Tectonic significance of plutonism in the Thirtymile Range, southern Yukon

T. Liverton[1,2], M.F. Thirlwall[1] and K.R. McClay[1]
University of London, United Kingdom

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ABSTRACT

Two distinct but undeformed suites of granitic plutons intrude deformed siliciclastic rocks in western Dorsey Terrane. A calc-alkaline hornblende-bearing gabbro to granodiorite stock has been dated at 181.5 Ma (by the Rb/Sr method). The second suite consists of highly evolved late-orogenic granites of the Thirtymile stock and Hake Batholith, which are approximately 100 Ma. The penetrative fabric of the metasedimentary rocks indicates generally eastward-vergent layer-parallel shear. The deformation of the siliciclastic rocks is thus constrained at older than 181 Ma. The absence of resetting of the Rb-Sr isotopic ratios of the Jurassic pluton indicates that the mid-Cretaceous magmatism was emplaced at a shallow crustal depth. Since the Jurassic pluton has both a 'juvenile' Sr isotopic ratio of 0.7045 and chemistry indicative of a largely mantle-derived source, a subduction-related setting for magma generation is likely. The spatial relationship of craton-derived clastic rocks and these plutons requires that subduction had an eastward polarity.

RÉSUMÉ

Deux cortèges de plutons granitiques distincts mais non déformés ont pénétré dans les roches silicoclastiques déformées présentes dans la partie occidentale du terrane de Dorsey. Un pluton dont la composition varie de gabbros à des granodiorites calco-alcalines contenant de la hornblende a été daté à 181,5 Ma par la méthode Rb/Sr. Le deuxième cortège est formé de granites tardi-orogéniques très évolués de l'amas Thirtymile et du batholite Hake, dont l'âge est d'environ 100 Ma. La fabrique pénétrative des roches métasédimentaires montre en général un cisaillement de vergence est qui est parallèle aux couches. La déformation des roches silicoclastiques est donc antérieure à 181 Ma. L'absence de remise à zéro des rapports isotopiques Rb-Sr du pluton du Jurassique indique que le magmatisme qui s'est produit au Crétacé moyen s'est mis en place à un niveau crustal peu profond. Puisque le pluton du Jurassique a un rapport isotopique Sr « juvénile » de 0,7045 et une composition chimique indicatrice d'une source provenant principalement du manteau, il est fort probable que ce magma soit le produit d'une zone de subduction. La relation spatiale entre les roches clastiques provenant du craton et les plutons permet de conclure que la polarité de la subduction était orientée vers l'est.

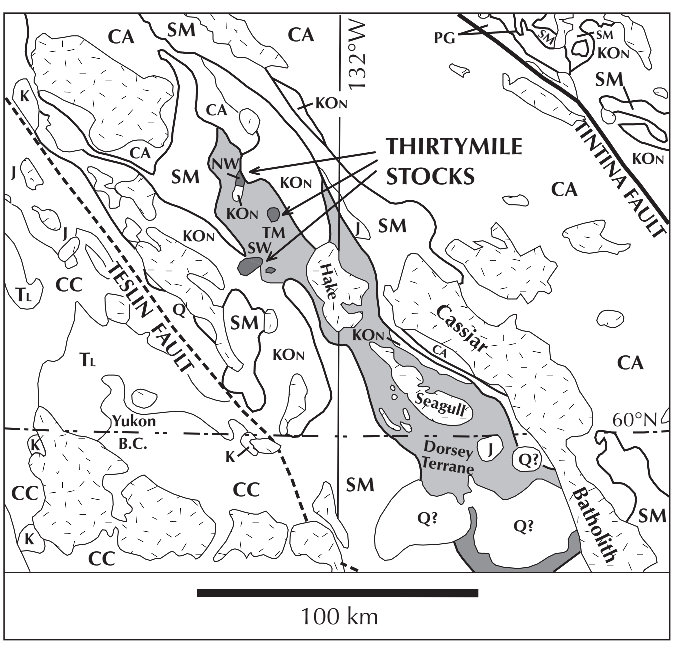
[1]*Department of Geology, Royal Holloway, University of London, Egham, Surrey, U.K.*
[2]*Box 393, Watson Lake, Yukon, Canada Y0A 1C0*

INTRODUCTION

This paper addresses aspects of regional structure and Rb-Sr characteristics of the Thirtymile (main, southwestern and northeastern bodies) and Hake plutons in south-central Yukon. Other chemical aspects of these intrusions have been described previously (Liverton and Alderton, 1994). These undeformed plutons clearly intrude penetratively deformed metasedimentary rocks, placing an upper limit on the age of deformation. Differences in the age of the intrusions and their Rb-Sr characteristics allow inferences relating to the tectonic history of the Thirtymile Range.

