E1. Project title

Tectonic feedback and the long-term evolution of the continents

E2. Background

The elements U, Th and K play a unique role in Earth evolution, providing much of the thermal energy that drives tectonic processes. These heat producing elements (HPE's) are largely concentrated in the continental crust where they provide a primary control on the thermal regimes and bulk mechanical properties of the continents. The way in which the HPE's are distributed within the continents must reflect primary tectonic processes such as magmatism, metamorphism, deformation and erosion. However, as noted by Oxburgh [1], there is little detailed understanding of how these processes impact on HPE distributions:

"*… the problem of crustal heat production and its distribution and re-distribution by physical and chemical processes during crustal evolution is of fundamental importance and is at present little understood.*"

Since tectonic processes are sensitive to the thermal structure of the continents, it seems probable that important feedback systems may link the long-term tectonic evolution of continents to the differentiation of the HPE's [2], but there is little understanding of these systems. This kind of thermally modulated "tectonic feedback" is likely to be particularly important in the formation of cratons in continental interiors [3]. The primary objective of this proposal is to explore how such tectonic feedback has influenced the long-term evolution of the Australian continent. This will be achieved by documenting case histories of ancient orogenic systems in which the tectonic redistribution of HPE's has had a profound impact on the long-term thermal structure of the crust.

Heat flow-heat production relations in the continents [4,5] imply that the HPE's are mostly confined to the upper half of the crust and account for between one half and two thirds of the surface heat flow of the continents. This characteristic stratification of the HPE's suggests that some kind of self organisation controls the long-term geochemical evolution of the continents. The absolute abundance of the HPE's in the continents and their concentration in the upper part of the crust is likely to reflect, at least in part, primary, magmatic-related crustal growth processes. In particular, the fact that HPE's are incompatible and thus readily partitioned during partial melting implies that they will be efficiently differentiated during magmatism associated with crustal growth. However, there is no compelling understanding of why magmatism should lead to the characteristic abundance and distribution of HPE's inferred from surface heat flow and heat production measurements [4,5], and it is important to recognise that the HPEs will also be redistributed by other tectonic process such as deformation. Since the abundance and distribution of HPE's exerts a crucial influence on continental thermal regimes it must also impact on the strength of the lithosphere [6,7]. Consequently, tectonic processes that redistribute the HPE's also impact on the long-term strength of the lithosphere, altering its susceptibility to further tectonic activity (Figure 1). Because the HPE's are mostly concentrated in the upper crust, they can be effectively redistributed by surface processes. In principle, the isostatic coupling of deformation together with a surface process that tends to restore the long-term surface elevation of the continents provides an efficient way of organising the HPE's in the crust [2]. Numerical simulations summarised in Figure 2 show that even mild-tectonic activity appropriate to continental interiors has the capacity to induce significant changes in the distribution of HPE's and thus significantly modify the long-term thermal and mechanical behaviour of the lithosphere. The recognition of a link between tectonic reworking and the distribution of HPE's suggests that "tectonic feedback" might also serve as a long-term control on the distribution of HPE's in the continents (Figure 2) and provides new impetus to tackling Oxburgh's [1] problem.

The primary objective of this proposal is to decipher the record of tectonic feedback in shaping the long-term evolution of the continents. This will be achieved by both documenting and modelling the causes and consequences of HPE redistribution by tectonic processes. Field studies focussing on intraplate orogeny in central Australia and cratonisation in the Pilbara region of north-western Australia, will provide constraints for the development of numerical models designed to simulate "tectonic feedback" processes. Model predictions will be tested against the thermal record of the terrains as revealed by thermochronological and metamorphic analysis.

E3 Significance and innovation

Investigations into the links between tectonic processes have emphasised the role played by transient processes, and particularly those processes associated with large-scale tectonic activity in plate margin orogens, where orogenic thermal structure is controlled primarily by advective heat transport mechanisms. For example, significant progress has been made in understanding how tectonic processes modify the thermal and mechanical evolution of the orogenic systems on orogenic time-sales [8-10]. In contrast, there is comparatively little understanding of the way in which the tectonic redistribution of the HPE's affects the long-term thermal and mechanical character of the continental lithosphere. In a number of recent papers (see section B), I have suggested a number of examples where "tectonic feedback" related to HPE redistribution appears to have played a central role in shaping the long-term evolution of the Australian continent. These pertain to:

- the evolution of intracratonic basins and mechanics of basin inversion;
- the selective reactivation of pre-existing structures in continental interiors
- the localisation and termination of orogeny in intraplate settings
- the style and distribution of basement-involved deformation in orogenic belts and
- the processes leading to cratonisation

The notion that tectonic reworking of continental interiors can help to order the distribution of HPE's [2] provides an new and **innovative** avenue to the problem outlined by Oxburgh [1]. The demonstration of this type of HPE-modulated "tectonic feedback" would have profound **significance** for our understanding of the processes responsible for the stabilisation of continental crust.

