Archean crust as revealed in the Kapuskasing uplift, Superior province, Canada

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ABSTRACT

In the central Superior province of the Canadian Shield, a 120-km-wide transition from the low-grade Michipicoten greenstone belt to the high-grade Kapuskasing structural zone represents an oblique section through some 20 km of Archean crust, uplifted along a northwest-dipping thrust fault. The restored vertical section through the upper and middle crust consists of three megalayers with undulating boundaries: (1) 0 to < 10 km, a metavolcanic-metasedimentary succession ("greenstone belts") with discordant plutons; (2) < 10 to ~ 20 km, tabular batholiths of gneissic and xenolithic tonalite and granodiorite; and (3) from 20 to > 25 km, a high-grade heterogeneous gneissic assemblage, in part older than the upper supracrustal succession.

INTRODUCTION

Accurate models of Precambrian crustal evolution require both depth and time dimensions. Zircon geochronology can provide resolution of a few million years in rocks 2,700 m.y. old. Structural relief generally provides the only direct evidence of variation in the vertical dimension, although gravity and seismic data give valuable information on large-scale crustal structure. Several regions with large-scale, gradational metamorphic zonation and compositional variation have been interpreted as oblique cross sections through the continental crust (Fountain and Salisbury, 1981). The central Superior province of the Canadian Shield (Fig. 1) is examined in this context.

The Superior province is an Archean terrane composed of east-west–trending belts of alternate volcanic-rich and sediment-rich character, termed subprovinces (Fig. 1). The continuity of the east-west belts is interrupted by a northeast-trending zone of high-grade metamorphic rocks, the Kapuskasing structural zone (Thurston et al., 1977). The Kapuskasing structure is fault-bounded on the southeast, but the western contact is complex and gradational over 120 km to low-grade rocks of the Michipicoten belt near Lake Superior (Fig. 1).

