Controls of gold-quartz vein formation during regional folding in amphibolite-facies, marble-dominated metasediments of the Navachab Gold Mine in the Pan-African Damara Belt, Namibia

Alexander F.M. Kisters
Department of Geology, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa
e-mail: akisters@sun.ac.za

ABSTRACT

The Navachab gold mine in central Namibia is situated in amphibolite-facies, marble-dominated metasediments of the Neoproterozoic Damara Sequence in the Pan-African Damara Belt. Gold mineralization is hosted by two main, and at least three minor, sets of auriferous quartz-veins that are developed on the subvertical northwestern limb of the regional-scale, shallow doubly-plunging anticline of the Karibib dome. The orientation, relative timing and progressive deformation of quartz veins indicate that veining occurred during folding and fold amplification of the Karibib dome. This deformation forms part of the main phase of northwest-directed collisional tectonics in the Damara belt at ~540 to 550 Ma.

The two main vein sets include (1) bedding-parallel, shallowly-plunging ore lenses and shoots situated at the base of a prominent marble unit, and (2) a laterally extensive swarm of shallowly-dipping quartz veins that truncate the host rocks at high angles. The bulk of the bedding-parallel lenses represent dilational jogs that opened during flexural flow along bedding-parallel slip planes during the amplification of the Karibib dome. Flexural flow and associated bedding-parallel fluid infiltration were concentrated close to the contact between marbles and the underlying siliciclastic formations. This lithological contact, in particular, represented a pronounced rheological contrast resulting in increased slip rates during fold amplification. The highly discordant sets of shallowly-dipping, sheeted quartz veins were emplaced during the fold lock-up stage of the Karibib dome. Quartz veining occurred when the northwestern limb of the dome was rotated to subvertical attitudes, so that bedding-parallel flexural slip ceased to be active. Extensional fracturing and veining was facilitated by the presence of transiently supralithostatic fluid pressures. The high-amplitude fluid pressure cycling associated with extensional fracturing is likely to have triggered gold precipitation in the shallowly-dipping veins. Although bedding-parallel veins and discordant veins are broadly contemporaneous, related to the regional-scale D2 phase of fold-and-thrust tectonics, cross-cutting relationships between the two main vein systems indicate that the two vein sets have represented separate entities and succeeded each other rather than forming an interconnected fracture mesh.

Introduction

Orogenic lode-gold deposits represent exhumed hydrothermal vein systems that reflect the presence of transient high-permeability conduits and the discharge of large amounts of fluids in upper- and mid-crustal rocks (Etheridge *et al.*, 1984; Cox *et al.*, 1991; Sibson, 1996). Lode-gold deposits are typically structurally controlled and although the actual controls of the fluid pathways may differ considerably in detail, the hydrothermal vein systems are commonly hosted by brittle and brittle-ductile deformation zones of either ancient fault-zone systems or associated with fold structures (Hodgson, 1989). This spatial and temporal relationship between deformation and fluid flow is now widely recognized to reflect the interplay between periods of seismic slip and associated fluid-pressure cycling related to the creation and subsequent sealing of fracture permeabilities in the deforming rocks (Sibson *et al.*, 1988; Ridley, 1993; Cox *et al.*, 1995; Robert *et al.*, 1995; Sibson ,1996; Sibson and Scott 1998; Oliver, 2001; Groves *et al.*, 2003).

The Navachab gold mine in the Damara Belt of central Namibia is the only known primary gold deposit in the extensive system of Pan-African (~550 to ~500 Ma) orogenic belts in southern Africa. The mine is located some 200 km west of Windhoek on the edge of the Namib desert. It is situated in amphibolite-facies metasedimentary rocks of the Damara Sequence, a Neoproterozoic marble- and schist-dominated continental shelf-type succession (Miller, 1983) (Figure 1). The gold mineralization was discovered in the early-1980's and production started in late-1989 from an open cast operation. Since then, some 900.000 oz of gold have been produced with a current annual production of ~2.4 t Au at average gold grades of ~2 g/t (Steven and Badenhorst, 2002).

Gold mineralization is hosted by a composite system of quartz- and quartz-sulphide lodes. The auriferous quartz-vein system is located on the steep northwestern limb of a northeasterly trending, kilometre-scale, shallow doubly-plunging anticline, the Karibib dome (Figure 2). Mining currently exploits two main, geometrically distinct ore body geometries. Early mining concentrated on linear, massive sulphide shoots and an associated skarn-type alteration confined to the base of the marble-dominated Okawayo Formation and most workers have emphasized the partly stratabound nature of the mineralization (Moore and Jacob, 1998; Nörtemann *et al.*, 2000). The massive sulphide ore shoots and skarn alteration have tentatively been related to the intrusion