Peperite in the Backdoor Formation and its significance to the age and tectonic evolution of the Bangemall Supergroup

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Abstract

Present constraints on the age of the Bangemall Supergroup are based primarily on c. 1465 Ma and c. 1070 Ma dolerite intrusions, which have been interpreted to approximate the ages of the Edmund and Collier Group respectively. New data from a dolerite sill on Kenneth Range support intrusion of the c. 1070 Ma suite into wet or inhomogeneously lithified sediments, resulting in the formation of localized peperite and associated fluidized sediment. The fluidized horizon is interpreted to affect the upper Edmund Group and basal Collier Group, suggesting that the significance of the intervening regional unconformity requires further investigation. Estimates of the depth of intrusion, combined with the dominantly below-wave-base depositional environment of the host rocks and distribution of other c. 1070 Ma sills, suggest that sedimentation and subsidence rates were high. Integration of palaeocurrent data further suggests that dolerite intrusion may have played an active role in the evolution of the Collier Basin, initially through the generation of local and regional uplifts, and later as a driver for subsidence through increased loading. The large volume of sills, combined with anomalous subsidence and sedimentation rates, may be related to mantle plume activity.

KEYWORDS: Peperite, fluidization, metamorphism, Bangemall Supergroup.

Introduction

Despite almost half a century of geological investigation, no reliable depositional ages have been determined for the Bangemall Supergroup. This situation is due mainly to the scarcity of contemporaneous volcanic units suitable for isotopic dating. Until recently, the Bangemall Supergroup was considered to be younger than 1638 ± 14 Ma (Nelson, 1995), but stratigraphic relationships with precisely dated granites in the underlying Gascoyne Complex show that it must be younger than c. 1620 Ma (Martin and Thorne, 2002). Currently the best constraints on the age of the Bangemall Supergroup come from SHRIMP U–Pb dating of zircon and baddeleyite in dolerite sills (Nelson, 2001; Wingate, 2002), integrated with palaeomagnetic studies (Wingate, 2002). These studies have identified sills belonging to two discrete mafic intrusive events at c. 1465 Ma and c. 1070 Ma that constrain the minimum ages of the Edmund Group and unconformably overlying Collier Group respectively. However, Wingate (2002) suggested that the sills mark the culmination of extensional basin cycles and constrain the approximate depositional ages of the groups.

Dolerite sills in sedimentary basins generally intrude at depths less than 10 km, prior to regional deformation (Francis, 1982). They may also feed extrusive magmatism. Sharp, planar contacts with well-defined chilled margins reflect intrusion into a lithified host, whereas vesicular upper contacts and mixing with host sediment are more characteristic of shallow-level intrusions and extrusive flows. Peperite records a specific kind of shallow-level magma–sediment mixing that typically develops at the margins of intrusions due to the interaction between hot magma and wet, unconsolidated sediment. This interaction involves fluidization of the host sediment and fragmentation of the cooling magma by a variety of processes (Kokelaar, 1982), and may also be accompanied by dynamic magma–sediment mixing (Busby-Spera and White, 1987). Fluidization also provides a mechanism whereby large volumes of host sediment can be passively displaced by the intruding magma (Kokelaar, 1982). The presence of peperite is therefore a reliable indicator of the broad contemporaneity of magmatism and sedimentation. This paper describes peperite and associated features related to a dolerite sill on Kenneth Range*, and considers the geochronological

* Capitalized names refer to standard 1:100 000 map sheets.

and tectonic implications, based on field relationships, petrography, and geochemistry.

Geological setting

The Bangemall Supergroup is the youngest tectonic element within the Capricorn Orogen, and unconformably overlies the Pilbara and Yilgarn Cratons, the Ashburton, Hamersley, and Earaheedy Basins, and the Gascoyne Complex. It comprises mainly lower greenschist facies, fine-grained siliciclastic and carbonate rocks that are divided into the Edmund, Collier, and Manganese Groups (Martin and Thorne, 2002). The Collier Group is separated from the underlying Edmund Group by a regional low-angle unconformity, across which there may be a 400 m.y. hiatus (Wingate, 2002). The erosional level is deepest in the east where the Collier Group and correlative Manganese Group are thickest. Uplift and erosion on this unconformity appears to be related to westward tilting of the Edmund Group.