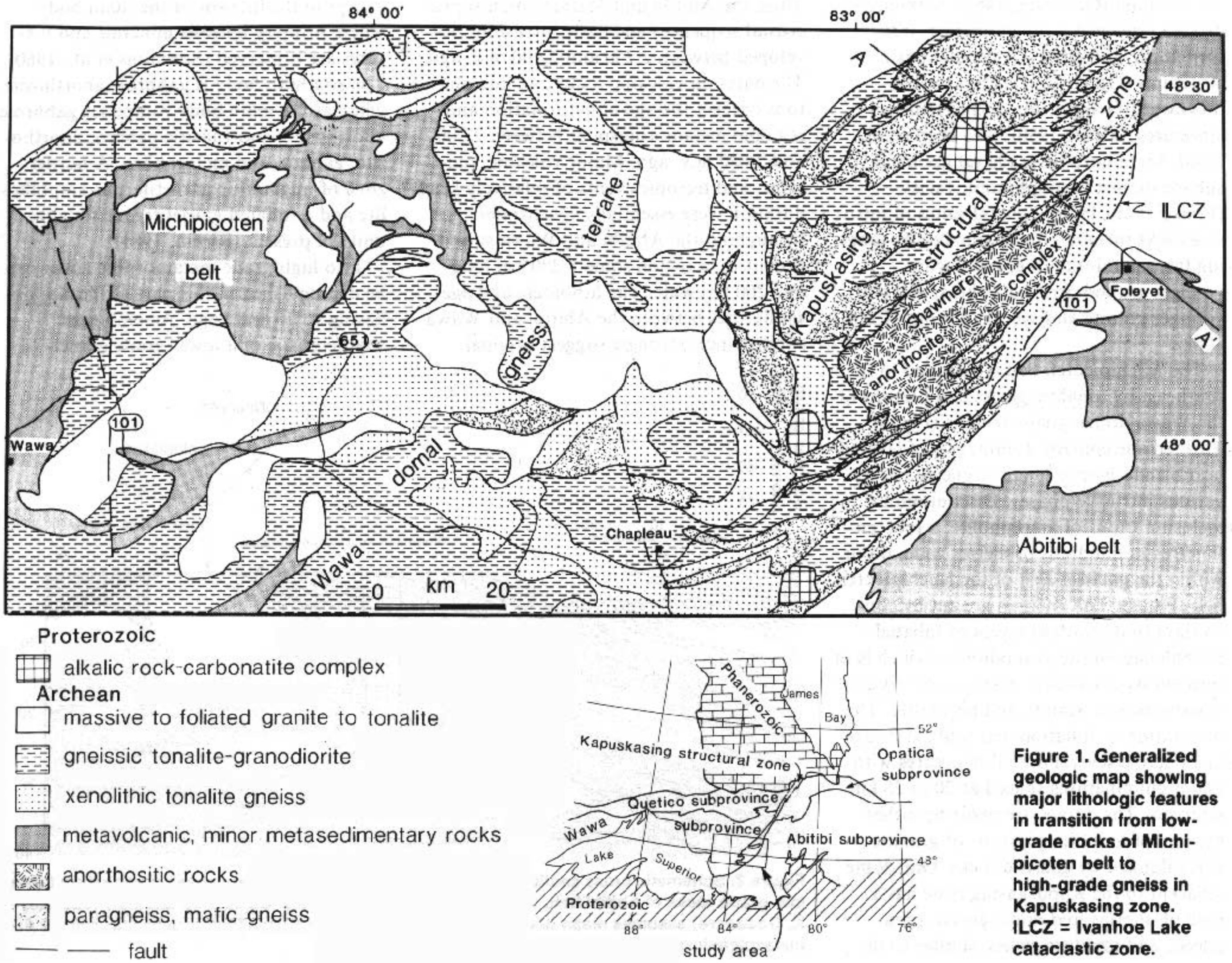

Figure 1. Generalized geologic map showing major lithologic features in transition from low-grade rocks of Michipicoten belt to high-grade gneiss in Kapuskasing zone. ILCZ = Ivanhoe Lake cataclastic zone.

The Kapuskasing "high," a prominent northeasterly gravity and aeromagnetic anomaly, was interpreted by Wilson and Brisbin (1965) to indicate pronounced upwarp of the Conrad discontinuity. Bennett et al. (1967) concluded that the Kapuskasing structure is a complex horst uplifted during the Proterozoic. The association of 1,100–1,000-m.y.-old alkalic rock–carbonatite complexes led Burke and Dewey (1973) to suggest that the Kapuskasing structure is a failed arm of the Keweenawan rift structure. Watson (1980) postulated that the Kapuskasing zone was uplifted during late Archean or early Proterozoic sinistral transcurrent movement. Recent earthquakes in the region indicate that the structure is still active (Forsyth and Morel, 1982).

GEOLOGY OF THE REGION

Figure 1 shows the geologic character of the region including the Michipicoten belt and Kapuskasing zone. The Michipicoten belt, part of the volcanic-rich Wawa subprovince, is mainly composed of metavolcanic rocks of ultramafic, mafic, and felsic composition (Goodwin, 1962), with intercalated graywacke, conglomerate, iron formation, and chert. Dome and basin structures (Goodwin, 1962) as well as downward-facing strata and overturned structures (Attoh, 1980) have been recognized. Metamorphic grade ranges from subgreenschist to amphibolite facies (Fraser et al., 1978). Several suites of intrusive rocks include synvolcanic bodies ranging from peridotite to granodiorite, younger granodiorite batholiths, and still younger granite and syenite plutons (Card, 1982).

