Ar-Ar geochronology and Pb isotopic constraints on the origin of the Rau gold-rich carbonate replacement deposit, central Yukon

Scott Kingston[1], James K. Mortensen[2] and Janet Gabites
Pacific Centre for Isotopic and Geochemical Research, University of British Columbia

Matt Dumala
Archer, Cathro & Associates (1981), Ltd.

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ABSTRACT

The Rau deposit in central Yukon is a gold-rich carbonate replacement deposit hosted in mid-Paleozoic carbonate rocks of the Mackenzie Platform in the footwall of the Dawson thrust. Gold-bearing sulphide mineralization is peripheral to a zone of hornfels and local tungsten-bearing skarn that is associated with several small bodies of granitic aplite and pegmatite that have yielded $^{40}Ar/^{39}Ar$ muscovite ages of 62.3 ± 0.7 Ma, 62.4 ± 1.8 Ma and 59.1 ± 2.0 Ma. These intrusions are geochemically different and slightly younger than the 65.2 ± 2.0 Ma McQuesten plutonic suite farther to the south. Most Pb isotopic analyses of sulphides from the Rau deposit cluster within compositions of igneous feldspars from the associated intrusions; however, some analyses fall on a trend toward more radiogenic compositions that were determined for the host carbonate rocks. The data are consistent with the Rau sulphide mineralization being genetically related to the early Paleocene felsic intrusions, and forming peripheral to more proximal zones of hornfelsing and tungsten-bearing skarns.

[1]*spk@dccnet.com*

[2]*jmortensen@eos.ubc.ca*

INTRODUCTION

Gold-rich carbonate replacement mineralization recently discovered by ATAC Resources Ltd. at the Rau property in west-central Yukon (Fig. 1) is an excellent example of a relatively poorly understood style of mineral deposit. Presently, similar mineralization is only known at the Ketza deposit in south-central Yukon (Fig. 1; Fonseca, 1998) and a small number of other occurrences elsewhere in the North American Cordillera.

An investigation of the character, age and origin of gold mineralization at the Rau occurrence was undertaken as a BSc thesis by Kingston (2009). The work focused on the analysis of drill core from two 2008 diamond drillholes (08-Rau-11 and 08-Rau-18). Results from $^{40}Ar/^{39}Ar$ dating and Pb isotopic studies that were carried out as part of that study are included in the following report, as well as the implications of these results for the age and genesis of gold mineralization at the Rau occurrence.

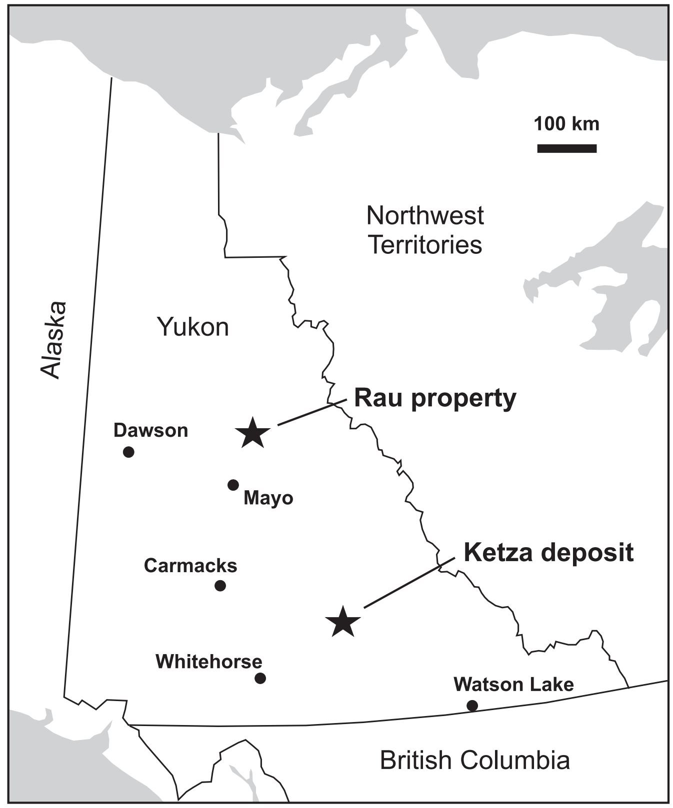

Figure 1. *Location of the Rau property and the Ketza River gold-bearing carbonate replacement deposit.*

GEOLOGY OF THE RAU PROPERTY

The Rau property is located approximately 100 km northeast of Mayo (Fig. 1). The geology of the study area is depicted in simplified form in Figure 2 (Abbott, 1990; unpublished data ATAC Resources Ltd., *http://www.atacresources.com/s/home.asp*). Initial work on the property focused on small zones of W (± Au) skarn and hornfelsing associated with a small granitic stock (the Rackla pluton) and associated dykes in the eastern part of the property (Fig. 2; Panton, 2008). Subsequent work on the property in 2008 led to the discovery of the Tiger zone,

