GP14A CC: 519 B Monday 1530h

Satellite Magnetic Missions Since Magsat: Recent and Proposed II

(joint with P, SA, T, SM)

Presiding: **P T Taylor,** NASA Goddard Space Flight Center**; J C Cain,** Florida State University

GP14A-01 1530h INVITED

External Field and its Stormtime Dynamics as Inferred From Empirical Magnetospheric Models.

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This paper surveys recent results of the modeling of the external geomagnetic field, based on multi-spacecraft data from the inner and near magnetosphere ($R < 15R_E$), supported by concurrent observations in the upstream solar wind. At quiet times, the magnetic field of external origin does not exceed a few tenths of percent of the total geomagnetic field at the Earth's surface. During large storms, the contribution from ionospheric and magnetospheric sources dramatically increases and can reach a few percent of the main field. At low latitudes, most of the large-scale external disturbance comes from the symmetric and partial components of the ring current; a significant effect is also due to the near-Earth part of the tail current. At higher latitudes, the largest contribution is made by Birkeland currents and the auroral electrojet. The external field is largely variable on a wide range of time scales, reflecting incessant variations in the incoming solar wind and the IMF. It also responds to diurnal and seasonal periodic changes of the tilt angle of the Earth's dipole. Early empirical models used a primitive parameterization, in which the data were simply binned into a few intervals of the Kp index. Subsequent studies were aimed at the development of more accurate models, parameterized by the observed geoeffective characteristics of the interplanetary medium. In our most recent work, a new approach has been developed, making it possible to represent the actual dynamics of the magnetospheric currents during interplanetary disturbances. In contrast with earlier efforts, the new model takes into account the entire history of the external solar wind driving of the magnetosphere during a storm. In doing so, we used spacecraft data taken during 37 storms in 1996–2000 [*Tsyganenko et al.*, JGRA, v.108(A5), SMP-18, 2003] and employed the idea that each major source of the magnetospheric field evolves in time according to its individual solar-wind/IMF driving function, has its own decay timescale and a nonlinear saturation threshold. A strikingly good agreement was found between the Dst field at Earth and that calculated from the model field, in spite of the fact that we did not include any ground-based data in the modeling dataset. An important corollary of this modeling effort is that it provides an accurate estimate of contributions to the ground Dst field from major magnetospheric currents, and their variation during the entire cycle of a storm. The obtained results can be viewed as a significant milestone in the pursuit of a realistic field model, based on spacecraft observations. Empirical magnetosphere models are sometimes dismissively termed as "static", "synoptic", or "climatology" models, to contrast them with dynamic MHD simulations. In that regard, our results clearly demonstrate that, once large sets of nearly continuous and accurate interplanetary and magnetospheric data become available, it is possible to develop a truly dynamical external geomagnetic field model and use it to reproduce (and forecast) the entire process of a magnetospheric storm, as it unfolds in time.

URL: http://nssdc.gsfc.nasa.gov/space/model/magnetos/data-based/modeling.html

GP14A-02 1545h

Torque Balances on the Taylor Cylinders in the Geomagnetic Data Assimilation

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In this presentation we report on our continuing effort in geomagnetic data assimilation, aiming at understanding and predicting geomagnetic secular variation on decadal time scales. In particular, we focus on the effect of the torque balances on the cylindrical surfaces in the core co-axial with the Earth's rotation axis (the Taylor cylinders) on the time evolution of assimilated solutions. We use our MoSST core dynamics model and observed geomagnetic field at the Earth's surface derived via Comprehensive Field Model (CFM) for the geomagnetic data assimilation. In our earlier studies, a model solution is selected randomly from our numerical database. It is then assimilated with the observations such that the poloidal field possesses the same field tomography on the core-mantel boundary (CMB) continued downward from surface observations. This tomography change is assumed to be effective through out the outer core. While this approach allows rapid convergence between model solutions and the observations, it also generates sever numerical instabilities: the delicate balance between weak fluid inertia and the magnetic torques on the Taylor cylinders are completely altered. Consequently, the assimilated solution diverges quickly (in approximately 10% of the magnetic free-decay time in the core). To improve the assimilation, we propose a partial penetration of the assimilation from the CMB: The full-scale modification at the CMB decreases linearly and vanish at an interior radius ra. We shall examine from our assimilation tests possible relationships between the convergence rate of the model solutions to observations and the cut-off radius ra. A better assimilation shall serve our nudging tests in near future.

