The intense climatic changes that characterized the Neoproterozoic world were marked by equally profound evolutionary changes that ultimately led to the Cambrian Explosion. Early and Middle Neoproterozoic oceans contained prokaryotes and diverse eukaryotic lineages, including crown-group red, green, and heterokont algae. The survival of diverse eukaryotic lineages through the Sturtian, Marinoan, and Gaskiers glaciations implies that, although these were among the most extreme glaciations Earth has ever experienced, sea ice was not as thick or pervasive as required by earlier "hard Snowball" models. Most molecular clocks predict the existence of animals well before 600 Ma and a few tantalizing hints have been found, but the oldest definite evidence of animal life are phosphatized eggs and embryos overlying Marinoan glacial deposits in China. The subsequent Late Neoproterozoic is characterized by the global occurrence of the Ediacara biota, an assemblage of cm- to m-scale fossils of soft-bodied organisms that probably represent a mixture of stem groups of modern phyla and "failed experiments" in evolution. The oldest Ediacaran fossils occur in eastern Newfoundland, and postdate the glacial diamictites and cap carbonate of the Gaskiers Formation (580 Ma) by only 5 million years, implying a causal relationship between the end of the Neoproterozoic glaciations and the proliferation of animal life. These fossils include architecturally complex fronds up to two metres long, implying either extremely rapid rates of evolution or a pre-glacial origin of the Ediacara biota. Fossils of the Mistaken Point biota (575-560 Ma) were completely sessile and show a similar fractal architecture that is difficult to relate to any existing life forms. Some of these taxa persisted into the White Sea biota (560-550 Ma), which also contains trace fossils and metameric fossils that confirm the evolution of mobile bilaterians. The youngest Ediacaran fossils (550-543 Ma) exhibit the first evidence of calcified animals and macrophagous predation. The abrupt disappearance of the Ediacara biota 543 million years ago corresponds to both oceanographic changes and the appearance of the skeletal predators that mark the beginning of the Cambrian Explosion.

GP23A-06 1450h INVITED

Why is construction of an Ediacaran-Cambrian global paleogeography so difficult?

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The foremost answer to the above question is that high-precision global biostratigraphy extends only to Early Cambrian time. A more challenging issue concerns paleomagnetic data from the Ediacaran (proposed terminal Proterozoic period) and earliest Cambrian intervals: each paleocontinent's apparent polar wander path shows a large spread in poles, intriguingly distributed around a great circle (excepting Baltica, see below), and implying rates of paleolatitude translation or rotation far exceeding typical values from the Cenozoic. Oscillatory true polar wander (TPW) has been proposed to explain these great-circle distributions, but as more data are gathered the number of required episodes increases steadily. Another mechanism to explain such jumpy datasets is a persistently nonaxial geomagnetic field, with greatly amplified paleosecular variation; however, such an interpretation is unattractive to many geodynamicists. A third approach to explain the anomalous data is to discount them altogether; this is unsatisfactory because some of the most reliable results (e.g., Grenville dykes B component and Bunyeroo Formation pole) must be discarded in order to simplify the paths. We propose a new technique for Ediacaran-Cambrian continental reconstruction, which uses these intriguing great circle pole paths regardless of how they were generated. Each paleocontinent's path yields a best-fit great circle and corresponding pole. In the TPW interpretation, that pole describes the long-lived, common (equatorial) axis to the oscillatory rotations. Given that age constraints on the poles is generally so poor, we may reconstruct each continent to this axis with azimuthal freedom. This is topologically identical to the longitudinal degeneracy of standard paleomagnetic reconstructions, but in the case of TPW uncertainties in positions along the great circle represent uncertainties in paleolatitudes, hence climate zones. Analysis of the global Ediacaran-Cambrian paleomagnetic database indicates that all reconstructed Gondwanaland fragments share the same great circle except Arabia, whose circle is offset slightly indicating late rotations during Pan-African accretion. Iapetus can be made wide or narrow, but the latter paleogeography is preferred according to the age of Appalachian rift successions. Siberia remains on the equator, near the pole to its great circle of paleomagnetic results. Baltica is the poorest constrained of any Ediacaran-Cambrian continent: no existing paleogeographic model, with or without TPW, can readily explain its highly divergent paleomagnetic poles.

