U-Pb Zircon and Titanite Dating of Intrusive Rocks in the Heffley Lake Area, South-Central British Columbia

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INTRODUCTION

This paper presents new U-Pb data and interpreted magmatic ages for two intrusions in the Heffley Lake area. The oldest of these, the mafic-ultramafic Heffley Creek Pluton (Ray and Webster, 2000a and b) is a pre or syntectonic intrusion related to a swarm of altered dikes and the Fe oxide-Cu-Au Heff skarn (BC MINFILE 092INE096). The other intrusion is part of a younger suite of feldspar megacrystic alkalic intrusions of syenitic to quartz monzodiorite composition that post-date the main tectonic event. These new radiometric ages are significant in dating the structural, plutonic and mineralizing history of the Heffley Lake area.

LOCATION AND GENERAL GEOLOGY

INTRODUCTION

The Heffley Lake area lies within the Intermontane Belt approximately 26 km northeast of Kamloops. Metasedimentary rocks of the Quesnel Terrane and younger intrusive rocks dominate the area (Figure 1). The area includes the west-northwest trending contact between Late Triassic Nicola Group calcareous sediments and tuffs to the north, and Paleozoic sediments and volcaniclastics of the Harper Ranch Group to the south (Figures 1 and 2). The contact between these two groups has been intruded by the Heffley Creek Pluton (Figures 1 and 2; Ray and Webster, 2000a and b), an elongate, large (> 13 km^2) body which includes magnetite-rich ultramafic pyroxenites, mafic gabbros and diorites, and more felsic marginal phases. The Nicola Group limestones adjacent to the northern margin of the pluton contain some magnetite-Cu-Au-bearing skarns that make up the Heff prospect (also known as the Iron Range, Hal or Mesabi claims). These skarns are spatially associated with a swarm of deformed, highly altered dioritic dikes and sills related to the nearby Heffley Creek Pluton (Figure 3; Ray and Webster, 2000a).

Small bodies of feldspar megacrystic syenitic rocks intrude the Harper Ranch Group, south of Heffley Lake, and are probably part of the Mount Fleet Complex farther south (Figure 1; Kwak, 1964; Webster and Ray, 2001).

STRATIFIED ROCKS

The stratified rocks in this area were originally mapped as Cache Creek Group (Cockfield, 1944, 1947), but subsequently Monger and McMillan (1989) included them in the Quesnel Terrane. Recent mapping (Ray and Webster, 2000a and b) and microfossil identification (M.J. Orchard, personal communication, 2000) suggest they can be separated into northern and southern packages that belong to the Nicola and Harper Ranch groups, respectively (Figure 2). The rocks in both groups comprise mainly steeply dipping, northwest-striking argillites and calcareous siltstones with lesser andesitic ash and lapilli tuff and some limestone. These were intruded by the Heffley Creek Pluton, probably during a period of folding and lower to sub-greenschist facies metamorphism that produced slatey and phyllitic fabrics. Immediately northeast of the pluton, the Late Triassic Nicola Group limestones and a swarm of altered dioritic dikes host the Heff magnetite-bearing garnet-pyroxene Cu-Au skarns (Figure 2 and 3).

The Harper Ranch rocks south of the Heffley Creek Pluton include units of crinoidal limestones containing Carboniferous-Permian age microfossils (Figure 2; M.J. Orchard, personal communication, 2000). Adjacent to the pluton these carbonates are bleached and recrystallized to marble but, unlike the Nicola Group limestones farther north, skarns are not present. The Heffley lakes obscure the northwest-trending contact between the Nicola and Harper Ranch groups but the contact continues southeastwards along Armour Creek (Figure 2). This stratigraphic contact was intruded by the Heffley Creek Pluton and has subsequently been the locus of brittle movement along the Armour Creek Fault (Figure 2).