HPE-modulated "tectonic feedback" is likely to be particularly significant for the evolution of the Australian continent which, on the basis of both heat flow [11] and geochemical (AGSO Rockchem database) data, appears to be the "hottest" of all continents. For example, the average heat flow in Australian Proterozoic crust is ~83 mWm^{-2} [11,12] reflecting a crustal HPE compliment almost twice that inferred in equivalent-aged terranes elsewhere in the world (Table 1). Such profound HPE enrichment has clearly affected the thermal evolution of the Australian crust, with attendant implications for the nature of tectonic processes. Indeed, many unique aspects of Australian crustal evolution, particularly in the Proterozoic [13], may simply reflect extreme differentiation necessitated by this extraordinary HPE enrichment [2]. This project will document the magnitude and rates of HPE fluxes associated with tectonic processes that have shaped the continent. The impact of these HPE fluxes on the long-term evolution of the continent, and their role in facilitating "tectonic feedback" will be quantified with numerical models coupling the thermal, mechanical and geochemical response to tectonic processing of the continental lithosphere.

Province	qs	q*	qc	hr
Central Australia	83±21	27±6	**56**	11
Eastern USA	57±17	33±4	24	7.5
Brazilian Shield	56±15	28±7	28	13.1
Indian Shield	71±11	38±2	33	14.8
Zambia	67±7	40±6	27	7.5

Table 1: Heat flow data (mWm^{-2}) from various Proterozoic provinces (from Table 5.5, [14]). **qs** is the average measured surface heat flow, **q*** is the estimated reduced heat flow, **qc** is estimated contribution of crustal HPE, and **hr** is the estimated characteristic length scale of HPE distribution. While such data are subject to large uncertainties [15], they do suggest extraordinary enrichment in HPE in the Australian Proterozoic.

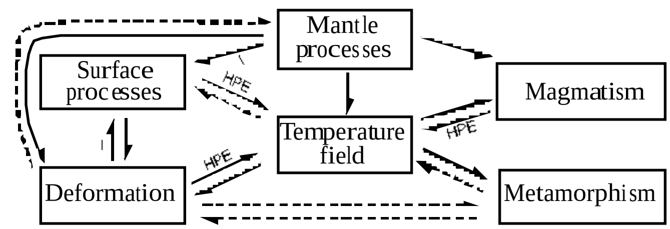

Figure 1. Some tectonic feedback loops involving the temperature field in modulating the interactions between the primary tectonic processes. Solid lines imply a first-order control, dashed lines imply a second-order control. **HPE** signifies a response that may be strongly modulated by HPE re-distribution. **I** signifies an isostatically-modulated response. Mantle processes refer to convective mantle, while surface processes refer to erosion and sedimentation consequent upon the isostatic responses of uplift & subsidence.

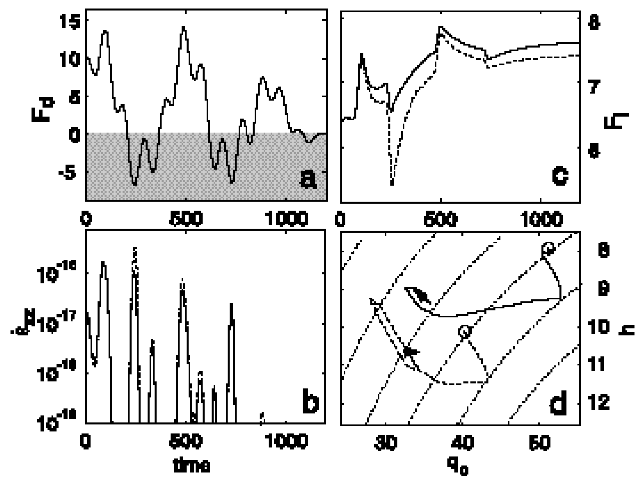

Figure 2: Quantitative model used to illustrate potential of mild tectonic activity (such as that associated with intraplate deformation) to produce changes in the distribution of HPE's (h, q_c) and lithospheric strength (F_l). **1a** shows the hypothetical force experienced by a part of a continental interior during 1200 Ma history. The force oscillates between compressional (+ve) and extensional (-ve) on a Wilson-cycle like time scale (F_d units are 10^{12} Nm^{-1}). **1b** shows the induced deformation (expressed as vertical strain rate in units of s^{-1}) assuming lithospheric strength is controlled by a combination of frictional sliding and temperature-dependant creep. The deformation, and the associated long-term surface response (erosion or sedimentation) which tends to restore surface elevation to near sea-level, induces changes in the distribution of heat producing elements (**1d**) here represented by the parameters q_c (the vertically integrated heat production in the lithosphere, units are mWm^{-2}) and the h, the mean depth of the heat production (units are kms). Changes in the distribution of heat production lead to long-term changes in the thermal structure and hence strength of the lithosphere as shown in **1c** (F_l units are 10^{12} Nm^{-1}). Two initial configurations are modelled, characterised by different initial HPE distributions (indicated by circles in **1d)**. Note that the long-term effect of tectonism is to "organise" the HPE distribution parameters which converge on $q_c \sim 35$ mWm^{-2}, and h ~10 kms, close to what in fact is commonly observed [14]. These calculations are reported in Sandiford & McLaren [2].

