T41B-05 0830h POSTER

Southeast Newfoundland Nonvolcanic Passive Margin: SCREECH Transect 3

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A continuous seismic reflection transect was recorded in the summer of 2000 across the nonvolcanic passive margin southeast of Newfoundland as part of a cooperative international effort (see related abstracts in session) to image the conjugate of the thoroughly-studied Iberia margin. Transect 3 is the southernmost of 3 profiles across different segments of the margin. The continental shelf, slope and rise are imaged in a continuous section over about 550 km, from a Precambrian platform into rifted continental crust, and then through a transitional region to unambiguous oceanic crust. The continental shelf and upper slope are also imaged in a parallel profile only about 20 km north of Transect 3 and are presented here. The slope and rise of Transect 3 are processed with prestack depth migration. Under the continental shelf, the Jeanne D'Arc Basin and associated bounding faults are imaged, as is a discontinuous Moho occurring generally between 12-13 s with widely-separated zones of dipping reflectors in the lower crust which may crosscut the Moho. Approaching the shelf-edge from the continent side, the Moho, along with an overlying lower crustal fabric, shallows until the reflections disappear at the point where the slope begins. Below the upper continental slope, the Carson and Salar basins are imaged along with the basement ridge separating the two basins. The basement ridge contains a deep reflection possibly representing Moho. Seaward of the basement ridge Moho is unclear. East of the Salar Basin, the Newfoundland Basin lies in the transition zone between extended continental crust and clear oceanic crust. The basement surface appears to be mildly block-faulted, with dipping reflections probably representing prerift sediments imaged in some of the blocks. The upper surface of the basement is not a strong reflector and is difficult to pick precisely especially in the presence of an overlying very reflective and pervasive horizon commonly referred to as U'. An intersecting profile in the area with pervasive near-vertical faulting with little or no throw suggests that the basement is highly fractured and perhaps has been heavily altered. The 120 km-wide transition zone has only moderate basement relief except in the 20 km adjacent to oceanic crust. Oceanic crust is characterized in the reflection data by a rough upper surface with little or no reflectivity below the surface and no apparent Moho reflection.

T41B-06 0830h POSTER

Anomalous Heat Flow and Basement Depth in the Newfoundland Basin Ocean-Continent Transiton Compared With the Iberia Abyssal Plain Conjugate

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A total of 30 new heat flow stations were taken in the Newfoundland Basin, in conjunction with seismic reflection and refraction profiles of the SCREECH and MARIPROBE programs, in order to constrain its lithospheric thermal structure. This was the first use of a new heat flow probe that allows high resolution sampling from up to 48 thermistors over a 4-6-m long sensor string, although only 24 sensors were used for these measurements. Data were taken at three multi-penetration sites: HF1 (12 stations) on oceanic crust seaward of magnetic anomaly M0 along Line 1 (SE of Flemish Cap); and HF2 (12 stations) and HF3 (8 stations) on Line 3 (NW of the Newfoundland Seamounts) on thin oceanic crust landward of the J-anomaly (HF2) and on thin continental crust within the ocean-continent transition (HF3). Temperature gradients are linear at all sites except within the uppermost 1 m at site HF2, where there is evidence for recent variations in bottom water temperature. Average thermal conductivity is very uniform at 0.88±0.8 W/m-K (HF1 and HF2) and 0.85±0.4 W/m-K (HF3). Mean heat flow values are similar at HF1 (57.5±2.1 mW/m^2) and HF3 (58.4±2.7 mW/m^2) and lower at HF2 (49.5±1.0 mW/m^2). Values of heat flow versus sediment-corrected basement depth are consistent with the lithospheric thermal model GDH1 of Stein and Stein (1992) and the expected age at HF2 (130 Ma), but they are 20-50 my younger than expected for HF1 and HF3. In comparison to plots of heat flow and basement depth for the Iberia Abyssal Plain, the Newfoundland Basin shows a significant anomaly in both basement depth (∼500-800 m shallower) and heat flow (5-18 mW/m^2 higher). The heat flow results indicate that differences in basement depth between these conjugate basins are compensated by significant differences in lithospheric thermal structure and not by differences in shallow crustal structure. The recent discovery of lower Albian diabase sills beneath the Newfoundland Basin at ODP Site 1276, might indicate lithosphere ∼15-20 my younger than expected. But this age difference would only result in differences of <200 m in basement depth and ∼5 mW/m^2 in heat flow, which are less than our observations require.