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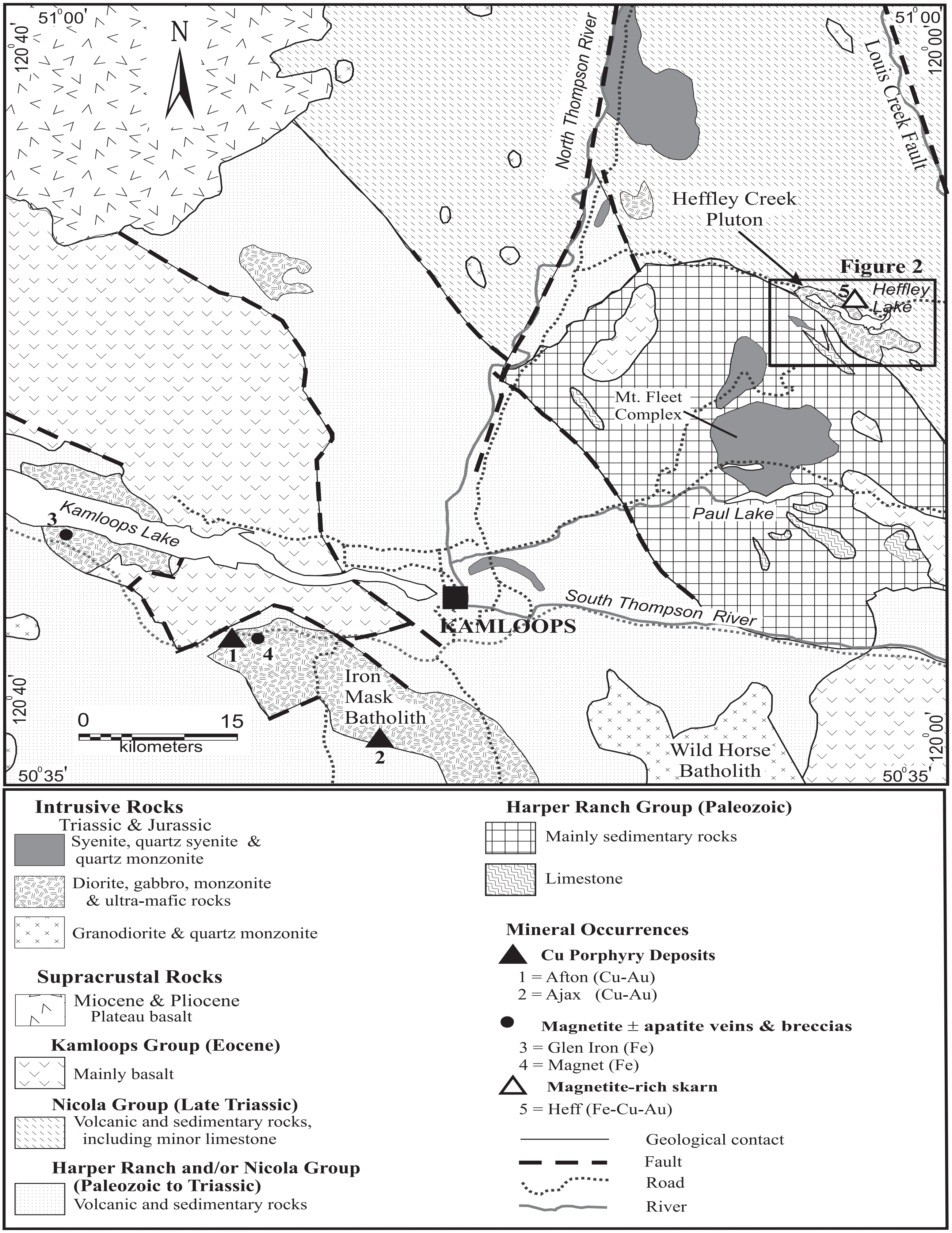

Figure 1. Regional geology and mineral occurrences in the Kamloops-Heffley Lake dis