GP24A CC: 519 B Tuesday 1530h

Endings and Beginnings: Paleogeography, Life, and Climate of the Terminal Neoproterozoic Through Cambrian Time II *(joint with U, T, C)*

Presiding: **P J McCausland,** University of Michigan**; C Mac Niocaill,** University of Oxford

GP24A-01 1530h INVITED

BALTICA FROM THE LATE PRECAMBRIAN TO THE EARLY ORDOVICIAN

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Current thinking supports the existence of the Rodinia supercontinent which consolidated at perhaps 1100 to 1000 million years ago and most probably disintegrated somewhere before 800 Ma. Within the Rodinian collage, Baltica was adjacent to, and probably welded to, Laurentia, with the modern eastern (Uralian) part of Baltica conjugate with the north of Laurentia. Laurentia was in turn attached to the South American terranes of Rio Plata and Amazonia, and possibly also West Africa. Baltica became an independent terrane when it split off from Laurentia, leaving a widening Iapetus Ocean between the two. When this rifting actually commenced is a matter of dispute due to very conflicting palaeomagnetic data from both Laurentia and Baltica; however, we favor that the southern part of the Iapetus, between Laurentia and South America, opened first at about 570 Ma and that this rifting spread gradually northwards until Baltica separated from Laurentia at approximately 550 Ma, near the end of Precambrian time at 543 Ma. New palaeomagnetic and geochronological data from the 616-610 Ma Egersund Dykes (SW Baltica) place Baltica at the south pole whereas subsequent Late Precambrian to Early Cambrian poles places Baltica at lower latitudes. During the late and middle Vendian, the NW margin of Baltica changed from an extensional tectonic regime to an active margin (Timanian Orogeny) in which microcontinental blocks in the Timan-Pechora, northern Ural and Novaya Zemlya areas were united with Baltica at 550-560 Ma. Largely between Middle Cambrian and Middle Ordovician times, the whole large terrane of Baltica underwent a very substantial rotation of about 120°, and the maximum rate of this rotation occurred in late Cambrian and early Ordovician times. Much of the craton of Baltica appears to have been submerged under shelf seas for long parts of this time, which lasted from 544 to 490 Ma. As a consequence the olenid trilobite fauna represent a fauna living largely in niches which were probably relatively deep on the shelf and in which the aeration was below normal, and thus similar animals are also found in comparable conditions in other terranes, such as Laurentia and Siberia. The Iapetus Ocean was at its widest at about Cambro-Ordovician boundary times, and thus Baltica was at its most isolated. The benthic invertebrate faunas of the shelf seas therefore underwent independent evolution, and the most abundant macrofauna, the trilobites and the brachiopods, were represented in Baltica not just by different species and genera but even families which were endemic to that terrane. Thus it can be safely inferred that both the Iapetus Ocean and also Tornquist's Ocean, which lay between Baltica and Gondwana, were wide enough in the early Ordovician to prevent the successful passage of larvae for a substantial proportion of the benthos.

GP24A-02 1550h

Paleomagnetism of the Grenville diabase dyke swarm and implications for the mid Vendian paleolatitude of Laurentia