REGIONAL FRAMEWORK

The plutons intrude the Dorsey Terrane of Monger et al. (1991); to the east are Cambrian to Mississippian strata of Ancient North America (the Cassiar Platform); to the west are mylonitized high-grade metamorphic rocks and plutons of the Teslin zone (Gordey and Stevens, 1994; Stevens et al., 1996; Fig. 1). The Thirtymile Range includes the westernmost siliciclastic metasedimentary rocks of Dorsey Terrane (Gordey, 1992; Harms, 1992). They are lithologically similar to lower Paleozoic North American strata and include detrital zircons, which appear to be derived from the neighbouring North American craton and miogeocline (Ross and Harms, 1998). Within Dorsey Terrane are lithostratigraphic assemblages broadly correlative with Yukon-Tanana Terrane (Nelson et al., 2000).



In the Thirtymile Range are plutons of Cretaceous and Jurassic age, and country rocks disrupted by myriad faults. Mylonite zones and inverted beds are reported from the lowest part of the sequence (Gordey, 1991). Tectonic 'slices' of marble within uppermost argillite and also small slices of volcanic rocks in the northern Thirtymile Range may be coeval, suggesting possible imbrication of the succession (Liverton, 1990, 1992). The eastern part of the terrane displays penetrative ductile deformation at its structural base (Stevens and Harms, 1995). Moderate to steeply dipping normal faults in the Range may be either pre- or post-tectonic (thrusting and mylonitization), or both. At least one pair of high-angle normal faults is structurally related to emplacement of the Cretaceous Ork granite stock (Liverton, 1990; 1992).

STRUCTURAL FABRIC OF THE METASEDIMENTARY ROCKS

In the central portion of the Thirtymile Range, wherever a crenulation has been observed in pelites, the axes trend between north-south and 010-190°, with plunges mostly 0-10° in either sense (Liverton, 1992). A mineral elongation has been observed in a few localities; it is parallel to those crenulation axes. Shear-sense indicators, either asymmetry of pressure solution cleavage fabric in the quartzite or C-S fabric in pelitic or calc-silicate lithology, consistently indicate a dextral sense of shear. This translates into top-to-east movement (Fig. 2), an important aspect of the tectonic evolution, considered in the discussion.

Figure 1. *Terrane map of the south-central Yukon after Wheeler et al. (1991). Terranes are: CA = Cassiar; SM = Slide Mountain; CC = Cache Creek; KO_N = Kootenay; Q = Quesnellia; T_L = Lewes River; PG = Pelly Gneiss. K, J = Cretaceous and Jurassic plutons. The Dorsey Terrane is shown in grey. Plutons mentioned are: NW = Northwest Thirtymile; TM = Thirtymile stock (and Ork stock); SW = Southwest Thirtymile; Hake = Hake Batholith; Seagull = Seagull Batholith. The western 'fork' of Dorsey terrane (west of Hake Batholith) contains the siliciclastic assemblages similar to Proterozoic to Paleozoic North American strata.*

