PROVINCE-SCALE CONTROLS ON ABITIBI LODE GOLD DEPOSITS

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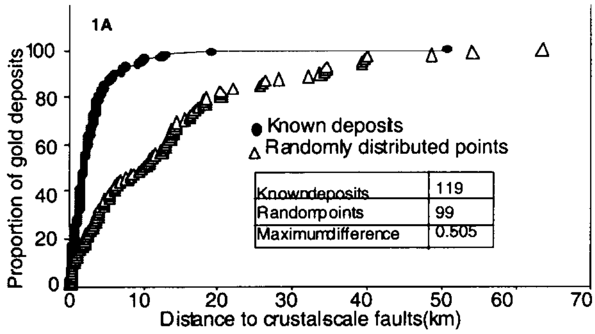
Introduction

The gold endowment of individual late-Archean granite-greenstone belts is highly variable. For example, most of Canada's world-class gold deposits occur within a small region of the 2.75 - 2.68 Ga Abitibi subprovince (Robert and Poulsen 1996). Gold production from this one area represents approximatly 5000 tonnes of the total 8000 tonnes extracted from the entire Superior Province (Spooner and Barrie 1993; Robert 1996). Phillips *et al.* (1996) have summarised the shallow-crustal terrane-attributes that optimise deposition of gold and favor the formation of world-class gold deposits. The first section of this extended abstract deals with empirical associations between specific structures and lithological associations and orogenic lode-gold deposits on the scale of the Abitibi Subprovince, and shows that similar factors operate to those discussed by Phillips et al (1996). However, given the highly irregular distribution of gold deposits in the Superior Province at the larger scale, there may be specific gold and/or source characteristics required for the generation of highly mineralised provinces containing giant gold deposits. These source factors must ultimately be related to the varying geologic histories of individual subprovinces. New data, including analyses of volcanic rock types only recently recognized in the Archean, Lithoprobe seismic interpretations, and previous structural studies in the area, allow the generation of a new conceptual model on the interrelationship of Abitibi belt geodynamics and its prodigious gold content in the second part of this extended abstract.

Regional-Scale Controls on Gold Deposits

A GIS-based study of the factors controlling the distribution of gold deposits inthe Abitibi subprovince has been carried out, using the methodologies of Knox-Robinson and Groves (1997), on a modified version of the 1:500,000 scale geological map of the subprovince produced by Provincial Surveys. At the largest scale, there is a strong association between the gold deposits and 100 km-long crustal-scale faults or shear zones ('breaks" in local terminology), with over 80% of the gold deposits sited less than 3 km from one of these structures (Figure 1A), with concentrations of deposits where they strike ENE to E-W and WNW. On a smaller scale, over 80% of gold production has come from deposits sited within 2 km of >10 km long regional-scale faults (Figure 1B). The deposits are sited in specific rock types within the greenstone belt and are sited closer to the lithological contacts than expected if their distribution was random: about 80% of the deposits are within 1 km of a regional-scale contact as shown at the scale of the map usedin the analysis. Deposits sited next to six of the thirteen contact types contribute > 90% of gold production, with four contributing > 75% of production. Lithological contatcs oriented between ENE and WNW account for the majority of gold, a similar control as for the crustal-scale faults. All of these defined parameters confirm the controls on the siting of lode-gold deposits at a regional scale by factors such as large-scale plumbing systems, gross orientation of litholigical packages to the far-field stress at the time of mineralisation, the physical and chemical properties of the liuthological units in the greenstone belts and the competing contrasts between them, as discussed by Phillips et al (1996).



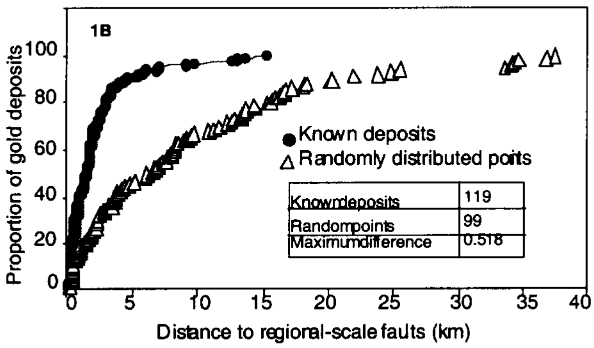


Figure 1. Known Relationships between Abitibi Gold Deposits and Crustal- and Regional-Scale Faults Versus Predicted Relationships Between the Faults and Randomly Distributed Points.

