METALLOGENY OF GRANITOID ROCKS IN THE CANADIAN SHIELD

L. D. AYRES AND P. ČERNÝ
Department of Earth Sciences, University of Manitoba,
Winnipeg, Manitoba R3T 2N2

ABSTRACT

Granitoid rocks ranging in age from 1.0 to 3.76 Ga are the dominant component of the Canadian Shield but are variable in abundance, composition, mode and depth of emplacement, magma genesis, and degree of deformation among the seven structural provinces and within provinces. Most plutons are syntectonic, mesozonal diapirs, but the plutons vary in tectonic setting from pre- and sub-volcanic to late- or post-tectonic and epizonal. The oldest granitoid units, which are volumetrically minor, 2.8–3.76-Ga-old deformed and gneissic tonalite–granodiorite, are present in most structural provinces and probably formed a basement for Late Archean supracrustal sequences. In the Late Archean, 2.55–2.75 Ga, a major granite-producing event resulted in craton stabilization when large composite batholithic complexes ranging in composition from tonalite to granite (dominantly granodiorite) intruded volcanic–sedimentary supracrustal sequences; both trondhjemitic and calc-alkaline trends are present. Late Archean plutons are more abundant and generally more sodic in greenstone-belt subprovinces than in paragneiss subprovinces and were derived largely by anatexis of lower crust and mantle; upper crustal anatexis is rare, and is most common in paragneiss subprovinces. In the Churchill and Grenville provinces, most granitoid plutons, apparently Archean in age, were metamorphosed, deformed, remobilized and partly melted by Proterozoic orogenic events. Proterozoic granitoid plutons are not abundant except in areas of Proterozoic greenstone-belt volcanism. Proterozoic granitoid plutons in areas away from greenstone belts are generally more potassic than Archean plutons.

Mineral deposits are sparse in and adjacent to granitoid plutons but include porphyry Cu–Mo, nonporphyry Cu–Mo, vein and porphyry Au–Ag, U–Th in pegmatites and larger plutons and aureoles of Be–Li–Cs–Nb–Ta–REE-bearing pegmatites. Except for the pegmatites, the genetic relationship of mineralization and plutons and the nature of the parent plutons are poorly documented. Cu, Mo, Au and Ag deposits are concentrated in small sub-volcanic to epizonal, tonalite–granodiorite plutons in greenstone-belt terranes, particularly in the southern Superior Province. Cu and Mo appear to be genetically related to the host plutons, but for many Au–Ag deposits the plutons are favorable hosts but are apparently not genetically related to the mineralization. Syenitoid plutons appear to be an equally favorable host for Au–Ag deposits. Pegmatite deposits are widespread in the Superior, Slave, Churchill and Grenville provinces, but appear to be most abundant in paragneiss–granitoid terranes of the Superior Province. Churchill and Grenville provinces are characterized by U–Th-enriched anatectic pegmatites and by a relative paucity of pegmatites related to granitoid intrusions. In contrast, Be–Li–Cs–Ta-bearing pegmatite swarms, fractionated from late-tectonic silicic leucogranites, are abundant in the Superior and Slave provinces. Abnormally high concentrations of U–Th also occur dispersed in large and commonly pegmatitic granite plutons in the Superior, Churchill and Grenville provinces.

Keywords: Canadian Shield, granitoid plutons, metallogeny, porphyry deposits, pegmatites, Cu, Mo, Au, Ag, U, Th, Li, Rb, Cs, Be, Ta, Nb, REE.

SOMMAIRE

Les roches granitoïdes, mises en place il y a 1.0 à 3.76 milliards d'années, forment la partie dominante du bouclier Canadien. Ces roches varient en abondance, composition, mode et profondeur de mise en place, origine du magma et degré de déformation entre les sept provinces structurales, voire...
à l'intérieur d'une même province. Dans la plupart des cas, les plutons sont des diapirs syntectoniques mésozonaux, mais leur environnement varie de pré-tertié et subvolcanique à post-tectonique et épizonal. Les unités les plus anciennes occupent un volume restreint; ce sont des tonalites et granodiorites déformées, gneissiques, vieilles de 2.8 à 3.75 Ga, présentes dans la plupart des provinces structurales, où elles forment un socle pour les séquences supracrustales de l'Archën supérieur. À cette époque, entre 2.55 et 2.75 Ga, un important événement a produit quantité de plutons granitiques qui a stabilisé le craton. C'est alors que les vastes complexes batholitiques, tonalitiques à grani- tiques, mais surtout granodioritiques, ont été mis en place dans les séquences supracrustales volcanosédimentaires; on y trouve les deux lignées trondhjémitiques et calcéo-alcalines. Ces plutons sont plus abondants et généralement plus sodiques dans les ceintures de roches vertes que dans les domaines paragneissiques; ils doivent leur origine surtout à l'anatexie de la croûte inférieure et du manteau. L'anatexie de la croûte supérieure est un phénomène rare que l'on rencontre surtout dans les domaines paragneissiques. Dans les provinces du Churchill et du Grenville, la plupart des plutons granitoïdes sont apparemment d'un âge archéen; ils ont été métamorphisés, déformés, remodelisés et partiellement fondus lors d'événements orogéniques protérozoïques. Les plutons d'âge protérozoïque ne sont pas communs, sauf dans les secteurs de volcanisme protérozoïque du type "ceinture de roches vertes". Les plutons plus éloignés des ceintures de roches vertes sont généralement plus potassiques que les plutons archéens.


Mots-clés: bouclier Canadien, plutons granitiques, métallogénie, gisement du type porphyre, Cu, Mo, Ag, Au, U, Th, Li, Rb, Cs, Be, Ta, Nb, terres rares.

INTRODUCTION

Granitoid rocks of various compositions and types are the dominant component of the Pre cambrian Canadian Shield, but are largely terra incognita in terms of composition, magma genesis, emplacement mechanisms, structural setting and metallogeny. This paucity of data reflects a number of factors, including the vast size of the granitoid terrane, inaccessibility, lack of economic incentive because of lack of known mineral deposits and, until recently, an apparent lack of appreciation of the importance of granitoid rocks in modeling early crustal evolution.

Intensive investigations of large granitoid terranes have been undertaken only recently (e.g., Ayres 1974, Breaks et al. 1978, Davidson 1972b, Dimroth et al. 1973, 1974, Ermanovios et al. 1979, McCrank et al. 1981, Schwerdtner & Lumbers 1980, Schwerdtner et al. 1979) and interest in the granitoid terranes has been increasing markedly. Thus, the time is ripe for a review of the granitoid terrane and its potential for mineral exploration. Previous reviews have been given by various authors listed in Price & Douglas (1972) and by Stockwell et al. (1970). In any review of this magnitude, the data and conclusions are, of necessity, generalized, but there are always exceptions to the generalizations. We recognize that in petrogenetic or metallogenic modeling, the exceptions may be just as important as the general trends. Accordingly, where data permit, we have attempted to present both general trends and anomalies, particularly anomalies of regional significance. Unfortunately, lack of systematic field, petrographic, structural and geochemical data, except for localized areas, prohibits comprehensive treatment of the granitoid plutons. Discussion of various subjects and areas in this paper is uneven, but this is a reflection of the data base.

SETTING AND TERMINOLOGY

The Canadian Shield is the geological core of North America (Fig. 1). It has an outcrop area
of about 4,780,000 km², mainly in Canada, but it extends beneath the relatively flat-lying Phanerozoic strata of the Interior Plains of Canada and the United States, the Canadian Arctic, and the inliers of the Hudson Bay and Foxe basins. It also extends beneath the inner parts of the Appalachian, Cordilleran and Inuitian orogenic regions. Outliers of the Shield are exposed in tectonically uplifted areas within and on the margins of the orogenic regions.

The outcrop area of the Shield forms almost half of Canada. On the south, it extends for a limited distance into the United States in the Lake Superior and Adirondack regions. On the northeast, it is essentially contiguous with Precambrian rocks of the Greenland Shield. In this contribution, we will consider only the contiguous parts of the Canadian Shield that outcrop in Canada. Furthermore, we will restrict our discussion to intrusive magmatic units of alkali feldspar granite, granite, granodiorite, tonalite (including trondhjemite), quartz monzonite, quartz monzodiorite and quartz diorite composition [fields 2, 3, 4, 5, 8°, 9°, and 10° of Streckeisen (1976)]. These granitoid plutons range from fresh and undeformed to high-grade metamorphosed orthogneiss. We have excluded granitoid gneisses derived from probable sedimentary or uncertain protoliths, and the minor granitoid phases of largely mafic plutons. Time terminology is summarized in Figure 2.

Mineral resources are widespread and economically important in the Canadian Shield, but are confined largely to weakly or moderately metamorphosed volcanic and sedimentary sequences and mafic plutons. For example, most of the iron, nickel, gold, silver, uranium and platinum-group metals and a large proportion of the copper and zinc produced in Canada come from these shield rock-units. The are-
ally more abundant granitoid rocks, on the other hand, contain only sparse mineral deposits. Uranium, thorium, tantalum, cesium, lithium, beryllium, rare-earth elements, copper, molybdenum, gold and silver deposits have been documented, but most of these are currently uneconomic. The rarity of mineral deposits in granitoid rocks of the Canadian Shield in part reflects a genuine scarcity, but in part may reflect a low intensity of mineral exploration and research.

Mineral deposits associated with granitoid plutons are generally in or near small plutons rather than the vast granitoid batholithic complexes that are the dominant rock-unit in much of the Shield. Concentrations of some elements, particularly uranium, thorium, tantalum, cesium, niobium, lithium, beryllium and lanthanide elements, which are mainly in pegmatites, appear to be a direct result of the magmatic evolution of granitic systems. For copper, molybdenum, gold and silver, however, there is some uncertainty about mechanisms of concentration. The major question is whether the elements are derived from the granitoid magma and concentrated by crystallization processes or by postcrystallization redistribution, or whether the plutons are simply favorable hosts for concentrating elements scavenged from adjacent strata by circulating aqueous solutions. Granitoid plutons of certain types could also be a direct factor in concentration of elements that formed volcanogenic gold-silver, massive sulfide and iron deposits.

**Subdivisions of the Canadian Shield**

The Canadian part of the Shield has been
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Fig. 3. Subdivisions of the Canadian Shield.

The Canadian Shield is divided into seven structural provinces on the basis of contrasting structural trends, style of deformation and isotopic ages (Fig. 3, Table 1). The provinces were originally defined from structural trends (Wilson 1939, Gill 1949, Wilson 1949). This was subsequently augmented by recognition of several orogenies that affected different provinces more or less contemporaneously and that could be isotopically dated (Stockwell 1961, 1964). The provinces thus defined also show lithologic and metamorphic differences.

Most provinces are now known to be composite and to include several deformational events varying in intensity and widely spaced in time. Consequently, in several provinces, although various events can be dated, there is some controversy regarding the age of the deformational event that defines the province. In spite of this uncertainty, the provinces can be grouped into three broad age-categories. From oldest to youngest, these are (Table 1): Archean (Superior, Slave and Nain or Nutak), Early Proterozoic (Southern, Churchill and Bear) and Middle Proterozoic (Grenville).

Except for the Nain Province, the defining elements in each province are a series of broadly contemporaneous, interrelated events that were initiated by the deposition of thick volcanic and sedimentary sequences on sialic or oceanic basement, and that culminated with deformation, metamorphism and plutonism. The deformation, which was termed orogeny by Stockwell (1961, 1964), established the subparallel structural grain of the province and, in places, stabilized the province as part of the craton. The deformation intensity, metamorphic grade and amount of plutonism, as indicated by the present surface of erosion, are variable both within and between provinces; the deepest levels of
### Table 1. Summary of Major Rock Units, Events, and Granitoid Plutons in the Seven Structural Provinces of the Canadian Shield in Canada

<table>
<thead>
<tr>
<th>Province</th>
<th>Area (x10^6 km²)</th>
<th>Major lithologies</th>
<th>Relative abundance of granitoid plutons</th>
<th>Regional stratigraphic-plutonic-deformational events</th>
<th>Nature and composition of granitoid plutons</th>
<th>Regional structural trends</th>
<th>Metamorphic grade</th>
<th>Late events</th>
<th>Major references</th>
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<tr>
<td>Grenville</td>
<td>6.4</td>
<td>quartz-feldspathic gneiss of uncertain protoliths; paragneiss; metavolcanic-metasedimentary sequences; anorthosites; quartz monzonite-gabbro batholiths; nesquehonites; granitoid plutons</td>
<td>uncertain; probably 20-50%</td>
<td>3.0 Ga - tonalitic orthogneiss</td>
<td>north-easterly</td>
<td>green schist to granite facies</td>
<td>diabase dikes; alkalic and locally granitoid plutons; block faults</td>
<td>Wynne-Edwards (1972)</td>
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<td></td>
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<td></td>
<td>2.8-2.7 Ga - Superior Province basement; dominant rock unit in most of province</td>
<td>unknown</td>
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<td>1.6-2.8 Ga - Sedimentation and minor volcanism and granitoid plutonism of the Southern and Churchill Provinces. Deformed during Hudsonian Orogeny</td>
<td>granodiorite-quartz, monzonite dike swarms, sheets, stocks, and batholiths (1.5-1.7 Ga); includes an early pegmatite phase, now gneissic and recrystallized as a result of superimposed deformation and metamorphism</td>
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<td>1.1-1.5 Ga - Anorthosite-granite plutons, in part remobilized</td>
<td>quartz monzodiorite-quartz monzonite-granite forming separate stocks and batholiths as well as being associated with anorthosite; now largely gneissic and recrystallized as a result of superimposed deformation and amphibolite to granulate facies metamorphism.</td>
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<td>1.0-1.5 Ga - Volcanism and sedimentation of Grenville Supergroup; mafic, alkalic and granitoid plutonism, deformation of Grenville Orogeny (Stockwell et al., 1970) which affected all pre-existing rock units</td>
<td>early tectonic, in part subvolcanic, plagioclase to mesozonal, tonalite-granodiorite stocks and batholiths (1.25 Ga); syntectonic, catazonal granodiorite-granite stocks and batholiths (1.125 Ga); late tectonic granite-alkali feldspar granitoid-biotite syenite dikes, stocks and batholiths (1.0-1.2 Ga) that are locally peraluminous and pegmatitic facies</td>
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<td>1.1-1.4 Ga - Keweenawan volcanism, sedimentation, mafic and felsic plutonism, metamorphism, and tilting</td>
<td>syenite dikes, stocks, and irregular plutons, and composite gabro-granite plutons</td>
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<td>2.8-3.5 Ga - granitoid plutonism</td>
<td>as in Superior Province</td>
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<td>2.05-2.25 Ga - Superior Province basement</td>
<td>syenite dikes, stocks, and irregular plutons, and composite gabro-granite plutons</td>
<td>as in Superior Province</td>
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<td>2.0-3.6 Ga in the United States</td>
<td>as in Superior Province</td>
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<td>1.9-2.2 Ga - Huronian and Anikwite sedimentation, minor volcanism, mafic and granitoid plutonism, metamorphism, and deformation (Penokean Orogeny)</td>
<td>syenite dikes, stocks, and irregular plutons, and composite gabro-granite plutons</td>
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<td>1.6-1.75 Ga - granitoid plutonism, metamorphism and deformation (Hudsonian Orogeny of Stockwell 1961)</td>
<td>syenite dikes, stocks, and irregular plutons, and composite gabro-granite plutons</td>
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<td>1.1-1.4 Ga - Keweenawan volcanism, sedimentation, mafic and felsic plutonism, metamorphism, and tilting</td>
<td>syenite dikes, stocks, and irregular plutons, and composite gabro-granite plutons</td>
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<td>2.8-3.5 Ga - granitoid plutonism</td>
<td>poorly documented</td>
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<td>2.55-2.75 Ga - volcanism, sedimentation, deformation, metamorphism and granitoid plutonism of Kenoran Orogeny (extensive basement terrain)</td>
<td>poorly documented</td>
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<td>1.1-1.4 Ga - Keweenawan volcanism, sedimentation, mafic and felsic plutonism, metamorphism, and tilting</td>
<td>poorly documented</td>
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### Notes:
- The table summarizes the major rock units, events, and granitoid plutons in the seven structural provinces of the Canadian Shield.
- The provincial areas are given in millions of square kilometers.
- The major lithologies and their relative abundance are listed.
- The regional stratigraphic-plutonic-deformational events are described.
- The nature and composition of granitoid plutons are specified.
- The regional structural trends and metamorphic grade are noted.
- Late events and major references are provided.

### Reference:
### Table 1 (Continued)

**Churchill (Continued)**

- **1.7-2.4 Ga** - volcanism and sedimentation within intracratonic and craton-margin mobile belts of different ages. Deformation, metamorphism, remobilization of basement, and granitoid plutonism at several periods from 1.7-2.2 Ga culminating with Hudsonian Orogeny.
- Highly variable depending on location; includes subvolcanic dikes, sills, and stocks of tonalite-granodiorite-granite; syntectonic, optional to catazonal, simple to composite tonalite-granodiorite-granite dikes, sheets, mushroom-shaped plutons, and batholiths that are locally charnockitic; syntectonic anatexis of sills of tonalite-granodiorite; late tectonic, sills, stocks, and batholiths of tonalite-granodiorite-leucogranite; post-tectonic stocks of fluorite-bearing leucogranite that are in part related to post-orogenic volcanism.

**Bear**

- **1.3 Ga** - clastic and carbonate sediments and metamorphic sequences;
- **30-50% of Wopmay Orogen, absent elsewhere**
- **2.55-2.7 Ga** - volcanism, sedimentation, deformation, and metamorphism of Churchill Orogen.
- North-easterly in west and north; north-west-easterly in southeast.

**Superior**

- **13 Ga** - metasomatized greenstone belt sequences;
- **40-60% of Wopmay Orogen, absent elsewhere**
- **2.85-3.05 Ga** - mafic to felsic volcanism and tonalite plutonism.
- **2.55-2.75 Ga** - mafic to felsic volcanism and concomitant sedimentation; early deformation and metamorphism was an outgrowth of crustal loading by the volcanoes; late deformation and metamorphism associated with diapiric emplacement of large granitoid batholithic complexes (Kenoran Orogeny of Stockwell 1965).

**Slave**

- **1.9 Ga** - metasomatism and less abundant metasomatic sequences of Yellowknife Supergroup; mixed gneisses, migmatites, and granitoid gneisses derived from metasediments;
- **30-45% of Wopmay Orogen, absent elsewhere**
- **2.04-3.15 Ga** - tonalite-granodiorite-granite plutonism.
- **2.55-2.7 Ga** - mafic to felsic volcanism and concomitant sedimentation; deformation and metamorphism associated with and older than emplacement of granitoid batholiths (Kenoran Orogeny).
deformation are recorded in the Nain, Churchill and Grenville provinces, where multiply deformed basement terranes are exposed.

Older sedimentation, volcanism, plutonism and deformational events of varied extent are recognized in each province. In most provinces, these older events have been partly to largely obscured by the main orogenic pulse, but in the Churchill Province, there are extensive older volcanic–sedimentary sequences, such as the Archean Rankin–Ennadai belt of the Kaminak Subprovince, that have been affected only weakly by the younger Proterozoic events. Post-orogenic events include uplift, erosion, block faulting, emplacement of minor mafic and alkalic plutons, and development of localized sedimentary basins.

Boundaries between provinces vary from stratigraphic to deformational and metamorphic; some may be plate boundaries or sutures (Baragar & Scoates 1981, Dewey & Burke 1973, Gibb & Walcott 1971, Gibb & Thomas 1977, Irving et al. 1972). In most areas, province boundaries were probably originally stratigraphic, with sedimentary and volcanic units overlapping onto or overlying the cratonic areas of older provinces. Some of the younger provinces were apparently continental margins, whereas others were intracratonic. Subsequent deformation affected both the basement and cover rocks and, in many areas where deep erosion has stripped off the deformed cover rocks, the deformational and metamorphic boundary is entirely within the basement.

**Superior Province**

As presently exposed, this is the second largest (Fig. 3, Table 1) and one of the best documented provinces. It is characterized by metavolcanic–metasedimentary sequences that define greenstone belts, paragneiss sequences, granitoid batholithic complexes and heterogeneous granitoid gneiss and granulite terranes. The distribution of the major lithologies define thirteen generally east-trending subprovinces (Fig. 4) that differ in lithology, structural style, metamorphic grade, and abundance and nature of granitoid rocks, but are broadly equivalent in age. The oldest dated events are volcanism and plutonism at 2.85–3.05 Ga (Clark et al. 1981, Corfu et al. 1981, Goodwin 1977, Nunes & Thurston 1980, Nunes & Woods 1980), but these have been identified at only a few widely scattered localities. Most of the volcanism, plutonism, metamorphism and deformation took place in the interval 2.55–2.75 Ga (Goodwin 1977). Although systematic Rb–Sr whole rock and U–Pb zircon age-data have been obtained from only a few areas, most of the volcanism appears to be in the interval 2.7–2.75 Ga (Corfu at al. 1981, Davis et al. 1980, Nunes & Jensen...
1980, Nunes & Pyke 1980, Nunes & Thurston 1980, Nunes & Wood 1980), but plutonism spans the longer interval of 2.55–2.75 Ga (e.g., Birk 1979, Birk & McNutt 1981, Corfu et al. 1981, Davis et al. 1980, Gower & Clifford 1981, Krogh et al. 1976, Turek et al. 1981, Wooden 1978). The regional deformation event, which may not have been synchronous in all parts of the province, has been termed the Kenoran Orogeny (Gower & Clifford 1981, Stockwell 1961). Late events that range in age from Archean to Phanerozoic include intrusion of widespread swarms of diabase dykes of several ages, intrusion of mafic and alkalic stocks including numerous carbonatites, and formation of faults (Goodwin et al. 1972).

Plutons emplaced during the 2.85–3.05 Ga event are deformed and metamorphosed to amphibolite facies and are now orthogneiss of quartz diorite, tonalite and locally granodiorite composition (Breaks et al. 1978, Clark et al. 1981, Ermanovics 1981, Ermanovics et al. 1979, Harris & Goodwin 1976, Hillary & Ayres 1980, Verpaelst et al. 1980). They commonly form enclaves in 2.55–2.75 Ga plutons, and their original size and extent are unknown. Some of the plutons were exposed to erosion prior to and during the 2.7–2.75 Ga volcanism, but it is not known whether these plutons are remnants of an older, dismembered but originally extensive cratonic basement or localized cratonic islands, not all of which are necessarily identical in age (Clark et al. 1981). The reported ages of some plutons may date the time of metamorphism rather than emplacement. For example, in northern Quebec, Verpaelst et al. (1980), using $^{87}Sr/^{86}Sr$, have proposed that gneissic tonalite which has a Rb–Sr isochron age of 3.06 Ga was originally formed about 3.6 Ga. Similarly in northwestern Ontario, Hinton & Long (1979), using ion-microprobe U–Pb data from single grains of zircon, have concluded that zircon in gneissic tonalite, which Krogh et al. (1976) determined to be 3.04 ± 0.04 Ga, are actually 3.3 ± 0.1 Ga. These 3.3–3.6 Ga ages are comparable to the oldest granitoid units

Fig. 4. Major lithological units and subprovinces of the Superior Province (modified from Douglas 1969).
Fig. 5. a) Plot of normative quartz–albite–orthoclase for basement (2.85–3.05 Ga) plutons of the Sachigo (■ Hillary & Ayres 1980), Berens River (○ Ermanovics et al. 1979) and English River subprovinces (× Harris & Goodwin 1976, △ Clark et al. 1981). Trend lines after Barker & Arth 1976). b) Chondrite-normalized REE patterns for 2.85–3.05 Ga basement plutons of the western Superior Province. Lined area is the envelope of variation for six samples of high-\(\text{Al}_2\text{O}_3\) tonalite from the English River Subprovince (Chou 1978) and Sachigo Subprovince (Hillary & Ayres 1980). The two individual REE trends represent low-\(\text{Al}_2\text{O}_3\) tonalite from the English River Subprovince (Chou 1978).
reported from the Southern and Nain provinces (Table 1).

In the western Superior Province, the original plutonic origin of the orthogneiss can be determined from relict magmatic plagioclase (Clark et al. 1981, Hillary & Ayres 1980) and zircon textures (Harris & Goodwin 1976) and by preserved, discordant, intrusive relationships among phases (Clark et al. 1981), which show, in turn, that some of these older plutons were originally composite. Chemically, the older plutons are characterized by a high value of Na/K, which results in a trondhjemitic trend (Fig. 5a; cf. Barker & Arth 1976). Most samples have enriched light-REE and flat, slightly depleted heavy-REE patterns (Fig. 5b) that are similar to those of high-AlO$_2$ trondhjemites (cf. Arth & Barker 1976), except for the absence of a positive Eu anomaly. A few samples, however are similar to Arth's & Barker's (1976) low-AlO$_2$ trondhjemite with flat REE patterns, a negative Eu anomaly and enriched heavy REE (Fig. 5b). The REE patterns of the high-AlO$_2$ tonalite suggest that the magmas may have been derived by partial melting of an older amphibolite, which implies a still older crustal event (Hillary & Ayres 1980). The REE patterns of the low-AlO$_2$ tonalite, on the other hand, may be due to "metamorphic segregation of a low-temperature felsic component" (Chou 1978, p. 153).

The subprovinces can be broadly grouped into 3 categories: 1) greenstone–granodiorite (Sachigo, Uchi, Wabigoon, Wawa, Abitibi) (Fig. 4), 2) paragneiss–granitoid (English River, Queenston, Pontiac), and 3) a variable group that includes gneissic to massive granitoid and granulite terranes of both plutonic and supracrustal protoliths (Pikwitonei, Berens River, Kapuskasing, Opatica, Northern Quebec). Metallogenically, the greenstone–granodiorite subprovinces are the most important and are the best documented, but reported mineral deposits occur mainly in the greenstone belts.

In the greenstone–granodiorite subprovinces, the greenstone belts appear to be isoclinally folded, partly dismembered remnants of subaqueous to subaerial, basaltic to rhyolitic volcanoes. The volcanoes had flanking volcaniclastic sedimentary aprons and formed coalescing, east-trending linear chains of islands in the Archean ocean (Ayres 1978). They were apparently erupted on a submerged sialic to simatic crust that developed during the Lac Seul (Table 1; Goodwin 1977) and possibly younger events (using zircon, Nunes & Thurston 1980) have dated volcanism in the Uchi Subprovince at 2.96, 2.8 and 2.74 Ga. The meta-volcanic–metasedimentary sequences are best preserved in the Abitibi Subprovince (Fig. 4), where they are more than 35 km thick (Jensen 1978). Regional metamorphic grade varies from subgreenschist to amphibolite facies.