Dolerite sills within the Bangemall Supergroup do not appear to be linked to feeder dykes, and in some cases are regionally discordant. The oldest, and volumetrically smallest, sills intruded the middle to upper Edmund Group at c. 1465 Ma (Wingate, 2002). However, the bulk of the sills in the Bangemall Supergroup intruded both the Edmund and Collier Groups at c. 1070 Ma (Wingate, 2002), occupy an area of about 143 000 km^2 (Muhling and Brakel, 1985), and may be part of a large igneous province (LIP; Pirajno et al., 2002). Most Bangemall sills are characterized by planar upper and lower contacts, well-defined chilled margins, and rare xenoliths, suggesting intrusion into a lithified host. The localized presence of fine-grained amygdaloidal to vesicular tops (Daniels, 1969) and plastically deformed sedimentary xenoliths (Muhling and Brakel, 1985) have been used as evidence that some sills may have been emplaced at relatively shallow depths. Individual sills may be more than 100 m thick, but thermal aureoles are generally thin (<30 cm) and characterized by silicification or development of hornfels. Many sills contain a coarse, locally granophyric phase in their central to upper parts. Both sets of sills were folded and metamorphosed under lower greenschist facies during the Edmundian Orogeny, which pre-dates the northeast-trending 755 Ma Mundine Well dyke swarm (Wingate and Giddings, 2000).

On central KENNETH RANGE, a regionally discordant dolerite sill, up to 125 m thick, intrudes the Edmund Group and transgresses the overlying unconformity into the Collier Group. At its northwestern end, the sill is concordant within the upper Edmund Group, but links into a dyke where it transects the unconformity, only to become weakly discordant within the lowermost Backdoor Formation (Fig. 1). Discordance within the Backdoor Formation can be traced by reference to the basal unconformity (Fig. 1a; Martin and Thorne, 2002). The base of this marker is displaced about 10 km in an apparent sinistral strike-slip sense, suggesting coincidence of the sill with a fault (Fig. 1a). The relative timing between fault displacement and sill intrusion is difficult to determine because the two structures are roughly coplanar. However, folds and cleavage preserved at a number of localities along the northern margin of the sill provide structural evidence for a component of steep reverse faulting that post-dates intrusion.

Contact relationships and petrography

This sill is of particular interest because features commonly interpreted to be the result of the interaction between magma and wet sediment are locally preserved along the upper contact. The sill is mostly intruded into siltstone, dolostone, and minor medium-grained quartz sandstone, in which there is little evidence of disruption or contact metamorphism, except along a strike length of 4 km between localities 1 and 4 (Fig. 1b). Here the contact is locally marked by either sediment-matrix dolerite breccia, or a thin unit of mixed and remobilized sedimentary rock that resembles lithic quartz-wacke in hand specimen and separates the dolerite sill from the overlying intact host rocks.

The sediment-matrix dolerite-breccia facies comprises large (decimetre- to metre-scale) angular blocks of medium-grained dolerite and smaller fine-grained sedimentary clasts in a matrix of fine- to medium-grained sandstone. The facies is exposed in a 65 × 30 m plug-like outcrop at the upper contact of the sill at locality 1 (Fig. 1b). Dolerite clasts have planar to curviplanar margins and locally display jigsaw-fit texture, indicating minimal dispersal (Fig. 2). The sandstone matrix also contains drusy vesicles, and sedimentary clasts with alteration rims. Large (decimetre-scale) sedimentary clasts are abundant close to the contact with the host sediments. The sediment-matrix dolerite-breccia facies is overlain by non-disrupted siltstone with planar lamination that conforms to local bedding. Lithofacies characteristics are consistent with interpretation as blocky peperite (Busby-Spera and White, 1987).

Southeast of locality 1, the contact is essentially planar but locally marked by a poorly exposed unit of mixed lithic quartz-wacke facies. At locality 2, outcrop and hand-specimen relationships indicate that the mixed lithic quartz-wacke facies intruded the overlying units, producing small rafts and clasts of sandstone, and locally displacing siltstone and dolostone by a process of stoping and assimilation (Fig. 3). There is no mixed lithic quartz-wacke facies at locality 3, where the sill is overlain by at least 5 m of amalgamated, thick-bedded quartz sandstone. In contrast, southeast of locality 3, the sill intrudes parallel-planar laminated siltstone that is typical of the bulk of the Backdoor Formation (Fig. 1b). In this area, the sandstone and overlying siltstone–dolostone have been eliminated by either faulting or fluidization along the upper contact of the sill, or a combination of these. The mixed lithic quartz-wacke facies is particularly well exposed at locality 4 where it intrudes laminated siltstone (Fig. 4), and contains numerous

