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MAGMATIC, HYDROTHERMAL AND SURFICIAL PROCESSES IN THE DEVELOPMENT OF MULTICOLOURED DIMENSION STONE GRANITES OF THE TOPSAILS PLATEAU AREA (NTS 12H/02)

A. Kerr
Newfoundland Mapping Section

ABSTRACT

Peralkaline granites of the Topsails Plateau area of central Newfoundland have good potential for high-quality dimension stone, and entered commercial production in 1993. The granites form a single geological unit, but exhibit a wide range of colours, including yellow, green, orange, brown, pink, red and mauve.

Field and petrographic studies indicate that the colour variation in the Topsails granites results from two processes of vastly different ages, related to hydrothermal and surficial alteration, respectively. The original starting material, or 'primary' granite, is interpreted to be a massive pastel-green granite found in the deeper levels of quarry excavations. Pervasively-coloured pink, brown, orange and red granites are associated with fracture systems that locally contain quartz and hematite-filled veins, and were probably formed by magmatic-hydrothermal alteration processes. The petrographic data indicate transformation of hastingsitic amphibole to the sodic amphibole arfvedsonite, and introduction and/or remobilization of iron contained in K-feldspar. In strongly altered mauve granites, strong oxidation is suggested by the replacement of all mafic silicates by iron oxide–quartz symplectites. The more abundant patchy yellow and yellow-green granites are consistently developed near the surface, and are interpreted to be derived by surficial alteration of the primary green granite. The depth of this alteration profile (2 to 6 m), and the local presence of glacially striated yellow granites, suggests that this surficial alteration is interglacial or preglacial in timing, and it may be related to the development of a Cenozoic peneplain under warm, humid, subtropical conditions.

These findings have important implications for quarry development. The green granites, although rare at surface, are probably the most abundant volumetrically, but the yellow and yellow-green varieties can be exploited using areally extensive, shallow quarries that follow the contours of the landscape. Pervasively coloured pink, brown, orange and red granites probably form subvertical zones, and will thus require small, deep quarries or long, linear excavations that exploit their intersections with the surface. The petrographic evidence for metasomatic alteration processes also has implications for the development and accentuation of peralkaline traits in igneous suites.

INTRODUCTION

Around the turn of the century, several granite quarries operated in the Topsails Plateau area of central Newfoundland (Figure 1). Dimension stone extracted from these was used mostly for construction of bridge abutments along the Newfoundland Railway line. The Topsails granite was also used to construct the railway terminus on Water Street West in St. John's, arguably one of the finest Victorian buildings in the City, and for cobblestones on parts of Water Street and Duckworth Street (Martin, 1983).

The Topsails plateau quarries lay dormant until the 1990's, when the Newfoundland Railway was closed and dismantled. Improved access, coupled with growing interest in dimension stone, resulted in staking for quarry exploration (Figure 1). In June 1993, Classic Stone Inc., of Buchans, opened a small quarry near the former site of 'Summit' Station; by September 1993, this had produced approximately 225 m^3 of massive yellow, yellow-green and green granite, which will be shipped for tile and slab manufacture. The Summit Quarry, as it is termed here, is the newest mining operation in the Province, and is a significant step in the development of a viable Newfoundland dimension stone industry.

Prior production from the Topsails Plateau area consisted mostly of massive, yellow-coloured granite, from two

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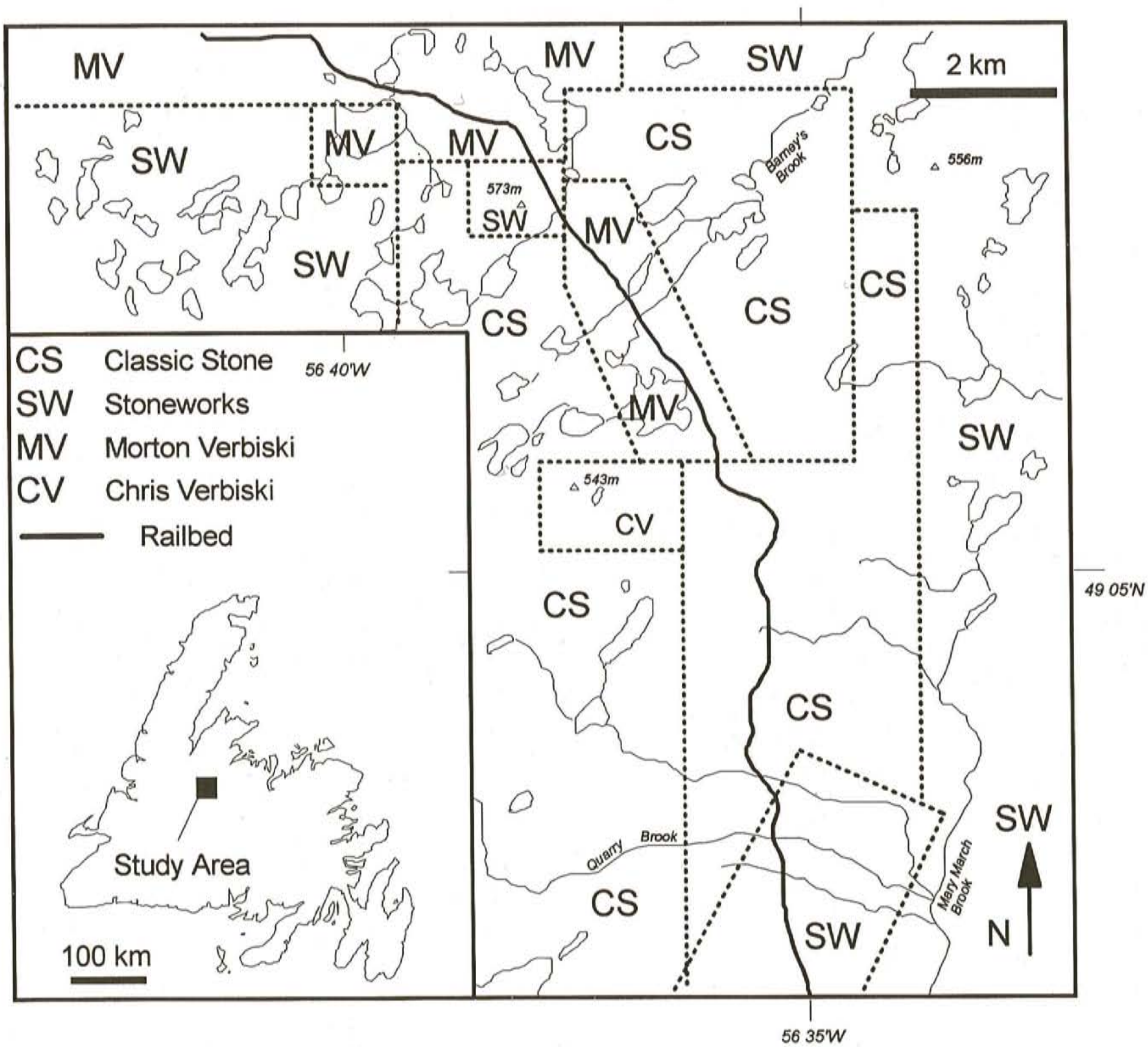

Figure 1. *Location of the study area in central Newfoundland, and distribution of quarry exploration rights.*

excavations located near 'Quarry' station (Figure 2). However, prospecting in the area has shown that the granite assumes a wide variety of colours including yellow-green, green, brown, orange, pink, violet and bright red. Regional colour variations were also noted during mapping (e.g., Taylor *et al.*, 1980; Whalen and Currie, 1988). Thus, the area has potential to yield a wide range of attractively-coloured stone products that are aesthetically compatible, as they are variants of a single granite with a common texture and grain size. In addition, some colours, notably yellow, green, orange and brown, are rare or unrepresented amongst existing granite tile product lines, and initial industry response suggests that they could command high prices if commercially developed.

The production of large granite blocks depends critically upon the availability of massive material, and also upon consistent colour and texture. Initial examination of areas along the railbed revealed rapid and apparently unsystematic variations in colour, which would cause problems if encountered within a quarry site. If a given site contains two or more colour variants in commercial quantities, a knowledge of their mutual geometric relationships is essential for quarry development. Thus, in the summer of 1993, a pilot project was initiated, with three main objectives.

1. To provide a generalized map of colour variations within a narrow corridor along the railbed, and assess colour variation patterns within previously recognized potential quarry sites.

2. To understand the causes of colour variations, the probable geometric relationships between colour

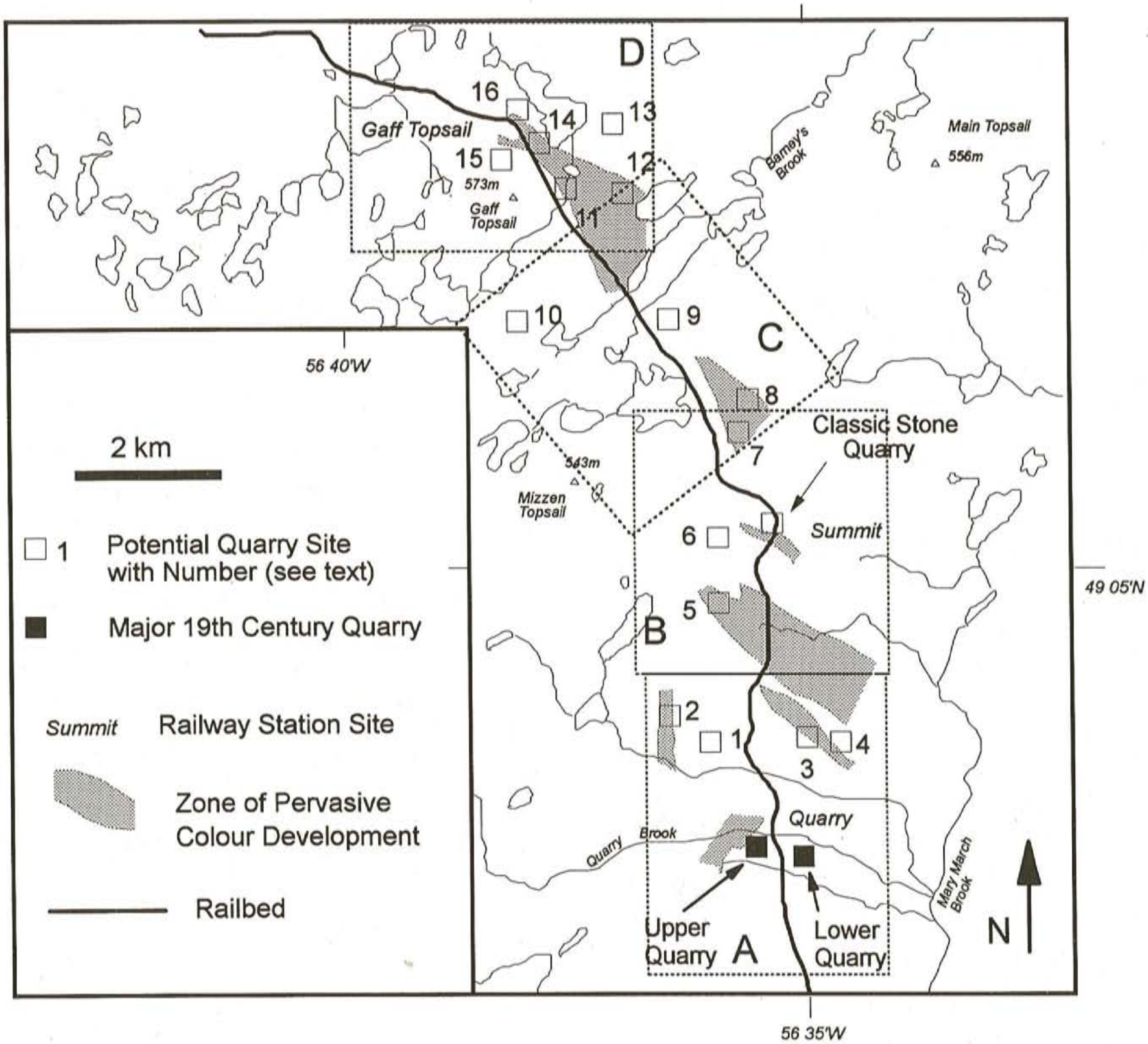

Figure 2. *Distribution of 19th Century and potential quarry sites recognized to date, and general distribution of regional zones of pervasively-coloured red, pink, orange, etc., granites. Note that only a narrow corridor along the abandoned railway has been examined in detail.*

variants, and the significance of both for future dimension stone quarry development, and