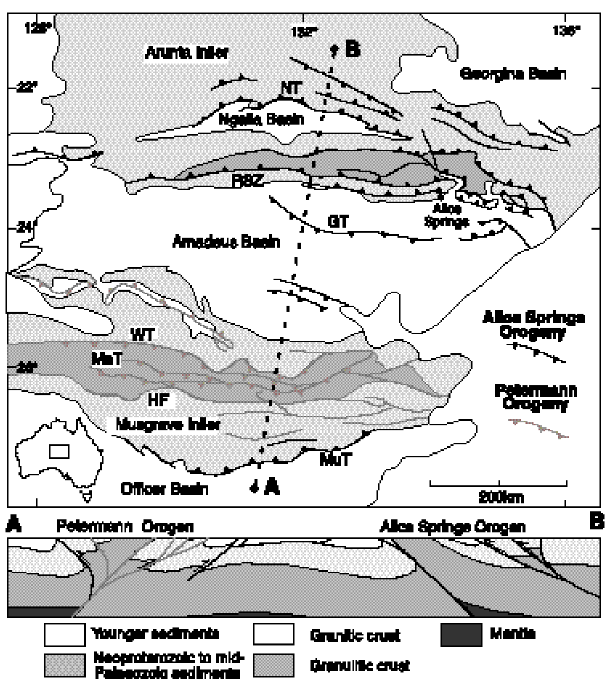

Figure 3. Geological map and crustal scale-cross section of the central Australian region, showing the structurally remnant Neoproterozoic basins (the Officer, Amadeus, Ngalia and Georgina Basins), separated by basement inliers (the Musgrave and Arunta Inliers). Within the basin inliers we can distinguish two distinct types of terrane: (1) gneissic granite terranes that form the peripheral regions of the inliers and which are unconformable overlain by the Neoproterozoic sediments; (2) mafic granulite terranes that define the cores of the inliers and which are tectonically juxtaposed with the gneissic granite terranes. This juxtaposition reflects, in part, the strain associated with intraplate orogeny accumulated during the exhumation of the basement inliers from beneath a formerly more or less continuous intracratonic basin. Crustal scale cross-sections based on seismic reflection profiling shows that the mafic granulite terranes are representative of the Central Australian lower crust, while the gneissic granite terranes are representative of the mid-upper crust. The central Australian intraplate orogens are characterised by extraordinary gravity anomalies [25]. These gravity anomalies are amongst the largest known from the continental interiors and clearly relate to structures that were active during the Petermann and Alice Springs Orogenies. GT: Gardiner Thrust, HF: Hinckley Fault, NT: Napperby Thrust; RSZ : Redbank Shear Zone, UT : Uluru Thrust; WT : Woodroofe Thrust.

This study will have broad implications for our understanding of the nature of metamorphism, magmatism and deformation in stabilizing the continental lithosphere. It will be particularly significant for our understanding of the factors controlling deformation in continental interiors (intraplate orogeny), and the crustal processes that are essential to the formation of cratons. It will contribute valuable new insights into the factors that control temporal and spatial variations in lithospheric strength, and thus will impact on our understanding of the distribution of seismicity in the continental interiors. Because an understanding of thermal regimes is central to almost all lithospheric processes, it is anticipated that this project will have important consequences for understanding the origin and distribution of mineral deposits within the Australian continent.

E4. Approach

Mechanics of intraplate orogeny: the Alice Spings Orogen

The Alice Springs Orogen (ASO) in central Australia is a classic intraplate orogen (Figure 3). It involved less than ~ 100 km of shortening [16, 17]), with deformation accumulating intermittently over a period perhaps as long as 130 Myr, between 430 and 300 Ma [Figure 4, 18-20]. Much of the shortening was accommodated on crustal penetrative shear zones such as the Redbank Zone which are now associated with some of the largest gravity anomalies known from the continental interiors [25]. Intriguingly, many suitably oriented structures in central Australia that had been active during a similar intraplate orogenic event several hundred million years earlier (the Petermann Ranges Orogeny), remained inactive during the ASO. Similarly, structures that were active during the ASO were largely inactive in the earlier Petermann Ranges Orogeny [21] suggesting a profound reorganisation of the pattern of crustal strength occurred in the interval between the two orogenies. This reorganisation can be understood in terms of the long-term thermal consequences of HPE redistribution associated with intraplate orogeny in central Australia [3, 21,22]. In particular, the exhumation of HPE-depleted deep crustal rocks from beneath a carapace of HPE enriched granites in the hanging wall of major structures such as the Redbank Shear zone must have profoundly modified the geochemical and thermal structure of the lithosphere.