Metamorphosed, calc-alkaline, subvolcanic to epizonal stocks, dykes, sills, and sill complexes (Table 1) are a ubiquitous but areally minor component of most greenstone belts, particularly of the more felsic upper portions, but are important metallogenically. They vary in texture from porphyritic to locally equigranular and from aphanitic to medium grained. Their composition ranges from gabbro to granite, but most are leucocratic tonalite (trondhjemite) or granodiorite. Quartz-poor syenitoid plutons are common in some greenstone belts, particularly in the Abitibi Subprovince. These are not generally considered to be part of the granitoid suite but will be considered briefly in this contribution because of their spatial association with gold and silver deposits. Subvolcanic sills occur below many syngenetic stratiform Cu–Zn–Ag deposits, and are apparently genetically related to these deposits (Campiglio & Darling 1976, Franklin & Thorpe 1982).

Syntectonic and late tectonic plutons are the dominant component of these subprovinces (Table 1). They range in size from small stocks to immense batholithic complexes, but most are magmatically or mechanically emplaced diapirs (Fyson et al. 1978, Schwerdtner et al. 1979) that resulted in deformation and dismemberment of the volcanic–sedimentary sequences. The plutons are typically medium-grained, equigranular to porphyritic, locally zoned (e.g., Birk & McNutt 1981, Wollhuter 1973) mesozonal intrusions. In some plutons, microcline megacrysts apparently developed after emplacement by volatile autometasomatism (Birk et al. 1979). The larger plutons are commonly variable in composition and are composite, with individual phases forming sills, sheets, stocks, small batholiths, dyke swarms and crescentic plutons. They include early gneissic quartz diorite – tonalite – granodiorite phases and later, more massive and commonly more leucocratic tonalite – granodiorite – granite phases (Card 1979, 1982, Cimon 1979a, Ermanovics et al. 1976, Ermanovics & Davison 1976, Gower & Clifford 1981, Sage et al. 1975, Schwerdtner et al. 1979, Ziehlke 1975); pegmatite and aplite are ubiquitous late phases. Hornblende and biotite are the dominant mafic constituents; muscovite is present in the more leucocratic potassic phases but muscovite granite is rare. The fabric of the various phases resulted from a combination of
maggmatic, deformational and cooling processes (Ayres 1978, Schwerdtner et al. 1979, Schwerdtner & Lumbers 1980). In many areas much of the deformation appears to be related to emplacement of younger phases and diapiric rise rather than to later superimposed events, although Park (1981) has proposed major post-emplacement deformation. Gower & Clifford (1981) have observed isoclinal to tight folds in some of the early gneissic units and related this to a combination of regional deformation and emplacement of younger phases. Percival (1981) and Schwerdtner et al. (1979) have proposed that prior to diapirism, the early quartz diorite – tonalite – granodiorite phases were discontinuous, horizontal sheetlike bodies beneath volcanic – sedimentary sequences.

Except where bounded by greenstone belts, many of the batholithic complexes have poorly defined boundaries. Thus, the impression given by generalized maps such as Figure 4 is a large irregular granitoid terrane that has the form of a flat sheet, 10–20 km thick (surface to base of upper crust), interrupted by vertically dipping greenstone belts. However, emplacement of such a granitoid pluton as a single unit is difficult to envisage. Furthermore, detailed mapping has shown that the granitoid terranes are composed of numerous discrete plutons that have a considerable age range (e.g., McCrank et al. 1981, Schwerdtner et al. 1979), and that were emplaced by a series of magmatic pulses. Schwerdtner & Lumbers (1980) have suggested that such piecemeal emplacement occurred beneath a volcanic–sedimentary cover at some depth below the present level of the plutons. Subsequent diapiric rise of the batholithic complexes to their present structural level occurred in response to a ductility decrease between the gradually heating metavolcanic–metasedimentary roof rocks and the gradually cooling pluton (Schwerdtner & Lumbers 1980). Hillary & Ayres (1980) have documented such progressive heating of 2.91 Ga trondhjemite by piecemeal pluton emplacement.

Chemically the granitoid rocks are varied in composition from monzodiorite to granite. There is a general decrease in REE abundances with increasing SiO₂ content (Schwerdtner & Lumbers 1980). The most comprehensive geochemical study of granitoid rocks has been made in the western Wabigoon Subprovince (Birk 1979, Birk & McNutt 1981, Birk et al. 1979, Longstaffe & Peterman 1978, Longstaffe & Birk 1981, Longstaffe et al. 1980, Sutcliffe 1978). The work of Birk and coworkers was concentrated on a group of small, apparently coeval, late tectonic stocks within a greenstone belt; the stocks include both homogeneous and zoned types and range in composition from monzodiorite to granite. Oxygen- and strontium-isotope data for both the stocks and a nearby batholithic complex indicate that the granitoid magmas were derived from lower crust or upper mantle sources and not from supracrustal metasedimentary rocks (Birk 1979, Birk & McNutt 1981, Longstaffe & Birk 1981, Longstaffe et al. 1980). REE patterns are light-REE-enriched and commonly lack a Eu anomaly (Fig. 7; Birk et al. 1979); there is a general decrease in REE abundances with increasing SiO₂ content (Fig. 7). Birk et al. (1979) stressed that many Archean granites of the Superior Province lack a Eu anomaly, whereas post-Archean granites and Archean granites elsewhere commonly have a negative Eu anomaly of varying magnitude (cf. Condie 1981). The lack of a Eu anomaly has been related to high Ba and Sr contents, which prevent Eu depletion by plagioclase crystallization except in the last differentiates (Birk et al. 1979).

The paragneiss subprovinces appear to represent, at least in part, major linear sedimentary troughs that developed between the chains of volcanic islands of the greenstone subprovinces
PLAGIOCLASE  ORTHOCLOASE

QUARTZ

Trondhjemitic trend
Calc-alkaline trend

Fig. 6. a) Modal variations in part of the North Trout Lake batholithic complex of the Sachigo Subprovince, northwestern Ontario [mean data for each phase from Ayres (1974) and unpublished]. In this complex, 20 phases have been identified in a 200-km² area and are numbered from N-1 (oldest) to N-20 (youngest). Phases N-1 to N-3 represent 2.9 Ga basement, whereas the other phases were emplaced during the younger Kenoran Orogeny. b) Plot of normative quartz-albite-orthoclase for selected samples from various phases of the North Trout Lake batholithic complex (●), located on the north side of the 13-km-wide Favourable Lake greenstone belt, and the Setting Net Lake (○) and Bear Head Lake (△) batholithic complexes, on the south side of the greenstone belt [data from Ayres (1974) and unpublished]. The North Trout Lake and Setting Net Lake batholithic complexes are in the Sachigo Subprovince but the Bear Head Lake complex is in the Berens River Subprovince. The contact between the two subprovinces in this area is a fault. Trondhjemitic and calc-alkaline trends after Barker & Arth (1976).
(Ayres 1978). They are characterized by a lower abundance of granitoid plutons and a higher metamorphic grade, with the metasedimentary component and some of the early plutons metamorphosed to amphibolite and, locally, granulite facies. Although data are sparse, the granitoid rocks appear to have a somewhat more potassic bulk composition than granitoid rocks of the greenstone subprovinces (Ermanovics et al. 1979). Smith & Williams (1980) have further suggested that the granitoid rocks have a greater compositional range than granitoid rocks of the greenstone subprovinces, reflecting a more varied magma source, but their data-base is small and may not be representative.

The granitoid rocks comprise both in situ diatexite and a varied suite of plutons. The diatexite grades into migmatitic paragneiss and is mainly medium-grained to pegmatitic granite, but includes some granodiorite and tonalite (Breaks et al. 1978, Pirie & Mackasey 1978). The plutons are most abundant and best documented in the English River Subprovince, where they are commonly composite and variable both in composition and in fabric. They comprise 1) strongly recrystallized, pre- to syntectonic sills, stocks and composite batholiths of foliated, medium-grained, equigranular to porphyritic quartz diorite – tonalite – granodiorite; and 3) unrecrystallized, syn- to post-tectonic dyke swarms, sills, stocks and composite batholiths of massive, medium-grained to pegmatitic equigranular to porphyritic granodiorite – granite (Breaks et al. 1978, Ermanovics et al. 1979). In places, the gneissic suite is metasomatized and migmatized by injection of younger phases, local in situ anatexis and development of microcline porphyroblasts (Breaks et al. 1978, Ermanovics et al. 1979). It includes both 2.85–3.05 Ga basement (Clark et al. 1981, Harris & Good-
metamorphic evolution. This is exemplified by the English River Subprovince, where an early trondhjemitic trend is succeeded by a negative Eu anomaly trend.

Some trace element and REE data have been presented by Breaks et al. (1978), Chou (1978), Smith & Williams (1980), and Williams (1978), but the only systematic study is that of Černý et al. (1981), who examined granitoid rocks in and adjacent to the Opatica Subprovince. This greenstone belt is metallogenically important because of the presence of pegmatites; its geochemistry is discussed in more detail in the section on pegmatites. Unlike the granites of the Wabigoon greenstone-granodiorite Subprovince, many of the granites of the English River and Opatica subprovinces have a negative Eu anomaly (Černý et al. 1981, Chou 1978, Williams 1978). The Eu anomaly is most pronounced in silicic leucogranite with low Ba and Sr contents (cf. Figs. 31, 32; Goad & Černý 1981).

In the Pontiac Subprovince, a composite tonalite-granodiorite batholithic complex has been investigated by Dimroth et al. (1973, 1974). It appears to be different from those in the greenstone-granodiorite subprovinces and is described as a stockwork batholith that was emplaced by slow opening and expansion of fractures and their gradual filling by a multitude of dykes and sills.

The five granite and granulite subprovinces include a wide variety of lithologic units. They have been grouped together because existing reconnaissance mapping hampers more detailed subdivision and comparison. The Berens River and Opatica subprovinces are mainly mesozonal to catazonal, gneissic to massive, composite batholithic complexes that range in composition from quartz diorite to granite and, in part, are recrystallized and metasomatized (Ermanovics & Davison 1976). In the Berens River Subprovince, an early trondhjemitic trend is succeeded...
by a later calc-alkaline trend with potassium enrichment (Ermanovics et al. 1979). Rocks of the Pikwitonei and Kapuskasing subprovinces have been metamorphosed to the granulite facies. The Pikwitonei consists mainly of metatonalite and metagranodiorite plutons (Weber & Scoates 1978), whereas the Kapuskasing is mainly a metavolcanic-metasedimentary sequence (Thurston et al. 1977) with some gneissic and xenolithic tonalite (Percival 1981). Northern Quebec is an unsubdivided assemblage of metavolcanic, metasedimentary and granitoid rocks of amphibolite- and granulite-facies metamorphic grade (Eade 1966, Herd 1978, Stevenson 1968).

Lithophile trace elements have been determined for 63 composite samples of granitoid rocks collected from several subprovinces (Table 2; Mulligan 1980). In general, K/Rb, which ranges from 150 to 400, is higher and lithophile element abundances lower than in Canadian Phanerozoic granitoid rocks. The Li content of muscovite granite associated with lithium-bearing pegmatite is 5–10 times higher than the mean value (Mulligan 1973). There is a poor negative correlation between K/Rb and K and Li contents, but no correlation with Sn (Mulligan 1980).

**Slave Province**

Although smaller and less well documented than the Superior Province (Fig. 3), the Slave Province is lithologically similar and records the same deformational–pluton events, but with different structural trends (Table 1). However, unlike the Superior Province, the Archean units do not define distinctive subprovinces, the ratio of metasedimentary to metavolcanic rocks is much higher, granitoid plutons are less abundant, and granite-facies rocks are rare (Fig. 9, Table 1; McGlynn & Henderson 1972, Thompson 1978). In addition, the timing of emplacement of granitoid plutons relative to deformation and metamorphism, and the nature of emplacement may be different (Fyson & Frith 1979, Thompson 1978).

Tonalite–granodiorite and granite basement units with zircon and Rb–Sr ages between 2.94 and 3.15 Ga have been identified at several localities, but the extent and nature of these plutons are largely unknown (Frith et al. 1977a, Henderson & Easton 1977, Henderson 1981, Jenner et al. 1981, Krogh & Gibbins 1978, McGlynn & Henderson 1972). Frith & Roscoe (1980) have proposed that basement is associated with most of the greenstone belts, and Henderson (1981) has suggested that the late Archean volcanism and sedimentation were related to extensional faulting and graben development in a 2.94–3.15 Ga granitoid crust that originally underlay the Slave Province. Much of this basement has been destroyed by emplacement of late Archean plutons. In places, the preserved basement-units are much less deformed than comparable units in the Superior Province (Henderson & Easton 1977), but elsewhere they were affected by pre-Kenoran metamorphism and metasomatism (Fyson 1978). Massive to gneissic granite, which forms an undetermined amount of the basement (Henderson 1981, Jenner et al. 1981), is the most potassic early Archean basement unit described to date in the Canadian Shield.

Subvolcanic granitoid plutons are relatively rare and poorly documented. They are mainly dykes, sills and small irregular to lenticular stocks of porphyritic tonalite–granodiorite with an aphanitic to fine-grained groundmass (Bostock 1980, Henderson & Brown 1966, Moore 1956).

Early syntectonic to late-tectonic mesozonal batholiths are the dominant granitoid unit in the Slave Province; these mainly consist of medium-grained, equigranular to porphyritic plutons (Davidson 1972b, McGlynn & Henderson 1972). They range in composition and fabric from early gneissic to foliated to locally massive quartz diorite–tonalite–granodiorite to late massive to foliated granodiorite–granite and minor tonalite; pegmatite is a major constituent of many of the late muscovite-bearing granitoid plutons (Bostock 1980, Frith & Loveridge 1982, Frith et al. 1977a, 1977b, Green & Baadsgaard 1971, McGlynn & Henderson 1972). Early plutons tend to be concordant with regional structure and stratigraphy, whereas younger more potassic plutons are more discordant (Fyson 1981). Early syntectonic emplacement of the Keskarrah granodiorite batholith (2.642 ± 0.015 Ga) in the central part of the Slave Province is indicated by intrusion of the batholith into the lower part of the volcanic greenstone-belt sequence but incorporation of clasts derived from the unroofing of the batholith in later conglomerate of the greenstone belt (Bostock 1980). Associated with the batholiths are large

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**Table 2. Arithmetic mean values of lithophile trace elements in 63 composite granitoid samples from the Superior Province (Mulligan 1980)**

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>3.1 ppm</td>
</tr>
<tr>
<td>Rb</td>
<td>153 ppm</td>
</tr>
<tr>
<td>K/Rb</td>
<td>168 ppm</td>
</tr>
<tr>
<td>Li</td>
<td>22 ppm</td>
</tr>
<tr>
<td>Cs</td>
<td>5 ppm</td>
</tr>
<tr>
<td>Sn</td>
<td>3 ppm</td>
</tr>
<tr>
<td>Be</td>
<td>2.8 ppm</td>
</tr>
<tr>
<td>Mo</td>
<td>2.2 ppm</td>
</tr>
<tr>
<td>W</td>
<td>1.7 ppm</td>
</tr>
<tr>
<td>F</td>
<td>0.04 ppm</td>
</tr>
</tbody>
</table>
areas of "mixed gneisses, migmatites, and granitic gneisses that appear to be highly metamorphosed and granitized equivalents" of the metasedimentary sequence (McGlynn & Henderson 1972, p. 519).

There is some controversy about the mechanism of emplacement of the plutons. Drury (1977) and other authors have proposed that most plutons were diapirically emplaced during deformation of the supracrustal sequences and
were the cause of this deformation. Fyson (1978, 1980, 1981) and Fyson & Frith (1979), on the other hand, have proposed that plutons were emplaced at various times during the deformational history and were not the sole cause of the deformation. According to these authors, many plutons postdate the development of major folds, but pluton emplacement modified earlier folds. Using metamorphic and structural data, Frith (1978) and Thompson (1978) have argued also that pluton emplacement postdated the culminations of both metamorphism and deformation.

Drury (1979) has shown that syntectonic granodiorite plutons have lower abundances of REE, particularly heavy REE, than late-tectonic granite plutons, which also have a negative Eu anomaly (Fig. 10). Isotopically undated gneissic granites of possible basement origin have varied REE abundances, but REE patterns are in part similar to those in the late-tectonic massive to foliated granites (Fig. 10; Jenner et al. 1981). The difference in REE between the plutons has been interpreted to indicate different sources for the magmas, the basement (?) granite magma being derived by partial melting of an intermediate to felsic source, the granodiorite magma by partial melting of mafic units at mantle depths, and the granite magma by partial melting of metasedimentary rocks (Drury 1979, Jenner et al. 1981). Strontium-isotope data (Green & Baadsgaard 1971) also support a mantle derivation for some of the granitoid magmas. The negative Eu anomaly of the granites constitutes a distinction with the granites from the greenstone–granodiorite subprovinces of the Superior

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**Fig. 10.** Envelopes of variation of chondrite-normalized REE patterns for syntectonic granodiorite (gnd) and late-tectonic granite (gr) of the Slave Province (data from Drury 1979). The three individual REE trends are for samples of isotopically undated gneissic granite that may be basement to the greenstone-belt sequences (Jenner et al. 1981).
Province (Fig. 7).

Post-tectonic plutons include 1) the 2.15 Ga Blachford Lake Complex on the shore of Great Slave Lake adjacent to the East Arm Fold Belt of the Churchill Province (Fig. 3; Badham 1979, Davidson 1978, 1982), 2) several small, 1.9–2.9-Ga granodiorite stocks near the boundary with the younger Bear Province on the west, which are related to plutonic events within the Bear Province (Frith et al. 1977a) 3) five periods of emplacement of Proterozoic diabase dykes and sheets (McGlynn & Henderson 1972), and 4) a single alkalic stock. Of particular interest is the Blachford Lake Complex, a batholith that is partly peralkaline in character and contains Nb, Ta, Y, Th, U and REE mineralization (Davidson 1982). The intrusive sequence in the complex is early alkalic gabbro followed by ferrodiorite, quartz syenite, granite, peralkaline perthite granite and late peralkaline syenite; the peralkaline units form the bulk of the complex (Davidson 1978). Emplacement of the

Fig. 11. Major lithological units of the Nain Province [modified from Taylor (1972), Emslie (1978) and Ermanovics & Raudsepp (1979)].
complex was apparently related to early development stages of the adjacent East Arm Fold Belt (Davidson 1982).

In the northeastern part of the province, the Archean is covered by Early to Middle Proterozoic (Aphebian and Hellikian) clastic and carbonate sedimentary rocks of the Kilohigok Basin (Fig. 9; Campbell & Cecile 1981). This has been referred to as the Bathurst Subprovince (McGlynn & Henderson 1972, Stockwell et al. 1970), but it is not comparable to the subprovinces as defined in the Superior Province.

**Nain Province**

This is the smallest, most poorly documented, and possibly the most complex of the structural provinces (Fig. 3, Table 1; Collerson et al. 1976, Collerson & Bridgwater 1979, Taylor 1972, 1979). The Nain Province contains the oldest rock units identified to date in Canada (Wanless et al. 1979). Most of the province is Archean, but the Archean units range in age from greater than 3.76 to 2.5 Ga and have undergone at least five periods of Archean deformation, high-grade metamorphism and granitoid plutonism (Table 1; Baadsgaard et al. 1979, Collerson et al. 1976, Collerson & Bridgwater 1979). The youngest Archean deformational event was the Kenoran Orogeny (2.5–2.7 Ga). Early granitoid plutons are commonly metamorphosed to the granulite facies, in part retrograded to the amphibolite facies, and can be documented only by detailed mapping (Collerson & Bridgwater 1979, Collerson et al. 1976).

In much of the province, the various Archean rock units and events have not yet been deciphered.

To compound the problem, Early Proterozoic (Aphebian) volcanism, sedimentation, metamorphism, deformation, and granitoid plutonism has been superimposed locally on the Archean units. This culminated with the Hudsonian Orogeny (Fig. 2; Cameron et al. 1981, Stockwell 1961) at about 1.8 Ga. Early Proterozoic units are best developed in the southeastern part of the province and characterize the Makkovik Subprovince (Fig. 11; Taylor 1972). Granite plutons resulting from six distinct magmatic pulses and ranging in age from 1.6 to 1.8 Ga have been identified in this subprovince (Clark 1979). They range from syntectonic, recrystallized gneissic plutons to late, massive plutons.

Post-tectonic plutons elsewhere include 1) Proterozoic granite stocks ranging in age from 1.3 to 2.4 Ga (Barton 1977) and 2) Middle...
Proterozoic (Paleohelikian) anorthosite – quartz monzonite – granite batholiths and layered troctolite – syenite plutons that were emplaced in the central part of the province at 1.4 –1.5 Ga (Fig. 11; Emslie 1978a). The anorthosite – granite batholiths hamper correlation of older units.

The pre-3.6 Ga plutons (Uivak Gneisses) are the best documented of the Archean units (Collerson & Bridgwater 1979). These plutons consist of two suites separated in time by a major period of deformation and metamorphism. The earlier Uivak I suite ranges in composition from gabbro to granite but is mainly tonalite – granodiorite. It has a distinct trondhjemitic trend, with potassium enrichment in the more silicic members (Fig. 12). Collerson & Bridgwater (1979) considered the potassium enrichment to be a metasomatic event produced during the deformation, and related to emplacement of the Uivak II plutons. The Uivak I suite is somewhat similar in composition to the 2.85–3.05 Ga granitoid units of the Superior Province (cf. Figs. 5, 12). The younger Uivak II suite ranges in composition from tonalite to granite and has higher potassium, iron and magnesium contents than Uivak I units with equivalent silica contents. Uivak II plutons were originally, at least in part, porphyritic and now consist of augen gneiss.

The anorthosite – quartz monzonite – granite batholiths are part of an extensive chain of similar plutons that extends southwesterly across the Churchill and Grenville provinces. However, unlike most anorthosite – granite batholiths elsewhere, those in the Nain Province have not been subjected to later metamorphism and deformation, and the relationship between the anorthosite and granite can be determined (Emslie 1978a, b). The plutons are mesozonal and were emplaced at depths of 10–20 km (Berg 1977, Emslie 1978a). The batholiths are distinctly bimodal, with only rare diorite, tonalite and granodiorite. The granite and quartz monzonite form large discrete plutons (Fig. 11) that intruded the anorthosite, and differ from calc-alkaline granite – quartz monzonite plutons in the presence of fayalite, inverted pigeonite, highly exsolved clinopyroxene and mesoperthite, all of which indicate a water-under saturated and high-temperature magma, and the local presence of a rapakivi texture (Emslie 1978a, b). They also characteristically have lower SiO₂ contents, and are enriched in total iron relative to MgO, and in total alkalis relative to CaO, compared to calc-alkaline granitoid suites (Emslie 1978b). Phases with low quartz content, such as quartz monzonite and quartz monzodiorite, commonly predominate over granite, and the granitoid suite is commonly referred to as mangerite and quartz mangerite. At the south end of the Nain Complex (55°30’–56°N, Fig. 11), the granite – quartz monzonite has been intruded by stocks of equigranular to locally porphyritic peralkaline granite containing arfvedsonite–riebeckite (Hill 1980).

Although the precise genesis is controversial (Emslie 1978a, b), the anorthosite and granite – quartz monzonite appear to be genetically related but not necessarily comagmatic. Emslie (1978b) has proposed that rising, mantle-derived aluminous gabbroic magma, which formed the anorthosite by fractionation, caused partial melting of crustal rocks to produce the granite – quartz monzonite.

Southern Province

This province (Fig. 3) is mainly a variably deformed and metamorphosed, southward thickening. Early Proterozoic (Aphebian) clastic sedimentary and minor volcanic sequence that unconformably overlies the south part of the Superior Province in Ontario and adjacent parts of the United States. The Southern Province coincides with a major suture in the underlying Archean basement: to the north is a typical 2.55–2.75-Ga greenstone–granodiorite terrane of the Superior Province, but to the south, a 2.8–3.5-Ga gneissic terrane predominates (Sims et al. 1980); the gneissic units outcrop only in the United States. Rock units range in age from <1.9 to >2.2 Ga (Card et al. 1972). The youngest sedimentary units cannot be dated precisely; for example, an Rb–Sr age of 1.556±0.064 Ga for the uppermost formation is a minimum age reflecting diagenetic re-equilibration of Sr isotopes (Franklin et al. 1978). Several distinct deformational pulses (1.6–2.2 Ga) produced structures ranging from isoclinal to broad open folds (Table 1). In Canada, the sedimentary sequence is as much as 5 km thick and becomes younger and less deformed and metamorphosed westward (Card et al. 1972). However, when the entire Southern Province, in both Canada and the United States, is considered, there is no lateral change in intensity of deformation or metamorphism.

In the Lake Superior Basin, the Middle Proterozoic (Helikian) Keweenawan sequence unconformably overlies the northern boundary between the Early Proterozoic sequence and the Superior Province basement. The Keweenawan sequence ranges in age from 1.1 to 1.4 Ga and
comprises up to 15 km of flood basalt, rhyolite flows and clastic sedimentary units.

Pre- to post-tectonic gabbro dykes and sills are widespread and range in age from 1.1 to 2.15 Ga (Card et al. 1972, 1978). Some of the sills contain late-stage granophyric layers. The Sudbury Ignite (1.85 Ga, Fig. 13) has a 1-1.5 km thick upper layer of granophyric granite (micropegmatite). This layer was injected into its present position late in the fractionation history of the original gabbroic magma, possibly as a result of subsidence of a central uplift produced by meteorite impact (Pẻredery & Naldrett 1975).

Granitoid plutons are rare in the Canadian portion of the Southern Province (Fig. 13), but are relatively abundant in a volcanic-plutonic terrane south of the sedimentary wedge in Wisconsin (van Schmus 1976). In Canada the plutons are variable in age and level of emplacement, and comprise 1) 2.2-Ga mesozonal, syntectonic, composite granodiorite - granite stocks (Dutch 1979), 2) 1.6-1.75-Ga syntectonic, epizonal to mesozonal, composite tonalite - granodiorite - granite batholiths (Cannon 1970, Lammers 1975a), 3) a 1.47-Ga, post-tectonic, epizonal, gabbro - quartz monzodiorite - granite stock, and 4) 1.1-Ga subvolcanic granite plutons (Card et al. 1972).

