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Timing of post-tectonic Cadomian magmatism on Guernsey, Channel Islands: evidence from $^{40}Ar/^{39}Ar$ mineral ages

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Abstract: The Channel Island of Guernsey exposes pre- and post-tectonic calc-alkaline plutonic rocks attributed to late Precambrian (Cadomian) subduction activity. $^{40}Ar/^{39}Ar$ mineral cooling ages presented here clarify the age and time-span of post-tectonic intrusions. Amphibole from the Bon Repos meladiorite yields an isotope correlation age of 605.3 ± 4.6 Ma, indicating emplacement during late stages of the tectonothermal event recorded within its host rocks. Igneous hornblendes from the Northern Igneous Complex record consistent isotope correlation ages (St Peter Port gabbro 570.2 ± 1.1 Ma, Bordeaux diorite complex 569.0 ± 1.1 and 565.3 ± 2.2 Ma, and a comagmatic enclave within Cobo granite 570.2 ± 1.5 Ma). Hornblende and biotite from contact-metamorphosed host rocks adjacent to the Cobo granite yield isotope correlation ages of 569.6 ± 1.1 and 563.8 ± 3.3 Ma respectively. These ages, together with field data, demonstrate that the various members of the Northern Igneous Complex were emplaced contemporaneously at *c.* 570 Ma, significantly earlier than a *c.* 500 Ma Rb-Sr whole-rock isochron age previously reported for the Cobo granite. The $^{40}Ar/^{39}Ar$ ages indicate that post-tectonic magmatism on Guernsey was broadly coeval with post-metamorphic cooling around the Baie de St Brieuc on the adjacent French mainland, and occurred *c.* 30 Ma prior to peak Cadomian deformation and metamorphism in the St Malo area.

The late Precambrian Cadomian orogen within the North Armorican Massif (Fig. 1) comprises magmatic arc and marginal basin complexes that were amalgamated during accretionary tectonism above a southerly dipping subduction zone (Auvray 1979; Graviou & Auvray 1985; Dissler *et al.* 1988; Graviou *et al.* 1988; Brown *et al.* 1990). Ductile shear zones and brittle faults separate the orogen into several tectonic elements (Dissler *et al.* 1988; Brun & Bale 1990), which are considered to represent displaced terranes (Strachan *et al.* 1989). Published geochronological studies suggest at least three discrete tectonothermal events: (1) pre-600 Ma (Guernsey & Sark; Dallmeyer *et al.* 1991*a*); (2) 590–560 Ma (Baie de St Brieuc; Guerrot & Peucat 1990; Dallmeyer *et al.* 1991*b*); (3) *c.* 540 Ma (St Malo–Mancellian region: Peucat 1986; Graviou *et al.* 1988). Various ages have been proposed for the termination of Cadomian subduction-related magmatism within the North Armorican Massif ranging from end-Precambrian (Auvray 1979; Guerrot & Peucat 1990) to Silurian (Brown *et al.* 1990).

On the island of Guernsey (Fig. 1) Icartian meta-igneous rocks and early Cadomian arc plutonic rocks were penetratively deformed prior to *c.* 600 Ma (Dallmeyer *et al.* 1991*a*). They were subsequently intruded by the Bon Repos meladiorite, the basic Vazon dyke swarm and the calc-alkaline Northern Igneous Complex (Fig. 1) (Lees & Roach 1987; Topley *et al.* 1990). These units are only locally deformed and for the most part retain original igneous textures and mineralogies, and are therefore considered to be post-tectonic with respect to the main regional Cadomian deformation in this part of the North Armorican Massif. $^{40}Ar/^{39}Ar$ mineral ages are presented here from the various igneous units exposed on Guernsey. These confirm a late Precambrian age for Cadomian magmatism on Guernsey and indicate an age of *c.* 570 Ma for the Northern Igneous Complex. This complex was thus emplaced either before or during regional deformation and metamorphism recorded within adjacent terrane elements in Northern Brittany. This is consistent with the interpretation of Dallmeyer *et al.* (1991*a*) that Guernsey may have constituted part of an outboard terrane, additional to those identified in Northern Brittany by Strachan *et al.* (1989). The $^{40}Ar/^{39}Ar$ ages also cast doubt on the geological significance of a Rb-Sr whole-rock isochron age previously reported for a post-tectonic intrusion on Guernsey.

Geological setting

The country rocks of the post-tectonic intrusions include Icartian meta-igneous rocks and the Perelle quartz diorite (Roach 1957, 1977; Power *et al.* 1990*a*). The most common Icartian lithology is variably deformed megacrystic granite, for which a U-Pb zircon age of *c.* 2000 Ma has been reported (Calvez & Vidal 1978). The foliated Perelle quartz diorite has yielded a U-Pb zircon crystallization age of *c.* 700 Ma (Dallmeyer *et al.* 1991*a*). Both the Perelle quartz diorite and Icartian granite display similarly-orientated solid-state L–S fabrics, indicating that the dominant fabric within both units developed after *c.* 700 Ma. $^{40}Ar/^{39}Ar$ hornblende mineral ages of *c.* 595–605 Ma for the Perelle quartz diorite record cooling following deformation and metamorphism (Dallmeyer *et al.* 1991*a*).

The *Bon Repos meladiorite* was emplaced into deformed Icartian granite on the south coast of Guernsey (Fig. 1) (Roach *et al.* 1991). The intrusion is not penetratively deformed, although a magmatic foliation that parallels the margins of the intrusion is defined by aligned brown igneous amphiboles.

The basic *Vazon dyke swarm* (Lees & Roach 1987) intrudes deformed Icartian granite and Perelle quartz diorite, and also the Bon Repos meladiorite: the dykes have not been observed to intrude the Northern Igneous Complex. They generally trend NNE, vary in width from *c.* 0.5 m to 15 m, and comprise up to 20% of local exposure. They are typically massive and composed of prismatic to fibrous green amphibole aggregates, variably altered plagioclase (An_{40-15}) and minor