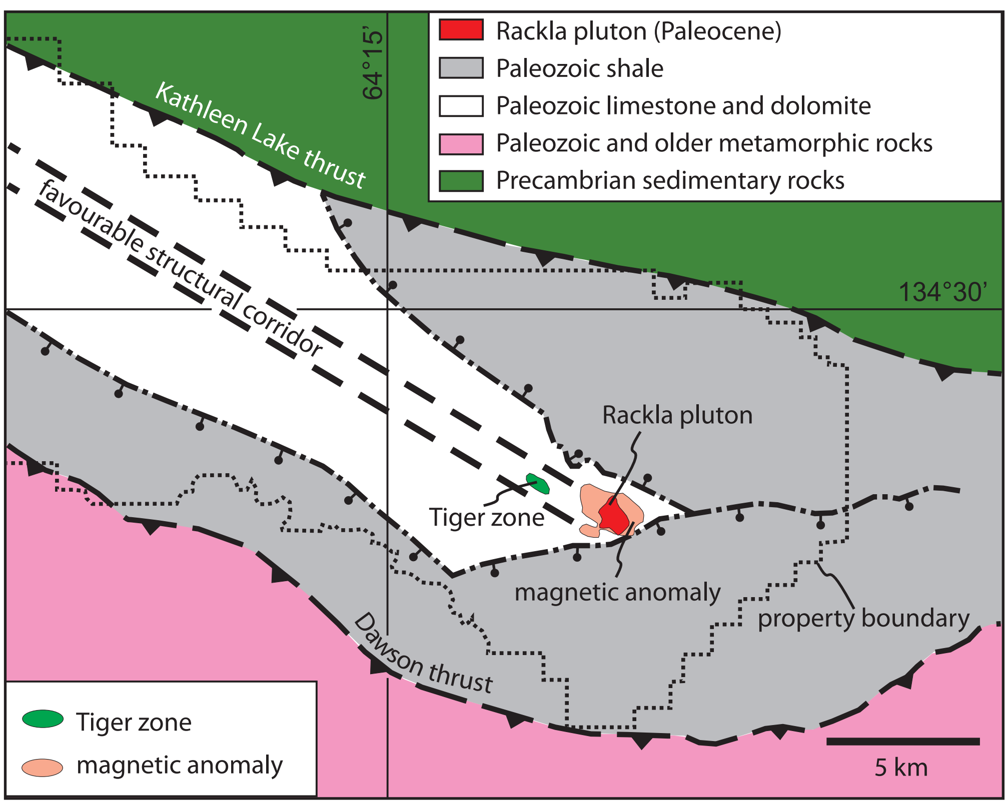

Figure 2. *Simplified geology of the eastern portion of the Rau property (based on unpublished geological mapping by ATAC Resources Ltd. geologists).*

which comprises Au-bearing carbonate replacement mineralization farther to the west of the zone of hornfelsing and skarn development that is directly associated with the Rackla pluton. A substantial portion of the Tiger zone has been strongly oxidized and all or most of the primary sulphide minerals have been replaced by iron oxides and hydroxides.

Tungsten and gold-bearing skarns, and the gold-bearing replacement-style mineralization of the Tiger Zone, are hosted mainly by carbonate rocks of the Devonian Bouvette Formation (Morrow, 1999), which makes up part of a southwest-dipping panel of mid-Paleozoic strata that is bounded between the Dawson thrust above and the Kathleen Lake thrust below (Fig. 2). The Bouvette Formation, in the vicinity of the Tiger zone, comprises medium grey to buff-weathering limestone and tan to pale grey dolomite. 'Zebra texture' is locally developed within the carbonate; this texture is commonly also observed in the vicinity of Mississippi Valley-type (MVT) Pb-Zn deposits elsewhere in the northern Cordillera (*e.g.*, Paradis and Nelson, 2007). Volcanic and volcaniclastic rocks are interlayered with the carbonates in the vicinity of the Tiger zone, including a layer up to 20 m thick that occurs in the immediate hangingwall of the mineralized zone. It is unclear what role, if any, these volcanic units played in the genesis of the mineralization. They contain abundant fine-grained biotite, which could, in part, be a product of hydrothermal alteration; however, the biotite is commonly weakly aligned, suggesting that it crystallized (or was recrystallized) during regional deformation.

Sulphide mineralization in the Tiger zone includes massive to semi-massive replacement of the host carbonate by fine to coarse-grained sulphides, as well as irregular sulphide veins. Sulphides present in the two 2008 drillholes in the Tiger zone that were examined in this study, comprise mainly pyrite with lesser pyrrhotite and arsenopyrite, and rare sphalerite, chalcopyrite and bismuthenite. Sulphide mineralization encountered during 2009 drilling in the Tiger zone was typically more arsenopyrite rich than that observed in the 2008 drillholes; arsenopyrite is present at equivalent or greater levels than pyrite, accompanied by minor pyrrhotite, bismuthinite and scheelite, and rare sphalerite and chalcopyrite. A number of other gold occurrences and anomalies have been identified by company geologists along strike to the northwest from the Tiger zone, within a belt referred to as the 'favourable structural corridor' (Fig. 2).

