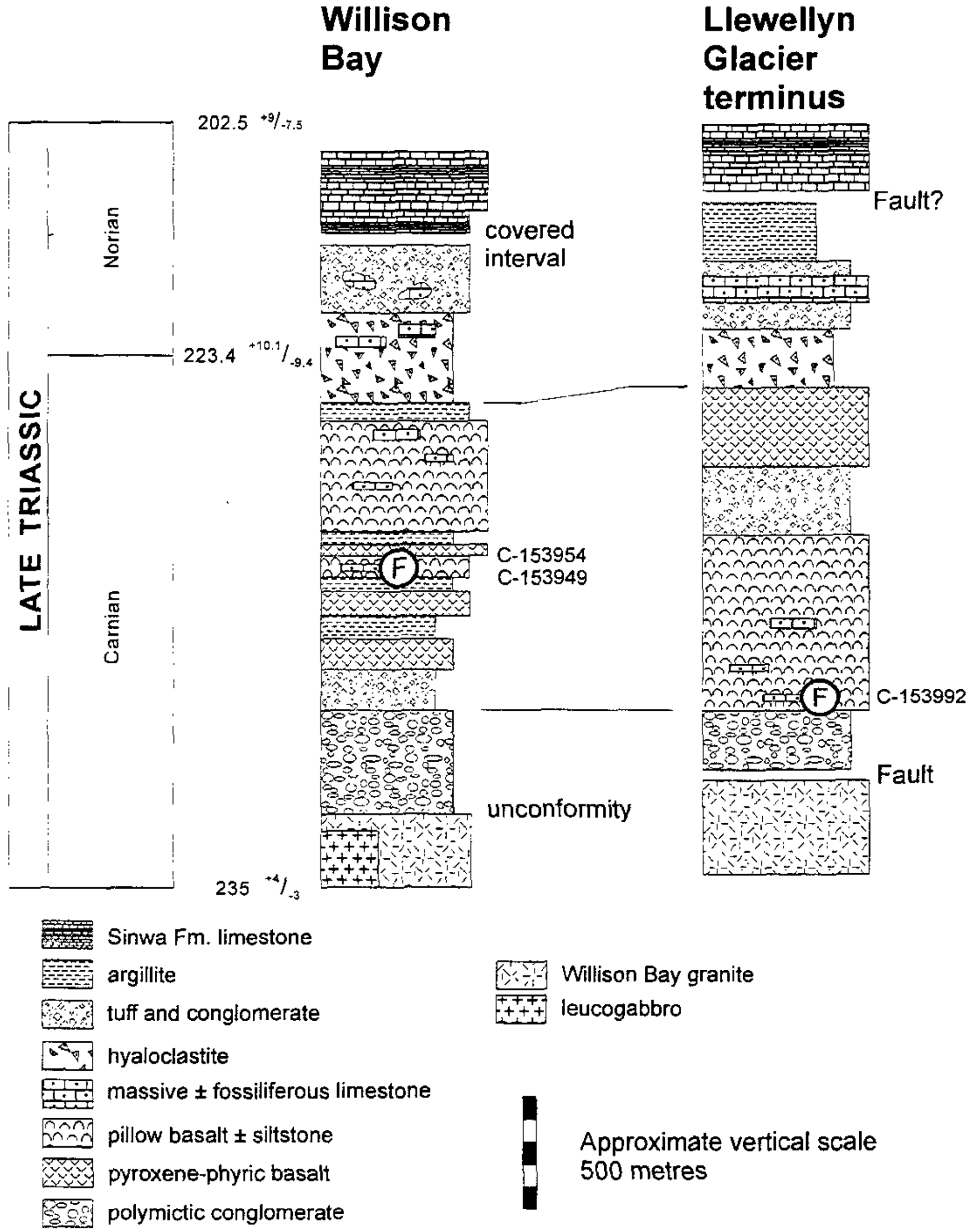

Figure 3. Stratigraphy of the Willison Bay area, location of the Willison Bay pluton chronostratigraphic tie point, and locations of micro and macrofossil faunas. Geologic time scale is that of Harland *et al.* (1990).

CARNIAN-NORIAN VOLCANO-SEDIMENTARY SUCCESSION

Volcano-sedimentary units that lie atop the Willison Bay pluton are described in Bultman (1979) and Mihalynuk and Mountjoy (1990). Readers interested in more comprehensive information about the Willison Bay section may wish to refer to these reports. Only selected parts of the succession are detailed here. A section from near the Llewellyn Glacier terminus is described here for the first time.