While the localisation of intraplate deformation implies relatively weak lithosphere, the extraordinary gravity anomalies associated with the main ASO structures indicate a very strong lithosphere, raising a profound conundrum of *how the orogen got its strength*? The very slow rates of deformation suggested by available thermochronological and biostratigraphic data [Figure 4, 18-20], imply that the ASO progressively hardened during its evolution, potentially stiffening sufficiently to lock-in the gravity anomalies [3]. Such local stiffening may also help explain the wide distribution of intraplate deformation, since it would tend to distribute rather than localise ongoing deformation. Significant ASO-aged deformation is now known from the northern Arunta in the Northern Territory, through to the northern Flinders Ranges in South Australia [27], some 1500 kms further south (Figure 5). These ideas suggest a novel-type of intraplate orogenic mechanics that differs in fundamental ways from more familiar plate margin orogens. Understanding the nature of the mechanical evolution of the ASO, and its response to the redistribution of HPE's, will provide the major objective of this phase of the study.

Deformation in plate margin orogens is normally allied to subduction of oceanic lithosphere. Since subduction forms an integral part of the natural convective pattern in the Earth's interior it is characterised by velocities (greater than about 1 cm/yr^{-1}) that prohibit significant conductive heating of the subducting slab during its descent into the deeper mantle. Indeed, the thermal density defect of the subducting slab provides a principal source of stress driving mantle flow. The connection between plate margin orogens and subduction implies that they also typically evolve at high thermal Peclet numbers, with their thermal evolution dominated by the advection of material through the orogen. Material advection through orogenic belts tends to cool deeper parts of the lithosphere where the flow is dominantly downwards (mantle downwelling), and heat the upper parts of the orogen, where flow towards the surface is induced by erosion. When flow stagnates, as may happen when advection of buoyant crustal material into the orogen exceeds its removal by erosion, then significant heating may accompany the accumulation of HPE's within the orogen. These factors tend to lead to crustal heating, at least in mature plate margin orogenic systems, with the consequence that they are considerably weakened with respect to typical continental lithosphere. Plate margin orogens are, consequently, susceptible to considerable tectonic denudation once the forces driving orogenesis are relaxed. Intracratonic orogens formed due to transmission of stress through the lithosphere, are not required to form at such fast rates. For convergence velocities lower than ~ 1 mm/yr (such as available data suggest the ASO [18-20]) the thermal effects of material advection is subordinate to conduction, even at the lithospheric scale. Moreover, the possibility of material stagnation and significant crustal thickening is greatly reduced if the material flux across the orogenic boundaries is very low. Such *low-thermal Peclet number intraplate orogens* will be sensitive to the readjustment of heat sources induced by material fluxes in the orogen, which may cause such orogens to "stiffen" considerably, independently of changes in the external forcing.

As noted above, the available data from the ASO (see Figure 4 for a recent compilation) imply that the time integrated deformation rates were very much slower than typical of plate margin orogens. However, these data are poorly constrained because the available bio-stratigraphic data pertaining to the onset of syn-orogenic sedimentation is subject to significant uncertainty. Similarly, the available geochronologic data does not contain sufficient geographic spread to evaluate the detailed spatial and temporal pattern of deformation during the ASO. In particular, it is not yet possible to discriminate whether the pattern of deformation in the ASO was

- episodic with brief periods of relatively fast, widespread deformation interspersed with long-periods of inactivity [20], or
- temporally continuous but spatially discontinuous, jumping from place to place, as various structures progressively locked.

Evaluating these alternatives is essential to unravelling the nature of the mechanical response of the ASO. In order to assess this it is proposed to significantly extend the thermochronological database using the $^{40}Ar/^{39}Ar$ technique, with the specific aim of extending the spatial distribution of data to a much broader region than currently available.

In addition to $^{40}Ar/^{39}Ar$ step heating analysis of micas formed within ASO shear zones [18-19], K-feldspars in coarse clastics from the Amadeus, Ngalia and Georgina Basin (Toko Syncline) sediments, and from the adjacent basement exposures, will be analysed. K-feldspars have complex $^{40}Ar/^{39}Ar$ spectra, potentially providing a memory of transit through a wide temperature window (~200-350°C) [23-24]. While the application of diffusion-domain modelling to K-feldspar $^{40}Ar/^{39}Ar$ spectra [23-24] remains contentious, the results from the CI's current ARC large grant in the Mount Painter region of South Australia (A3994312) have shown that such modelling from traverses across basement-cover interfaces yields self-consistent thermal histories [27]. These histories have provided a unique insight into the thermal structure of the upper crust at Mount Painter during denudation associated with the ASO (Figure 5). On the basis of this experience, it is proposed to analyse samples along profiles traversing the major basin-bounding, ASO structures at the following locations.