The syntectonic plutons were emplaced at different crustal levels (epizone to deep mesozone) during two distinct pulses of deformation. In texture, they are medium grained and equigranular to porphyritic, with porphyritic varieties predominating. Pegmatite is rare except in the westernmost pluton (Fig. 13), which was emplaced passively into deep mesozonal metasediments by segregation of anatectic magma during deformation (Cannon 1970). Other plutons were forcefully emplaced, possibly as diapirs remobilized from the Archean (Superior Province) basement (Dutch 1979).

The 1.1-Ga subvolcanic granite plutons are restricted to the Keweenawan volcanic sequence of the Lake Superior area. They are commonly porphyritic, with aphanitic to fine-grained groundmasses, but locally consist of aphyric felsite or granophyre (Annells 1974). They form dykes, sills, irregular plutons and composite gabbro - granite stocks (Giguère 1975), all of which are intimately related to rhyolite volcanism.

**Churchill Province**

This is the largest (Fig. 3, Table 1), but the most poorly understood of the structural provinces. The restricted geological data-base is a
function of the large size of the province, the
deformational nature of much of the mapping,
inaccessibility except by aircraft, Arctic climate,
and the paucity of exploitable mineral deposits in much
of the province, generally high to medium meta-
rorphic grade, and superposition of several
major deformational, metamorphic and plutonic
events (Table 1). The province is characterized
by both intracratonic and possible craton-mar-
gin, Early Proterozoic (Aphebian) mobile belts.
Several different mobile belts are present and
apparently developed at different times during the Early Proterozoic (Davidson 1972a).
The intracratonic mobile belts comprise linear, in
part disrupted, metavolcanic – metasedimentary
sequences that were deposited on Archean sialic crust similar to that now exposed in the Su-
perior and Slave provinces. This basement was
defomed and metamorphosed during the Hud-
sonian Orogeny (1.7–1.8 Ga, Table 1), and in
much of the province the basement has been
exhumed by deep erosion. In many areas, the
amphibolite- and granulite-facies metamorphic
grade hampers the distinction between Archean
and Early Proterozoic rock-units and events (Fig. 14). Possible craton-margin metavolcanic-
metasedimentary sequences are less deformed
and metamorphosed, and rock-units and events
can be more readily deciphered (Baragar & Scoates 1981). They also contain most of the
known mineral deposits. Middle Proterozoic
(Paleohelikian) undeformed sedimentary and
volcanic sequences accumulated in two intrac-
ratonic basins (Fig. 14).

The boundaries between the Churchill and
the older Nain, Superior and Slave provinces
range from depositional to tectonic-metamor-
phic. The position of the boundary with the Nain Province in the east is controversial
(Douglas 1972, Taylor 1971), but appears to be
a fault (Taylor 1972) that probably represents
late adjustment between two crustal blocks. The
main boundary marker is the eastern limit of
Early Proterozoic sedimentation, deformation
and metamorphism.

The Churchill–Superior boundary is partly
obscured by Phanerozoic deposits of the Hudson
Bay Basin. On the east, in northern Quebec, the
boundary is depositional with metasedimentary-
metavolcanic strata of the Circum-Ungava Geo-
syncline (subprovince 7, Fig. 14) unconform-
ably overlying Archean basement of the Su-
perior Province (Dimroth et al. 1970, Dimroth &
Dressler 1978). The depositional contact has
been modified by Hudsonian deformation and
metamorphism, the outer limit of which is now,
at least in part, within the Superior Province
basement (Brooks 1980, Dimroth & Dressler
1978).

On the west in northern Manitoba, an early
defformational boundary is in part overlapped by younger metavolcanic-metasedimentary strata
(Weber & Scoates 1978). The fault separates
Early Proterozoic strata on the northwest
(Southeastern Zone Subprovince; 14 on Fig. 14)
from Archean basement on the southeast, but the southeastern limit of Early Proterozoic,
1.7–1.8-Ga Hudsonian deformation and meta-
morphism extends eastward beyond this faulted
boundary (Weber & Scoates 1978). In the north-
est, adjacent to the Phanerozoic cover of the
Hudson Bay Basin, the fault boundary is uncon-
formably overlain by the 1.7-Ga metavol-
canic-metasedimentary sequence of the Fox
River Belt (15 on Fig. 14). The Fox River
sequence postdates the main Hudsonian de-
formation in this area but is itself deformed,
possibly by late Hudsonian events. Variable
ages of Hudsonian deformation are character-
istic of the Churchill Province elsewhere; the
province apparently evolved by a series of de-
positional and orogenic events that culminated
at different times in different places (Davidson
1972a, Jackson & Morgan 1978). Gibb & Wal-
cott (1971) and Baragar & Scoates (1981) have
proposed that the Churchill–Superior boundary
represents a fossil plate-boundary.

In most places, the Slave–Churchill boundary
is a zone 5–10 km wide termed the Thelon
Front, in which Archean rocks of the Slave
Province become increasingly deformed and
metamorphosed (Davidson 1972a). Major faults
are common along the boundary and, in places,
they mark an abrupt change in intensity of de-
formation. This boundary was originally thought
to be the result of Hudsonian events. However,
recent work by Henderson et al. (1982) along
the boundary between the Slave Province and
the Queen Maud Block (1 on Fig. 14) of the
Churchill Province has shown that the rapid
eastward increase in metamorphic grade, from
greenschist to granulite facies, and change in
structures, from curvilinear on the west to con-
sistently northerly on the east, are the result
of Archean events. Superimposed on this are
Early Proterozoic cataclastic zones and inter-
mediate-pressure metamorphism. The best de-
finite of these cataclastic zones may be the prov-
ince boundary (Henderson et al. 1982).

Gibb & Thomas (1977) have suggested that
the Thelon Front may be a cryptic suture pro-
duced by Early Proterozoic collision of two
Archean crustal blocks. Lewry & Sibbald (1980)
have questioned the suture interpretation. They
proposed instead that the Western Craton Subprovince of the Churchill Province (11 on Fig. 14) is a continuation of the Slave Province craton. They further suggested that the major tectonic boundary lies well within the Churchill Province and is the junction of the Western Craton and Cree Lake Zone subprovinces (11 and 12 on Fig. 14; Lewry & Sibbald 1980).

In the south, the Slave and Churchill provinces are separated by the fault-bounded East Arm Fold Belt (10 and Fig. 14), which contains a weakly deformed unmetamorphosed, Early Proterozoic sedimentary sequence. This is probably an aulacogen related to the development of the Coronation geosyncline of the Bear Province to the west (Fraser et al. 1972, Hoffman 1973).

The Churchill Province has been partly divided into subprovinces (Fig. 14) that have been variously termed fold belts, zones, domains, blocks, tectonic belts, geosynclines and other names (Davidson 1972a, Godfrey & Langenberg 1978, Heywood & Schau 1978, Jackson & Taylor 1972, Lewry & Sibbald 1977, 1980, Lewry et al. 1978, 1981, M.M.R.D. 1979, Schledewitz 1978, Stockwell et al. 1970). The nomenclature and boundaries are still somewhat controversial, and names used herein (Fig. 14) generally reflect most recent usage. The subprovinces can be broadly grouped into five categories: 1) Archean greenstone - granodiorite terrane that has not been greatly modified by Hudsonian deformation (Kaminak, Committee Bay Block, Committee Fold Belt), 2) Archean gneiss and plutonic terrane that was variably reworked and remetamorphosed during the Hudsonian Orogeny (Queen Maud Block, Armit Lake Block, Western Craton, Ennadai Fold Belt (?); note that many of these subprovinces are as yet unnamed), 3) intracratonic (ensialic), Early Proterozoic mobile belts (East Arm Fold Belt, Foxe Fold Belt, Dorset Fold Belt, Cree Lake Zone), 4) possible craton-margin, Early Proterozoic mobile belts (Southeastern Zone, Fox River Belt, Circum-Ungava Geosyncline), and 5) Early Proterozoic granitoid plutons (Rottenstone-Chipewyan). Granitoid plutons differ in nature and abundance from subprovince to subprovince.

Granitoid, quartzofeldspathic and migmatitic gneisses of tonalite - granodiorite composition dated at 2.8-3.48 Ga by Rb-Sr isochron and zircon U-Pb methods (Cranstone & Turek 1976, Wanless 1979) have been found in several subprovinces. However, because of multiple deformation, the extent of gneisses in this age range and the nature of their protoliths are unknown. As in the Archean structural provinces (Table 1), the gneisses are probably base-ment to volcanic and sedimentary rocks formed during the main period of Archean volcanism and sedimentation (2.65-2.75 Ga; Wanless 1979).

Archean (2.55-2.75 Ga) metasedimentary and metavolcanic rocks and granitoid plutons that were lithologically similar to those in the adjacent Superior and Slave provinces may be the dominant rock-units in the Churchill Province. Some Archean units, such as the greenstone belt and associated granitoid plutons of the Kaminak Subprovince (8 on Fig. 14) and locally the Committee Bay Block (2 on Fig. 14), are well preserved (Ridler & Shilts 1974, Schau 1977). However, most of the Archean units have been affected by Early Proterozoic deformation and amphibolite- to granulite-facies metamorphism; the extent of the Archean terrane and of various lithologic units within this terrane are generally poorly defined, particularly in the Northwest Territories (Fig. 14). Numerous K-Ar ages have been obtained from the Churchill Province, but most of these date the Early Proterozoic Hudsonian deformation. The true extent of the Archean terrane is being realized only now as mapping progresses and as Rb-Sr isochron and U-Pb zircon ages become more abundant.

Greenschist-facies Archean units are exten-sively preserved in the Kaminak greenstone belt, which is the second largest known Archean greenstone belt in the Canadian Shield (Ridler & Shilts 1974). In the Kaminak belt, granitoid plutons comprise 1) porphyritic to equigranular, aphanitic to fine-grained, subvolcanic dykes, sills and irregular plutons (Davidson 1970b, 1972a, Eade 1974, Ridler & Shilts 1974); their compositions are unspecified but are probably tonalite - granodiorite - granite, and 2) epizonal to mesozonal, syntectonic to late tectonic, composite stocks and small batholiths within and on the margins of the belt; these are commonly medium-grained, equigranular to porphyritic, massive to gneissic, tonalite - granodiorite - granite plutons with minor gabbro and diorite phases (Davidson 1970a, b, c, 1972a). The general temporal sequence in the plutons is tonalite, followed successively by granodiorite and granite, but this sequence may be repeated in cyclic fashion (Davidson 1972a). The youngest phases are always the most potassic. Some plutons consist of an older gneissic granodiorite - granite unit, in part derived from supracrustal sequences, and younger massive granodiorite - granite phases (Eade 1974). Toward the margins of the Kaminak Subprovince, the Archean granitoid rocks become recrystallized, with development of a gneissic structure and a decrease in grain
size (Davidson 1970a).

Reworked Archean granitoid rocks appear to be the dominant component of the gneiss sub-provinces (Queen Maud Block, Armit Lake Block, Western Craton, Ennadai Fold Belt, and other unnamed areas), and a major and, in places, dominant component of three of the intracratonic mobile belts (Foxe Fold Belt, Dorset Fold Belt, Cree Lake Zone) (Eade 1978, Fraser 1978, Godfrey & Langenberg 1978, Jackson & Morgan 1978, Lecheminant et al. 1981, Lewry & Sibbald 1980). The reworking is generally assumed to be the result of Early Proterozoic Hudsonian deformation, but in some of the gneiss subprovinces, such as the Western Craton (11 on Fig. 14), where Early Proterozoic supracrustal sequences are rare, the deformation may be largely Archean (Lewry & Sibbald 1980). Based on the work of Henderson et al. (1982), a similar conclusion may apply to parts of the Queen Maud Block (1 on Fig. 14). The reworked Archean granitoid plutons vary in structure from massive to gneissic (Lewry & Sibbald 1980), but also include cataclastic, augen and metasomatic phases (Eade 1973, Lewry & Sibbald 1977, Money et al. 1970) and local anatectic pegmatite (Jackson & Morgan 1978, Tippett 1979). Lewry & Sibbald (1980) have speculated that the structural differences may be due either to age differences between the plutons (syntectonic Kenoran versus late-tectonic Kenoran; see also Ray & Wanless 1980) or to differences in the intensity of the Proterozoic Hudsonian deformation. The reworked plutons range from homogeneous to inhomogeneous on a large scale (Lewry & Sibbald 1980), and range in composition from gabbro to granite, but are dominantly tonalite–granodiorite–granite–quartz monzonite (Fig. 15; Davidson 1972a, Lewry & Sibbald 1980). In places, the plutons are hypersthene-bearing (charnockitic) because of superimposed granulite-facies metamorphism; these have been locally retrograded to the amphibolite facies (Godfrey & Langenberg 1978, Lewry & Sibbald 1977, 1980, Schledewitz 1978, Weber et al. 1975a). The charnockitic units have a more potassic bulk-composition than amphibolite-facies plutons and represent mesozonal to catazonal plutons (Davidson 1972a). In the Cree Lake Zone (12 on Fig. 14), the charnockitic rocks are intruded by hypersthene-free, foliated granite plutons (Weber et al. 1975b). In the intracratonic or ensialic mobile belts of the Foxe Fold Belt, Dorset Fold Belt and Cree Lake Zone subprovinces (4, 6 and 12 on Fig. 14), remobilized, metamorphosed plutons of the Archean basement form intrusions, gneiss domes

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Fig. 15. Modal composition of Archean basement (○), late-tectonic (△) and post-tectonic Nueiltin Lake (●) granitoid plutons from the southwestern part of the Churchill Province (after Eade & Flint 1973, Money et al. 1970).

Proterozoic granitoid plutons are present in all subprovinces but, in many areas, they have not yet been distinguished from the Archean plutons (Fig. 14); in the various subprovinces the Proterozoic plutons range in abundance from a minor to the dominant component. In the Early Proterozoic strata of the East Arm Fold Belt (10 on Fig. 14), granitoid rocks are restricted to quartz monzodiorite phases of calc-alkaline diorite to quartz monzodiorite laccoliths up to 25 km long (Badham 1978, Hoffman et al. 1977).

Proterozoic syntectonic to post-tectonic granitoid plutons are present in both the intracratonic and the gneiss subprovinces. The syntectonic plutons are highly variable, with their habits and compositions in part reflecting their depth of emplacement. On Baffin Island, 1.9-Ga dykes, sheets, mushroom-shaped plutons and irregular plutons of massive granite, both hypersthene-bearing (charnockitic) and hypersthene-free, are present in granulite-facies country rocks (Jackson & Morgan 1978, Pidgeon & Howie 1975). High initial $^{87}Sr/^{86}Sr$ ratios indicate that the plutons were probably derived by partial melting of Archean basement (Jackson & Morgan 1978). In the Cree Lake Zone of Saskatchewan (12 on Fig. 14), in situ anatexis produced extensive migmatites in the central Mudjatik domain, but in the eastern Wollaston domain, where deformation style was different, the anatectic melts were segregated and mobilized to form several generations of massive to weakly foliated, semiautochthonous to allochthonous granodiorite–quartz monzonite–granite plutons (Lewry & Sibbald 1980, Lewry et al. 1981). The junctions between major crustal elements of the Cree Lake Zone, which are marked by major shear zones, were the loci for emplacement of late syntectonic plutons (Lewry & Sibbald 1980, Ray & Wanless 1980); these plutons are generally characterized by the presence of coarse-grained Kfeldspar megacrysts. In the Queen Maud Block (1 on Fig. 14), a megacrystic granite characterized by mesoperthite and minor hypersthene was emplaced into Archean gneisses as a large diapir; the mineral assemblage and structures suggest emplacement at relatively high crustal levels under hot, dry conditions (Bostock 1981).

Elsewhere in the Churchill Province, syntectonic plutons comprise variably deformed stocks and batholiths that range in age from 1.77 to 1.94 Ga (Wanless & Eade 1975, Weber et al. 1975a). They range from massive to gneissic rocks, in part augen gneiss, and include medium- to coarse-grained granodiorite and granite. Some plutons are composite and zoned (Wanless & Eade 1975). In the Armit Lake Block (5 on Fig. 14), deformed Proterozoic plutons that were intruded into Archean tonalite–granodiorite orthogneisses can be distinguished from the Archean plutons by their more potassic composition and lower degree of deformation (Lecheminant et al. 1981).

Late-tectonic plutons include widespread granodiorite–granite–pegmatite sills and dykes on Baffin Island (Jackson et al. 1975, Jackson & Morgan 1978), and massive, medium- to coarse-grained, equigranular to porphyritic, quartz diorite–tonalite–granodiorite–granite stocks and batholiths in the western Churchill Province (Fig. 15; Money et al. 1970, Weber et al. 1975a). As stressed by many authors (e.g., Davidson 1972a, Eade 1978, Jackson & Morgan 1978), the timing of deformation varied from place to place, and syntectonic plutons in one part of the Churchill Province may be the same age as late-tectonic or post-tectonic plutons elsewhere.

Post-tectonic granitoid plutons include the 1.7-Ga Nueltin Lake plutons in the western part of the province (Wanless & Eade 1975) and the granitoid phases of the 1.4–1.5-Ga anorthosite–quartz monzonite–granite batholiths, some of which have rapakivi texture, in the southeast corner of the province (Fig. 14; Emslie 1978a, Emslie et al. 1980). The Nueltin Lake plutons were originally defined in the northern part of the Cree Lake Zone (12 on Fig. 14; Wright 1967), but similar plutons have been found in the Armit Lake Block, Ennadai Fold Belt and Western Craton subprovinces (5, 9, and 11 on Fig. 14; Lecheminant et al. 1979a, b, 1980, 1981, Tella et al. 1981, Wright 1967). These plutons form a distinctive suite of medium- to coarse-grained, generally porphyritic, massive, fluorite-bearing leucocratic granite, quartz syenite, and alkali-feldspar granite and syenite stocks and batholiths (Eade & Flint 1973). Near the common boundary of the Armit Lake Block, Ennadai Fold Belt and Western Craton subprovinces (14), many of the plutons are hypabyssal with miarolitic cavities, a well-developed chilled margin, and a granophyric to fine-grained groundmass (Lecheminant et al. 1979a, b, 1980, 1981, Tella et al. 1981); the rapakivi texture is present in several plutons (Lecheminant et al. 1980, 1981). These hypabyssal plutons are apparently the intrusive equivalent of rhyolites of the Pitz Formation at the top of the post-
orogenic Dubawnt Group (Lecheminant et al. 1980, 1981). The Nueltin Lake and similar plutons are the most potassic plutons in the Churchill Province (Fig. 15).

The possible craton-margin mobile belts (Southeastern Zone, Fox River Belt, Circum-Ungava Geosyncline; 14, 15 and 7 on Fig. 14) have sedimentary and volcanic facies suggestive of craton-margin deposition (Baragar & Scoates 1981), but are bounded on both sides by Archean sialic terrane. These belts have been interpreted to represent either deposition and deformation on the margin of an Archean craton, with subsequent juxtaposition of Archean terrane on the opposite side of the belt (Lewry & Sibbald 1980, Ray & Wanless 1980), or fracturing and rifting of a larger Archean craton producing narrow seaways (Baragar & Scoates 1981). Granitoid plutons are rare in the Circum-Ungava Geosyncline (Dimroth et al. 1970), except in the eastward extension of the geosynclinal units, where metamorphic grade is high (Taylor 1979), and in the Fox River Subprovince, but are common in the Southeastern Zone Subprovince (Fig. 14). The Southeastern Zone consists of two east-trending Early Proterozoic greenstone belts that are separated by the Kisseynew sedimentary basin. As in the Superior Province, the greenstone belts appear to represent deformed chains of volcanic islands that provided clastic detritus to the intervening basin (Bailes & McRitchie 1978). Archean basement has been reported only rarely (Coleman 1970, Lewry et al. 1981), but includes both greenstone and granitoid components. In the greenstone belts, where metamorphic grade is generally green schist facies, granitoid plutons, which are the major if not the dominant component, include 1) texturally variable subvolcanic dykes, sills, sill complexes and stocks of tonalite – granodiorite – granite; textures range from aphanitic to medium-grained, and porphyritic to equigranular; some of the plutons are simple or zoned, whereas others are composite (e.g., Baldwin 1980, Černý et al. 1981, Chute & Ayres 1977), and 2) pre- to post-tectonic, composite, epizonal to mesozonal tonalite – granodiorite – granite stocks and batholiths, many of which were diapirically emplaced (Bailes 1971, Lewry et al. 1978). The pre- to post-tectonic plutons comprise two distinct groups: 2a) pre-tectonic to early syntectonic plutons (in part gneissic), in which the emplacement sequence is generally early quartz diorite – tonalite followed by granodiorite, and leuco-granodiorite – aplite, and 2b) late syntectonic to post-tectonic, massive to foliated, equigranular to locally porphyritic quartz monzonite – granodiorite – granite (Bailes 1971, Lewry et al. 1978, 1981). Late pegmatitic granite and pegmatite plutons are locally abundant (Černý et al. 1981). In the amphibolite-facies sedimentary basin, granitoid plutons are less abundant and are mainly tonalite – granodiorite sills and sheeted sill and dyke complexes that were formed by anatexis of the greywacke–shale metasedimentary sequence (Bailes & McRitchie 1978). The products of anatexis range from thin, in situ concordant segregations to large remobilized gneissic plutons (Bailes & McRitchie 1978, Lewry et al. 1978).

The Rottenstone-Chipewyan Subprovince (13 on Fig. 14) is a granitoid batholithic complex ranging in composition from diorite to granite. It comprises syntectonic gneissic diorite – tonalite – granodiorite and associated migmatites, intruded by late- to post-tectonic quartz monzonite – granite plutons (Lewry et al. 1978, 1981, Schledewitz 1978). Some of the older plutons are the result of anatexis of supracrustal units, but most of the plutons had a deeper source (Lewry et al. 1981). Lewry et al. (1981) stressed that plutons in the subprovince and adjacent parts of the Cree Lake Zone to the west are dominantly granodiorite – quartz monzonite – granite, and are thus more potassic than plutons in the Southeastern Zone to the east, where tonalite is abundant. A large part of the Rottenstone-Chipewyan Subprovince is a late syntectonic batholith, the Wathaman-Chipewyan batholith, that is at least 50 km wide and has a lateral extent of more than 800 km. The batholith has limited compositional variation (granodiorite – quartz monzonite – granite), an average composition of monzogranite, and 10-30% K-feldspar megacrysts up to 9 cm long (Lewry et al. 1981, Ray & Wanless 1980). Ray & Wanless (1980) suggested that the Wathaman-Chipewyan batholith is a composite pluton possibly emplaced over an extended time span. Lewry et al. (1981), on the other hand, concluded that the batholith was emplaced as a single pluton or a limited number of related plutons, and is the largest coherent pluton in the Canadian Shield.

**Bear Province**

This province forms the northwesternmost part of contiguously exposed shield and several inliers on the mainland and on Arctic islands; on the west it is covered by Paleozoic strata (Fig. 3). On the east it is in fault, sedimentary, and deformation-metamorphic contact with the Archean Slave Province (Fraser et al. 1972,
The main tectonic element is the Wopmay Orogen, which consists of Archean and Early Proterozoic (Aphebian) units that were deformed during the Hudsonian Orogeny (Fraser et al. 1972, Hoffman 1973, 1980, Stockwell 1961) at about 1.8 Ga (Frith et al. 1977a). The Wopmay Orogen is overlain to the north by unmetamorphosed, ho-

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**Fig. 16.** Major lithological units and subprovinces of the southern part of the Bear Province. Modified after Fraser et al. (1972, 1978), Hoffman (1980) and Hoffman & McGlynn (1977).
moclinal, Middle to Late Proterozoic (Paleohelikian, Neohelikian and Hadrynian) sequences of clastic and carbonate sedimentary rocks and flood basalt flows that were intruded by extensive gabbroic dykes and sheets including the Muskox layered intrusion (Fraser et al. 1972); all of the inliers in the Paleozoic are part of the Middle to Late Proterozoic, post-Hudsonian sequence. Except for granophyric layers in the Muskox and some of the other gabbroic plutons, there are no post-Hudsonian granitic rocks in the Bear Province (Fraser et al. 1972).

The Wopmay Orogen comprises three subprovinces (Fig. 16). The Epworth Basin or Fold Belt on the northeast consists of un metamorphosed to low-rank metamorphic, weakly deformed, Early Proterozoic (Late Aphiabian) clastic and carbonate sedimentary strata of the shelf and platform facies (Fraser et al. 1972) that correlate with those in the Kilohigok Basin of the Slave Province and the East Arm Fold Belt of the Churchill Province to the east. The shelf and platform facies grade westward into more highly deformed and metamorphosed, continental-rise, sedimentary and volcanic rocks within the central Hepburn metamorphic-plutonic subprovince. On the west is the slightly younger volcanic-plutonic terrane of the Great Bear batholith (Hoffman & McGlynn 1977).

In the Hepburn Subprovince, Early Proterozoic sedimentary and volcanic rocks were deformed and intruded by various granitoid plutons prior to and during the Hudsonian Orogeny. The plutons appear to form less than 25% of the subprovince and comprise 1) large anastomosing, syenogranitic sills of porphyritic granite with fine-grained groundmass textures (Hoffman 1980), 2) sparse granodiorite – granite – pegmatite stocks that were emplaced during early stages of the orogeny at about 1.95 Ga; these extend eastward into bordering parts of the southern Slave Province (Frith et al. 1977a), 3) mesozonal to epizonal, porphyroblastic granodiorite stocks and batholiths of remobilized Archean basement plutons that were emplaced as diapirs and gneiss domes about 1.8 Ga (Frith et al. 1977a, Frith 1978), and 4) syntectonic to post-tectonic, in part funnel-shaped, composite batholiths of the Hepburn intrusive suite that range in composition from pyroxenite to granite but are dominantly granite (Hoffman 1980, Hoffman et al. 1978, 1980, St-Onge 1981). In contrast to many plutons in other provinces, granite, which is locally gneissic and in places contains orthoclase porphyroblasts, is the earliest phase of the syntectonic to post-tectonic plutons; successive phases become more mafic and more massive. This inverse sequence of emplacement and the local presence of garnet and sillimanite in the granite suggest that the granitic magma was derived by anatexis of upper crustal or sedimentary units (St-Onge 1981). Emplacement of the syntectonic plutons by magmatic stoping caused partial anatexis and migmatization of the immediately adjacent meta- sedimentary country rocks (Hoffman et al. 1980, St-Onge 1981). The remobilized Archean basement contains microcline porphyroblasts that are commonly deformed into augen, and a locally developed rapakivi texture (Fraser et al. 1972, Frith 1978). During remobilization, anatectic alaskitic pegmatite developed in both the granodiorite and adjacent metasedimentary rocks, producing migmatite (Frith et al. 1977a).

