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Geodynamic constraints on mineralization and metamorphism at the Griffin's Find gold deposit, Western Australia, from calibrated T-t trajectories

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Summary

Metamorphosed hydrothermal gold and massive sulfide deposits are now widely recognized in multiply-reworked Precambrian terranes around the world. In most cases the absolute timing of pre-metamorphic mineralization can only be inferred and is based largely on the absence of tell-tale hydrous alteration assemblages and the occurrence of unusual retrograde native metal and sulfide assemblages and textures diagnostic of sulfide partial melting. In this contribution, I demonstrate that a significant portion of the prograde and peak temperature-time (T-t) history at the metamorphosed (granulite-facies) Griffin's Find deposit, Western Australia, is preserved by: 1) inclusion suites in poikiloblastic garnet cores; 2) core-to-rim Y, Cr, Sc, P and REE zoning in garnet; 3) the ages of sub-solidus monazite inclusion in garnet, and; 4) the ages of neoformed monazite and zircon that crystallized in leucosomes. The result of integrating these datasets demonstrates that host rocks to the Griffin's Find deposit encountered lower amphibolite facies conditions (540ºC) at 2645 ± 5 Ma and passed into the melt-stability field above 3.5 kbar based on the discontinuous nature of Cr zoning in garnet. The rocks subsequently reached peak P-T conditions of 850ºC and 6.5 kbar at or before 2625 ± 5 Ma based on the timing of monazite and zircon crystallization in leucosomes. If this 20 Ma record of prograde metamorphism is considered as a single 'event', then the calculated heating rate is ~15ºC/Ma, roughly an order of magnitude higher than estimates for collisional orogenic belts (e.g., Foster et al., 2004). These compressed timescales and high heating rates are diagnostic of contact metamorphism rather than collisional orogenesis. Basic magmatic activity across the Lake Grace Terrain, including charnockitic plutons south of Griffin's Find, have zircon crystallization ages as old as 2652 Ma, hinting at a possible mechanism to produce both hydrothermal (intrusion-related?) gold mineralization followed shortly by inversion of pre-heated crust to produce low-P granulites.

Introduction

The Griffin's Find gold deposit in the eastern Lake Grace Terrain (LGT) of the Southwest Yilgarn Craton, Western Australia, has been of peripheral interest of economic geologists and metamorphic petrologists since it was highlighted as the type example of the 'continuum' model (Groves et al., 1998) for orogenic gold deposition. A recent reassessment of peak P-T conditions and gold and sulfide textures at Griffin' Find (e.g., Tomkins & Grundy, 2009) has shown that this deposit is more correctly interpreted as a metamorphosed deposit. Details of the timing and geodynamic context of pre-metamorphic gold mineralization remain to be established.

Methodology

Examination of garnet in neosome domains in residual granulites at Griffin's Find revealed a ubiquitous core-overgrowth structure characterized by inclusion-packed cores surrounded by inclusion-free overgrowths. These locally idioblastic overgrowths are typically in contact with cuspate or blocky melt pools occupied largely by quartz (Figure 1). Leucosome domains in the same rock are composed of quartz, K-feldspar, and plagioclase with large (up to 1 cm) peritectic cordierite and orthopyroxene. Large (50-200μm) monazite and zircon grains are ubiquitous accessory minerals in leucosome domains. All analyses described below were carried out at the Australian National University, Research School of Earth Sciences.

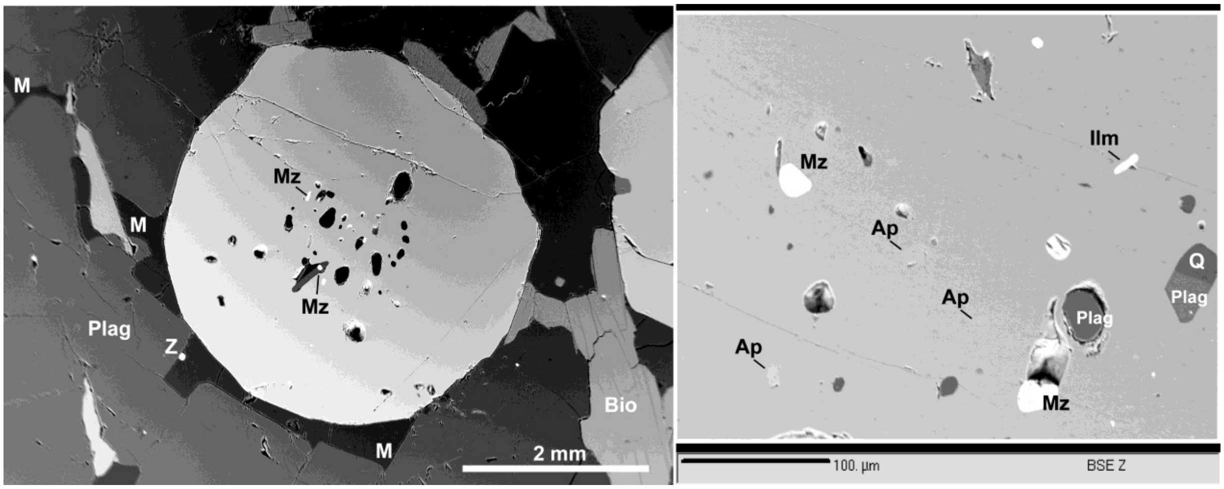

Figure 1: Core-overgrowth structure in garnet porphyroblast and melt pools (M) in the adjacent matrix. Equant zircon (Z) is typically present with melt pools. In addition to quartz (Q), plagioclase (Plag), poikiloblastic cores also contain monazite (Mz), apatite (Ap), ilmenite (Ilm) and rare pyrrhotite.