- Mt Liebig & Mt Rennie in the western part of the Redbank Shear Zone. Access to the Mount Leibig samples, is to be provided by Dr Ian Scrimgeour. Dr Scrimgeour is a former PhD student of the CI, and is now with the NTGS and is currently mapping this region.
- Glen Helen (where Ar feldspar data from basin sequences will be used to compliment the existing basement feldspar Ar data [20] from either side of the Readbank Shear Zone in the Ormiston region)
- Alice Springs near the eastern limit of the Redbank Shear zone.
- the Napperby Thrust along the northern margin of the Ngalia basin, where available biostratigraphic data suggest some of the youngest Alice Springs aged deformation is located [26].
- the Toko syncline of the Georgina Basin and adjacent Toomba fault in the eastern most part of the Arunta.
- the Delny – Mt Sainthill shear zone in the north eastern Arunta (complimenting data recently acquired by Dr Scrimgeour).

This data set will include three profiles across the Redbank spaced at ~150 km intervals allowing the assessment of the regional thermal structure of the upper crust during ASO. This will provide a unique opportunity to evaluate whether regional variations in thermal structure of the crust influence the style and pattern of deformation on a major, crustal scale structure [eg. 30].

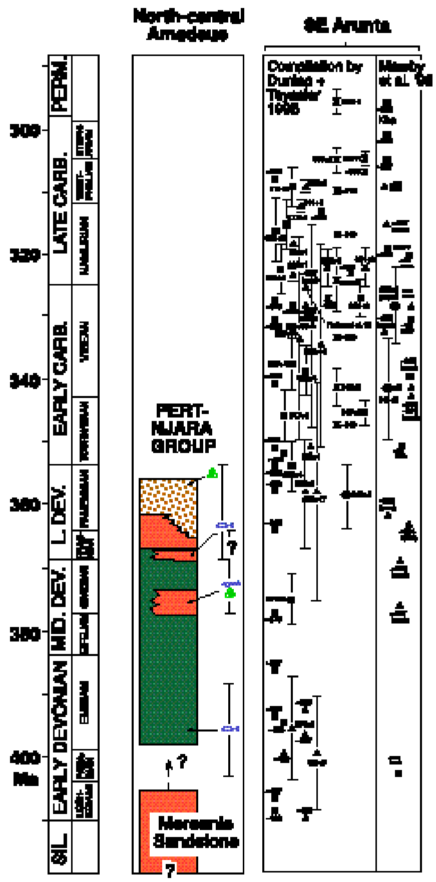

Figure 4. Compilation of timing constraints on syn-orogenic sediment and available thermochronometers from the ASO.

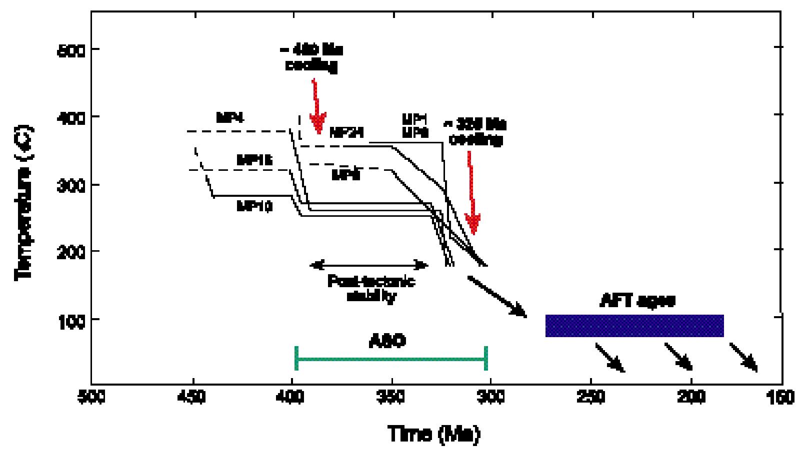

Figure 5. Temperature-time paths for the post-Delamerian history of Mount Painter rocks from various stratigraphic/structural levels. This figure summarizes the results of hornblende K-Ar age determinations, mica K-Ar and $^{40}Ar/^{39}Ar$ data and multiple-diffusion-domain thermal modelling of K-feldspar $^{40}Ar/^{39}Ar$ data. A period of rapid cooling may have followed the Delamerian orogeny at ~500 Ma, but our models only bear directly on two subsequent periods of cooling, the first at ~ 400 Ma and the second at ~ 325 Ma. These latter two cooling episodes are separated by an isothermal period, corresponding to a period of tectonic stability. Cooling at ~ 400 Ma is associated with an average temperature drop of ~ 130°C for samples from the basement, and ~ 65°C for samples from the cover sequence. Cooling at ~ 325 Ma is associated with an average temperature drop of ~ 100°C for cover samples whereas samples from the basement cooled by ~ 150 °C over the interval between 350 Ma and 330 Ma. Pegmatite samples cooled by at least 175°C in the interval 325-300 Ma. The amount of cooling during the 325 Ma episode is well constrained by the model fits for the K-feldspar samples. The cooling at ~ 400 Ma is constrained by K-Ar ages from hornblende and muscovite samples. Samples progressively higher in the stratigraphic and structural sequence model at lower temperatures: a self-consistent result that lends credence to the multiple diffusion domain modelling method.