GP14A-03 1600h INVITED

Modeling and Interpretation of Magnetic Fields at Low-Earth-Orbit Altitudes Associated with Ionospheric and Geomagnetic-Field-Aligned Currents

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Ionospheric currents and their associated geomagnetic-field-aligned currents produce a variety of signatures in the geomagnetic field measured at low-Earth-orbit (LEO) altitudes. Analysis of these signatures with the aid of simulation models can provide a wealth of information about ionospheric electric fields, currents, and conductivities; about thermospheric winds; about magnetospheric processes; and about magnetosphere-ionosphere-thermosphere interactions. We survey the observations and simulations of LEO magnetic fields associated with ionospheric and geomagnetic-field-aligned currents, and discuss what they tell us about the ionosphere, thermosphere, and magnetosphere.

GP14A-04 1615h

Magnetic Field Anomalies Recorded Prior to the M=7.6 Chi-Chi Earthquake in Taiwan, Inferred Ground Currents, and the Electrical Conductivity of Rocks

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During seven weeks before the M=7.6 Chi-Chi earthquake in Taiwan on Sept. 21, 1999 and during the month-long aftershock sequence, strong magnetic field anomalies were recorded by two ground stations LY and TT close to the 100 km long, N-S trending fault line that broke during the Chi-Chi event. The magnetic anomalies occurred in hour-long pulses and reached total field intensities of 200 nT (above a 5 nT background). They imply powerful E-W trending ground currents of the order of 500,000 Amp. Assuming the magnetic anomaly to arise from a linear source, the signal strength at satellite altitudes of 300-700 km is estimated to be of the order of 3.3 - 1.5 pT, respectively. Modeling the ground conductor we find current densities of the order of 0.1 mAmp per square meter. We report on a laboratory study to measure the electrical conductivity of igneous rocks placed under stress. We find that the increase in conductivity is due to electronic charge carriers, which are positive holes (p-holes), e.g. defect electrons in the valence band of the otherwise insulating minerals. The current densities obtained from the rock deformation experiments are of the same order of magnitude as those inferred from modeling the Chi-Chi ground conductor.

GP14A-05 1630h

Large Magnetic Anomalies over Russia revealed by Balloon Data

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A stratospheric balloon flight at 30 km altitude measured the geomagnetic field intensity along a 6000 km track extending from Kamchatka to near the Ural Mountains. When the Comprehensive Model based on satellite and ground data (Sabaka et al.,2003) was used to remove the main and external fields from the observed data, magnetic anomalies of several 100 nT amplitude and 250 to 750 km wavelength are observed. They have not been observed before because the wavelength of these anomalies is too short for them to be revealed in geomagnetic field models. Also they do not appear in Russian aeromagnetic data where the balloon track and the aeromagnetic coverage overlap. Two dimensional (2D) magnetic models show that balloon anomalies may be caused by very magnetic, sometimes deep geologic bodies, although such bodies do not correspond to recognized geologic features. In the eastern part of the track these anomalies appear to be due to the bodies of up to 5 km depth and magnetizations of 0.12 SI (0.01 cgs). Magnetizations required for 2D magnetic modeling were compared with measured rock samples data from Magnetic Petrology Database and attempt was made to estimate how well the sample magnetization can represent the average magnetization for the source bodies for the balloon magnetic models. The locations of magnetic petrology data close to balloon track are related to the Urals Mountains (South Mougodjar area, basalts), Mongolia and Tuva ophiolites (serpentinites), Central Siberian Platform (dunites), and Kamchatka (basalts).