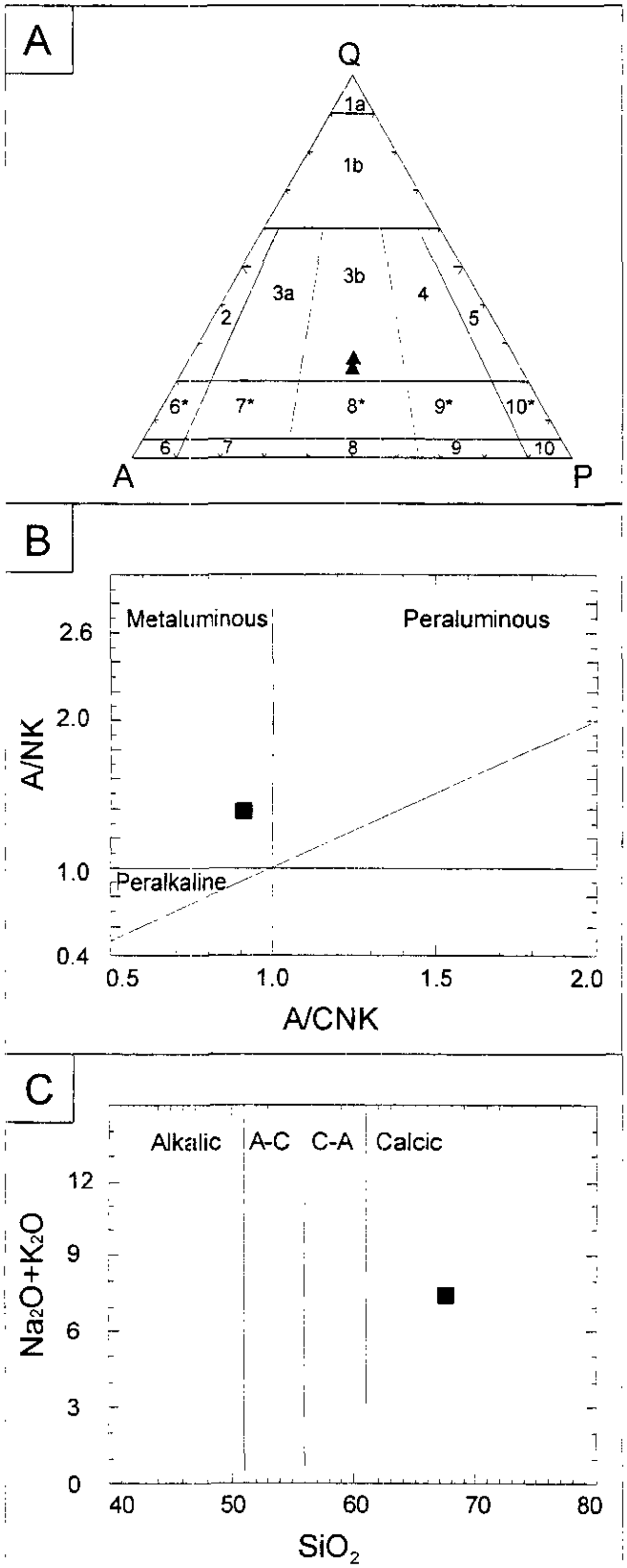

Figure 4. (a) Modal mineralogy plot of the Willison Bay Pluton where Q = quartz, A= alkali feldspar and P = plagioclase. (b) Granite classification diagram of Maniar and Piccoli (1989) shows the ratio of A/(N+K) versus A/(C+N+K) where A= Al_2O_3, C=CaO, N=Na_2O, K=K_2O. (c) Granite classification diagram of Peacock (1931) showing the ration of SiO_2 versus K_2O and Na_2O. Data are from X-ray fluorescence analysis of sample MMI89-2-2.

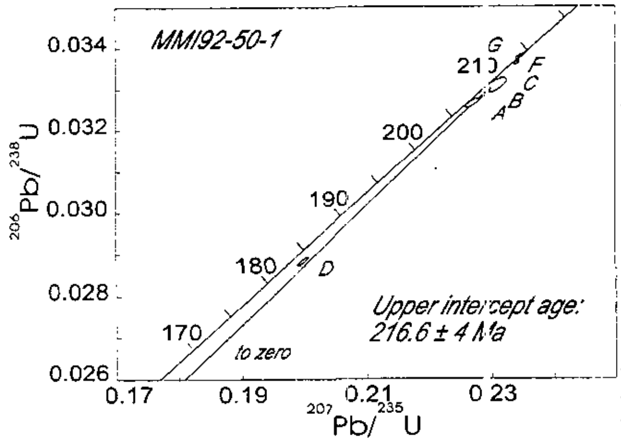

Figure 5. Concordia diagram for Willison Bay pluton sample number MMI92-50-1. Six fractions are plotted. Data is summarized in Table 1.

