

Subeclogitic rocks and their implications for crustal structure in the western Musgrave Block, central Australia

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Subeclogitic rocks — rocks metamorphosed under conditions transitional from granulite to eclogite facies — are known in Australia only in the Musgrave Block (Clarke 1993: AGSO Research Newsletter, 18, 6–7; Clarke et al. 1995a: AGSO Journal of Australian Geology & Geophysics, 16, 127–146; Scrimgeour & Close in press, Journal of Metamorphic Geology; Fig. 17). In the Bates 1:100 000 Sheet area, subeclogitic rocks that formed at ~40-km depth crop out over an area of 2000 km². They are characterised by regionally developed garnet-bearing coronas around mafic grains in Meso- to Neoproterozoic granulite, granite, and mafic dykes. This paper discusses the crustal structure of the western Musgrave Block, and presents two competing schemes for explaining the present crustal structure.

Regional setting

The Musgrave Block (Fig. 17) consists of metamorphic rocks, granites (some meta-

morphosed), layered mafic-ultramafic intrusions (Giles Complex), and mafic dykes. Regional metamorphic facies ranges from greenschist to subeclogite. Major east-striking low to high-angle faults cut the block and penetrate the crust. The largest is the Woodroffe Thrust. North of it, felsic gneisses and deformed granite have amphibolite-facies mineral assemblages dated at 1600–1550 Ma. South of it, felsic and subordinate mafic volcanic and shallow-water sedimentary rocks accumulated between ~1580 and 1300 Ma, and were metamorphosed to granulite facies at about 1200 Ma. Voluminous granite masses dated at about 1190 Ma, outliers of the Giles Complex, and three generations of mafic dykes succeeded the granulites. The relationship of the two regions before they were juxtaposed is not known in the Bates area.

The Woodroffe Thrust dips gently south, and formed during the Petermann Ranges Orogeny at 550–530 Ma in response to north-south compression of the Australian plate (Lambeck & Burgess 1992: Australian Journal of Earth Sciences, 39, 1–19). The

Mount Aloysius Fault crosses the Bates area in the south, is steeply south-dipping and normal, and has granulite-facies rocks on both sides. It is inferred from coincident magnetic and topographic lineaments along the northern edge of the Mount Aloysius massif, and from pressure estimates by Clarke et al. (1995a: op. cit.) of 1000–1400 MPa (equating to a depth of formation of 40 km) to the north of the fault and 300–500 MPa to its south.

The subeclogitic rocks, products of regional metamorphism during the Petermann Ranges Orogeny, display ubiquitous and spectacular garnet-bearing coronas around mafic grains in the hanging-wall rocks of the Woodroffe Thrust. Mineral assemblages in the intensely deformed thrust zone range from subeclogitic to greenschist, indicating changing metamorphic conditions as the overridding rocks travelled up-dip.

The subeclogitic and other rocks were mapped in detail during 1991 as part of a National Geoscience Mapping Accord investigation of the Giles Complex and its host granulites (Glikson et al. 1996: AGSO

