# Post-Palaeoproterozoic thermochronology of the Precambrian northern Western Australian Shield

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**Abstract:**

Reconnaissance $^{40}Ar/^{39}Ar$ dating of K–feldspars and muscovites, and fission track and (U–Th)/He thermochronometry on apatites has been applied to ~1 x $10^6$ $km^2$ of the northern Western Australian Shield. The study area includes the Archaean northern Yilgarn Craton and Pilbara Craton, and the intervening Proterozoic basins. K–feldspar $^{40}Ar/^{39}Ar$ data reveal cooling from ~1800–1600 Ma or 1200–1000 Ma depending on the sample and the $^{40}Ar/^{39}Ar$ muscovite ages lie between ~900–1000 Ma. Apatite fission track data yield ages between 290–180 Ma with confined horizontal mean track length ranging between 11.5–14.3 $\mu$m and standard deviations of track length distributions falling between 1.1–2.2 $\mu$m. Preliminary (U–Th)/He apatite data yield ages ~250 Ma or older. Numerical modelling of $^{40}Ar/^{39}Ar$ and fission track data reveals phases of accelerated cooling, which can be related to major tectonic Proterozoic and Phanerozoic events hitherto unrecorded in this vast area.

**Keywords:**

$^{40}Ar/^{39}Ar$ dating, apatite fission track dating, (U–Th)/He thermochronology, thermal history, Western Australian Shield

In this reconnaissance study we present new thermochronological data ($^{40}Ar/^{39}Ar$ dating of K–feldspars and muscovites, apatite fission track and (U–Th)/He thermochronometry) from the northern part of the Western

Australian Shield (Fig.1). The region encompasses an area of ~$1x10^6$ $km^2$ and includes Archaean rocks of the Pilbara Craton, the northern part of the Yilgarn Craton including the Narryer Gneiss Complex, and the Proterozoic Gascoyne, Rudall and Northampton Complexes. The Palaeo- to Mesoproterozoic Hamersley, Ashburton and Bangemall Basins and the Neoproterozoic Savory and Officer Basins to the east of the study area developed on the Pilbara and Yilgarn Cratons. Numerical modelling of the data provides constraints on possible time-temperature paths for the shield from temperatures below ~450˚ C.

Previous U/Pb zircon SHRIMP data (Nutman et al., 1993) from the northwestern part of the Yilgarn Craton and $^{40}Ar/^{39}Ar$ analyses of hornblende, muscovite and biotite (Zegers et al., 1999) from the Pilbara Craton revealed mainly middle to late Archaean ages. Mesoproterozoic sphene fission track ages from the Pilbara Craton were reported by (Ferguson, 1981). These data suggest that the cratons have not been affected by any significant cooling events since Mesoproterozoic time. The geomorphology of the study area also reveals a subdued relief, which is characteristic for Australian cratonic landscapes. The fact that the shield consists entirely of Precambrian rocks with low topographic relief has led to the widely held view that the West Australian Shield has been tectonically stable for a long period (Twidale, 1997). Further, Fairbridge and Finkl (1980) suggest that the surface of the West Australian Craton has not been effectively lowered by erosion since the Mesoproterozoic.

$^{40}Ar/^{39}Ar$ K–feldspar data indicates slow cooling from either ~1800–1600 Ma or ~1200–1000 Ma, depending on the sample. Some samples yield minimum ages of ~500 Ma, which suggests either a small amount of reheating and minor argon loss at that time, or a minor pulse of increased cooling. Two muscovite samples produced $^{40}Ar/^{39}Ar$ cooling ages at ~900 Ma and 1000 Ma.

Apparent apatite fission track ages range between 290–180 Ma and confined horizontal mean track lengths lie between 11.5–14.3 $\mu$m with standard deviations of track length distributions falling between 1.1–2.2 $\mu$m.

Preliminary apatite (U–Th)/He results yield ages ~250 Ma or older, although most samples do not duplicate well, probably indicating the presence of U and/or Th-bearing micro-inclusions and zoning of U in the apatite grains (as indicated by mica detectors used for fission track dating).