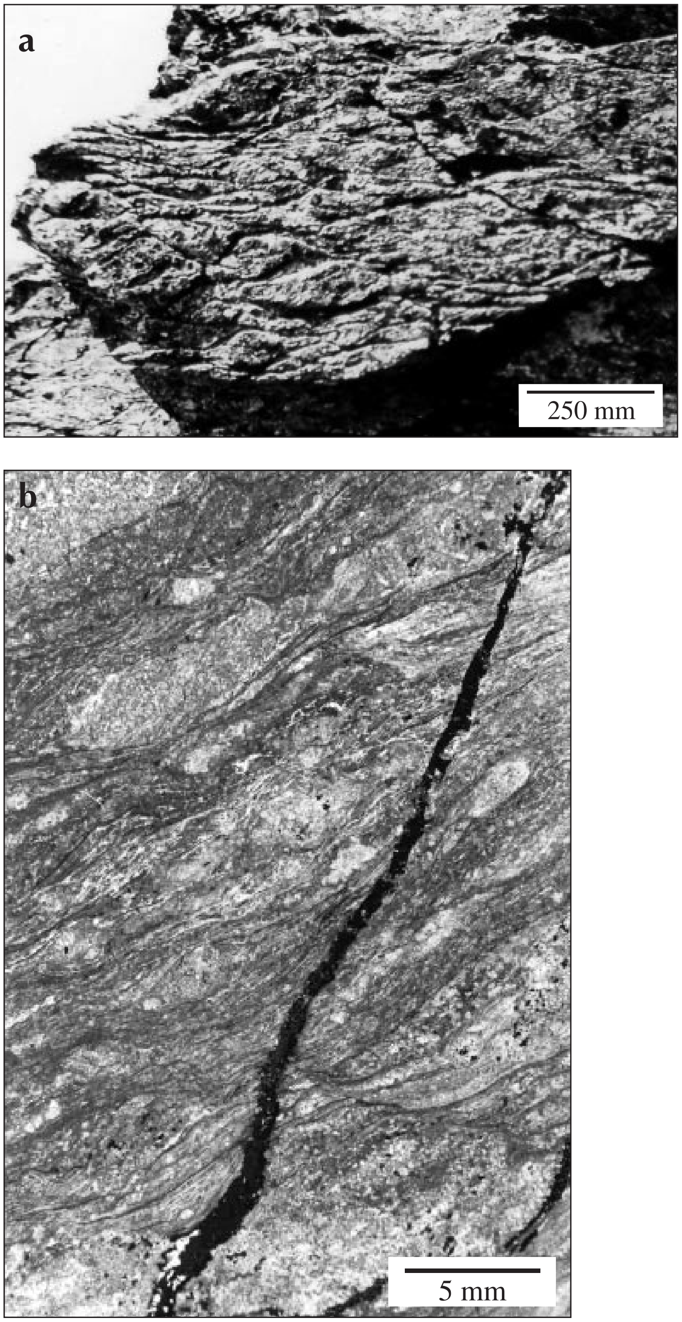


Figure 2. Two examples of fabrics in Thirtymile Range siliciclastic metasedimentary rocks. (a) Asymmetrical pressure solution cleavage in quartzite. This northward view shows a top-to-east shear sense. Taken in the Thirtymile Range at 60°43'10"N, 132°31'16"W. (b) Thin section is viewed under transmitted light. Boudinage and S-C fabric preserved in calc-silicate hornfels at the Mindy prospect (60°37'33"N, 132°19'34"W). Porphyroclasts are of scapolite/salite and the finer matrix is pyroxene. The crosscutting sulphide vein is a result of skarn overprint. A top-to-southeast (i.e., left) shear sense is indicated.

PLUTONISM

In southern Yukon are at least two suites of mid-Mississippian plutons (Mihalynuk et al., 1998, 2000; Roots and Heaman, in press), one or more Permian intrusions (Stevens, 1996), an inferred Early or mid-Jurassic tonalite through diorite suite, and Cretaceous plutons (Seagull, Hake and Cassiar batholiths). Among the latter are two mineralogically distinct suites of granitic plutons within the Thirtymile, Englishman's and Dorsey ranges (Fig. 3):

(i) Leucocratic, highly evolved biotite to lepidolite granites *(sensu stricto)* of the Thirtymile and Ork stocks, and Hake and Seagull batholiths (Fig. 1; Liverton and Alderton, 1994). These are sub-alkaline granites (Liverton and Botelho, in press) having a chemical signature closely