The Rackla pluton is approximately 1 km in diameter at the present level of exposure; however, an extensive magnetic anomaly that encompasses and surrounds the pluton has been delimited by aeromagnetic surveys of the property by ATAC Resources (*http://www.atacresources.com/s/home.asp)* and may suggest that the stock is considerably larger in the subsurface (Fig. 2). Exposure of the pluton is generally poor; however, Panton (2008) describes it as primarily coarse-grained biotite-muscovite granite with finer grained aplitic phases common near the margins that contain local garnet, tourmaline and fluorite. Miarolitic cavities are common, suggesting a relatively high level of emplacement. Small dykes and sills, within the area of hornfelsing to the west of the pluton, range from aplite to pegmatite, and commonly contain tourmaline and garnet (Panton, 2008). Biotite-garnet, tremolite and actinolite skarn that developed west of the Rackla pluton contain sporadic values of W, Cu and Au.

AGE AND LITHOGEOCHEMISTRY OF INTRUSIVE ROCKS ON THE RAU PROPERTY

The felsic composition and mineralogy of intrusive rocks of the Rackla pluton and associated dykes and sills suggest that they are peraluminous magmas produced through crustal melting. Previous attempts to date the Rackla pluton using U-Pb dating of zircons (Mortensen and Abbott, unpublished data, 1991) indicated a minimum emplacement age of ~61 Ma, and this age, in addition to the geographic location of the Rackla pluton, led to the initial inference that the Rackla pluton and associated intrusions in the vicinity were related to the 65.2 ± 2.0 Ma McQuesten plutonic suite that occurs in an east-trending belt approximately 50 km south of the Rau occurrence (Murphy, 1997).

In this study, we used $^{40}Ar/^{39}Ar$ step-heating methods to date muscovite from three samples of muscovite-bearing aplite and pegmatite from small intrusive bodies. These intrusive bodies are northwest of the Rackla pluton and occur within the zone of strong hornfelsing where there is locally developed tungsten skarn mineralization. Analyses were completed at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) laboratories at the University of British Columbia, using methods as described by Mortensen *et al.* (in press). Age spectra for the three samples are shown in Figure 3a-c and analytical data is listed in Table 1. The three ages overlap at a two-sigma level; however, we consider the best age for