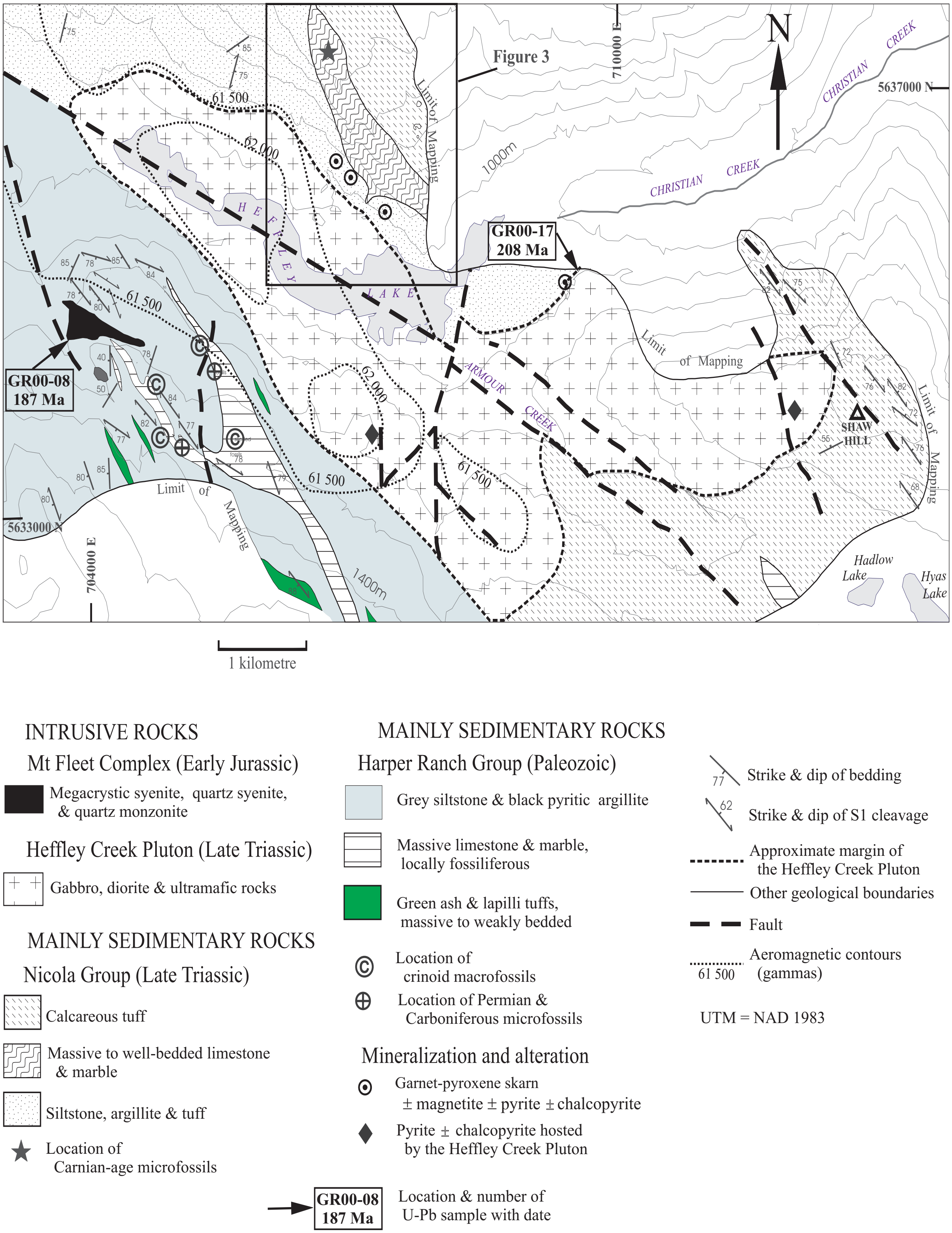

Figure 2. Geology of the Heffley Lake area showing location of the microfossil and U-Pb zircon samples. Geology after Ray and Webster (2000a and b).

