GREENSTONE BELTS: THEIR BOUNDARIES, SURROUNDING ROCK TERRAINS, AND INTERRELATIONSHIPS

J.A. Percival and K.D. Card, Geological Survey of Canada
Ottawa, Canada K1A 0E4

Introduction

Greenstone belts are an important part of the fragmented record of crustal evolution, representing samples of the magmatic activity that formed much of Earth's crust. Most belts developed rapidly, in less than 100 Ma, leaving large gaps in the geological record. Surrounding terrains provide information on the context of greenstone belts, in terms of their tectonic setting, structural geometry and evolution, associated plutonic activity, and sedimentation.

Tectonic Setting

Major controversy exists as to whether greenstone belts were deposited in oceanic, or marginal oceanic (1-3) or on rifted or thinned sialic crust (4-8). Archean volcanic sequences have much in common with Cenozoic volcanic arcs in terms of linear arrangements, rock types, and sequences, including calc-alkalic volcanic cones built on basal, subaqueous tholeiitic flows. Life spans are 5 to 20 Ma for individual volcanoes and 50 to 100 Ma for individual greenstone belts; some granite-greenstone terrains have several volcano-plutonic cycles differing in age by 200-300 Ma. Associated sediments consist of thin sequences of iron formation, chert, carbonate, and shale, and aprons of immature volcanogenic turbidites. Significant differences include the relative abundance of komatiites, the bimodal nature of some Archean sequences compared to the dominantly andesitic Cenozoic volcanoes, and the paucity of shelf sediments in Archean belts.

Direct evidence of oceanic settings for greenstone belts is rare. A well-preserved ophiolite sequence of Early Proterozoic age is reported from the Kainuu area of Finland (Kontinen, A., written communication, 1985) and a dismembered Archean ophiolite sequence has been interpreted in the southern Wind River Range (9). Neither is evidence for a dominantly continental setting compelling. Although sialic basement to the 2.7 Ga greenstone belts of the Slave and Superior Provinces of Canada has been recognized or inferred at several localities (4,10-13), most granitoid rocks are intrusive into, or in tectonic contact with, the volcanic rocks. Plutonic rocks, commonly with remnants of still-older supracrustal sequences, formed the basement to some volcanic piles, in a continental, micro-continental, or dissected arc setting.

A minor but significant component of Late Archean greenstone belts of the Superior Province is alkaline volcanic rocks, commonly associated with coarse alluvial-fluvial sediments, that unconformably overlie the major volcanic-plutonic successions, only a few Ma older (14-16). These sequences have many similarities to shoshonites formed in recently stabilized arcs (17).

Relationship of Greenstone Belts to Surrounding Terrains

In addition to rare unconformable relationships, fault, intrusive, and conformable depositional contacts characterize greenstone belt margins. Structure within greenstone belts is highly variable in both style and intensity of deformation. Common

features include sinuous, bifurcating folds, steep foliation and lineation and internal shear zones. Deformation may result from several causes, including: 1) tectonic emplacement of the belt (18-21); 2) diapiric rise of external and internal granitoid bodies (18,22-24); and 3) regional compression and/or transpression (25-27). In Slave Province stratigraphic onlap relationships between overlying greywacke-shale sequences and underlying volcanic rocks are common. This contrasts with the Superior Province, where belts of sedimentary rock, fault-bounded for the most part, alternate on a 50-150 km scale with major volcanic-plutonic belts.

As well as discrete fault contacts that form many belt boundaries, complex intercalation of volcanic and plutonic or sedimentary rocks by thrusting has been recognized in widespread locations (19,28-31). Thrusting at infrastructural levels may be an important process in high-grade gneissic terrains (32). Transcurrent displacements of at least several tens of kms have been estimated along some subprovince boundaries in the Superior Province (27,33,34), leading to the suggestion that greenstone and sedimentary subprovinces are accreted blocks. (27, 47, 59)

Plutonic Terrains. Plutonic rocks are particularly abundant in Archean volcano-plutonic terrains where they surround and intrude greenstone belts. Lithologically, these include variably xenolithic tonalite gneiss and more homogeneous bodies ranging from diorite to granite and syenite. Many syn-to post-kinematic plutons were emplaced during early magmatic and late diapiric stages spanning time intervals of ca 20 Ma (35). External plutons are generally similar in composition and age to plutons within belts. Although some plutonic rocks are older than and may represent basement to supracrustal sequences, contacts are generally intrusive or tectonic; precise zircon dating in Superior Province has demonstrated that many tonalite-diorite plutons are coeval with the volcanic hosts (13,36,37). Plutons of granodiorite-granite composition commonly post-date the youngest volcanic rocks and major tectonism by 5-25 Ma. Abbott and Hoffman (38) accounted for voluminous Archean tonalitic magmatism by tapping of low-temperature melts from large volumes of hydrous oceanic lithosphere consumed in shallow subduction zones. The equally voluminous granodiorite-granite magmatism may be the result of lower-crustal melting induced by thickening during collisional or accretionary events. (47).

Plutonic terrains east and west of the Kolar Schist belt have been interpreted as distinct continental fragments, sutured along the schist belt (39). Collisional processes between Precambrian blocks have not been substantiated paleomagnetically (40).

Metasedimentary Belts. Large tracts of metasedimentary rock, predominantly greywacke and shale deposited in turbidite sequences, are distinguished from the iron formation-chert-carbonate-shale successions commonly associated with greenstone belts. Metasedimentary belts, commonly metamorphosed to amphibolite facies gneiss and migmatite, constitute a significant supracrustal component of many Archean terrains, most notably the Slave and Superior Provinces of Canada.