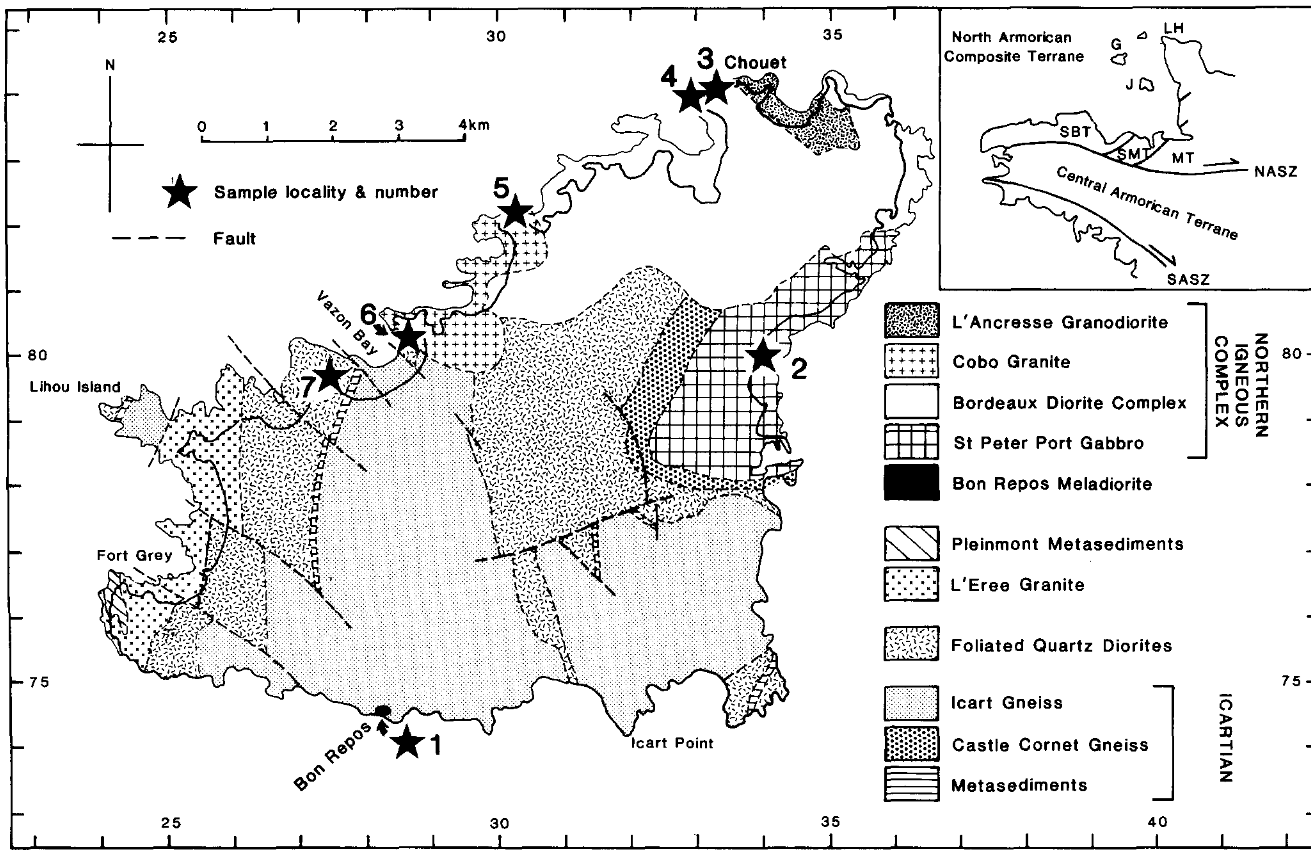

Fig. 1. Simplified geological map of Guernsey (after Roach *et al.* 1991) showing sample localities. Inset, tectonic sketch map for the North American Massif (from Strachan *et al.* 1989). NASZ, North Armorican shear zone; SASZ, South American shear zone; SBT, St Brieuc Terrane; SMT, St Malo Terrane; MT, Mancellian Terrane; J, Jersey; G, Guernsey; LH, La Hague.

biotite. Locally they underwent ductile deformation and are foliated.

Lees & Roach (1987) considered amphibole within the Vazon dykes to have developed through replacement of initial igneous clinopyroxene during a regional (Cadomian) greenschist-facies metamorphism. However, brown magmatic amphiboles within the host Bon Repos meladiorite exhibit only minor development of actinolitic fringes. This, together with the retention of unmodified primary igneous textures within the meladiorite (C.G. Topley pers. comm.), appears inconsistent with thorough-going post-crystallization greenschist-facies metamorphism.

The calc-alkaline *Northern Igneous Complex* (Topley *et al.* 1990 and references therein; Roach *et al.* 1991) comprises four distinct intrusions (Fig. 1). In probable order of emplacement these are: the St Peter Port gabbro, the Bordeaux diorite complex, the Cobo granite, and the L'Ancresse granodiorite.

The *St Peter Port gabbro* is a *c.* 800 m thick, layered sheet-like hornblende gabbro intrusion. The gabbro is intruded by numerous hornblende gabbro dykes considered to have been broadly coeval with the intrusion as a whole. Xenoliths of partially remobilized leucocratic augen-gneiss (Icartian?) occur locally.

The *Bordeaux diorite complex* consists of a variety of intimately associated hornblende-bearing meladiorites, diorites, tonalites and less common granodiorite. Near Chouet (Fig. 1) three distinct igneous suites have been distinguished (Brown *et al.* 1980; Topley *et al.* 1982). (1) The Diorite Group comprises homogeneous, mesocratic, even-grained to acicular diorite with local development of appinite. (2) The Granodiorite Group is a distinctive, homogeneous, coarse-grained leucocratic unit which locally contains abundant rounded dioritic enclaves. (3) The Inhomogeneous Suite is a highly variable, partially magma-mixed suite which ranges in composition from meladiorite to leucocratic tonalite. Although geochemically distinct, the three suites show widespread evidence of co-mingling, and are therefore considered to have been emplaced contemporaneously.

The *Cobo granite* is a homogeneous, orange-weathering, medium-grained biotite leucogranite. Its contacts with the Bordeaux diorite complex (Fig. 1) are characterized by a *c.* 200 m wide transitional zone of mixed-magma and co-mingled hybrid rocks (D'Lemos 1986, 1987*a*). These features demonstrate that emplacement of the Cobo granite occurred into partially crystallized magmas of the Bordeaux diorite complex. Dioritic enclaves in the granite with lobate and crenulate chilled margins provide further evidence for the approximate contemporaneity of magma emplacement. At Vazon Bay (Fig. 1) the granite contains angular blocks both of Perelle quartz diorite and fine-grained mafic lithologies believed to be derived from the Vazon dykes. It cuts across the foliation in the Perelle quartz diorite, which has locally recrystallized as a result of contact metamorphism.