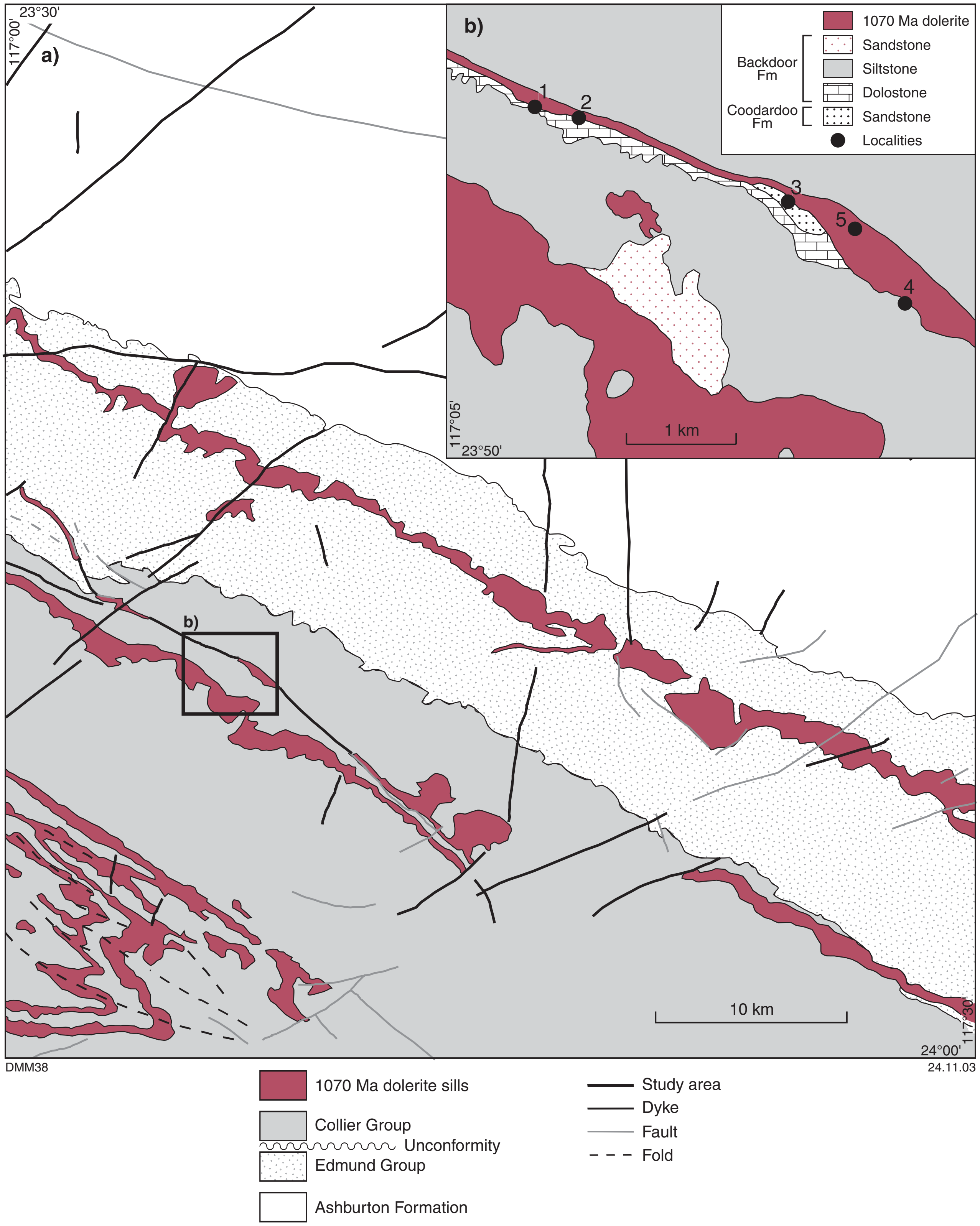

Figure 1. a) Simplified geological map of KENNETH RANGE *showing the distribution of c. 1070 Ma dolerite sills, and the location of the study area. b) Detailed geological map of the exposed limits of magma – wet sediment interaction showing the position of localities 1–5.*

Figure 2. Blocky peperite at locality 1, showing jigsaw-fit between dolerite clasts (arrow)

plastically deformed siltstone clasts and amygdales (Fig. 5) that are lined with drusy K-feldspar and filled with calcite (Fig. 6). The contact between the mixed lithic quartz-wacke facies and dolerite is not exposed, but the upper contact is sharp and conformable at outcrop scale.