Numerical modelling of the K–feldspar data (Lovera et al., 1997) shows monotonic cooling histories for most samples, commencing at some time in the Proterozoic depending on the sample. The cooling histories are nonlinear with phases of accelerated cooling alternating with slower cooling and quiescent periods. Modelling of time-temperature history paths of apatite fission track data (Gallagher, 1995) reveals a late Carboniferous to early Permian regional cooling episode and a minor late Mesozoic cooling episode. Modern heat flow measurements on the Western Australian Shield (Cull, 1982) fall in the range 40–50 $mW.m^{-2}$. Assuming a thermal conductivity of 2.5 $W.m^{-1}.K^{-1}$ suggests a present-day average geothermal gradient of ~18±2° C/km. If this gradient was representative of much of the Phanerozoic then a minimum of ~50° C of late Palaeozoic cooling is calculated, suggesting denudation of ~2.5–3.1 km of section. A further ~25˚C of cooling, predicted for some time during the Mesozoic, translates into ~1.2–1.5 km of denudation. However, this cooling was from higher crustal levels (~85–60°C) and is therefore less well constrained. The interpretation of the (U-Th)/He apatite data is currently problematic, probably due to slow cooling rates, microcrystalline U and Th-rich inclusions in apatites such as zircon and monazite, and U-Th zoning.

Accelerated cooling at ~1100 Ma, ~650 Ma and ~500 Ma, as inferred by some of the $^{40}Ar/^{39}Ar$ data, probably reflects a response to the waning stages of the Grenvillian, Paterson and Pan-African Orogenies respectively. Similarly the Permo/Carboniferous cooling, inferred by the apatite fission track data, is probably related to the commencement of the development of the passive continental margin to the west and north of the shield, which subsequently led to the break-up of Greater India from the Australian continent.

Further independent evidence for Proterozoic cooling is provided by biotite Rb/Sr ages from the northern part of the Yilgarn Craton where ages decrease from ~2500 Ma in the east to 630 Ma along the western cratonic margin (Libby et al., 1999). They argue that resetting of the younger ages towards the west either resulted from a dyke swarm or from heating due to tectonic loading by thrusting in late Neoproterozoic/early Phanerozoic time.

During the Palaeozoic, Western Australia experienced widespread tectonism during the formation of Pangea, which subsequently broke-up during the Mesozoic. Phanerozoic sedimentary basins, e.g. the Perth, Carnarvon and Canning Basins, developed to the west, north and east of the Western Shield accumulating up to 15 km of sedimentary strata. Killick (1998) independently calculated the volume of sediment deposited in these basins marginal to the Western Shield between early Ordovician to late Cretaceous time, after which time clastic sedimentation effectively ceased. This led to an estimated overall removal of ~4.1 km of basement from the Western Shield since the onset of basin development and sedimentation in the early Ordovician. The basins are likely to have been depocentres for denudational unloading from adjacent continental terranes during the Phanerozoic such as the Cimmerian Blocks, Greater India, Antarctica and Western Australia (Baillie et al., 1994). This has been confirmed by provenance studies on Permo-Triassic sediments from the Perth Basin, using U/Pb SHRIMP ages from detrital zircons, revealing Archaean to early Palaeozoic ages (Cawood & Nemchin, 2000).

The results of the thermochronological data suggest that the northern Western Shield has experienced overall regional cooling from temperatures of ~400-450˚C since late Palaeoproterozoic time. Proterozoic and Phanerozoic basins, that partly continue offshore, contain predominantly clastic sediments and are likely to have been depocentres for much or at least some of the detritus derived from the denudation inferred by the thermochronological data. The post-Palaeoproterozoic thermotectonic history presented here complements previous geochronological data revealing the early history of the Western Shield.

**Figure 1**: Geological map of the study area. Cratons are Archaean, intervening tectonic units are Proterozoic, while westernmost basins (Perth and Carnarvon) are Phanerozoic.

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