3. To locate additional potential quarry sites.

This project thus has both pragmatic aspects (e.g., colour mapping and quarry-site evaluation) and a research-oriented aspects (e.g., causes of colour variation). However, these two aspects cannot be divorced entirely, as a knowledge of processes is important for prediction of geometric relationships. Part 1 focuses mostly on field relationships and petrographic data from the granites, and discusses the origins of colour variations, and their implications. Part 2 presents an initial assessment of major potential quarry sites in the light of these results. A program of laboratory studies, including geochemical analysis, will be initiated during the winter of 1993-94.

GENERAL GEOLOGY

The Topsails Plateau area forms a high (>350 m elevation), largely barren, area that divides the watersheds of Red Indian Lake and Grand Lake (Figure 1). The most prominent features are four massive granite 'tors' (Fore, Main, Gaff and Mizzen Topsail), which reach a maximum elevation of 573 m at Gaff Topsail. Although outcrop is extensive in many areas, there are also large expanses of fly-infested swamp and hummocky till ridges. House-sized glacial erratics are widespread and, where partially submerged in swamps, are difficult to distinguish from *in-situ* outcrops. The only land access to the area is via the abandoned railway, either from Millertown Junction (east) or Howley (west). The railbed is rough, but passable by high-clearance vehicles.

The plateau is underlain by essentially two groups of granitoid rocks (Whalen and Currie, 1988). The older suite consists of foliated to gneissic granodiorite and tonalite of probable Ordovician age (Hungry Mountain Complex and equivalent units), which occur mostly on the east and west flanks of the plateau, outside the area of interest. These are intruded by the posttectonic Topsails intrusive suite, of Silurian age (~ 429 Ma), which includes several discrete metaluminous and peralkaline granite units (Taylor *et al.*, 1980; Whalen and Currie, 1988). In the study area, the dominant phase is a coarse-grained, one-feldspar, pyroxene–amphibole granite of peralkaline affinity (unit Sp of Whalen and Currie, 1988); minor amounts of other rock types, notably quartz-feldspar porphyry and felsite, occur on an outcrop scale. Both 19th century quarries, and most potential quarry sites, are hosted by the coarse-grained granite. Over most of the area, natural granite outcrops exhibit deep and intense chemical and physical weathering, and their upper surfaces convey little about true colour or texture. Relatively 'fresh' material occurs on lower outcrop surfaces, and beneath overhanging parts of outcrops, but it can be extremely difficult to sample. There is, however, a link between the intensity of weathering and colour; the less abundant red and orange varieties are commonly fresher and harder than the dominant yellow granites. As discussed below, this is considered to be significant in terms of their origin.

The Topsails Plateau granites are undeformed, and no faults exist in the area (Whalen and Currie, 1988). This is generally true, but local shearing and brittle deformation of coarse granite was observed, and is presumably related to minor faults. Also, many prominent joints may be small faults, although evidence for displacement across them is rare. Although joint orientations are locally variable, high-angle or vertical fractures are dominated by two orthogonal sets of northeast–southwest (030°-060°) and northwest–southeast (120°-160°) orientation. This conjugate pattern may reflect shortening in a broadly east–west direction during post-emplacement regional deformation, and the northeast–southwest joint set is subparallel to most regional structures in central Newfoundland (Colman-Sadd *et al.*, 1990).

Glaciation has had an obvious impact on the landscape of the Topsails Plateau. This highland region was probably an ice centre, as Topsails-type granite boulders occur in tills to the west (e.g., Batterson and Vatcher, 1992), in central Newfoundland (Klassen, 1993), and on the Baie Verte Peninsula (D. Liverman, personal communication, 1993). In general, the coarse-grained granites do not display good striated surfaces, but a few observations suggest local transport to the northeast (030°-040°). Bulk 'quarrying' of granite by glacial action is suggested by huge erratics littered over the area. The prominent hilltops of Fore, Main and Mizzen Topsail are aligned subparallel to this direction and are linked by a prominent ridge of accumulated gravelly material. There are no lithological contrasts between the hilltop tors and granite outcrops in lower-lying areas, but the tors are characterized by a relative paucity of joints oriented at right angles to glacial flow, suggesting that they were more resistant to bulk quarrying action. The amount of erosion during glaciation is difficult to assess, but the relative elevation of Main Topsail above the surrounding plateau (100 m +) may provide estimate for part of the area, although this does not account for any preglacial topography, and may reflect several episodes (R. Klassen, personal communication, 1993).

PART 1: FIELD RELATIONS, PETROLOGY AND ORIGINS OF COLOUR VARIATIONS

COLOUR VARIANT GROUPS AND TERMINOLOGY

Mapping along the railbed corridor (Figures 2 and 3) indicates that the dominant coarse-grained granites can be divided into two colour variant groups, for which the terms 'patchy' and 'pervasive' colour variants are used here. The generalized distribution of patchy and pervasive colour variants is indicated in Figure 2; a more detailed view of individual colour variants is given in Figure 3, which is a 'strip map' of the railbed corridor. Both maps locate individual potential quarry sites, which are described in more detail in Part 2 of the report. Patchy and pervasive colour variants, and individual colours within the groups, all belong to a single geological unit. The contacts between the two colour variant groups are always gradational, although they are in many cases abrupt transitions.

The terms patchy and pervasive, as applied to colour variation, are partly self-explanatory. Patchy colour variants are characterized by uneven colour development, in which the overall hue is composite and developed mostly in K-feldspar crystals. The dominant patchy colours in outcrops are orange-yellow (or 'gold') and yellow; yellow-green is present sporadically, and green is very rare. Over 90 percent of natural outcrops comprise 'patchy yellow granite' (subunit pY). Pervasive colour variants exhibit a broadly uniform K-feldspar colouration, and are dominated by 'warm' colours such as orange, orange-brown, red, brown, pink and mauve (subunits vO, vOB, vR, etc.). Of these, orange-brown is probably the most abundant variety. The various subunits defined in Figure 3 are, to some extent, arbitrary, as there is in actuality a continuum of colours; classification was conducted by visual observation in the field, and via cut slabs, without reference to any standard colour charts or similar classification devices. More rigorous methods may be required for more detailed site evaluations.

PATCHY COLOUR VARIANTS

Field Relationships

Patchy colour variants underlie at least 90 percent of the study area; both major 19th century quarry sites are

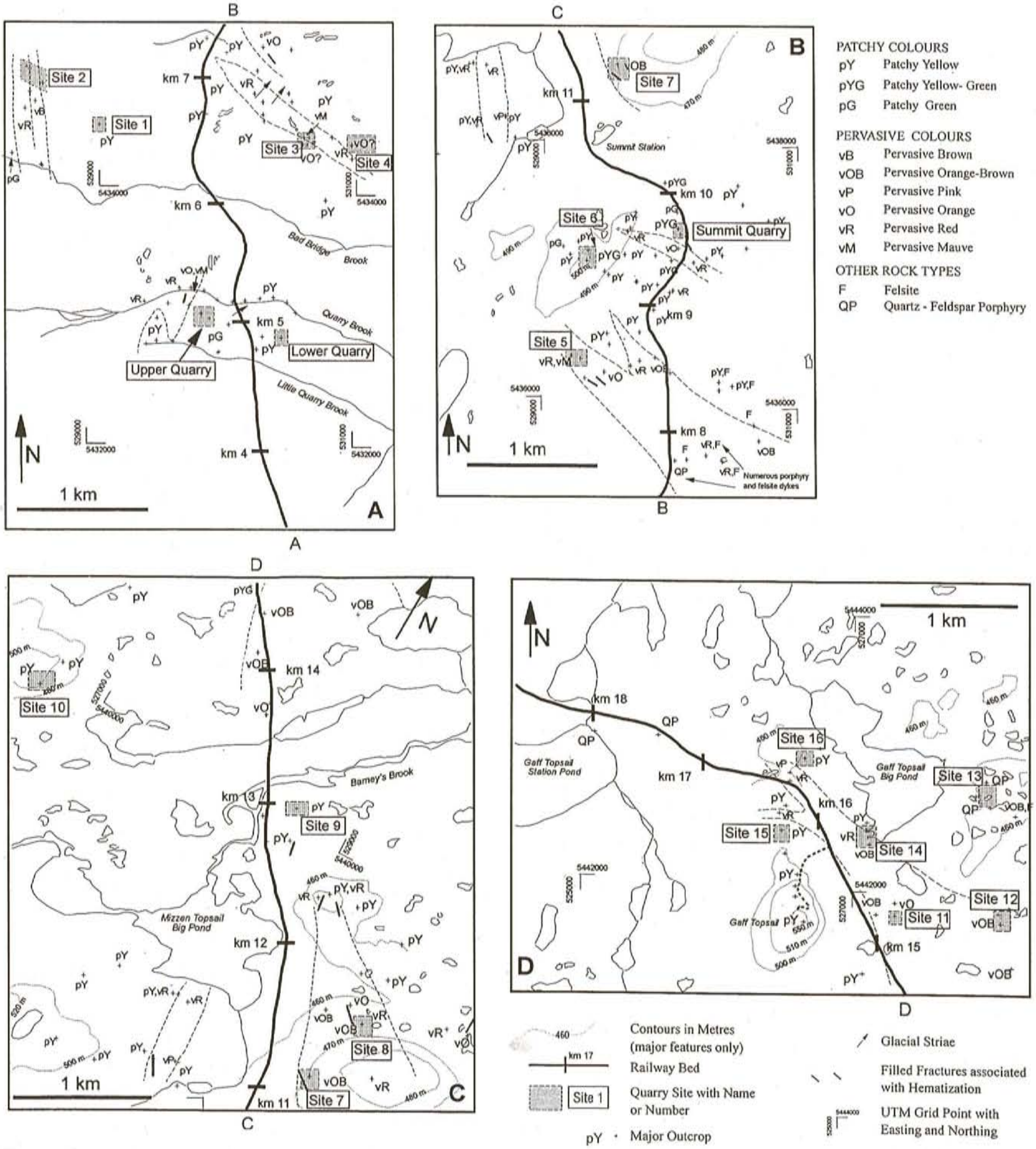

Figure 3. *'Strip map' of the railway corridor, illustrating outcrop and colour distribution, and potential quarry sites. For locations of individual panels, see Figure 2. Quarry sites are described in text according to map number.*

dominated by this material, as is the new Summit Quarry (Plates 1a and 1b). Patchy colour variants can be subdivided according to colour into orange-yellow ('gold'), yellow, yellow-green and green granites.