The Great Bear Batholith Subprovince consists of a thick un metamorphosed to weakly metamorphosed, gently folded, subaerial basaltic to rhyolitic volcanic sequence intruded by comagmatic epizonal plutons (Badham 1973, Hoffman 1980, Hoffman & McGlynn 1977). The volcanic sequence is mainly calc-alkaline, rhyolitic and dacitic ash-flow tuff that was erupted in a volcano-tectonic depression at about 1.8–1.9 Ga. Plutons predominate over volcanic rocks (Fig. 16) and consist of concordant, subvolcanic tonalite – granodiorite – granite sills and stocks, and discordant, post-volcanic syenogranite dyke swarms, stocks and batholiths. The plutons are collectively termed the Great Bear batholith; granite is the dominant rock type. The plutons range in texture from porphyritic with aphanitic groundmass to coarse-grained and equigranular; the coarse-grained plutons are locally porphyritic. Some of the early plutons are layered owing to gravity settling. The granitic magma was derived from deeper crustal or mantle sources than the granitic magmas of the Hepburn Subprovince (Badham 1973, Hoffman 1980).

Grenville Province

This province forms the southeastern margin of the Canadian Shield (Fig. 3) and records the youngest major tectonic event in the Shield, the Grenvillian Orogeny (Table 1, Fig. 2; Stockwell et al. 1970). Rock units range in age from Archean to Middle Proterozoic, with the Archean and Early Proterozoic units having been subjected to several deformational events prior to the Grenvillian Orogeny at about 1.0–1.2 Ga (Table 1). The result is a polydeformed, generally intermediate- to high-rank metamorphic terrace that is still poorly documented (Davidson et al. 1979).
The boundary between the Grenville and the adjacent Southern, Superior, Churchill and Nain provinces (Fig. 3) is the Grenville Front Tectonic Zone (2 on Fig. 17; Davidson et al. 1979, Gower et al. 1980, Lumbers 1978, 1979, Wynne-Edwards 1972). In this zone, which is up to 80 km wide, rocks of the older provinces were intensely deformed, metamorphosed and uplifted during the Grenvillian Orogeny. In places, a major fault occurs near the northern margin of the tectonic zone and separates cataclastic rocks on the northwest from gneissic rocks on the southeast. In the south, the Grenville Province is covered by Phanerozoic strata (Fig. 17).

The Grenville Province has been divided into six subprovinces on the basis of differing metamorphic intensity, age of rock units and styles of deformation (Fig. 17; Wynne-Edwards 1972). Boundaries between subprovinces are, at least in part, major tectonic zones, and similar tectonite zones separate various domains within the Central Gneiss Segment Subprovince (2 on Fig. 17; Davidson et al. 1982). The tectonite zones apparently formed as a result of northwesterly directed deep-seated thrusting (Davidson et al. 1982). Except for the Central Metasedimentary Belt Subprovince (3 on Fig. 17), rock units are generally much older than the Grenvillian Orogeny, and record older events.
However, the exact age of rock units within, and the relationships between the various subprovinces are controversial (Baer 1976, 1981, Davidson et al. 1982, Dewey & Burke 1973, Irving et al. 1972, Lumbers 1978, Wynne-Edwards 1972), in part reflecting the polyphase deformation, high metamorphic grade and lack of detailed geological mapping in many areas. The abundance and nature of granitoid plutons are variable from subprovince to subprovince (Fig. 17); in most subprovinces, granitoid plutons do not seem to be abundant. However, recent work in the Ontario portion of the Central Gneiss Belt (2 on Fig. 14) has shown that deformed granitoid plutons are more abundant than previously believed (Davidson et al. 1982, Schwerdtner & Lumbers 1980). Thus the high abundance of plutons in Ontario (Fig. 14) may be representative of pluton abundance in the more poorly documented Quebec portion of the Grenville Province.

Quartzofeldspathic grey gneisses of probable Archaean age, but derived from uncertain protoliths, underlie much of the Central Granulite, Baie Comeau and Eastern Grenville subprovinces (4, 5 and 6 on Fig. 17; Wynne-Edwards 1972). They apparently represent a continuation of the Archean terrain of the Superior and Nain provinces; by analogy with these provinces, granitoid orthogneiss of tonalite - granodiorite composition probably is a common constituent. Frith & Doig (1975) have documented the presence of tonalitic gneiss older than 3.0 Ga, but the exact age of most of the Archean gneisses is unknown. In places, these gneisses were remobilized during the Grenvillian Orogeny.

The Archean terrane was intruded by extensive anorthosite - quartz monzonite - granite batholiths prior to the culmination of the Grenvillian Orogeny. The plutons have been deformed and metamorphosed, and it is uncertain whether the reported age range of 1.1-1.5 Ga (Emslie 1978b, Martignole & Schrijver 1977, Wynne-Edwards 1972) represents a sequence of plutonic events or a single magmatic pulse, partly modified isotopically by superimposed metamorphism and deformation. Emslie (1978b) proposed that most of the anorthosite - granite complexes were emplaced at about 1.4-1.5 Ga. In conjunction with those in the Churchill and Nain provinces (Figs. 11, 14) and elsewhere in North America and Europe, these complexes form a linear zone that may reflect a Middle Proterozoic rifting event several hundred million years prior to the Grenvillian Orogeny (Emslie 1978b). The younger ages may reflect tectonic remobilization during the Grenvillian Orogeny (Baer 1976, 1981). Martignole & Schrijver (1977), on the other hand, considered that the 1.1-1.2 Ga ages of anorthosite - granite batholiths in the Central Granulite Subprovince (4 on Fig. 17) represent early-tectonic diapiric emplacement of the plutons at catazonal depths during the Grenvillian Orogeny.

In the Central Gneiss Belt Subprovince, Early Proterozoic (Aphebian) metasedimentary rocks unconformably overlie the Archean basement (2 on Fig. 17). Deformed and metamorphosed anorthosite - quartz monzonite - granite batholiths also are present but, unlike those further east, granitoid rocks greatly predominate here over anorthosite (Lumbers 1975a, 1978, Schwerdtner & Lumbers 1980). The granitoid rocks were originally massive, but during the Grenvillian Orogeny (1.0-1.3 Ga) they were deformed to different degrees to produce gneisses, and the plutons were diapirically reactivated and moved to higher structural levels (Schwerdtner & Lumbers 1980). The batholiths range in age from 1.1 to 1.5 Ga; this range in ages is believed to represent igneous emplacement during a 400-Ma time-span (Lumbers 1975a, 1978). Modal compositions of the granitoid phases are presented in Figure 18.

Deformed and metamorphosed, 1.5-1.7-Ga calc-alkaline granitoid plutons are also present in the Central Gneiss Belt. They are mainly medium- to coarse-grained porphyritic granodiorite - quartz monzonite dyke swarms, sheets, stocks and batholiths (Lumbers 1975a, 1978); folded sheets are particularly common (Davidson et al. 1982). These plutons are now commonly gneissic and locally migmatitic.

Middle Proterozoic (Helikian) volcanism and sedimentation that culminated with the Grenvillian Orogeny are largely restricted to the Central Metasedimentary Belt Subprovince (3 on Fig. 17). Granitoid plutons associated with these events include 1) an early tectonic, in part subvolcanic, recrystallized tonalite - granodiorite suite of epizonal to mesozonal stocks and batholiths emplaced in metavolcanic sequences at about 1.25 Ga (Lumbers 1967); these plutons have a trondhjemitic trend, 2) syntectonic, catazonal granodiorite - granite stocks and batholiths that were emplaced in intermediate- to high-grade metasedimentary sequences at about 1.125 Ga (Lumbers 1967), and 3) late tectonic granite - alkali feldspar granite - monzonite - syenite dykes, sills and stocks emplaced at about 1.0-1.1 Ga (Davidson et al. 1979, Lumbers 1967). Pegmatite is locally abundant and is confined largely to terranes in the amphibolite facies and at higher grades. In the locally developed greenschist-facies terrane, fluorite-bearing...
ing, in part granophytic, epizonal stocks of peralkaline granite are present (Davidson et al. 1979, Saha 1959). During the Grenvillian deformation, Early Proterozoic tonalite–granodiorite basement gneiss was locally remobilized to form mantled gneiss domes (Bright 1977).

Elsewhere in the Grenville Province, syntectonic and late-tectonic granitoid plutons appear to be rare (Baer 1976, Wynne-Edwards 1972), except in the Eastern Grenville Subprovince where they are poorly documented (6 on Fig. 17; Bourne 1978). The late tectonic plutons are characteristically potassic and include ubiquitous pegmatite dykes and sills and granite–alkali feldspar granite stocks and batholiths emplaced 1.0–1.2 Ga ago (Davidson et al. 1979, Lumbers 1978). During the Grenvillian Orogeny, in situ anatexis in intermediate- to high-grade metamorphic areas produced migmatitic units in both paragneiss and orthogneiss (Lumbers 1975a).

Post-tectonic plutons are rare but small Late Proterozoic to Early Paleozoic alkali plutons that locally have granitoid phases were intruded along and adjacent to the St. Lawrence Rift System (Doig & Barton 1968). These plutons are best documented along the Ottawa–Bonnechère Graben, an arm of the rift system that extends northwesterly across the Grenville Province along the Quebec–Ontario border. Plutons with granitoid phases are among the youngest of this group; they were emplaced at about 450 Ma (Doig & Barton 1968).

Summary of granitoid plutonism in the Canadian Shield

As shown in Table 1, tonalitic to locally granodioritic and, rarely, granitic orthogneiss, 2.8 Ga and older, occurs in most structural provinces. The nature and extent of the old plutons are unknown, but the presence of the plutons implies still older supracrustal sequences into which the plutons were emplaced. As yet, these supracrustal sequences have been identified only in the Nain and Superior provinces (Table 1; Collerson & Bridgwater 1979, Nunes & Thurston 1980). The older plutons also imply the development of a widespread, although possibly segmented 3.0-Ga cratonic terrane (Clark et al. 1981, Goodwin, 1977, Walker 1978) that could have been both a potential source-area for younger sediments and an anatectic source for younger granitoid plutons (Hargraves 1976). The 3.0-Ga and older plutons are characteristically deficient in potassium and have trondhjemitic chemical trends (Figs. 5, 12).
At the close of the Archean, extensive granitoid plutonism associated with the Kenoran Orogeny (2.55–2.65 Ga) produced a sialic cratonic terrane throughout the Canadian Shield. Although the Archean structural provinces were not necessarily in their present positions, the areal extent of the post-Kenoran sialic terrane was approximately equal to the present Canadian Shield. Subsequent Proterozoic events modified the sialic terrane but did not greatly change its size, at least in the presently exposed part of the Shield. In the Slave and Superior provinces, the cratonic terrane remained relatively stable throughout the Proterozoic, except for epeirogenic and tensional tectonics. The Bear, Southern and southwestern Grenville provinces represent Early and Middle Proterozoic sedimentation, volcanism and subsequent deformation on the margins of, or within, the Archean craton. Middle Proterozoic events are restricted to the Grenville Province. In the Churchill, Nain and northeastern Grenville provinces, the Archean basement was extensively reworked by Proterozoic orogenic events of variable intensity and age. Two major orogenic events have been recognized: the Hudsonian (1.6–2.2 Ga), which appears to comprise a series of possibly unrelated events within this general time-interval, and the areally restricted Grenvillian (1.0–1.2 Ga). There are no Late Proterozoic orogenic events.

The Archean craton was apparently segmented in the Early Proterozoic. The present shield represents either 1) several diverse cratonic blocks that collided during the Hudsonian Orogeny, or 2) an original large craton in which Proterozoic rift zones, that are in part ensimatic, produced major crustal extension and ocean development followed by later convergence and re-establishment of a single craton. The latter model is supported by paleomagnetic data (Irving & McGlynn 1976), but in either model, sedimentation and volcanism of the Circum-Ungava Geosyncline, Southeastern Zone and Fox River Belt subprovinces of the Churchill Province (Fig. 14), which are now bounded on both sides by Archean terrane, apparently took place on craton margins. These craton-margin sequences were deformed and welded onto or into the Archean craton during the Hudsonian Orogeny. Other rift and suture zones have also been proposed (e.g., Gibb & Thomas 1977), although some of these are controversial (e.g., Lewry & Sibbald 1980).

Elsewhere in the Churchill and parts of the Nain and northeastern Grenville provinces, the Archean craton was variably downwarped, overlain by thick sedimentary and volcanic sequences, deformed and metamorphosed. In places, the Archean basement was remobilized during this deformation.

Granitoid plutonism was an integral component of the three major orogenic events (Fig. 2), but the abundance of granitoid plutons appears to decrease with decreasing age (Table 1); the Grenville Province may be an exception to this trend, but many of the plutons in the Grenville Province are preorogenic. There is also a positive correlation between the abundances of metavolcanic rocks and of granitoid plutons. For example, in the Superior Province, Archean granitoid plutons are most abundant in the greenstone-belt subprovinces (Fig. 4); in the Slave Province, where the ratio of metasedimentary to metavolcanic components is considerable higher than in the Superior Province, granitoid plutons are less abundant. In other provinces, Proterozoic granitoid plutons associated with the Hudsonian and Grenvillian orogenies are most abundant in association with volcanic and metavolcanic sequences of the Southeastern Zone and Rottenstone–Chipewyan subprovinces of the Churchill Province (Fig. 14), the Central Metasedimentary Belt Subprovince of the Grenville Province (Fig. 17), and the Great Bear batholith of the Bear Province (Fig. 16). All of the Proterozoic volcanic–granitoid terranes are characterized by relatively low metamorphic grade and the probable absence of earlier sialic crust. Proterozoic granitoid plutons are generally less abundant in the deformed Archean basement and the higher-grade deformed metamorphic sequences that overlie the basement, although again the Early Proterozoic sequence of the Central Gneiss Belt of the Grenville Province (Fig. 17) is an exception. Remobilization of the basement resulted in emplacement of gneiss domes in some provinces.

The plutons span the complete spectrum of granitoid compositions and range in depth of emplacement from subvolcanic to catazonal, and in tectonic position from pretektonic to posttektonic. However, some general conclusions can be drawn:

1) All volcanic sequences that include a calc-alkaline component contain subvolcanic granitoid plutons similar in composition to the volcanic sequence.

2) Syntectonic plutons are commonly composite and include early gneissic to foliated tonalite–granodiorite phases, and later foliated to massive, more leucocratic granodiorite–granite phases, but the actual sequence of emplacement in any one pluton is complex. Major ex-
ceptions to this generalization are the composite batholiths of the Hepburn Subprovince of the Bear Province, in which early granite was succeeded by later more mafic phases, and the immense Wathaman–Chipewyan batholith of the Rottenstone–Chipewyan Subprovince of the Churchill Province, which is apparently a single-phase pluton.

3) Most tonalitic plutons are associated with low-grade metamorphosed metavolcanic sequences; plutons intruded into intermediate- to high-grade paragneiss and reworked basement terranes are generally more potassic than those in greenstone-belt terranes.

4) In general, plutons associated with younger deformational events appear to be more potassic than those associated with older events, although plutons associated with metavolcanic sequences invariably have early tonalitic phases; the temporal increase in potassium correlates with decreasing abundance of metavolcanic rocks and increasing abundance of metasedimentary rocks.

5) The apparent temporal increase in potassium content of granitoid plutons may indicate that older paragneiss and granitoid crustal rocks through which the magmas moved to their present position contributed to the higher potassium content by contamination or anatexis.

6) Both trondhjemitic and calc-alkaline chemical trends are represented in the plutons, but trondhjemitic trends are most common in early syntectonic plutons associated with greenstone belts.

7) As regional metamorphic grade of the country rocks increases, the style of pluton emplacement changes, with catazonal plutons in higher-grade terranes and mesozonal and epizonal plutons in lower-grade terranes.

8) Many syntectonic, epizonal to mesozonal plutons were originally emplaced as a series of discrete magmatic pulses at some depth below their present level of exposure and were subsequently diapirically emplaced at their present structural level.

9) Plutons metamorphosed during superimposed intermediate- to high-grade metamorphism are commonly gneissic and recrystallized, and in places show evidence of cataclasis, metasomatism, isotopic re-equilibration, and partial remelting. This deformation commonly resulted in remobilization of the plutons to form diapirs, gneiss domes and nappes; these structures have been best documented in the Churchill Province.

10) Post-tectonic plutons are rare except adjacent to younger structural provinces or tectonic zones or associated with post-orogenic volcanism. These plutons are potassic and, in places, peralkaline.

11) Emplacement of large granitoid batholiths is probably the major factor in crustal thickening, leading to the production of large, stable cratonic terranes. In the Canadian Shield, this was primarily a late Archean event. Thus the late Archean (2.55–2.75 Ga) was the major magma-producing epoch in the geological evolution of North America. The magma produced is represented by both extensive tholeiitic basaltic metavolcanic rocks of the greenstone belts and calc-alkaline granitoid plutons and was thus essentially bimodal (cf. Barker et al. 1981).

The origin of the granitoid plutons is controversial; several different mechanisms have been proposed including: 1) derivation of magma from the mantle by either fractionation of basaltic magma (Wilson et al. 1974) or by partial melting (single or multiple stage, wet or dry) processes with only minor subsequent fractionation (Birk 1979, Collerson & Bridgewater 1979, Drury 1979, Wooden 1978), 2) anatexis of sialic basement or paragneiss and intrusion at higher crustal levels (Clark et al. 1981, Drury 1979, Emslie 1978b, Jackson & Morgan 1978, Lewry & Sibbald 1980, St-Onge 1981), 3) anatexis of granulite-facies lower crust (Collerson & Fryer 1978), 4) in situ anatexis of paragneiss with only local remobilization (Bailes & McRitchie 1978), 5) diapiric remobilization of earlier granitoid units without extensive anatexis (Frith et al. 1977a, Lewry et al. 1978, Schwerdtner et al. 1979, Verpaelst et al. 1980), and 6) contamination of mantle-derived magmas by older crust (Wooden 1978). All of these processes appear to have operated at different places and different times, reflecting differences in lithologic, tectonic and thermal settings.

In areas of low metamorphic grade, such as in greenstone belts, Sr- and O-isotope and REE data suggest that most of the magma was probably derived from the mantle (e.g., Birk 1979, Birk et al. 1979, Drury 1979, Green & Baadsgaard 1971, Longstaffe & Birk 1981), although late-tectonic potassic plutons may have been derived by anatexis of sedimentary rocks that had a short period of crustal residence (Drury 1979). In some plutons, such as the Preissac–Lacorne batholith (Abitibi Subprovince of the Superior Province), magmas from several sources are spatially associated (Card 1981): early tonalite–granodiorite was apparently derived from the mantle but late granite was derived from ana-
tectis of metasedimentary rocks. Similar complexities can be expected in other Archean batholiths as well (e.g., the Lac-du-Bonnet batholith in the English River Subprovince of southeastern Manitoba; Černý et al. 1981, Černý 1982a). In areas of higher metamorphic grade, crustal anatexis and remobilization are common processes. However, as pointed out by Collerson & Fryer (1978) and Birk et al. (1979), present isotope ratios and REE patterns may represent a combination of various magmatic and post-magmatic events. The problems are compounded in areas of more intense deformation and metamorphism. Consequently, interpretation of isotope and REE data must be done with caution, particularly if only limited data are available.

**Metallogeny**

To date, only sparse mineral deposits have been documented in granitoid plutons of the Canadian Shield. These comprise porphyry copper and molybdenum deposits, non-porphyry copper and molybdenum occurrences, gold and silver deposits that are spatially (although not necessarily genetically) related to granitoid plutons, uranium- and thorium-bearing pegmatites and related granitoid rocks, lithium-, cesium-, beryllium-, tantalum- and rare-earth-element-bearing pegmatites, and rare deposits of other elements or types. Tin and tungsten mineralization are conspicuously absent, except subeconomic but widespread tin concentrations in rare-element pegmatites. Many pegmatites and granitoid plutons have been mined for feldspar and mica, or quarried for building stone, but we have excluded these and other industrial products from this discussion.

In this compilation we have attempted to include most published descriptions of mineral deposits in or associated with granitoid rocks where the description is sufficiently detailed to document a spatial or genetic relationship. The sources used to compile the distribution maps (Figs. 19, 22, 23, 28, 36 and 40) are too numerous to document individually, but many important deposits are discussed in the text.

**Copper–Molybdenum–Gold**

Copper ± molybdenum ± gold mineralization occurs within or adjacent to mafy relatively small granitoid and syenitoid plutons in greenstone belts of the Canadian Shield (Fig. 19), but has been reported only rarely from large batholithic complexes and from small plutons emplaced in metasedimentary sequences or re-worked basement. Consequently, this type of mineralization appears to be restricted largely to small Archean plutons of the Superior Province; a few mineralized plutons of Archean age occur also in the Slave Province and a few of Early Proterozoic age in the Southeastern Zone Subprovince of the Churchill Province (Fig. 19). Although high-grade zones have been mined from several deposits, most occurrences are subeconomic and poorly documented, particularly in remote areas. The paucity of reported occurrences from the Slave Province may reflect inaccessibility and the reconnaissance nature of the geological investigations rather than a low abundance. Similarly, although the lack of reported occurrences in metasedimentary sequences, large batholithic complexes and re-worked basement probably reflects a true low abundance, these terranes have not been extensively prospected for this type of mineralization.

The apparent concentration of occurrences in the southern part of the Superior Province (Fig. 19) may reflect a number of factors including relative inaccessibility elsewhere and uneven prospecting activity, but is probably largely a function of the size of the greenstone belts. In the Slave and northern Superior provinces, the greenstone belts are commonly narrower and contain fewer internal plutons than those in the southern Superior Province.

Most of the mineralized plutons are subvolcanic to epizonal tonalite (including trondhjemite) and granodiorite, and include simple to composite dykes and dyke swarms, sill complexes, stocks and small batholiths. Texturally they range from medium-grained equigranular to porphyritic with aphanitic to medium-grained groundmasses; phenocrysts are medium- to coarse-grained and comprise one or more of quartz, plagioclase, K-feldspar, biotite and hornblende. Pegmatitic and primary potassic phases are rare. Mineralized plutons are most common in the larger greenstone belts associated with, or stratigraphically below, calc-alkaline, felsic to intermediate metavolcanic sequences. Many syngenetic Cu–Zn–Ag deposits are spatially associated with mineralized or unmineralized, commonly sill-like granitoid plutons that occur near the base of the volcanic cycle that hosts the deposits (Franklin & Thorpe 1982). Many plutons have been metamorphosed to the same grade as adjacent units, but the intensity of penetrative deformation is generally somewhat lower, reflecting the originally more massive nature of many plutons.

Some of the mineralized plutons have attributes of porphyry deposits (Table 3) but most
### Table 3. Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Age</th>
<th>Nature of pluton</th>
<th>Granitoid type(s)</th>
<th>Nature of mineralization</th>
<th>Nature of Deposit</th>
<th>Alteration</th>
<th>Reference</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Jogn</td>
<td>Archean</td>
<td>marginal phase of batholith</td>
<td>ton (plag, py, Cu, ep, chl)</td>
<td>in chl filled fractures</td>
<td>0.052 MoS₂, 0.192 Cu</td>
<td>Upper zone</td>
<td>Blecha</td>
<td>Small size but typical porphyry mineralization and low intensity alteration; larger porphyry plug found at depth below one breccia; mineralization occurs in 3 of 5 known breccia pipes in Archean granitoid batholiths and metasomatized rocks; high grade sections previously mined; related to adjacent Southern Province.</td>
</tr>
<tr>
<td>8</td>
<td>Strib</td>
<td>Archean</td>
<td>stock; 5.7 km thick tectonic</td>
<td>single phase py</td>
<td>in qtz veins and locally diss</td>
<td>0.15-0.25% Cu, 0.03-0.05% MoS₂, 1.35 ppm Au</td>
<td>Upper zone</td>
<td>Elbers, Maskins &amp; Stephenson (1976)</td>
<td>Occurs in several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.</td>
</tr>
<tr>
<td>9</td>
<td>Oxtf</td>
<td>Archean</td>
<td>still complex 100 m thick</td>
<td>ton (plag, py, Cu, ep, chl)</td>
<td>in qtz-cc-ep-ep-chl veins &amp; locally diss</td>
<td>0.4% Cu, 0.06% MoS₂, 0.04% Cu</td>
<td>Upper zone</td>
<td>Ayres et al. (1982)</td>
<td>Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.</td>
</tr>
<tr>
<td>10</td>
<td>Lang</td>
<td>Archean</td>
<td>still-like lens 2.4 km thick &amp; 1.4 km long</td>
<td>ton with cp, py, sp, &amp; ncl</td>
<td>in qtz-cc-ep-plg veins and micro-fractures</td>
<td>0.065% Cu</td>
<td>Upper zone</td>
<td>Finlay &amp; Ayres (1977)</td>
<td>Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.</td>
</tr>
<tr>
<td>11</td>
<td>Beide</td>
<td>Archean</td>
<td>concordant, somewhat irregular lens 1.8 km long</td>
<td>ncl &amp; py in felsite matrix</td>
<td>diss and in fractures</td>
<td>0.08% Cu, 0.05% Mo, 1 ppm Au</td>
<td>Upper zone</td>
<td>Finlay &amp; Ayres (1981)</td>
<td>Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.</td>
</tr>
<tr>
<td>12</td>
<td>Monk</td>
<td>Archean</td>
<td>gnd-gr</td>
<td>gnd-gr, py in felsite matrix</td>
<td>diss and in fractures</td>
<td>9x10⁵ t</td>
<td>Upper zone</td>
<td>Griffiths (1962)</td>
<td>Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.</td>
</tr>
</tbody>
</table>

**Superior Province**

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Jogn
- **Age:** Archean
- **Nature of pluton:** Marginal phase of batholith
- **Granitoid type(s):** Ton (plag, py, Cu, ep, chl)
- **Nature of mineralization:** In chl filled fractures
- **Nature of Deposit:** 0.052 MoS₂, 0.192 Cu
- **Alteration:** Upper zone
- **Reference:** Blecha
- **Remarks:** Small size but typical porphyry mineralization and low intensity alteration; larger porphyry plug found at depth below one breccia; mineralization occurs in 3 of 5 known breccia pipes in Archean granitoid batholiths and metasomatized rocks; high grade sections previously mined; related to adjacent Southern Province.