Willison Bay

One of the most complete and best exposed sections of Stuhini Group strata is exposed along the shores of Willison Bay. Between 2.5 (north shore) and 3 km (south shore) of strata are preserved above the Willison Bay pluton. Clast populations exhibit a 'reverse stratigraphy' recording exhumation of the Stuhini arc. Volcanic derived clasts dominate the lower conglomerates (Photo 3), plutonic clasts and finally metamorphic clasts gain importance in higher conglomerates. Where conglomerate directly overlies the Willison Bay pluton it is locally comprised of only pluton clasts. This makes it difficult to determine the exact contact location. Moving outwards from *bona fide* igneous textures in the pluton, feldspars become turbid and grain boundaries indistinct. At about 2m, vague boulder outlines (up to 1m diameter) with K-feldspar phenocrysts truncated at boulder margins, are apparent in what otherwise appears to be an intrusive rock. A few metres farther upsection, bedding with hydrodynamic sorting of mineral granules is apparent, and rare quartzite cobbles are present. Farther up section, intermediate volcanic clasts become an important, locally dominant, component. Some volcanic clasts are recycled volcanic conglomerate, all are apparently derived from the exhumed Stuhini arc as probable source rocks can be mapped to the north. Metamorphic clasts become more important upward, and at about 450m from the base, pyritic, siliceous phyllite chips dominate a 5-20m thick layer. Fine-grained clastic layers become more prominent and are punctuated by maroon and green tuffite (Photo 4). Increasingly sparse pluton clasts and common layers of pyroxene crystal-rich clastics mark a transition from arc erosion to another constructional phase. Sheets of pyroxene-phyric basalt (2-20m thick) punctuate deposition of calcareous siltstone and argillite (1-3m thick). About 350m above the first basalt flows (~1100m above the base) are flows comprised of large pillows (2m diameter) with interpillow micrite (Photo 5). These sit

TABLE 1. U-PB ANALYTICAL DATA FOR WILLISON BAY PLUTON SAMPLE MMI92-50-1.

Fraction[1,2]		Wt.	U[3]	Pb[3]	^{206}Pb[4]	Pb[5]	^{208}Pb	Isotopic Ratio (± %1σ)			Apparent Age (Ma, ±2σ)	
		mg	ppm	ppm	^{204}Pb	pg	%[6]	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
A	+a	0.709	420	14	3193	185	8.2	0.03265 (0.18)	0.227 (0.24)	0.05042 (0.14)	207.1 (0.7)	214.6 (6.4)
B	-b+c	0.491	485	16	10571	45	8.7	0.03286 (0.22)	0.229 (0.22)	0.05054 (0.05)	208.4 (0.9)	220 (2.2)
C	-c+d	0.170	552	18	4176	46	9.3	0.03308 (0.27)	0.2308 (0.36)	0.05061 (0.25)	209.8 (1.1)	223.2 (12)
D	-d na	0.278	795	23	3280	122	9.4	0.02884 (0.19)	0.1998 (0.22)	0.05025 (0.08)	183.3 (0.7)	206.4 (3.8)
F	+b	0.182	408	14	2831	55	8.7	0.03362 (0.07)	0.2341 (0.09)	0.05051 (0.06)	213.1 (0.3)	218.7 (2.7)
G	+b tips	0.208	402	13	5027	35	8.3	0.03376 (0.10)	0.2346 (0.13)	0.05039 (0.08)	214.1 (0.4)	213.1 (3.6)

Notes: Analyses by J.E. Gabites, in the Geochronology Laboratory, Department of Earth and Ocean Sciences, U.B.C. IUGS conventional decay constants (Steiger and Jäger, 1977) are: $^{238}U\lambda=1.55125x10^{-10}a^{-1}$, $^{235}U\lambda=9.8485x10^{-10}a^{-1}$, $^{238}U/^{235}U=137.88$ atom ratio.

1. Column one gives the label used in the Figure.
2. Zircon fractions are labelled according to magnetic susceptibility and size. NM = non-magnetic at given amperes on magnetic separator. Side slope is given in degrees. All fractions are NM2A/1°, abraded except where indicated (na). Size fractions are: a 149, b 104, c 74, d 44μm. The - indicates zircons are smaller than, + larger than the stated size.
3. U and Pb concentrations in mineral are corrected for blank U and Pb. Isotopic composition of Pb blank is 206:207:208:204 = 17.299:15.22:35.673:1.00, based on ongoing analyses of total procedural blanks of 37 ± 1 pg (Pb) and 6 ± 0.5 pg (U) during the time of this study.
4. Initial common Pb is assumed to be Stacey and Kramers (1975) model Pb at the $^{207}Pb/^{206}Pb$ age for each fraction.
5. Radiogenic Pb.
6. Total Common Pb in analysis.
7. Errors are % 1σ except $^{207}Pb/^{206}Pb$ age errors which are 2 σ in Ma.

above a scoured bed of *Halobia*-bearing siltstone-argillite. The interpillow micrite contains Carnian conodonts (see below).