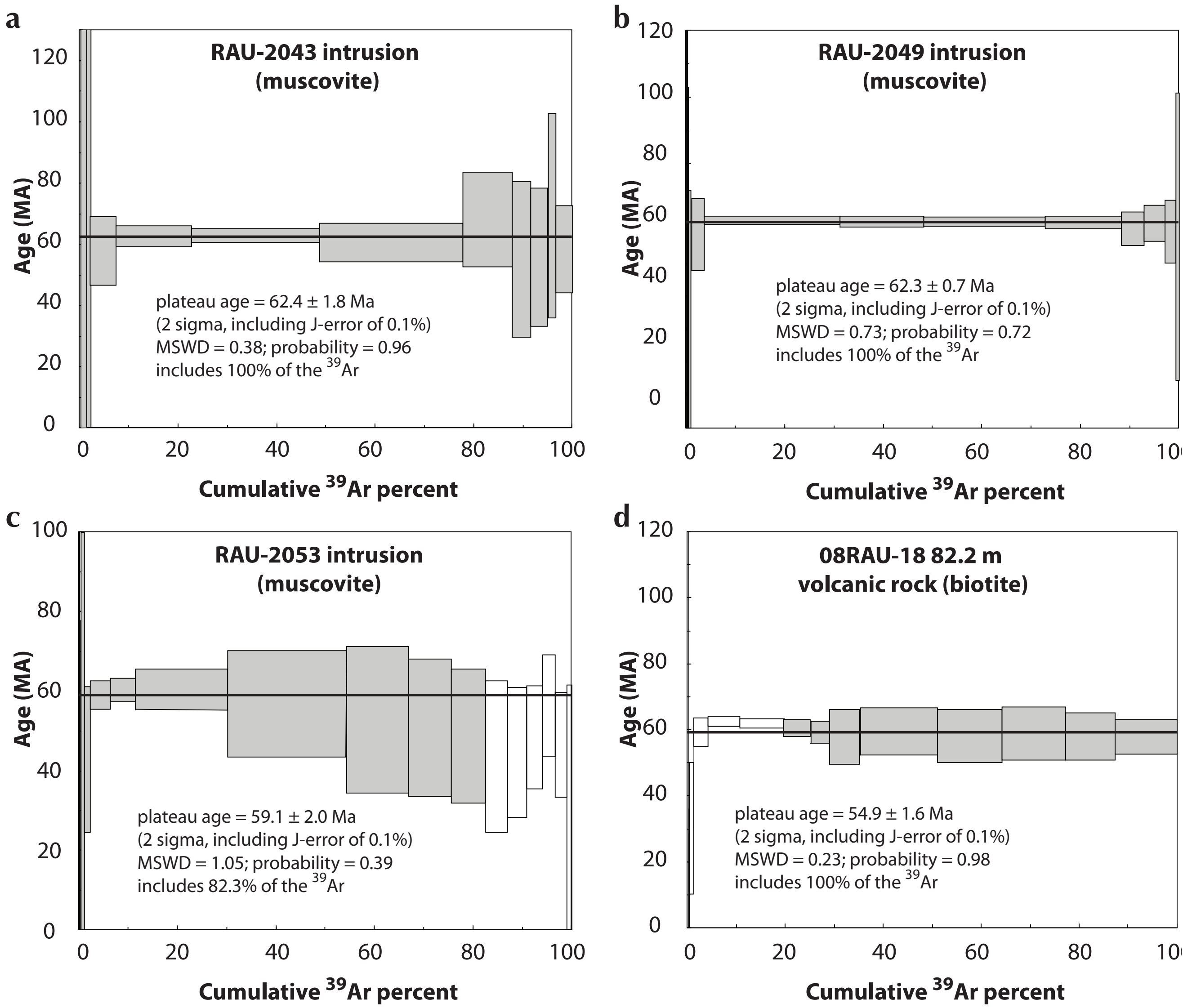

Figure 3. *$^{40}Ar/^{39}Ar$ dating results from intrusive and volcanic rocks on the Rau property. Shaded analyses were used in calculation of the plateau ages; MSWD = mean square of the weighted deviates.*

the magmatism to be given by a weighted average of the two oldest and most precise age determinations, at 62.3 ± 0.6 Ma. This result is in good agreement with a recent U-Pb zircon age of 62.9 Ma for the Rackla pluton (V. Bennett, pers. comm.). Together, the new $^{40}Ar/^{39}Ar$ and U-Pb ages for the Rackla pluton and associated dykes in the vicinity, indicate that intrusive rocks on the Rau property are early Paleocene in age; this represents a slightly younger pulse of magmatism than that represented by the latest Cretaceous to earliest Paleocene McQuesten plutonic suite to the south.

Major, trace and rare earth element analyses were reported by Panton (2008) for two fine to medium-grained samples from granitic dykes within the main zone of hornfelsing adjacent to the western margin of the Rackla pluton (Fig. 2). Geochemical analyses of the Rackla pluton itself are not available. The dyke compositions are plotted on total alkali vs. SiO_2 and Rb vs. Yb+Ta diagrams (after Le Bas *et al.*, 1986) in Figure 4. Five analyses of McQuesten suite intrusions are included on the plots for comparison (data from Murphy, 1997). The Rau dykes overlap with part of the range of McQuesten suite in terms of major elemental compositions (Fig. 4a). On the Pearce *et al.* (1984)

Table 1. *$^{40}Ar/^{39}Ar$ analytical results for micas from intrusive and volcanic rocks from the Rau property.*