The most abundant variety found in natural outcrops is patchy yellow granite. This is commonly strongly weathered in natural outcrops, but the yellow colour persists into fresher, more massive material at depth. The granite is typically very

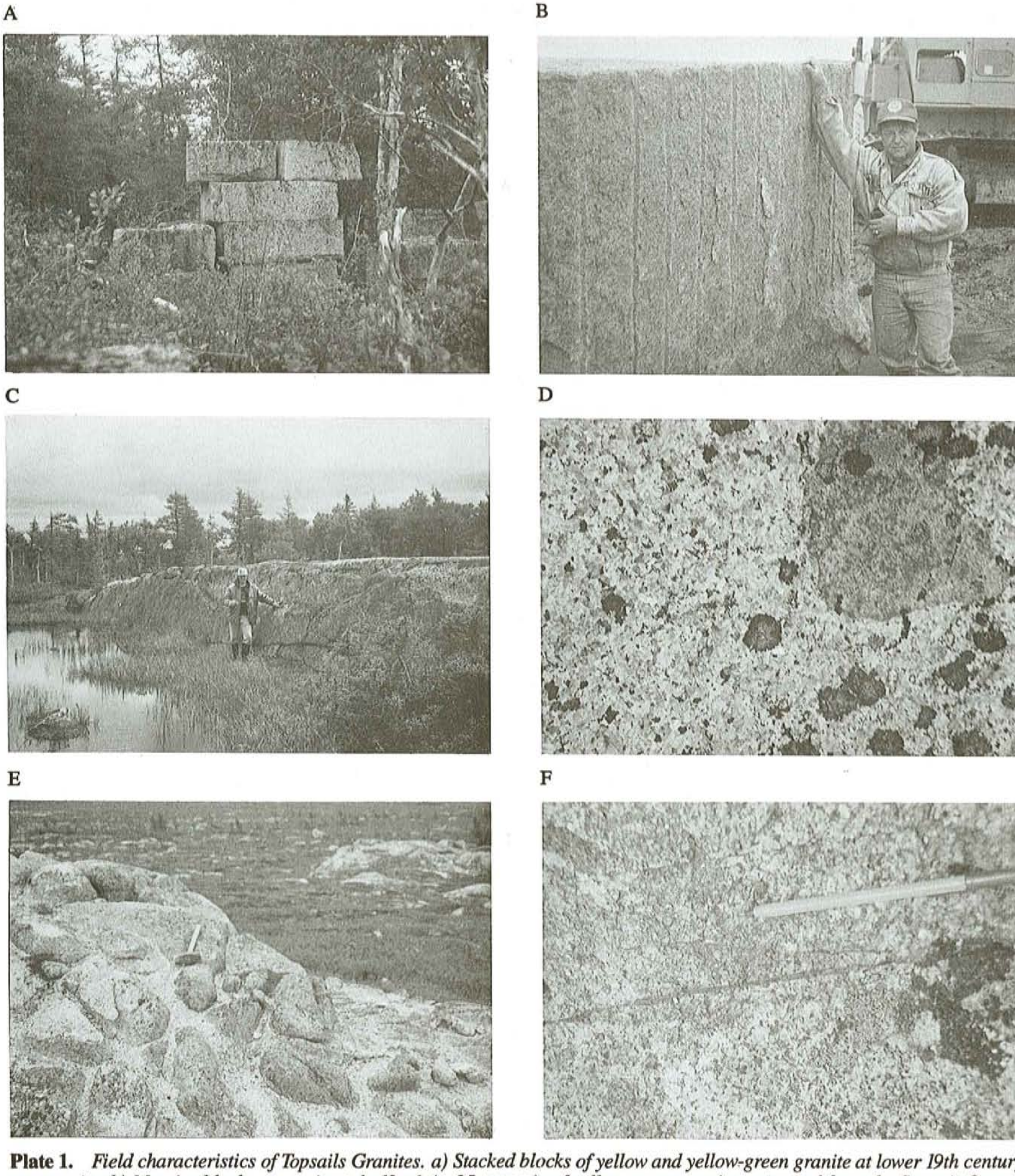

Plate 1. *Field characteristics of Topsails Granites. a) Stacked blocks of yellow and yellow-green granite at lower 19th century quarry site. b) Massive block, approximately 12 m³ (~25 tonnes), of yellow-green granite, extracted from the Summit Quarry in July 1993. c) Massive yellow granite benches, virtually free of high-angle jointing, at a 'natural' quarry site about 1 km east of the railbed (site 4). d) Small volcanic enclave in massive patchy yellow granite, Gaff Topsail. e) Outcrop of pervasively coloured red granite; note higher fracture density. f) Thin quartz-filled fractures in pervasive red granite zone.*

massive and homogeneous, and forms large, flat outcrop benches from 1 to 3 m in height, in which vertical joints are commonly 2 to 3 m apart (Plate 1c); on resistant hilltops such as Gaff Topsail, joint-free surfaces up to 15 by 15 m are not uncommon. It is coarse-grained, with individual K-feldspar crystals and quartz aggregates from 6 to 10 mm in average size, and is leucocratic, with less than 5 percent mafic minerals in total; the mafic minerals have a distinct oikocrystic, or interstitial habit, suggesting late crystallization in interstices between feldspars and quartz. It is texturally homogeneous, and generally inclusion-poor. However, most outcrops contain a few small, rounded enclaves (normally <3 cm in diameter) which are either volcanic xenoliths (with feldspar-porphyritic textures) or fine-grained hornfelses of uncertain origin (Plate 1d). Pegmatite and aplite veins are only rarely observed to cut massive outcrops. The granite is ideally suited to dimension stone production, and numerous potential quarry sites have been identified (Figure 3; see Part 2 for descriptions).

In detail, the yellow colour of the granite is composite. Quartz is massive, fresh and invariably pale grey. However, K-feldspar, which is dominant (typically 60 percent or more), shows significant colour variation within individual samples, and within individual crystals. Yellow and orange-coloured zones are developed around the margins of K-feldspar crystals, and along tiny fractures or imperfections, but the central cores of crystals remain white to pale green. The composite colour of the stone is further accentuated by small (<2 mm) bright orange interstitial patches, interpreted in the field as late-crystallizing feldspar or interstitial granophyre, and by the green to black interstitial mafic minerals. Patchy orange-yellow and yellow-green granites are simply variations of this general theme. Yellow-green granites occur in 19th century quarries and at the Summit Quarry, and show less intense and more sporadic marginal colouration of a pale green K-feldspar. They are less common in natural outcrops, but are observed on some smooth, glacially-polished hilltop outcrops. Orange-coloured patchy granites are the opposite extreme; they retain no hints of white or green in K-feldspar; are commonly weathered and friable, and are always associated with patchy-yellow variants in fresher parts of the outcrops. Although their colour may be superficially similar, these are entirely different from pervasively-coloured orange granites (see below).

The rarest of the patchy colour variants in surface outcrops are massive, fresh, pastel-green granites, in which K-feldspar is entirely pale green to grey-white. These granites are texturally identical to the yellow variants, and contain the distinctive, interstitial, orange feldspar or granophyre patches. Most occurrences of green granites are located in 19th century quarries, where they form the lowermost 'benches' in excavations; identical massive green granite was also encountered in the lower benches at the Summit Quarry. Green granite is also present in rare natural outcrops where recent mass wastage has shifted overlying material, and also on Gaff Topsail (J.G. Whalen, personal communication, 1993), where granite was excavated to provide a better foundation for a microwave tower (this effort was futile, for the tower was demolished by high winds).

Three-dimensional exposures provided by 19th century quarry sites and the Summit Quarry suggest that there is a consistent relationship between colour and proximity to the surface. The uppermost 'bench' of granite is yellow or gold, and grades with depth into massive yellow-green material, which eventually grades at depth into pastel-green granite of very fresh appearance. At Summit Quarry, this entire progression occurs over a vertical distance of about 6 m. Significantly, the same progression to massive green granite was observed when a single yellow-green granite 'bench' was excavated laterally into the hillside (i.e., away from the surface). This consistent pattern, repeated at different topographic elevations, coupled with the extreme rarity of natural green granite outcrops, strongly suggests that yellow and yellow-green granites are linked to surface processes, and that they are derived from a 'primary' massive green granite at depth. The nature and significance of this process are discussed in a subsequent section. Although these colour variations are apparently of surficial origin, they result in consistent, massive zones that are amenable to quarrying and, according to industry tests (F. Thorne, personal communication, 1993), they have no effect on the integrity of the stone for tile and slab production. However, the green granites are extremely hard and resistant, and the practical difficulties of working this material with Victorian technology may explain why 19th century quarrymen wisely decided to leave most of it in place.

Petrography

Patchy colour variants of the Topsails Granite display individually complex mineralogy and petrography, but samples from widely separated localities have consistent features, confirming that all are representatives of a single geological unit.

Typical examples consist dominantly of K-feldspar (55 to 70 percent), quartz (25 to 40 percent), albitic plagioclase (<< 1 percent) and mafic minerals (2 to 5 percent). The most common mafic minerals are greenish-blue to brown hornblende (probably a member of the hastingsite series), and a green, pleochroic, pyroxene identified as the sodic variety aegirine. Colourless to pale-green pyroxene (probably hedenbergite) and altered, yellow-brown iron olivine (fayalite) are also common, but are normally relict phases, and may be absent. Blue to brown sodic amphibole (probably arfvedsonite) is locally present, but rarely abundant. Minor phases include zircon, sphene, apatite, iron oxide and a deep red-brown mineral, tentatively identified as aenigmatite.

The dominant K-feldspar is a fine string perthite, and forms subhedral, 6 to 10 mm crystals having local preservation of simple twin structure and primary growth structures such as rings of fine-grained quartz. Quartz forms interstitial aggregates and large anhedral masses, and is locally weakly recrystallized. Albitic plagioclase is a trace constituent only; it occurs as small crystals in interstices between K-feldspars, and as aggregates of tiny grains along grain boundaries between feldspars. The grain boundary development may reflect exsolution as part of perthite formation, or introduction and/or remobilization of sodium. The bright orange flecks noted in hand samples are difficult to locate in thin section. Strongly hematized interstitial patches of very fine-grained, reddish (potash?) feldspar (± quartz) were observed in some samples; in others, an amorphous, hematitic material resembling devitrified volcanic glass has a similar habit. These probably represent small pockets of trapped, residual, liquid, cooled at different rates.

Mafic minerals form interstitial aggregates of 1 to 4 mm grains and, with the possible exception of fayalite, all crystallized after the K-feldspar. Hedenbergite, where present, is commonly enclosed within a rim of green aegirine, or forms relict cores to larger green-brown amphibole grains. Aegirine is variably enclosed by amphibole of either green-brown (hastingstite) or, more rarely, blue-brown amphibole (arfvedsonite). Fayalite, where present, occurs as small, cracked, relict yellow grains entirely enclosed within amphibole, and is extensively altered to iron oxide and serpentine-like material. These paragenetic relationships (Plate 2a) suggest early crystallization of hedenbergite and fayalite, followed by stabilization of amphibole, probably due to increasing H_2O in the magma. A shift toward more alkaline compositions with increasing solidification resulted in the formation of sodic pyroxenes and amphiboles, and the early hedenbergite and fayalite were variably preserved in relict form. In some samples, a zonation effect is seen within individual amphibole crystals, which have green-brown cores and blue-brown arfvedsonite rims. This is particularly evident in parts of the area where pervasive colour variants also occur, and is considered significant (see below). However, sodic amphibole is usually a minor component of patchy colour variants, which are commonly dominated by greenish amphibole of probable hastingsite composition.