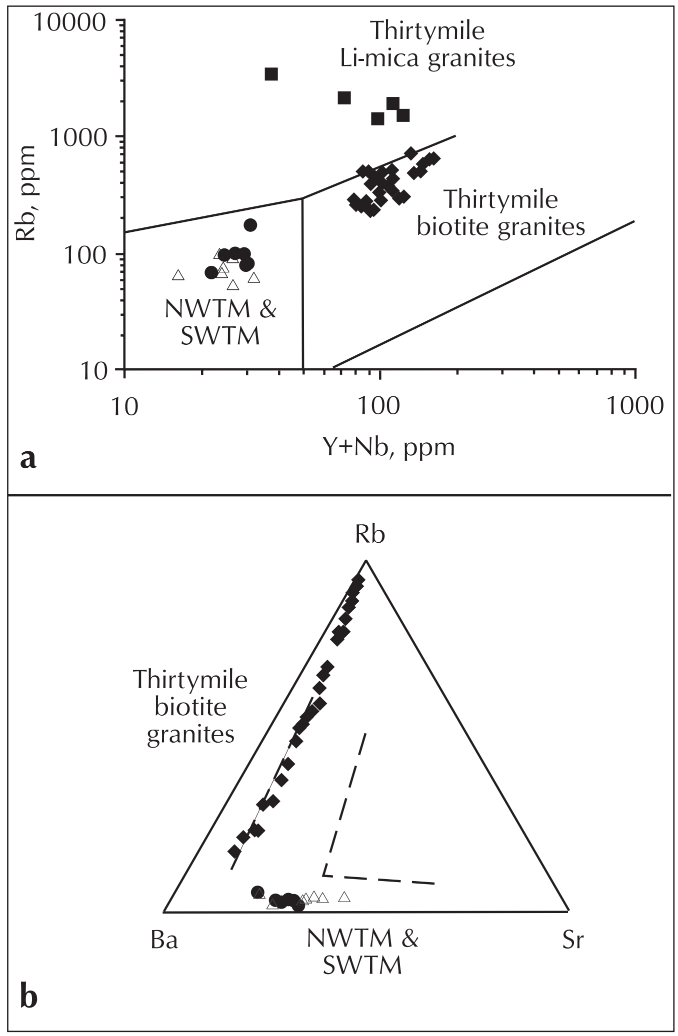


Figure 3. Tectonic discrimination diagram (a) (Pearce et al., 1984) and Rb-Ba-Sr ternary plot (b) for the Jurassic NW and SW Thirtymile (TM) plutons and the Cretaceous Thirtymile stock.

resembling the hybrid late-orogenic type (H_{LO}) of Barbarin (1990), and are associated with F-B-Sn ± W contact metasomatic mineralization in the Thirtymile Range. They are one-mica metaluminous to weakly peraluminous granites. Hornblende is present only in the volumetrically inferior, least-evolved porphyry facies of the Thirtymile stock, which is interpreted to be a synplutonic dyke.

(ii) Hornblende-rich granodiorites are present in the Northwest and Southwest Thirtymile stocks (distinct from the main Thirtymile stock, Fig. 1). The two are considered co-magmatic (Liverton, 1992; Liverton and Alderton, 1994) and have similar trace element geochemistry. Their Rb to (Y+Nb) contents place them distinctly in the volcanic-arc granite field (Pearce et al., 1984; details are given in Liverton and Alderton, 1994). The Northwest Thirtymile stock is a mineralogically homogeneous hornblende granodiorite that frequently carries prominent epidote and sphene, has 61.7 - 64.1% SiO_2 and a Peacock Index of 55.2. In contrast, the east side of the Southwest Thirtymile stock (cf. hybrid calc-alkaline type, H_{CA} of Barbarin, 1990) consists of sharply discordant gabbro to quartz-diorite intrusions and near-vertical dykes (<1 m wide) that clearly truncate the fabric of the metasedimentary rocks. A large leucocratic hornblende granodiorite extends westward from the more basic body and contains xenoliths of the diorite in the contact region (Liverton, 1992). These lithofacies have a range of 50.9 to 62.0% SiO_2 and Peacock Index of 57.4.

