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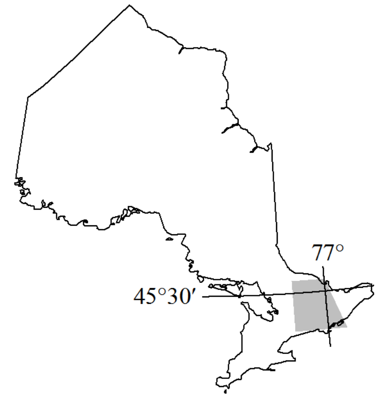
12. Project Units 11-004 and 13-013. Geology and Mineral Potential of the Late Syenite Suite (1090–1030 Ma) and Associated Rocks, Central Metasedimentary Belt Boundary Tectonic Zone, Grenville Province



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INTRODUCTION

Since their initial description (Adams and Barlow 1908), the belt of alkali syenites, nepheline-bearing gneisses and associated alkalic rocks located in Bancroft terrane, and extending from Minden to the Ottawa River (Figure 12.1), has both fascinated and befuddled researchers for over a century. Interest in these rocks has been both academic and economic in focus. From an economic standpoint, these rocks have been past-producers of corundum, molybdenum and uranium (cf. Storey and Vos 1981; Carter, Colvine and Meyn 1980; Masson and Gordon 1981), and have potential for hosting rare earth element (REE) mineralization.

Improved understanding of the geology and mineral potential of these alkali syenite and associated rocks is a focus of the ongoing 1:50 000 scale compilation mapping project of the Brudenell area (NTS 31 F/6) begun in 2011 (Easton, Duguet and Magnus 2011; Easton 2012; Easton and Clarke, this volume, Article 11). Expanding on that project, work on these rocks moved northeast to the Ottawa River, with approximately 6 weeks of the 2013 field season devoted to mapping in the Cobden area (NTS 31 F/10). This article reports on new insights into the origin and mineral potential of these alkali syenite and associated rocks, garnered from field work in both the Brudenell and Cobden map areas.

GEOLOGICAL OVERVIEW

The belt of alkali syenites, nepheline-bearing gneisses and associated rocks occurs in Bancroft terrane, stretching from Minden to the Ottawa River (*see* Figure 12.1). They occur in the immediate hanging wall of the Central Metasedimentary Belt boundary tectonic zone (CMBBTZ), which separates older rocks of the Central Gneiss Belt to the northwest from supracrustal rocks of the Central Metasedimentary Belt to the southeast (*see* Figure 12.1).

For simplicity, the alkali syenites, nepheline-bearing gneisses and associated rocks will be referred to herein as the Late Syenite suite. The Late Syenite suite encompasses several previously defined lithodemic units, including the Nepheline Syenite, Kensington–Skootamatta (Monzonite-Diorite suite of Lumbers et al. 1990) and the “alkalic” (Lumbers 1982a, 1982b) or Fenite-Carbonatite suites (Lumbers et al. 1990; Easton 1992). As described in detail by Easton (2012), these different suites likely represent a continuum of syenitic magmatism spanning roughly 60 million years, from *circa* 1090 to 1030 Ma, rather than being separate, disparate, magmatic events.

Summary of Field Work and Other Activities 2013,
Ontario Geological Survey, Open File Report 6290, p.12-1 to 12-12.

Based on relative age relationships, coupled with new absolute ages, there are at least 3 main periods of syenite emplacement within the Brudenell and Cobden areas (Easton 2012).

1. early syenites (1090 to 1070 Ma) were regionally distributed and form discrete low U-Th, magnetic plutons. These plutons correspond to the Kensington–Skootamatta Suite.
2. medial syenites (*circa* 1050 Ma, low U-Th, magnetic), some of which are nepheline bearing, were localized along shear zones within 20 km of the CMBBTZ. These syenite plutons correspond in part to the Nepheline Syenite Suite, but, for the most part, are much younger than the age of *circa* 1290 Ma suggested for this suite by Lumbers et al. (1990). Nepheline syenite intrusions from the Brudenell and the Tory Hill areas have yielded U/Pb TIMS ages of 1042±3 Ma and 1055±2 Ma, respectively, as reported in Easton (2012).
3. late syenites (*circa* 1035 Ma, less magnetic, high Th) (Photo 12.1) are associated with metasomatic fluid that interacted extensively with its host rocks, and are found almost exclusively within 20 km of the CMBBTZ. They correspond roughly to the Fenite-Carbonatite Suite of Lumbers et al. (1990).