The Michipicoten belt is intruded to the southeast by tonalitic gneiss and plutons of the Wawa domal gneiss terrane (Fig. 1). This terrane consists dominantly of layered hornblende-biotite tonalitic gneiss, cut by various intrusive phases. Discontinuous inclusion trains of amphibolite, a few centimetres to hundreds of metres wide, occur within the gneisses east of the Michipicoten belt (Fig. 1). The gneisses are cut by concordant to discordant layers of foliated hornblende-biotite granodiorite, which is in turn cut by discordant plutons and dikes of massive biotite granite and pegmatite. The orientation of foliation and fold axial surfaces define several domal structures with major culminations spaced at 20 to 25 km intervals. The domes are made up either entirely of tonalitic gneiss or of granitic cores flanked by gneissic rocks. One dome adjacent to the Kapuskasing zone has a core of interlayered mafic gneiss, paragneiss, and tonalitic gneiss, similar to the lithologic assemblage of the Kapuskasing zone to the east.

The Abitibi belt has many characteristics in common with the Michipicoten belt, including a volcanic-dominated supracrustal succession, low metamorphic grade (Jolly, 1978), and dome and basin structures (Pyke, 1982). Gneissic and plutonic rocks intrude the Abitibi belt to the north and south.

A time framework for events in the Michipicoten and Abitibi belts can be constructed from U-Pb zircon dates. In the western Abitibi belt, volcanic rocks range in age from 2,725 to 2,703 m.y. (Nunes and Pyke, 1980; Nunes and Jensen, 1980), and in the Michipicoten belt they range from 2,749 to 2,696 m.y., with synvolcanic plutons at 2,744 and 2,737 m.y. (Turek et al., 1982). Several late- to post-tectonic plutons from the Abitibi and Michipicoten belts have zircon dates within a few million years of 2,680 m.y. B.P. (Krogh et al., 1982). In the Wawa domal terrane, tonalite gneiss has a minimum age of 2,707 m.y., partly reset by intrusion of granodiorite at 2,677 m.y. (Percival and Krogh, 1983). Thus, the Abitibi and Michipicoten supracrustal sequences and early intrusions developed between 2,750 and 2,700 m.y. ago. The dates on volcanic rocks and late plutons bracket the age of deformation and regional metamorphism at between 2,700 and 2,680 m.y. ago. Major volcanic, plutonic, and tectonic events of relatively brief duration were essentially synchronous throughout the Abitibi and Wawa subprovinces, a region some 1,200 km long and 200 km wide. The lithologic and age similarities between the Abitibi and Wawa subprovinces strongly suggest original continuity, now interrupted by the Kapuskasing structural zone.

KAPUSKASING STRUCTURAL ZONE

The Kapuskasing structural zone comprises northeast-striking, northwest-dipping belts of paragneiss, mafic gneiss, gneissic and xenolithic tonalite, and rocks of the Shawmere anorthosite complex (Bennett et al., 1967; Thurston et al., 1977). Migmatitic paragneiss has garnet, biotite, and quartz-rich and rare graphitic varieties with concordant tonalitic leucosome. Migmatitic mafic gneiss has garnet-clinopyroxene-hornblende-plagioclase-quartz-ilmenite ± orthopyroxene assemblages, with tonalitic leucosome. Discrete belts of tonalite contain garnet, hornblende, and biotite; some have enclaves of mafic gneiss, paragneiss, amphibolite, and rare ultramafic rocks. The Shawmere anorthosite complex comprises northern and southern bodies measuring 50 × 15 and 15 × 5 km, respectively. Gneissic textures and metamorphic mineral assemblages, including garnet and hornblende, prevail except in the interior of the main body where primary igneous minerals and textures are preserved (Simmons et al., 1980). The southern body is gabbroic anorthosite, whereas the main body comprises gabbroic anorthosite, anorthositic gabbro, anorthosite, gabbro, and melagabbro. A border zone of migmatitic garnetiferous amphibolite and a foliated garnetiferous tonalite unit are present (Riccio, 1981).