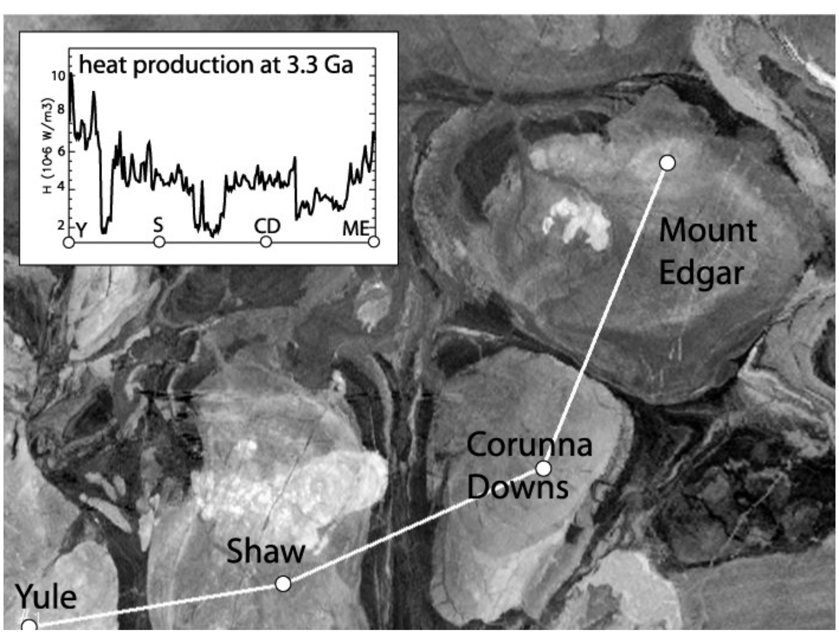

Figure 6. Heat production image of the eastern Pilbara craton, calculated at 3.3 Ga, using AGSO radiometric data. Granite heat production is typically 4-6 μWm^{-3}. Given that these granites extend to ~ 14 kms depth, the integrated heat production in any dome could have been as much as ~70 mWm^{-2}, or approximately twice the the heat production in typical modern day crust! The thermal implications of this are extraordinary as indicated in Figure 7. Data, provided by AGSO, was processed by the CI, and will provide a key ingredient in assessing the thermal and mechanical consequences of "dome" evolution.

The $^{40}Ar/^{39}Ar$ data will provide temporal constraints on the denudation record of the ASO, with samples collected in the context of field studies linking this record to the displacement history on individual ASO structures as well as the distribution of sediments in the associated foreland sequences of the Amadeus, Ngalia and Georgina basins

A major objective of this phase of the project is the testing of the notion that intraplate orogens may lock due to the thermo-mechanical consequences of redistribution of HPE's [3,22]. Of particular concern to this will be the origin of the gravity anomalies associated with the Alice Springs Orogen. Orogenic mechanics will be investigated by incorporating thermochronological constraints on the distribution and timing of deformation as tests of numerical models of lithospheric deformation that explicitly incorporate geochemical stratification of heat producing elements inferred form analysis of heat production patterns in present-day outcrop [3]. Numerical models will be developed in collaboration with Prof. Chris Beaumont's group at Dalhousie University, Canada, and Dr Jean Braun at ANU, RSES, who have established credentials in the field of lithospheric geodynamic computation. These models, based on 2D, finite-element algorithms implementing elasto-visco-plastic rheologies, will be used to assess the thermal and mechanical evolution of the ASO subject to displacement histories consistent with the interpreted kinematic and denudation and depositional record, deduced from the $^{40}Ar/^{39}Ar$ analytical program and the associated field work.

A crustal perspective on cratonisation : the Pilbara experience.