Laser Power (watts)	^{39}Ar (cum. %)	Age (Ma)	Error (2 sigma)	^{40}Ar (rad.) (%)	^{39}Ar (%)	K/Ca	Error (2 sigma)
Rau-2043 (muscovite)							
2	0.057	437.19	679	81.750	0.057	0.75	1.22
2.2	1.267	40.04	151	5.713	1.210	7.73	9.01
2.4	2.158	67.11	112	16.245	0.892	0.87	0.23
2.7	7.284	57.93	11.14	43.161	5.125	2.91	0.63
3	22.579	62.59	3.29	64.922	15.296	98.89	135.21
3.3	48.661	62.90	2.34	78.465	26.082	167.02	170.33
3.6	77.798	60.56	6.28	73.373	29.137	143.53	70.75
3.9	87.761	68.05	15.41	65.748	9.963	67.06	62.84
4.2	91.586	55.07	25.41	42.125	3.825	19.42	34.48
4.6	95.049	55.75	22.49	50.332	3.463	21.87	17.90
5.1	96.810	69.37	33.30	49.743	1.760	9.89	6.12
5.7	100.000	58.45	14.22	56.890	3.190	24.01	22.23
Rau-2049 (muscovite)							
2	0.018	-324.67	1605	-7.905	0.018	135.30	140808
2.2	0.117	-127.94	294	-15.426	0.099	1.02	1.59
2.4	0.335	-22.88	126	-2.325	0.217	2.56	4.15
2.7	0.909	12.45	59.27	1.969	0.574	7.94	13.71
3	3.597	58.49	10.82	58.840	2.688	1391.39	758588
3.3	31.105	62.67	1.21	94.825	27.508	229.53	288.48
3.6	48.235	62.40	1.64	96.081	17.131	822.02	4206.45
3.9	72.963	62.27	1.28	97.302	24.728	983.93	4110.63
4.2	88.358	62.04	1.84	96.498	15.394	293.38	590.51
4.5	92.881	60.10	5.05	91.192	4.523	152.70	634.11
4.9	97.145	61.74	5.43	93.514	4.264	36.97	35.72
5.3	99.468	59.32	9.45	87.877	2.323	43.86	127.82
5.8	100.000	57.85	43.22	66.066	0.532	388.73	28716
Rau-2053 (muscovite)							
2	0.006	-138.70	586	-23.147	0.006	-0.17	0.29
2.2	0.093	-34.66	112	-4.323	0.086	-2.73	3.75
2.4	0.299	-117.41	105	-13.564	0.207	-39.55	276.49
2.7	1.015	0.04	100	0.009	0.715	2.43	0.39
3	2.252	42.76	18.25	24.129	1.237	-38.82	67.37
3.3	6.229	58.97	3.50	69.803	3.977	77.28	65.23
3.6	11.320	60.15	2.93	62.324	5.091	167.14	399.08
3.9	30.188	60.34	5.11	74.649	18.868	93.29	35.62
4.2	54.266	56.71	13.34	63.310	24.078	89.52	36.35
4.3	66.922	52.85	18.35	53.237	12.656	52.84	28.68
4.4	75.675	50.80	17.16	51.146	8.753	145.02	129.41
4.6	82.587	48.69	16.80	49.249	6.912	42.80	13.85
4.9	86.961	43.62	19.01	41.826	4.375	34.54	26.55
5.2	90.928	44.56	16.21	46.047	3.966	92.94	179.69
5.6	94.120	48.40	12.95	46.069	3.192	73.38	70.50
6	96.635	56.25	12.70	52.156	2.515	216.49	939.03
6.5	99.089	46.47	13.14	44.991	2.454	56.33	75.12
7	100.000	27.86	33.70	19.307	0.911	191.17	2261.86
Rau-08-18 82.2a (biotite)							
2	-0.001	2845.46	2121	100.000	-0.001	-0.03	0.05
2.2	0.063	-53.21	61.60	-22.910	0.064	-12.68	80.80
2.4	0.183	-9.70	38.33	-4.594	0.120	3.93	3.38
2.7	0.381	-13.63	49.77	-5.759	0.197	6.48	7.98
3	1.203	30.17	19.87	22.296	0.823	6.18	2.14
3.3	4.114	59.23	4.39	74.213	2.910	7.69	0.91
3.6	10.646	62.51	1.56	89.919	6.533	22.92	3.97
3.9	19.567	61.80	1.37	90.119	8.921	33.89	5.49
4.2	25.024	60.40	2.42	83.252	5.456	35.03	13.59
4.5	28.960	59.15	3.28	74.511	3.936	32.38	10.64
4.9	35.114	57.77	8.23	63.186	6.154	15.13	3.30
5.3	50.940	59.38	7.16	67.595	15.827	24.27	3.33
5.7	64.237	57.93	8.01	64.841	13.296	18.09	1.90
6	77.145	58.83	8.00	65.916	12.909	14.85	2.18
6.3	87.280	57.87	7.13	65.514	10.135	11.01	0.94
7	100.000	57.71	5.16	69.923	12.720	3.70	0.23

discriminant plot shown in Figure 4b, the McQuesten suite intrusions fall either within the "volcanic arc granite" or "syncollisional granite" fields, whereas the Rau dykes fall in the "within-plate granite" field. Although the available analyses are from dykes in the Rau area and not from the Rackla pluton itself, the lithogeochemical evidence suggests that intrusions in the Rau area may not be directly related to the McQuesten plutonic suite.