K-feldspar is cloudy and turbid in all samples, but the degree of alteration is greater in yellow and orange-yellow granites than in those that retain a greenish colour. Very commonly, the central portions of larger feldspars are less altered than their margins (Plate 2b). In addition, many patchy yellow and orange-yellow granites display clear evidence of surficial alteration, such as tiny hematite-filled cracks, and yellowish-brown staining along grain boundaries and other lines of weakness. Such features are less common in yellow-green and green variants. Variations in freshness and alteration are entirely consistent with field observations suggesting that orange, yellow and yellow-green granites were derived by surficial alteration of 'primary' green granite.

PERVASIVE COLOUR VARIANTS

Field Relationships

Pervasive colour variants of the Topsails Granite are less abundant than patchy yellow to green granites, and their K-feldspar colour is pervasive and uniform, in shade. The most common varieties are pale orange-brown, orange and various shades of red; less common are brown, pink and mauve or violet. In contrast to the patchy colour variants, which typically have deep, crumbly weathering, pervasively coloured granites are relatively fresh and hard. The distinctions between early K-feldspar and later interstitial material, characteristic of patchy yellow granites, are normally absent, and the distinct oikocrystic habit of mafic minerals is less clear. Some, notably bright red and mauve granites, have a slightly recrystallized appearance in the field. There are also important contrasts in fracture density between patchy and pervasive colour variants (Plate 1e). The latter show more closely-spaced jointing, and outcrops with potential block sizes greater than 1 m^3 are uncommon. The most intense fracturing and jointing are associated with the brightest orange and red colours; brown granites are normally less jointed, but are rarely as massive as the yellow and green quarry sites.

Pervasive colour variants are developed on a variety of scales. On a regional scale, several elongated, northwest-southeast and north-south trending zones can be defined (Figure 2), although these are not of uniform colour. In detail, these zones probably have a complex, anastomosing geometry, as 'islands' of yellow granite occur within them. Pervasively coloured zones are also widely developed on an outcrop scale, where it is possible to trace patchy yellow granite into a zone of massive red material, and then back out into yellow granite. The contacts of the red zones, although abrupt, are gradational, and there is commonly a marginal zone of less intense colour, such as pale orange-brown or pink. Outcrop-scale red zones invariably have a higher fracture density than surrounding yellow granite (Plate 1e), and their margins are oriented subparallel to the dominant fracture direction. A good example of an outcrop-scale zone exists in the Summit Quarry, where a zone of pink granite up to 1 m wide transects the excavation, associated with a subvertical fracture system striking at 155°, and affects all of the subhorizontal patchy colour zones. The pink material, although attractive, is not amenable to quarrying, and must be removed as waste. The orientation of such outcrop-scale zones is varied, but 120 to 160° is a common strike direction, and the associated fracture systems are commonly subvertical. Although these fracture systems are broadly subparallel to one of the dominant high-angle joint sets (see above), they are not simply joints or microfaults. In many outcrops, fractures are filled with thin (< 1 to 5 mm), red-stained silica veinlets, and/or soft, hematitic material (Plate 1f). In the larger fractures, crystalline quartz veins occur, and at one locality, some fractures contain quartz-porphyritic felsite. Generally, regional-scale zones of pervasive colour development have a greater frequency of intrusive vein and dyke material compared to patchy colour variants, although the distribution of veins is very uneven at an outcrop level. These minor rock types include felsite, quartz-feldspar porphyry and (more rarely) pegmatite with acicular blue amphibole.

The outcrop-scale field relationships strongly suggest that pervasive colour variants represent an 'overprint' of some type that has been imposed on the more abundant green to yellow granites. The spatial association between pervasive colour development, filled fracture systems and the presence of assorted dykes and veins indicates that this overprint is of hydrothermal origin, and vein fillings suggest introduction and/or remobilization of iron (to produce the red colours) and possibly also silica. The term 'hydrothermal', as used here, includes fluids both of magmatic and external (country rock) derivation. The presence of silicate liquids (felsite),

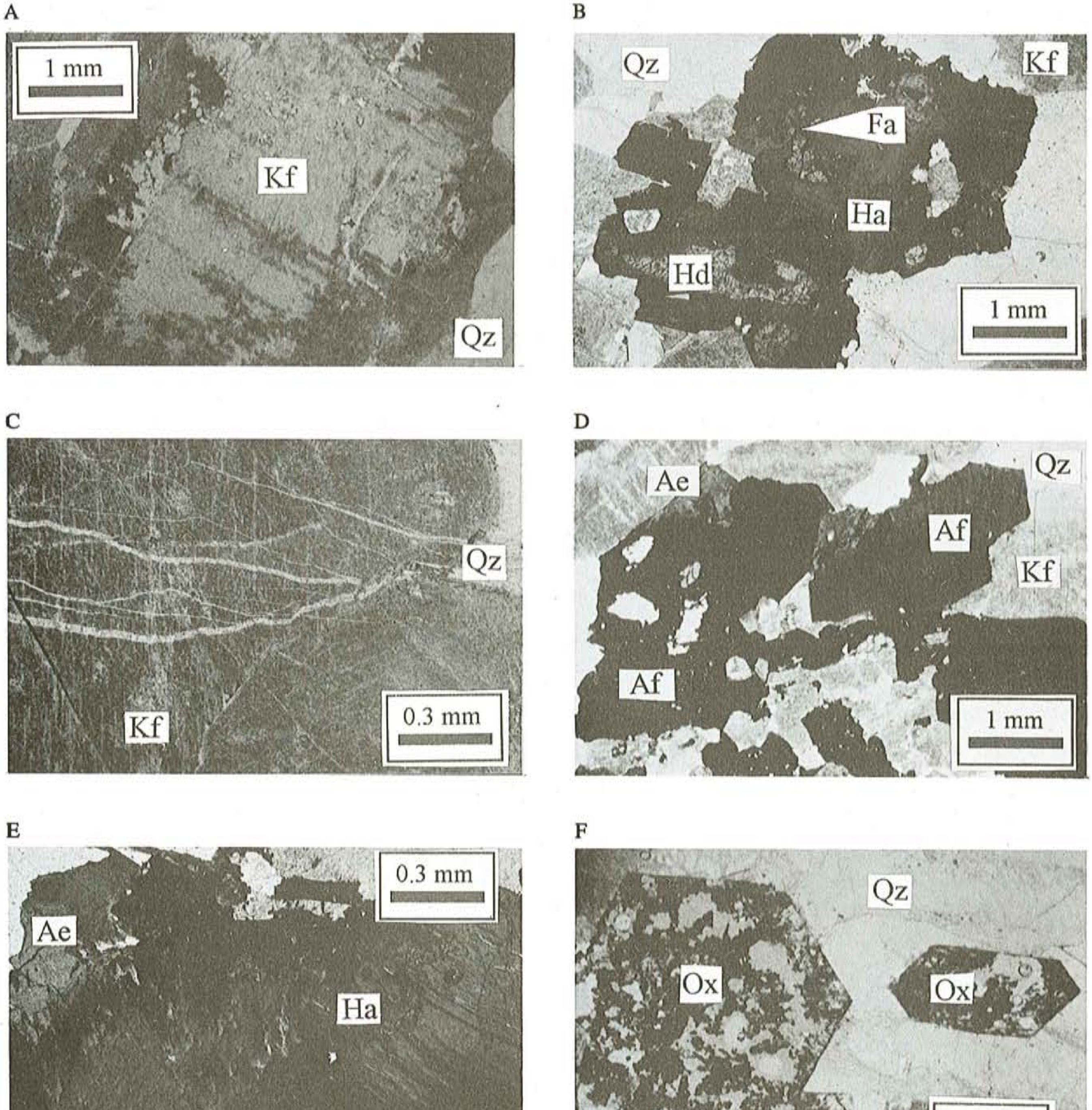

Plate 2. *Petrographic features of Topsails Granites. a) K-feldspar in patchy yellow granite; note the more turbid and cloudy areas at the edges of the grains. b) Well-preserved mafic mineral assemblage in yellow-green granite, including fayalite, hedenbergite and green (hastingsitic) amphibole. c) Quartz-filled fracture systems in pervasively coloured red granite, note microbrecciation. d) Intensely pleochroic brown-blue amphibole in pervasively coloured red granite. e) Zoned amphibole crystals with hastingsitic cores and arfvedsonite rims, from the margin of a pervasive red zone, note replacement of core region along cleavage traces. f) Skeletal iron-oxide–quartz symplectites provide striking pseudomorphs, probably after aegirine, in a strongly altered pervasive mauve granite. Mineral abbreviations: Qz–quartz, Kf–K-feldpsar, Fa–fayalite, Hd–hedenbergite, Ae–aegirine, Ha–hastingsitic amphibolite, Af–ferric (?) arfvedsonite, Ox–iron oxide, mostly magnetite. All photographs taken in Plane Polarized Light (PPL).*

silica and hematite in fracture systems implies protracted circulation, and indicates that the development of pervasive colour zones was a very 'early' feature relative to the very recent surficial process implicated for production of patchy colour variants.

Petrography

Pervasive colour variants of the Topsails Granite are significantly more varied in mineralogy and microscopic texture than patchy colour variants. For the purposes of description, they are divided into three subgroups.

Pervasive red and orange granites resemble patchy yellow granites in that they are dominated by perthitic K-feldspar (55 to 70 percent) and grey, variably interstitial quartz (25 to 40 percent), with a grain size range of 6 to 10 mm. The K-feldspar displays similar grain-boundary albite development, although it is locally more intense. The K-feldspar is very dark and turbid, suggesting more intense hematization, and commonly contains visible clusters and patches of iron oxide. In some samples, microfractures cut feldspar crystals, and are filled with very fine-grained quartz and/or amorphous hematite. Samples containing numerous veins display microbreccia textures indicative of brittle fracturing (Plate 2c). Quartz is varied in appearance; locally, it is clearly recrystallized, with serrated grain boundaries that resemble metamorphic quartz, but elsewhere it is massive and optically continuous. The mafic mineral assemblage of these granites is distinctive, and consists of aegirine and an intensely pleochroic dark-brown to black amphibole (Plate 2d). Locally, this mineral has a bluish tinge suggesting that it may be arfvedsonite, although the related variety barkevikite also matches some of its features (Deer *et al.*, 1967). The intense brown colour may be a function of a high Fe^{3+}/Fe^{2+} ratios, as in the oxidized variety of common hornblende found in volcanic rocks (lamprobolite); possible oxidation effects are also suggested by hematite-filled fractures and inclusions within larger crystals.

The most striking pervasively coloured granites are those of mauve or violet colour. These are also dominated by strongly hematized K-feldspar and quartz, but commonly also contain abundant clear albite grains. They are completely devoid of mafic silicates, but contain spectacular skeletal iron oxide–quartz pseudomorphs after amphibole and pyroxene (Plate 2e). The oxide is probably mostly magnetite, with some associated hematite. Such features suggest that mauve and violet granites have suffered very strong alteration, and perhaps represent the end product of the alteration process seen in red and orange granites. Their high albite content may indicate Na-metasomatism (albitization).