T41B-07 0830h POSTER

Crustal Structure of the Central Nova Scotia Margin from Seismic Refraction Data: New Evidence for Non-volcanic Rifting

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The Nova Scotia margin off Eastern Canada is located at a transition from volcanic margins in the south to non-volcanic margins in the north. The southern Nova Scotia margin is largely volcanic, evidenced by seaward dipping reflections (SDR) coinciding with a strong East Coast Magnetic Anomaly (ECMA). The northern part of the margin shows no evidence of major volcanism where the ECMA weakens and eventually disappears. In the central part of the margin, no SDRs have been observed but the ECMA is still prominent. This raises doubt about where the transition from a volcanic to a non-volcanic style margin exactly occurs. In order to study this transition, three wide-angle refraction lines were acquired in 2001 across the northern, central and southern parts of the margin, respectively. The middle line extends from the Lahave Platform into the Sohm Abysmal Plain. The velocity model derived from the refraction data shows no evidence for a magmatic underplated layer beneath the continental crust, suggesting non-volcanic rifting. In addition, a 120-km wide region of partially serpentinized mantle is observed within the ocean-continent transition zone, similar to other non-volcanic margins in the North Atlantic. Together, these observations are difficult to reconcile with significant volcanism, and the ECMA with reduced amplitude in this region is not likely to be related to volcanic activity as it is farther to the south. The velocity model also shows that the continental crust is thinned during rifting initially within the middle and lower crust beneath the hinge zone, and subsequently within the upper crust. The thinned upper continental crust extends over a distance of 180 km up to a highly faulted basement structure; the continent-ocean boundary is then located some 60 km farther seaward than an earlier interpretation by Keen et al. (1991) based only on reflection seismic data. Keen C. E., MacLean B. C. & Kay W. A., 1991. A deep seismic reflection profile across Nova Scotia continental margin, offshore eastern Canada. Can. J. Earth Sci., 28, 1112-1120.

T41B-08 0830h POSTER

The Hydrocarbon Potential of the Deep Offshore Along the Argentine Volcanic Rifted Margin - A Numerical Simulation

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In the Late Jurassic / Early Cretaceous, continental break-up of Gondwana led to the opening and northward propagating of the South Atlantic. Since 135 Ma, the Paraná / Etendeka continental flood basalts were emplaced, associated with seaward dipping reflector sequences (SDRS), possibly caused by the Tristan da Cunha hot spot. After break-up, thermal subsidence affected predominantly the development of the rifted volcanic continental margin, especially the elongated zone of the SDRS and a thick sedimentary column was deposited onto this transition zone between the continental and the oceanic crust where locally up to 5.400 m of sediments were accumulated. With the thermal calibration to available maturation data from multiple wells drilled in the nearby Colorado Basin integrated 1-D and 2-D basin modeling was applied to evaluate the thermal history of the sedimentary column. In combination with the interpretation of more than 20.000 km of MSC reflection / refraction seismic data and the mapping of the sedimentary units this led to a maturity model for deposits of marine black shales, potential source rocks in the deep domain of the South Atlantic region, correlated to Cretaceous anoxic events. With the results of the 2-D basin modeling a zone favorable for the generation of hydrocarbons from proposed Aptian source rocks was defined based on the deposition and the thickness of the overburden rocks and the timing of the generation and the migration of the generated hydrocarbons was estimated. Migration pathways were modeled and possible stratigraphic oil plays were localized in onlap structures below the Danian Pedro Luro Formation along the lower continental rise in 1.500 to 2.000 m water depth approximately 3.000 m below the sea bottom.

T41C CC: 516 D Thursday 0830h

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

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

T41C-01 0835h

What is a craton? How many are there? How do they relate? And how did they form?

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What is a craton? A craton is a large, coherent domain of Earth's continental crust that has attained and maintained long-term stability, having undergone little internal deformation, except perhaps near its margins due to interaction with neighbouring terranes. Stable continental crust is an end product of intense magmatic, tectonic, and metamorphic reworking; hence, cratons consist of polydeformed and metamorphosed crystalline and metamorphic rocks (e.g., typically "granite-greenstone terrains" in the most ancient cratons). Reworked crust only becomes a craton once the cumulative tectonic, magmatic, and metamorphic reprocessing has self-organized the crust and underlying lithosphere into a stable density, compositional, and thermal profile. Major late-stage "granite bloom" events play a critical role in attaining such stable lithospheric profiles. Once above average stability has been reached, deformation will be concentrated in adjacent domains with weaker strength profiles. Significant rifting events, assisted by mantle plume activity and mafic dyke swarms, are then needed to break up cratonic lithosphere. Where cratons are exposed, they form "shields" dominated by crystalline and metamorphic rocks; where younger, weakly deformed cover overlies cratonic basement, these areas are referred to as "platforms". Shields and platforms are physiographic terms rather than tectonic entities. Another

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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