Two high-grade metamorphic zones can be distinguished in this part of the Kapuskasing structural zone. Assemblages characteristic of a lower grade garnet-

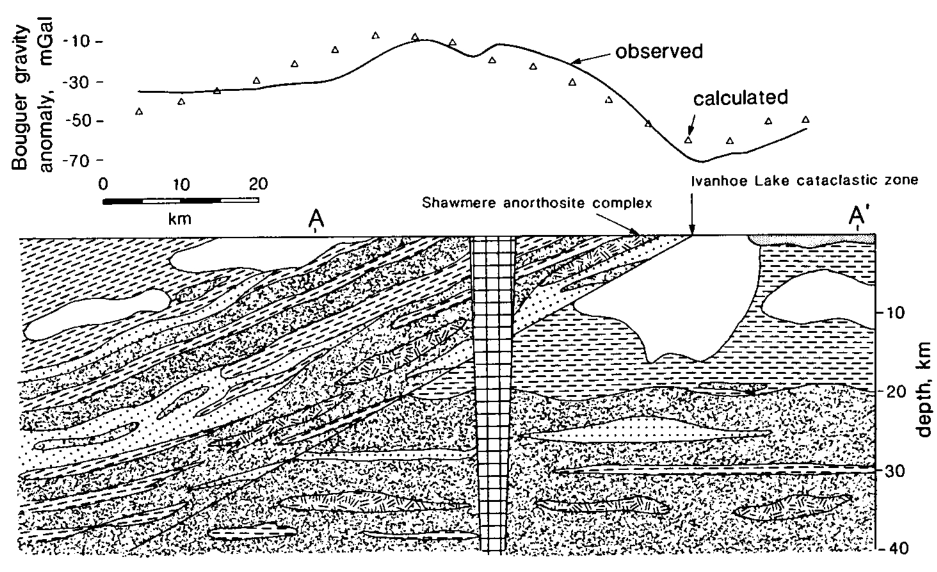

Figure 2. Schematic cross section showing high-grade rocks of Kapuskasing zone thrust over low-grade rocks of Abitibi belt, with resulting gravity anomaly. Calculated anomaly (courtesy A. K. Goodacre) assumes mean densities (tonalite gneiss, granite: 2.70; Kapuskasing zone: 2.82; metavolcanics: 2.90). Symbols as in Figure 1.

clinopyroxene-plagioclase zone are developed in mafic gneiss. Orthopyroxene, present in four areas in most rock types, is diagnostic of a higher grade orthopyroxene zone (Percival, 1983).

Rounded zircons of probable metamorphic origin from Kapuskasing mafic gneiss gave a concordant date of 2,650 m.y. and from a leucosome layer in paragneiss a date of 2,627 m.y. (Percival and Krogh, 1983). A minimum age of emplacement for foliated tonalite from the Shawmere complex is provided by zircons (2,765 m.y.), but the U-Pb system has been strongly affected by the high-grade metamorphism (Percival and Krogh, 1983). The rocks intruded by the tonalite are thus older than dated volcanic rocks of the Abitibi and Michipicoten belts. Alkalic rock-carbonatite complexes associated with the Kapuskasing zone have K-Ar ages of 1,655 to 1,720 m.y. and 1,050 to 1,100 m.y. (Gittins et al., 1967).

RELATIONSHIP OF KAPUSKASING STRUCTURAL ZONE TO ADJACENT SUBPROVINCES

The eastern contact of the Kapuskasing zone with the Abitibi and Opatica subprovinces is a zone of faulting and cataclasis, the Ivanhoe Lake cataclastic zone. The contact coincides with the trough of a paired high (Kapuskasing)–low (Abitibi and Opatica) gravity anomaly (Fig. 2). The dip of the fault zone is not well constrained. Gneissosity and some fault-rock veinlets dip northwest; other veinlets have random orientation. The juxtaposition of high-grade against low-grade rocks indicates reverse displacement across the fault. The paired high-low gravity anomaly is characteristic of many well-documented, large-scale thrust contacts (Smithson et al., 1978; Fountain and Salisbury, 1981) and suggests that the Ivanhoe Lake structure is a northwest-dipping thrust fault (Fig. 2).