To better understand the nature of the textural discontinuity between cores and overgrowths in garnet, a series of trace element X-ray maps were constructed using a Cameca SX100 microprobe operated at 25kV, 1 µA, and 0.25s dwell time for trace elements (Sc, Ti, Cr, Y) and 25kV, 200nA and 0.2s dwell time for major elements (Fe, Mg, Ca, Mn).

Core-to-rim trace element concentration variations in these mapped garnets were measured by LA-ICP-MS using a custom-built 193nm Excimer laser and small-volume two-volume sample cell connected to an Agilent 7500 quadrupole mass spectrometer.

Monazite included in poikiloblastic garnet cores and monazite and zircon in leucosomes was then targeted for in-situ U-Pb geochronology using the SHRIMP RG. For both monazite and zircon, the primary oxygen beam was focused through a 70µm Kohler aperture generating a ~14µm spot on the target surface and a beam current of 1.5nA. Thompson Mine monazite (1766 Ma) and FC1 zircon (1099 Ma) were used as primary calibration standards. Ages are reported as ^{204}Pb-corrected ^{207}Pb/^{206}Pb ages unless otherwise noted.

Examples

Compositional X-ray mapping (Figure 2) revealed internal zoning preserved by slow-diffusing trivalent cations (Sc, Cr, Y). Most notably, the Cr X-ray map shows an abrupt discontinuity between a patchy low-Cr (350-400 ppm) core with an idioblastic outline and a higher-Cr (600 ppm) rim in contact with the aforementioned melt pools. The transition between these two compositional domains marks the textural transition from poikiloblastic core to inclusion-free overgrowth. The poikiloblastic core is also characterized by a bell-shaped Y zoning profile with a maximum concentration of 750 ppm, and uniformly low Y concentrations (30-50 ppm) in the overgrowth domain. For major elements, Ca and Mn display subtle antithetic zoning (Ca falling, Mn rising) whereas Fe and Mg have been homogenized and then locally reset adjacent to neighbouring biotite grains. P-T estimates based on major-element thermobarometers are, therefore, unlikely to yield near-peak P-T conditions for Griffin’s Find.

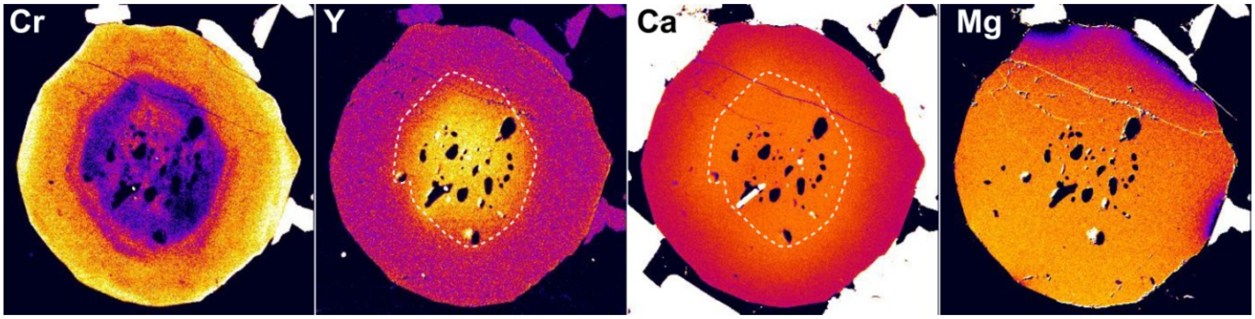

Figure 2: Core-overgrowth compositional domains in garnet porphyroblast revealed using microprobe X-ray mapping. Dashed polygon shows position of Cr-discontinuity.

The patchy Cr zoning in garnet cores is interpreted to reflect overprint zoning (e.g., Yang & Rivers, 2001) whereas the abrupt change outboard of the poikiloblastic core is interpreted to reflect the onset of vapour-absent melting of muscovite and biotite concomitant with renewed garnet growth (e.g., Spear & Kohn, 1996). The latter interpretation requires that the P-T trajectory passed into the dehydration melting field without an intervening sub-solidus interval of garnet growth (i.e., above ~3.5 kb in KFMASH space).

Core-to-rim spot analyses obtained by LA-ICP-MS also reveal systematic changes in garnet REE profiles across the transition (Figure 3). The two textural and compositional domains display changes in MREE and HREE diagnostic of: 1) sub-solidus Rayleigh fractionation in cores, and; 2) garnet growth in equilibrium with anatectic melt and zircon (Hermann & Rubatto, 2003) in overgrowths. Higher P in overgrowths may also reflect dissolution of OH-apatite during vapour-absent melting.