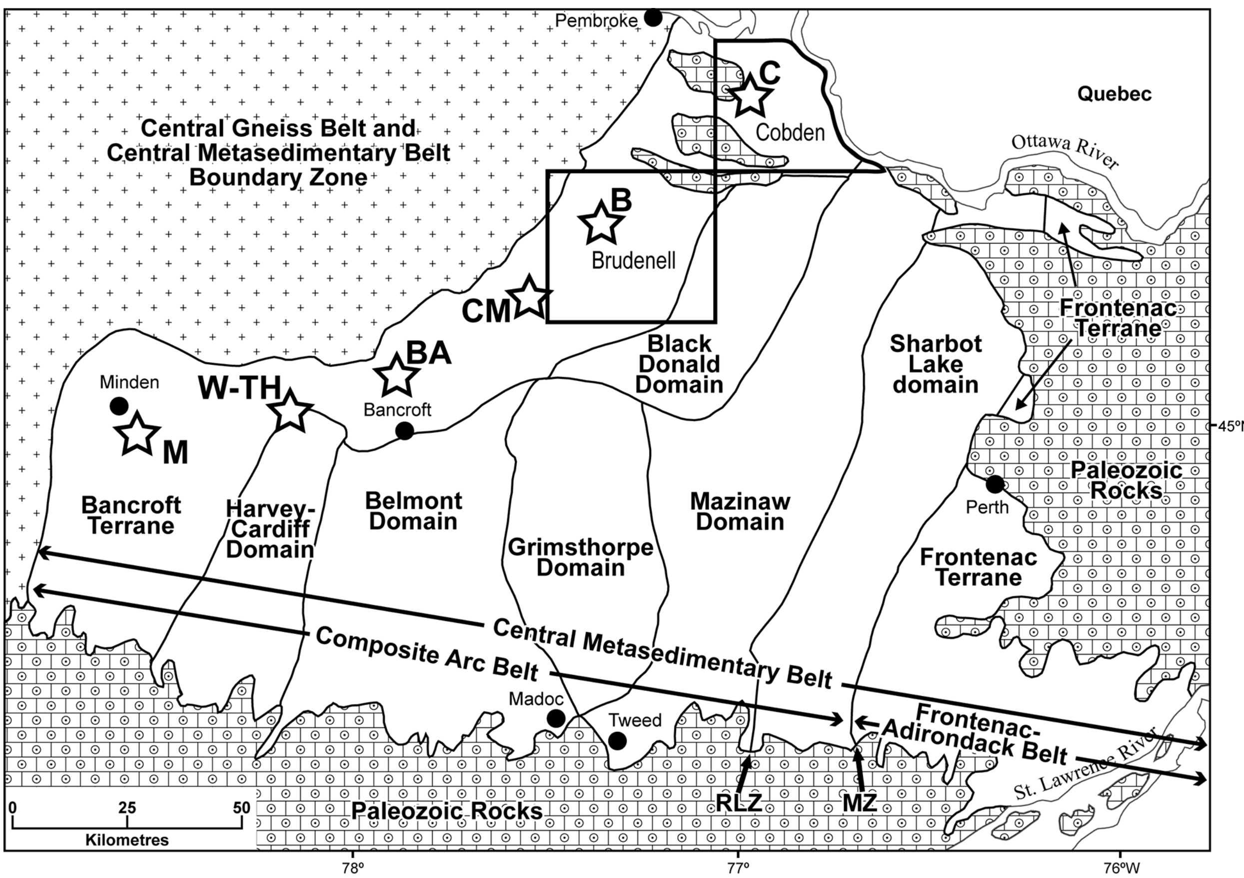

Figure 12.1. Terrane and domain subdivision of the Central Metasedimentary Belt (*modified from* Easton (1992) and Carr et al. (2000)) showing the location of the Brudenell and Cobden study areas, and the location of major subareas of the Late Syenite suite belt within the Bancroft terrane. The Central Metasedimentary Belt is composed of the Composite Arc Belt and Frontenac terrane. Abbreviations: B, Brudenell subarea; BA, Bancroft subarea; C, Cobden subarea; CM, Craigmont subarea; M, Minden subarea; W-TH, Wilberforce–Tory Hill subarea; MZ, Maberly shear zone; RLZ, Robertson Lake mylonite zone.

The age of the youngest syenites is now constrained at 1033±1 Ma by a U/Pb zircon age determined by chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) on a sample from the Lorwell syenite in the Brudenell area (Kamo 2013). The same sample also contained several zircon grains that yielded slightly older ages of 1064 to 1060 Ma. These older ages are interpreted to be due to the presence of minor inheritance in the grains (Kamo 2013). The presence of inheritance would explain the wide range of ages (1062 to 1033 Ma) obtained by Childe, Mungall and Martin (2000) from the nearby Lake Clear syenite in the Brudenell area. Notably, their youngest ages also indicate an emplacement age of *circa* 1033±1 Ma.

Metasomatic rocks are closely associated with intrusive rocks of the Late Syenite suite, and include pyroxenite veins and pods, pink and orange-pink calcite veins and replacement of older white carbonates by pink and orange-pink calcite ± diopside veins (Photos 12.2 and 12.3), and trace-element–enriched carbonate rocks that have been referred to as carbonatites or pseudo-carbonatites (cf. Mungall 1989; Lumbers and Vertolli 1998; Mitchell 2005).