URL: http://core2.gsfc.nasa.gov/research/terr_mag/php/MPDB/frames.html

GP21A CC: 220 C-E Tuesday 0830h

Satellite Magnetic Missions Since Magsat: Recent and Proposed III Posters *(joint with P, SA, T, SM)*

Presiding: **P T Taylor,** NASA Goddard Space Flight Center

GP21A-01 0830h POSTER

Newly developed maps of Moho and Curie discontinuities for Levant as a basis for innovative models of the Earth's crust in Cyprus and southern Israel

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A new map of Moho discontinuity for Levant (Israel, Jordan, Syria, Lebanon and eastern part of the Mediterranean Sea (including Cyprus and Eratosthenes)) has been constructed using integrated analysis

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of geothermal, seismic, gravity, magnetic, tectonic and some other geophysical and geological data. The developed map indicates that position of Moho in Levant is minimal in the eastern part of Mediterranean Sea (22-26 km), excluding regions of Cyprus (26-36 km) and Eratosthenes (27 km), and it is maximal for southern Israel 36-40 km) and SW Jordan (38-40 km). On example of Israel and adjoining regions of the Eastern Mediterranean is shown that in the regions with low heat flow and low vertical geothermal gradient the depth of the Curie point could be greater than that of the Moho discontinuity. The new map of Moho discontinuity, along with the improved methods of temperature calculation at depth and geothermal gradients computing, were employed for development of a first Curie point depth map for Israel and adjoining areas. Performed analysis indicates that difference in rocks composition, values of the Curie point for magnetite and titanomagnetite together with the transition between ferric (FeIII) and ferrous (FeII) iron may lead to significant mistakes and ambiguity for the Curie point depth determination in different regions. The obtained results also demonstrate that magnetic data analysis may be used for determination of the bottom edges of magnetized bodies/layers, but for the Curie point depth determination (estimation) it is preferably to apply geothermal methods. Examination of available geophysical data for Levant points at very complex structure of the earth's crust in Cyprus and southern Israel. Some preliminary analysis allowed to suggesting a presence of doubled oceanic crust in Cyprus and fragments of ancient oceanic crust in the upper mantle of southern Israel.

GP21A-02 0830h POSTER

A Physical Model of Seismo-Associated Electromagnetic Emissions Propagating in Layered Lithospheric and Atmospheric Media

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A study is proposed to describe the propagation of electromagnetic (EM) waves from the preparation hypocentral focal volume to the Earth's neutral atmosphere. The study is based on primary concepts and on phenomenological aspects related to previous observations and models. A realistic layered lithosphere and the location of the focal volume at depth, have been defined from seismic data. Two different vertical conductivity profiles have been used for the lithosphere, while the neutral atmosphere (below the troposphere) is considered as a homogeneous insulator with constant conductivity. According to the dilatancy-diffusion and crack-avalanche models the source of preseismic EM-waves at depth is assumed to be constituted by an ellipsoidal volume of cracked rock in which micro-cracks are elementary emitters. The two cases of elementary oscillating electric and magnetic dipoles and of an ensemble of coherent elementary oscillating dipoles have been studied. In the latter case a space distribution function has been used to characterize the source. Then, using the full set of Maxwell's equations and applying potential theory (with opportune gauge and boundary conditions) vector potential components are obtained in integral form and the corresponding electric and magnetic fields are estimated as a function of frequency, distance, and medium parameters. Displacement currents are considered and no limits have been applied *a priori* to the frequency spectrum of the EM source radiation. As expected, results indicate that the upper lithospheric conductive layer acts as a low-pass filter with a cut-off frequency in the ULF/ELF frequency bands, depending on the electric conductivity. The electric and magnetic field amplitudes and related spectra, estimated at the Earth's surface, are in agreement with observations. The study of interactions between ULF/ELF preseismic electromagnetic waves and ionospheric plasma as well as of the same waves with radiation belt particles is in progress.

