concept, related but not identical to cratons is that of "structural provinces" and the two are commonly confused. Perhaps there is a slight bias for Archean cratons with buoyant mantle keels to form relatively high-standing areas, thus forming shields. However, large parts of Archean cratons are buried underneath platformal cover. There is no strict age connotation to the term "craton", and implied age depends on context. In a context of mantle keels, diamonds and kimberlites, there often is an implicit tendency to equate cratons with stable crust of Archean age. Elsewhere, however, e.g. in the context of younger continental reconstructions such as that of Rodinia or Pangaea, cratons are typically large crustal fragments (e.g., Laurentia) that were only amalgamated and attained stability during the Proterozoic. There are ca. 35 large crustal fragments of Archean age around the globe,the Archean cratons (s.s.). These originated from break-up of larger, transient, late Archean landmasses, which we refer to as "supercratons". Hence, although commonly neglected, the evolution of Archean cratons (and their lithospheric keels) should always be considered in the context of these ancestral landmasses. Given good correlation between some well-known cratons but not others, the ensemble of ca. 35 remaining Archean cratons probably originated from more than one supercraton rather than a single late Archean supercontinent. The fact that the mean age of continental crust is ca. 2 Ga, in conjunction with Archean cratons only representing ca.7-10 percent of the exposed continental crust, must mean that the 35 remaining cratons represent a biased sample of Archean crust and lithosphere, their preservation guided by the Darwinian principle of "survival of the fittest".

T41C-02 0850h INVITED

Dynamics of Cratons

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Dynamics of Cratons Xenolith data provide the best data on cratons and platforms. Cratonal lithosphere formed in the Archean in part associated with subduction. Lithospheric material has remained in place since then. The thickness of the larger cratons (defined by where the conductive geotherm intersects the mantle adiabat) is about 200 km. Cratonal lithosphere persisted despite being entrained by stagnant-lid convection and plate collisions. Fluid dynamics is helpful for understanding why cratons persisted. Stagnant-lid convection supplies the bulk of the heat flow to the base of cratonal lithosphere. Plumes are subordinate, but can cause transient heating. Buoyant plume material ponds beneath regions of thin lithosphere. Cratonal lithospheric mantle needs to be more buoyant by 50 kg/m^3 and more viscous by a factor of least 20 relative normal mantle at the same pressure and temperature. It also needs to have a higher yield stress than normal mantle. Fluid dynamics relates to why platforms differ from cratons. Platform lithosphere formed later and is not chemically buoyant. At the present, the platform lithosphere in equilibrium with stagnant-lid convection is about 200-km similar to cratons. The lithosphere beneath platforms has thickened over time has the interior of the Earth cooled and stagnant-lid convection waned. This caused platforms to preferentially subside relative to cratons.