The *L'Ancresse granodiorite* is a homogeneous, weakly

Table 1. *$^{36}Ar/^{40}Ar$ v. $^{39}Ar/^{40}Ar$ isotope correlations for incremental heating experiments on amphibole and biotite concentrates Guernsey, Channel Islands.*

Sample	Isotope correlation Age (Ma)*	$^{40}Ar/^{36}Ar$ intercept†	MSWD	Increments included (°C)	% of total ^{39}Ar	Calculated $^{40}Ar/^{39}Ar$ plateau age (Ma)
Hornblende						
Bon Repos meladiorite						
1A	605.3 ± 4.6	463.2 ± 21.3	1.66	910–fusion	70.78	no plateau defined
St Peter Port gabbro						
2	570.2 ± 1.1	413.5 ± 32.1	1.91	925–fusion	97.13	573.9 ± 1.2
Bordeaux diorite complex						
3	565.3 ± 2.2	520.8 ± 38.4	1.11	840–fusion	88.73	571.5 ± 1.1
4	569.0 ± 1.1	272.3 ± 16.1	0.73	830–1115	93.62	570.8 ± 1.4
Dioritic enclave in Cobo granite						
5	570.2 ± 1.5	745.1 ± 69.2	0.39	915–fusion	63.21	no plateau defined
Contact aureole of Cobo granite						
6	569.6 ± 1.1	344.4 ± 33.2	1.5	880–955	72.10	573.1 ± 0.9
Vazon dykes						
7A‡	553.1 ± 2.3	360.3 ± 21.2	2.1	835–885	57.36	557.9 ± 1.4
7A§	550.4 ± 2.3	392.6 ± 29.3	1.9	835–990	67.48	no plateau defined
7B	559.5 ± 3.0	411.6 ± 35.2	1.63	830–895	68.84	564.0 ± 1.5
Biotite						
Contact aureole of Cobo granite						
6	563.8 ± 3.3	2852 ± 381	1.79	595–670, 950–fusion	62.12	no plateau defined
Vazon dyke						
7A	550.2 ± 4.3	1481 ± 162	0.91	580–620, 860–980	68.56	no plateau defined

* Calculated using the inverse abscissa intercept ($^{40}Ar/^{39}Ar$ ratio) in the age equation.
† Inverse ordinate intercept.
‡ Analysis 1.
§ Analysis 2.

foliated, fine- to medium-grained granodiorite which contains biotite and minor hornblende. The NW-trending foliation within the intrusion probably developed during emplacement. The granodiorite contains angular stoped blocks of dioritic members of the Bordeaux diorite complex, although there is local evidence that magma-mingling may have occurred.

The development of a contact metamorphic aureole to the Cobo granite, the formation of prominent chilled margins to basic dykes, and the preservation of magmatic features (e.g. igneous zoning, disequilibrium textures) indicate that the post-tectonic igneous units were emplaced at upper crustal levels and cooled relatively rapidly. The Northern Igneous Complex generally preserves original igneous textures and mineral assemblages. However, in some units plagioclase has been partially replaced by sericite (St Peter Port gabbro, Cobo granite), biotite has been partially chloritized (Cobo granite, L'Ancresse granodiorite) and hornblende locally displays narrow rims of actinolite (Bordeaux diorite complex, St Peter Port gabbro). These features indicate at least local post-magmatic mineralogical alteration, possibly reflecting either hydrothermal processes or low-grade metamorphism.

Previous geochronology

Adams (1967, 1976) reported an imprecise, five-point, Rb-Sr combined mineral and whole-rock isochron age of *c.* 535 Ma for the Cobo granite (recalculated from original data using $\lambda^{87}Rb = 1.42 \times 10^{-11}$ a^{-1}). He also reported K-Ar hornblende and biotite ages from various components of the Northern Igneous Complex (587–494 Ma), and from the Perelle quartz diorite (596–504 Ma). D'Lemos (1987b) presented an eight-point, Rb-Sr whole-rock isochron age (MSWD 2.2) of 496 ± 13 Ma for the Cobo granite.

Bremond d'Ars (1990) undertook Rb-Sr whole-rock isotope analysis of various components of the Northern Igneous Complex and plotted all results together on a single isochron diagram. Thirteen analyses (selected from a total of 22) were used to calculate a reference age of 553 ± 9 Ma. The approach requires that all components of the complex formed by fractionation of a single, isotopically homogeneous parent magma. However, several workers (Brown *et al.* 1980, 1990; D'Lemos 1987*a*; Topley *et al.* 1990) have argued that, although various components of the complex were comagmatic, the main units do not form a single geochemical suite and were variably contaminated by crustal components. Hence, the reference isochron of Bremond d'Ars (1990) must be regarded as having uncertain geological significance.

Results

Eight amphibole and two biotite concentrates were prepared from samples collected within various post-tectonic igneous units and adjacent country rocks. Sample localities are indicated in Fig. 1: grid co-ordinates and petrographic descriptions of the samples are given in the Appendix. The $^{40}Ar/^{39}Ar$ analytical data are summarized in Table 1. The full list of analytical data is available as Supplementary Publication No SUP 18073 (6 pp) from the British Library Document Supply Centre, Boston Spa, Wetherby, W. Yorks LS23 7BQ, UK and from the Society Library. They are portrayed as incremental age and apparent K/Ca spectra in Figs 2–9. Analytical methods and calculation of ages are similar to those described in detail by Dallmeyer *et al.* (1991*a*) after Steiger & Jager (1977), Dalrymple *et al.* (1981) and Dallmeyer & Keppie (1987).

Most of the hornblende concentrates display slightly discordant $^{40}Ar/^{39}Ar$ age spectra in which variable apparent ages are recorded at low release temperatures. These are matched by variations in apparent K/Ca ratios, suggesting evolution of argon at low temperatures from compositionally distinct and relatively non-retentive phases. These could be: (1) very minor, optically undetectable, mineralogical contaminants in the concentrates; (2) petrographically unresolvable exsolution or compositional zoning; (3) minor chloritic replacement of amphiboles, and/or (4) intracrystalline inclusions. Intermediate- and high-temperature increments are characterized by minor intrasample variation in apparent K/Ca ratios, suggesting Ar release from compositionally uniform intracrystalline 'sites'.