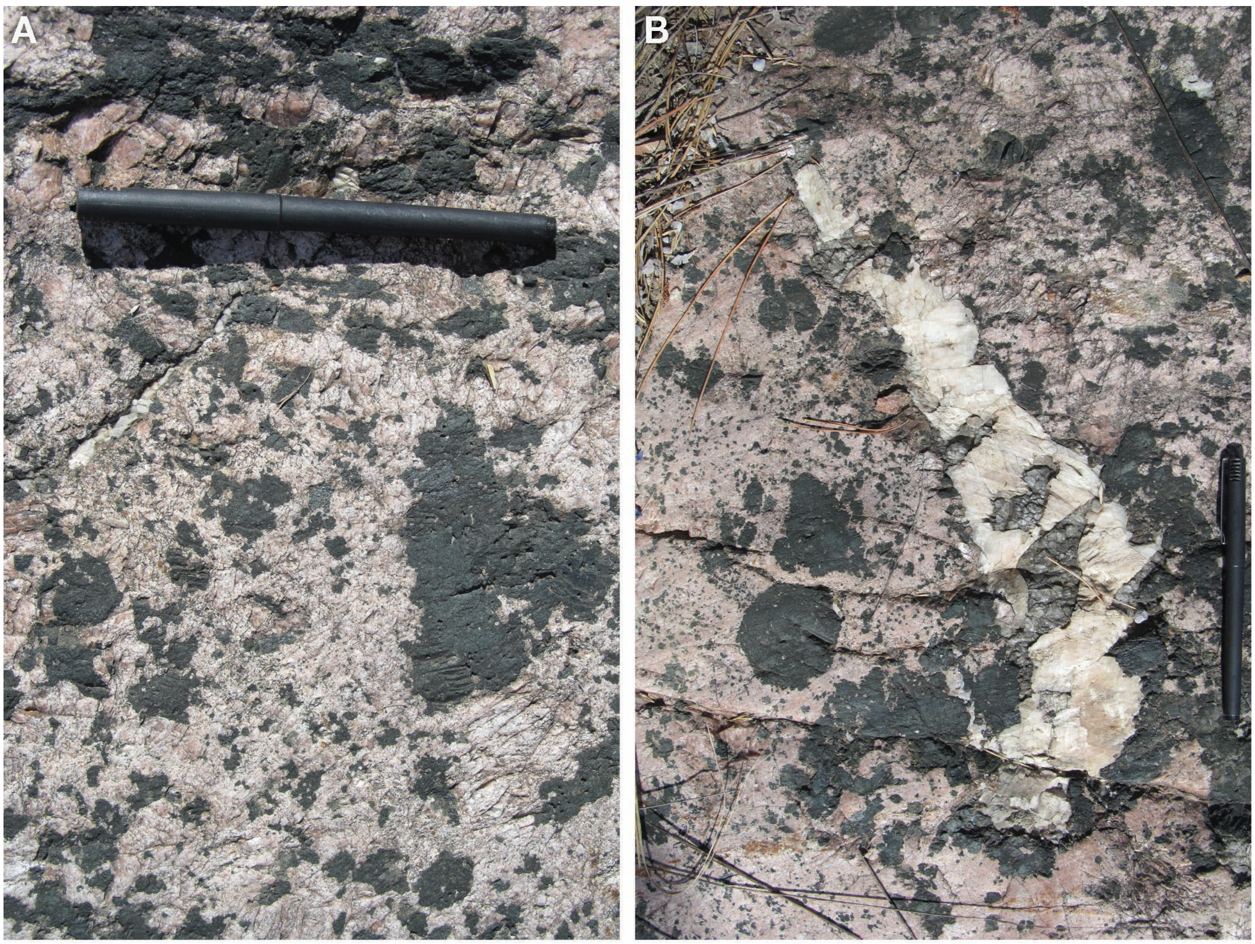

Photo 12.1. Examples of Lake Clear type syenite. **A)** Typical vari-textured and vari-grained pyroxene syenite. **B)** Lake Clear type syenite with a discrete calcite pod. Pods such as these are common in the Late Syenite suite rocks, and may result from crystallization from a CO_2-rich immiscible liquid co-existing with the syenite magma. Pen in both images is 14 cm long. Both images are from an outcrop on the south side of Highway 17, south of Cobden. (UTM 354285E 5053553N, NAD83, Zone 18).

COMPARISON BETWEEN BRUDENELL AND COBDEN AREAS

Surprisingly, the character of the Late Syenite suite rocks in the Cobden area is markedly different from those in the Brudenell area. Table 12.1 compares observations on Late Syenite suite and associated metasomatic rocks from the 2 areas. The most significant differences between the 2 areas are listed below:

- rocks of the Late Syenite suite intruded into, and metasomatized, straight gneisses characteristic of the CMBBTZ (*see* Photo 12.3)
- metasomatic alteration, particularly of Grenville Supergroup carbonate rocks (mainly marble tectonic breccias) is more pervasive, both on outcrop and regional scales (*see* Photo 12.2)