The link between the distribution of HPE's and the strength of the continental lithosphere implies that the differentiation of HPE's is essential for the long-term stability of the continental lithosphere and, consequently, craton development. While craton formation is undoubtedly a complex process, most probably involving long-term changes in crust-mantle interaction, the crustal-scale differentiation of HPE's is a necessary precursor to cratonisation. While cratons are manifest by long-term tectonic stability, cratonistation is usually presaged by a lengthy 'early' history involving not only crustal growth but also extensive crustal reworking during episodic tectonism spanning many hundreds of millions of years. From a thermal and mechanical sense such reworking can be viewed in terms of the way it redistributes the HPE's [2]. Indeed, such a view may be consistent with the observation that that compared to younger geological provinces Archaean cratons are characterized not only by lower surface heat flow (~40 mWm^{-2}), but also more differentiated HPE distributions. For example, the available data suggests that the mean (and standard deviation) length-scale for heat production in Archaean terranes is 6.9 ± 1.7 km, compared to 10.1 ± 3.6 kms in younger terranes [14]. In part, the low surface heat flow in Archaean cratons is due to the low present-day abundance of HPE's, but also to the presence of very thick mantle lithosphere which has the effect of diminishing the mantle contribution. For example, McLennan & Taylor [14] have suggested that the mantle heat flow beneath Archaean cratons is typically ~14 mWm^{-2}, implying that the HPE's contribute ~ 25 mWm^{-2}. Given that at 2.5 Ga heat production was about twice modern day rates, the characteristic Archaean HPE's contribution in typical cratons must have exceeded ~ 50 mWm^{-2} (ie., some 50-66% greater than typical of the modern continents). One way to mechanically stabilize lithosphere with such high values of crustal radiogenic heat production is to concentrate the HPE's at shallow levels in the crust (i.e., low h). In many Archaean cratons the crustal HPE complement is carried in granites which for the cores of large "diapiric" domes [27]. The origin of the characteristic *dome and basin* geometry of these Archaean granite-greenstone terranes has been the subject of much discussion [28-30]. Sandiford & McLaren [2] have speculated that such geometries may reflect a distinctive "high-q_c" mode of stabilizing continental crust by redistributing the HPE's into the shallow crust, and this phase of the project will explore the long-term thermal ramifications of dome and basin development in the Pilbara Craton of north-western Australia (Figure 6).

This sensitivity of the thermal and mechanical properties of the continental lithosphere to the distribution of HPE's motivates an analysis of Archaean tectonic processes in terms of their effects on their distribution of HPE's. For example, the burial of a enriched felsic crust beneath thick piles of mafic crust (emplaced either by magmatic or structural processes) will lead to long-term conductive heating of the lower crust (Figure 7). Likewise, the partial convective overturn (associated with the development of dome and keel structures) in granite-greenstone terranes produces a significant shallowing of the HPE distribution leading to long-term deep crustal cooling.

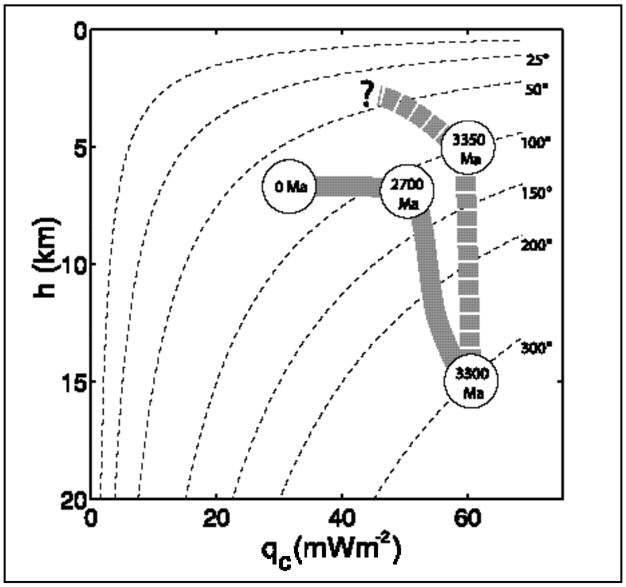

Figure 7 : Schematic illustration of the evolution of HPE distributions appropriate to the Pilbara, in terms of the HPE distribution parameters, h and q_c (see Figure 2) . Early crust forming events at 3500-3400 Ma produceda felsic crust enriched in HPE's. This crust was buried beneath a thick (~10km) pile of mafic volcanics leading to a dramatic increase in h, but only a small increase in q_c. Subsequent amplification of domes by magmatism and deformation between 3350 and 2700 Ma caused a shallowing of HPE's, with secular decline in heat production leading to further reduction in q_c in the system eventually to the modern day parameters. The contours show the long-term (conductive) influence of h and q_c on the temperature at some deep crustal or upper mantle level. The change in h associated with burial and subsequent dome amplification are predicted to lead to long-term changes in lower crustal temperatures of the order of 200°C, sufficient to cause dramatic changes in the strength of the lithosphere.

The Pilbara craton (Figure 6) is a classic granite greenstone terrane comprising granite-cored domes that have penetrated through a mafic carapace developed early in the tectonic cycle. The structuring responsible for the current dome and keel geometry has operated episodically over many hundreds of millions of years [28-29], implying that significant "feedback" between ongoing tectonic processes and the thermal and mechanical state of the crust, as HPE distributions evolve. The question posed by this study is *how did the structuring of the craton, and particularly the amplification of the domes, effect the strength distribution*? The recent acquisition of a superb calibrated, airborne radiometric dataset by AGSO (Figure 6), means that the Pilbara can be uniquely quantified in terms of the present-day distribution of HPE's. The objective of this program will be to quantify the way in which the HPE distribution has evolved in time, by integrating the airborne radiometric data with geological models for the structural and magmatic evolution of the domes [eg., 28]. A number of geological models for dome amplification have already been proposed [28-29], and these will be used as a basis for exploring how the tectonism has modified HPE distributions. Numerical models which explicitly predict the thermal evolution of the domes and keels will be tested against the metamorphic record of the various parts of the structure [eg., 28], as established by previous observations [28] and by further field work. This study will build upon the existing field mapping experience of AGSO, who have provided the CI with access to the critical airborne radiometric dataset.