ISOTOPIC STUDIES

METHODS

The authors selected four specimens from the Thirtymile megacrystic granite lithofacies (Liverton, 1990) and one from the porphyry for whole-rock Sr isotope determination using the techniques of Thirlwall (1991) on the VG354 mass spectrometer at Royal Holloway, University of London. Rb and Sr contents were determined by X-ray fluorescence spectrometry on pressed pellets, with matrix correction based on major element composition and calibration using international standards analyzed by isotope dilution mass spectrometry. One specimen of mica (zinnwaldite) from a Li-mica topaz leucogranite sill in the main Thirty Mile Stock (#97/28-4 on Fig. 4), one biotite from the Hake Batholith, and one biotite from the granodiorite of the Southwest Thirtymile stock were analyzed for Rb, Sr and $^{87}Sr/^{86}Sr$ by isotope

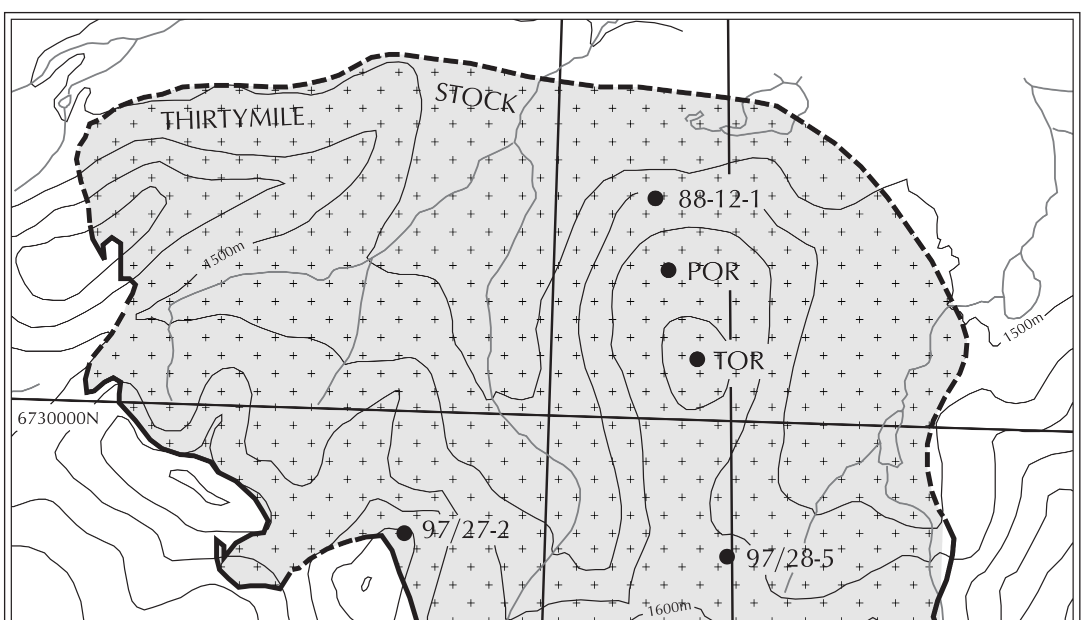


Figure 4. *Sample locations in the Thirtymile stock.*

***Table 1.** Summary of chemical data for the Thirtymile plutons and results of Rb-Sr isotopic analyses.*

Pluton	SiO_2	CaO	A/CNK	D	Rb/Sr	Ga/Al
Thirtymile Li-mica	74.1-77.6	0.01-0.23	1.048	86.7-96.3	858-7588	6.69 ± 0.54 (6)
Thirtymile Biotite	70.0-78.0	0.35-1.46	0.919	96.6-99.4	1.8-66.8	3.07 ± 0.28 (31)
NWTM	60.2-64.1	4.36-4.91	0.885	60.9-68.7	006-0.12	2.33 ± 0.04 (5)
SWTM	50.9-62.0	4.44-6.35	0.823	38.4-69.7	0.09-0.13	2.17 ± 0.19 (7)