The Wawa-Kapuskasing boundary has gradational lithological, structural, and metamorphic characteristics. High-grade gneiss typical of the Kapuskasing zone also occurs in the core of a dome in the Wawa domal terrane. Paragneiss and tonalitic gneiss units in domes of the Wawa subprovince can be traced eastward into strongly foliated and lineated gneiss with the northeasterly trend of the Kapuskasing zone. The gradational nature of lithologic contacts as well as the structural and metamorphic continuity between tonalites and high-grade gneisses suggest that the contacts were established prior to doming, and that rock units of the Kapuskasing zone locally occur structurally below the Wawa tonalite gneiss.

STRUCTURE OF KAPUSKASING CRUSTAL CROSS SECTION

The transition from the Michipicoten belt to the eastern boundary of the Kapuskasing zone can be interpreted as an oblique crustal cross section, on the basis of the following: (1) metamorphic grade increases eastward from low greenschist facies in the Michipicoten belt through amphibolite facies in the Wawa domal gneiss terrane to upper amphibolite and granulite facies in the Kapuskasing zone; (2) the proportion of plutonic to supracrustal rocks increases eastward in the Wawa subprovince; (3) the oldest rocks (2,765 m.y.) are in the Kapuskasing zone at the inferred base of the section; (4) the gravity anomaly can be best modeled by using a west-dipping crustal slab (Fig. 2).

Construction of a generalized crustal cross section (Fig. 3) requires several assumptions: (1) the dip of the crustal slab is constant; (2) pressure is a function of depth so that estimates of metamorphic pressure can be used to derive the thickness of the section; (3) the metamorphic assemblages are the product of a single metamorphic event; and (4) postmetamorphic vertical displacement on faults within the section is negligible. The highest grade assemblage from the Wawa area is garnet-andalusite in metagraywacke (Ayres, 1969), indicating a maximum pressure of 3.3 kb and a depth of about 11 km (Carmichael, 1978). The range of pressures estimated from the Kapuskasing zone, based on Newton and Perkins's (1982) garnet-clinopyroxene-plagioclase-quartz barometer, is 5.4 to 8.4 kb (average of 6.3 kb, Percival, 1983), but the lower values may result from re-equilibration during cooling. These values correspond to depths of 18 to 28 km (average 21 km). The minimum erosion-level difference is therefore 7 km, but the difference is probably closer to 15 km. The minimum and maximum dip estimates over a constantly dipping slab 120 km long are about 5° and 10°.

The generalized crustal cross section, constructed using a dip of 10° (Fig. 3), has at its base a sequence of upper amphibolite to granulite facies gneiss and anorthosite, the full thickness of which is unknown, and of which some 5 to 10 km are exposed in the Kapuskasing zone. Structurally above are 10 to 15 km of tabular batholiths of gneissic and xenolithic tonalite. Massive granitic rocks occur as sheets and deep-rooted plugs at this structural level. In the upper 5–10 km, both granitic rocks and gneissic migmatitic haloes surround the low-grade Michipicoten belt. The interfaces between the adjacent, generally horizontal megalayers are undulating surfaces with several kilometres of relief, manifest as gneiss domes at intermediate structural levels and as intrusive bodies at higher levels.

In the western Superior Province, two seismic discontinuities, at 16–19 and 21–22 km, define upper, middle, and lower crust (Hall and Brisbin, 1982). Using the Kapuskasing model, the upper discontinuity corresponds to the boundary between a structurally higher granitoid gneissic layer and a subjacent heterogeneous high-grade gneiss complex, whereas the lower discontinuity, corresponding to the middle-lower crustal boundary, is probably a metamorphic isograd (orthopyroxene isograd?) within the heterogeneous gneiss.