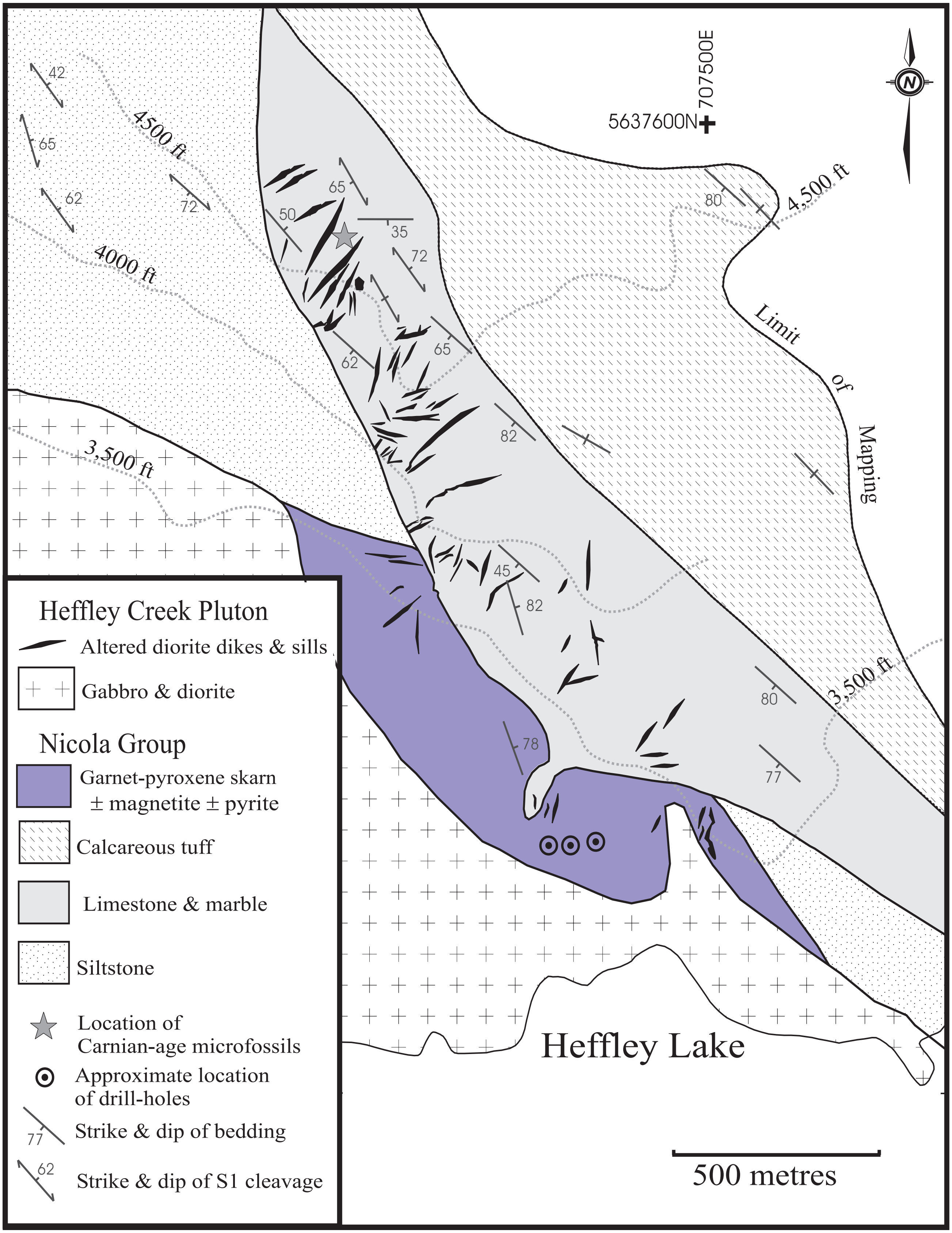

Figure 3. Geology of the Heff Fe-Cu-Au skarn, south-central British Columbia. After Casselman (1980), Arseneau (1997) and Ray and Webster (2000a and b).

INTRUSIVE ROCKS

Introduction

Two intrusive phases are recognized. The oldest and largest of these is the Heffley Creek Pluton and its marginal dike-sill swarm (Figure 2 and 3). This phase either predates or was coeval with the district-wide folding, and was affected subsequently by younger brittle movement along the Armour Creek Fault (Figure 2).

A younger generation of intrusions post-dates the folding but have undergone late brittle faulting. This phase resulted in several minor bodies of distinctive feldspar megacrystic syenitic intrusions, the largest of which outcrops 2 km southwest of Heffley Lake (Figure 2).

Heffley Creek Pluton and its Related Dike-Sill Swarm

The elongate Heffley Creek Pluton is traceable over a 13 km^2 area from Heffley Lake eastwards to Shaw Hill (Figure 2). The pluton, which intrudes the Nicola and Harper Ranch groups, includes early ultramafic rocks and younger gabbros and diorites. In addition, the swarm of sills and dikes on the Heff skarn property, north of Heffley Lake, is probably related to the pluton.

The ultramafic rocks, including pyroxenites and hornblendites, occupy the central parts of the pluton. They are dark, coarse grained (up to 0.5 cm) massive rocks that commonly contain up to 2 % disseminated pyrite and up to 10 % disseminated magnetite. The latter mineral gives rise to a 6 km-long magnetic anomaly as outlined by a government aeromagnetic survey (Map 4411G) (Figure 2).

Feldspar Megacrystic Syenitic Intrusions

These minor, <3 metre-thick dikes and sills are widely scattered throughout the area and they intrude both the Nicola and Harper Ranch groups. Southwest of Heffley Lake, however, larger bodies up to 300 m wide and 1 km in strike length occur (Figure 2). These syenitic rocks are believed to be a northern extension of the Mount Fleet Alkaline Complex, which intrudes Harper Ranch Group rocks farther south (Figure 1). The complex includes large subcircular bodies of quartz monzonite and megacrystic syenite as well as smaller bodies of garnetiferous and mafic shonkonite (Kwak, 1964). The Mount Fleet Complex has been identified as a potential host for platinum-group-element (PGE) mineralization (Webster and Ray, 2001).

The syenites in the Heffley Lake area form leucocratic, buff coloured rocks that contain up to 7 % remnant mafic amphibole and biotite, both of which are extensively chloritized, as well as trace to minor amounts of glassy quartz. The syenites are characterized by abundant (up to 30 %), elongate, euhedral to subhedral megacrystic feldspar laths which are generally between 2 and 4 cm long, although locally crystals exceed 15 cm. Some of these pale brown phenocrysts have thin, light coloured margins and are partially resorbed. Many crystals show a pronounced parallel orientation due to igneous flow. Where intrusive-country-rock contacts are exposed, no chilled margins are detectable, although thin (<0.5 m wide) zones of silicification and hornfels occur adjacent to some dikes. In areas of faulting, many syenitic outcrops are cut by sets of parallel, tension-filled white quartz veins up to 1 cm thick.