D = Thornton-Tuttle Differentiation Index; Ga/Al = ppm/% A/CNK = Al/Ca + Na + K

Pluton/Facies	Specimen		Rb	Sr	Method	Rb/Sr	$^{87}Sr/^{86}Sr$ ± 2 S.E.	$^{87}Rb/^{86}Sr$	Age (Ma ± 2σ)
Thirtymile Megacrystic	97/28-5	Rock	483	73.2	XRF	6.59	0.734721 ± 12	19.06	
Thirtymile Megacrystic	TOR	Rock	323	52.2	XRF	6.19	0.733384 ± 9	17.90	101 ± 5.6
Thirtymile Megacrystic	88/12-1	Rock	394	73.9	XRF	5.33	0.729086 ± 18	15.41	
Thirtymile Megacrystic	97/27-2	Rock	370	110.2	XRF	3.36	0.721347 ± 11	9.70	
Thirtymile Porphyry	POR	Rock	261	147.4	XRF	1.77	0.713364 ± 15	5.10	
Thirtymile Li-mica	97/28-4	Mica	15,491	6.69 ± 0.1	ID		135 ± 5	94379	100 ± 4*
Hake Batholith	08/17-2	Mica	1479	7.38 ± 0.02	ID		1.586 ± 1	627.4	98.3 ± 2.9*
Southwest Thirtymile	08/20-4	Mica	404.0	69.25 ± 0.01	ID		0.74836 ± 8	16.89	181.5 ± 2.5
Southwest Thirtymile	08/20-4	Rock	102.1	961	XRF		0.70529 ± 1	0.3063	

Notes: * Indicates that the age is calculated using Sr_i = 0.7074 = initial Sr ratio; S.E. = standard error.

Sample locations other than shown in Fig. 2 are: SW Thirtymile Stock, Specimen 08/20-4: 60°32'17"N, 132°30'00"W, and Hake Batholith, Specimen 08/17-2: 60°26'05"N, 132°01'22"W

dilution. Error in $^{87}Rb/^{86}Sr$ is estimated at <1% (2σ) by repeat analysis of SRM607 K-feldspar. Results of these two sets of measurements are shown in Table 1. Isochrons were calculated using least squares fitting according to the method of York (1969). An isochron diagram for megacrystic granites is Figure 5.

RESULTS

The four ('megacrystic') specimens from Thirtymile stock were used for calculation of the whole-rock errorchron (Fig. 5), which yielded an age of 101 ± 5.3 Ma (2σ analytical error increased by the mean square weighted deviation) and $^{87}Sr/^{86}Sr_i$ = 0.7074 ± 0.0011 (2σ). The isotope ratios of specimen POR (location in Fig. 4) were used to calculate $^{87}Sr/^{86}Sr_i$ for the 'porphyry' lithofacies yielding 0.7060, using t (time) = 101 Ma. Isotope dilution determination of Rb and Sr contents and isotope ratios of zinnwaldite mica from the Li-mica lithofacies of the main Thirtymile stock (sill) indicate that this mineral is sufficiently radiogenic (ratio of Rb:Sr is 2316:1) to allow an age of 100 ± 4 Ma to be calculated using the Sr_i value of the megacrystic facies. This age for the Thirtymile Li-mica lithofacies provides a cooling age for the pluton. Since the mica age is concordant with the whole-rock age, 100 Ma is probably close to the emplacement age of the entire Thirtymile Complex. The Hake pluton yielded an errorchron age of ~98.3 ± 2.9 Ma.

An age of 181.5 ± 2.5 Ma for the Southwest Thirtymile stock was calculated using separated mica from sample 08/20-4, with the corresponding whole rock defining an