Geochemical and Isotopic Constraints

The Abitibi belt of the Superior Province of Canada is the worlds largest preserved granite-greenstone terrane. The Northern Volcanic Zone (NVZ) and Southern Volcanic Zone (SVZ) are the most fundamental subcomponents of the Abitibi belt (Chown *et al.* 1992). The NVZ is considered a coherent arc sequence, whereas the SVZ consists of diverse lithotectonic assemblages that are widely regarded as allochthonous. Most komatiites in the Abitibi belt occur in a semi-contiguous trend that extends across the width of the subprovince along the NVZ- SVZ boundary.

Precise U-Pb age dates indicate that komatiite-bearing volcanic sequences and arc-style tholeiitic to calc alkalic sequences of the Abitibi subprovince overlap in terms of eruption ages (Corfu 1993). Some arc-type sequences, such as the ~ 2730 Ma Hunter Mine Group, predate Abitibi komatiites, whereas the youngest arc-type sequences, such as the 2701 Ma Blake River Group and 2705 Ma Val d'Or

Formation, post-date komatiites. Komatiitic basalts and komatiites cross-cut and conformably overlie the calc-alkalic rifted-arc sequence of the Hunter Mine Group. These relationships are consistent with ~ 2725 Ma impingment of a mantle plume on the early Abitibi arc as represented by lower assemblages of the NVZ (Dostal and Meuller 1997). Wyman *et al.* (1999) established that, further west along the trend, the Kidd Creek giant massive sulphide deposit occurs at a komatiite to arc-tholeiite transition. A class of low-Ti tholeiites (LOTI) are intercalated with komatiites and ~ 2714 Ma rhyolites in the footwall of the massive sulphide deposit in the Kidd Volcanic Complex. The LOTI flows possess distinctive geochemical characteristics, such as high MgO contents (12-18 wt. %), low Ti contents (TiO_2 < 0.4 wt %), very high Al_2O_3/TiO_2 and strongly fractionated HREE. These geochemical features occur in younger rocks associated with boninites in proto arc or juvenile arc sequences (e.g., Tasmania) and result from high degrees of prior melting in their source regions as a result of extreme crustal extension in overlying juvenile arcs.

A suite of Low-Ti tholeiites has now also been identified in the komatiite-bearing Central and Southern structural domains of the Malartic Block, a structural unit in the eastern Abitibi belt initially defined by Desrochers *et al.* (1993). The tholeiites are strongly depleted in incompatible elements and display many boninitic characteristics, including high Mg contents (MgO to 11.5 wt. %), high Al_2O_3/TiO_2 ratios (up to 65), and fractionated HREE (Gd_N/Yb_N = 0.44 - 0.66; Fig. 2A). The Malartic Block occurences are directly comparable to LOTI located at the western end of the Abitibi komatiite trend. The distinctive geochemical features of these rocks, and their presence in volcanic sequences containing komatiites, requires a hybrid mantle plume – (proto) arc tectonic setting at the time of eruption where the two distinct sources required for these rocks must have co-existed. These new results extend the evidence for plume-arc interaction across the entire width of the Abitibi belt.

Rhyolites in the Malartic Block southeast of Val d'Or lack Nb anomalies and have trace element patterns similar to those of high-silica rhyolites from Iceland that are derived from melting of plume-related oceanic crust during rifting. Accordingly, these felsic rocks likely reflect a period of extension and partial melting within the underlying accreted sequences of the Malartic Block. This origin is consistent with an episode of extension within accreted plume-derived sequences as proposed by Desrochers *et al.* (1993). The rhyolites are cross cut by weakly deformed to undeformed feldspar porphyry dykes. Similar dykes at the Sigma mine, at the western end of the Val d'Or domain, have been dated at 2694 ± 2.5 Ma by conventional zircon dating, whereas deformed porphyritic diorite at the mine has an age of 2703.7 ± 2.5 Ma (Wong *et al.* 1991).