T41C-03 0910h

Effects of Basal Drag and Ablation on the Evolution of Cratonic Lithosphere

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The evolution of the cratonic lithosphere is controlled by a balance between processes that thin and thicken the lithosphere. Conductive cooling thickens the lithosphere. Shear at the base of the keel, due to its motion over the underlying mantle, should erode lithospheric material and hotter mantle flowing at depth may heat and ablate the colder lithosphere. Our 2D models assess the role of basal drag with and without the presence of buoyancy forces (edge-driven convection) considering the effects of temperature and pressure-dependent viscosity and plate speed. We focus on the evolution of the lithosphere over a 100 Myr time period, a rough estimate of time between major periods of continental breakup and plate reorganization. Temperature-dependent viscosity has a large effect on the erosive power of basal drag by controlling the part of the lithospheric keel that can flow in response to viscous stress. For cases with a strong temperature-dependence as expected for creep in the mantle, only a thin layer at the very base of the keel is heated by the replacement of eroded lithosphere with hotter mantle. For a reasonable activation energy and volume and plate velocities 3-6 cm/yr, the volume of the initial (compositionally defined) lithosphere is reduced by only 1-2% over 100 Myr. Therefore on timescales of one spreading episode, no correlation should be expected between current plate speed and lithosphere thickness. Although the erosion is small during the time span considered here, it may cumulatively sum up to a more sizable portion over the whole history of the lithosphere. In the presence of plate motion and as time progresses, the subcratonic keel grows laterally asymmetric. Viscosity strongly affects the timescale for the development of edge driven convection. In the presence of buoyancy forces and with an asthenospheric viscosity less than 10^{20} Pa s, convective drips driven by lateral thermal gradients begin at edge of the thick subcratonic root. With plate motion, drips forming at the edge are advected along the base of the keel, leaving behind wakes of colder material. The migration of edge-initiated drips to the base of lid may substantially affect small-scale convection at the base of the lithosphere and therefore its thermal evolution. For sufficiently low values of viscosity, edge-driven convection is the dominating force in eroding the keel. In the presence of edge-driven convection, plate motion actually decreases the rate of erosion because are underplated beneath the keel instabilities instead of dripping downward. Increasing the plate velocity decreases the net erosive power of the edge-driven drips. However this finding maybe a result of the 2D geometry since in 3D drips may form narrow vertical sheets aligned with plate motion. We are currently exploring the effects of a more realistic 3D geometry on our results.

T41C-04 0925h

Particular Mantle Dynamics Induced by Continental Roots

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Continental roots represent extensive regions of seismically fast, cold and buoyant material compared to the surrounding mantle. These cold masses may affect circulation in the mantle and impart thermal conditions at their base which determine to some extent the style of convection. The effects are studied using a 2-D Cartesian viscous flow model in which both the mantle and lithosphere are described as compressible, Newtonian fluids. The freely-moving continental root is modelled as a highly viscous region with a viscosity 10^3 times that of the mantle. The mantle is internally heated and heat production by the decay of radioactive elements U,Th,K in the lithosphere is incorporated into the model. Values of lithospheric heat production are poorly constrained by xenolith and heat flow analysis. Vertical temperature gradients beneath the continent are significantly super-adiabatic and the horizontal temperature gradients are large between continent and ocean. Consideration of the ensemble of continental geometry, mantle heat flow, internal heating and lithospheric heat production suggest that mantle temperatures evolve in time as a function of the free parameters. The similar characteristic times for conduction, convection and heat production bring to question whether the continental lithosphere is in thermal equilibrium.

T41C-05 0940h

Thermal-material linkage between Archean crust and mantle

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Thick, refractory, buoyant lithosphere keels appear to have developed as part of Archean cratons contemporaneously with the crust, through high degrees of fusion. Mantle depletion may be linked to tonalite-trondhjemite-granodiorite (TTG) genesis through production of mafic magmas that accumulated in the deep crust and remelted in the garnet stability field to produce fractionated felsic compositions. The absence of predicted thick, residual, mafic-ultramafic lower crust has led many workers to postulate Rayleigh-Taylor (RT)-type removal of portions of the lithosphere or full mantle lithosphere delamination. We suggest that these processes based on modern analogues were less likely in Archean cratons owing to the low density of mantle lithosphere and its apparent durability since craton formation. Rather, we introduce the concept of lithosphere keel inversion, in which mafic lower crust enters the eclogite field upon post-orogenic cooling, triggering rollover of a lithosphere cell that is lighter than asthenosphere but internally gravitationally unstable. Consequences include: 1) juxtaposition of ca. 1250oC basal lithosphere with the new Moho, driving deep-crustal metamorphism, melting, and a widespread granite bloom; 2) topographic uplift, followed by subsequent thermal subsidence; 3) introduction of mafic material to lower lithosphere conditions, with potential for further melt extraction; and 4) development of complex textural and compositional features observed in some mantle peridotite and eclogite xenoliths, resulting from thermal re-equilibration following movement of upper lithosphere units to greater depth. A series of parameterized numerical experiments were conducted to quantify the dynamical evolution of the crust and mantle lithosphere during instability of dense eclogite at the base of the crust. Depending on the material rheologies and densities, the behaviour was characterised by either viscous RT-type downwelling of the eclogite, or rollover of a more coherent lithospheric block. The eclogite-induced lithospheric rollover is enhanced by tractions at the base of the lithosphere which may represent the effect of subduction-related mantle dynamics. The numerical models indicate that lithospheric overturn can lead to elevated temperatures in the deep crust for periods of tens of millions of years. Viscous RT downwelling of eclogite has less thermal impact on the lower crust since the upward return flow of hot lower lithosphere material tends to be more distributed and diffuse.