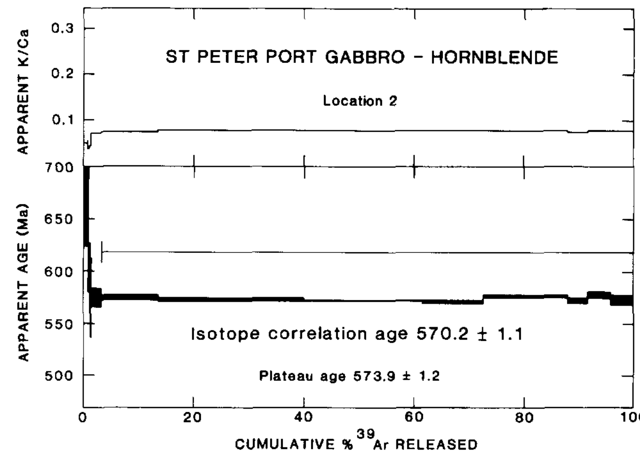

Fig. 3. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a hornblende concentrate from the St Peter Port gabbro (locality 2) (see also caption to Fig. 2).

Bon Repos meladiorite

Hornblende was analysed from a sample of Bon Repos Meladiorite (locality 1). Fifteen intermediate- and high-temperature increments record apparent $^{40}Ar/^{39}Ar$ ages between 598.7 ± 4.1 Ma and 634.0 ± 4.7 Ma (Table 1, Fig. 2). Although the data do not rigorously define a plateau, they exhibit a well-defined $^{36}Ar/^{40}Ar$ v. $^{39}Ar/^{40}Ar$ isotope correlation (MSWD = 1.66; York 1969). The inverse ordinate intercept of 463.2 ± 21.3 is higher than the $^{40}Ar/^{36}Ar$ ratio in the present-day atmosphere and suggests slight intracrystalline contamination with extraneous argon. Using the inverse abscissa intercept ($^{40}Ar/^{39}Ar$) in the age equation results in an age of 605.3 ± 4.6 Ma. Because calculation of isotope correlation ages does not require assumption of a $^{40}Ar/^{36}Ar$ ratio they are more reliable than ages calculated directly from the $^{40}Ar/^{39}Ar$ analytical data (McDougall & Harrison 1988). The *c.* 605 Ma age is therefore considered geologically significant and interpreted a dating post-magmatic cooling. Harrison (1981) indicated that closure temperatures for Ar systems in igneous hornblende are not significantly affected by compositional variations, and suggested a value of 500 ± 25 °C as appropriate for most geological settings. The time period between emplacement of the meladiorite and cooling through this closure temperatures cannot be estimated.

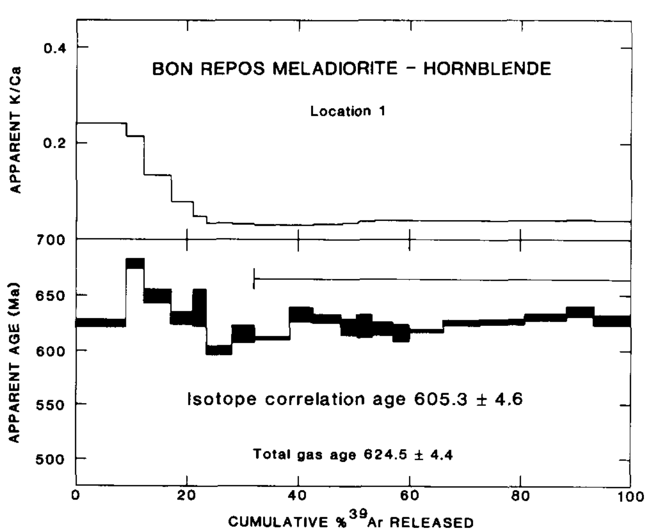

Fig. 2. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a hornblende concentrate from the Bon Repos meladiorite (locality 1). Analytical uncertainties (two sigma, intralaboratory) are represented by vertical width of bars. Experimental temperatures increase from left to right. For this and Figs 3 to 9, isotope correlation ages are given for increments defined by bars (see also Table 1). Where these increments also define a plateau age, this is also given. If no plateau is defined then a total gas age is quoted.

St Peter Port gabbro

A hornblende concentrate was analyzed from massive, medium-grained hornblende gabbro (bojite type of Topley *et al.* 1990) within the St Peter Port gabbro (locality 2). The $^{40}Ar/^{39}Ar$ age spectrum (Fig. 3) displays variable apparent ages at low experimental temperatures, but the 925 °C–fusion increments, which comprise *c.* 97% of the total ^{39}Ar evolved from the concentrate, record a plateau age of 573.9 ± 1.2 Ma. The plateau data also yield a well-defined isotope correlation (MSWD = 1.91) with an inverse ordinate intercept of 413.5 ± 32.1. The $^{40}Ar/^{39}Ar$ intercept value gives an age of 570.2 ± 1.1 Ma, which is interpreted as dating post-magmatic cooling.

Bordeaux diorite complex

Hornblende was separated from massive quartz diorite (homogeneous member of the Inhomogeneous Suite) and massive granodiorite (Granodiorite Group) from localities 3 and 4 respectively. The two concentrates display $^{40}Ar/^{39}Ar$ age and apparent K/Ca spectra with characteristics similar to those of sample 2 (Fig. 4): the intermediate- and high-temperature portions define plateaux of 571.5 ± 1.1 Ma (3) and 570.8 ± 1.4 Ma (4). Isotope correlations of the plateau data are well-defined (Table 1) with inverse ordinate intercepts of 520.8 ± 38.4 (3) and 272.3 ± 16.1 (4), and corresponding ages of 565.3 ± 2.2 Ma (3) and 569.0 ± 1.1 Ma (4).