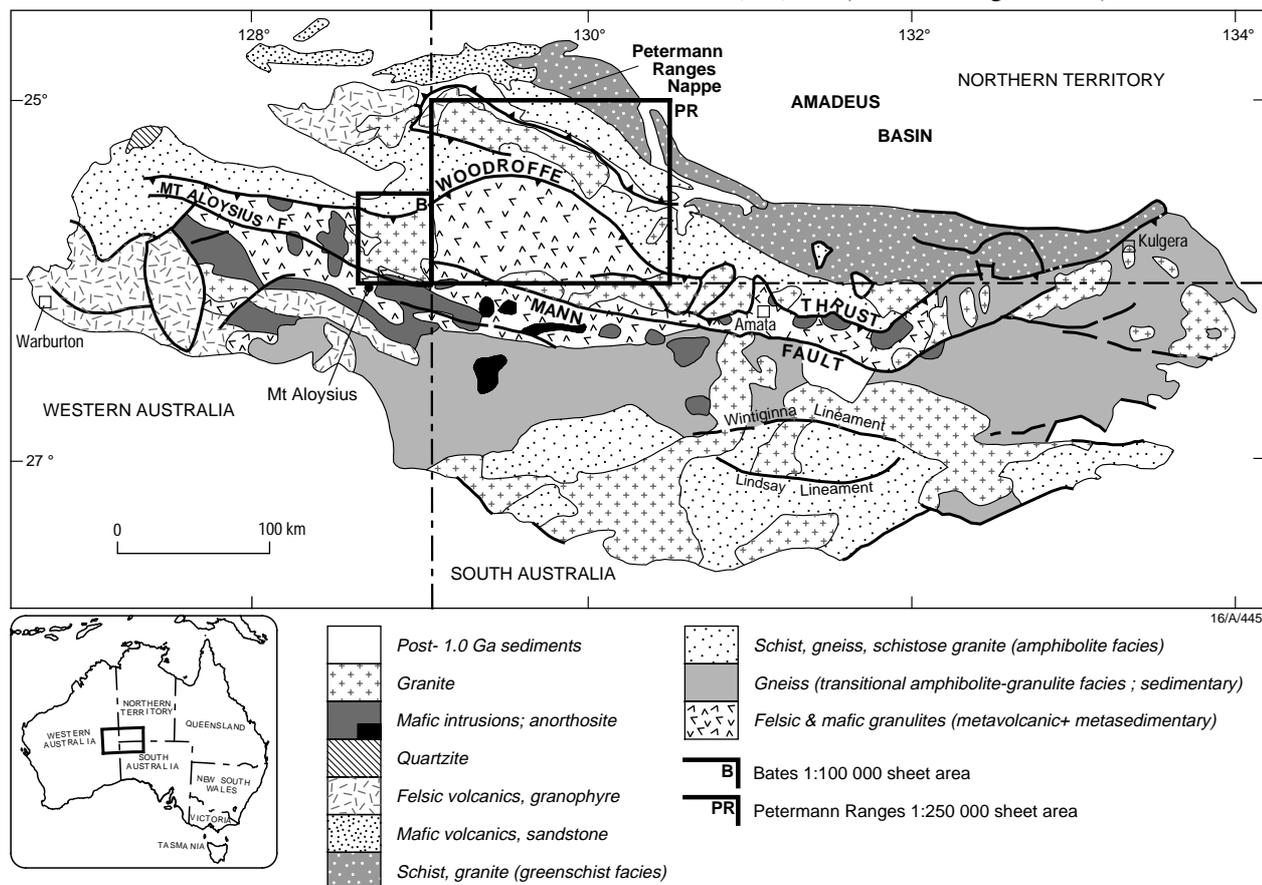


Fig. 17. Simplified geology of the Musgrave Block. The location of the Woodroffe Thrust is from Scrimgeour & Close (in press: op. cit.) in the southwest Northern Territory (cf. D'Addario et al. 1976: Geology of the Northern Territory, 1:2 500 000 geological map, Bureau of Mineral Resources/AGSO, Canberra); and from Edgoose et al. (1992: Kulgera, 1:250 000 geological map, second edition, Northern Territory Department of Mines & Energy) in the Kulgera area.

Bulletin 239; Stewart 1997: AGSO Record 1997/5).

Mylonite zones

A mylonite zone 400 m thick in the northern Bates Sheet area delineates the Woodroffe Thrust (Stewart 1995: AGSO Journal of Australian Geology & Geophysics, 16, 147–153), and separates subeclogite-facies metamorphic rocks to the south from deformed granite, from which the mylonite is derived. Similar mylonite (but also containing abundant clasts of garnet derived from metagranite south of the thrust) forms hills tracing a north-northwest-striking tear fault cutting the thrust.

Numerous mylonite zones 1–20 m wide and several hundred metres long cut the subeclogitic rocks south of the Woodroffe Thrust. They comprise subeclogite-facies minerals (White & Clarke 1997: Journal of Petrology, 38, 1307–1329). Their sense of shear is dextral, sinistral, reverse, and normal in about equal proportions (at different exposures). Most dip gently to moderately southwards, and have a subhorizontal west-southwest-plunging stretching lineation. These are the same orientations observed in the Woodroffe Thrust, suggesting that the mylonites and thrust are coeval. This is supported by the subeclogite-facies mineral assemblages in the mylonites, which are probably lower-crustal splays of the thrust.