T42A CC: 516 D Thursday 1030h

Assembly and Poststabilization Evolution of the Cratonic Lithosphere III *(joint with G, GP, S, V, NS, MR)*

Presiding: **S Rondenay,** Massachusetts Institute of Technology**; D B Snyder,** Geological Survey of Canada

T42A-01 1030h INVITED

Anatomy of an Archean Craton: Seismic Structure Beneath Southern Africa

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In this talk, we will summarize the results of a broad range of studies from the multidisciplinary Kaapvaal Project conducted by the Carnegie Institution of Washington, MIT, and several southern African academic institutions and industry collaborators. The primary goal of the project was to investigate craton formation and evolution processes by providing detailed geologic, geochemical, petrologic, and geophysical constraints of the structure of the crust and mantle beneath the Kaapvaal and Zimbabwe cratons of southern Africa. P- and S-wave tomography images provide clear evidence for a thick (∼250-300 km) mantle keel beneath the Kaapvaal craton and a slightly thinner (∼225-250 km) keel beneath the Zimbabwe craton and parts of the Limpopo mobile belt. No low velocity channel exists across the region, consistent with surface wave analyses. Near the Bushveld Complex, a ca. 2.054 Ga layered mafic intrusion, the mantle is characterized by relatively low seismic velocities indicating that the Kaapvaal craton was modified by the Bushveld magmatic event. The reduced velocities may be due either to mantle refertilization during the Bushveld intrusion, or they may be caused by a thermal perturbation of more recent origin, perhaps related to the Karoo magmatic event. Receiver function images indicate that the crust beneath undisturbed Archean cratonic regions is comparatively thin (∼35-40 km), unlayered, and characterized by a strong velocity contrast across a sharp Moho. Post-Archean terranes and Archean regions disrupted by large-scale Proterozoic events tend to be characterized by a combination of thicker (> 40 km) crust, complex Moho boundaries, and higher lower crustal velocities. These results will be discussed in light of geochemical and petrological results, which strongly suggest that although the deep root structures beneath the southern Africa cratons have been essentially stable since the Archean, they have been repeatedly subjected in post-Archean time to thermal perturbations and varying degrees of metasomatic modification.

URL: http://www.ciw.edu/kaapvaal

T42A-02 1050h

Depth of the tectosphere beneath Kaapvaal craton

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Although the existence of a thick, cold, highly depleted lithosphere – the so called tectosphere – beneath Archean cratons is generally accepted, its exact thickness is still controversial. Imaging the chemically distinct tectosphere using seismic methods have been hindered by two fundamental problems: (1) the difficulty in separating effects of temperature and composition on seismic velocities and (2) the poor depth resolution of seismic tomography. A recent study, however, suggested that V_p/V_s ratio could be used in diagnosing major compositional (e.g., $Mg\#$) and thermal anomalies since V_p/V_s ratio is more sensitive to composition than to temperature. Geodynamic studies, on the other hand, suggest that seismic observations of the topography of the 410-km discontinuity could be used as constraints on the thickness of tectosphere. We have measured the S-P travel-time residuals across the Kaapvaal Seismic Array and found a systematic difference between the craton and the surrounding mobile belts. The Kaapvaal craton shows a larger negative S-P residual, and therefore a lower V_p/V_s ratio, than the adjacent mobile belts, which indicates the existence of the highly depleted tectosphere ($Mg\#$ ∼92-94) beneath the Kaapvaal craton. We also processed high-quality receiver functions with common-conversion-point gathering and pre-stack depth migration techniques and two-dimensional velocity reference models. The resulting images consistently show a flat 410-km discontinuity beneath the entire array. This observation, combined with the results of geodynamical modeling, allows us to place limits on the thickness of the tectosphere, which is between ∼160 and ∼370 km.