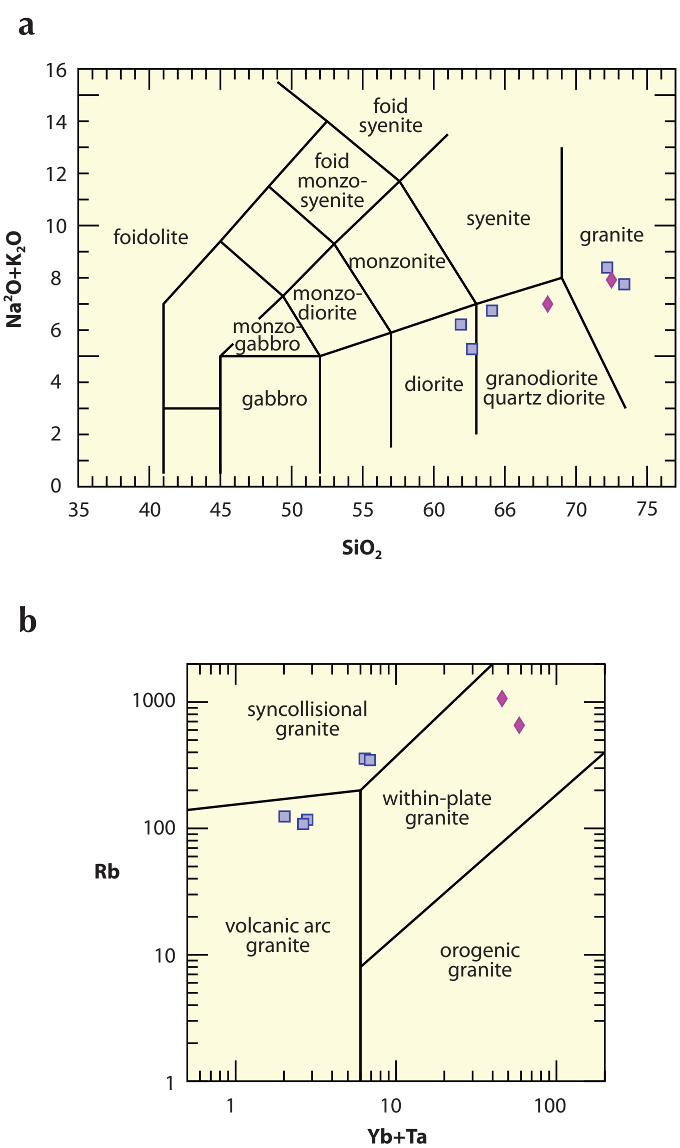

Figure 4. *Geochemistry of felsic dykes on the Rau property (diamonds) in comparison to the McQuesten plutonic suite (squares; from Murphy, 1997).*

OTHER DATING STUDIES

Biotite from within one of the volcanic/volcaniclastic units was separated and dated using $^{40}Ar/^{39}Ar$ methods. A plateau age of 59.4 ± 1.6 Ma was obtained from the sample (Fig. 3d). The significance of this age is uncertain; it may reflect either cooling following the emplacement of the Rackla pluton, or a slightly younger thermal event.

LEAD ISOTOPE STUDIES

Lead isotopes can be used to constrain the source(s) of metals contained within a mineral deposit (*e.g.*, Tosdal *et al.*, 1999). This approach is particularly valuable when one is able to directly measure the isotopic composition of potential reservoirs from which metals contained within a deposit might have been derived.

In the case of the Rau sulphide mineralization, there are three potential reservoirs in the immediate vicinity of the mineralization that could potentially have contributed Pb to the deposit: 1) the host carbonate rocks; 2) the volcanic/volcaniclastic rock units that are spatially closely associated with at least some of the mineralization; and 3) felsic intrusive rocks adjacent to the mineralization.

In order to assess the contribution of Pb (and by inference, the other contained metals) from the three potential reservoirs, and to determine whether other unidentified sources might have played a role in the genesis of the mineralization, we measured the Pb isotopic compositions of several representative samples. These samples included K-feldspar separated from four discrete felsic dykes within the main zone of hornfelsing and tungsten skarn development west of the Rackla pluton; two samples of the host carbonates distal from any sulphide mineralization; one sample of unaltered volcaniclastic rock; and a total of 17 samples of pyrite, representing the range of styles of mineralization present in the two 2008 drillholes that we studied. Analytical data are listed in Table 2 and are plotted on a conventional $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram in Figure 5a, and a $^{208}Pb/^{206}Pb$ vs. $^{207}Pb/^{206}Pb$ diagram in Figure 5b. Also shown for comparison are isotopic compositions of K-feldspars from both the 92-94 Ma Tombstone and the 65.2 ± 2.0 Ma McQuesten plutonic suites, and a field of Pb isotopic compositions of galenas from veins in the Keno Hill Mining District. The "shale curve" of Godwin *et al.* (1982), which closely approximates the Pb isotopic evolution of the North American miogeocline in the northern Cordillera, is shown for reference.

Table 2. *Lead isotopic compositions of sulphide, whole rock (wr) and feldspar samples from the Rau property.*