STRUCTURE

One episode of major folding is recognized (F1), which overprints both the Nicola and Harper Ranch rocks. This resulted in the moderately to steeply dipping beds and a southeast-trending axial planar slatey cleavage (S1). Very few minor F1 folds have been identified, but bedding-cleavage intersections in the Nicola Group limestones north of Heffley Lake reveal the presence of several tight synforms and antiforms.

During the F1 episode, limestones throughout the area underwent ductile deformation. The Heffley Creek Pluton generally lacks any S1 tectonic cleavage, although it occurs locally along the pluton margins. Many dikes on the Heff property were disrupted by boudinage and brittle extension, and some are folded and cut by the S1 slatey cleavage. Stereo plots of bedding and S1 cleavage measurements indicate that the tight F1 folds have subhorizontal to gently south-easterly plunging axes and their axial planes are southeast-striking and steeply northeast-dipping (Ray and Webster, 2000b). Most of the altered sills and dikes on the Heff property strike northeasterly (Figure 3) and are structurally controlled by a-c fractures developed during the F1 folding. The folding of some sills and dikes together with their a-c joint control is strong supportive evidence that both the intrusions and the skarns were coeval with the F1 deformation.

CHEMISTRY OF THE INTRUSIVE ROCKS

Figure 4 includes chemical plots of analytical data (Ray and Webster, 2000a and b) for the main body of the Heffley Creek Pluton, its related dike swarm, and the younger megacrystic syenites. All are metaluminous and representative of volcanic-arc granitoids, as defined by Pearce *et al*., 1984 (Figures 4F and G). The syenitic suite is alkalic (Figures 4A, D and E) and ranges in composition from syenite to quartz-monzodiorite. The gabbroic and dioritic samples from the main part of the Heffley Creek Pluton range from felsic quartz diorite to mafic gabbro-diorite, and their total alkali-silica content indicates a weak alkalic affinity (Figures 4A, D and E).

MINERALIZATION

The following two types of mineralization are identified in the Heffley Lake area, both of which are associated with the Heffley Creek Pluton (Ray and Webster, 2000a and b; Webster and Ray, 2001):