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The Vendian-early Cambrian drift of Laurentia is important for theories of Snowball Earth' and the continental breakup that formed the Iapetus Ocean. However, estimates of Laurentia's paleolatitude in this period differ widely. Some authors have proposed that Laurentia remained in low latitude throughout this period, whereas others have supported rapid drift of the continent from low to high and back to low latitude. To assist in evaluating these models, a paleomagnetic study was conducted on the mid Vendian Grenville dyke swarm of southeastern Laurentia. This 700 km long swarm was emplaced along the Ottawa graben, an aulacogen associated with rifting that preceded the opening of the Iapetus Ocean. The swarm was the subject of an early paleomagnetic study by Murthy (1971). More recently, U-Pb baddeleyite and zircon ages of ca. 590 Ma have been described for three Grenville dykes (Kamo et al. 1995). At one of these sites, on the Mattawa' dyke, a positive paleomagnetic baked contact test was also reported (Hyodo and Dunlop 1993). In that detailed test thermoremanent overprinting in the zone of hybrid magnetization was shown to match that expected from heat conduction for a cooling dyke. Nevertheless, Hyodo and Dunlop suggested that the steep down remanence in the dyke, although primary, was likely acquired during a geomagnetic excursion because it did not appear to fit the then-available polar wander path. In our study, paleomagnetic sampling was carried out at 36 sites, including all three dated locations. A detailed analysis has been completed for the dated sites and preliminary analysis for the remaining sites. A stable steep down remanence was obtained for all samples in the Mattawa dyke, and in most samples from a second dated site. The third dated site is less stably magnetized and has not yielded a usable remanence direction. Ten additional sites yield stable steep down or occasionally steep up remanences. The presence of a steep remanence in two dated dykes and several others demonstrates that the remanence was not simply acquired during a short-term geomagnetic excursion. The positive baked contact test suggests that it is a primary remanence. If so, this would indicate that Laurentia was at high latitude 590 Ma ago. This would correspond to interpretations of steep magnetizations in the 577 Ma Callander Complex of the Ottawa graben (Symons and Chiasson 1991). However, other dykes in our study do not carry the steep down remanence. Six have an intermediate up WNW magnetization (or its reversal to the SE), suggesting that these dykes may not be 590 Ma in age. The WNW remanence is similar to that reported for the poorly-dated Buckingham volcanics of the Ottawa graben (Dankers and Lapointe 1981). Five additional sites carry other SE directions (both up and down) that are scattered along or near a great circle through the Mattawa and Buckingham volcanic directions, indicating that unresolved overprinting may have smeared the site directions. Therefore, caution should be exercised in interpreting the overall paleomagnetic data set until further U-Pb dating and paleomagnetic analysis have clarified whether more than one age of dyke swarm is present and whether significant overprinting has occurred. References: Dankers and Lapointe, 1981, Can. J. Earth Sci. 18: 1174; Hyodo and Dunlop, 1993, J. Geophys. Res. 98: 7997; Kamo, Krogh, and Kumarapeli, 1995, Can. J. Earth Sci. 32: 273; Murthy, 1971, Can. J. Earth Sci. 8: 802; Symons and Chiasson, 1991, Can. J. Earth Sci. 28: 355.

GP24A-03 1605h

Paleomagnetic confirmation of a low-latitude Laurentia by 534 Ma

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The paleogeography of the Precambrian-Cambrian transition is still poorly known, but is fundamental for understanding Late Neoproterozoic climate extremes and the spatial associations of the rapidly-evolving Ediacaran and Cambrian fauna. This period has also been proposed to host unusual geodynamic events such as rapid plate motions and/or the bulk tumbling of the Earth with respect to its spin axis, called true polar wander (TPW). New paleomagnetic and Ar-Ar hornblende results have been obtained from a pair of shallowly-emplaced syenitic intrusions in western Quebec, the Mont Rigaud and the Chatham-Grenville stocks, which are related to the development of the Laurentian failed rift arm during the opening of the Iapetus Ocean. Both intrusions bear hornblende which provides overlapping Ar-Ar plateau ages of 534.3±1.2 (Mont Rigaud) and 533.0±1.0 Ma (Chatham-Grenville), corresponding to

Early Cambrian (Nemakit-Daldynian) time. The intrusions represent the youngest known Iapetan rift-related magmatism for Laurentia, extending the period of final 'Iapetan' rifting magmatic activity to more than 80 myr. Characteristic paleomagnetic (reversed) directions from both intrusions are easterly and shallow, and the Mont Rigaud intrusion also carries some antipodal normal-polarity directions. The combined preliminary result from 12 sites places the Montreal region at 24° ± 8° S paleolatitude at 534 Ma, in good agreement with Middle and Late Cambrian paleomagnetic results from Laurentia. Laurentia likely resided at low southerly paleolatitudes throughout the Cambrian, ruling out a major inertial-interchange TPW event for Early to Middle Cambrian time. A comparison with Early to Middle Cambrian paleomagnetic results from Gondwana implies that by Early Cambrian time a large paleolatitudinal gap existed between the high latitude proto-Andean margin and its presumed conjugate rift margin Laurentia, likely corresponding to a wide Iapetus Ocean between them. The Late Neoproterozoic apparently rapid latitudinal motion of Laurentia from the south pole at 570 Ma to low paleolatitudes by 550-534 Ma remains enigmatic.

GP24A-04 1620h

An equatorial Laurentia at 550 Ma confirmed by Grenvillian inherited zircons dated by LAM ICP-MS in the Skinner Cove volcanics of western Newfoundland.