Sample	Mineral	$^{206}Pb/^{204}Pb$	Error	$^{207}Pb/^{204}Pb$	Error	$^{208}Pb/^{204}Pb$	Error	$^{207}Pb/^{206}Pb$	Error	$^{208}Pb/^{206}Pb$	Error
Rau 5	pyrite	19.868	0.10	15.693	0.10	40.101	0.12	0.7898	0.05	2.0184	0.05
Rau 7	pyrite	20.014	0.04	15.729	0.05	40.491	0.07	0.7859	0.04	2.0232	0.03
Rau 11	pyrite	20.233	0.03	15.757	0.04	40.574	0.06	0.7788	0.04	2.0053	0.03
Rau 19	pyrite	20.037	0.05	15.736	0.05	40.421	0.08	0.7854	0.04	2.0173	0.04
Rau 6	pyrite	20.031	0.28	15.647	0.17	40.018	0.36	0.7812	0.22	1.9978	0.22
Rau 9	pyrite	19.665	0.09	15.596	0.10	39.784	0.11	0.7931	0.04	2.0231	0.04
Rau 10	pyrite	20.144	0.04	15.768	0.05	40.392	0.07	0.7828	0.04	2.0052	0.03
Rau 11	pyrite	19.969	0.11	15.739	0.08	40.333	0.14	0.7882	0.09	2.0197	0.08
Rau 12	pyrite	19.854	0.04	15.699	0.05	40.173	0.07	0.7907	0.04	2.0234	0.03
Rau 14	pyrite	19.962	0.08	15.769	0.09	40.209	0.10	0.7900	0.04	2.0143	0.03
Rau 15	pyrite	20.020	0.03	15.714	0.05	40.434	0.07	0.7849	0.04	2.0197	0.03
Rau 16	pyrite	21.046	0.87	15.940	0.83	38.510	0.93	0.7574	0.25	1.8298	0.33
Rau 17	pyrite	19.588	0.08	15.710	0.09	39.826	0.10	0.8020	0.04	2.0332	0.03
Rau 18	pyrite	19.871	0.13	15.845	0.12	40.248	0.14	0.7974	0.06	2.0255	0.04
Rau 23	pyrite	19.105	0.03	15.635	0.05	38.976	0.06	0.8183	0.04	2.0401	0.03
Rau 21	pyrite	19.997	0.06	15.729	0.05	40.306	0.09	0.7866	0.06	2.0156	0.04
Rau 22	pyrite	20.329	0.52	15.808	0.49	40.915	0.55	0.7776	0.19	2.0126	0.15
Rau 1	carbonate wr	20.627	0.10	15.791	0.10	40.507	0.12	0.7656	0.06	1.9638	0.04
Rau 2	carbonate wr	20.316	0.44	15.695	0.43	40.259	0.44	0.7726	0.06	1.9816	0.04
Rau 3	volcanic wr	19.958	0.16	15.911	0.16	39.751	0.18	0.7972	0.05	1.9918	0.05
Rau 20	feldspar	19.945	0.04	15.767	0.05	40.189	0.08	0.7905	0.04	2.0150	0.05
Rau 45	feldspar	19.821	0.03	15.711	0.04	40.037	0.06	0.7927	0.04	2.0200	0.03
Rau 49	feldspar	19.797	0.03	15.697	0.05	40.028	0.07	0.7929	0.04	2.0220	0.03
Rau 53	feldspar	19.768	0.17	15.676	0.15	40.136	0.18	0.7930	0.09	2.0303	0.05

Results normalized using a fractionation factor of 0.12% based on multiple analyses of NBS981 standard lead, and the values in Thirlwall (2000). Errors are reported at the 2-sigma level.

Several observations can be made from the Pb isotopic data array. The isotopic compositions of feldspars in the Rau dykes fall in a tight cluster that is much more radiogenic than corresponding clusters for the McQuesten suite intrusions, indicating very different sources for the magmas. The measured isotopic compositions of most of the sulphides that were analysed plot relatively close to the compositions measured for feldspar from felsic dykes on the Rau property. Some of the Rau sulphide analyses trend towards the compositions of the host carbonates, which yield substantially more radiogenic compositions than the Rau intrusions themselves. A few of the Rau sulphide analyses trend towards somewhat less radiogenic compositions than those of the Rau feldspars. The single isotopic analysis of the volcanic rocks on the Rau property plots well away from the array of compositions for Rau feldspars and the carbonate host rocks (Fig. 5).

Taken together, the Pb isotopic data strongly suggest that most metals in all of the various styles of sulphide mineralization present within the two 2008 Rau drillholes that were examined in this study represent variable mixtures with most Pb derived from the Rau felsic intrusions (or more probably a larger associated intrusive body at depth) and a lesser component from the host carbonates. The small number of sulphide analyses that are less radiogenic in composition than the Rau intrusion feldspars indicate that some other less radiogenic reservoir also contributed metals to some of the deposit. The volcanic rocks on the property did not appear to have contributed any significant amount of metal to the mineralization.