The regional metamorphic grade in the Bangemall Supergroup is very low, except in contact aureoles around dolerite sills, and is characterized by quartz–sericite–chlorite assemblages in siliciclastic rocks and recrystallization in carbonates. Contact metamorphism adjacent to the sill in question has significantly modified syndepositional fabrics within the peperite, mixed lithic quartz-wacke facies, and adjacent reactive host rocks. The thermal aureole is seldom greater than about 20 cm in the laminated siltstone, where it is characterized by patchy silicification or development of spotted slate, but is up to 20 m thick in the more reactive siltstone–dolostone unit. Metamorphism of the siltstone–dolostone is characterized by patchy alteration or complete recrystallization to form the assemblage dolomite–quartz–calcite–diopside–tremolite. Veinlets and patches of this mineral assemblage extend into adjacent interbedded siltstones. Clearly identifiable detrital quartz grains in the sandstone immediately adjacent to the sill have undergone mild recrystallization to form a granoblastic-polygonal texture in a matrix of chlorite. At locality 1, the matrix of the peperite consists of a mixture of fine- to medium-grained quartz sand, and angular clasts of siltstone and dolerite in a matrix of chlorite, biotite, and rare calcite (Fig. 7). Dolerite clasts show strong chlorite–sericite alteration. The lithic quartz-wacke at locality 4 consists of granoblastic-polygonal and rare embayed quartz, poikiloblastic cloudy K-feldspar and biotite, and fine-grained (0.02 – 0.3 mm), spongy porphyroblastic grossularite in a matrix of radiating acicular aggregates of muscovite, chlorite, and biotite (Fig. 8). These assemblages contrast with the lower greenschist facies chlorite–sericite assemblages in the enclosing host-sedimentary facies.

Dolerite petrology and geochemistry

No distinction can be made in hand specimen or thin section between the c. 1465 Ma or the c. 1070 Ma sills. Both suites are characterized by medium-grained quartz dolerite with fine-grained chilled margins, and localized veins and enclaves of coarse-grained granophyre or pegmatoid leucogabbro (Wingate, 2002). In thin section, they contain subophitic plagioclase, augite, orthopyroxene, magnetite, minor granophyric intergrowths of quartz and K-feldspar, pyrite, and rare olivine (Muhling and Brakel, 1985). Secondary minerals, attributed to deuteric alteration, include biotite, sericite, hornblende, clinozoisite, leucoxene, chlorite, and bastite (Muhling and Brakel, 1985). This uniformity in petrology throughout the Bangemall Supergroup

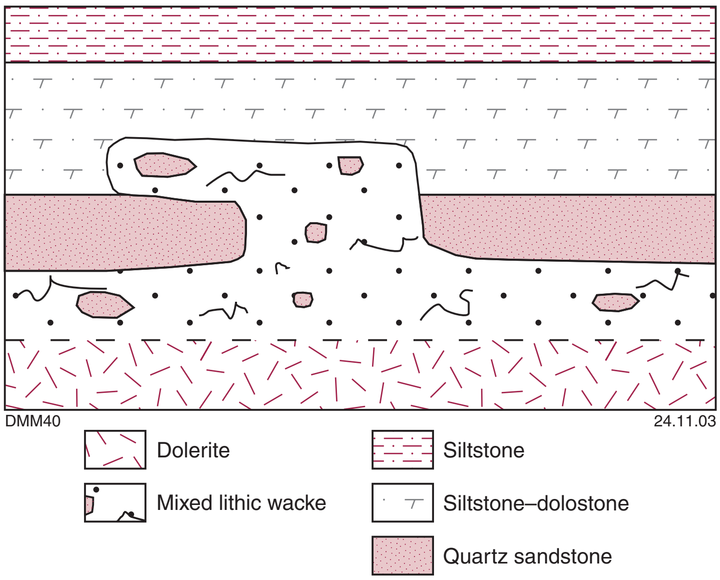

Figure 3. Schematic representation of the intrusive relationships seen in both outcrop (metre-scale) and hand-specimen (decimetre-scale) between the dolerite, mixed lithic quartz-wacke, and siltstone–dolostone facies at locality 2. Note the stoping of siltstone–dolostone and the inclusion of rafts of sandstone in the lithic quartz-wacke facies. Not to scale

was interpreted by Muhling and Brakel (1985) to indicate rapid emplacement of a single suite from a homogeneous source, without assimilation of country rock.