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Strib
- **Age:** Archean
- **Nature of pluton:** Stock; 5.7 km thick tectonic
- **Granitoid type(s):** Single phase py
- **Nature of mineralization:** In qtz veins and locally diss
- **Nature of Deposit:** 0.15-0.25% Cu, 0.03-0.05% MoS₂, 1.35 ppm Au
- **Alteration:** Upper zone
- **Reference:** Elbers, Maskins & Stephenson (1976)
- **Remarks:** Occurs in several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Oxtf
- **Age:** Archean
- **Nature of pluton:** Still complex 100 m thick
- **Granitoid type(s):** Ton (plag, py, Cu, ep, chl)
- **Nature of mineralization:** In qtz-cc-ep-plg veins & locally diss
- **Nature of Deposit:** 0.4% Cu, 0.06% MoS₂, 0.04% Cu
- **Alteration:** Upper zone
- **Reference:** Ayres et al. (1982)
- **Remarks:** Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Lang
- **Age:** Archean
- **Nature of pluton:** Still-like lens 2.4 km thick & 1.4 km long
- **Granitoid type(s):** Ton with cp, py, sp, & ncl
- **Nature of mineralization:** In qtz-cc-ep-plg veins and micro-fractures
- **Nature of Deposit:** 0.065% Cu
- **Alteration:** Upper zone
- **Reference:** Finlay & Ayres (1977)
- **Remarks:** Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Beide
- **Age:** Archean
- **Nature of pluton:** Concordant, somewhat irregular lens 1.8 km long
- **Granitoid type(s):** Ncl & py in felsite matrix
- **Nature of mineralization:** In qtz veins and micro-fractures
- **Nature of Deposit:** 0.08% Cu, 0.05% Mo, 1 ppm Au
- **Alteration:** Upper zone
- **Reference:** Finlay & Ayres (1981)
- **Remarks:** Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.

**Table:** Characteristics of the Better-Documented Porphyry Copper and Molybdenum Occurrences in the Canadian Shield.

- **Name:** Monk
- **Age:** Archean
- **Nature of pluton:** Gnd-gr
- **Granitoid type(s):** Gnd-gr, py in felsite matrix
- **Nature of mineralization:** In qtz veins and micro-fractures
- **Nature of Deposit:** 9x10⁵ t
- **Alteration:** Upper zone
- **Reference:** Griffiths (1962)
- **Remarks:** Several occurrences; major anomaly occurs in qtz-dol veins, breccia zones, and with nearby felsic metavolcanic units.
plutons simply contain localized chalcopyrite--pyrite--gold--molybdenite occurrences in fault, fracture- or breccia-controlled veins, stockworks or disseminations. For example, in the central Superior Province of Ontario, about 100 mineralized plutons were examined by Colvine & Sutherland (1979a). Of these, 60% have some attributes of Phanerozoic porphyry deposits, 20% resemble porphyry deposits in several aspects, but only one deposit closely resembles Phanerozoic deposits (Colvine &ameron 1981).

**Porphyry-type deposits**

In spite of uncertainties in classification and the fact that some workers do not recognize the existence of porphyry-type mineral deposits in the Canadian Shield, many Precambrian deposits with porphyry affinities are now known or postulated. Many of these are still poorly documented, particularly as to the nature and distribution of the mineralization and alteration. Since these are essential parameters for most definitions of porphyry deposits, many Precambrian occurrences cannot be readily classified. Accordingly we have used the less precise definition of Kirkham (1972b), which emphasizes that some workers do not recognize the fact that some deposits occur in plutons and adjacent country rocks; Au- Ag--py deposits occur nearby and some have been classified as porphyry Au deposits; high grade zones have been mined within at 1.45 x 10^4 as a source of silicic flux for copper smelting; most mineralization predates late felsite phases, but veins may represent remobilization during subsequent deformation & greenstone facies metamorphism.

**TABLE 3. (Continued)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Province</th>
<th>Age</th>
<th>Stock &amp; Dike Characteristics</th>
<th>Mineralization Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Archean</td>
<td>Sy &amp; Qtz</td>
<td>Cu, minor</td>
<td>0.05--0.15 Cu, high grade</td>
</tr>
<tr>
<td>11</td>
<td>Rouyn</td>
<td>Py &amp; Cu</td>
<td>Cu, high grade</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Chibougamau</td>
<td>Py &amp; Cu</td>
<td>Au deposits</td>
<td>high grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations.** Rock Types: gnd, granodiorite; gr, granite; mtd, monzodiorite; sy, syenite; ton, tonalite; Textures: f, fine-grained; mg, medium-grained; porph, porphyritic; ph nos, phenocrysts; gm, groundmass; dis, disseminated; Minerals: bi, bornite; cp, chalcopyrite; g, galena; hem, hematite; mag, magnetite; mtd, monzodiorite; po, pyrrhotite; py, pyrite; sp, sphalerite; t, tetrahedrite; al, albite; am, anhydrite; an, ankerite; bi, biotite; carb, carbonate minerals; ca, calcite; ch, chlorite; do, dolomite; ep, epidote; holde, holdeite; is, iron sulfides; ksp, K-sp model; p, pyrite; ppy, pyrrhotite; qtz, quartz; ser, sericite; tour, tourmaline; others: ppm parts per million (= grams/tonne), t tonne.
intermediate porphyritic plutons, rather than zonal distribution of sulfide minerals and alteration (Lowell & Guilbert 1970). Using these definitions, we have tabulated the major characteristics of the better documented Precambrian copper and molybdenum occurrences with porphyry affinities (Table 3). A somewhat similar tabulation is given by Franklin & Thorpe (1982, Table 6).

Even in the best-documented occurrences, al-
Fig. 19. Distribution of granitoid plutons that contain copper, molybdenum and gold mineralization within the Superior and part of the Churchill provinces. Numbered occurrences refer to Table 3.

teration and sulfide mineral zoning are difficult to evaluate. In part this reflects the superimposed metamorphism and deformation that have affected many occurrences (Kirkham 1972a). Metamorphism has commonly converted the original alteration-mineral assemblages to metamorphic assemblages. Alteration can still be recognized by increasing abundances of metamorphic minerals, but 1) the alteration cannot be compared directly to that in younger, unmetamorphosed deposits, and 2) any original zonal variations defined by relative abundances of specific species of minerals, such as kaolinite or sericite, will have been converted into a simple abundance zoning of metamorphic minerals, in this case sericite. Deformation may have caused regional tilting of the pluton and its contained mineralization and alteration. In
many greenstone belts, isoclinal folding produced subvertically dipping stratigraphic sequences, and if the pluton was emplaced prior to deformation it would have been tilted along with the country rocks (e.g., Elbers 1976). Thus the present outcrop surface would represent a near-vertical cross-section through the deposit, and any present pattern of horizontal zoning would represent an original vertical zoning. In places, penetrative deformation has destroyed original textures or caused remobilization of sulfide and gangue minerals.

With the possible exception of the McIntyre mine (now Schumacher Division of Pomour Porcupine Mines Limited; No. 9 on Fig. 19, Table 3), the porphyry-type deposits identified to date are all subeconomic, and many are of relatively small size compared to commercial Phanerozoic deposits. In the McIntyre deposit, copper is currently being mined from steeply plunging ore-shoots within a concordant, fine-grained, strongly altered, schistose felsic unit that contains quartz and albite megacrysts (Davies & Luhta 1978). In addition to the ore shoots, which contain more than 0.8% copper plus minor molybdenum and gold, disseminated copper occurs throughout a large volume of the felsic unit. The origin of the felsic unit is controversial. Griffis (1962, 1979) and most other geologists (e.g., Ferguson et al. 1968, Pyke & Middleton 1970) consider that the felsic unit is a deformed, subvolcanic porphyritic pluton. Pyke & Middleton (1970) have further interpreted the McIntyre to be a porphyry copper deposit; the zone being mined is a high-grade section within a large low-grade deposit. On the other hand, Davies & Luhta (1978, 1979), on the basis of detailed study, have proposed that the host rock is a felsic metavolcanic unit in which quartz and albite porphyroblasts developed during late-stage metasomatism. According to them, zoned alteration-assemblages and the megacrysts postdate penetrative deformation. Davies & Luhta (1978) concluded that, although alteration and mineralization are somewhat analogous to those in porphyry deposits, the lack of intrusive rocks and the late-stage development of alteration preclude the possibility that the McIntyre is a porphyry deposit. Identical problems of host-rock identification have been encountered in other occurrences (Sutherland & Colvine 1979). This controversy illustrates the problems involved in dealing with metamorphosed and deformed deposits, particularly those in host rocks that have a fine-grained groundmass or matrix and poorly exposed or nebulus contact-relations.

In the Canadian Shield, there are two basic types of porphyry-type occurrences: 1) Middle Proterozoic, unmetamorphosed plutons that are genetically and temporally unrelated to Archean country rocks in which they occur, and 2) Archean and Early Proterozoic metamorphosed to unmetamorphosed plutons, many of which are genetically related to the host volcanic rocks. Middle Proterozoic porphyry-type occurrences have been reported only from the south-central Superior Province (No. 7, 8, Table 3, Fig. 19). These occurrences are close to exposures of Keweenawan volcanic rocks (Southern Province) of similar age, and the host plutons appear to be genetically related to Southern Province volcanism. One of these Middle Proterozoic occurrences, the Tribag deposits, from which high-grade sections were previously mined, appears to be the best example of breccia-pipe, porphyry deposits yet reported from the Canadian Shield (No. 7, Table 3; Blecha 1974). The Tribag breccias were emplaced at about 1.055 Ga into Archean granitoid and greenstone units. Middle Proterozoic deposits appear to have higher silver contents and to be in or associated with more potassic plutons than Archean and Early Proterozoic occurrences (Table 3). Although all known Middle Proterozoic deposits are restricted to a relatively small area (Fig. 19), small copper occurrences and breccia pipes have been found elsewhere in the Superior Province close to the Keweenawan volcanic sequence of the Southern Province.

Archean and Early Proterozoic plutons that host porphyry-type occurrences differ greatly in composition, texture, habit, size, and mode and depth of emplacement (Table 3). Most are tonalite or granodiorite (Table 3, 4) but granite occurs in more than 40% of the occurrences shown in Table 3; the granite varies from a minor to a widespread phase. The Matachewan occurrences (No. 10, Table 3, Fig. 19; Sinclair 1979, 1982) are associated with a zoned syenite – quartz syenite stock and small satellite plutons. They are included here for comparison with occurrences in granitoid plutons and to indicate the wide range in composition of host plutons.

Most plutons are either single-phase but compositionally varied and locally zoned, or single-phase with relatively minor late dyke-phases and both cognate and country-rock xenoliths. Multiphase composite plutons are relatively rare; the best examples are the sill complexes (No. 1, 5, Table 3). These are sill-like plutons up to 500 m thick that are composed of 100% sheeted sills; individual sills range in thickness from 1 cm to 30 m (Chute & Ayres 1977,
Plutons are generally subvolcanic or epizonal. Subvolcanic plutons form plugs, small stocks and sills complexes that have a ubiquitous porphyritic texture with an aphanitic to fine-grained groundmass. Epizonal plutons form larger stocks and small batholiths, many of which are crudely concordant, that range in age from synvolcanic to locally late-tectonic. Many of the epizonal plutons are more sparsely porphyritic than the subvolcanic plutons and have a fine-to-medium-grained groundmass. Epizonal plutons form textural zoning associated with mineralization and some are intercalated with comagmatic volcanic-tectonic systems.

In the Chibougamau occurrences (No. 12, Table 3), the late porphyritic dykes are spatially associated with mineralization and some are intermineral, i.e., they were intruded after early stages of mineralization but before the late stages (Cimon 1979b, Kirkham 1972a). In the late-tectonic Setting Net Lake pluton (No. 4, Table 3; Fig. 20A), marked textural zoning reflects uneven cooling of the pluton.

Although most mineralized plutons are small and within greenstone belts, several occurrences are found in or adjacent to the margins of large batholithic complexes (Elbers 1976, Wilkinson 1979). In some of these occurrences, such as those at Oxford Lake (No. 3, Table 3), the fine-grained groundmass of the granitoid host indicates that these are epizonal plutons rather than the more normal mesozonal batholithic complexes. Elbers (1976) has proposed that at Oxford Lake, the occurrence of a fracture-controlled transition from subvolcanic porphyritic dykes in the greenstone belt through epizonal margins of the batholith to mesozonal interiors represents a tilted crustal section through a comagmatic volcanic-tectonic system.

Mineralization is simple and consists mainly of pyrite, chalcopyrite, bornite, molybdenite and, locally, gold. It is generally fracture-controlled, with sulfide minerals occurring either in one or more sets of relatively planar, dilational fractures or in more irregular and diversely oriented fractures, producing stockworks. In many occurrences, the sulfides are associated with quartz and carbonate veinlets that are generally less than 1 cm thick and that locally contain tungsten minerals and fluorite; some fractures have coatings of alteration minerals such as epidote, chlorite or sericite. Disseminated sulfides are present also in most occurrences. Zoning of sulfide minerals has been reported only rarely (Goldie et al. 1979). Although small breccia-zones are present at

---

**Table 4. Selected chemical analyses of Archean granitoid plutons hosting porphyry copper-molybdenum occurrences in the Superior Province of the Canadian Shield**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>51O₂</td>
<td>72.25</td>
<td>74.10</td>
<td>73.40</td>
<td>75.20</td>
<td>75.73</td>
<td>74.60</td>
<td>69.30</td>
<td>67.40</td>
<td>70.10</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.28</td>
<td>0.14</td>
<td>0.20</td>
<td>0.20</td>
<td>0.29</td>
<td>0.29</td>
<td>0.27</td>
<td>0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.96</td>
<td>0.98</td>
<td>1.39</td>
<td>0.80</td>
<td>0.71</td>
<td>0.71</td>
<td>0.71</td>
<td>0.71</td>
<td>0.71</td>
</tr>
</tbody>
</table>

FeO 1.93 3.83 | 1.90 2.35
MgO 0.05 0.06 0.07
CaO 0.62 0.38 0.52 0.35 0.25 0.70 1.14 0.97 0.80
Na₂O 1.62 1.26 1.56 0.86 1.06 1.10 1.90 2.42 2.31
K₂O 4.06 3.80 3.98 3.38 5.15 4.30 5.58 4.53 3.16
CaO 3.38 4.25 3.23 4.67 1.25 0.56 1.87 2.66 5.12
Fe₂O₅ 0.18 0.19 0.17 0.10 0.03 0.02 0.46
CO₂ 0.00 0.29 0.37 0.47 0.84 0.58 3.14
H₂O 0.85 0.95 0.72 0.55 0.44 1.49 1.65 1.20 1.34

Cu (ppm) 7 24 72

---

1. Total iron as Fe₂O₃
2. Total iron as FeO
3. Setting Net Lake stock (No. 4, Table 3; after S.A. Averill, unpub.). The emplacement of the pluton is from alteration in the south part of the stock (Fig. 20B). 3.4 Country rock between mineralized veins. Both samples have intense alteration of plagioclase. Some K metasomatism possibly occurred in Sample 3.
4. Beidelman Bay stock (No. 6, Table 3; after Franklin 1978a). Trace elements include Rb = 25 ppm, Sr = 110 ppm, Y = 5 ppm, Zr = 340 ppm, Nb = 23 ppm, Ba = 380 ppm.
5. Powell stock hosting Don Rouyn deposit (No. 11, Table 3; after Goldie et al. 1979). Mean of 3 samples collected within 1 km of mineralized zone.
6. Setting Net Lake stock (No. 12, Table 3; after Cimon 1976). 7-Tonalite away from mineralization. 8-Tonalite in mineralized zone. 9-Carbonate-sericite-epidote alteration. Trace elements include Zn = 15 ppm, Pb = 10 ppm, Ag = 0.6 ppm, S = 0.03s. 8-Tonalite in mineralized zone; potassic alteration.
Medium-grained porphyry
Fine-grained porphyry
Western muscovitic lobe of fine-grained porphyry
Equigranular facies
Area in which pegmatite is present
Per cent coarse-grained potassic feldspar phenocrysts
Molybdenite zone
Fault

Per cent alteration of plagioclase
Molybdenite zone
Fault

Km.

Km.
many occurrences, large breccia-zones have been described only from the Chibougamau occurrences (No. 12, Table 3). Only minor mineralization occurs in the breccia matrix; most mineralization is present in several generations of fractures that cut the breccia (Cimon 1979b). At Beidelman Bay (No. 6, Table 3), mineralization is best developed in areas of abundant metavolcanic xenoliths (Poulsen & Franklin 1981); irregular breccia zones occur locally in the xenolith-rich areas; in contrast to breccia zones in the Chibougamau occurrences, mineralization is confined to the breccia matrix.

Most occurrences contain both copper and molybdenum, but, of the occurrences listed in Table 3, copper is the dominant metal in all except that at Setting Net Lake (No. 4, Table 3). However, molybdenum predominates in some of the more poorly documented occurrences (Fig. 19; Colvine & Marmont 1981, Colvine & Sutherland 1979b). Colvine & Sutherland (1979b) have postulated that molybdenum is more abundant in deeper-seated plutons than in high-level plutons. Gold is present in variable amounts but analyses for gold are not available for all occurrences. In many porphyry occurrences, the zone of dispersed mineralization in Cu or Mo (or both) grades outward
into a zone containing discrete gold-bearing veins (Franklin & Thorpe 1982, Kirkham & Thorpe 1973). Considering the current high price of gold, mineralized plutons should be re-examined for low-grade porphyry-gold potential (Friske et al. 1979). At Matachewan (No. 10, Fig. 19), both porphyry copper–molybdenum–gold and copper-poor porphyry-gold deposits are present in a single plutonic complex (Sinclair 1982).

Most mineralized zones described to date are relatively small, but many have not been completely delineated. All are currently sub-economic as porphyry deposits, although high-grade zones have been mined or are currently being explored (Table 3).

As exemplified by the Setting Net Lake pluton (Fig. 20B), all occurrences have widespread alteration that decreases in intensity away from the mineralized zone. In most occurrences, alteration is poorly documented and cannot always be distinguished from normal metamorphic effects. Furthermore, some unmineralized metamorphosed plutons show alteration patterns similar to those associated with mineralization (Baldwin 1980). Alteration comprises uniform replacement of primary minerals, more intense replacement adjacent to fractures and deposition of minerals in fractures that are both sulfide-bearing and sulfide-free. The common alteration minerals are sericite, albite, epidote, pyrite, carbonate minerals, chlorite and quartz (Table 3). Hematite is locally developed, particularly in wall rock adjacent to fractures. Secondary biotite, potassium feldspar and muscovite have been reported from only a few Precambrian occurrences (Table 3). Thus potassium metasomatism, a characteristic feature of many Phanerozoic, ore-grade porphyry deposits, appears to be absent or poorly developed in most Precambrian occurrences. It is best documented in the Chibougamau batholith (Table 4, columns 7–9) and Matachewan deposits (Sinclair 1982).

Trace-metal contents of the host granitoid plutons have been examined at several of the porphyry occurrences. Copper and molybdenum are anomalous only in areas of observed sulfide mineralization (Table 5, Figs. 20C, 21; Friske et al. 1979, Sinclair 1982, Wolfe 1974). Elsewhere in the plutons, copper and molybdenum contents are identical to those in unmineralized plutons. Zinc content of the Setting Net Lake pluton (No. 4, Table 3) is identical (30 ppm) in both unmineralized and mineralized parts of the pluton (Wolfe 1974), but at Beidelman Bay (No. 6, Table 3), there is a wide zinc-rich halo (75 ppm) surrounding the copper-rich zones (Friske et al. 1979). Thus, although extensive studies have not yet been made, plutons that contain mineralization do not seem to be geochemically anomalous except in the vicinity of the mineralization (Table 4); in the absence of visible mineralization, there is as yet no geochemical parameter that can be used to distinguish unmineralized from potentially mineralized plutons.

The genesis of mineralization and alteration in porphyry-type deposits is controversial. The lack of geochemical anomalies has led some authors (e.g., Friske et al. 1979) to suggest that the source of the copper, molybdenum and hydrothermal fluids was the country rocks rather than the pluton. The pluton is simply an ap-

### Table 5. Copper and Molybdenum Contents of Three Granitic and One Syenitic Plutons That Contain Porphyry Occurrences

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Rock type</th>
<th>Copper (ppm)</th>
<th>Molybdenum (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting Net Lake</td>
<td>Granodiorite</td>
<td>Mean of 25 samples collected in and adjacent to the mineralized zone in the north part of the stock (Fig. 20C). Samples selected to avoid contamination by mineralized veins.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and granite</td>
<td>61</td>
<td>1.7</td>
</tr>
<tr>
<td>Beidelman Bay</td>
<td>Tonalite</td>
<td>600</td>
<td>12</td>
</tr>
<tr>
<td>Whitefish Lake</td>
<td>Quartz monzodiorite</td>
<td>234</td>
<td>17</td>
</tr>
<tr>
<td>Matachewan (No. 10)</td>
<td>Syenite</td>
<td>835</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Boundary between mineralized and non-mineralized areas arbitrarily placed at 50 ppm Cu.</td>
</tr>
</tbody>
</table>
On the other hand, in many Phanerozoic porphyry deposits whose host plutons also lack anomalous Cu and Mo, except in and adjacent to mineralization (Olade & Fletcher 1976), the metals and much of the hydrothermal system appear to have been derived from the magma during crystallization (McMillan & Panteleyev 1980). The mineralization may have been later modified and possibly augmented by convective circulation of country-rock fluids driven by the heat of the pluton, but the major source of metals was the pluton. It has also been proposed that the hydrothermal fluids and metals originated in the same source-area as the magma, but moved to higher crustal levels independently of, and somewhat later than the magma (McMillan & Panteleyev 1980).

Other mineralized plutons

These plutons are distinguished from plutons hosting porphyry-type occurrences by the smaller size or more restricted nature of the mineralization, the less intense and more restricted alteration and, in places, the greater thickness of individual veins within vein systems. There are no apparent differences in composition, texture, habit, depth of emplacement or relationship to volcanism. Some of these mineral occurrences may represent insufficiently explored porphyry-type occurrences (Fig. 19).

Sulfide mineralization in these plutons occurs in several habits (Colvine & Sutherland 1979a, b, Colvine & McCarter 1977, Studemeister & Colvine 1978, Sutherland 1978, Sutherland & Colvine 1979). 1) Single or multiple quartz and, locally, quartz-carbonate veins, lenses, pods and irregular masses. Individual veins and pods are generally much wider (up to several metres) than veinlets in porphyry-type occurrences, and more restricted in extent. Many of the veins occur in faults or follow lithologic contacts rather than occupy simple dilational fractures as in porphyry occurrences. Vein boundaries range from sharp to diffuse. 2) Planar to irregular fractures, in part associated with narrow veinlets of quartz, or along the margins of pegmatite dykelets. These resemble porphyry-type occurrences but are of much more localized extent. 3) Disseminations. 4) Pegmatite dykes. This type of habit is restricted to molybdenum mineralization and will be mentioned under pegmatites (Table 8).

Mineralization in most plutons appears to have the same rather nebulous origin as porphyry-type occurrences. In other plutons, however, the mineralization can be related to re-
mobilization or assimilation of pre-pluton sulfide occurrences in country rocks (Studemeister & Colvine 1978, Sutherland & Colvine 1979).

Summary

Copper, molybdenum and gold mineralization of both porphyry and non-porphyry types is confined largely to small pre-tectonic or early-tectonic granitoid plutons that are genetically related to volcanism and that occur within greenstone belts, particularly those in the southern Superior Province; late-tectonic plutons that are unrelated to the host volcanic sequences appear to be mineralized only rarely. Mineralized plutons are generally tonalite – granodiorite, but they are apparently indistinguishable from unmineralized plutons of similar composition, texture, habit and tectonic position.
Mineralization also occurs in late, post-tectonic granitoid plutons, but these are spatially and genetically related to nearby younger volcanism of overlapping structural provinces. Mineralization is apparently rare in the subvolcanic plutons of the Bear Province, although these plutons have not been extensively explored. Hoffman & Cecile (1974) considered that plutons in the Bear Province are unlikely hosts for porphyry deposits, although Badham & Morton (1976) have reported minor porphyry-copper-type mineralization.

The spatial and apparent temporal and genetic association of many mineralized plutons with volcanism suggests that 1) greenstone belts and older crustal terranes adjacent to younger volcanic sequences are the prime prospecting targets for additional discoveries, and 2) metals
Fig. 23. Locations of major gold–silver deposits in the western Churchill Province of the Canadian Shield. Possible porphyry-gold deposits after Franklin & Thorpe (1982).
concentrated in the plutons may have been scavenged from the volcanic sequence rather than being concentrated by magmatic crystallization.

**GOLD–SILVER**

In addition to the copper–molybdenum–gold association just described, granitoid rocks also host gold–silver occurrences that lack (or contain only minor) copper; some have been classified as porphyry–gold deposits (Franklin & Thorpe 1982, Sinclair 1982). Gold-bearing plutons are relatively small, subvolcanic and epizonal dykes, sills, stocks or small batholiths of both granitoid and syenitoid compositions. Pluton-hosted gold occurrences are restricted almost entirely to greenstone-belt terranes in the Superior Province (Fig. 22). A few occurrences have been reported from the Southeastern Zone Subprovince of the Churchill Province (Fig. 23) and the Central Metasedimentary Zone Subprovince of the Grenville Province (Fig. 22), but these plutons are also associated with greenstone belts. Gold-bearing plutons are rare in the large granitoid batholithic complexes, paragneiss terranes, reworked basement, and sedimentary cover sequences. Numerous gold–silver deposits occur in the Slave Province, but except for a large deposit in a tonalite dyke near Indin Lake (Annis et al. 1976, p. 75), all of the major deposits are in metavolcanic–metasedimentary sequences and not directly associated with granitoid plutons. Scarce gold–silver deposits in the Southern and Bear provinces are also not associated with granitoid plutons. No gold deposits of any type have been reported from the Nain Province. Unlike the copper–molybdenum occurrences, many of the gold–silver deposits have been mined; only the mines and larger prospects are shown in Figures 22 and 23.