Turbidites make up some 80% of the supracrustal sequences within the Slave Province (70). Deposition of sediments of felsic volcanic and plutonic derivation (41), is thought to be broadly coeval with eruption of marginal volcanic sequences of about 2670 Ma age (10), possibly in response to regional extension (42). The turbidites have alternatively been interpreted (20) as trench-fill deposits in a prograding accretionary complex. Sialic basement of 3 Ga age (43,44), recognized at several locations, has

been variably interpreted as continuous pre-greenstone sialic crust or as microcontinental fragments. Low-pressure regional metamorphism results from the rise of thermal domes (45), possibly associated with the intrusion of plutons.

Three major linear metasedimentary belts separate granite-greenstone terrains of the Superior Province (46,47): the English River, Quetico and Pontiac belts. Although volcanic rocks are rare or absent from the turbiditic sequences, a felsic volcanic (48) or mixed volcanic and plutonic provenance (49) is inferred. Sedimentary sequences are generally in fault contact with adjacent terrains and increase in metamorphic grade from low at the margins to high (migmatite to low-P granulite) in axial regions, where plutons, particularly peraluminous monzogranites, are abundant. It is apparent that these belts developed as elongate sedimentary basins collecting detritus from adjacent volcanic-plutonic highlands and were later subjected to deformation, axial plutonism and high-level metamorphism.

The oldest detrital zircons in metasedimentary belts are commonly derived from ancient terrains either not yet recognized, at great distance from sediment deposition, or destroyed, buried or allochthonous subsequent to the erosional event. Examples include 4.2 Ga zircons in the 3.5 Ga Mt. Narryer quartzite (50), 3.1 Ga zircons in the 2.7 Ga Pontiac belt (51), and 3.8 Ga zircons in the 3.7 Ga Nulliak quartzite (52).

Relationship Between Low and High-Grade Terrains. High-grade terrains form large parts of some Archean cratons and have variable relationships to adjacent greenstone belts. Characterized by upper-amphibolite to granulite-facies metamorphic grade in mainly intrusive rock types, high-grade terrains have been interpreted as either lateral equivalents of greenstone belts, in a different tectonic environment (53,2), or as the deeply-eroded roots to greenstone belts (54). Geobarometry is a useful tool in distinguishing between alternative interpretations in specific areas. Recognition of geological and geophysical criteria of crustal cross-sections (55) may also guide interpretation.

Examples of both lateral and vertical transitions from low to high-grade terrains are documented in the Superior Province. A lateral relationship has been inferred for the high-grade Quetico metasedimentary belt and adjacent low-grade Wabigoon and Wawa metavolcanic-plutonic belts. Volcanic rocks were deposited 2750-2695 Ma ago (13,26). Coeval turbiditic metagreywackes of the Quetico belts, about 2744 Ma old (56) have an axial high-temperature, low pressure zone of schist, migmatite, S-type granites and local granulite (58-60), suggesting a major thermal anomaly at high structural levels. Different tectonic settings and evolution are proposed for the low- grade volcanic (arc) and high-grade metasedimentary (marginal basin) terrains. Differences in structural style between belts can be attributed to variable levels of exposure (60) or mechanical character.

Evidence of dextral transpressional deformation characterizes the Wawa-Quetico-Wabigoon boundary region. This includes: 1) assymetric folds and other kinematic indicators in the northern Wawa (26), Quetico (60) and southern Wabigoon (27) belts, and 2) conglomerate and alkaline volcanic deposits associated with strike-slip faults (27,26). The event is bracketed between 2695 and 2685 Ma by zircon dates (13).

Adjacent high and low-grade Archean terrains have been interpreted, by analogy with the Cenozoic Rochas Verdes complex (2), as deeply-eroded arcs and adjacent back-arc basins respectively.

Vertical relationships between low and high-grade regions have been interpreted in the intracratonic Kapuskasing uplift (61,62) and marginal Pikwitonei region (63) of the Superior Province, as well as in the Kaapvaal Craton (64). An uninterrupted oblique cross-section through the Michipicoten greenstone belt to lower crustal granulites is exposed across a 120-km-wide transition in the southern Kapuskasing uplift. Well-preserved metavolcanic and metasedimentary rocks of the greenstone belt, metamorphosed to greenschist facies at 2-3 kbar, are intruded and underlain by some 10-15 km of tonalitic rocks which increase in structural complexity from homogeneous plutons to contorted gneisses with increasing depth. Lowermost in the section is a heterogeneous granulite complex, at least 10 km thick, of interlayered supracrustal (15%) and intrusive (85%) rocks recording metamorphic conditions of 700-800°C, 7-8 kbar (66). The crustal slab was emplaced onto low-grade rocks of the Abitibi belt on the Ivanhoe Lake thrust (66) some 2 Ga ago.

In the Pikwitonei region, distinctive rock types including iron formation, pillow basalt, calc-silicates and anorthosite can be traced along strike from the low-grade Sachigo Subprovince into Pikwitonei granulites (63). Supracrustal rocks step up in metamorphic grade across faults (67) as intrusive rocks become more abundant. Metamorphic pressure increases within the granulites from 7 to 12 kbar (68) toward the western boundary, the Nelson Front. Both the Kapuskasing and Pikwitonei structures have diagnostic features of crustal cross-sections including gradients of metamorphic grade and pressure, high proportions of intrusive rock types and paired gravity anomalies.

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