More recently, discrimination between the c. 1465 and c. 1070 Ma sills has been based on geochronology and palaeomagnetic remanence (Wingate, 2002), but can also be made on geochemical grounds (Morris, P. A., 2003, written comm.). Regardless of the extent of fractionation, c. 1465 Ma sills have lower incompatible-element ratios (e.g. Th/Nb) than c.1070 Ma sills, are less enriched in light rare earth elements (LREE), and have flatter heavy rare earth element (HREE) patterns. Dolerite from locality 5 (GSWA 156562; Fig. 1b) has a c. 1070 Ma geochemical signature, supporting the age implied from intrusive relationships.

Discussion

The contact relationships between dolerite and host sediments described above are atypical of sills within the Bangemall Supergroup. Similar features are commonly associated with shallow-level intrusions into wet, unconsolidated sediment (e.g. Kokelaar, 1982; Busby-Spera and White, 1987). Blocky peperite provides good evidence for the injection of fluidized sand into fractures generated by the thermal contraction of the dolerite, and possibly the explosive conversion of water to superheated steam (Kokelaar, 1982). The restricted distribution of blocky peperite may be attributed either to inhomogeneities in the distribution of pore water, or to the isolation of pockets of wet sand along the contact during intrusion, thereby restricting the lateral escape of steam.

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Figure 4. Intrusive relationship between mixed lithic quartz-wacke facies (M) and planar-laminated siltstone (S) at locality 4

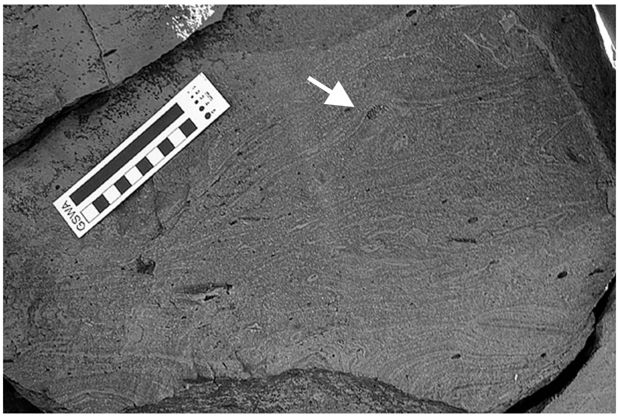

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Figure 5. Deformed platy siltstone clasts (light coloured) and amygdales (arrow) characteristic of the mixed lithic quartz-wacke facies at locality 4

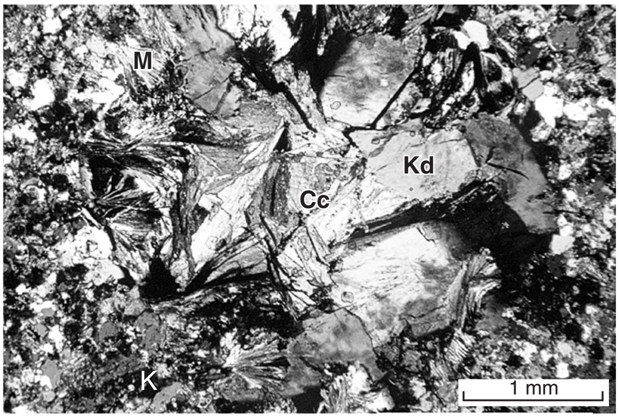

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Figure 6. Thin-section photomicrograph of an amygdale in lithic quartz-wacke at locality 4, showing drusy K-feldspar rim (Kd) and late calcite fill (Cc). Also note the radiating acicular muscovite (M) and poikiloblastic K-feldspar (K) in the matrix

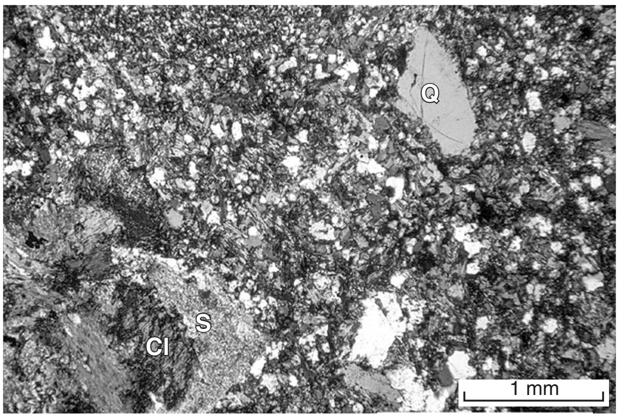

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Figure 7. Thin-section photomicrograph of blocky peperite at locality 1. Note chlorite (Cl) and sericite (S) alteration of a dolerite clast, and the matrix of quartz (Q) grains and fine chlorite–biotite