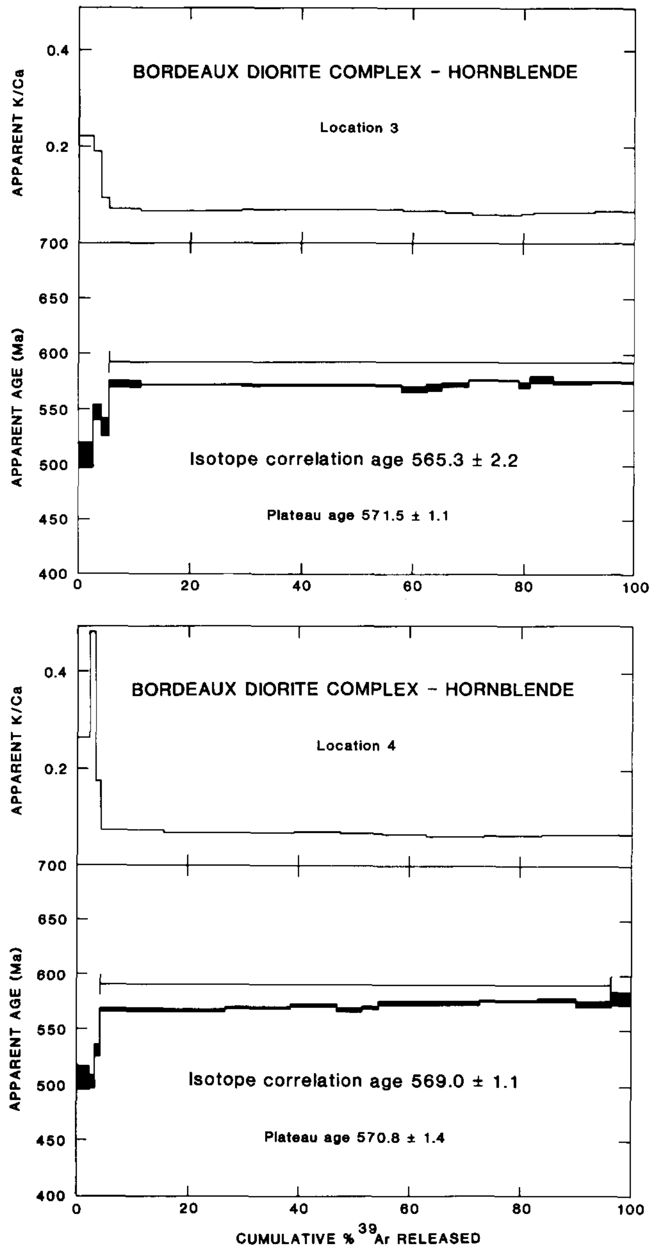

Fig. 4. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for hornblende concentrates from the Inhomogeneous Suite (locality 3) and Granodiorite Group (locality 4) members of the Bordeaux diorite complex (see also caption to Fig. 2).

Dioritic enclave within the Cobo granite

Hornblende was separated from a mafic dioritic enclave within the Cobo granite at locality 5. The enclave exhibits lobate and crenulate chilled margins, and is interpreted as a mafic pillow formed during mingling between co-existing magmas of the Bordeaux diorite complex and Cobo granite (D'Lemos 1986, 1987*a*). The 780 °C–fusion increments record generally similar apparent ages ranging between *c.* 560 Ma and 580 Ma. The 915 °C–fusion increments give a tighter range of 560–570 Ma, and a well-defined isotope correlation (MSWD = 0.39) with an inverse ordinate intercept of *c.* 745. The inverse abscissa intercept corresponds to an age of

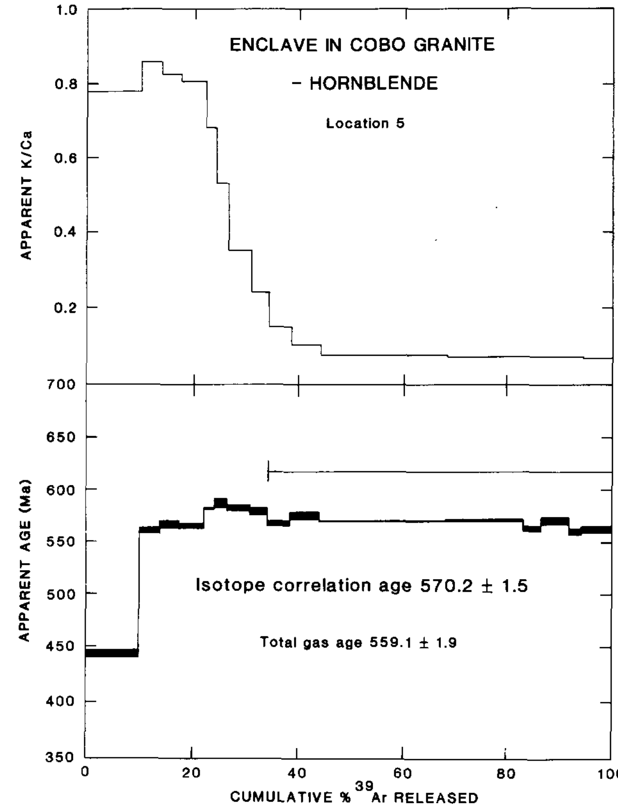

Fig. 5. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a hornblende concentrate from a pillowed dioritic enclave within the Cobo granite (locality 5) (see also caption to Fig. 2).

570.2 ± 1.5 Ma, considered as the time of cooling of the enclave and host granite to about 500 °C following emplacement of the Cobo granite.

Contact aureole of the Cobo granite

Biotite and hornblende were concentrated from a sample of contact-metamorphosed Perelle quartz diorite collected *c.* 50 cm from the contact of the Cobo granite at locality 6. The hornblende concentrate displays $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra with characteristics similar to those described for samples 2–4. The 880–955 °C increments record a $^{40}Ar/^{39}Ar$ plateau corresponding to an age of 573.1 ± 0.9 Ma (Fig. 6). The plateau data yield a well-defined isotope correlation (MSWD = 1.5), with an inverse ordinate intercept not significantly different from the present-day $^{40}Ar/^{36}Ar$ atmospheric ratio (Table 1) and a calculated intercept age of 569.6 ± 1.1 Ma.

The biotite concentrate from sample 6 displays markedly discordant $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra (Fig. 7). Anomalously young apparent ages are recorded in the 450–575 °C increments which display increasing apparent K/Ca ratios. The 595–670 °C increments record relatively high and generally constant apparent K/Ca ratios, and define apparent $^{40}Ar/^{39}Ar$ ages ranging between 578.9 ± 2.0 Ma and 583.0 ± 1.9 Ma. The 720–920 °C increments are characterized by a decrease in apparent K/Ca ratios, matched by an increase in apparent ages. The 950 °C–fusion increments display less variation in apparent K/Ca ratios and yield apparent ages