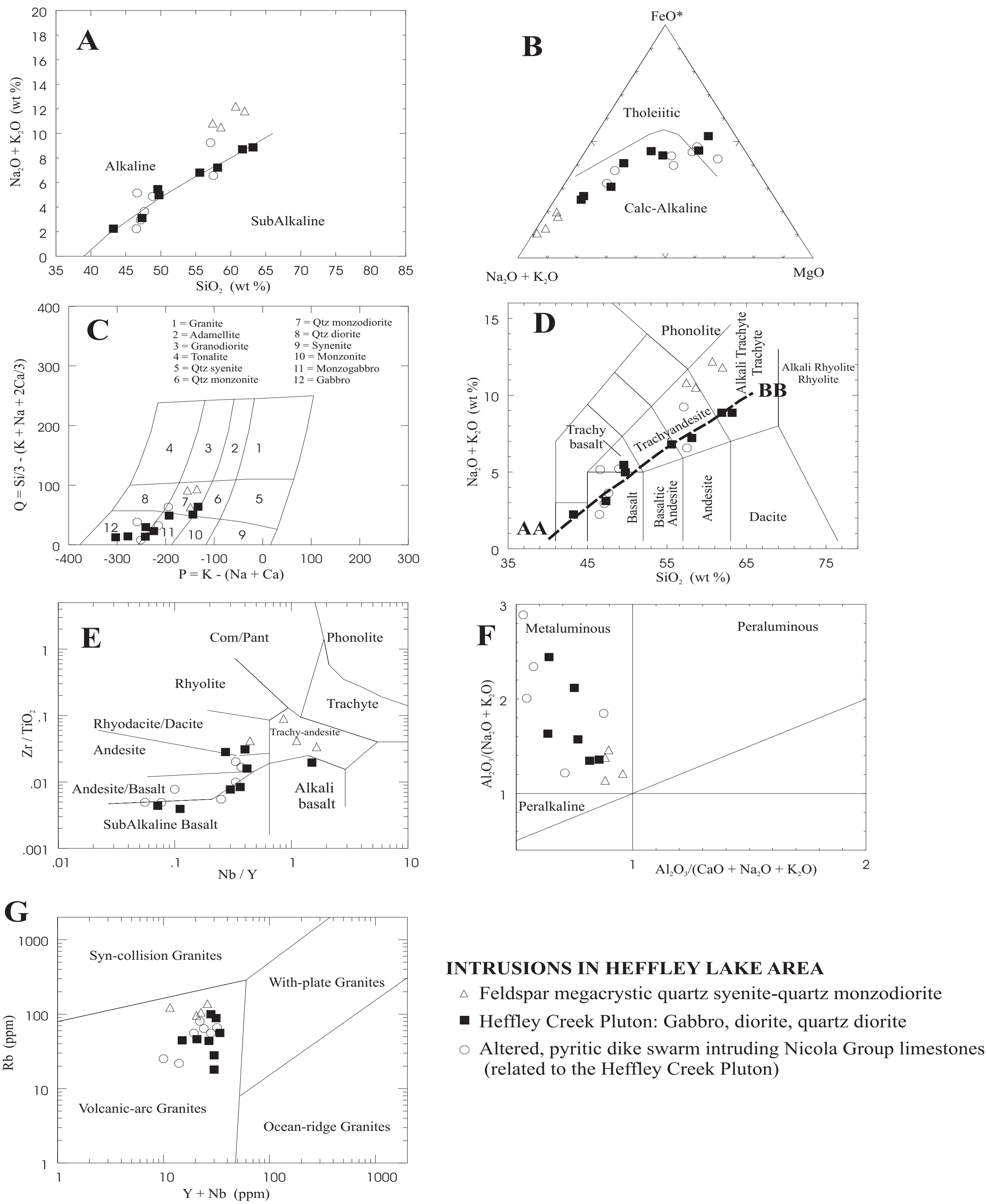

Figure 4. Major and trace element plots of the intrusive rocks, Heffley Lake area (data from Ray and Webster, 2000a and b).
A&B: Alkali-silica and AFM plot (after Irvine and Baragar 1971).
C: Q - P plot (after Debon and Le Fort, 1983).
D: Alkali versus silica plot (after Le Maitre *et al*., 1989). Line AA-BB represent alkaline-subalkaline line in Figure 4A.
E: Zr/TiO2 versus Nb/Y discrimination plot (after Winchester & Floyd, 1977).
F: Aluminum saturation plot (after Maniar and Piccolli, 1989).
G: Log Rb versus Log Y+Nb tectonic discrimination plot (after Pearce *et al*., 1984).

1. Magnetite-rich chalcopyrite ± Au ± REE garnet-pyroxene skarns as seen at the Heff prospect, and
2. Disseminations and veins of chalcopyrite ± magnetite-pyrite mineralization, possibly representing porphyry Cu-style mineralization as hosted by the Heffley Creek Pluton (Figure 2).

In addition, both the Heffley Creek Pluton and the younger megacrystic syenitic have a potential for hosting sulphide-rich PGE mineralization, similar to that identified in other alkalic complexes (Nixon *et al*., 2001).

U-Pb GEOCHRONOLOGY

Zircons for U-Pb dating were extracted from two samples collected from the Heffley Creek Pluton and a smaller syenitic body in the Heffley Lake area. Sample locations are shown in Figure 2 and listed in Table 1. The Heffley Creek Pluton material (GR00-17) is a leucocratic quartz diorite taken from the margin of the intrusion, while the other (sample GR00-08) is a megacrystic quartz-bearing syenite. The U-Pb data are presented in Table 1 and plotted at the 2 sigma level of uncertainty on standard concordia diagrams (Figure 5A, 5B). U-Pb analytical techniques at The University of British Columbia, Geochronology Laboratory, where all work was carried out, are given in Friedman *et al*. (2001).

The Heffley Creek Pluton sample (GR00-17) yielded good quality, clear, euhedral prismatic zircons and clear, pale yellow euhedral titanites. U-Pb results for four multi-grain zircon fractions and three multigrain titanite fractions are plotted on Figure 5A. Zircon and titanite data define a linear array interpreted as a Pb-loss chord; there is no indication of inherited components in any of the analyses. An interpreted age of 208.1 ± 6.1 Ma is based on the weighted mean of $^{207}Pb/^{206}Pb$ dates for all of the analyses, but is strongly controlled by relatively precise zircon data.

The syenite sample (GR00-08) yielded abundant clear, pale to vivid pink, euhedral, equant zircons. Many grains were broken or had a high density of cracks. Faint igneous zoning was observed in some grains but no cores were seen. The coarsest (>149 micrometres), unbroken, crack-free grains with the palest colour and highest clarity were selected for analysis. These were then strongly air abraded so that an estimated 15-25 volume percent of the outer portions of grains were removed. The abraded grains were divided into five multigrain fractions, consisting of five to eleven grains or pieces of grains in each (Table 1).