The porphyries are distinguished geochemically from the predominant calc-alkalic volcanic rocks of the Val d'Or domain by stronger LREE enrichments and more pronounced Nb, Zr-Hf and Ti depletions in combination with generally higher incompatible element abundances (Fig. 2C). These characteristics are shared with volumetrically minor feldspar- and hornblende-phyric volcanic flows located within calc alkaline sequences overlying accreted plateau basalts and komatiites. All of the sodic porphyritic rocks are derived from subduction-modified sources and are likely to represent relatively small-degree mantle melts generated during extensional episodes within the overlying Malartic Block.

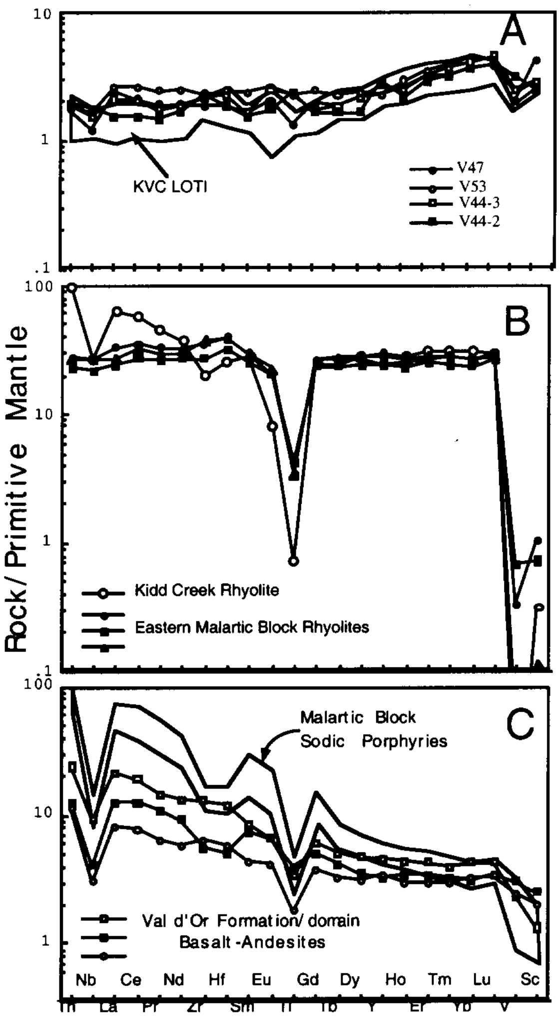


Fig. 2. Primitive mantle normalized plots for selected rock types of the Malartic Block.

In summary, the combination of new geochemical data and previous structural studies suggest that: (1) early accretionary events in the Malartic Block were associated with contemporaneous mantle plume and island arc volcanism; (2) the earliest examples of non-plume volcanism in the Malartic Block represent proto-arc or juvenile arc volcanism; (3) extensional episodes within the accretion complex were accompanied by sporadic emplacement of sodic porphyries and sodic trachyte volcanism and a distinct c. 2704 Ma, or younger, generation of rhyolites derived from oceanic crustal melts. These observations imply that a new subduction zone was initiated as a result of plume-arc interaction and therefore that subduction beneath the NVZ likely stepped back outboard of accreted plateau-type crust. The site of the early subduction zone is likely to correspond closely to the Manneville Fault where north over south thrusting occurred between 2697 and 2690 Ma (Fig. 3; cf. Mueller *et al.* 1996).

Implications for Abitibi Gold Deposits

Couture *et al.* (1994) have established that two distinct quartz-carbonate lode-gold mineralization events occurred in the Val d'Or area. They showed that a tourmaline-poor event occurred prior to intrusion of a 2692 ± 2 Ma tonalite dyke, whereas a markedly tourmaline-rich mineralization event (e.g. the Sigma Mine) post-dates this intrusion.