Approximately 700m of basalt flows and interflow sediments overly the Carnian fossil locality and are in abrupt contact with a distinctive, 200m thick, continuous belt of bright green, poorly lithified hyaloclastite breccia. These coarse pyroxene-phyric rocks display a sheared contact with overlying cherty, tuffaceous argillite and succeeding planar-bedded, quartz-rich, volcanic conglomerate and coarse lithic sandstone. Near the mouth of Willison Bay the volcanic conglomerate is structurally overlain by Sinwa Fm. carbonate, but the contact is intruded by The Cathedral pluton. On the south shore carbonate clasts within the conglomerate are common, suggesting a depositional tie with the overlying carbonate, but the contact is not exposed. Similar nebulous contact relations between Sinwa Formation and underlying volcanic conglomerate exist farther south along Atlin Lake.

Llewellyn Glacier terminus

Near the terminus of the Llewellyn Glacier, the Willison Bay pluton is in fault contact with up to 260m of basal conglomerate. Like the section north of Willison Bay, the lower part of the basal conglomerate is dominated by clasts derived form the pluton. Contained within the conglomerate are layers of red ash tuff, disrupted argillite and oncolitic carbonate. Metamorphic clasts are abundant at the top of the conglomerate, where it is overlain by pyroxene-feldspar crystal tuff and pyroxene-porphyry flows and flow breccia. Overlying, dark green, pillow basalt flows are porphyritic with medium to coarse-grained, crowded pyroxene (25%) and medium to fine-grained, tabular plagioclase (20%;). Laminated micrite at pillow intersections contains Carnian conodonts (Table 2). An approximate 800m thickness of flows is exposed in semi-continuous outcrop. A covered interval separates them from presumably overlying maroon lapilli tuff comprised mainly of fine plagioclase porphyry.

Fossil age dates

Siliceous argillite and fine siltstone containing *Halobia* (NWI89-4-3c and MMI89-4-3c; Table 2) are directly overlain by pillow basalt with interpillow micrite containing Carnian conodonts (MMI89-4-3; Table 2; Photo 5). *Halobia* are not sufficiently well preserved to permit identification to the species level. Thus, an age no more precise than Late Triassic can be assigned.

Photo 3. Polymictic conglomerate derived in part from the Willison Bay pluton. Farther down section this conglomerate is composed entirely of pluton-derived clasts.

Conodonts were extracted from samples of interpillow micrite from the Willison Bay and Llewellyn Glacier terminus areas. They occur 1000m and 300m respectively, above the main conglomerate unit (MMI89-4-3 and MMI91-29-2-3, Table 2; Figures 1, 2). Both samples contain Metapolygnathus identifiable only to the genus level; nevertheless, a Carnian age can be assigned.

Photo 4. Tuffaceous interbeds within the basal conglomerate indicates the onset of an arc constructional phase. Note white granitoid boulders at right.

DISCUSSION

New age data from the Willison Pluton and overlying strata indicate that the present age assigned to the Carnian-Norian stage boundary is too old. Revision is in order if the following conditions are true: (1) the estimated isotopic age is an accurate reflection of the true age of the pluton, and (2) there are no cryptic thrust faults between plutonic conglomerate and fossil-bearing strata.

Condition 1 appears satisfied since the U-Pb age reported here (216.6 ±4Ma) is the most precise age determination from this body to date, is concordant with an earlier K-Ar age determination (222 ±5 Ma; Bultman, 1979), and is concordant with a U-Pb date from the Tally Ho leucogabbro along the Llewellyn fault in the Yukon (213.6 ±0.6 Ma; Hart, 1995). Tally Ho leucogabbro is correlated with the leucogabbro at Willison Bay which, based upon textural evidence, is believed to be a coeval precursor intrusive pulse of the Willison Bay pluton.

Condition 2 also appears to be satisfied. Although the section contains a mapped fault, it is a high angle fault which does not repeat stratigraphy. Preservation of an original stratigraphic succession without repetition is supported by: (1) lack of any near bedding parallel

TABLE 2. CARNIAN-NORIAN FOSSIL COLLECTIONS FROM THE WILLISON BAY AND NEARBY CORRELATIVE STRATA.