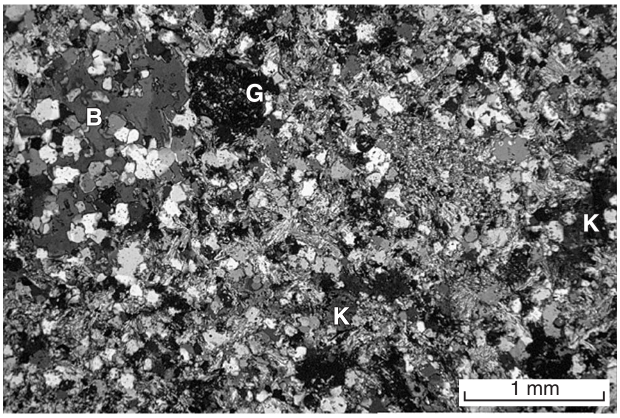

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Figure 8. Thin-section photomicrograph of the mixed zone at locality 4 showing poikiloblastic K-feldspar (K) and biotite (B), and euhedral spongy grossularite (G), in a matrix of granoblastic quartz and fine-grained muscovite–chlorite–biotite

However, the textural features and contact relationships of the mixed lithic quartz-wacke facies, and the lateral discontinuity of the quartz sandstone, suggest that magma interaction was dominated by streaming of a steam-sediment slurry along the contact. This slurry was mainly produced by fluidization of the more permeable quartz sand by heated pore water that also interacted with the magma to produce K-rich fluids. Fluidization appears to have been passive, with flow mainly in the plane of the contact, but a small vertical component resulted in stoping and rafting of overlying sediments. The poikiloblastic textures that characterize the mixed lithic quartz-wacke facies are interpreted to reflect rapid crystallization of the K-rich slurry. Assimilation of host dolostone and rapid crystallization is further supported by the presence of fine, spongy grossularite.

The seemingly contradictory evidence for cohesive behaviour (stoping and fragmentation) and fluidization along the same contact, and the localized distribution of blocky peperite, suggest dolerite intrusion at relatively high confining pressure into inhomogeneously lithified sediments. Theoretical critical-pressure estimates suggest that fluidization due to heating cannot occur above 312 bars, equivalent to 3.1 km of seawater or 1.6 km of wet sediment (Kokelaar, 1982). Since the Backdoor Formation has a compacted thickness of 1.7 km in this area, and was deposited mainly below storm wave-base (>50 m), we can assume that the sill was intruded prior to deposition of the overlying Calyie Formation. The stratigraphic relationships, sedimentological characteristics, and regional distribution of the quartz sandstone that underlies the siltstone–dolostone unit suggest that it belongs to the Coodardoo Formation (Fig. 1). However, the evidence for fluidization of this unit along the dolerite contact is at odds with previous interpretations of a significant hiatus between the Edmund and Collier Groups (Martin and Thorne, 2002; Wingate, 2002). The observed relationships therefore imply that both the Coodardoo and Backdoor Formations may not be significantly older than c. 1070 Ma, and that at least part of the former could belong to the Collier Group.

The presence of sills at stratigraphic levels above the lower Backdoor Formation (Wingate, 2002) suggests that sedimentation rates were extremely high at c. 1070 Ma. Furthermore, the predominance in the Collier Group of facies deposited below storm wave-base is indicative of high subsidence rates. This coincidence of high rates of sedimentation and subsidence is most likely tectonically driven, and may be related to intrusion of the sills. The expected effects of dolerite intrusion are a combination of dynamic uplift and subsidence due to increased loading. A change in palaeocurrent direction from southwesterly to southeasterly in the upper third of the Backdoor Formation may reflect local uplift due to sill emplacement. Since there is no evidence for feeder dykes within the Collier Basin, the sills may have been emplaced from outside the exposed limits of the Bangemall Supergroup. Elsewhere, large intrusions such as this have been interpreted as the product of gravitational flow away from the culmination of a mantle plume (e.g. Aspler et al., 2002). A northwesterly palaeocurrent reversal in the Calyie Formation is a response to rapid shallowing and delta progradation from the southeast, most likely due to uplift. A mantle-plume origin for this uplift would be consistent with the LIP hypothesis of Pirajno et al. (2002), and could explain the apparent absence of intra-basinal feeders and anomalous subsidence history of the Collier Basin.

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