E5. National benefit

This study will have broad implications for our understanding of the nature of metamorphism, magmatism and deformation in shaping the continental lithosphere. It will be particularly significant in understanding factors controlling deformation in continental interiors (intraplate orogeny), and will contribute valuable new insights into the factors that control lithospheric strength. Because understanding thermal regimes is central to all lithospheric processes, this project will have important consequences for understanding the origin and distribution of mineral deposits within the Australian continent.

The significance of the proposed work can be appreciated in the light of our current understanding of the role played by tectonic processes in shaping the continents. In the last 30 years, since the formulation of plate tectonics, the processes of crustal growth and differentiation have been framed almost exclusively in terms of plate boundary interactions. Implicitly, geologists now view primary tectonic process (eg., deformation, metamorphism and magmatism) as responses to *tectonic forcing* at plate boundaries, where the principal control is the rate and obliquity of relative plate margin motion. While this approach has been tremendously successful, it has obscured the role played by the evolving internal configuration in understanding feedback between ongoing tectonic processes. One of the main contemporary challenges is to distinguish the *tectonic signals* that reflect the *boundary conditions* from those that reflect the changes in the *internal configuration* of orogenic belts. By exploring the hypothesis that the intrinsic properties of the continental interiors (specifically HPE distributions) exert a profound influence on their long-term evolution this project directly tackles this challenge. Furthermore, as the strength of the lithosphere is closely allied to its thermal regime [6,7], the results of this project should have considerable impact on our understanding of its long-term mechanical behaviour.

Recent years have seen a tremendous resurgence of interest in the causes and consequences of tectonic activity in continental interiors, and there is now a growing awareness that that continents have been significantly shaped by intraplate processes (eg. 1997 Penrose Conference entitled "Tectonics of Continental Interiors"). This is nowhere better illustrated than in central Australia where major tectonic activity in the Phanerozoic lead to widespread deformation and metamorphism of the crust in settings remote from active plate boundaries [16]. Dramatic testimony to the significance of these central Australian "intraplate" orogens is evident in their extraordinary gravity anomalies [25], which are amongst the largest known on the continents. Understanding the controls on, and links between, the tectonic processes affecting continental interiors will have a major impact on the way geologists view the evolution of the continents and will provide a major focus of this project.

This project stems from ongoing collaboration developed between the applicant and a number of scientists in Australia and abroad, and it is envisaged that this project will see further extensive collaboration with these people. The collaborators include Dr Jean Braun (RSES, ANU), Dr Martin Hand (University of Adelaide), Prof. Chris Beaumont (Dalhousie, Canada), Dr. Roberto Weinberg (UWA) and Dr Richard Blewett (AGSO).

E6 Communication of results

The CI has a strong record of publishing new conceptual work in high profile international journals (see attached references), and the results of this project will continue to be presented in these journals, as well as at international conferences. In addition, the CI is committed to use of the world-wide-web as a venue for distributing the results of research, especially in the fields of computational geology where both animations and interactive computations allow much greater insight into complex physical processes than the more traditional "static" modes of publishing provided by printed media. To this end the applicant is currently involved in the implementation of new web-based techniques that will be used to further enhance the impact of the proposed research (examples can be seen on the applicants website *http://jaeger.earthsci.unimelb.edu.au/ msandifo.html)*.

E7. Description of personnel

The CI is the key person. This application seeks logistic support for the CI's current ARC Senior Research Fellowship (see section D - note that this present application was foreshadowed in the original SRF proposal). As such the CI will be full-time engaged in this research program. The CI will carry out detailed field work and sample collection, and sample analysis in both Central Australia (in conjunction with research students -see below) and in the Pilbara. The CI will implement the numerical models designed to evaluate the thermal and mechanical significance of "tectonic feedback".

It is anticipated that 2 PhD research students will be involved in this program. One student will focus on documenting the displacement record of ASO shear zones, with the objective of building a kinematic framework for understanding the displacement history of the ASO over the 100-150 Ma history. The second student will focus on the syn-orogenic sedimentary record of the flanking basins, with the objective of quantifying the sediment budgets, and dynamics of accommodation space. These two integrated projects will provide critical data for building up a comprehensive picture of the denudation record of the ASO.

A Research Assistant (RA at 40% time) will be employed from the middle of the first year of the project, on completion of the first field season. The RA duties will include routine sample preparation for thermo-chronological analysis, and analysis of thermal properties of key rocks sequences (primarily thermal conductivity using the CI's divided bar apparatus and HPE assay data).

E8. References

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