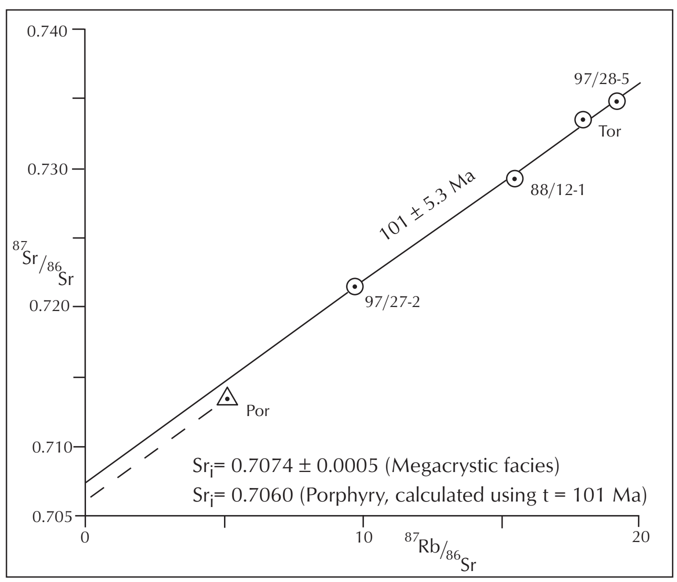


***Figure 5.** Rb-Sr errorchron for the megacrystic facies of the Thirtymile stock.*

initial $^{87}Sr/^{86}Sr$ of 0.7045 ± 0.0003 (2σ). Note that this initial ratio is distinctly lower than those of the main Thirtymile stock facies.

DISCUSSIONS

1. Possible source region of the granites

The Southwest Thirtymile cooling age of 181.5 ± 2.5 Ma is considerably older than those of the main Thirtymile stock (100 ± 4 Ma). This indicates that Cretaceous peak temperatures did not exceed the Rb-Sr blocking temperature for biotite and, hence, that the main Thirtymile stock is likely to have cooled rapidly. This observation is in accordance with the probable shallow depth of emplacement (<<3.5 km) that may be inferred from the presence of miarolitic cavities in several lithofacies of the stock.

The coeval dates calculated for the main Thirtymile stock and Hake Batholith suggest that a single intrusive suite extends southeast; the adjacent Seagull Batholith yielded Rb/Sr dates between 101 ± 4 and 99.8 ± 2.2 Ma (reported in Sinclair, 1986). The Sr-initial ratio (Sr_i = 0.707) obtained from the megacrystic facies of the Thirtymile stock, however, is lower than those of the Seagull Batholith, which has a more distinct 'S-type' isotopic signature (0.712; Sinclair, 1986), although it remains markedly higher than those within the Intermontane Belt to the west (usually <0.704; Armstrong, 1988). Mineralogy and chemistry of the Thirtymile pluton (Liverton 1990 & 1992; Liverton & Alderton 1994) are broadly indicative of an ilmenite-bearing, I-type magma, although the Sr-initial ratio suggests that some metasedimentary source rocks are involved in the genesis of this granite (cf. Kistler, 1990). The large radiogenic component of the mid-Cretaceous magmas in general within the Cordillera has been ascribed to elevated lower crustal temperatures at that time. Some of these have no apparent mantle component (Armstrong, 1988).

2. Tectonic model

The tectonic model for the northern Cordillera developed by Struik (1987) is discussed here. Westward-directed subduction of the oceanic Cache Creek Terrane beneath fragments of the continental margin gave rise to the island-arc terrane of Quesnellia. Continued westward A-type subduction (Whalen et al., 1987) during the Early Jurassic resulted in accretion of terranes to the ancient continental margin. However the boundary between the allochthonous terranes of the Intermontane Belt and displaced North American strata has been difficult to resolve. The initial interpretation of the Teslin Zone was a suture that was thrust eastwards over the Cassiar Platform (Tempelman-Kluit, 1979). Subsequent re-interpretations include: a root zone for nappes and steeply dipping tectonites (Hansen, 1990; 1992a, b), a crustal-scale flower structure (Stevens, 1994); bivergent thrusting above a thrust detachment (Stevens and Erdmer, 1996), and a large-scale F_3 synform (de Keijzer et al., 1999, especially p. 481; deKeijzer and Williams, 1999). The latter interpretation suggests that the Teslin Zone is not a terrane boundary, and ancient continental crust may extend beneath the Teslin Zone tectonites.

Obduction of the Slide Mountain oceanic terrane occurred no later than 183 Ma (Gabrielse and Brookfield, 1988), which is close to the age determined for the Southwest Thirtymile pluton. Middle Jurassic plutonism is recorded from the accreted terranes in BC (Gabrielse, 1991, p. 601; Woodsworth et al., 1991, p. 504, 506), but is extremely rare in the continental margin (Armstrong, 1988; J.K. Mortensen, pers. comm., 1993).