T42A-03 1105h

Relict Slabs Within the Roots of the Slave and Superior Provinces Observed With Deep-Looking Magnetotellurics

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Important clues to the ancient origin of cratonic lithosphere can be found with deep looking magnetotelluric methods. Electrical strike direction observed in the western Superior Province of Canada show a dramatic correlation with crustal fabrics possibly related to Archean subduction. Upper mantle conductors with resistivities as low as 10 Ohm m embedded within the lithosphere of the Slave and Superior Provinces are approximately two orders of magnitude higher than petrophysical modelling predict for an olivine or pyroxene mineralogy dominated upper mantle. Given the depth location, age, and tectonic setting as well as the observed conductivity of these electrical conductors, we conclude that they are likely due to carbon in the form of interconnected graphite. The evidence for deep-seated graphitic conductors spatially related to other deep-seated geophysical and geochemical anomalies may be taken together with recent independent estimates of upper mantle oxygen fugacities that suggest the mantle was at some point within two log units of the iron-wüstite buffer to suggest that partial melting and formation of the cratonic root may be related to redox melting during Meso and Neo Archean times. The geometrical form of these conductors, in addition to other lines of evidence, can be taken as evidence for Archean subduction near the end of the major phase of craton formation.

T42A-04 1120h

3-D Imaging of the Precambrian Winagami Sill Complex in Northwestern Alberta, Canada: Continental Rebar Revealed?

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The Winagami sill complex, discovered by Lithoprobe's CAT'94 and PRAISE'95 multichannel seismic reflection experiments, was intruded during the Paleoproterozoic into the crystalline basement underlying the Western Canada Sedimentary Basin of northwestern Alberta, Canada. Spanning an area of at least 120,000 km^2, the extent of this upper crustal feature is comparable to large Phanerozoic igneous provinces. The intrusion of such sill complexes has been interpreted as a fundamental stage in the process of cratonization and a key to the strength of cratonic blocks. The very presence of such structures in northwestern, and also southwestern, Alberta may have contributed to the development of cratonic arches along the ancient rifted margin of North America which significantly impacted regional depositional environments. Using a 3-D seismic reflection dataset collected for exploration purposes by the Canadian petroleum industry that probed to depths of approximately 15 km, we have undertaken a 3-D investigation of the Winagami reflectors. To date, we have imaged the top of the Winagami sequence in 3-D over an area of 400 km^2, producing the first areal seismic image of a Precambrian sill complex at depth. Secondly, we have obtained polarity constraints from known shallower reflections for comparison with the Winagami reflections to characterize the impedance contrast. Lastly, we have extracted areal characteristics using amplitude analyses and attributes on both pre-stack and post-stack data to better map local variations in reflectivity. These may be revealing thickness or lithological variations. Our results represent the first attempt to gain a better understanding of the nature of these important structures using industry 3-D seismic reflection techniques.