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Volcanics of the Skinner Cove Formation of western Newfoundland carry a primary remanence acquired at 550 Ma at a paleolatitude of 19°S. There has been doubt that this represents the latitude of the Laurentian margin at 550 Ma, because the Skinner Cove Formation is allochthonous. We present new evidence from inherited zircons in the volcanics that should remove this doubt. Zircon crystals extracted from an ankaramite flow and a trachyte flow were dated individually using a laser ablation microprobe (LAM) linked to an inductively-coupled-plasma mass spectrometer (ICP-MS). Most of the zircons from the ankaramite are concordant and yield a 550±5 Ma date indistinguishable from the 550+3/-2 Ma date previously reported using multi-grain thermal ionization mass spectrometry. About half of the zircons from the trachyte are also concordant yielding an overlapping date of 556±5 Ma. The other half cluster at ∼ 1000 Ma and at 1500-1600 Ma, which are characteristic ages of the Grenvillian basement exposed nearby in the Long Range Inlier. These zircon xenocrysts were very likely picked up as the Skinner Cove magma ascended through Grenvillian basement of the Laurentian margin. There can now be little doubt that the ∼19°S Skinner Cove paleolatitude represents Laurentia's southern margin at 550 Ma.

GP24A-05 1635h

Neoproterozoic Juvenile Crust Development in the Peri-Rodinian Ocean Coeval With Grenvillian Orogenesis: Accreted Terranes in Late Neoproterozoic Orogens

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The supercontinent Rodinia is thought to have been formed by 1.2 to 1.0 Ga continent-continent collisions and to have dispersed between 0.75 and 0.6 Ga. The existence of Rodinia implies the presence of a Panthalassa-like peri-Rodinian ocean between ca. 1.0-0.75 Ga within which juvenile crust developed. Although the vast majority of this crust was later subducted, vestiges are preserved in terranes that accreted to the leading edges of the dispersing continents following the breakup of Rodinia. These terranes are recognized by their ca. 1.2 to 0.75 Ga Sm-Nd T(DM) model ages, coeval with the life of Rodinia. They include ca. 0.9 to 0.8 Ga ophiolites and ensimatic arc complexes, and ca. 0.8 to 0.6 Ga recycled mafic to felsic arc complexes. Formed within the peri-Rodinian ocean, these terranes were accreted to their respective continental margins in the Late Neoproterozoic. For orogens in which subduction culminated in Late Neoproterozoic continental collision (e.g., Southern Yangste margin, Brasiliano, Trans-Saharan), vestiges of peri-Rodinian crust became cratonized within the suture zones between the colliding cratons. In accretionary orogens, in which subduction was not terminated by continental collision (e.g., Arabian Shield, peri-Gondwana), terranes were subsequently involved in Paleozoic orogenesis. More generally, crustal formation in Panthalassa-type oceans and the subsequent recycling of this crust can be recognized by Sm-Nd depleted mantle (TDM) model ages that overlap with the life-span of the supercontinent.

GP24A-06 1650h INVITED

Geochronological Constraints on Neoproterozoic Glaciations, the first appearance of Metazoans, and the Cambrian Explosion.

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Studies of Neoproterozoic climate fluctuations, plate reconstructions, biological evolution and their interrelationships have been hindered by a lack of high-precision geochronological constraints. The correlation and estimates of duration for Neoproterozoic glaciations has relied on physical/chemo-stratigraphy, and thermal subsidence models respectively. New geochronological constraints from Neoproterozoic successions worldwide have sharpened the debate as to the number, synchroneity, and duration of glacial episodes and the relationship, if any, between Metazoan evolution and global glaciation(s). Crucial to the debate are correct interpretation of geochronological data that range from U-Pb zircon studies of intercalated volcanic ash-beds, U-Pb detrital zircon studies, Re-Os from black shales, Rb-Sr from clay-rich rocks, U-Pb and Pb-Pb from carbonates and phosphates, and Lu-Hf from phosphates. Development of a highly resolved Neoproterozoic timescale will require integration and cross-calibration of multiple dating techniques and consideration of what is actually being recorded by each chronometer. A review of available geological and geochronological data indicate that there were at least three and perhaps as many as five periods of Neoproterozoic glacial deposition including rocks from United States (Idaho and Virginia), Newfoundland and the Northwest Territories of Canada, Namibia, and Oman. What must be evaluated is how the paleogeographic distribution of glaciated regions varied with time during the Neoproterozoic. Do Neoproterozoic glacial successions distributed worldwide record a small number of globally synchronous, long-lived glaciations, or numerous diachronous glacial epochs, or a combination of both? At present, the duration of only one glacial deposit, the ca 581 Ma Gaskiers Formation (Newfoundland), is known and it is on the order of 1 Ma, at odds with a long-lived global glaciation predicted by the snowball Earth hypothesis. Other major issues are the timing of the first appearance of animal fossils (south China and Newfoundland) relative to the last global glaciation and whether a major extinction occurred at the Cambrian/Precambrian boundary. These important issues will only be resolved by the integration of high-resolution geochronology and stratigraphy.