At the other end of the spectrum, brown, orange-brown and some pink granites have features suggestive of less intense alteration, such as local preservation of interstitial orange feldspar or glassy material and, most importantly, partial preservation of the more varied mafic mineral assemblages typical of yellow granites. They typically contain zoned amphibole crystals, with green-brown cores and intensely pleochroic brown to blue-black rims. In prismatic sections, the darker amphibole replaces the green-brown variety along cleavage traces; such features suggest alteration, rather than primary igneous zoning (Plate 2f). These less intensely coloured granites probably represent 'arrested development' of pervasive colour via hydrothermal alteration; as noted previously, similar zoned amphiboles also occur locally in yellow granites that are within regional zones of pervasive colour development.

In summary, strong petrographic contrasts between patchy and pervasive colour variants also suggest that the latter developed via hydrothermal alteration, and indicate that the intensity of alteration increases from brown and orange-brown granites, through pink, to orange and red, and (ultimately) to mauve and violet granites, in which the mafic mineral assemblage has been completely destroyed. In hand specimen, the most obvious effect of alteration is the introduction and/or remobilization of iron, resulting in strongly hematized K-feldspar. The mineralogical changes that result from alteration strongly suggest that the process resulted in significant shifts in bulk composition. However, this requires confirmation through geochemistry.

QUARTZ-FELDSPAR PORPHYRY VARIANTS

In addition to the coarse-grained granites, minor fine-grained phases, including felsite and quartz-feldspar porphyry, occur on an outcrop scale, particularly in areas where pervasive colours are developed. In most cases, outcrops of these rock types are far too small to have any potential for dimension stone. However, one potential quarry site was discovered in quartz-feldspar porphyry in the north of the area. The full dimensions of this porphyry body are unknown, as it is on the edge of the area examined, but it underlies an area of at least 2500 m^2. This is a buff to pink, homogeneous rock, containing round quartz phenocrysts up to 4 mm in diameter and euhedral K-feldspar laths up to 8 mm long, set in a ca. 1 mm groundmass of quartz, K-feldspar, green amphibole and red biotite. The groundmass also contains graphic quartz-feldspar intergrowths indicative of quenching. On the basis of mineralogy, the quartz-feldspar porphyry is compositionally similar to the coarse-grained granites that it intrudes, and to other small bodies of similar porphyry noted during mapping elsewhere in the area.

DISCUSSION

Symptoms of Colour Variations

Colour variation in Topsails Granites is primarily related to the characteristics and alteration state of K-feldspar crystals. This is hardly surprising, as K-feldspar makes up at least two-thirds of the granite, and the common red, pink and white colour variations seen in granites everywhere reflect feldspar characteristics. The most common cause of colour in feldspars is hematization , in which Fe^{3+} substituting for Al^{3+} in the feldspar structure is exsolved, and forms miniscule hematite grains (Deer *et al.*, 1967). Hematization can similarly result from the introduction of iron by percolating solutions, from which hematite is deposited along cleavage planes, imperfections, and grain boundaries. K-feldspars in peralkaline granites commonly have relatively high Fe contents, as these magmas are, by definition, deficient in Al_2O_3. Generally, most of the colour variations seen in the Topsails Granites can be interpreted in terms of variable levels and styles of hematization of K-feldspar, and the introduction of various iron oxide and hydroxide phases. However, field and petrographic observations indicate that these variations are systematic, and result from two very different geological processes. The inferred relationships between patchy and pervasive colour variants are illustrated schematically in Figure 4.

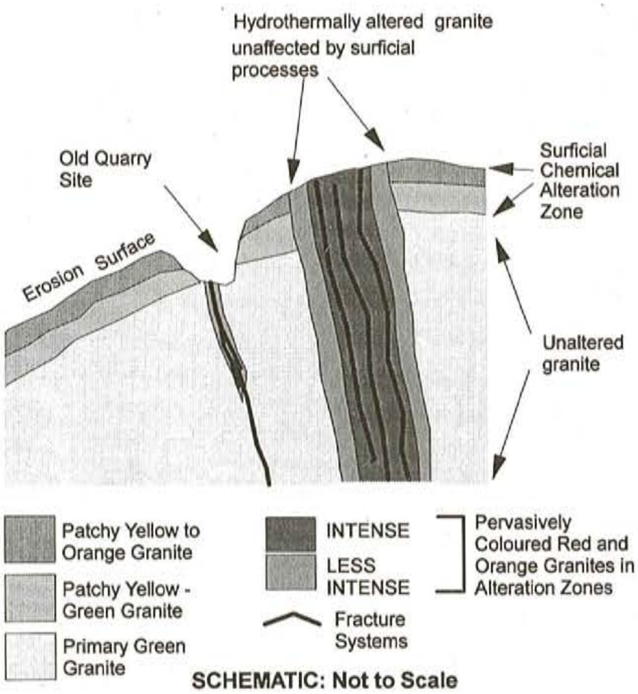

Figure 4. *Schematic illustration of geometric relationships and origin of patchy and pervasive colour variants in the Topsails Granites.*

The Primary Topsails Granite

The best candidates for 'primary' material are pastel green granites found in the deep levels of quarry excavations. These granites have the clearest igneous textures, the least turbid and hematized K-feldspars, and their mafic mineral assemblages are well preserved. However, despite this generally pristine appearance, these 'primary' Topsails granites display some evidence of mild post-crystallization alteration, notably in the form of grain-boundary albite development. It is also possible that the green colour of the K-feldspar reflects mild alteration of some type, although it may be a primary feature. However, green is not a common primary colour for K-feldspar, except for a rare semiprecious gem variety of microcline, known as amazonite (Deer *et al.*, 1967).

Stage 1: Hydrothermal Alteration Processes

The distribution of pervasive colour variants in subvertical zones, associated with fracture systems that locally contain quartz, hematite and fine-grained phases, suggests that large quantities of fluids may have percolated outward from fracture systems into the surrounding granites, and altered them. This is interpreted to be an early process, which followed solidification of the granites to the point where brittle fracturing could occur, but predated their cooling and uplift. The fluids involved were probably predominantly of magmatic origin, although some component of externally derived fluid may also have been present. The regional zones of pervasive colour are interpreted to be 'conduits' through which this fluid flow was channelled on a pluton-wide scale. Their orientation may reflect regional stress fields that controlled fracturing.

The effects of this magmatic-hydrothermal alteration can be inferred from petrographic data. The transformation of green-brown hastingsitic amphibole to arfvedsonite indicates introduction of sodium, as does albitization in strongly altered granites. The greater hematization of K-feldspar may reflect exsolution processes promoted by fluids, but there has probably also been some introduction of iron, as suggested by hematite and iron-stained silica veinlets. Strongly altered granites also show signs of severe oxidation, in the conversion of mafic silicates to iron oxide–quartz symplectites. All of these features suggest bulk chemical changes (metasomatism), which can be confirmed and perhaps quantified by geochemistry.

Stage 2: Surficial Alteration Processes

The consistent relationship of colour zones to the present surface, and petrographic studies, indicate that patchy yellow and yellow-green granites represent surficial alteration products of primary green granites. Available quarry exposures suggest that primary green granite commonly occurs at depths of 6 to 10 m, although some small 19th century trackside excavations penetrated green granites within 2 m of the surface. The colour changes associated with the surficial zone probably result from leaching of iron from the surface zone by percolating meteoric waters, and its deposition around grain boundaries, and along cleavage traces and fractures in the margins of K-feldspar grains. Granites that were previously hydrothermally altered were less susceptible to surficial alteration, perhaps due to more extensive grain boundary recrystallization and/or mild silicification.

It is not clear if surficial alteration was entirely postglacial (i.e., within approximately the last 10,000 years) or an interglacial or preglacial phenomenon that is partly preserved. Deep weathering of bedrock is commonly associated with warm and humid climates, and postglacial Newfoundland certainly does not fit this description. A 5-m alteration profile developed over 10 Ka implies a production rate of 0.5 mm / year, which seems unreasonably fast. Green granite blocks and benches at the lower 19th century quarry have been exposed to the elements for around 100 years, and their outer surfaces have a yellowish colour. However, post-1900 alteration is easily removed with a single hammer blow, and there is no sign of the thick rind that should result from such high alteration rates. Thus, an interglacial or preglacial origin seems likely, which in turn suggests only relatively minor erosion over much of the Topsails Plateau during and since the last glaciation. This is also supported by the fact that glacially striated surfaces are locally developed on granites that exhibit the characteristic yellow colour, which, at face value, implies that the granites were altered before ice action.

As Newfoundland has experienced denudation for at least 150 Ma, alteration could have occurred at any time during the Mesozoic or Cenozoic. Three peneplains have been recognized in Newfoundland (Rogerson, 1981), and the general elevation of the Topsails Plateau ($\sim$400 m) suggests that it forms part of the intermediate elevation High Valley Peneplain, suggesting a post-Cretaceous feature. The Newfoundland climate during the Cenozoic has not been well-established, but it was certainly more benign than at present, and may have been subtropical. It is interesting to speculate that the yellow granites of the Topsails Plateau record a time when Newfoundland was covered by savannah or lush rain forest, rather than the present flora of wind-stunted spruce and muskeg vegetation.

Implications for Development of Dimension-Stone Quarries

The recognition that two contrasting processes of very different age were responsible for producing colour variation in the Topsails Granites has very important implications for dimension-stone production. The field observations provide a method by which the geometric relationships between different colour variants can be predicted (Figures 4 and 5).

First, the rarest of the colours observed on surface (massive pastel green granite) is probably the most abundant resource volumetrically. Most quarry sites initiated in patchy yellow granites will eventually yield this material. The depth at which the primary green granite will be encountered is harder to predict, but available 3-D exposures indicate that it is unlikely to exceed 10 m, and may be significantly less. The supply of pastel-green granites should prove inexhaustible. However, this does not necessarily indicate that potential reserves of patchy yellow and yellow-green granites are seriously limited, as they are developed over very large areas close to surface. Exploitation of this upper material will require areally extensive, shallow, quarries that follow the contours of the landscape and expand laterally (Figure 5a). Significantly, this is exactly the form of the extensive 19th century upper quarry, from which much of the yellow granite used to build the St. John's railway station is inferred to have been extracted. However, given the variations in the depth at which primary green granite occurs (see above), the depth of the surface alteration profile should be tested before excavation. A single, short, low-cost packsack-type drillhole producing narrow core should be adequate for this purpose.

Second, pervasively-coloured granites present an entirely different set of concerns, as they will have no fixed geometric relationship to the 'natural' quarrying directions provided by the interaction of glacial action and high-angle joints. Field observations suggest that most will form subvertical or high-angle zones, and are very unlikely to follow subhorizontal benches like the patchy colour variants. Quarry sites will probably have to be small and relatively deep, and they can only expand downward, or along the strike of the coloured zone, to become long, linear, excavations (Figure 5b). Both alternatives have engineering implications, and these granites will inevitably be more expensive to quarry than the patchy colour variants. As noted above, pervasive colour variants commonly have a much higher fracture density than the yellow granites, and many outcrops are totally unsuitable for dimension-stone purposes. However, several good potential quarry sites (see Part 2) contain material of adequate block size in commercial quantities, without significant veining, but most also contain local zones of more intense fracturing, which must be removed as waste.