All analysed fractions give discordant results with $^{207}Pb/^{206}Pb$ dates of ~184-189 Ma (Table 1; Fig. 5B). Discordance is attributed to Pb loss in these very high uranium-bearing zircons (~1500-2000 ppm). An age estimate of 186.9 ± 1.7 Ma for the crystallization of this syenite is based on the weighted mean of $^{207}Pb/^{206}Pb$ dates for the five analysed fractions.

SUMMARY AND CONCLUSIONS

These new U-Pb zircon dates are important because they reveal the timing of the deformation, plutonism and skarn mineralization in the Heffley Lake area. They are interpreted as follows:

1. The 208 Ma (Late Triassic) age for the Heffley Creek Pluton (sample GR00-17) is believed to date both the emplacement of the pluton and the subsequent development of the Heff Fe-Cu-Au skarn mineralization.
2. The intrusion of the megacrystic syenite took place circa 187 Ma during the Early Jurassic. This probably also dates the emplacement of the Mount Fleet Alkalic Complex farther south (Figure 1).
3. Field evidence indicates that the Heffley Creek Pluton is likely a syntectonic intrusion while the younger syenites are post-tectonic. This suggests that the deformation in this district took place circa 208 Ma and was terminated by 187 Ma. The deformation that affected the Heffley Creek Pluton and its country rocks is probably related to the docking of Quesnellia with Ancestral North America.
4. The Heffley Creek Pluton and the megacrystic syenites are separated by a 20 million year time interval which strongly suggests the two suites are unrelated.
5. Chemical analyses provide evidence that the Heffley Creek Pluton has alkalic affinities. This and its Late Triassic age closely resemble the Iron Mask Batholith (Preto *et al*., 1979; Kwong, 1987) southwest of Kamloops (Figure 1). The batholith hosts the Afton and Ajax porphyry copper deposits (Carr and Reed, 1976; Ross *et al*., 1995) and, like the Heffley Creek Pluton, is associated with magnetite-apatite-bearing mineralization at the Glen Iron and Magnet occurrences (Figure 1; Cann and Godwin, 1983; Hancock, 1988). This implies that the Heffley Creek Pluton and any satellite bodies warrant prospecting as a porphyry copper target.

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TABLE1
U-Pb ANALYTICAL DATA FOR INTRUSIVE ROCKS FROM THE HEFFLEY LAKE AREA

Fraction[1]	Wt (µg)	U^2 (ppm)	Pb^{*3} (ppm)	$^{206}Pb^4/^{204}Pb$	Pb^5 (pg)	$^{208}Pb^3$ (%)	Isotopic ratios (1 sigma, %)[6] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Apparent ages (2 sigma, Ma)[6] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
GR00-17 hornblende quartz diorite, Heffley Creek Pluton; UTM: zone 10, E 709570, N 5635364, NAD83; interpreted age: 208.1 ± 6.1 Ma												
A c,cl,pp,b,2	17	1198	42	3843	10	25	0.02909 (0.12)	0.2016 (0.24)	0.05028 (0.18)	184.8 (0.6)	186.5 (0.8)	207.9 (8.4)
B c,cl,pp,p,b,6	21	930	31	3795	9	21	0.02899 (0.12)	0.2009 (0.30)	0.05026 (0.24)	184.2 (0.4)	185.9 (1.0)	207 (11)
D f,cl,vp,p,b,14	14	721	24	1579	12	21	0.02922 (0.12)	0.2029 (0.59)	0.05035 (0.55)	185.7 (0.4)	187.5 (2.0)	211 (25/26)
F ff,cl,pp,b,50	13	739	24	1617	10	22	0.02760 (0.16)	0.1916 (0.67)	0.05035 (0.63)	175.5 (0.6)	178.0 (2.2)	211 (29/30)
T1 cc,y,py,cl	527	61	3.1	139	472	48	0.02880 (0.45)	0.1988 (1.5)	0.05005 (1.3)	183.0 (1.6)	184.1 (5.2)	197 (58/60)
T2 cc,y,py,cl	479	130	3.8	114	1190	7.3	0.02995 (0.57)	0.2091 (1.9)	0.05064 (1.5)	190.3 (2.1)	192.8 (6.6)	224 (70/73)
T3 cc,y,py,cl	409	273	7.9	100	2550	4.7	0.03057 (0.68)	0.2131 (2.2)	0.05057 (1.8)	194.1 (2.6)	196.2 (7.9)	221 (82/86)
GR00-08 megacrystic syenitic body; UTM: zone 10, E 703982, N 5634867, NAD83; interpreted age: 186.9 ± 1.7 Ma												
A cc,cl,pp,b,5	40	1494	46	20598	5	19	0.02748 (0.09)	0.1888 (0.16)	0.04984 (0.08)	174.8 (0.3)	175.6 (0.5)	187.7 (3.9)
B cc,cl,pp,b,11	40	1679	54	24058	4	23	0.02733 (0.09)	0.1877 (0.16)	0.04981 (0.08)	173.8 (0.3)	174.7 (0.5)	186.3 (3.8)
C cc,cl,pp,b,5	40	2059	68	28543	7	27	0.02665 (0.12)	0.1830 (0.18)	0.04982 (0.08)	169.5 (0.4)	170.7 (0.6)	186.4 (3.7)
D cc,cl,pp,b,6	74	1676	53	21798	10	23	0.02727 (0.11)	0.1871 (0.17)	0.04975 (0.08)	173.4 (0.4)	174.1 (0.5)	183.5 (3.8)
E cc,cl,pp,b,5	44	1986	64	15270	10	24	0.02739 (0.11)	0.1883 (0.17)	0.04987 (0.09)	174.2 (0.4)	175.2 (0.6)	188.8 (4.0)