The chemistry of the Northwest Thirtymile and Southwest Thirtymile stocks (Liverton and Alderton, 1994) and Sr_i of 0.7045 for the Southwest stock are consistent with juvenile magma. The source could have been either subducted oceanic crust or a mantle wedge above a subduction zone. The continental crustal component was minor.

The polarity of the subduction zone is deduced to have been eastward. Detrital zircons indicate that the siliciclastic sedimentary rocks of the Thirtymile Range have a western Canadian shield and northern Cordilleran miogeocline provenance (Ross and Harms, 1998); thus this area is effectively 'tied' to the continent. A west-facing arc could not have been built upon these sediments because they would have been dragged into the subduction zone. Instead undeformed Jurassic plutons cut the fabric of the Thirtymile Range metasedimentary rocks and therefore place an upper age limit on the penetrative deformation.

3. Angular dispersion of regional structures

The orientation of the mesoscopic-scale linear fabric is consistent with its having been generated by oblique obduction. In transpressive regimes the orientation of fold axes marginal to the main fault is at 45° to that structure, and a simple shear model for deformation has been suggested (Jamison, 1991). This is in contrast to purely convergent terranes (pure shear), which produce fold axes parallel to the fault. The analogue modelling of transpression by Odonne and Vialon (1983) produced similar results. During simple shear, folds are progressively developed and their axes become rotated parallel to the fault. Fold axes are curved, although at greater distances from the fault they remain at the initial 40-45° angle to its strike. Furthermore, axial planes of folds become progressively flatter away from the fault; in cross-sections they resemble a fan or flower structure.

Lineations are similarly affected. Escher and Watterson (1974) proposed that L-S tectonite fabrics in which the planar element dips at a low angle away from the foreland, and where the stretching element is transverse to the boundary of the belt, originate by simple shear deformation. Early formed folds would be rotated so that their axes approximate the original stretching lineation. The C-S fabrics observed in the Thirtymile Range are considered to indicate layer-parallel extension in sheared lithologic units. Mechanisms of such foliation-boudinage formation as a layer-parallel extension phenomenon have been addressed by Platt and Vissers (1980): extension along the foliation results in brittle failure (shear band development) and, where the deformation is non-coaxial, forms an asymmetric boudinage. Furthermore, the cleavage orientation does not appear to be related directly to axes of finite strain. The structural mechanism described above can produce the eastward vergence observed in the central Thirtymile Range.

The pre-183 Ma deformation is deduced from Rb/Sr geochronology. At least two possibilities exist. The deformation may represent the effect of oblique obduction of the Dorsey Terrane onto the North American continent immediately before intrusion of the hornblende-rich plutons, or it could be much older, such as the Mississippian-aged fabrics determined for parts of the Yukon-Tanana Terrane (J.K. Mortensen, pers. comm., 1992; Colpron and Reinecke, 2000).

The chemical and Sr isotopic evidence of the mid-Jurassic calc-alkaline plutons indicates subduction. Oceanic crust may have been subducted or underplated ('wedging'; Price, 1986), or the melting of thickened crust produced juvenile magma. Could subduction in the Jurassic have had a short-lived westward polarity, consuming oceanic crust developed in a late Carboniferous to early Permian rift basin? In contrast, the Sr-isotope initial ratios and chemistry of the Seagull-Thirtymile plutons is entirely consistent with generation in a thickened continental crust. It bears much similarity to the Cassiar Batholith (Driver et al., 2000). Cretaceous magmatism, although widespread, maintained low upper crustal temperatures in the Thirtymile Range because it did not reset the Sr isotopic system of the Jurassic Southwest Thirtymile pluton.

CONCLUSIONS

The tectonic history of the western assemblages of the 'Dorsey Terrane' is open to discussion. Detrital zircon geochronology indicates that the siliciclastic strata in the Thirtymile Range were derived from the continental margin (Ross and Harms, 1998). Penetrative deformation of that part of the succession is constrained at no younger than 181 Ma by the geochronology presented here. The mid-Jurassic magmas have a distinct subduction-related chemistry. Magma generation during eastward-directed subduction is most likely.

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