Alteration processes, in general, tend to vary in their intensity, and examination of some larger pervasively-coloured sites indicates internal variations in colour, from orange-brown to pink and red or mauve. Although surface weathering effects are minor compared to those seen in patchy colour variants, they complicate any attempt at detailed field mapping of more subtle variations. Lateral and vertical variations in colour shade and intensity must be anticipated in these areas, and (ideally) should be investigated prior to development. Surface colour distribution could easily be assessed by extraction of short (30 to 40 cm) cores using a portable sampling device similar to that utilized for paleomagnetic work; this need not spoil material for commercial purposes, as any weathered upper surface would eventually be trimmed from blocks. Vertical colour variations are much harder to assess without spoiling commercial material but, as the zones themselves are controlled by high-angle structures, they could be less rapid.

In summary, pervasive colour variants will present more complex and challenging development problems than patchy colour variants. However, fracture density and small block sizes are universal problems with red granites, and are in part reflected in their significantly higher value per cubic metre. Thus, the extra costs and difficulties inherent in extracting pervasively-coloured material may be counterbalanced by market response and higher profit margins.

Petrological Implications

The results of this study also have some implications for granite petrogenesis, and particularly for the origins and causes of peralkaline compostional traits. Although these are of no direct relevance to dimension-stone potential, they are of general geological interest, and may also have relevance to other types of commercial mineral deposits, notably rare metals (e.g., Zr, Nb, Y, REE). An early study of the Topsails Granites (Taylor *et al.*, 1980; 1981) suggested that their peralkaline and REE-enriched compositions were not original 'igneous' features, but resulted from metasomatic activity linked to magmatic-hydrothermal processes. Some of the

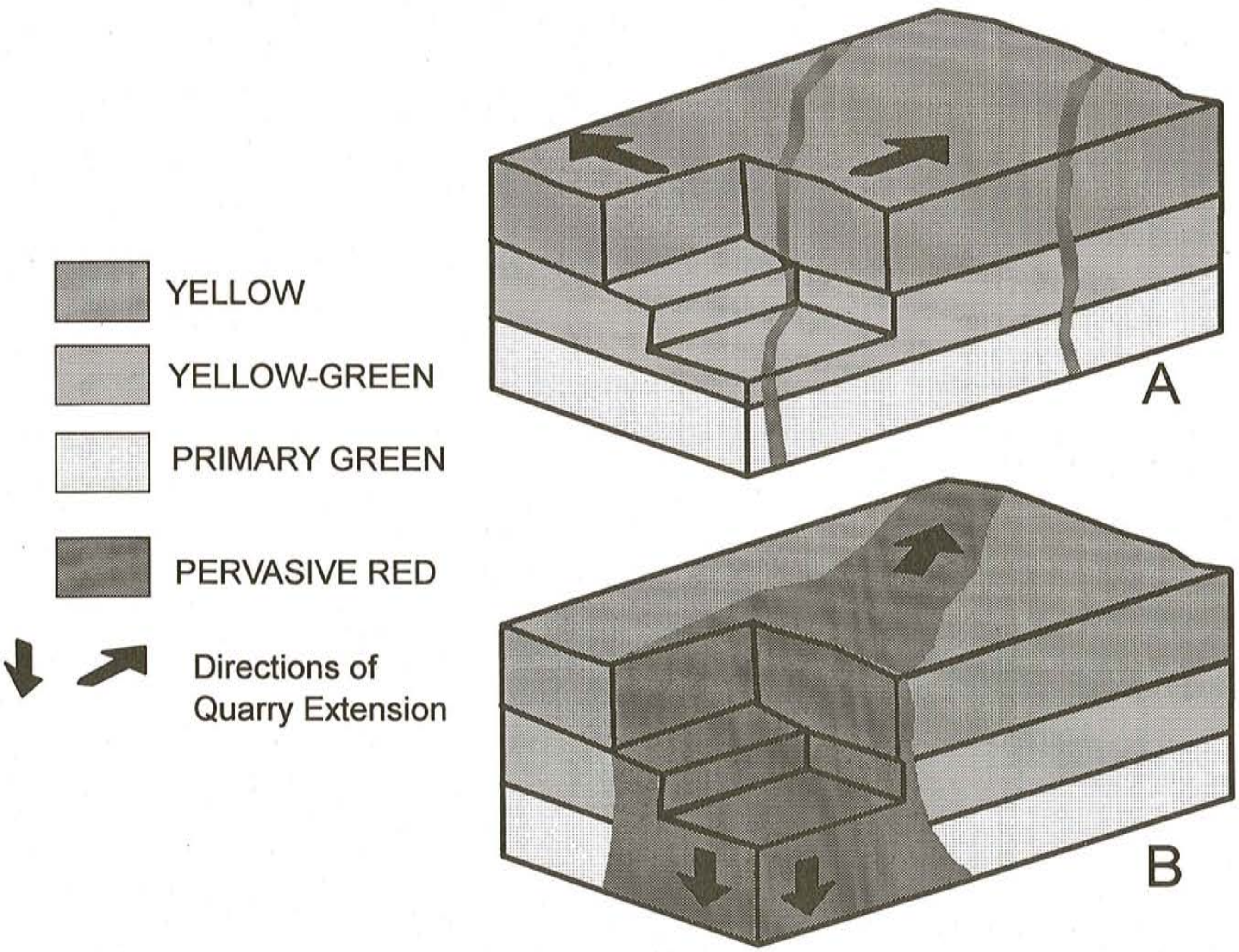

Figure 5. *Schematic illustrations of the implications of the genetic model for quarry development strategy. (A) Quarries in patchy yellow and yellow-green granites must be shallow, and expand laterally. (B) Quarries in pervasive red, orange, etc., granites must either be small in area, and deep, or expand in a linear fashion, following the strikes of alteration zones.*

petrographic features described in this report were also briefly noted by Taylor *et al.* (1980) and cited as supporting evidence; however, the links to colour variation and filled fracture systems were not established. Whalen *et al.* (1987) subsequently argued that the the large areas of compositionally homogeneous peralkaline granites in the area argued against the operation of any hydrothermal process, which they believed would result in rapid local compositional variations. They suggested that the compositional traits were largely magmatic.

The field and petrographic data presented here provide very strong evidence for the operation of hydrothermal alteration processes and, on the basis of mineralogy, indicate rapid, outcrop-scale, variations in composition. As the pervasively altered granites commonly contain abundant sodic amphibole (arfvedsonite), they probably have more strongly peralkaline compositions. However, most patchy yellow to green granites, which lack hydrothermal alteration, contain primary (igneous) aegirine-bearing mafic mineral assemblages, locally with minor sodic amphibole. Thus, these granites must have had original (magmatic) peralkaline compositions. In summary, Taylor *et al.* (1980) and Whalen *et al.*, (1987) were both partially correct, as primary subalkaline to slightly peralkaline granites appear to have suffered metasomatic alteration processes that led to the development of more strongly peralkaline compositions. Whole-rock and mineral geochemical data are required for further assessment of this aspect of the project, and a more detailed discussion will be presented elsewhere. From the perspective of mineral potential, trace-element geochemical data from pervasively altered granites will test for indications of transport and deposition of rare metals by hydrothermal activity, and will augment the regional evaluation of rare metal mineralization potential by Miller (1992).

PART 2: DESCRIPTION AND ASSESSMENT OF POTENTIAL QUARRY SITES

GENERAL STATEMENT

Major quarries and potential sites are located in Figure 3, and are numbered arbitrarily from south to north; most potential sites were identified prior to the initiation of this project, with the exception of Sites 5 and 13. The assessment of these sites presented below is primarily a geological viewpoint; engineering and quarry design aspects will require further assessment from specialists in those fields.

The Topsails Plateau is a relatively undisturbed and ecologically sensitive region, which is part of the range of a caribou herd. Observations over two summers, and local lore, suggests that caribou are fairly plentiful on high ground in early summer, but migrate into lower, forested terrain on the east flank of the plateau by July. Environmental issues are inherent in any long-term development plan for the area, and must be addressed at the exploration stage. The greatest threat comes from unrestricted vehicular access, and particularly the indiscriminate use of all-terrain vehicles (ATV's), which have already damaged some areas, notably the thinly vegetated gravel ridge leading to Main Topsail. The proposed restrictions on ATV usage, if enforced properly, should protect much of the plateau from this abuse. The development of new dimension-stone quarries may be a contentious issue in future years but, if planning and operations are conducted with reference to environmental concerns, the short-term impact can be minimized, and long-term impacts virtually eliminated. Dimension-stone quarrying extracts large blocks with minimal use of explosives, and typical quarry blasts have a distal noise level similar to that of a shotgun. Also, although individual blocks may be large, the total quantity of material removed is extremely small. As outlined earlier in this report, many quarry sites will of necessity be rather shallow excavations, and need not disrupt the landscape excessively. The Topsails granites are high-quality material, and there is little wastage, and no onsite processing of stone. The reclamation of quarry sites should be straightforward, as illustrated by the 19th century quarry sites, which have revegetated to the point where they are extremely difficult to find. The most significant environmental issues for individual sites are access, as short feeder roads will be required, and proximity to water systems that may require silt filtration systems, such as those used during highway construction. The wider question of the railbed right-of-way and responsibility for its maintenance is very important in the context of the Topsails Plateau and is beyond the scope of this report.

Three prominent quarry sites of huge potential are specifically excluded from further discussion. The large tors of Main Topsail, Mizzen Topsail and Gaff Topsail are all formed from massive, homogeneous patchy yellow granite that forms huge joint-free outcrop surfaces, and presumably gives way to primary green material at depth. They form prominent viewpoints and natural landmarks. The mountains are very severe environments, and are frequently immersed in cloud cover, or swept by powerful winds capable of demolishing microwave towers. Also, in the case of Gaff Topsail, there is a higher-than-normal abundance of larger volcanic xenoliths, which is particularly undesirable. However, there are several potential yellow to green quarry sites in less prominent areas.

19th Century Quarry Sites

Upper Quarry

'Upper Quarry' is an extensive series of shallow excavations located west of, and topographically above, the railway line (Figures 2 and 3). These are less prominent than the relatively deep Lower Quarry (see below), and less frequently visited; however, there are indications that substantial quantities of material have been removed. It is difficult to estimate production, as the original height of the granite outcrops in the area is unknown. Unlike Lower Quarry (see below), there are no stockpiled blocks here, but there are several small piles of wedge-shaped pieces that probably represent the tapered ends of quarry benches, discarded as waste. F. Thorne (personal communication, 1993) is of the opinion that much of the railway construction material came from Upper Quarry.

This area, (and also exposures in Quarry Brook), exhibits a closely-spaced (50 to 75 cm) low-angle joint set that dips at shallow angles (10 to 15°) to the southwest. High-angle joints at ~060° and ~120°, but locally variable, have spacings of up to 2 m, and yielded rhomb-shaped slab-like primary blocks. The entire area is formed of patchy yellow granite, although much of the material now exposed is massive yellow-green to green granite, as the upper benches have been completely removed. There are no pervasive red granites in the site, but these rock types are exposed in nearby Quarry Brook. The relatively close spacing of flat joints in this area provided an ideal situation for extraction of small blocks for bridge construction and possibly for the St. John's railway station, which were probably split 'ready-made' from 50 to 75 cm thick slabs. However, it is far less suitable for production of the larger blocks required for commercial tile production. It is possible that joint spacing increases with depth, as is common in granites (e.g., Twidale, 1982), but there would be water-control problems with a deeper site in this area, because of adjacent brooks and swamps. Any future production at this site would be dominated by green granites.