The tectonic history of the Abitibi belt outlined above is consistent with the presence of multiple generations of lode gold deposits in the SVZ, given that tectonic disturbances to subduction zones can generate such mineralization (e.g., gold deposit ages in the Alaskan Chugach terrane coincide with a thermal anomaly related to subduction of the Kula–Farallon spreading ridge: Goldfarb, et al., 1998).

The events can be incorporated into a model that relates the prodigeously gold-rich nature of the southern Abitibi belt to the accretionary history of the subprovince. The distinctive aspects of the history of the Abitibi belt began with mantle plume ascent, at approximately 2725 Ma, in close proximity to an intraoceanic island arc. This relationship resulted in a hotspot topographic high or small plateau immediately outboard of the subduction zone (Fig. 3A) and the local eruption of the plume-related volcanic rocks through disrupted fore-arc sequences. The eruption of komatiites would have produced unusually depleted and bouyant upper mantle beneath the plateau (Abbott 1996). The resulting topographic and thermal anomaly resisted subduction and jammed the Abitibi subduction zone, leading to accretion of plateau fragments as envisioned by Desrochers *et al.* (1993). Plate rearrangement required a zone of proto-arc-type volcanism, intercalated with varying proportions of plume related volcanic rocks, along the hotspot track boundary by ~ 2716 Ma (Fig. 3B).

A new subduction zone was established by southerly step back by 2705 Ma, resulting in: (1) removal of oceanic slab associated with the first subduction zone, (2) metasomatism of depleted plateau mantle subcreted beneath the NVZ, (3) the development of arc volcanism in the Val d'Or Formation, and (4) the isolation of some unaccreted plateau fragments inboard of the new trench (Fig. 3B,C). At about this time, the northern-most part of the Abitibi was juxtaposed with the Opatica belt, but subducted oceanic crust at this suture did not delaminate and only minor gold mineralization occurred (Fig. 4A; Clowes et al., 1998).

At the suture associated with the NVZ-SVZ boundary, however, the effect of subduction step back was likely to have disturbed the hanging slab associated with transport of plateau fragments. As a result, upwelling hot asthenophere may have had limited access to the base of the NVZ-SVZ collision zone. However, this exposure would be short-lived if old delaminated subducted slab were rapidly replaced by new subducted slab (Fig. 4B). Accordingly, lode gold deposits formed at this time (~ >2690 Ma) were developed from comparatively minor hydrothermal systems and moderate thermal anomalies that failed to utilize the full potential of the gold source regions.

The young arc developed on top and south of the accreted plateau, resulting in the tholeiitic to calc alkalic sequences of the Val d'Or domain. As is typical in the Pacific, the young arc underwent extension that may have generated the Malartic Block crustal melt rhyolites, described above, and resulted in the eruption of Heva Formation tholeiites. Further extension resulted in back arc development via ~ 2701 Ma eruption of the Mg and Fe-tholeiite Kinojevis Formation along a propagating east-west oriented spreading centre (present coordinates). This back arc extension episode isolated fragments of plateau crust and early rhyolites (e.g., the komatiite-bearing Larder Lake Group and overlying ~ 2705 ± 2 Ma pyroclastic rocks: Corfu 1993) from the main komatiite trend along the NVZ boundary. A new locus for arc volcanism generated the 2701 to 2698 Ma tholeiite to calc alkalic Blake River Group arc–volcanic sequence (Fig. 3C).