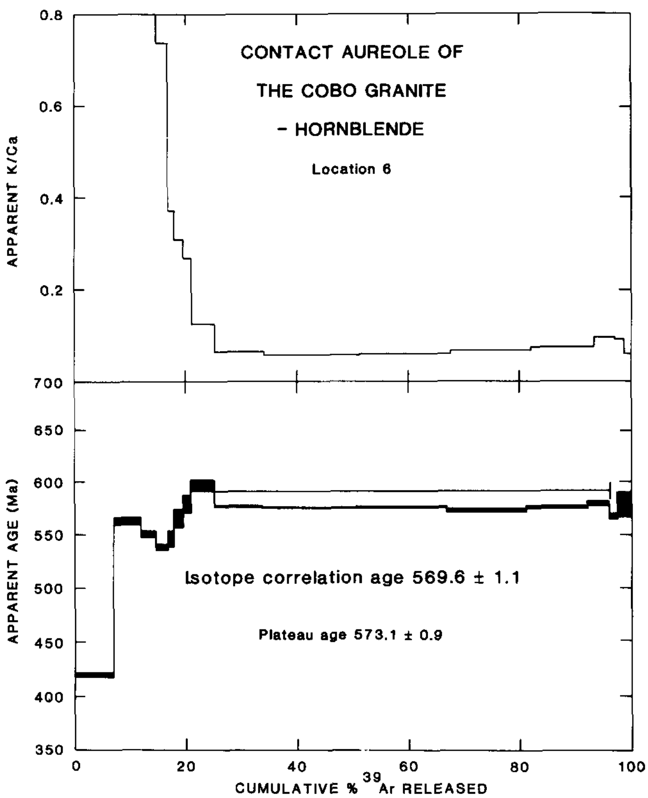

Fig. 6. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a hornblende concentrate from contact metamorphosed Perelle quartz diorite adjacent to the Cobo granite (locality 6) (see also caption to Fig. 2).

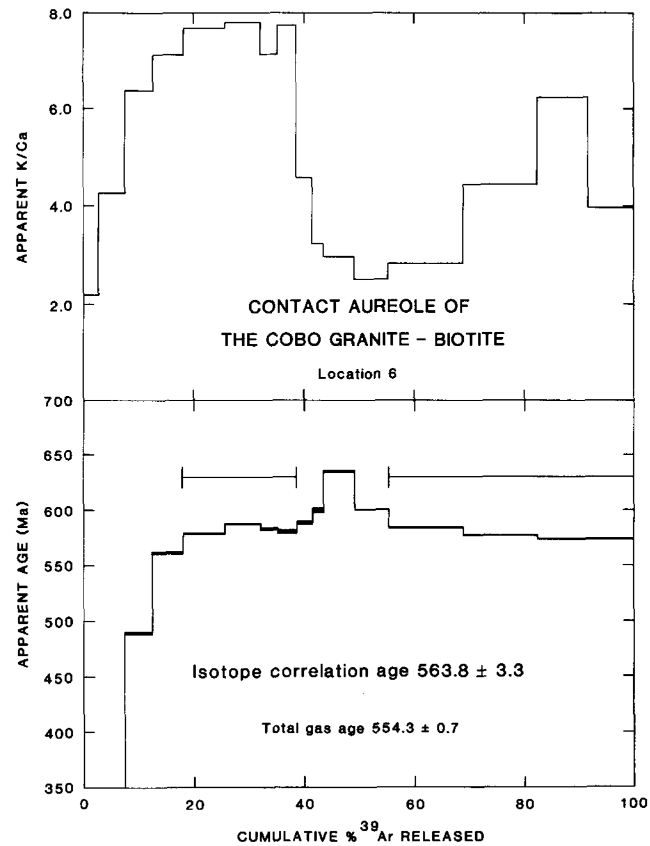

Fig. 7. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a biotite concentrate from same sample as depicted in Fig. 6 (see also caption to Fig. 2).

ranging between 573.2 ± 1.5 Ma and 577.0 ± 1.3 Ma. This type of spectral discordance was described by Lo & Onstott (1989) for partially chloritized biotite in granitic plutons from Taiwan, and was interpreted by them in terms of the combined effects of high partial pressures of ^{40}Ar during chloritization and ^{39}Ar and ^{37}Ar recoil into chlorite during neutron irradiation. In the present case the 595–670 °C and 950 °C–fusion increments together yield an isotope correlation (MSWD = 1.79) with a large inverse ordinate intercept (2852 ± 381) and an age of 563.8 ± 3.3 Ma (Table 1) that could date cooling through the biotite blocking temperature. Harrison *et al.* (1985) demonstrated that biotite closure temperatures for Ar diffusion are dependent upon composition and increase with decreasing Fe/Mg ratio, but suggested that closure occurs at *c.* 300 ± 25 °C in most geological settings. Both hornblende and biotite ages are interpreted as dating cooling following contact metamorphism.

Vazon dykes

Samples were collected from two Vazon dykes that intrude foliated Perelle quartz diorite at locality 7. Actinolitic amphibole was concentrated from both samples (7A and 7B) and biotite from sample 7A. The amphibole concentrate from 7A was analysed in duplicate in separate irradiations. The intermediate-temperature fractions of the amphiboles show relatively little intra-sample variation and define plateau ages of 557.9 ± 1.4 Ma (7A) and 564.0 ± 1.5 Ma (7B) (Fig. 8). Corresponding isotope correlations are well-defined (Table 1): they yield ages of 553.1 ± 2.3 Ma and 550.4 ± 2.3 Ma (two analyses of 7A) and 559.3 ± 3.0 Ma (7B), considered as representing cooling of the Vazon dykes.

The biotite concentrate from sample 7A displays patterns of variation in apparent age and apparent K/Ca ratio similar to those described for biotite from sample 6 (Fig. 9) and are similarly interpreted. The 580–620 °C and 860 °–fusion increments display relatively large and constant apparent K/Ca ratios, and yield an isotope correlation (Table 1) with an inverse ordinate intercept of 1481 ± 162 and an age of 550.2 ± 4.3 Ma. This probably dates cooling of biotite to about 300 °C following dyke emplacement.

Conclusions

$^{40}Ar/^{39}Ar$ mineral cooling ages determined for post-tectonic intrusions on Guernsey are generally younger than the *c.* 605–595 Ma range recorded in the deformed and metamorphosed country rocks (Dallmeyer *et al.* 1991a). The hornblende age of the Bon Repos meladiorite (605.3 ± 4.6 Ma) overlaps with that for post-metamorphic cooling of the Perelle quartz diorite, and implies that the meladiorite was emplaced during latest stages of that regional tectonothermal event.