Both granitoid and syenitoid plutons host gold deposits (Fig. 22). Gold-bearing granitoid plutons are mainly tonalite (some of which is trondhjemite) and granodiorite with minor granite (Table 6; Boyle 1979, Riley et al. 1971, Whitmore 1970) and range from simple single-phase bodies to composite, locally zoned plutons, some of which have dioritic phases. Gold-bearing syenitoid plutons include diorite, monzodiorite, monzonite, syenite and quartz syenite and form either discrete plutons or phases of granitoid plutons. Syenitoid plutons associated with gold–silver mineralization are restricted largely to the Abitibi Subprovince of the Superior Province (Fig. 22), with the best examples being the various mines of the Kirkland Lake area (Ridler 1970, Thomson et al. 1950), the Matachewan area (Sinclair 1982), and some mines in the Val d’Or area (Latulippe & Germain 1979). Published chemical data on gold-bearing granitoid plutons, particularly trace-element data, are sparse. Consequently, only a few data have been given in Table 6 to show the compositional range and alteration effects. Plutons hosting gold deposits are slightly enriched in gold compared to plutons that lack gold deposits (Table 7, Kerrich et al. 1980, Wolfe 1975).

Texturally, there are two main types of plutons: 1) porphyritic subvolcanic dykes, sills, irregular plugs and small stocks that contain medium-grained phenocrysts of quartz or plagioclase (or both, more rarely with orthoclase) in an anaphitic to fine-grained groundmass. Lithologically, these are commonly referred to as quartz porphyry, feldspar porphyry or quartz feldspar porphyry (Figs. 24, 25, 26). 2) Porphyritic to equigranular medium-grained epizonal
Veinlets are largely restricted to a tonalitic quartz porphyry unit that was interpreted by Horwood (1948) and Pirie (1981) to be an intrusive dyke, and by Ferguson (1968) to be a pyroclastic flow unit. The country rocks that in part were mapped as diorite by Horwood (1948) and Pirie (1981), have been interpreted by Ferguson (1968) to be more mafic pyroclastic flows. Franklin & Thorpe (1982) consider that this may be a porphyry-gold deposit.

![Diagram showing gold-quartz veinlets in the former Howey mine of the Red Lake district, Ontario.](image)

**Fig. 24.** Distribution of gold–quartz veinlets in the former Howey mine of the Red Lake district, Ontario. Veinlets are largely restricted to a tonalitic quartz porphyry unit that was interpreted by Horwood (1948) and Pirie (1981) to be an intrusive dyke, and by Ferguson (1968) to be a pyroclastic flow unit. The country rocks that in part were mapped as diorite by Horwood (1948) and Pirie (1981), have been interpreted by Ferguson (1968) to be more mafic pyroclastic flows. Franklin & Thorpe (1982) consider that this may be a porphyry-gold deposit.
in which are anomalously enriched in Na, volatiles, Au and $^{18}$O (Table 7) compared to plutons that lack gold mineralization. The alteration is most intense near gold concentrations, but the entire pluton is somewhat anomalous (Table 7). In other plutons, however, Na and Ca have been strongly depleted, with K and, in places, Mg enriched adjacent to gold-bearing veins (Poulsen & Franklin 1981, Studemeister et al. 1981).

As a result of the combined deformation, metamorphism and alteration, primary textures in the groundmass are poorly preserved in many subvolcanic plutons. This has led to some controversy about the origin of the porphyry units (e.g., Hopwood 1976) and the distinction between plutons and texturally similar flows and pyroclastic units. The data are not always unequivocal, but in most areas, plutons can be distinguished by their more massive character and by their contact relations. Although some bodies originally mapped as plutons have been suggested, on more detailed examination, to be altered pyroclastic units (Figs. 24, 25; Davies & Luhta 1978, 1979, Ferguson 1968, Karvinen 1981, Sutherland & Colvine 1979), other workers have questioned this interpretation (e.g., Griffis 1979, Pirie 1981). The presence of many subvolcanic plutons is well documented but, in spite of these data, some authors (e.g., Boyle 1976) have suggested that all porphyry plutons are metasomatic replacement zones.

The deposits are mainly hypogene, epigenetic, single- to multi-stage quartz and quartz-carbonate veins, lodes, lenses, stockworks, silicified zones and disseminations within or marginal to
faults and fracture zones (Boyle 1979, Whitmore 1970), some of which are ductile shear zones developed prior to or during metamorphism (Poulsen & Franklin 1981). In some gold-bearing plutons, the gold mineralization is apparently preferentially concentrated near country-rock xenoliths and hybrid zones (Mackasey et al. 1974), or in the marginal zone and adjacent country rocks (Studemeister et al. 1981). Most deposits are confined to planar, curviplanar or irregular zones within which there may be one or more vein systems; vein boundaries range from sharp to gradational. Many veins contain several generations of quartz, not all of which are auriferous. The carbonate, where present, comprises ankerite, dolomite and calcite. Scheelite, tourmaline, pyrite, arsenopyrite, chalcopyrite and other sulfide and telluride minerals are present in varying amounts in gold-bearing quartz and quartz-carbonate veins at many deposits, although at some deposits the quartz and quartz-carbonate veins contain only native gold and silver. Most of the gold is native and is commonly associated with pyrite and arsenopyrite and alloyed with native silver; the gold commonly fills brittle fractures in both quartz and sulfide minerals (Goman et al. 1981). Gold is generally more abundant than silver by a factor of 3 to 5 (Boyle 1979); in some deposits, the ratio Au/Ag decreases with depth (Boyle 1979, Fitzgerald et al. 1967). Deposits in which silver predominates over gold are rare in granitoid plutons (Boyle 1968).

Some gold-bearing plutons have been clas-
Fig. 27. Distribution of gold-quartz veins in a vertical section through the Lamaque mine, Quebec (after Wilson 1948). Veins occur along faults and are largely restricted to the zoned granodiorite-diorite plug.
sified as porphyry-gold deposits (Figs. 22, 23, Franklin & Thorpe 1982, Sinclair 1982). They differ from other pluton-hosted gold deposits in that areally extensive gold and associated pyrite are disseminated or present in minor fractures (Fig. 24) within the pluton rather than related to a major vein or shear-zone system. Alteration appears to be less extensive than related to a major vein or shear-zone system. However, statistical analysis of relationships between mafic and ultramafic plutons and felsic plutons, although Preston and Paymaster porphyry plutons (1980, 1982), although Is-rigons (1980) and Sinclair (1982) have described potassic alteration at several deposits. Franklin & Thorpe (1982) have identified 13 possible porphyry-gold deposits in the Slave, Churchill and Superior provinces (Figs. 22, 23). Grade ranges from 1 to 2.8 ppm, with reserves of 1–18 × 10⁴ tonnes (Franklin & Thorpe 1982); some deposits in the Superior Province, such as Howie-Hasaga (Red Lake, Fig. 24) of the Uchi Subprovince and Camflo (Val d’Or), Sigma (Malartic) and Young-Davidson (Matagami) of the Abitibi Subprovince have been or are currently being mined.

There is considerable controversy about the role of granitoid and syenitoid plutons in the genesis of gold deposits. In the greenstone belts, most gold–silver deposits are in metavolcanic and metasedimentary country-rocks rather than in felsic plutons, although plutons commonly occur nearby (Franklin & Thorpe 1982). However, statistical analysis of relationships between host rock and gold–silver deposit shows that gold deposits are preferentially concentrated in or near small plutons, at least in some areas. For example, in the west-central part of the Superior Province of northwestern Ontario, Riley et al. (1971) found that 30% of the 253 gold occurrences, including some producing mines, were, at least in part, in small felsic plutons, yet these plutons comprise less than 5% of the greenstone belts in the region examined (Riley 1973). Even in the case of deposits not in felsic plutons, plutons occur in the immediate vicinity of many of them. Where plutons are associated with gold–silver deposits, the vein system may be largely confined to the pluton and immediately adjacent country rocks, or it may occupy a fault or fracture system that crosses both pluton and country rocks, i.e., it is not related obviously to pluton emplacement. However, in some of the latter deposits the gold content of the vein system is higher where the veins cross the pluton.

Riley et al. (1971) found also a spatial association between mafic and ultramafic plutons and gold–silver deposits, but not for any of the metavolcanic or metasedimentary rock units tested. On the other hand, in the Abitibi Subprovince, Ridler (1970, 1976) has shown that carbonate-rich units are greatly enriched in gold and host many gold occurrences. Ridler (1970) considered that the carbonate-rich units were chemically precipitated sedimentary rocks (exhalites), but chemical and textural data now indicate that these units are carbonatized, possibly volcanic ultramafic rocks (Tihor & Crocket 1977). Elsewhere in the Abitibi Subprovince, Pyke (1975) has shown that gold deposits are associated with ultramafic metavolcanic units.

Although there appears to be a spatial association in many areas between gold–silver deposits and felsic plutons, there is some controversy about whether the deposits are genetically related to the emplacement of the plutons (e.g., Latulippe & Germain 1979, Riley et al. 1971) or whether the plutons are structurally and chemically favorable hosts for mineralization that is not genetically related to pluton emplacement (Boyle 1979, Franklin & Thorpe 1982, Gorman et al. 1981, Kerrich et al. 1980). Boyle (1979) based his conclusion favoring no genetic link on several factors: 1) some vein systems occupy regional structures that only accidentally cross plutons, 2) the gold–silver–quartz veins occur in structures that postdate pluton consolidation, and 3) felsic plutons have a low gold content, although Wolfe (1975) and Kerrich et al. (1980) found that Archean felsic plutons associated with gold deposits are slightly enriched in gold. These arguments, however, are equivocal; points 2 and 3, with appropriate substitution of copper and molybdenum for gold and silver, could be applied also to porphyry-copper and porphyry-molybdenum deposits, for which most authors agree that the host porphyritic plutons are genetically related. The uncertainties are the source of the metals and the concentrating mechanisms.

As in porphyry deposits, the heat introduced by rising magma, particularly in relatively long-
lived volcanic conduits, could have caused convective movement of formational and introduced waters which, in turn, led to leaching and migration of gold and other elements toward the plutons (e.g., Mackasey et al. 1974, Sutherland & Colvine 1979). In this model, the veins were deposited in fractures and faults, either in the plutons or in country rocks, that developed after consolidation but prior to final cooling. The actual depositional site would be a function of location and nature of favorable structures, temperature gradients, and chemistry, pressure and temperature of the fluids vis-à-vis those of the rock sequence. The plutons initiated gold migration but did not necessarily control the final site of deposition. Poulsen & Franklin (1981) have proposed that, in some deposits, widely dispersed gold within a porphyry deposit may have been concentrated and redeposited into shear zones during metamorphism, with consequent destruction of the original porphyry deposit.

Arguments presented by Kerrich & Fryer (1981), on the other hand, suggest that the above mechanism is an unlikely concentrating agent for gold deposits hosted by subvolcanic plutons, although it could possibly apply to deposits in deeper-seated plutons. These authors stressed that, although copper can be concentrated from country rocks by large volumes of circulating water, concentration of gold without copper requires low fluid-to-rock ratios. They suggested that the most likely fluids for gold concentration are those produced during the transition from low to moderate grades of metamorphism at some time after pluton emplacement. However, if, as suggested by Ayres (1978), granitoid batholiths are the major sources of heat for metamorphism of greenstone-belt sequences, then batholiths are a potential driving force for gold concentration. In this case, plutons are both the host and driving force, although the host and driving plutons would generally be different, particularly for deposits hosted by early subvolcanic plutons. Lower-epizonal gold-bearing plutons, however, could be both hosts and concentrating agents.

The enrichment of some gold-bearing plutons in sodium and volatiles (Table 7) has been attributed to early interaction between the plutons and large volumes of seawater at temperatures of <200–350°C, producing extensive albitization (Gorman et al. 1981, Kerrich et al. 1980). The gold is considered to have been introduced later by metamorphically produced fluids at higher temperatures (420–480°C), but the early albitization apparently was a prerequisite for gold deposition (Kerrich et al. 1980, Kerrich & Fryer 1981). According to Kerrich et al. (1980), plutons that lack early interaction with seawater will not contain gold deposits.

In summary, the spatial association between gold and subvolcanic to epizonal tonalite–granodiorite and syenite plutons cannot be ignored. Although many of these felsic plutons have no associated mineralization, and the plutons are not the sole, nor necessarily the most important host for gold deposits, they are spatially associated with some gold–silver deposits. The nature of the genetic association, if any, is more controversial, but irrespective of genetic models, such plutons in greenstone belts of the Canadian Shield are a favorable target for prospecting. They may host or be adjacent to major vein or other structurally controlled deposits. As stressed by a number of authors, with the rapid rise in the price of gold, felsic plutons should be examined also for the presence of large low-grade, porphyry-type gold deposits.

As with copper–molybdenum–gold occurrences, gold–silver deposits are concentrated in the southern part of the Superior Province (cf. Figs. 19, 22). This probably also reflects the greater width of the greenstone belts and greater abundance of internal plutons in this region (Goodwin 1970).

**Granitic Pegmatites**

**Introduction**

The Canadian Shield is relatively rich in mineralized granitic pegmatites, and the number of recognized pegmatite fields and districts can be expected to increase with continued prospecting. However, the petrogenetic aspects of most pegmatite localities have not been studied in sufficient detail; the relationship of the pegmatites of granitic intrusions and anatectic events is poorly understood in many cases. Consequently, broad generalizations are not feasible for many provinces and subprovinces. Several case-histories of better-known fields and districts are emphasized instead, as examples that may be typical of pegmatites generated by granitic fractionation in different host-units. Pegmatites of metamorphic parentage are also briefly mentioned to complement the review and to provide contrast to magmatogenic pegmatites.

Rare-element pegmatites are not known from the Nain, Southern and Bear provinces, although late leucogranitic and pegmatite intrusions are typical of some segments of the latter two (Cannon 1970, Frith et al. 1977a, Hoffman & McGlynn 1977). These three provinces are thus excluded from the following discussion. A
separate section is devoted to each of the other four provinces because of gross differences among the pegmatite types populating them.

Detailed listings and brief characteristics of pegmatites with Li, Cs, Be, Nb-Ta, Sn, Mo, U and Th in the Canadian Shield are available in Mulligan (1961, 1965, 1968, 1975), Lang et al. (1962), Vokes (1963), Hewith (1967) and Dawson (1974). These references also contain production and reserve data; for lithium, this information has been recently updated by Flanagan (1978), Lasmanis (1978) and Williams & Trueman (1978).

Superior Province

In the complex structures and lithologies of the Superior Province, most occurrences of rare-element pegmatites are concentrated (1) within the paragneiss–granitoid subprovinces (English River, Quetico and Pontiac), (2) along and near the boundaries of these subprovinces with the greenstone–granodiorite subprovinces, and (3) along the boundaries of other subprovince types (Fig. 28). The remaining occurrences are scattered in the northern parts of the Sachigo and Opatica subprovinces, in part spatially related to their paragneissic segments. Their geological setting cannot be specified in more detail because the regional geology of these parts of the shield is still poorly understood.

In terms of age relationships, all rare-element pegmatites dated so far are related to the main 2.6 Ga (Kenoran) event (e.g., Dawson 1966, Penner & Clark 1971). Within this event, better-known pegmatite occurrences have originated during its latest tectonic and intrusive stages (e.g., the Winnipeg River pegmatite district: Černý et al. 1981).

Structurally, many pegmatite occurrences are spatially associated with large-scale systems of deep faults that separate (locally) the subprovinces (Pashkokogan Lake, Roadhouse Lake and other localities along the Lake St. Joseph fault bounding the English River and Uchi subprovinces) or slice their interiors, commonly in directions subparallel to the subprovince boun-

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**Fig. 28.** Distribution of mineralized pegmatites in the Superior Province. Most individual symbols represent larger groups of pegmatites. Symbols: 1. subprovinces and terranes with predominant paragneiss; 2. subprovince boundaries. Localities of pegmatite fields and districts: 1. Cat Lake – Winnipeg River field, 2. Falcon Lake district, 3. Dryden district, 4. Fort Hope district, 5. Zigzag Lake field, 6. Georgia Lake field, 7. Preissac–Lacorne field, 8. Lac-La-Croix field. See Table 8 for characteristic features of some of these fields and districts.
daries (Winnipeg River and Cat Lake–Maskwa lake districts in the English River Subprovince; Red Cross Lake district in the Sachigo Subprovince) or along orthogonal greenstone-belt patterns (Fort Hope district in the Uchi Subprovince). These fault systems have had a long history of displacements, although their present expressions appear to be rather late, postdating most of the regional metamorphic fabric and plutonic structure (Jolly 1978, Schwerdtner et al. 1979). Pegmatite-generating granitoids and their pegmatite aureoles are mostly related to these final stages of faulting. In some areas, contacts of large batholiths represent the regional structural element controlling the emplacement of satellite granitoid and their pegmatite suites. However, emplacement of the batholith was apparently structurally controlled (Breaks et al. 1978). Late intrusive activity along their contacts, possibly reflecting a re-activation of the old structures along the relatively weak margins of the batholith, may have healed the original structure.

Most of the rare-element pegmatites were intruded into greenstone-belt sequences or, to a lesser degree, into paragneiss. During late-tectonic disturbances along reactivated fault systems, and in regional compressional regimes (Fyson et al. 1978), the highly deformed and jointed supracrustal sequences evidently provided dilated structural traps much more readily than the relatively competent orthogneiss suites and younger plutons. However, some pegmatite groups are also hosted by these more competent lithologies (Černý et al. 1981). Mineralized pegmatites occur only exceptionally within their parent granitoid complexes (Dawson 1966); even in these complexes the pegmatites seem to be external in relation to their parent intrusive phases.

The metamorphic environment in which rare-element pegmatites and their parent granitoids have been intruded is characterized, in most cases, by (1) steep regional gradients, (2) upper greenschist- to lower-amphibolite grade of the host rocks, and (3) proximity (at least relative) to thermal highs marked by sillimanite occurrences or to local areas of low-pressure granulite-facies metamorphism. The steep metamorphic gradients have been documented in several pegmatite districts (e.g., Pirie & Mackasey 1978, Thurston & Breaks 1978, Breaks et al. 1978, Trueeman 1980). In the English River Subprovince, low-pressure granulate terranes were documented (e.g., Trueeman et al. 1976, Thurston & Breaks 1978) in close proximity to the low-grade pegmatite-bearing terranes. Sillimanite is generally rare but typical of greenstone belts near the boundaries of the English River, Quetico and Berens River subprovinces (Ayres 1978) close to but not within areas populated by mineralized pegmatites. Metapelite components of supracrustal sequences hosting mineralized pegmatites commonly contain muscovite along with andalusite, staurolite, cordierite, anthophyllite and garnet, individually or in different combinations (Breaks et al. 1978, Pirie & Mackasey 1978, Trueman 1980).

Granitoid complexes parental to the rare-element pegmatites have been unambiguously identified in relatively few areas. They generally (1) are emplaced at late-tectonic to post-tectonic stages, (2) consist of relatively small stocks and plugs that are, in some cases, satellite to intrusions of batholithic proportions, but not necessarily related to them genetically, (3) are leucocratic with biotite, biotite + muscovite, muscovite, or muscovite (+ garnet) as mafic minerals, and (4) are silicic and Ca-poor in bulk composition, lack normative diopside and contain 0–5% normative (CIPW) corundum. Li, Rb, Cs, Be, Sn, Ga, Nb and Ta typically are enriched in the parent granites, whereas Ba, Sr, Ti, Zr, LREE and Eu are depleted. Although accurate data are too scarce for generalized quantitative characterization, some individual examples are given in the subsequent sections. Lack of data is even more conspicuous with respect to the genesis of pegmatite-generating melts. Anatectic of supracrustal sequences is suggested (Breaks et al. 1978, Černý et al. 1978, Breaks, pers. comm. 1980), but I-type magmas generated in the lower crust and contaminated during their ascent through supracrustal lithologies may also be represented (Černý et al. 1981, Goad & Černý 1981, Longstaffe et al. 1981).

Geochemical distinction of parental lithologies, however, appears to be difficult since the leucogranites and pegmatitic granites must have undergone a volatile-promoted fractionation in liquid state, beyond the levels attainable by simple crystal–melt fractionation (which is currently the only one amenable to quantitative modeling). Hildreth’s (1979) thermogravitation-al convection-diffusion may have operated in the internal evolution of the “fertile” granites, compounded by the effects of vapor transfer in separating supercritical fluids (Černý 1982a, Černý & Brisbin 1982).

The rare-element pegmatites of the Superior Province are considerably diversified in their mineralogy and geochemistry, but most of them can be correlated with one or another of the six pegmatite types listed in Table 8. However, distinction of these categories on the basis of published descriptions commonly is difficult.
Thus, a modified classification of pegmatite types is used in Figure 28, which does not include, for sake of simplicity, the few localities of types 1.5A, 5B and 6.

Pegmatites of most of the tabulated types may occur in isolation or as parts of more or less zoned regional sequences. Anatectic pegmatites (types 5B, 6) and radioactive pegmatites related to late potassic plutons (type 1) are the only exceptions. The absence of garnet, sillimanite and cordierite is the best criterion for distinguishing igneous U-Th-bearing pegmatites from the products of partial melting (type 6; Breaks et al. 1978, Breaks 1980, Franklin 1978b, Pryslak 1976). Igneous U-Th-bearing pegmatites are also more fractionated than the anatectic U-Th-bearing pegmatites related to late potassic plutons (type 1). The absence of garnet, sillimanite and cordierite is the best criterion for distinguishing igneous U-Th-bearing pegmatites from the products of partial melting (type 6; Breaks et al. 1978, Breaks 1980, Franklin 1978b, Pryslak 1976). Igneous U-Th-bearing pegmatites are also more fractionated than the anatectic U-Th-bearing pegmatites related to late potassic plutons (type 1).

Lithium pegmatites with primary Fe-enriched spodumene (type 2) are one of the most widespread types of rare-element pegmatite in the province. However, they are commonly difficult to assign to specific parental intrusions (Cerny et al. 1981). Their structural position and internal structure frequently reflect the high-P regime of their crystallization, as indicated experimentally (Stewart 1963, 1978, London 1981, London & Burt 1982). In contrast, the geochemically more diversified type (4), enriched in Li, Rb, Cs, Ta-Nb, Sn, Be, B and F, commonly carries the low-pressure phase petalite as the primary Li-aluminosilicate (see the references above) and, locally, pollucite, which also crystallizes in low-pressure environments (Cerny & Simpson 1978, Cerny 1979, 1982b).

The Mo-bearing pegmatites of igneous descent (type 5) are commonly transitional into feldspar-bearing quartz veins with more diversified mineralization (Dawson 1966, Vokes 1963). Anatectic leucosome with molybdenite is, however, characterized by very simple assemblages of minerals (Cerny & Turnock 1971b). In the following sections, two examples of pegmatite districts and fields are demonstrated that encompass all of the geochemical pegmatite types of igneous derivation.

The Winnipeg River pegmatite district. This district is located predominantly in the Bird River greenstone belt, along the boundary separating the southern Winnipeg River batholithic belt from the northern Manigotagan – Ear Falls greiss belt of the English River Subprovince in southeastern Manitoba (Fig. 28, No. 1, Fig. 29; Beakhouse 1977, Trueman 1980). An upper greenschist metamorphic grade predominates in most of the metasedimentary and metavolcanic rocks of the greenstone belt, but the grade in-
METALLOGENY OF GRANITOID ROCKS IN THE CANADIAN SHIELD

Fig. 29. The Winnipeg River pegmatite district. 1. gneissic "schollen"-zone of the Winnipeg River batholithic belt (I) and paragneiss of the Manigotagan—Ear Falls belt (II); 2. Bird River greenstone belt; 3. Maskwa Lake (MWL) and Marijane Lake (MJL) composite batholiths; Lac-du-Bonnet (LdB) batholith; 4. early hornblende-biotite granodiorite, 5. leucogranite parental to the SHL pegmatite group; 6. biotite granite; 7. pegmatitic granites (GL Greer Lake, ENL Eaglenest Lake, AX Axial, TL Tin Lake and OL Osis Lake bodies). Pegmatite groups (see inset for symbols): LdB Lac-du-Bonnet, SHL Shatford Lake, GL Greer Lake, BIS Birs Lake, RL Rush Lake, ENL Eaglenest Lake, AX Axial, BL Bernic Lake. From Černý (1982a).

creases to the upper amphibolite facies in the northwestern part of the area shown in Figure 29. Several periods of folding and metamorphism, partly contemporaneous with diapirc emplacement of the Maskwa Lake and Marijane Lake tonalites, shaped the belt into a broad synclinorium that was subsequently segmented by regional east-trending subvertical faults (Černý et al. 1981, Trueman 1980). The volcanic, metamorphic and plutonic evolution of the area spanned the period from 2.7 to 2.5 Ga (Farquharson & Clark 1971, Farquharson 1975, Penner & Clark 1981).

Three sequences of granitoid intrusions can be distinguished in the district, mostly separated in time but partly overlapping, and apparently of independent origin: (1) syntectonic diapiric tonalite batholiths, (2) late-tectonic potassic biotite granites, and (3) late- to post-tectonic leucogranites and pegmatitic granites (Fig. 29; Černý et al. 1981).

Diapiric tonalite – trondhjemite batholiths, emplaced during the main episode of dynamic metamorphism of the greenstone belt, display a foliation due to a range of processes, from igneous flow to metamorphic recrystallization. Plagioclase (\(\text{An}_{35-50}\)), hornblende, quartz, biotite and minor K-feldspar constitute these rocks, with accessory zircon and apatite, and secondary epidote, chlorite and sericite. Rare barren pegmatite stringers are associated with the tonalites. In chemical composition, as shown in Table 9 and in Figures 30 to 32, they are typical of Arth's (1979) class of continental tonalites derived from lower crust or upper mantle by partial melting of amphibolite.