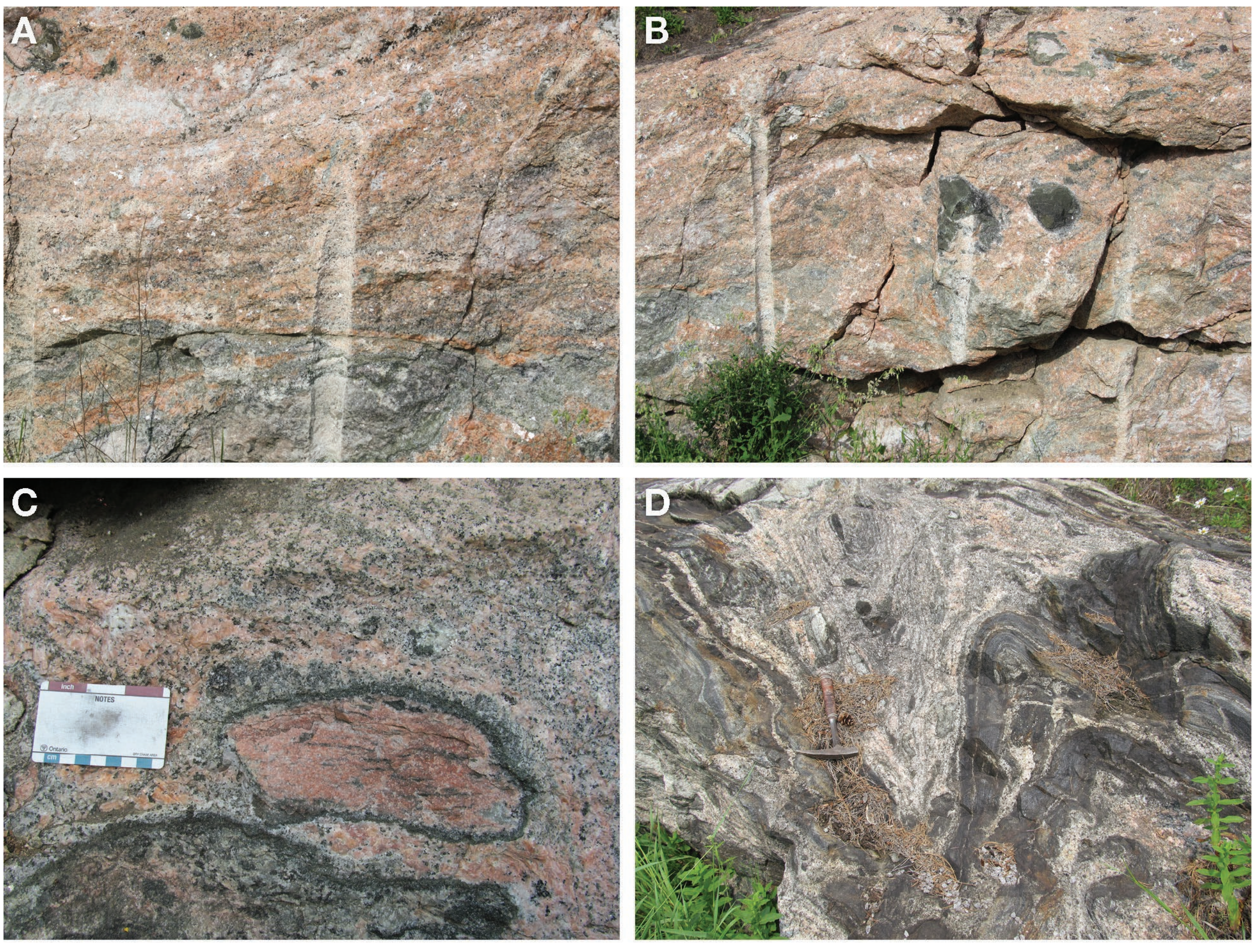

Photo 12.2. Examples of pink metasomatic carbonate rocks that are widespread in the Cobden map area. **A)** Typical massive, coarse-grained, pink calcite rock. The pink calcite forms due to metasomatism of an originally white marble. Diamond-drill hole trace is 35 cm long. **B)** Similar to Photo 12.2A, but containing dark-coloured fragments, which are diopside-rich fragments derived from metasomatism of pre-existing silicate fragments. The presence of these fragments indicates that the protolith was a marble tectonic breccia. Diamond-drill hole trace on left is 70 cm long. **C)** Syenite fragment with dark diopside alteration rim. The presence of syenite fragments indicates that deformation was occurring during and after intrusion of the syenite and accompanying metasomatism. Scale card is 9 cm wide. Photos 12.2A, 12.2B and 12.2C are all from a roadcut on the north side of Highway 60 (UTM 344426E 5045006N, NAD83, Zone 18). **D)** Folded mafic gneiss layers within pink-grey, partly metasomatized marble breccia. Hammer handle is 33 cm long. Photo from the northeast side of Dombroskie Road, immediately south of Highway 17 (UTM 358640E 5048120N, NAD83, Zone 18).

- syenite fragments are common in metasomatized marble breccias, indicating deformation during or after intrusion of the syenite (*see* Photo 12.2C)
- calcite± diopside ± alkali feldspar veins are more abundant in the Cobden area, and are commonly observed cutting country rock (*see* Photo 12.3), not just syenite
- fluorite and green apatite are common in both syenite and quartz syenite veins and in calcite ± diopside ± alkali feldspar veins in the Cobden area. Neither mineral was observed in the Brudenell area, which is characterized by red apatite. Scapolite is more abundant in the metasomatized marbles in the Cobden area. All of these mineralogical changes suggest the presence of a more fluorine-rich, and likely more reactive, metasomatic fluid in the Cobden area.