T42A-05 1135h

Pre- and Post-Cratonization History of the Northern Wyoming Province

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Cratonization of the northern Wyoming Province (NWP) occurred 2.8-2.9 Ga with the cessation of convergent margin magmatism and the development of passive margin sedimentary sequences. Cratonization was preceded by an extended period of crustal growth via episodic, convergent margin magmatism; major events are dated at 2.8-2.9 and 3.2-3.5 Ga. Earlier events are recorded by numerous detrital zircon and Nd model ages, which indicate felsic magmatism was ongoing by at least 4.0 Ga. TTG magmatism at 2.8-2.9 was the culminating event and is clearly imprinted in the isotopic systems of mantle xenoliths. Cratonization was followed by tectonic and magmatic quiescence from 2.8-1.9 Ga. Subsequent tectonism is marked by a 2-stage Paleoproterozoic incorporation of the NWP into Laurentia. Stage 1 (1.8-1.9 Ga) involved the juxtaposition of the NWP with the Archean Superior and Hearne cratons and the production of minor calc-alkaline magmatism (e.g., Little Belt Mountains of the Great Falls Tectonic Zone). Stage-2 (1.7-1.8 Ga) involved the accretion of Paleoproterozoic terranes (2.4-1.8 Ga) to the amalgamated Wyoming-Laurentian continent, resulting in granulite facies metamorphism, but little magmatism, in the NWP (e.g., Tobacco Root Mountains). Paleoproterozoic tectonism in the NWP is distinctive because of: 1) a paucity of contemporaneous magmatism and 2) a lack of tectonic activity away from the active margins. These observations suggest that the NWP developed a long-lived and structurally robust tectosphere contemporaneously with the stabilization of a felsic crust 2.8-2.9 Ga. This tectosphere appears to have had a substantial impact on the subsequent geologic evolution of the northern Rocky Mountain crust, including the development of the Belt basin, the Yellowstone- Snake River Plain system, and a range of Laramide and Sevier-style structures.

T51A CC: 220 C-E Friday 0830h

Structure and Dynamics of the Crust-Lithosphere-Mantle System: Observations and Models Posters

(joint with G, GP, S, V, SEDI)

Presiding: **M I Billen,** University of California, Davis**; M A Soofi,** University of Calgary

T51A-01 0830h POSTER

Investigating Plume Mobility and Heat Transport in 3D Numerical Mantle Convection Models Incorportating Plate-like Surface Motion

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The influence of plate-scale motion on mantle plume generation and mobility is not well understood. The issue takes on a particular importance as some authors have pointed out that a significant fraction of core heat flux could be carried into the mantle by plumes that are subsequently entrained by upwelling currents associated with the large scale flow beneath diverging plates. It has independently been suggested that, in the absence of the organising influence of plate scale flow, many plumes may not have the individual buoyancy required to traverse the mantle. Both of these scenarios separately suggest that estimates of core heat loss based on the buoyancy flux calculated at well defined hotspots could be potentially underestimated. We invesigate the ratio of surface to basal heat loss as well as plume mobility in a suite of 3-D numerical convection calculations. This is done by modelling different tectonic plate settings where each model is characterised by an isothermal bottom boundary and different depth-dependent internal heating rates. We investigate the influence of plate size and the ratio of poloidal to toroidal power in the specified plate motion in a series of calculations. We also examine the influence of viscosity stratification and thermal expansivity depth-dependence on plume mobility. Plume characteristics including longevity and relative fixity are measured, as is the rate of basal heat loss. Our findings are compared with results from laboratory models and previous numerical studies and are finally used to comment on conventional estimates of core heat loss.

T51A-02 0830h POSTER

Numerical Convection Modeling and the Ocean Floor Topography Constraint on Mantle Layering

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The amount of ocean floor topography caused by upwelling mantle plumes can be used as a constraint on the degree of layering of convection in the Earth's mantle (Davies, 1998). In this contribution, we present a suite of numerical models of convection in the Earth's mantle with varying degrees of layering at 660 km depth. An oceanic plate is modeled by imposing a constant surface velocity boundary condition and requiring a condition of 0 net tangential stress at the base of the lithosphere where a large viscosity jump is imposed. For convection models with Earth-like Rayleigh numbers, we calculate the surface topography for varying degrees of mantle layering and for various strengths of internal heating and viscosity stratification. The efficacy of this constraint on the degree of mantle layering is examined.