Granulite-facies metamorphism (1200 Ma)

Where they are unaffected by subeclogitic metamorphism, garnet-bearing assemblages in intermediate and mafic granulites from the area south of Bates have yielded temperature and pressure estimates of 750°C and ~500 MPa for D₂. D₃ pressure estimates are 400–600 MPa for a temperature of 700°C (Clarke et al. 1995a: op. cit., p. 130). Gray (1978: Journal of the Geological Society of Australia, 25, 403–414) dated the granulite metamorphism as 1222 ± 39 Ma (Rb–Sr whole-rock isochron), which Sun & Sheraton (1992: AGSO Research Newsletter, 17, 9–10) confirmed with a SHRIMP U–Pb zircon age of 1200 Ma for synmetamorphic augen gneiss.

Subeclogite-facies metamorphism (535 Ma)

Subeclogite-facies coronas around orthopyroxene, clinopyroxene, hornblende, and opaque grains in rocks south of the Woodroffe Thrust comprise concentric shells of garnet ± plagioclase ± biotite ± clinopyroxene ± hornblende ± rutile. Pressure estimates are consistently 1000–1400 MPa; temperature estimates range from 700–875°C (Clarke et al. 1995a: op. cit., p. 141; White & Clarke 1997: op. cit.). The subeclogitic metamorphism was dated by Clarke et al. (1995b: AGSO Journal of Australian Geology & Geo-

physics, 16, 25–39) with Sm–Nd mineral-pair ages of 536 ± 16 and 533 ± 16 Ma for a metagabbro dyke. This agrees with Rb–Sr and Ar–Ar ages of 550–530 Ma for the Petermann Ranges Orogeny 250 km to the east (Maboko et al. 1992: Australian Journal of Earth Sciences, 39, 457–471; Camacho & Fanning 1995: Precambrian Research, 71, 155–181), and with an Sm–Nd garnet–hornblende–whole-rock–mineral isochron age of 494 ± 59 Ma in the adjoining Petermann Ranges 1:250 000 Sheet area (Scrimgeour & Close in press: op. cit.).

Implications for crustal structure

The present-day crustal structure of the Musgrave Block dates from the Petermann Ranges Orogeny. It has been determined by Lambeck & Burgess (1992: op. cit.) from teleseismic travel-time studies. Overthrusting along the Woodroffe Thrust accounts for the upward movement of the subeclogitic rocks to their present position in Bates, but the mechanism of their descent to 40 km is unclear. Following Lambeck & Burgess, I previously depicted the Woodroffe Thrust as steepening at depth, and invoked underthrusting of the footwall block (Stewart 1997: op. cit., fig. 17). This left the mid-crustal granulites of the hanging wall stranded well above 40 km. Scrimgeour & Close (in press: op. cit.) presented a possible solution when they recognised the regional extent of subeclogitic rocks immediately east of Bates, and concluded that the Petermann Ranges Orogeny involved substantial crustal thickening.

According to one possible sequence of events (Fig. 18a–d), crustal compression and thickening depressed the 1200-Ma-old mid-crustal granulites to subeclogitic-facies depths of 40 km at about 550 Ma (Fig. 18b). East-northeast overthrusting along the Woodroffe Thrust transported the subeclogitic rocks from the lower crust onto upper-crustal amphibolite-facies rocks (Fig. 18c), and accompanied high-angle reverse faulting along equivalents of the Lindsay and Wintiginna Lineaments.