Photo 12.3. Relationship between Late Syenite suite and associated rocks and gneiss of the Central Metasedimentary Belt boundary tectonic zone (CMBBTZ). **A)** Subhorizontal white calcite-fluorite-apatite vein (fluorite and apatite are only visible on fresh broken surfaces) in lower half of image cuts the gneissosity in the host granitoid gneiss at a high angle. In the centre of the image, a thin vertical vein extends upward, also cutting gneissosity. Right-hand side of vein is 60 cm thick. **B)** Close-up of vein shown in Photo 12.3A. Note large block of syenite in the vein, as well as the development of coarse diopside and amphibole crystals in the adjacent gneiss along the vein contact. Diopside ± amphibole ± apatite ± alkali feldspar rims are commonly developed along calcite-rich veins cutting older host rocks throughout the Cobden area. **C)** Close-up of margin of calcite vein showing that it cuts the gneissosity in the host gneiss. Pen is 14 cm long. All 3 photos are from a roadcut on the north side of Kohlsmith Road, which is also the location of the Cobden apatite-fluorite occurrence, MDI31F10SW00005. (UTM 344426E 5045006N, NAD83, Zone 18).

Table 12.1. Comparison of Late Syenite suite intrusive and associated rocks from the Brudenell and Cobden areas.

Geological Feature	**Brudenell Area**	**Cobden Area**
Syenite types	Buff syenite (e.g., Lorwell syenite), diopside-alkali feldspar syenite (Lake Clear syenite), minor quartz syenite	Diopside-alkali feldspar syenite (Lake Clear type) predominant (*see* Photo 12.1), mafic-poor pink to red syenite, quartz syenite (latter is typically foliated to gneissic)
Syenite chemical characteristics	Miaskitic, metaluminous to locally peralkaline, typically trachyandesite to trachyte in bulk composition, typically magnesian and alkali in Frost et al. (2001) classification	Preliminary data indicate the presence of a medium-grained barium and REE-rich syenite not observed in the Brudenell area
Relationship to CMBBTZ	Syenites occur structurally above CMBBTZ rocks, there is little or no evidence that they intruded or metasomatized gneiss in the CMBBTZ	Syenites were intruded into and have metasomatized straight gneisses and other gneisses of the CMBBTZ
Mineralogy		Fluorite present in both calcite veins and in syenite and quartz syenite veins
	Red, stubby apatite (fluor-apatite) in both syenites (predominantly) and marbles and metasomatized calcite rocks (locally)	Red and apple green, stubby and elongate apatite, equally common in syenite and metasomatized calcite rocks. Green apatite could be the result of high strontium content.
		Scapolite and diopside abundant in association with metasomatized marble breccia
	Corundum abundant in western Brudenell area, continuing westward toward the Craigmont area	Corundum not known to be present in Cobden area
Metasomatism of marble breccia units	Local alteration zones and veins producing pink and pink-orange calcite rocks, typically near syenite intrusions	Regional widespread development of pink and pink-orange calcite rocks, syenite intrusions need not be present
Nature of marble breccia	Dominated by country rock fragments (paragneiss, amphibolite), only locally are fragments and matrix metasomatized	In addition to mainly metasomatized country rocks fragments (now mainly pyroxenite or scapolite), locally contains abundant fragments of syenite
Timing of marble breccia development	Marble breccia formed before syenite emplacement	Earlier formed marble breccia was metasomatized to create pink syenite breccias (*see* Photos 12.2A to 12.2D), but the presence of syenite fragments suggests that deformation was still occurring during syenite emplacement
Calcite veins	Small patches and elongate lenses in buff syenites and diopside-alkali feldspar syenites, rarely extend into country rocks (*see* Photo 12.1B)	Patches and elongate lenses in diopside-alkali feldspar syenite (*see* Photo 12.1B), also large veins that cut metasomatized country rocks (*see* Photo 12.3), pink-orange calcite rock may be injected into and/or structurally interleaved with CMBBTZ gneisses
Mineralization	REE locally enriched in metasomatized marbles adjacent to youngest syenites	Fluorite, thorium in quartz syenite pegmatite veins, REE data pending, all associated with youngest syenites
	Molybdenum associated with medial syenites, which include nepheline syenites	No medial syenites observed in the Cobden area (may simply reflect exposed structural level)
	Numerous uranium-thorium anomalies associated with medial syenite intrusions and thorium anomalies associated with youngest syenite intrusions	Only one area of significant thorium mineralization in the Cobden area (1800 ppm Th, 370 ppm U by scintillometer), located immediately south of the Sullivan Island carbonatites complex

Abbreviations: CMBBTZ, Central Metasedimentary Belt boundary tectonic zone; REE, rare earth element.

DISCUSSION

Central Metasedimentary Belt Boundary Tectonic Zone

The observation that rocks of the Late Syenite suite intruded into, and metasomatized, gneiss of the CMBBTZ is consistent with the current geochronological constraints on the timing of main fabric development within the CMBBTZ. Along the length of the CMBBTZ in Ontario, this event is constrained to between 1078±3 and 1052±3 Ma (McEachern and van Breemen 1993; van Breemen and Hanmer 1986), which is older than the ages obtained from the Brudenell area for emplacement of the Wolfe nepheline syenite and the Lorwell syenite (1042±3 and 1033±1 Ma, respectively; reported *in* Easton 2012).