ARCHEAN EVOLUTION OF THE KAPUSKASING CRUSTAL STRUCTURE

The oldest rocks recognized are the paragneiss and mafic gneiss of the Kapuskasing zone, interpreted as part of a sedimentary-volcanic succession intruded by tonalite of the Shawmere complex prior to 2,765 m.y. ago. Eruption of volcanic rocks, emplacement of synvolcanic intrusions, and deposition of sediments occurred between 2,750 and 2,700 m.y. ago in the Abitibi and Michipicoten belts. Large volumes of tonalite, now gneissic, intruded and engulfed the lower parts of the greenstone belts as well as the older Kapuskasing-type gneiss complex, probably during the latter stages of volcanism. Intrusion of voluminous tonalite sheets at intermediate crustal levels is considered an "intraplating" mechanism of significant vertical crustal accretion and also as a

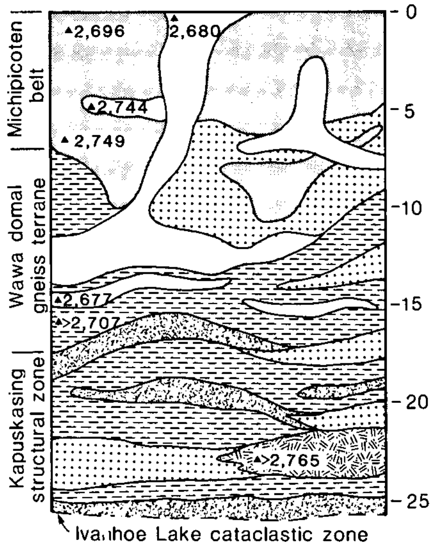

Figure 3. Restored vertical section through Michipicoten belt, Wana domal gneiss terrane, and Kapuskasing zone. Numbers are U-Pb zircon dates (± 4 m.y.). Symbols as in Figure 1.

major agent of heat transfer into the upper crust during metamorphism.

Major deformation occurred in the Abitibi and Wawa subprovinces between 2,700 and 2,680 m.y. ago. Tectonic quiescence generally followed intrusion of massive plutons. However, later Archean events are indicated in the Kapuskasing zone where metamorphic zircons yield ages of 2,650 and 2,627 m.y. These dates could indicate renewed activity in the Kapuskasing zone 25 to 50 m.y. after tectonic stabilization of the adjacent terranes. However, they could also be the result of high-temperature lead diffusion out of zircon during slow cooling following regional metamorphism (Percival and Krogh, 1983).

UPLIFT OF KAPUSKASING STRUCTURE

The time of uplift of the Kapuskasing zone is not well constrained. Evidence of late Archean transcurrent movement was cited by Watson (1980) and Percival and Coe (1980); however, its magnitude was probably small, judging by the minor apparent offset of the Abitibi-Opatica contact (Fig. 1). Major thrusting could also have occurred at that time, setting U-Pb and K-Ar isotopic systems in the high-grade rocks at 2,650–2,445 m.y. ago.

Geochronologic evidence indicates activity at 1,655–1,850 m.y. Three alkalic rock–carbonatite complexes near Kapuskasing have K-Ar ages of 1,655–1,720 m.y. (Gittins et al., 1967). A biotite–whole-rock Rb-Sr isochron from tonalite of the Shawmere anorthosite complex is 1,850 m.y. (Simmons et al., 1980). A whole-rock ^{40}Ar/^{39}Ar analysis of blastomylonite from the Ivanhoe Lake cataclastic zone gave a date of 1,720 m.y. (Percival, 1981).

Three alkalic rock–carbonatite complexes in the southern Kapuskasing zone have K-Ar ages of 1,050–1,100 m.y. (Gittins et al., 1967). Plagioclase from amphibolite in the footwall of the Ivanhoe Lake cataclastic zone yields a ^{40}Ar/^{39}Ar plateau at 1,107 m.y., suggesting mild resetting, possibly due to faulting. Lower concordia intercepts of zircon discordia in the range 827–1,108 m.y. (Percival and Krogh, 1983) may relate to uplift at 1,100–1,000 m.y. ago.

The coincidence of Proterozoic events along the Kapuskasing structure with major orogenic activity elsewhere in the Canadian Shield suggests that the structure is an intracratonic basement uplift related to a distant cause. Further elaboration on the relationship among major structures will be aided by more precise age determinations throughout the region.

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