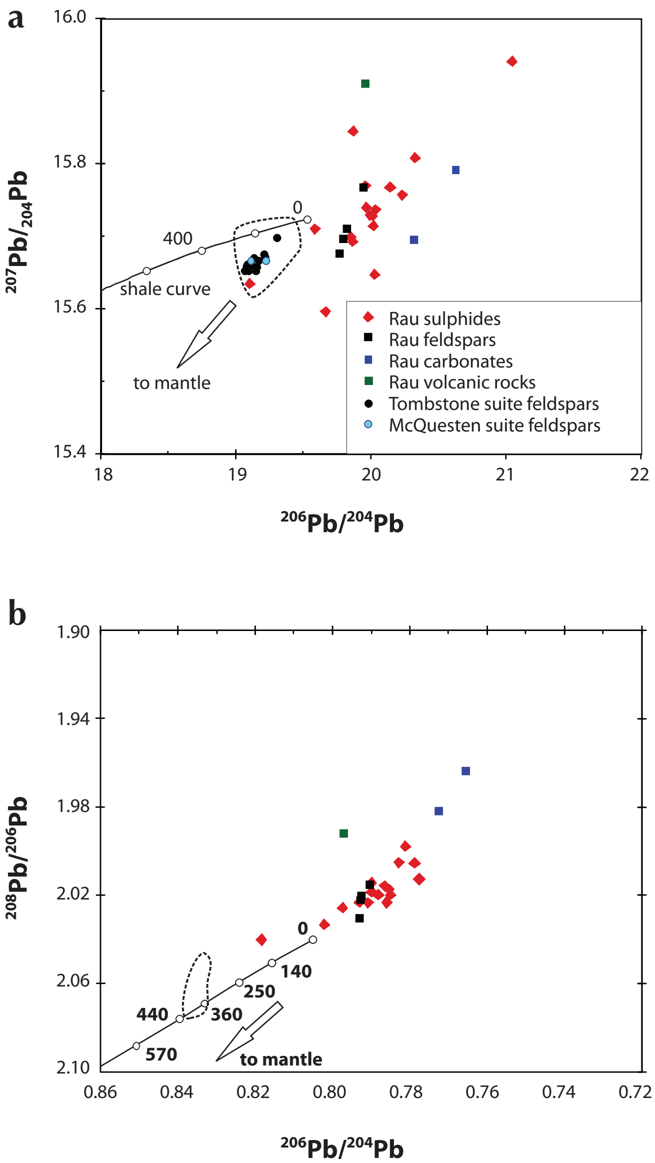

Figure 5. *Lead isotopic compositions of sulphide minerals, igneous feldspars and country rock at the Rau property. The "shale curve" of Godwin et al. (1982) is shown for reference. Lead isotopic compositions of Tombstone and McQuesten suite intrusions (black and blue circles, Figure 5a) and galenas from Keno Hill (area outlined by dashed line, Figs. 5a and 5b) are from Mortensen (unpublished data).*

DISCUSSION

Although the genesis of base metal carbonate replacement deposits is reasonably well understood (*e.g.*, Nelson, 2005), the nature and origin of the much less common gold-rich carbonate replacement mineralization such as that in the Tiger zone on the Rau property are still poorly understood. Fonseca (1998) inferred, but could not directly prove, that the Ketza River gold-rich manto deposit in south-central Yukon (Fig. 1) was part of an intrusion-centered, gold base-metal system. The only other example of a gold-rich carbonate replacement deposit in the northern Cordillera is the Mosquito Creek gold deposit in the Wells-Barkerville camp in the Cariboo Gold District of east-central British Columbia (*e.g.*, Alldrick, 1983; Rhys *et al.*, 2009), and there is no evidence for any association with intrusive rocks at that deposit. Although the Ketza River and Mosquito Creek deposits are the only other gold-rich carbonate replacement deposits that have ever been studied in any detail, it appears that there is no consistent genetic association between this style of mineralization and intrusions.

Results of the present study shed new light on some aspects of the Rau occurrence; however, many questions still remain concerning the genesis of this exciting new gold discovery. Two main conclusions arising from the present study bear on the genesis of gold mineralization on the Rau property and exploration for similar styles of mineralization elsewhere in this part of Yukon.

Firstly, the Pb isotopic data strongly suggest that sulphide mineralization in the Tiger zone that was sampled in the two 2008 drillholes that were examined for this study is genetically related to the early Paleocene Rackla pluton and related dykes and sills (and possibly a larger associated intrusion at depth). This is consistent with the presence of both gold and tungsten in skarns in a more proximal relationship with the Rackla pluton, and suggests a possible metallogenic zonation developed concentrically outwards from the central stock, as described elsewhere in the world by Sillitoe and Bonham (1990). It is recommended that additional Pb isotopic analyses be carried out on the more arsenopyrite-rich sulphide mineralization discovered in the Tiger zone during 2009 drilling in order to determine whether this style of mineralization is also related to the Rau intrusions, or represents a different, and possibly unrelated, mineralizing event.

Secondly, the Rackla pluton and related dykes and sills are distinct from the McQuesten plutonic suite in terms of age (early Paleocene as opposed to latest Cretaceous-earliest Paleocene), geochemistry and geographic location. Both the McQuesten suite and the Rackla pluton and related dykes and sills are inferred to be products of crustal melting; however, the two sets of intrusions yield tightly clustered, but very different Pb isotopic compositions, indicating that the magmas were not derived by melting of the same source rocks. Very little mineralization of any kind is known to be associated with the McQuesten suite intrusions (Murphy, 1997), and we suggest that potential for Rau-type gold mineralization associated with the McQuesten suite intrusions is unlikely.

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