From a mapping perspective, the presence of the Late Syenite suite rocks and metasomatic carbonate rocks within the CMBBTZ in the Cobden area makes locating the transition from the CMBBTZ into the Central Metasedimentary Belt more difficult than was the case in the Brudenell area. Historically, the lithologically defined boundary between the CMBBTZ and the Central Metasedimentary Belt corresponds to the first appearance of marble, be it marble tectonic breccia or belts of more massive dolomite or calcite marbles. The first appearance of marble is also generally coincident with the disappearance of large expanses of shallow-dipping, highly strained gneisses (e.g., straight gneisses), which constitute most of the CMBBTZ. The presence of syenite intrusions, large calcite veins, and large tracts of pink metasomatic carbonate rocks cutting rocks of the CMBBTZ in the Cobden area means that the presence of a calcite-rich rock (“marble”) does not automatically mean that one is now within the Central Metasedimentary Belt. As discussed in greater detail by Easton (this volume, Article 13), the true transition into the Central Metasedimentary Belt may actually be approximately 15 km further south than previously indicated.

Subareas Along the Alkali Syenite Belt

The differences noted between the Brudenell and Cobden areas may not be restricted to the Barry’s Bay to Cobden region, but may occur along the entire length of the alkali syenite belt in Ontario (*see* Figure 12.1). At least 6 subareas may be present along the alkali syenite belt, spaced approximately 40 to 50 km apart, as shown in Figure 12.1. Each subarea is likely characterized by its own unique mix of syenite intrusions, degree and type of metasomatism, and mineralogy. For example, corundum is abundant in the Craigmont and the western Brudenell subareas, but is scarce to absent elsewhere in the alkali syenite belt.

Figure 12.2 attempts to illustrate the differences between 3 of the subareas where the author has conducted detailed mapping. In the Minden subarea, metasomatism appears to be less widespread than in the Brudenell subarea, even though there are broad geometric similarities between the 2 subareas. In both, syenite and nepheline syenite intrusions occur in stratigraphically intact marbles that are separated from the main marble breccia zone overlying the CMBBTZ by thrust sheets of orthogneiss (*see* Figure 12.2). In the case of the Brudenell and Cobden subareas, the most significant difference is that syenite magmatism and metasomatism occur at a much lower structural level, such that the CMBBTZ is directly affected (*see* Figure 12.2).

More importantly, mineral potential may also vary from subarea to subarea, such that exploration techniques developed for one subarea may be less effective in another subarea. As illustrated in Table 12.1, there appear to be subtle differences in rare earth and uranium and thorium potential between the Brudenell and Cobden areas. Other differences in mineral potential may be present between subareas, and will be a topic for further work as part of this study. Finally, variation between subareas may in part explain why previous researchers, each working on different parts of the alkali syenite belt, often reached very different interpretations of the same rocks.