Lower Quarry

Lower Quarry is a deeper excavation about 200 m east of, and topographically below, the railway line, associated with a number of shallower pits. It is in a forested area, and is invisible from the railway line; the excavations are extensively revegetated with alders and other nuisance flora. The largest site consists of two adjacent pits each 20 to 25 m in diameter, and with an upper face at least 10 m in height; these are both flooded, and the true depth and nature of the lowermost bench are difficult to establish. As the area slopes to the east, the lower face is much smaller. On the basis of a 10 m face, and accounting for topography, but not for waste, these quarries could have produced up to 5,000 m³ of stone.

Lower Quarry is remarkable for the large number of stacked blocks, which are piled in several pyramids across the site, and give it an eerie resemblance to a ruined prehistoric temple. Some blocks have dimensions up to 2 by 1 by 1 m, but the majority are of the same general size range as bridge pier stonework, i.e., 1 by 0.5 by 0.5 m. The stacked blocks exhibit wide variations in colour. The majority are yellow, yellow-green and green patchy coloured granites, and are presumed to come from various depths of the surficial alteration zone (see Part 1). However, there are also lesser numbers of pink and red granite blocks. One block with a pale violet or mauve colour was also observed. It is not easy to examine outcrop benches at Lower Quarry, as they are partly inaccessible, but a yellowish cast is evident in some areas at the lower part of the face, suggesting that the alteration profile is fairly deep at this location. No red or orange granites were located in outcrops, but the presence of such blocks suggests that at least one pervasively-coloured zone existed within the site. Flat joint spacing is fairly narrow (~50 to 75 cm) in the upper regions, but there is a suggestion of more massive material below. The abandonment of the site presumably reflects completion of railway construction in the early 20th century, after which only small quantities of material were needed for repair and maintenance.

The Lower Quarry area certainly has potential for the opening of new patchy yellow to green granite quarry sites along the same general 'horizon'. However, the upper benches in the area are thin (as at Upper Quarry) and are more amenable to the production of small (< 1 m³) blocks than large blocks of > 10 m³. Both Quarry Brook and Little Quarry Brook expose massive yellow granite east of the railbed, and the slightly more elevated region between them represents the best area for further investigation. Also, although the jointing patterns may not be ideal, both 19th Century quarries have the advantage of being established sites of mining activity, and may have some regulatory advantages over completely new sites that require access routes.

Other 19th Century Sites

Small 19th Century excavations occur all along the railway corridor, usually immediately beside the line, but locally up to 30 or 40 m from it. In many cases, these appear to be areas where outcrops in the path of the line were removed to facilitate construction, and/or small quantities of stone were removed for local bridge piers. Several sites in the vicinity of the Summit Quarry expose primary green granite at relatively shallow depths. Unless drill marks are preserved and easily visible, these small pits can be very difficult to distinguish from natural jointed outcrops.

Summit Quarry

The Summit Quarry is located immediately west of the railbed, about 1 km south of Summit Station. In this area, dry, well-drained ground with only thin till cover slopes gently upward from the railbed, toward a flat-topped hill of ~ 500 m elevation (Figure 3). The site is ideal for efficient quarrying, as it has prominent subhorizontal jointing, which dips very gently (5 to 10°) toward the railbed, with spacings of up to 2 m. This greatly aids the process of block separation and removal, as the force of gravity acts in the preferred direction of movement. Northeast–southwest and northwest–southeast striking, orthogonal, high-angle joints have spacings generally in excess of 2 to 3 m, and locally 5 m and greater. At the quarry site, there are essentially 3 'benches' of granite, each up to 2 m thick. The upper bench is yellowish, and is underlain by yellow-green material, in turn underlain by massive, virtually fresh, pastel-green granite. The benching angle is slightly shallower than the slope of the hill, and the yellow-green bench becomes green as it moves into the hill. Below the line are two small 19th century excavations that expose the green granite at shallow depths. The general situation at the quarry site is summarized schematically in Figure 6; the colour variation is assumed to continue 'uphill', subparallel to the surface, but it is suggested that much of the upper yellow granite has been glacially removed below the line. Some of it may be represented as a large field of massive yellow granite erratics in this area.

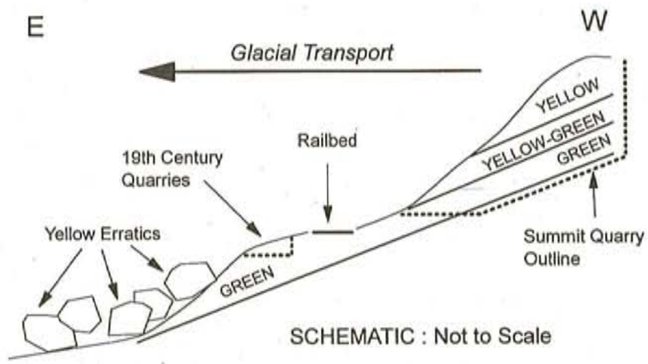

Figure 6. *Schematic cross section of the Summit quarry site showing distribution of colour zones relative to the surface.*

The stone at Summit Quarry is of exceptionally high quality, and both primary and secondary block extraction was accomplished economically with widely-spaced (up to 50 cm) blast holes. A few small (typically < 3 cm diameter), rounded enclaves of dark material are present; some are recognizably volcanic, and others are nondescript hornfels. As noted previously, a zone of pervasive pink granite transects the site at about 150°, associated with a fracture system; a coarse pegmatitic zone with bright red feldspar, probably related to this, also afflicted one block.

In terms of expansion, the area to the south of the site contains pervasively coloured red and orange granites that are not of dimension stone quality; similarly, part of the hilltop west of the site has poor material. The best expansion direction for yellow and yellow-green granite is uphill toward the northwest, although the area east of the site (below the railbed) has potential for massive green material.

Potential Quarry Sites

Site 1

Site 1 is located about 500 m west of the railbed at kilometre 6.5 (Figure 3). It consists of three main outcrop ridges of yellowish-brown weathering granite that has an attractive beige-yellow colour away from immediate surface weathering. High-angle joint spacing exceeds 2 m. The texture is very consistent, with well developed bright orange interstitial flecks, and interstitial mafic minerals. A few amphibole crystals are large poikilitic aggregates up to 1 cm in diameter, but these are sporadic. The site is interpreted to yield yellow-green and green granites at depth. The location is surrounded by swamp, which suggests potential difficulties with water control, and also access. Overall, Site 2 (see below) is a better prospect, and hosts closely similar granites.

Site 2

Site 2 is a composite quarry site that includes beige-coloured patchy granites identical to Site 1, coupled with pervasively coloured brown and red varieties. It is located 400 to 500 m northwest of Site 1, and is about 1300 m southwest of the Classic Stone base camp at kilometre 8 (Figure 3). Although farther from the railbed by this route, the potential access road stays on high, dry ground, and would be easier to construct and maintain, and less disruptive, than a route via Site 1.

Site 2 is one of the best potential sites in that two, and possibly three, different varieties of granite can be extracted. The eastern portion of the site comprises at least 3 parallel outcrop benches of patchy beige-yellow granite similar to Site 1, with high-angle joint spacings in excess of 5 m. Subhorizontal joint spacing is harder to assess but, based on the height of the outcrops, is at least 1 to 2 m near the surface. About 100 m northwest of these is a long north–south trending outcrop bench of massive brown granite, with an overall colour that is best described as 'khaki'. This retains some textural features common in patchy granites (e.g., interstitial red patches), but is interpreted to have suffered a mild hydrothermal overprint, as outlined in Part 1. It is very massive, and only slightly weathered, and high-angle joints are spaced at 2 to 4 m. There is no visible evidence of veining. This material has significant strike extent, as a large (100 m^2) outcrop of identical material occurs about 200 m due south. Both of these outcrops are flanked to the west by more intensely fractured pervasive red and orange granites, which are interpreted to represent a more strongly altered facies. This material is massive and fresh, but average high-angle joint spacings of 50 cm to 1 m indicate that it will present quarrying difficulties. However, as the beige-yellow and brown granites by themselves are clearly of economic interest, the more strongly coloured variants can be evaluated further during development; there may be localized zones where medium-sized blocks can be removed.

The zone of pervasive colour at Site 2 strikes north–south, but its full extent is unknown; however, orange-brown granite also occurs in Bad Bridge Brook, some 500 m south of Site 2. The western edge of the zone has also not been positioned with confidence, but the total width is estimated to be at least 75 m.

Sites 3 and 4

Sites 3 and 4 are closely adjacent, located about 1 km east of the railbed at kilometre 6.5 (Figure 3). The area between the railbed and Site 3 also contains some moderate sized outcrops of patchy yellow granite that may have some quarry potential, but are not specifically described here. Sites 3 and 4 are situated on either side of a 1.2 km long northwest–southeast trending zone of pervasively coloured granite that seems to be spatially associated with dykes of finer-grained porphyry and felsite that have a similar trend. This zone includes some very attractive red and unusual mauve granites but, as is commonly the case, fracture density presents problems with these.

Sites 3 and 4 are difficult to classify. They are extremely difficult to sample adequately, but both appear to have a warm pale orange colour. They seem to be more massive and less friable than is typical for patchy orange-yellow ('gold') granites, which suggests that they may represent a mildly-altered pervasive marginal zone associated with the more intensely altered red and mauve granites. However, the colour is superficially similar to that seen in the uppermost levels of patchy colour zones, so a simple test of vertical extent with a single drillhole is strongly recommended. Site 3 is a fairly small, but prominent outcrop in which a single high-angle joint set with spacings of 3 m and greater is developed. It is cut by a 10-cm-thick pegmatite containing acicular amphiboles, but is otherwise homogeneous. The outcrop is immediately adjacent to pervasively coloured bright red granites, which form a zone up to 100 m wide. Site 4 is lithologically identical, is located about 250 m east of Site 3, and is a superb 'natural' quarry site (see Plate 1c). It consists of several east–west trending outcrop benches that are symmetrically dispersed to north and south of a small valley; the benches rise in a step-like pattern on each side. On the basis of outcrop height, flat-lying joints are estimated to be spaced at 2 to 3 m; high-angle joints trending east–west have spacings greater than 3 m, and there are very few cross-joints. The quarry site is ideal for large block production, and two faces could be worked simultaneously. The material is so massive that it is almost impossible to sample with a sledgehammer. As noted above, a simple test of vertical extent is strongly recommended to ensure that this does not represent a surface colouration, but, given its massive character, this is considered unlikely.

A potential access route to Sites 3 and 4 would leave the railbed at kilometre 7, and pass through a dry, lightly wooded area. If Site 4 is developed, this route would provide opportunities to further assess the strongly pervasively-coloured granites in the area. The mauve granites are extremely attractive, but have not yet been proven in sufficient quantity.