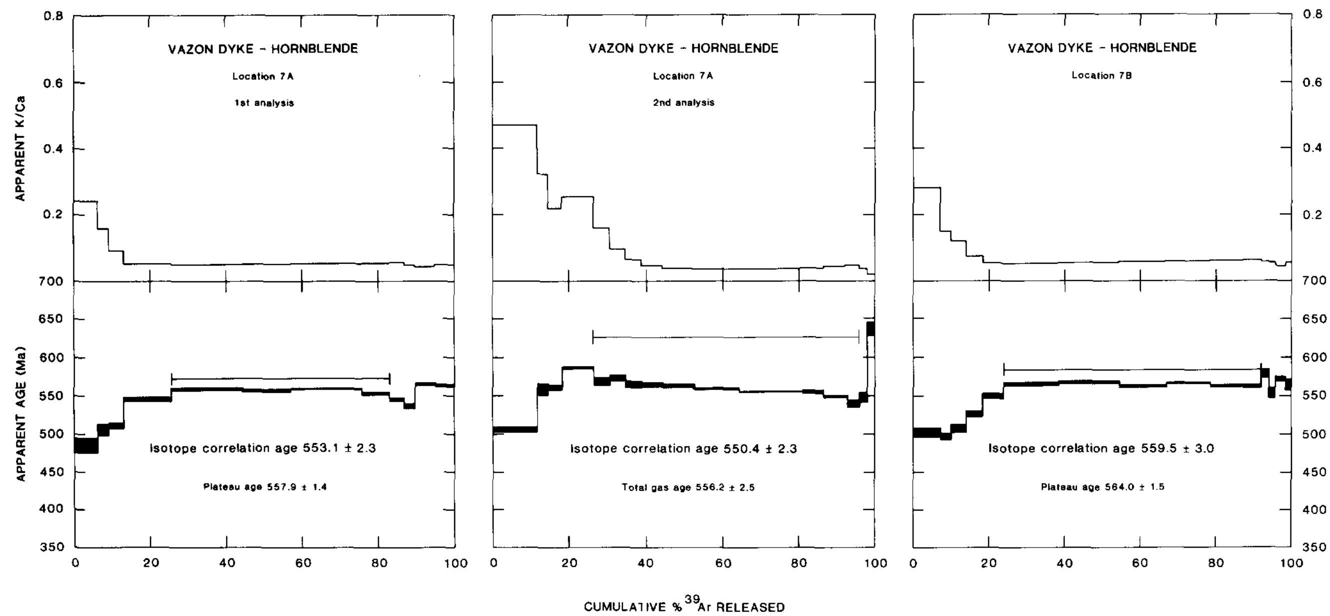

Fig. 8. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for two amphibole concentrates from Vazon dykes in Vazon Bay (locality 7) (see also caption to Fig. 2).

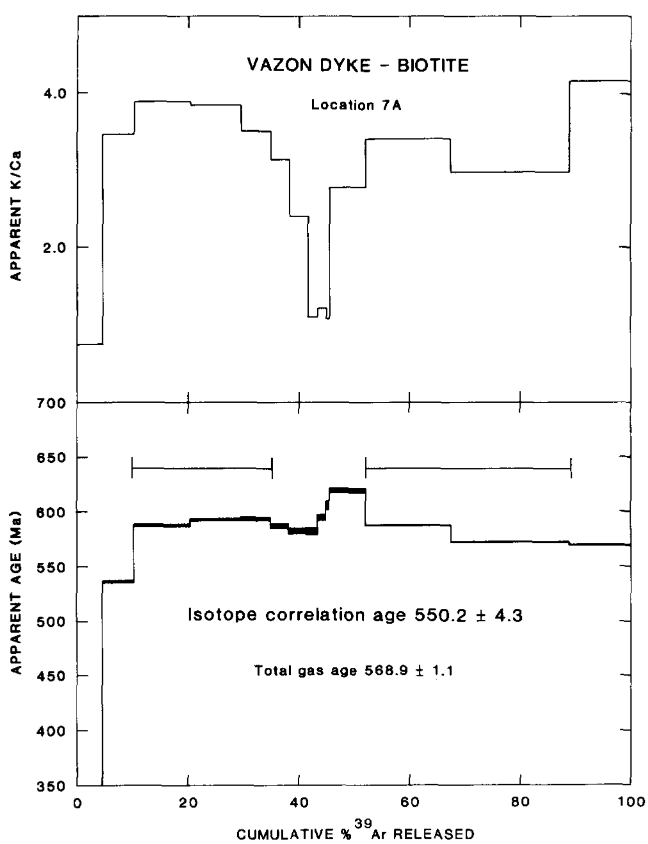

Fig. 9. $^{40}Ar/^{39}Ar$ apparent age and apparent K/Ca spectra for a biotite concentrate from a Vazon dyke, Vazon Bay (locality 7) (see also caption to Fig. 2).

Post-magmatic cooling ages of 570–565 Ma are recorded by igneous hornblende from three basic-to-intermediate representatives of the Northern Igneous Complex. In the light of the field and petrographic evidence which suggests that these rocks were emplaced at an upper crustal level and cooled rapidly, the $^{40}Ar/^{39}Ar$ hornblende cooling ages are considered as essentially dating magma emplacement. Igneous hornblende from a comagmatic enclave within the Cobo granite provides an indirect age of *c*. 570 Ma for emplacement of the granite. Hornblende and biotite ages of *c*. 570 and 564 Ma respectively from contact-metamorphosed Perelle quartz diorite immediately adjacent to the Cobo granite are significantly younger than hornblende ages reported from Perelle quartz diorite elsewhere on Guernsey (Dallmeyer *et al.* 1991a). They are therefore interpreted as dating relatively rapid cooling following local contact metamorphism associated with emplacement of the Cobo granite. Collectively the $^{40}Ar/^{39}Ar$ results indicate that various units of the Northern Igneous Complex were emplaced between *c*. 570 and 565 Ma, and support the conclusion of Topley *et al.* (1990) that the various units were broadly contemporaneous.

Slightly younger isotope correlation ages of 560–550 Ma were determined for amphiboles from two Vazon dykes. However, previously reported field relations have been taken to indicate that the Vazon dyke swarm was emplaced after early Cadomian deformation, but *prior* to intrusion of the Northern Igneous Complex (Lees & Roach 1987). There are several possible solutions to this apparent paradox: (1) the Vazon dyke swarm does not comprise a single intrusive suite and the dated dykes are younger than the Northern Igneous Complex; (2) the dykes are older than the Northern Igneous Complex and their contrasting cooling ages reflect differential blocking temperatures of amphiboles of contrasting compositions;

and/or (3) the amphiboles within the (older) dykes were formed by deuteric (hydrothermal?) alteration and/or low-grade metamorphism following or associated with intrusion of the (younger) Northern Igneous Complex. We favour interpretation of the Vazon dykes as a 'swarm' comprised of dykes emplaced over a protracted time period, as a result of which some dykes pre-date the Northern Igneous Complex, whilst other post-date it.