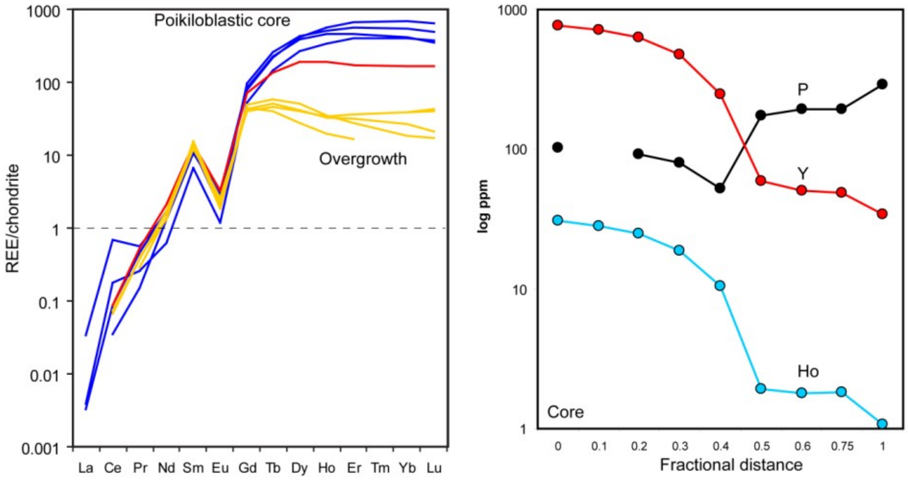

Figure 3: Core-overgrowth REE profiles (left) and select concentration profiles (right) revealed by LA-ICP-MS (note log scale).

The presence of monazite, apatite, and plagioclase as inclusions in garnet, combined with the bell-shaped Y zoning profile in garnet (Figure 2 and 3) suggest that application of the Pyle et al. (2001) Monazite-YAG thermometer may be appropriate. Using the compositions of apatite (X_{OH}=0.1), plagioclase (X_{An}=0.2), garnet (X_{grs}=0.06), and monazite (X_{YPO4}=0.03) measured by electron microprobe and a garnet Y content of 750 ppm (X_{YAG} = 0.0015) measured by LA-ICP-MS, an estimate of ~540ºC for garnet cores is obtained.

The results of in-situ SHRIMP geochronology are shown in Figure 4 and highlight the timing of zircon and monazite crystallization in leucosomes (2625 ± 4 Ma, *n* = 8) compared to older 2645

Ma higher-Y monazites included in sub-solidus garnet cores. The onset of basic magmatism (white star) preceded growth of monazite in garnet cores by 5-10 Ma.

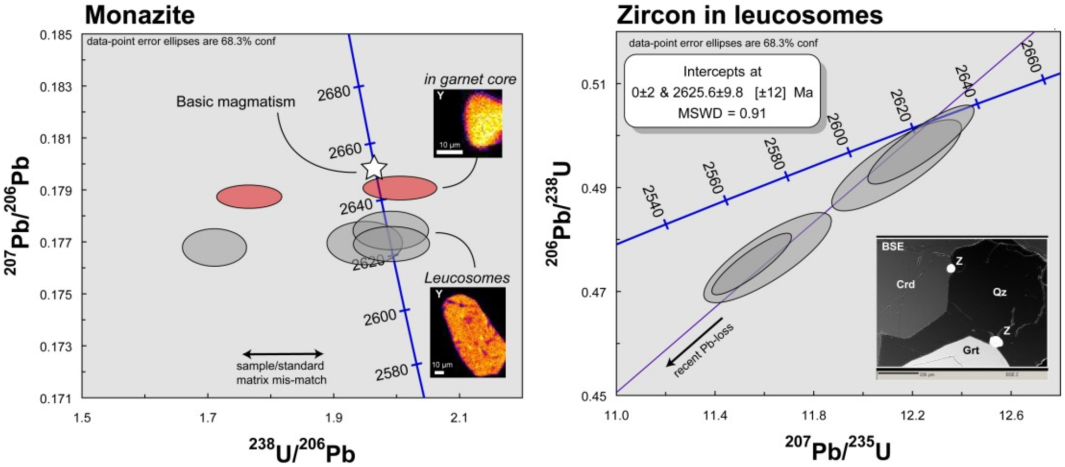

Figure 4: Summary of preliminary in-situ monazite (left) and zircon (right) U-Pb geochronology obtained by SHRIMP. Hot colours are higher concentrations in inset Y maps of monazite.

Conclusions

With estimates for prograde heating trajectories (2645 to 2625 Ma @ 15ºC/Ma), timing of high-T anatexis (2625 Ma), and complimentary evidence for significant additions of basic magmas to the Lake Grace Terrane crust prior to 2645 Ma, gold mineralization and the generation of low-P granulites can now be interpreted with greater confidence. Namely, this 'externally' heated scenario provides the ingredients to preserve magmatic-hydrothermal gold deposits that form as conductive geotherms propagate upwards through the crust. This makes pre-metamorphic deposits available for reworking during subsequent horizontal accretion of pre-heated crust.

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