GP21A-03 0830h POSTER

Magsat to CHAMP–Magnetic Satellite Explorations of Lithospheric Anomalies over Kursk, Bangui and the Antarctic

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We compare crustal magnetic anomaly maps over the Kursk (Russia) and Bangui (Central African Republic) isolated anomalies and the Antarctic derived from the Magsat, Ørsted and CHAMP satellite fields. We wish to demonstrate how progress in satellite magnetic missions has improved the recovery of the crustal magnetic field. The 6-month long Magsat mission of 25 years ago generated two major methods of processing satellite magnetic anomaly data for lithospheric studies. The first was a global perspective using spherical harmonics that emphasize the more regional and global lithospheric fields. However, these fields commonly do not resolve local anomaly features in any detail. Therefore a second procedure involved the use of the individual satellite orbit or track data to recover small-scale anomalies on a regional scale. We present results over prominent magnetic anomalies such as Kursk, Bangui and the large Antarctic continent that demonstrate how the various analysis methods affect the recovery of crustal anomalies. The more recent Ørsted and CHAMP missions are successfully recording data with an improved accuracy and with full spatial and temporal coverage. We show and interpret the total magnetic intensity anomaly maps over these areas from all three satellite magnetometer data sets.

GP21A-04 0830h POSTER

Integration of NASA/GSFC and USGS Rock Magnetic Databases.

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A global Magnetic Petrology Database (MPDB) was developed and continues to be updated at NASA/Goddard Space Flight Center. The purpose of this database is to provide the geomagnetic community with a comprehensive and user-friendly method of accessing magnetic petrology data via the Internet for a more realistic interpretation of satellite (as well as aeromagnetic and ground) lithospheric magnetic anomalies. The MPDB contains data on rocks from localities around the world (about 19,000 samples) including the Ukranian and Baltic Shields, Kamchatka, Iceland, Urals Mountains, etc. The MPDB is designed, managed and presented on the web as a research oriented database. Several database applications have been specifically developed for data manipulation and analysis of the MPDB. The geophysics unit at the USGS in Menlo Park has over 17,000 rock-property data, largely from sites within the western U.S. This database contains rock-density and rock-magnetic parameters collected for use in gravity and magnetic field modeling, and paleomagnetic studies. Most of these data were taken from surface outcrops and together they span a broad range of rock types. Measurements were made either in-situ at the outcrop, or in the laboratory on hand samples and paleomagnetic cores acquired in the field. The USGS and NASA/GSFC data will be integrated as part of an effort to provide public access to a single, uniformly maintained database. Due to the large number of data and the very large area sampled, the database can yield rock-property statistics on a broad range of rock types; it is thus applicable to study areas beyond the geographic scope of the database. The intent of this effort is to provide incentive for others to further contribute to the database, and a tool with which the geophysical community can entertain studies formerly precluded.

URL: http://core2.gsfc.nasa.gov/research/terr_mag/php/MPDB/frames.html

GP21A-05 0830h POSTER

Satellite Geopotential Anomaly Constraints for the Crust of the Greenland-Iceland Region

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Satellite magnetometer observations of the Greenland-Iceland region compare quite well with lower altitude data. The satellite magnetic data suggest magnetically enhanced crust was emplaced by the Iceland Plume. Crustal thicknesses, which may be more than 30 km for the Greenland-Scotland Ridge, were obtained from inversion of the compensating terrain gravity effects that were estimated by spectral correlation analysis of the free-air gravity anomalies and terrain gravity effects. Regional magnetic anomaly maxima overlie possible thickened crust from eastern Iceland to the Greenland Coast. The Iceland-Faeroe Ridge may involve thinner crust than the Greenland-Iceland portion of the Greenland-Scotland Ridge. The gravity derived crustal model exceeds a 0.7 correlation with available seismic estimates. In thermally active areas our gravity Moho estimates are systematically deeper than the seismic estimates suggesting local density reductions of the underlying lower crust/upper mantle. In south central Greenland, on the other hand, the gravity Moho estimates are shallower than seismic estimates to suggest a local enhancement of the lower crust/upper mantle density. The dichotomous crust of the Greenland-Iceland and Iceland-Faroe Ridges suggests unequal crustal development by the Iceland Plume and the Mid-Atlantic Ridge, where more crustal material may have been contributed to the North Atlantic Plate than the Eurasian Plate. A new thermal modeling scheme based on Poisson's relation between point pole gravity and thermal potentials allows estimation of magnetic crustal thicknesses. Subsequent magnetic anomaly inversion for susceptibility contrasts infers crustal development of the Greenland-Scotland Ridge by temporally variable pulses in plume strength.