Biotite granites, which dissect and mantle the tonalite diapirs, are massive and mostly nonfoliated, with weak recrystallization effects. Plagioclase (\(\text{An}_{35-60}\)), K-feldspar and quartz predominate over biotite; apatite, zircon and allanite are the main accessory constituents, along with epidote, sericite, carbonate and other alteration products. Minor potassic pegmatites with U-Th mineralization and allanite (type 1) crosscut the margins of the biotite granites as well as the adjacent host-rocks. By their chemical composition represented in Table 9 and in Figures 30 to 32, these granites are classified as granodioritic to granitic calc-alkalic to alkali-
calcic intrusions, genetically independent of the
tonalites, and generated probably by partial
melting of shortlived greywacke at
(1975) developed a convincing model based on
segmenting and bounding the greenstone belt
during a regional dilation. The granites show a
complex fingering-out of contacts in schistose
host-rocks, and simple straight boundaries plus
angular xenoliths in massive hosts, suggestive
of stoping. They consist of a wide diversity of
phases, including equigranular fine-grained leu-
cogranites, megacrystic pegmatitic leucogranites,
sodic aplites, and potassic pegmatite layers and
pods. They are composed of plagioclase (An$_{2-4}$),
K-feldspar and quartz, subordinate but highly
fractionated in terms of K/Rb, K/Cs,
and Ca-poor, K-rich in bulk composition, and
their alkali-calcic affinity; they are highly silicic
and Ca$_2$O,

### Table 9: Chemical Composition of plutonic granitoid rocks of the Winnipeg River pegmatite district

<table>
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<tr>
<th>Mineral</th>
<th>An</th>
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<th>Or</th>
<th>K$_2$O</th>
<th>Na$_2$O</th>
<th>CaO</th>
<th>Nb</th>
<th>TiO$_2$</th>
<th>P$_2$O$_5$</th>
<th>Hf</th>
<th>Ta</th>
<th>Zr</th>
<th>Sn</th>
<th>Mo</th>
<th>Ba</th>
<th>Sr</th>
<th>Pb</th>
<th>Zn</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>Al$_2$O$_3$</th>
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<td>LiClO$_4$</td>
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<td>99.78</td>
<td>99.39</td>
<td>99.97</td>
<td>99.50</td>
<td>100.02</td>
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<td>K$_2$O</td>
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<tr>
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Fig. 30. Na₂O–K₂O–CaO, Ab–Or–Q and Ab–Or–An (mesonorm) diagrams for granitoid rocks of the Winnipeg River pegmatite district. Maskwa Lake batholith (long dash), Marijane Lake batholith (dots) and Lac-du-Bonnet batholith (solid line): tonalites (heavy) and biotite granites (light); Lac-du-Bonnet leucogranite (short dash), metarhyolites of the Peterson Creek Formation (dash–dot) and fine-grained leucogranite phases of the pegmatitic granites (extra heavy outline); tr. trondhjemitic trend, c.–a., calc-alkaline trend (after Barker & Arth 1976). In the Ab–Or–Q mesonorm diagram, thin line connecting solid dots marks granitic minima and eutectics from 1 to 10 kbar (after Tuttle & Bowen 1958, Luth et al. 1964). In the Ab–Or–An mesonorm diagram, the low-temperature trough covers the range of 1 to 10 kbar (after Kleeman 1965). After Černý et al. (1981).
initiation of their origin (Černý et al. 1981, Goad & Černý 1981, Longstaffe et al. 1981). Fractionation from a juvenile I-type granitoid source modified by reaction with supracrustal sequences, is one possibility. It may include a relationship to one of the rhyolite formations of the greenstone belt (Table 10, Figs. 30 to 32). Shallow anatexis of greenstone-belt lithologies, particularly metapelitie and metarhyolite, followed by crystal–melt and liquid fractionation is another possible mechanism.

Table 11 summarizes the geochemical and mineralogical characteristics of the individual leucogranites and pegmatitic granites, and of the pegmatite groups in the district. In conjunction with Figure 29, these data indicate a good correlation between the major intrusions and their spatially associated pegmatite aureoles. Further geochemical documentation is given by Černý et al. (1981). Current research conducted in the western part of the Superior Province indicates that the petrogenetic relationships of mineralized pegmatites established in the Winnipeg River district are characteristic of numerous other districts and fields (Breaks 1982, Ucakuwun 1981, Černý, unpubl. data).

At present market conditions, some pegmatites in this district are marginally economic for Ta and Be, and several pegmatites can produce refractory-grade spodumene. The only deposit currently productive is the Tanco pegmatite, a member of the Bernic Lake group, with major reserves of Li, Ta, Be and Cs (Crouse et al. 1979).

The Preissac-Lacorne pegmatite district. This pegmatite district is located in the Abitibi Subprovince, just north of its faulted boundary with the Pontiac Subprovince in Quebec (Fig. 28, No. 7; Fig. 33). Most of the information on this district comes from Tremblay (1950), Rowe (1953), Ingham & Latulippe (1957), Siroonian et al. (1959), Dawson (1966), Goodwin & Ridler (1970) and Jolly (1978).

The pegmatite district is centred around the Preissac–Lacorne batholith, which upwarped an anticlinal dome in the greenstone sequence. The batholith is surrounded by synformal troughs with coincident regional faults. The regionally developed greenschist grade of the metavolcanic rocks is elevated to amphibolite facies in a contact-metamorphic aureole mantling the batholith. Dawson (1966) considered 2.63 Ga to be the most probable age of the Preissac–Lacorne batholith.

The batholith outcrops in three massifs, Preissac, Lamotte and Lacorne, separated by synclinal schist bands on the surface but continuous at depth (Fig. 33). The batholith consists mainly of hornblende monzonite, granodiorite and leucogranite, with minor hornblende diorite and monzodiorite.

Bulk chemical compositions and Li contents of whole rocks and their micas are given in Table 12 for the three major rock-types. A partial overlap of the hornblende monzonite and granodiorite categories of Siroonian et al. (1959) and Dawson (1966) is not detrimental to the present survey but should be kept in mind. According to Dawson, granodiorite represents the parent-melt composition, which yielded the leucogranite by fractionation; all other lithologies, which are quartz-poor and mafic, originated by contamination of the granodiorite via digestion of metavolcanic rocks.
whose abundant xenoliths are dispersed throughout these rock types. However, Card (1981) suggested that the leucogranite formed by anatexis of metasediments (possibly Pontiac gneisses underlying the Abitibi belt), and it happened to intrude the early granodiorites to tonalites indigenous to the metavolcanic belt.

Leucogranite generated the rare-element pegmatites in this district (Siroonian et al. 1959). The Li contents of the leucogranite and its micas increase from the pegmatite-free Preissac massif through the Lamotte to the Lacorne massif, which is surrounded by the most extensive and diversified pegmatite aureole (Table 12). The pegmatites are concentrated along the intrusive contacts of the batholith, apparently controlled by longitudinal and cross joints. The clusters of highly mineralized pegmatites are located mainly in heavily fractured structural traps along the contacts and in the adjacent greenstones.

A narrowly spaced but distinct zoning is developed around the Lamotte and Lacorne massifs: (1) barren pegmatites and aplite swarms occur in the interior, (2) beryl-bearing pegmatites also are of the interior type but are located closer to the contacts, (3) spodumene-bearing pegmatites are typically marginal, on both sides of the contacts, and (4) molybdenite-bearing pegmatites transitional into Mo-, Bi-, Fe-bearing quartz veins are external, followed by a zone of hydrothermal Au mineralization.

Pegmatites of geochemical types 3A, 2 and 5A are thus represented in the district, with a single pollucite-bearing pegmatite approaching type 4. Features typical of the different types of pegmatite are given in Table 13. Molybdenum, beryllium and lithium reserves are quoted by Vokes (1963), Mulligan (1968) and Flanagan (1978), respectively.
In conclusion, current activities in the district have revealed that the leucogranites, at least in part, are pegmatitic; detailed investigation may prove the regional relationships to be much more complex than outlined above (J.S.D. Parker, pers. comm. 1981, Card 1981).

Summary. The rare-element pegmatites of the Superior Province, as classified in Table 8, can be correlated with Kuzmenko’s (1976) general subdivision of magmatogenic pegmatites, with our classes 1 to 4 corresponding to his types 1 to 4, respectively. The whole population of pegmatites of the Superior Province may possibly be considered a giant-size pegmatite province of Gordyenko’s (1974) Li-, Cs-bearing type A, because of the widespread occurrences of pollucite. Such a designation definitely applies to the western part, west of the Kapuskasing Subprovince. In the eastern part, there is only a single occurrence of pollucite on record, but there is a potential for further discoveries of highly fractionated pollucite-bearing pegmatites in this largely unexplored region.

Internally, three pegmatite belts may be distinguished within the province: (1) the Li,Rb, Cs, Ta, Be, Sn-bearing English River pegmatite belt, (2) the Li,Be(Nb-Ta)-bearing Quetico pegmatite belt, and (3) the less distinct Li, Be(Nb-Ta, Cs)-bearing Pontiac pegmatite belt; each of these belts also includes the pegmatites occurring along the outside of their boundaries. Definition of belt-size units is not feasible at present in the northern Sachigo and Opatica subprovinces owing to insufficient exploration and lack of regional geological understanding. It is mainly in these regions that a great potential remains, even for surface pros-
<table>
<thead>
<tr>
<th>Major intrusion</th>
<th>Avg. whole rock K/Rb,K/Cs</th>
<th>Typical accessory minerals</th>
<th>Associated pegmatites</th>
<th>Geochemical type (Table 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marjome Lake biotite granite</td>
<td>173; 13,250</td>
<td>zircon, allanite</td>
<td>zircon, thorite, uraninite, allanite</td>
<td>Border pegmatites (U,Th,Zr,REE) 150; 23 1</td>
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<td>Lac-du-Bonnet group (LdB) Li 14; 580 2</td>
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<tr>
<td>Lac-du-Bonnet leucogranite</td>
<td>190; 18,000</td>
<td>zircon, allanite, (garnet)</td>
<td>beryl, garnet, topaz, allanite, monazite, zircon, thorite, uraninite, columbite-tantalite, gadolinite, cassiterite</td>
<td>Shatford Lake group (SHL) Be,Be/Ta,Sn,REE,U,Th,Zr/H 66; 61 3B</td>
</tr>
<tr>
<td>Tin Lake pegmatitic granite (TL)</td>
<td>176; 6,800</td>
<td>garnet (tourmaline)</td>
<td>tourmaline, beryl</td>
<td>Birse Lake group (BIS) Be((Li,Nb/Ta)) 119; 52 3A</td>
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<tr>
<td>Greer Lake and Eaglenest pegmatitic granites</td>
<td>81; 4,750</td>
<td>garnet, cordierite, (gahnite)</td>
<td>garnet, cordierite, beryl, columbite-tantalite (garnite, monazite, zircon, cassiterite)</td>
<td>Greer Lake and Eaglenest Lake groups (GL,ENL) Be,Be/Ta 40; 125 3A</td>
</tr>
<tr>
<td>Osis Lake pegmatitic granite (OL)</td>
<td>131; 2,800</td>
<td>garnet, tourmaline,apatite, (triphylite)</td>
<td>tourmaline, beryl, spodumene, petalite, amblygonite, triphylite, (Nb/Te-oxide minerals, cassiterite) (pollucite)</td>
<td>Rush Lake group (RL) Li,Rb,(Cs),Be,Sn,Nb/Ta,F,8 50; 265 4</td>
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<td>Bernic Lake group (BL) Li,Rb,Cs,Be,Sn,Nb/Ta,F,B 9.5; 1262 4</td>
</tr>
</tbody>
</table>

*adjusted after Černý et al. (1981); ( ) rare, (((() very rare.

pecting. However, geochemical exploration for hidden bodies should reveal new deposits also in the better-known belts in the south.

The granites parental to rare-element pegmatites are typically biotite–muscovite–, muscovite–, or muscovite–garnet-bearing, silicic, peraluminous, potassic to sodic, late-tectonic to post-tectonic stocks and plutons of small to intermediate size; they are characterized by increased Li, Rb, Cs, Be, Sn, B and Ga contents. These granites and the accompanying pegmatite swarms should be sought (1) along large-scale structural breaks, particularly the deep faults bounding and crossing major sedimentary troughs, and along subprovince boundaries marked by high geothermal gradients, (2) along margins of regional batholiths bordered by greenstone belts, (3) inside the metasedimentary subprovinces in areas of steep thermometamorphic gradients, and (4) mainly in regions of greenschist-facies metamorphism as represented by chlorite, muscovite, andalusite, cordierite, anthophyllite and staurolite in metapelites. In the first two cases, greenstone belts were the preferred hosts, providing structural traps in the waning stages of tectonic activity. In the third case, the anatectic granites commonly appear nearly autochthonous within their meta-
Fig. 33. The Preissac–Lacorne pegmatite field. Blank areas are undivided greenstone-belt schist and minor paragneiss, 2 gabbro, serpentinite, 3 hornblende diorite, 4 hornblende monzonite, 5 biotite granodiorite, 6 leuco-granite, 7 satellite and unrelated granitic rocks. 8. beryl-bearing pegmatite, 9. Nb-Ta-bearing pegmatite, 10. spodumene pegmatite, 11. molybdenite-bearing pegmatite. After Siroonian et al. (1959), Mulligan (1965) and Dawson (1966).

### TABLE 12. CHEMICAL COMPOSITION OF THE MAIN PHASES OF THE PREISSAC-LACORNE BATHOLITH

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<td>99.81</td>
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### TABLE 13. REGIONAL ZONING OF PEGMATITES IN THE PREISSAC-LACORNE FIELD

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<tr>
<th>Relation to Contacts** (Table 8)</th>
<th>Pegmatite Type</th>
<th>Shape and Internal Structure</th>
<th>Characteristic Accessory Minerals</th>
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<tr>
<td>Interior barren</td>
<td>-</td>
<td>irregular to fracture-filling; homogenous to poorly zoned</td>
<td>garnet</td>
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<td>Interior Be(Nb-Ta) 3A</td>
<td>fracture-filling; garnet, beryl</td>
<td>well zoned</td>
<td>(columnite, tantalite)</td>
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<tr>
<td>Marginal Li(Be,Nb-Ta) 2</td>
<td>fracture-filling; poorly to well zoned</td>
<td>spodumene, beryl (garnet, tourmaline, columnite-tantalite, Li-alcal) (pollucite, fluorite, bismuth, sphaerolite, molybdenite)</td>
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<tr>
<td>Exterior Mo(Be,Bi) 5A</td>
<td>fracture-filling; molybdenite poorly to well zoned; pyrite, bismuth, transitional lute, beryl, quartz veins</td>
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</table>

* After Vokes (1963), Mulligan (1965)

** This relates to the outer contacts of internally complex plutons, not necessarily to the contacts of parental intrusive phases (leucogranites).

sedimentary sources, and the pegmatites may have entered earlier structures dilated during granite segregation and intrusion.
The Slave Province

To date, only a single pegmatite-bearing region has been identified in this province. The Yellowknife pegmatite field is located in its southernmost part and extends over an area of approximately 8,000 km². However, beryl occurrences near Lac-de-Gras and Aylmer Lake and spodumene at Clinton–Golden Lake suggest the presence of additional pegmatite districts (Lord 1951, Henderson et al. 1982). The following compilation of data on the Yellowknife field is based mainly on papers by Joliffe (1944), Rowe (1952), Hutchinson (1955), Boyle (1961), Kretz (1968), Green & Baadsgaard (1971), Ramsay & Kamineni (1977), Lasmanis (1978), Drury (1979) and Jenner et al. (1981), and on a current investigation by R. E. Meintzer and P. Černý (unpubl. data). The age data are quoted mainly from Green & Baadsgaard (1971).

The Yellowknife pegmatite field. This pegmatite field is hosted by the basal metavolcanic rocks and superposed metasediments of the Yellowknife Supergroup (Fig. 34). The subordinate metavolcanic rocks (2.67 Ga) outcrop only as a segmented fringe of the complexly folded metasedimentary sequence, probably uptilted by the intrusion of syntectonic to late-tectonic tonalite–granodiorite–granite batholiths (2.64–2.59 Ga). The Western, Southeastern, and Ross Lake granodiorites and the granite east of François Lake delineate the extent of the pegmatite field. Numerous small stocks to bath-
ololiths of biotite–muscovite granite (2.575 Ga), with a pegmatitic facies along their margins and accompanied by pegmatite swarms, per- forate the metasedimentary rocks and the mar- gin of the Ross Lake granodiorite. Most of these post-tectonic granites were emplaced along the axes of north- to northwest-trending crossfolds.

The metasediments comprise a monotonous sequence of metagreywacke and metapelite me- metamorphosed to the greenschist facies, with the chlorite–muscovite assemblage upgraded locally to biotite–garnet–staurolite-bearing amphibolite- facies assemblages. These areas of increased grade are due to incipient thermal doming, fol- lowed by intrusion of granodiorite and granite. Contact-metamorphic effects of these late plutons superimposed over the earlier assemblages produced an inward-zoned sequence of cor- dierite (gedrite), andalusite and sillimanite. The variable extent of these thermal aureoles sug- gests that the process was much more intense around the post-tectonic granites than at the borders of the early granodiorite and granite batholiths.

The syntectonic batholiths have variable abundances of plagioclase–quartz–K-feldspar– hornblende (or biotite, or both). The biotite– muscovite granites are much more diversified in mineralogy: the ratio K-feldspar/plagioclase is somewhat variable, as is the biotite/muscovite ratio and the spatial distribution of the micas (Kretz et al. 1982). Garnet and tourmaline are widespread in some granites but may be absent in others. Beryl and spodumene occur sporadically in the outer pegmatitic portions of the granites.

Chemical compositions of the main types of granitoid rocks are shown in Table 14 and in Figure 35. The silicic, potassic and peralumin- ous bulk composition of the late granites is clearly distinct from the more intermediate compositional characteristics of the earlier to- nalties and granodiorites. The granites are also distinguished from the syntectonic batholiths by the Rb/Sr ratios and REE abundances. Drury (1979) proposed a derivation by partial melting at mantle depth for the syntectonic batholiths, and a high degree of partial melting of the Yellowknife metasediments for the generation of the post-tectonic granites (Fig. 10). This mode of formation of the latter type of granite is also supported by Jenner et al. (1981).

<table>
<thead>
<tr>
<th>TABLE 14. CHEMICAL COMPOSITION OF THE PRINCIPAL GRANITOID ROCKS OF THE YELLOWKNIFE PEGMATITE FIELD</th>
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<td>Sm</td>
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<tr>
<td>Eu</td>
</tr>
<tr>
<td>Gd</td>
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<td>Tb</td>
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<tr>
<td>Dy</td>
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<tr>
<td>Lu</td>
</tr>
<tr>
<td>Yb/Rb</td>
</tr>
<tr>
<td>Rb/Sr</td>
</tr>
</tbody>
</table>

* total Fe as Fe₂O₃; nd not detected. 1. granodiorite, Western granodiorite (Drury 1979, anal. 2); 2. granite, Western granodiorite (Drury 1979, anal. 1); 3. tonalite, Southeastern granodiorite (Green & Baadsgaard 1971, anal. 2); 4. granodiorite, Southeastern granodiorite (Drury 1979, anal. 3); 5. granodiorite, Southeastern granodiorite (Green & Baadsgaard 1971, anal. 3); 6. granodiorite, Ross Lake granodiorite (Green & Baadsgaard 1971, anal. 4); 7. granite, Prosperous Lake granite (Drury 1979, anal. 4); 8. granite, Prosperous Lake granite (Drury 1979, anal. 5); 9. granite, Prosperous Lake granite (Green & Baadsgaard 1971, anal. 7).
The rare-element pegmatites are more or less tightly clustered around the late granite plutons, within their contact aureoles. They also occur in a narrow zone along the southwestern margin of the eastern granite batholith. Structural control of the pegmatites is complex, including different types of fracture sets, bedding, foliation and pre-existing intrusive contacts. As documented by Kretz (1968, Figs. 5, 16) on a relatively small scale, the structural control can be expected to have been widely different across the pegmatite field.

From a gross geochemical viewpoint, the Yellowknife pegmatites belong to Kuzmenko's (1976) types 2, Li@elNb--Ta), and 3, Be(Nb-Ta), with Sn rather low in both types. Characteristic accessory minerals, variable in abundance depending on the pegmatite type and area, are spodumene (up to 25%), beryl, columbite–tantalite, tapiroite, garnet and tourmaline; sporadically found are gahnite, andalusite, cordierite, lithiumphillite and ambyggonite. Only rarely are lepidolite, scheelite, cassiterite, fluorite, zircon and (unconfirmed) petalite encountered.

Despite the lack of detailed information on the mineralogy of some of the pegmatite swarms (particularly those in the southeast), and the general absence of trace-element data, three principal types of pegmatite populations can be tentatively distinguished. (1) In the Prosperous Lake – Prelude Lake area, most of the mineralized pegmatites consist of large, poorly zoned to homogeneous bodies with abundant spodumene and beryl; they occur in local dyke swarms; Nb-Ta-oxide minerals are scarce; regional zoning of pegmatite types around the granites is developed only locally. (2) East and west of Ross Lake, beryl and Nb-Ta-oxide minerals are much more abundant; internal zoning of rare-element pegmatites is better developed; a classic regional zoning is developed around the Redout Lake granite (Hutchinson 1953), with an outward sequence of barren, Be-, Be,Nb-Ta-, and Li,Nb-Ta-bearing pegmatites. (3) Between Buckham Lake, Francois Lake and Hearne Channel, most pegmatites are well zoned; Nb-Ta-oxide minerals are widespread; the only occurrence of petalite reported in the whole field, suggestive of a low-pressure regime, is suspected to occur in this area; regional zoning is not evident.

The above sequence of pegmatite areas is marked by decreasing size of outcrop of the granites that are potentially or actually parental to the pegmatites. The three granite-cum-pegmatite groups may possibly represent horizontal sections through essentially identical intrusive systems but at three different vertical levels. Sizeable hidden bodies of granite are indicated by the wide contact-metamorphic aureole in the third area, out of proportion to the small granite intrusions. This suggests that this area, near Hearne Channel, could be the most promising for exploration, with a potential for discovery of additional highly fractionated but largely hidden pegmatites.

Fig. 35. (a) Plot of Rb versus Sr of the granitic rocks of the Yellowknife pegmatite field; pegmatitic granites (crosses), Western granodiorite units (solid dots) and Southeastern granodiorite (open circle), (b) REE abundances in the post-tectonic Prosperous Lake granite (PGR), and in the early-tectonic Western granodiorite (WGD) and Southeastern granodiorite (SEGD). From data by Drury (1979).
The Churchill Province

Mineralized pegmatites are sporadically distributed in this province; they have been reported only in its southwestern part (Fig. 36). However, the areal restriction may be apparent only, owing to insufficient exploration. Several recent finds of uranium mineralization in Melville Peninsula, the Nonacho Belt (N.W.T.) and the Labrador Fold Belt (Quebec) suggest possibilities in the northern and eastern parts of the Churchill Province (Ruzicka 1978, 1979). Isolated occurrences of columbite (Lord 1951) and lepidolite (R. Mulligan, pers. comm. in Bell 1978) on Baffin Island may also be significant.

Two principal types of rare-element pegmatites can be distinguished in the southwest: (1) the U-Th-bearing pegmatites widespread in most structural subprovinces in Saskatchewan and Manitoba, and (2) the Li-Be-bearing pegmatites confined to the Southeastern Zone Subprovince (Fig. 36).

U-Th bearing pegmatites. Sibbald (1975), Sibbald et al. (1977) and Tremblay (1978) distinguished two types of radioactive pegmatites: (1) those generated by Hudsonian remobilization of Archean basement, and (2) those derived from and located within graphitic pelitic gneiss of the Proterozoic (Aphebian) succession.

Remobilization of gneissic and granitoid rocks of the Archean basement produced a multitude of leucocratic, alaskitic granites and pegmatites with elevated contents of U and Th. They are
**TABLE 15. CHEMICAL COMPOSITION OF GRANITES ASSOCIATED WITH RADIOACTIVE PEGMATITES, BEAVERLODGE AREA, CHURCHILL PROVINCE**

<table>
<thead>
<tr>
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<th>1</th>
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<tr>
<td>SiO₂</td>
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<td>73.80</td>
<td>74.20</td>
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<td>15.50</td>
<td>15.90</td>
<td>15.10</td>
<td>13.95</td>
<td>15.20</td>
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<tr>
<td>TiO₂</td>
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<td>0.06</td>
<td>0.07</td>
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<td>0.14</td>
</tr>
<tr>
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<td>0.95</td>
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<tr>
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<td>0.36</td>
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<td>0.02</td>
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</tr>
<tr>
<td>Na₂O</td>
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<td>0.74</td>
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<td>0.15</td>
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<tr>
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<td>0.45</td>
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<tr>
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<td>4.50</td>
<td>2.53</td>
<td>0.86</td>
<td>5.31</td>
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<tr>
<td>H₂O</td>
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<td>0.05</td>
<td>0.02</td>
<td>0.10</td>
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<tr>
<td>CIPW</td>
<td>1.72</td>
<td>2.23</td>
<td>4.26</td>
<td>-</td>
<td>2.04</td>
<td>3.23</td>
</tr>
<tr>
<td>K/Rb</td>
<td>109.60</td>
<td>101.47</td>
<td>100.54</td>
<td>100.29</td>
<td>101.32</td>
<td>99.39</td>
</tr>
</tbody>
</table>

1 - Wilson Lake granite, part of a large migmatic-granite complex; anal. no. 7
2 - Higgons Lake granite, large elliptical intrusion; anal. no. 16
3 - Marmac Bay granite sill; anal. no. 6
4 - Gravel pit pegmatic granite, conformable with enclosing amphibolite; anal. no. 11
5 - Athina mine granite, forked sill in metagabbro; anal. no. 3
6 - Cayez granite, still in chlorite-sericite schist; anal. no. 14

* From Beck (1969)

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widespread in the Western Craton, Cree Lake Zone and Southeastern Zone subprovinces, but missing in the Proterozoic plutonic Rottenstone–Chipewyan Subprovince. The granites range from nebulous autochthonous masses through masses representing increased degrees of aggregation of granitic materials to clearly intrusive, cross-cutting bodies. In this succession, the granites tend to become more silicic and leuco-sive, cross-cutting bodies. In this succession, the anatectic massifs (Sibbald et al. 1977). How-ever, most of the pegmatites are conformable with migmatitic gneiss and foliated granitoid rocks and can be regarded as direct products of partial melting (Tremblay 1978). Cross-cutting dykes are subordinate, but some of them carry the most diversified mineralization known in this pegmatite type, which is otherwise fairly simple. Oligoclase, K-feldspar and quartz are associated with biotite and subordinate muscovite; late albite is rare. Apatite, fergusonite,

allanite, molybdenite, pyrite, pyrrhotite, pyro-chlore–microlite, thorite, uranothorite, uraninite, monazite, xenotime, zircon, hematite and ilmenite have been recognized as accessory minerals (Robinson 1955, Watkinson & Mainwaring 1976). Uraninite and other radioactive species are closely associated with biotite.