Field No.	GSC No.	UTM E Zone 8	UTM N	Fossil Genus and Species	Determined Age
Norian Conodonts					
87JR-45-5	C-153920	52375	6625350	Epigondolella ex gr. bidentata Mosher	Late Norian
Carnian Conodonts					
MMI89-4-3	C-153954	553500	6572000	Metapolygnathus sp.	Carnian
MMI91-29-3-2	C-153992	559450	6555800	Metapolygnathus sp.	Carnian
Carnian Macrofossils					
NWI89-4-3c	C-153949	553500	6572000	*Halobia* sp.	Upper Triassic
MMI89-4-3c	C-153962	553500	6572550	*Halobia* sp.	Upper Triassic

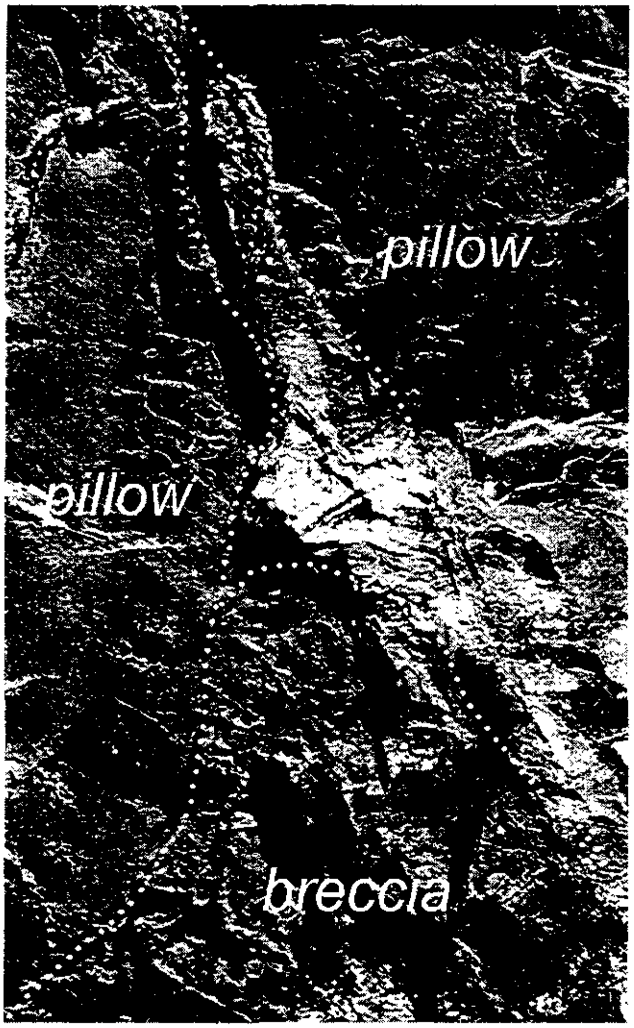

Photo 5. Pillow basalt with interpillow micrite containing Carnian conodonts sits atop a scoured set of silty argillite beds containing Halobia.

foliated zones, (2) upsection decrease in abundance of igneous clasts derived from the Willison Bay pluton, (3) upsection increase in pyroxene crystal tuff component of sediments upon approaching pyroxene basalt flow units.

Exposed sections indicate that at least 1 km of strata was deposited atop the eroded Willison Bay pluton prior to deposition of strata containing Carnian fossils. Hence, the Carnian fossils must be younger than 216.6 ±4 Ma. The Carnian-Norian boundary set by Harland *et al.*, at 223.4 $^{+4}/_{-3}$ Ma, is concordant with the new U-Pb date, but only at the very limit of combined errors. A downward revision of the Carnian-Norian boundary by a minimum of 2.8 Ma is required to agree with the maximum age indicated by the U-Pb date (220.6 Ma). This still assumes that no time elapsed while the Willison Bay pluton was intruded, cooled, exhumed, eroded and buried by 1 km of sediment. The youngest exposed granitoid pluton known on Earth has a solidification age of 2.2 ±0.3 Ma and was probably exposed in middle Pleistocene time (Harayama, 1992). If Willison pluton exhumation was equally quick, and if immediately following exhumation, the overlying sediments were instantaneously deposited, the Carnian fossil site would have a minimum absolute age of about 214.4Ma.

A more precise Late Triassic time scale for the British Columbian Cordillera will be of benefit to mineral explorationists, regional mappers and researchers with interest in this important metallogenic epoch. Ongoing revision of the Late Triassic time scale will also complement the work of J. Pálfy (e.g. Pálfy, 1996) which focuses on revision of the Jurassic Time Scale.

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