[1] Upper case letter = zircon fraction identifier; T1, T2, etc, for titanites. All zircon fractions air abraded. All titanites unabraded; Grain size, intermediate dimension: cc=>149µm, c=<149µm and >134µm, m=<134µm and >104µm, f=<104µm and >74µm, ff <74µm; Grain character codes: b= broken, cl=clear; eq=equant; p=prismatic; pp=pale pink; py=flattened pyramid; vp=vivid pink; y=pale yellow. Zircons nonmagnetic on Franz magnetic separator at field strength of 1.8A and sideslopes of 1°-2°. Titanites nonmagnetic at 0.6A and 20° sideslope, and magnatic at 1.8A and 5° sideslope. Front slope of 20° for all.

[2] U blank correction of 1pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.004/amu).

[3] Radiogenic Pb

[4] Measured ratio corrected for spike and Pb fractionation of 0.0037/amu ± 20% (Daly collector), which was determined by repeated analysis of NBS Pb 981 standard throughout the course of this study.

[5] Total common Pb in analysis based on blank isotopic composition.

[6] Corrected for blank Pb (2-10 pg, zircon; 20 pg, titanite), U (1 pg, all) and common Pb concentrations based on Stacey and Kramers (1975) model Pb at the age or the $^{207}Pb/^{206}Pb$ age of the rock.

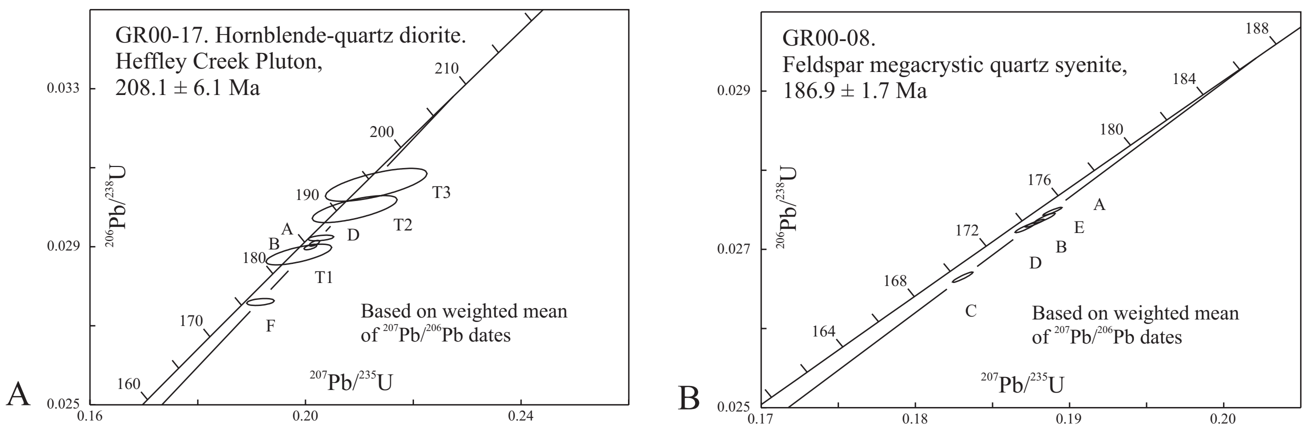

Figure 5. Concordia plots. A. Plot showing 2 sigma error ellipses for zircon fractions A, B, D and F and titanite fractions T1-T3, from quartz diorite of the Heffley Creek Pluton (sample GR00-17). B. Plot showing 2 sigma error ellipses for zircon fractions A-E from a sample of megacrystic syenite (sample GR00-08). *See* text for a discussion of these data.

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