Radioactive pegmatites located in Early Proterozoic (Archean) graphitic pelitic gneisses are rather restricted in their abundance as well as in regional distribution. They are only known from the Cree Lake Zone Subprovince, particularly from the vicinity of its boundaries with the neighboring subprovinces (Fig. 36; Sibbald et al. 1977, Weber et al. 1975b). The pegmatite bodies are mostly conformable with their gneissic hosts, and homogeneous to crudely zoned. Oligoclase, subordinate K-feldspar, quartz, biotite and subordinate muscovite are the rock-forming constituents. Garnet, zircon, titanite and apatite are common; microscopic uraninite associated with biotite, molybdenite and pyrite are the least abundant species (Mawdsley 1951, Sibbald 1975). Pegmatites of this type appear to have been derived by metamorphic segregation from or anatexis of the enclosing metasediments (Sibbald 1975, Weber et al. 1975b). No evidence is available to suggest an origin by fractionation from a magma. The uranium was probably syngenetic with the metapelitic sequences, particularly the black shale horizons, and it was readily mobilized under conditions of incipient anatexis.

**Li–Be-bearing pegmatites.** Occurrences of pegmatites of this type are restricted to the two greenstone belts of the Southeastern Zone Subprovince (Fig. 36). Only a single occurrence of beryl has been recorded from the Lynn Lake belt (Mulligan 1965), but pegmatites are more abundant and diversified in the Flin Flon belt. Beryl-bearing pegmatites with biotite, muscovite, garnet, monazite, magnetite and rare columbite–tantalite occur at the western termina-

tion of the belt near Birch Portage (Mulligan 1965, Radcliffe & Campbell 1966), and a field of Li–Be-bearing pegmatites is located in its eastern extremity at Wekusko Lake (Fig. 37). Both fields are located in severely faulted areas that have steep metamorphic gradients. No further generalities can be deduced from two isolated areas; some details on the second area are presented below.

**The Wekusko Lake pegmatite field.** Most of the information on the geology and petrology of this field comes from Bailes (1971, 1975, 1980), Moore & Froese (1972), Froese & Gasparini (1975), Froese & Moore (1980), Bell (1978), Shanks (1979) and Černý et al. (1981); the last
The predominant rocks within the pegmatite field belong to two metavolcanic–metasedimentary sequences typical of greenstone belts, the Amisk and Missi groups. Their complex lithologies are not distinguished in Figure 37. Paragneiss and migmatite in the eastern and southeastern extremities of the area covered by Figure 37 may represent high-grade counterparts of the metasediments. In general, however, metamorphic grade increases from a metapelitic chlorite + garnet assemblage predominant in the south through staurolite-in, sillimanite, and beyond the staurolite-out isograds to beginning metatexis along the northern margin.

A series of granitoid intrusions is largely, but not totally, confined to a northeasterly-trending belt bounded by prominent fault systems (Fig. 37). The syntectonic gneiss dome in the northeastern part of this belt belongs to the earliest intrusions emplaced during the peak of regional dynamometamorphism. It probably represents a diapiric rise of low-density rhyolitic volcaniclastic rocks (Bailes 1980). The Rex Lake pluton central to the region is a late-tectonic gabbro–diorite–granodiorite–granite complex that preceded the intrusion of the Wekusko and Tramping Lake biotite granites in the southwestern part of the belt. These are late- to post-tectonic, rarely showing indications of post-consolidation deformation.

A series of pegmatitic granite intrusions closely follows the two fault zones. They are distributed over the whole metamorphic gradient, from the metapelitic chlorite + garnet assemblage in the south across the staurolite-in, sillimanite, and beyond the staurolite-out isograds. Most of the pegmatitic granites are elongate, ovoid to crescentic in shape, and have forcibly deflected the neighboring schists. Those along Grass River are smaller, lenticular and conformable with the enclosing schists and with the strike of the regional fault. K-feldspar, plagioclase (An$_{8-9}$) and quartz are accompanied by subordinate muscovite ± biotite,
garnet and sporadic tourmaline. Interlayering of granitic, aplitic and pegmatitic units is common.

The compositions of the late-tectonic granites are given in Table 16 and Figures 38 and 39. The Wekusko and Trambling Lake granites are closely related on a calc-alkaline trend, the latter differing mainly by more advanced plagioclase fractionation. The leucogranite facies of the pegmatitic granites cannot be related to any of the plutonic bodies; the pegmatitic granites were evidently generated by a different process. In keeping with the general petrochemical character of other intrusive rocks and of greenstones in the region, the granitoid rocks also are rather primitive in terms of fractionation of rare-alkali elements (Table 16).

Rare-element pegmatites are found in three localities confined to the chlorite + garnet area in the southern part of the field (Fig. 37). In contrast to the forcible intrusive style of the pegmatitic granites, the Li–Be-bearing pegmatites are fracture-filling bodies related to different dilation systems in a fairly complex structural setting. Despite the distances separating them and some differences in internal structure, all three groups of pegmatites have nearly identical mineral compositions and overall geochemical character. K-feldspar, albite, quartz and muscovite are associated with spodumene (up to 23%) and accessory biotite, beryl, garnet, tourmaline and apatite; altered triphylite is rare. The general level of fractionation, as shown by major and rare-alkali elements in rock-forming minerals, increases from the Sherritt Gordon group to the northeastern Green Bay pegmatites (1 and 3 on Fig. 37, respectively). However, even pegmatites of this last group do not approach the levels of fractionation attained by spodumene-rich pegmatites in other pegmatite fields with complex rare-element specialization (e.g., in the Winnipeg River district, Table 10).

Genetic affiliation of the Wekusko Lake peg-
matites is uncertain. A link to the pegmatitic granites is a possibility but is rendered questionable by differences in paragenesis and in structural affinities. The source rocks that generated the Li–Be-pegmatites are probably not exposed at the surface.

Summary. In the Churchill Province, the U–Th, REE(Zr,Nb-Ta,Mo)-bearing pegmatites generated from remobilized Archean basement and the U-Th(Zr,Ti,Mo)-bearing pegmatites in graphitic pelitic gneiss are commonly anatetic. However, the first kind does occur locally with-
in anatectic granite and may represent a product of their fractionation. Both types can be expected wherever the combined requirements of source lithology, metamorphic grade and structure are realized. A delicate interplay of structural and metamorphic factors is evidently necessary to produce significantly large deposits of these two types. Both types are widespread but, so far, not economic. The northern extensions of the Western Craton and Cree Lake Zone subprovinces and other lithologically related subprovinces in northern Churchill Province could harbor more occurrences of both types.

As for the Li-Be-bearing pegmatites, they belong to Kuzmenko's (1976) categories 2 and, partly, 3. Major occurrences of this type are restricted to the greenstone belts of the Southeastern Zone Subprovince. With the general lack of information about their parent granitoid rocks, it is only possible to speculate that silicic, per-aluminous, Ca-poor granites enriched in rare alkalis similar to those found in pegmatite-generating sequences of other greenstone belts, may be the progenitors. If the primitive fractionation levels characteristic of the Wekusko Lake field prove to be predominant in the granitoid rocks of the Flin Flon and Lynn Lake belts, the chances of finding more diversified pegmatite mineralization will be slim. However, better prospects are suggested by the Baffin Island occurrences mentioned earlier.

**Grenville Province**

The southwestern extremity of the Grenville Province hosts the classic pegmatite fields that have been intermittently investigated since the beginning of the century. However, geochemical and petrological studies have been neglected in the past, and the existing mineral and locality descriptions are not conducive to a clear-cut distinction of different pegmatite districts and groups. Defining the genetic affiliation of the Grenville pegmatites is also a problem. There is a general preference expressed in the literature for an anatectic origin based on stratigraphic, metamorphic and structural considerations. However, a total absence of pegmatites generated by igneous fractionation within the complex igneous and metamorphic terranes represented in the Grenville Province is difficult to imagine; this consideration, as well as the lack of geochemical data, leaves the present interpretation open to some doubt. Thus the following treatment of the Grenville pegmatites has to be general and descriptive.

Granitic and related pegmatites of the Grenville Province yield ages between 1.1 and 0.9 Ga (Lumbers 1979), coincident with the waning stages of the Grenvillian high-grade metamorphism, and at concluding stages of the major intrusive events. The pegmatites are restricted to four subprovinces: the Central Gneiss Belt, the Grenville Front Tectonic Zone, the Central...
Fig. 40. Distribution of mineralized pegmatites in the Grenville Province. 1. the Sudbury-Britt field, 2. the Mattawa district, 3. the Parry Sound field, 4. the Madawaska field, 5. the Bancroft field, 6. the Perth-Verona field, 7. the Gatineau-Buckingham field, 8. the Mont-Laurier field. Compiled from Ellsworth (1932), Spence (1932), Dawson (1974), Mulligan (1961, 1965, 1968, 1975) and Robertson (1978).

In the Central Gneiss Belt, four pegmatite-bearing areas can be delineated: the Sudbury-Britt field (1), which appears to extend into the Grenville Front Tectonic Zone, the Mattawa district (2), the Parry Sound (3), and an ill-defined Madawaska field (4 in Fig. 40). The pegmatites have a granitic composition; they range from biotite- and biotite-muscovite- to muscovite-bearing, with tourmaline and garnet being particularly distinctive of pegmatites of the Mattawa district. Rare-element mineralization is very subordinate, with an assemblage of Nb-Ta,Ti,REE,Y(U,Th,Zr,Be) minerals (Ellsworth 1932). Euxenite, polycrase, pyrochlore, betafite, samarskite, fergusonite, monazite, columbite, thucholite, allanite, thorite, uraniumite, zircon and beryl are characteristic; pyroxene, hornblende and sulfides occur sparsely. A recent find of autochthonous anatectic U-bearing pegmatites in metasediments at Parry Sound represents, to date, an isolated occurrence (Robertson 1978).

Four pegmatite fields may be suggested in the Central Metasedimentary Belt Subprovince: the Bancroft field (5), the Perth-Verona field (6), the Gatineau-Buckingham field (7) and the Mont-Laurier field (8 in Fig. 40). However, pegmatites appear to be widespread throughout this subprovince, and a final subdivision is not feasible at present. No economic rare-element concentrations are known from the Perth-Verona, Gatineau-Buckingham and Mont-Laurier fields, all of them having produced only ceramic materials. Beryl and minor Nb-Ta,Ti, U-Th-mineral occurrences characterize the first of these fields; minerals of REE, Nb-Ta, Ti and Th are typical of the second, along with the only Li-bearing pegmatite in the Grenville Province (Mulligan 1965); sparse Nb-Ta, REE and Ti mineralization is found in the Metasedimentary Belt and the Central Granulite Terrain (Fig. 40).
Tourmaline is common in the pegmatites of the Central Metasedimentary Belt, in contrast to its near-absence in the Central Gneiss Belt. Recent investigations in the Perth-Verona field have led to the discovery of extensive uranium mineralization in anatectic pegmatites in the Sharbot Lake area (Ford 1982, Ford & Charbonneau 1979). This type of U-bearing pegmatite is also known from the Mont-Laurier field (Henderson 1982). The Bancroft pegmatite field is the largest, most densely populated and best mineralized in the subprovince; a brief description is given below.

Little is known about the predominantly Be-bearing pegmatites scattered in the Central Granulite Terrain Subprovince and farther to the northeast (Fig. 40). Judging from the minerals associated with beryl (tourmaline, garnet, muscovite, locally topaz; Mulligan 1968), these pegmatites evidently are of a simple granitic composition, and most of them lack the mineralization in U, Th, Nb-Ta, REE, Ti and Zr typical of the other subprovinces.

The Bancroft pegmatite field. The pegmatites
of this field are associated with a series of partly mobilized, high-grade granitoid and syenitoid gneiss bodies, some of which display prominent domal structures (Fig. 41). The pegmatites are contained within these gneisses or in the adjacent metasediments. Most of the pegmatites are conformable with the fabric of the enclosing rocks and relatively homogeneous internally. The less common fracture-filling bodies that cut across regional structures tend to be better differentiated and zoned. A simple classification of U-bearing pegmatites of the field was developed by Satterly & Hewitt (1955): A zoned, B unzoned, B–1 red, B–2 white; it is still in use today (Robertson 1978), although other classification schemes have started to appear (Masson & Gordon 1981, Storey & Vos 1981).

A granitic to syenitic range of bulk compositions reflects the wide range in silica content of the pegmatites, even to the point of appearance of abundant feldspathoids. The ubiquitous presence of pyroxene, hornblende and biotite relates the pegmatite compositions to the amphibolite (or higher) metamorphic grade of the enclosing sequences. Rare-element mineralization comprises a variety of U, Th, Nb-Ta, REE, Y, Ti, Zr and Be species (uraninite, uranothorite, thorite, euxenite, polycrase, columbite, pyrochlore–mierolite, allanite, magnetite, beryl, garnet, monazite, titanite and zircon: Ellsworth 1932, Satterly & Hewitt 1955, Masson & Gordon 1981, Ford 1982). Other typical accessory minerals are garnet, scapolite, magnetite, fluorite, sulfides of Fe, Cu, Mo and Pb, calcite and, locally, anhydrite and gypsum (Little 1969). Most of the uraninite is intergrown with magnetite or the somewhat altered mafic minerals (Haynes 1979). More exotic assemblages of minerals, with corundum, nepheline, cancrinite, sodalite, scapolite, garnet, anhydrite, etc., are restricted to the interior of the nepheline syenite belts along the northwestern boundary of the Central Metasedimentary Subprovince (Fig. 41).

Despite earlier correlations of pegmatite occurrences with high metamorphic grade (Lumbers 1964), the Bancroft pegmatite field has been related to igneous differentiation until recently (Little et al. 1972, Robertson 1974). More recent work suggests that the pegmatites could have been generated during the Grenvillian deformation, which mobilized Early Proterozoic basement gneisses and their cover, locally yielding mantled gneiss domes (Bright 1977, Lumbers 1975b). However, Masson & Gordon (1981) suggested that differentiation of granitoid melts could also provide some of the uranium and other rare elements.

Summary. In conclusion, it can be said that the pegmatites of the Grenville Province deserve much more attention in future than they have received in the past. Better understanding of their geochemistry and origin is required in the well-prospected southwestern part of the province, and new discoveries can be expected in the relatively unexplored central and northeastern parts. However, a severely limited distribution of pegmatites can be expected in the predominately unfavorable terranes of granulite-facies metamorphism.

Uranium and Thorium in Granitoid Plutons

In addition to the uranium–thorium-bearing pegmatites described in the previous section, potentially important concentrations of uranium and thorium are found also in many Archean and Proterozoic granitoid and some syenitoid plutons in the Superior, Slave, Churchill, Bear and Grenville provinces (Darnley 1982, Gandhi 1978, Ruzicka 1979). Many of these plutons have only recently been located by extensive regional airborne radiometric surveys carried out by the Geological Survey of Canada as part of the Uranium Reconnaissance Program. Follow-up geological and geochemical investigations on the ground are still in progress. Consequently, the nature, age and genesis of the uranium-bearing plutons and the nature, distribution, habit and control of uranium mineralization are poorly documented. It should be stressed, also, that granitoid plutons may be the ultimate source of uranium now found in sedimentary and other nongranitoid hosts (Ruzicka 1982).

Two main types of uranium mineralization have been recognized: 1) veins, and 2) dispersed mineralization. Vein deposits are best documented from the Bear Province, where pitchblende ± quartz veins occupy subsidiary fractures associated with major faults (Gandhi 1978). These veins occur in both Early Proterozoic rocks of the Great Bear batholith and adjacent country rocks; some veins contain important concentrations of Ag, Bi, Co, Ni and Cu and have been mined (Badham 1975). The mineralization was apparently deposited by hydrothermal solutions derived from the Great Bear batholith (Badham 1975, Gandhi 1978), although Gandhi (1978) stated that the Ag, Bi, Co, Ni and Cu represents a later mineralizing event unrelated to the granitoid rocks.

Other uraniferous veins have been reported from Early Proterozoic plutons in and adjacent to the East Arm Fold Belt, a subprovince of
the Churchill Province that is an eastward extension of the Bear Province onto the craton. These occurrences include: 1) actinolite + apatite + magnetite + hematite ± uraninite veins in quartz monzonite laccoliths within the fold belt; these laccoliths are texturally and compositionally similar to the earliest phases of the Great Bear batholith (Badham 1978, Gandhi & Prasad 1982); and 2) albite veins that are in part associated with pegmatite in late peralkaline syenite of the gabbro – granite – peralkaline granite – syenite Blachford Lake complex in the Slave Province at the margin of the fold belt; these veins are mineralogically complex and contain fluorite, carbonate, zircon and rare minerals rich in Ta, Nb, Be, Li, Th, Y, U and REE (Davidson 1978, 1982). These vein deposits appear to be genetically related to the evolution of the magma, although the final deposition in veins is probably the result of late hydrothermal activity (Davidson 1982, Gandhi & Prasad 1982). Uranium appears to be a minor constituent in the deposits in the Blachford Lake complex but, according to company reports (Highwood Resources Ltd.), the complex may contain a major Nb-Ta deposit.

Vein deposits, both in plutons and in country rocks, may be an integral part of the emplacement and cooling of uraniferous granitoid plutons (Darnley 1982). Such plutons, defined by Darnley (1982) as those containing 8 ppm or more U, will cool more slowly than nonuraniferous plutons because of heat generated by radioactive decay. As a function of prolonged cooling, any hydrothermal convection systems generated by the heat of the pluton will be more long-lived, with a consequent higher possibility of development of vein deposits containing uranium and other elements (Darnley 1982). On the other hand, uraniferous vein deposits may result also from epigenetic processes, either supergene or hydrothermal (Maurice 1982).

Dispersed mineralization is best documented from the Superior, Churchill and Grenville provinces, but also occurs in the Bear Province. The uranium–thorium-bearing plutons are equigranular to porphyritic, fine- to coarse-grained, in part pegmatitic sills, dykes, stocks and batholiths. Most are granite, but the composition ranges from tonalite to leucogranite (commonly referred to as alaskite) (Bond & Breaks 1978, Breaks 1982, Hauseux 1977, Maurice 1982, Sibbald et al. 1977, Weber et al. 1975b, 1982). Pegmatites, in the form of both discrete dykes and irregular patches, are common constituents of many uranium-bearing plutons. In some plutons, uranium is concentrated in the pegmatite phase (Sibbald et al. 1977, Rimsaite 1982), but late-tectonic Proterozoic intrusions (Burwash & in other plutons there is no preferential concentration of uranium in pegmatite.

The tectonic positions and structures of uranium-bearing plutons differ from province to province. In the Superior Province, many of the plutons are poorly foliated, unmetamorphosed, late-phase, syntectonic or late-tectonic bodies (Bond & Breaks 1978, Breaks 1982, Weber et al. 1982), some of which were emplaced in the deep mesozone. In the Churchill Province, they range from metamorphosed gneissic, Archean basement plutons to massive, Cape 1981, Sibbald et al. 1977, Soonawala et al. 1979, Weber et al. 1975b). Uranium in association with fluorite is concentrated in the contact-metamorphic aureoles around some late-tectonic, fluorite-bearing plutons (Miller 1979). In the Grenville Province, many uranium-bearing plutons are foliated to gneissic as a result of superimposed metamorphism (Hauseux 1977), but relatively undeformed plutons have been reported also (Kerswill & McConnell 1982).

The data available at present indicate that uranium mineralization is dominantly disseminated uraninite (Darnley 1982, Hauseux 1977, Kerswill & McConnell 1979, Ruzicka & Littlejohn 1981, Soonawala et al. 1979, Weber et al. 1975b), but pitchblende and uranothorite have also been reported (Hauseux 1977, Kerswill & McConnell 1982); phosphuranylite stain is associated with many occurrences (Bond & Breaks 1978, Hauseux 1977). In many plutons the uraninite is associated with magnetite (Hauseux 1977), with biotite, chlorite, and locally garnet (Bond & Breaks 1978, Delpiere 1982, Kerswill & McConnell 1979, 1982), with concentrations of accessory minerals such as sphene, zircon, allanite and apatite (Bond & Breaks 1978, Schau & Ashton 1979), or with molybdenite, pyrite and fluorite associated with garnetiferous biotite-rich schlieren (Kerswill & McConnell 1982).

In plutons in which the uranium and thorium contents are anomalous but only several times background, the uranium and thorium appear to be incorporated largely in the radioactive accessory minerals zircon, allanite, titanite, monazite and thorite (Burwash & Cape 1981, Charbonneau 1982). Characteristic features of many uranium-bearing plutons are the presence of smoky quartz, quartz lenses, pervasive alteration (including deep reddening of feldspars), muscovite in addition to biotite, cordierite, garnet and sillimanite in some plutons, and negative Bouguer gravity anomalies (Bond & Breaks 1978, Breaks 1982, Darnley 1982, Hauseux 1977, Kerswill & McConnell 1979).
Some uranium-bearing plutons, however, are characterized by whitened rather than reddened feldspars (Breaks 1982).

The ratio U/Th is variable from pluton to pluton and within plutons (Delpierre 1982, Rimsaite 1982). Reported values from a few plutons in the Superior and Churchill provinces are in the range 0.1–0.2 (Charbonneau 1982, Maurice 1982) but Breaks (1982) and Delpierre (1982) have reported values greater than 2. In the Grenville Province, U/Th ranges from 0.2 to 4, with many values greater than 1 (Ford 1982, Kerswill & McConnell 1979, Rimsaite 1982). Charbonneau (1982) has suggested that an increase in the ratio U/Th of a pluton with increasing U content is indicative of uranium mobilization; such plutons may host epigenetic uranium deposits. On the other hand, a decrease in the ratio U/Th with increasing Th indicates that the distribution of U and Th within the pluton was fixed at an early stage of magmatic evolution (Charbonneau 1982).

In most radioactive plutons, the uranium is unevenly distributed. The highest concentrations are generally in irregular to lenticular areas up to several metres long; many of the lenticular areas are concordant with foliation and gneissosity (Bond & Breaks 1978, Hauseux 1977). In some plutons the mineralization has been partly redistributed into fractures and faults (Kerswill & McConnell 1982, Maurice 1982). In the Churchill Province, uranium contents of 15 to 30 ppm have been reported for large areas by Sibbald et al. (1977), Soonawala et al. (1979) and Weber et al. (1975b), but local concentrations of more than 1% uranium are also present. In the Grenville Province, plutons in the Johan Beetz area of Quebec contain 100–200 ppm uranium with an estimated reserve of several hundred million tonnes (Ruzicka 1979).

The origin of the uranium mineralization in Proterozoic plutons is generally ascribed to anatexis and remobilization of uranium-bearing sedimentary units, older granitoid plutons or unspecified Archean gneisses (Hauseux 1977, Kerswill & McConnell 1979, 1982, Sibbald et al. 1977, Weber et al. 1975b). The anatexis concentrated uranium from the parental rocks. The origin of uranium in the Archean plutons is unknown, although Burwash & Cape (1981) proposed that mineralization in at least one Archean pluton of the Churchill Province was the result of assimilation of uranium-bearing sedimentary rocks by the pluton and later remobilization and concentration of the uranium during Proterozoic deformation.

Conclusions

For ease of understanding, the accounts of the geology and most of the mineral deposit types have been summarized at the end of the appropriate sections. This information will not be repeated here.

In the Canadian Shield, granitoid plutons are extensive but poorly documented. They range in age from Archean to Middle Proterozoic and differ considerably in their compositions, habits, sizes, emplacement depths and positions in tectonic cycles. There are both similarities and differences among the granitoid plutons in the various structural provinces. Certain types of plutons are hosts for, or are genetically associated with, many mineral deposits, particularly those of Cu, Mo, Au, Ag, U, Th, Be, Cs, Li, Ta, Nb and lanthanide elements. However, except for pegmatite deposits, mineral deposits in or associated with granitoid plutons have not been studied as a discrete class. Their genetic relationships with associated plutons and the nature of assumed parental plutons are even more poorly documented. Integrated geological and geochemical investigations are essentially nonexistent, although research is in progress on uranium-bearing granitoid plutons. Thus, the metallogeny of granitoid rocks in the Canadian Shield is largely descriptive, and it offers a fertile field for both research and prospecting.

As a first approximation, future prospecting for Cu, Mo, and Au–Ag in granitoid rocks should be concentrated in greenstone-belt terranes, particularly the Archean of the Superior and Slave provinces. Only a few granite-related deposits are currently known in the Slave Province, but this may reflect inaccessibility rather than lack of deposits. The less extensive Archean and Proterozoic greenstone belts of the Churchill and Grenville provinces are also favorable targets for exploration. The volcanomagmatic units of the Bear Province are apparently unfavorable for this type of mineralization.

Pegmatite deposits are widespread in the Superior, Slave, Churchill and Grenville provinces; the more inaccessible parts of these provinces, particularly in the Churchill Province, should be actively prospected for new pegmatite fields. Paragneiss–granitoid subprovinces of the Superior Province appear to be the most favorable loci, but greenstone sequences in other types of subprovince should not be overlooked.

The genetic control for uranium mineralization in granitic plutons is largely unknown. To date the most extensive and richest deposits are in the Churchill and Grenville provinces.
ACKNOWLEDGEMENTS

This paper benefited by informal discussions of Precambrian granitoid rocks and related mineralization with numerous colleagues, particularly F. W. Breaks, G. S. Clark, G. P. Beakhouse, J. M. Franklin and D. L. Trueman. J. M. Franklin, R. I. Thorpe and W. D. Sinclair helpfully provided preprints of papers. The graphic work of Ron Phyhitko is also appreciated. The manuscript has been critically reviewed by A. Davidson, J. M. Franklin, R. I. Thorpe and two anonymous referees.

REFERENCES


(1978): Magnetite—apatite—amphibole—uranium and silver-arsenide mineralizations in Lower Proterozoic igneous rocks, East Arm, Great Slave Lake, Canada. Econ. Geol. 73, 1474-1491.


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& Thorpe, R. I. (1973): Studies of gold-copper deposits suggest red metal may be used as guide to gold. *Northern Miner*, Nov. 29, 55, 57.


Kuzmenko M. V. (ed.) (1976): Rare-Element Granitic Pegmatite Fields (Geochemical Specialization and Distribution). Nauka, Moscow (in Russ.).


METALLOGENY OF GRANITOID ROCKS IN THE CANADIAN SHIELD


_____ (1975): Gold in early Precambrian plutonic rocks; the relation between geochemical abundance and concentration to exploitable levels. Soc. Mining Engineers and Amer. Inst. Mining Engineers, Preprint 75-L-5.


Received November 1981, revised manuscript accepted July 1982.