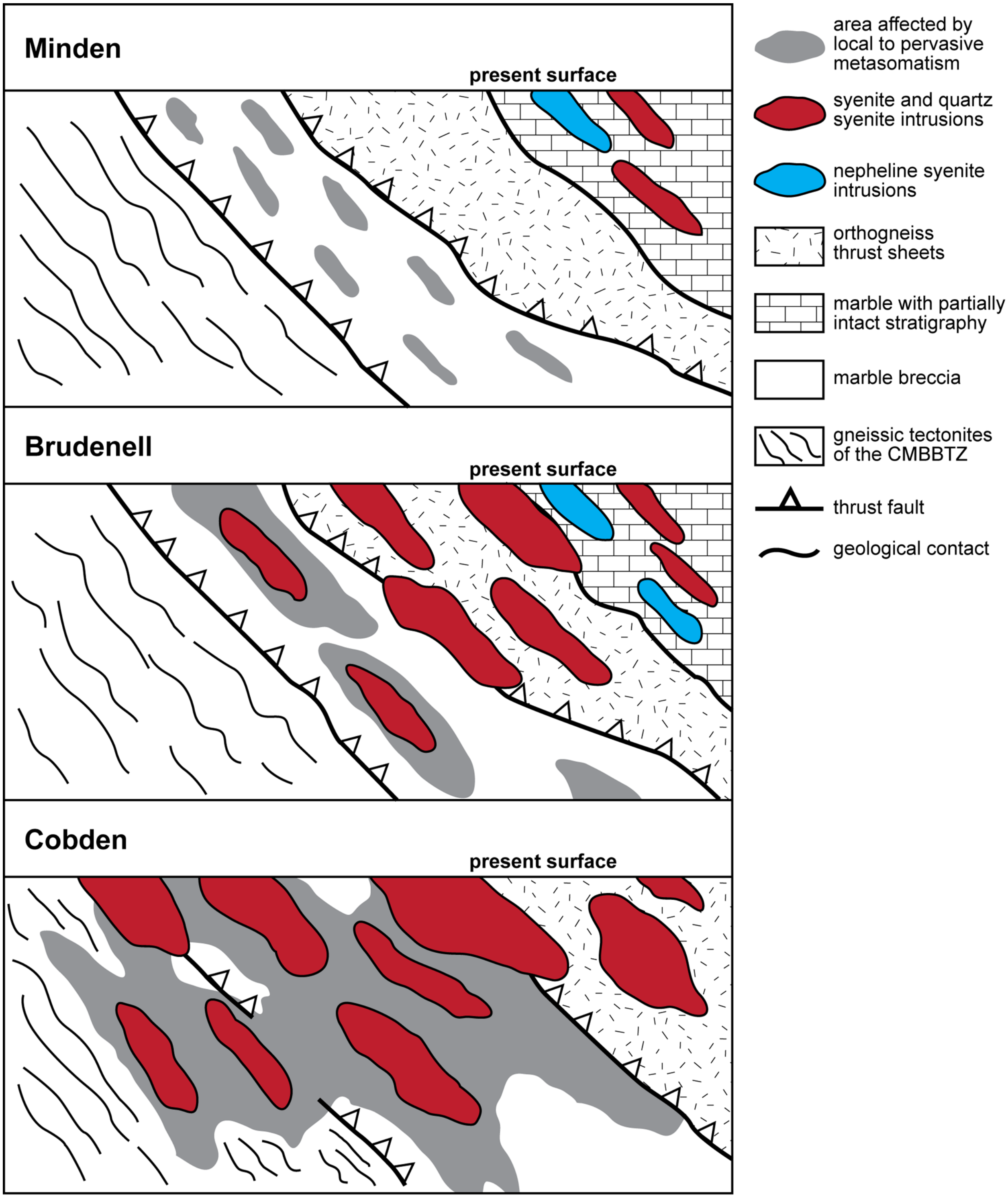

Figure 12.2. Cartoon cross-sections from the Minden, Brudenell and Cobden subareas. The 3 cross-sections illustrate the relationship of the Late Syenite suite intrusions and their metasomatic effects on their host rocks. Three different subareas along the CMBBTZ are shown (*see* Figure 12.1 for location of subareas). In the west (i.e., the Minden subarea, syenite intrusions and metasomatism are relatively distal from the CMBBTZ; both migrate closer to the CMBBTZ in the east (i.e., the Cobden area). Within the metasomatized areas, small syenite veins may be present, and metasomatism may vary greatly in degree, ranging from thin alteration rinds along veins to pervasive metasomatism (fenitization) of the host rocks. In general, metasomatism increases in intensity from west to east along the CMBBTZ.

Preliminary Model of Late Syenite Suite Emplacement

Figure 12.3 is an attempt to synthesize the knowledge collected from mapping the alkali syenite belt in the Brudenell and Cobden areas into a preliminary model for emplacement of the Late Syenite suite. It is divided into 3 time intervals, which correspond roughly to the emplacement of the older, medial and youngest syenites described above.

1090 TO 1070 MA

Between 1090 and 1070 Ma, during the peak of the Ottawan orogeny, the Grenville collision is in full force, resulting in northwestward-directed thrusting along the Central Metasedimentary Belt boundary tectonic zone and other major shear zones within the Central Metasedimentary Belt. At the same time, melting in the mantle begins southeast of the CMBBTZ, possibly due to mantle delamination. Whatever the cause, the mantle melts, and the resultant magmas rise into the crust, resulting in the emplacement of ovoid syenite intrusions (Kensington–Skootamatta suite) (*see* Figure 12.3). As these magmas come directly from the mantle, from moderate degrees of partial melting, little or no metasomatism is associated with these intrusions. The lack of significant crustal interaction, and the high calcium contents of these first-stage melts, makes them unlikely candidates for alkali porphyry copper-gold or radioactive mineralization.

1070 TO 1045 MA

Between 1070 and 1045 Ma, gravitational collapse of the orogen begins. This allows for localized extension along earlier developed shear zones, which most likely localizes the emplacement of the linear, medial, syenite and nepheline syenite intrusions (*see* Figure 12.3). The melting regime during this interval likely involves more interaction with the lower crust, and perhaps lesser degrees of partial melting, resulting in more quartz-undersaturated and fluid-rich (mix of aqueous and CO_2 fluids) magmas and increased metasomatism, generally proximal to the intrusions themselves. In the Brudenell subarea at least, the association of molybdenum and uranium-thorium mineralization with the medial syenite intrusions is suggestive of significant crustal interaction as well as an aqueous-dominated fluid (Richards 2010).

1045 TO 1030 MA

By 1045 and 1030 Ma, major tectonic activity in the orogen is coming to an end, and isostatic adjustment begins, although there may be localized movement along the CMBBTZ. The youngest syenites, accompanied by reactive late-stage fluids (likely more CO_2 and, locally, fluorine rich), are emplaced along the CMBBTZ and in its immediate hanging wall (*see* Figure 12.3). Differences in permeability, magma and fluid generation, and host-rock characteristics all likely influence where these late-stage magmas and their accompanying fluids rise into the upper crust.

IMPLICATIONS FOR EXPLORATION

The mineral potential of each subarea of the Late Syenite suite intrusive and associated metasomatic rocks is unique, resulting from the interplay of the host rocks with the syenites, the abundance and composition of the syenites themselves, and the composition and temperature of the accompanying metasomatic fluids. Thus, at the moment, it appears unlikely that it will be possible to construct a single, comprehensive exploration model for the entire belt of Late Syenite suite rocks from Minden to the Ottawa River. Each subarea has its own unique potential for various metallic and industrial minerals. Thus, an exploration approach that works in one area might not work in another.