Site 5

Site 5 is a small but interesting locality about 500 m west of the railbed at kilometre 8.6 (Figure 3), where it may be possible to extract pervasive red and pink granites. It is located at the northwestern extremity of a large and diffuse zone of pervasively-coloured granites that extends to the east of the railbed; its continuation to the northwest of Site 5 is uncertain. Site 5 comprises two outcrops about 75 m apart. The eastern outcrop is located in a small stream, and is a massive, benched outcrop of deep red granite with high-angle joint spacings up to 2 m. Subhorizontal jointing is visible in the outcrop, and is spaced at 60 cm to 1 m; the outcrop surfaces have a gentle slope. The second outcrop is located a short distance upstream, and has closely similar physical features. However, it has a subtle violet-pink colour; in thin section, it is seen to be strongly altered, with spectacular oxide-quartz pseudomorphs after mafic minerals.

Although Site 5 does not have potential to give blocks of comparable size to the Summit Quarry, blocks of 4 to 5 m^3 may be extractable. It is also the only site with potential to give granites with mauve or violet hues. Further work is needed here, in particular some stripping to ascertain the extent of outcrop beyond exposures provided by the stream. The stream is very small, and could be diverted. Site 5 is roughly equidistant between the base camp at kilometre 8 and the Summit Quarry; the route from the latter site is dry and easy. It is also less than 1 km from Site 6 (see below) and could possibly be developed in conjuction; it could also be accessed from any route constructed from the base camp to Site 2.

Site 6

Site 6 is located on a hilltop about 500 m west of the railbed at kilometre 9, and about the same distance west-southwest of the Summit Quarry (Figure 3). The summit of the hill consists of three granite tors, and there is extensive bedrock exposure, most of which is patchy yellow-green granite with well-developed interstitial red patches, and oikocrystic mafic minerals. In general, this site has a distinct greenish hue compared to more typical patchy yellow variants, and it is possible that some overlying yellow material has been stripped off by glacial action or mass wastage; several enormous yellow erratics are present downslope from the site. Although there is surface weathering and frost shattering, the material is fresh on lower surfaces, and it seems very likely that pastel green 'primary' granite is present at very shallow depths. There are four other smaller massive outcrops within 100 m of the main site; two of these are yellow-green, and two are fresh, pastel-green material, again suggesting a very thin alteration profile here.

The main outcrop has two high-angle joint sets, trending at 340 to 010° and 80 to 110°, respectively, and both have spacings ranging from 2 m to over 10 m. A few more strongly fractured areas are located at the edges of outcrop benches, but may result from glacial plucking, rather than indicating deep, penetrative fracturing. The other outcrops are similarly massive. Site 6 enjoys good access from Summit Quarry, or from the base camp, via Site 5. There is, however, little potential for patchy yellow or yellow-green granite, due to the thin alteration profile. The major product would be green granite.

Sites 7 and 8

Sites 7 and 8 occupy part of a large hilltop area located 250 to 500 m east of the railbed at kilometre 11.5 (Figure 3). This entire area is part of a large zone of pervasively coloured granites trending roughly northwest–southeast. Its continuation to the southeast is unknown, as is its relationship to a similar zone north of Barney's Brook (Figure 3). The hilltop area includes extensive outcrop, with variable fracture densities; it is variable in colour, but is dominated by pervasive pale orange-brown granite, with local areas of red. Access is easy, and is entirely over dry ground, with thick till.

Site 7, closest to the railbed, contains some areas where blocks of up to 2 m^3 could be extracted, and prominent high-angle joints trending at 025 to 040° are spaced at 1 to 2 m; however, other parts of the site contain numerous fractures trending at 130 to 145°, with spacings in the 20 to 30 cm range. This site contains good examples of quartz, hematite and felsitic fracture fillings, and hydrothermal veining may present problems. Site 8, about 300 m to the northeast, is slightly more massive and includes some long benches of orange-brown granite that could provide moderate-sized blocks; the outcrop is more homogeneous in terms of fracture density, and filled fracture systems are less evident. Observations at both sites, and in surrounding outcrops, suggest that there are lateral variations in colour within this area, that presumably reflect variations in the intensity of alteration. More information is required about the scale of this variation. These sites are part of a larger area, which is generally quite strongly fractured. In quarry development, it is commonly held that fracturing diminishes with depth. Although this is undoubtedly true where fracturing is caused by surface processes such as freeze-thaw cycles, it may not be the case for filled fractures that are associated with hydrothermal processes, which may persist to considerable depths.

Site 9

Site 9 is located only 200 m east of the railbed at kilometre 13, overlooking Barney's Brook. It consists of a massive northeast–southwest trending outcrop that contains only a few widely-spaced high-angle joints, and is clearly suitable for production of large blocks. The granite is a yellow colour, and is considered to be a patchy colour variant, but it is subtly different to the predominant coarse-grained granite. It appears to be slightly finer grained, with an average grain size of 4 to 6 mm, but has a similar texture, with interstitial mafic aggregates. It appears to be slightly poorer in quartz, and transitional toward quartz syenite in composition.

Although attractive and massive, some features of this site raise concerns. First, random sampling across the outcrop suggests that there may be internal grain size variations, with some regions being more typical coarse-grained yellow granite. A slabbed sample was afflicted by a linear zone in which dark amphibole was concentrated; as the outcrop shows replacement of green amphibole by arfvedsonite, and is situated within a larger zone of pervasive colour, this is probably a hydrothermal effect. Third, there is a higher proportion of small volcanic xenoliths than is typical for the Topsails Granites. This combination of problems suggests that the site should be approached with caution.

Site 10

Site 10 is in a rather remote location, about 1.5 km southwest of the railbed at kilometre 14 (Figure 3). This is an impressive site on a low hill, with a relatively dry access corridor leading directly from the railbed. It consists of enormous outcrops of massive, patchy, yellow-orange granite, with high-angle joint spacings up to 6 m. The individual outcrops are up to 20 by 20 m, and there are several of them on the gentle east slope of the hill. The material is extremely homogeneous, and is essentially inclusion-free. As in most of the patchy colour variants, central portions of feldspar grains retain hints of green. It is anticipated that this site would yield yellow-green and green granites at depth, but there is a large area available for lateral expansion to exploit patchy yellow granites. There are no indications of pervasively coloured granites in the area. The area is well-removed from any stream courses or lakes.

Site 11

Site 11 is located less than 200 m east of the railbed at kilometre 15 (Figure 3). It includes three outcrops of pervasive orange-brown and red granite. These are well jointed, but include regions where high-angle joint spacings are in the 1 to 2 m range. There is a dominant 130 to 160° fracture system, presumably associated with the alteration process, and red granites are developed in areas of more intense fracture development. Orange and orange-brown are the dominant colours seen. In some areas, it is hard to differentiate between outcrop and large slabs that may be erratics. The site clearly has potential, but it requires assessment of internal colour variations and mapping to separate waste from potential block material.

Site 12

Site 12 is located approximately 1 km east of the railbed at kilometre 15 (Figure 3). It is possibly one of the most impressive potential quarry sites in pervasive pale orange-brown granite. It consists of a series of massive outcrop benches on a gentle hill, and is almost a 'natural' quarry site. Subhorizontal joints spaced at around 2 m, dip gently into the hill. Well-developed high angle joint systems at ~ 060 and 180° (subordinate) have spacings of the order of 3 m, and would produce rhomb-shaped primary blocks. The rock appears homogeneous, and colour variations seem less marked than at Site 11.

Site 13 (Quartz-Feldspar Porphyry)

Site 13 was discovered during 1993 field work, and is located approximately 1 km northeast of the railbed at kilometre 15.5 (Figure 3). This site is unique in that it is the only potential quarry hosted by a unit other than coarse-grained granite. It consists of three outcrops of quartz-feldspar porphyry in a triangular arrangement, with about 75 to 100 m between outcrops. The rock is a buff-pink, homogeneous porphyry containing small (4 mm diameter) round quartz phenocrysts and tabular (up to 8 mm long) white K-feldspar laths that lack preferred orientation, set in a slightly seriate groundmass. Red biotite is prominent in hand specimen. Most other porphyry outcrops are very small and/or heterogeneous, but these outcrops all have potential for blocks in the 4 to 5 m^3 range. If the area in between outcrops is also underlain by porphyry, as seems likely, there may be potential for a fairly extensive quarry here. Further assessment of this site depends on extraction of a larger block for production of some test slabs; as subvolcanic porphyritic rock types tend to be heterogeneous and fractured, this unusual occurrence may be of commercial interest. Access from the railbed is along a fairly dry ridge, and the sites are about 300 m east of the large pond at Gaff Topsail.

Site 14

Site 14 is located less than 200 m east of the railbed at kilometre 16, adjacent to and above a large pond (Figure 3). This site is probably the single most impressive location for pervasive red granite. The core of the site consists of several massive benches of red granite, trending at ~080°. There is a prominent joint set in this orientation, but no well-developed subhorizontal jointing. A set of joints striking ~080° and dipping at 30 to 40° northwest defines a series of inclined bench surfaces. The jointing pattern is locally complex, but many areas of the outcrop clearly have potential for blocks in the 4 to 5 m^3 range. About 70 m south of the red zone, a series of closely similar inclined benches expose homogeneous pervasive orange-brown to orange granites that are similarly massive. The transition from orange-brown to red appears to be parallel to the 080° fracture system, but it is not clear if it is vertical, or follows the northwest-dipping set. A short distance to the north of the red zone, patchy yellow granites occur. Of all pervasively-coloured granite occurrences, this site probably contains the least evidence for a hydrothermal origin, and no filled fracture systems have been identified.

No other red granite site contains the quantities of massive material present in Site 14. However, Site 14 also has some disadvantages. The proximity of the site to a large pond raises engineering problems, as it may place limits on depth of excavation due to water control problems. Also, as the lake drains into the Grand Lake watershed, there may be some environmental concerns. The relatively steep benching of the red outcrop is also less-than-ideal, as blocks would have to be removed over a 30° incline in places. However, even with these potential difficulties, the sheer quantity of material in Site 14 merits serious consideration.

Site 15

Site 15 is located on the north slope of Gaff Topsail, about 300 m southwest of the railbed at kilometre 16, and about 150 to 200 m from a disused access road up the east flank of the mountain, used in the construction of the ill-fated microwave tower. It is a large, high-standing outcrop, between 50 and 75 m in diameter, consisting entirely of massive, orange-yellow weathering patchy yellow granite. The material is extremely homogeneous, and has a clean surface texture with interstitial red flecks and oikocrystic mafic aggregates. Upper outcrop surfaces are orange-tinted and strongly weathered, but grade downward into 'fresher' yellow granite. This site will almost certainly yield yellow-green and pastel green granites with increasing depth. High-angle joint sets are orthogonal at 070 and 160°, with spacing from a minumum of 1 m to greater than 5 m. Subhorizontal joints are harder to define, but their spacing is estimated to be at least 2 m. The site has clear potential to produce very large blocks. Similar, but somewhat smaller, outcrops occur downslope, but thin zones of pervasive red granite occur some 200 m north of the site.

Site 15 is impressive, but its location close to the prominent tor of Gaff Topsail may be a disadvantage.

Site 16

This site is located about 200 m north of the railbed at kilometre 16.5 (Figure 3). It consists of massive outcrops of patchy yellow granite with very little jointing. The greenish tint in feldspars suggests that it will eventually yield yellow-green and pastel green granites at depth. A second outcrop about 80 m to the northeast has similar features. In many respects, this site resembles Site 15 in its potential, but it enjoys a far less prominent and controversial location, and has better elevation above the pond than Site 14.

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