Movement directions on the Mann Fault (Fig. 18d) have long been problematical. Lambeck & Burgess (1992: op. cit., p. 17) considered it to be a thrust. However, their figure 11, which depicts the hanging-wall block above the Woodroffe Thrust as upper crust, conflicts with their textual reference (pp. 11–12) to this block as having a lower-crustal velocity (7.0 km/s). Thus, lower crust south of the Mann Fault is displaced downwards relative to the hanging-wall block of the Woodroffe Thrust — i.e., the nett movement on the Mann Fault was normal. The Mount Aloysius Fault in the south of the Bates region is a splay or *en echelon* offshoot of the Mann Fault to the east. Normal (or transtensional) faulting along the Mount Aloysius–Mann Fault left a crustal wedge as the highest part of the region (Fig. 18d). The subeclogitic lower-crustal rocks in the lower portion of this wedge are preserved as the

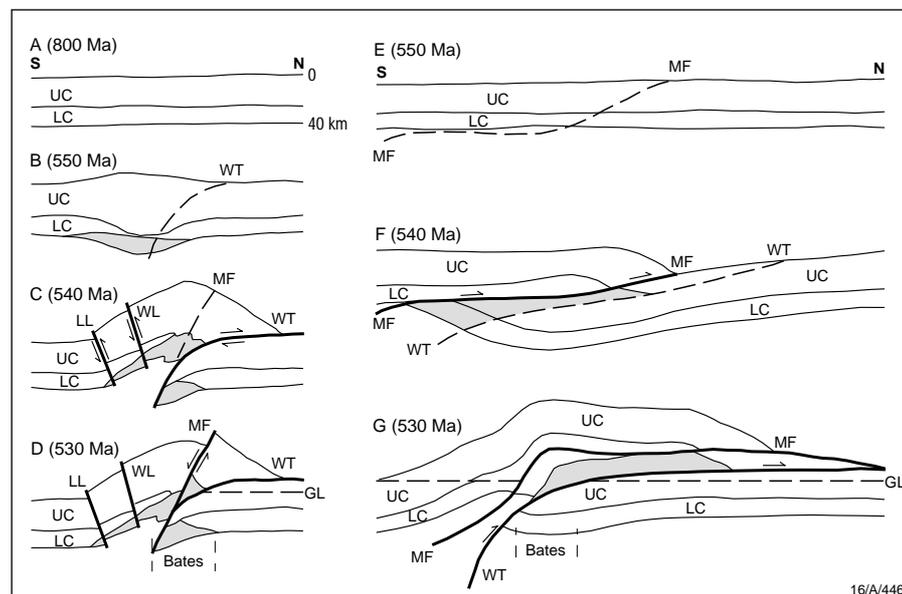


Fig. 18. Two diagrammatic cross-sectional models of Neoproterozoic–Cambrian evolution of the western Musgrave Block (and projected locations of the Bates 1:100 000 Sheet area and present ground level, GL; hatching represents subeclogitic rocks): a–d — after Lambeck & Burgess (1992: op. cit., fig. 11); e–g — after Butler (1986: op. cit., fig. 11). (a) Initial crust (LC, lower crust; UC, upper crust) at 800 Ma. (b) Crustal thickening and position of the Woodroffe Thrust (WT). (c) Overthrusting along the Woodroffe Thrust; reverse faulting along equivalents of the Wintiginna (WL) and Lindsay Lineaments (LL; projected onto the section from the east); and position of the Mann–Mount Aloysius Fault (MF). (d) Normal faulting along the Mann–Mount Aloysius Fault. (e) Initiation of the proto-Mann Fault. (f) Overthrusting along the Woodroffe Thrust. (g) Overthrusting along the Woodroffe Thrust and steepening of the Mann Fault.

hanging-wall block of the Woodroffe Thrust in Bates.

An alternative scheme, based on modelling of the Alps and Himalayas (Butler 1986: *Journal of the Geological Society of London*, 143, 857–873), involves two episodes of thrusting. In Figure 18e–f, underthrusting along the proto-Mann Fault (low-angle) depresses a slab of crust to subeclogitic-facies depths. Subsequent initiation of the Woodroffe Thrust and renewed contraction elevated the subeclogitic

rocks to their present level, and steepened the Mann Fault to its present attitude (Fig. 18g).

The two models differ significantly in their sense of movement — normal or reverse — on the Mann Fault, and in their depiction of the Moho just south of the Bates region. The differences could be tested by detailed structural study of the Mann Fault and its adjoining rocks to determine the sense of shear, and by a deep seismic survey across this part of the Musgrave Block.

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