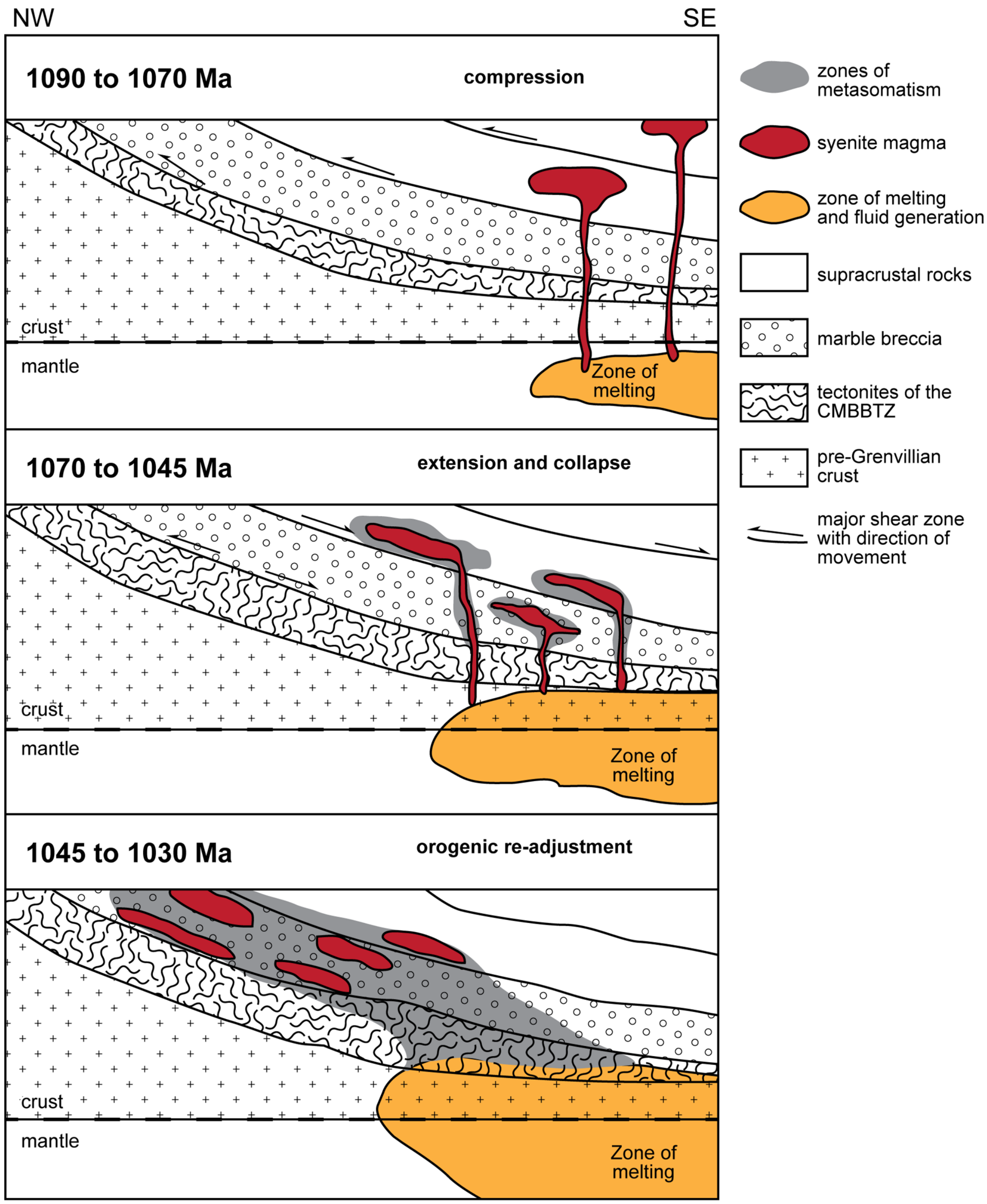

Figure 12.3. Cartoon cross sections from the Brudenell subarea illustrating the emplacement and evolution of the Late Syenite suite. Between **1090 and 1070 Ma**, the Grenville collision is in full force, resulting in northwestward thrusting along the Central Metasedimentary Belt boundary tectonic zone (CMBBTZ) and other major shear zones within the Central Metasedimentary Belt. At the same time, melting in the mantle begins southeast of the CMBBTZ, resulting in the emplacement of ovoid syenite intrusions with minimal metasomatism of their country rocks. Between **1070 and 1045 Ma**, gravitational collapse of the orogen begins. This allows for localized extension along earlier developed shear zones, which localizes the emplacement of linear syenite and nepheline syenite intrusions. The melting regime during this interval involves more interaction with the lower crust, and perhaps lesser degrees of partial melting, resulting in more fluid-rich magmas and increased, but localized, metasomatism. By **1045 to 1030 Ma**, major tectonic activity in the orogen ends and isostatic adjustment begins, although there may be localized movement along the CMBBTZ. The youngest syenites, accompanied by reactive late-stage fluids, are emplaced at this time along the CMBBTZ and in its immediate hanging wall.

Topics still under investigation include additional work on the geochemistry of the syenites in order to better assess their potential for copper-gold porphyry systems, alkali copper, as well as assessing the role and influence of fluid composition (aqueous versus CO_2 rich ± fluorine) with respect to mineral potential (cf. Richards 2010).

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