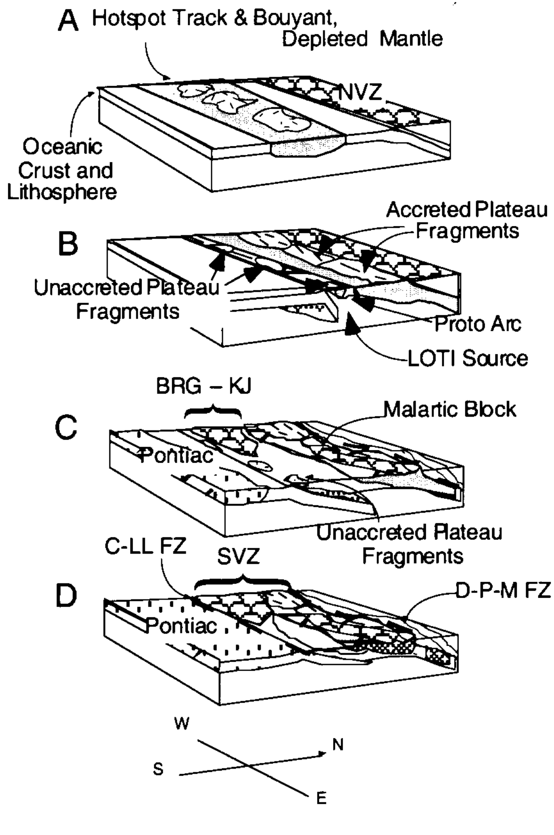


Fig. 3 Geodynamic History of the Abitibi belt Southern Volcanic Zone (SVZ).

Arc volcanism was soon terminated in the southern Abitibi subprovince with the convergent approach of the Pontiac subprovince. Within ~10 m.y., the latter was underthrust beneath an SVZ which comprised plateau, arc and back-arc volcanic sequences along with sedimentary basins and a variety of plutonic rock types (Mueller *et al.* 1996). Pontiac underthrusting in the Val d'Or area introduced a substantial source of boron at mid- to lower-crustal levels that is likely to have been responsible for the presence of abundant tourmaline in younger SVZ lode gold deposits (Robert *et al.* 1995).

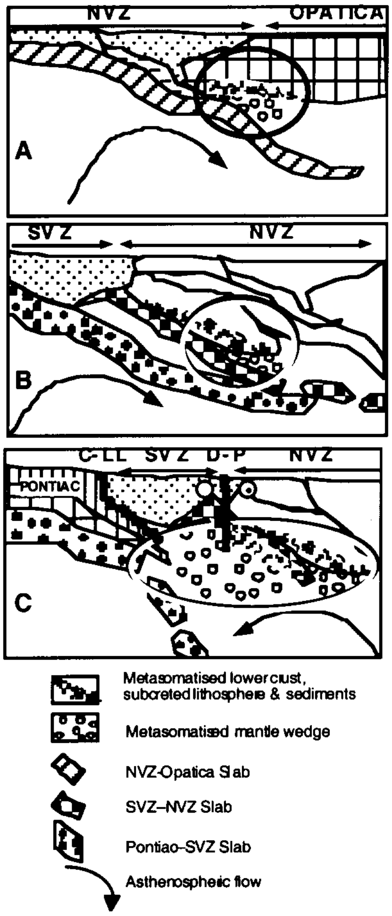


Fig. 4. Gold Potential of Abitibi Suture Zones. See text for discussion.

Underthrusting beneath the NVZ and Malartic Block gave way to strike-slip tectonics focussed along the regional Destor Porcupine-Mannville fault. Slab delamination at the Pontiac-Abitibi collision zone preceded final cratonization beneath the Abitibi and probably occurred between ~ 2685 Ma and 2674 Ma concurrently with: (1) the change to strike-slip tectonics, (2) deposition of Timmiskaming alluvial-fluvial sediments in transtensional basins, and (3) late calc alkalic to shoshonitic magmatism (Wyman and Kerrich 1993; Mueller *et al.* 1996). In contrast to the preceeding NVZ-SVZ slab delamination, the loss of the second slab was not related to renewed subduction and no thermal barrier was present to impede upwelling hot asthenosphere. As a consequence, the lower parts of the double accretion complex (Pontiac-Abitibi; NVZ-SVZ) was subjected to a major late- to post-accretionary thermal event (Fig. 4C).

Given the well-documented association of Archean to modern lode-gold deposits with accretionary tectonic settings, the doubling factor imposed by two successive accretion events may be sufficient to account for the location of the vast majority of Canada's world-class examples within a small part of the Abitibi belt. However, the presence of subducted high degree melts (komatiites) and perhaps second degree melts (low-Ti tholeiites) along the length of the NVZ-SVZ boundary may also have further upgraded the gold-potential of the region because these rock types are intrinsically enriched in noble metals.

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