GP31A CC: 220 C-E Wednesday 0830h

Geomagnetism and Paleomagnetism General Contributions Posters *(joint with T, V, NS)*

Presiding: **K P Kodama,** Lehigh University**; M A Hamilton,** University of Toronto

GP31A-01 0830h POSTER

MAGNETIC MODEL TRAP FORMATION OF VOLYN

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Abstract In the article technique of magnetic modelling trap formation of Volyn (north-west Ukraine) is considered. It is investigated magnetic properties of rock trap formation, anomalous magnetic field and connection of these parameters with a technique of maning model. The model of a magnetic field was made. The comparative analysis with others trap formations of the world was carried out. Introduction Study of trap magnetism constantly attracts attention of geoscientists throughout the world and may be determined, on the one hand, by connection of a number of important mineral products (copper-nickel, iron and other ores) with trap formations, and on the other hand, has a great importance for solution of general and vital theoretical problems of geosciences.The works of the last ten years' [1-3] study of trap magnetic parameters make it possible to obtain information of magnetism age, geological structure of the territory. Investigations related to making of trap models are of great interest. Making of Volyn region trap formation magnetic model Model 1. The lower limitation is an upper reflection of a ground M. Magnetization of a basalt layer is changed laterally from 1,0 SI units to 5,5 SI units. The field selected in that way is different from the initial field to 30-40 nTl that can be sufficient for modelling of a regional field. Model 2. The lower limitation of a magnetoactive layer is a lower reflection of the M limit. In this case the changes of a lateral magnetization were received from 1,0 to 4,5 SI units. Conclusion. The approach of a model making proved a true possibility for use of a magnetic field not only for traditional study of a near-surface but also deep zones of the earth's crust in conditions of platform areas, zones of spreading of trap formations. The evaluation of contribution of the upper part of the earth's crust to the anomalous field made it possible to mark a regional component of the field by geotraverse II related to the deep parts of the earth's crust. References. 1. Glevasskaya A., Kravchenko S., Mikhaylova N. Vendian geomagnetic poles of East-European platform (EEP) based on paleomagnetic studies of West-Ukrainian sections. JAGA Abstr. boocs. Sec. 1.11. - Upsala, 1997. - P.59 2. Yusypiv M. To creation of magnetic model of trap formation of Volyn. International Geophysical Conference "Geophysics of the XXI Century - Leap into the Future" .Abstr. boocs. Sec. OS 9. - Moscow, 2003 3. Yusypiv M. Features of the magnetic properties of trap formation Volyn in connection with construction of their magnetic model. IV International Geological-Geophysical scientific and technical conference of young scientists and specialist. Abstr. boocs. - Sankt-Petersburg, 2003. - P. 229

GP31A-02 0830h POSTER

Quipus and System of Coordinated Precession

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The Incas of ancient Peru possessed no writing. Instead, they developed a unique system expressed on spatial arrays of colored knotted cords called Quipus to record and transmit information throughout their vast empire. In their thorough description of quipus, Ascher & Ascher observed that in two cases the numbers registered in their strings have a very special relationship to each other. For this to occur the numbers must have been obtained through the multiplication of whole numbers by fractions or decimals, operations apparently beyond the arithmetic knowledge of the Incas. The quipus AS120 and AS143, coming from Ica (Peru) and conserved in the Museum of Berlin has the suitable characteristics previously. In the AS143 there is a the relationship with the systems of coordinated precession (tilt of Earth's spin axis (40036); eccentricity of Earth's