The $^{40}Ar/^{39}Ar$ mineral cooling ages reported for post-tectonic intrusions on Guernsey indicate that the main tectonothermal and magmatic activity within this part of the Cadomian belt occurred prior to *c.* 570–565 Ma. This is consistent with the pre-570 Ma age for Cadomian subduction-related magmatism suggested for the French mainland (Auvray 1979; Graviou *et al.* 1988; Guerrot & Peucat 1990). The cooling ages are broadly coeval with uplift following regional deformation and metamorphism in the St Brieuc terrane (Dallmeyer *et al.* 1991*b*: see Fig. 1 inset), but are significantly older than the *c.* 540 Ma age suggested for Cadomian tectonothermal events in the St Malo terrane (Peucat 1986). The terms 'pre-','syn-' and 'post-' tectonic as applied to igneous intrusions must be used with caution and are only applicable within the strict structural limits of the tectonic unit under consideration: they cannot be applied to the belt as a whole. Moreover, synchronous magmatism which appears to be 'diachronous' with respect to tectonic events in different parts of the belt provides further confirmation for the existence of discrete terranes. There is no indication in any of the $^{40}Ar/^{39}Ar$ results for any late Palaeozoic (Variscan) metamorphic rejuvenation of intracrystalline argon systems within Cadomian units exposed on Guernsey (see also Vidal 1980).

$^{40}Ar/^{39}Ar$ mineral cooling ages recorded within, and adjacent to, the Cobo granite (*c.* 570–565 Ma) are significantly older than the 496 ± 13 Ma Rb-Sr whole-rock isochron age reported for the Cobo granite by D'Lemos (1987*a*). This implies that the Cobo granite has not behaved as a closed system with respect to Rb-Sr following primary magmatic crystallization, possibly due to a low-temperature hydrothermal alteration that is manifested by widespread sericitization of feldspar and local chloritization of biotite within the Northern Igneous Complex. Cadomian granites in similar tectonic settings on Jersey and at La Hague (Fig. 1) have yielded Rb-Sr whole-rock isochron ages in the range *c.* 550 to 425 Ma (Bland 1985; Power *et al.* 1990b). These have been considered to represent crystallization ages and have been used to suggest that subduction-related magmatism within the Cadomian belt continued into Palaeozoic times (Brown *et al.* 1990), despite an absence of any granitic intrusions of this age range within Palaeozoic sedimentary sequences exposed on the French mainland. The $^{40}Ar/^{39}Ar$ results from Guernsey suggest that further isotopic dating is required before Rb-Sr whole-rock ages obtained for Cadomian plutons elsewhere within the belt (in particular those which have been attributed anomalously young ages) can be interpreted with confidence.

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Appendix

Sample localities and petrography

(1) *Meladiorite, Bon Repos; GR 281 743.* Massive, medium-grained rock comprising mainly unzoned pale green to brown pleochroic amphibole (75%) containing exsolved ilmenite, moderately sericitized andesine (20%) and quartz (5%) exhibiting weak undulose extinction. Accessories include ore, apatite and chlorite.

(2) *Hornblende gabbro, St Peter Port gabbro, Hougue a la Perre; GR 340 800.* Medium-grained rock comprising brown to deep brown pleochroic amphibole (60%) poikilitically enclosing unaltered labradorite (35%). Ore (5%) occurs interstitially to plagioclase. Rock exhibits a moderate igneous foliation.

(3) *Quartz diorite, Inhomogeneous Suite, Chouet; GR 334 843.* Mesoscopically homogeneous, medium-grained member of the Inhomogeneous Suite containing pale green to deep olive green hornblende (7%), biotite (7%), complexly zoned oligoclase/andesine (65%), quartz (20%) and accessory perthite, apatite, titanite and ore.

(4) *Granodiorite, Granodiorite Group, Chouet; GR 330 842.* Homogeneous medium-coarse grained granodiorite comprising pale green to olive green pleochroic hornblende (4%), biotite (6%), oligoclase (55%), quartz (30%) and perthite (5%). Accessory apatite, ore, chlorite.

(5) *Dioritic enclave, Cobo granite, Port Soif; GR 303 822.* Sample collected from the centre of a *c.* 1 m × 1 m pillowed diorite enclave (see also fig. 2b, D'Lemos 1986) within Cobo granite *c.* 50 m from the contact with the Bordeaux diorite complex, western side of Port Soif.

The enclave exhibits a very fine grained crenulate margin and gradual increase in grain-size towards the core of the enclave. The sample is fine- to medium-grained, homogeneous and comprises acicular, rarely skeletal, green to olive-green pleochroic hornblende (20%), biotite (10%), sericitized plagioclase (50%) and quartz (20%). Textural features are typical of microgranitoid enclaves formed during mingling of intermediate and acidic magmas (see for example Vernon 1983).

(6) *Perelle quartz diorite, north Vazon Bay; GR 282 803.* Sample collected 50 cm from contact with Cobo granite. Rock exhibits a moderately strongly developed foliation defined by ribbons of mafic minerals and long axes of oval plagioclase porphyroclasts (aspect ratio 1.5:1) and quartz aggregates (aspect ratio > 10:1). Pale greenish brown to olive-green pleochroic hornblende (10%) is commonly rimmed by fine biotite, but is generally free of inclusions. Biotite (20%) occurs as mats of abundant fine laths which are randomly oriented and, in part, replacing earlier biotite. Plagioclase (50%) porphyroclasts have been partially replaced by numerous subrectangular crystals of albite. Despite the marked elongation of quartz aggregates, individual grains are equant, exhibit straight to sutured boundaries and display only weak (if any) undulose extinction. The textures present contrast with specimens of Perelle quartz diorite away from the Cobo granite contact (Power *et al.* 1990*a*; Dallmeyer *et al.* 1991*a*) which retain a wider range of strain-related microfabrics. The collected sample shows evidence for annealing of quartz, static recrystallization of biotite and plagioclase, and minor recrystallization of hornblende, consistent with contact metamorphism.

(7a) *Vazon dyke, west side of Vazon Bay; GR 273 796.* Sample collected from 1.5 m wide massive dyke intrusive into Perelle quartz diorite. Fine-grained homogeneous rock comprising pale green to green actinolitic hornblende (30%) forming both prismatic crystals and very fine needles, plagioclase (50%), very fine biotite (5%), ore (15%) and minor quartz. Acicular apatite is a common accessory.

(7b) *Vazon dyke, west side of Vazon Bay; GR 273 796.* As 7a, but collected from centre of 5 m wide dyke and exhibiting a fine to medium grain-size.

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