GP21A-06 0830h POSTER

Stress-Induced Changes in the Electrical Conductivity of Igneous Rocks

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If we ever hope to understand the non-seismic signals that the Earth sends out before major earthquakes, we need to understand the physics of rocks that are coming under increasing levels of stress. In particular we need to understand the generation of electrical currents in the ground. We have begun to study how the electrical conductivity of igneous rocks changes under stress and what types of charge carriers are involved. We show that granite and (quartz-free) anorthosite under stress generate electronic charge carriers. These charge carriers are positive holes (p-holes), e.g. defect electrons on the oxygen anion sublattice. The p-holes spread out of the stressed rock volume, the "source volume", into the surrounding unstressed rocks. This outflow of charges is probably the mechanism by which ground currents can be generated. Large ground currents are necessary to generate local magnetic field anomalies and low-frequency electromagnetic emissions reported in the literature. The outflow of p-holes is expected to also lead to changes in the ground potential and is implicated in the reported "thermal anomalies", which consist of rapid variations of the land surface temperature detected in night-time mid-IR satellite images.

GP21A-07 0830h POSTER

Study on Seismomagnetism in Taiwan

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Since Taiwan is located in high seismicity zone, seismic hazard mitigation is extremely needed. In order to find out any potential precursors before large earthquakes, geomagnetic transfer functions and demodulates are calculated using the geomagnetic data with a sampling interval of one minute at Lunping, Taiwan, Geomagnetic Observatory from 1988 to 2000. These results were correlated to earthquake occurrences. First, traditional transfer functions for the frequencies from 0.1 to 10 cycles/hour are calculated day by day. Monthly means are statistically obtained from these daily values of transfer functions. All the transfer functions show the significant anomalous frequencies at 2, 3, 4, and 6 cycles/hour. Some remarkable changes of transfer function Au, possibly related to the earthquakes which occurred near the Lunping Observatory are found. Second, the Complex demodulation method (CDM) is applied to (1) study the background of the geomagnetic field; (2) set up the method on extraction seismomagnetic signals from the geomagnetic data; and (3) study the characteristics of the seismomagnetic precursory. The results show that the 'demodulate' of 1 cycle/day decrease significantly 30 days before high seismicity and retrace to normal value after main shock.

GP23A CC: 519 B Tuesday 1330h

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

Presiding: **P J McCausland,** University of Michigan**; B Murphy,** St. Francis Xavier University

GP23A-01 1330h

Mexican data indicating ca.700 Ma breakup of Rodinia and ca.550 Ma separation of Avalonia: analogous to events in western Laurentia

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The supercontinent, Rodinia, appears to have been amalgamated by ca.1 Ga, however, its breakup in Laurentia appears to have occurred in two stages. Current hypotheses suggest that East Gondwana or Siberia separated from western Laurentia at ca.700 Ma followed by separation of (?) South China at ca.550 Ma producing two superposed passive margin sequences. Although prevailing wisdom suggests that the birth of Iapetus between North and South America occurred at ca.550 Ma, a similar 2-stage process is evident in both eastern Laurentia and Mexico. At ca.1 Ga, Mexico appears to have been located in or close to the North-South America suture and so provides crucial data. Geochronological data indicate that cooling following ca.1 Ga granulite facies orogenesis in Mexico followed two different paths. In southern Mexico the rocks initially cooled through ca.450°C at a rate of ca.8°C/my between 978 Ma and 945 Ma related to flat-slab subduction, followed by a cooling rate of ca.2°C/my through ca.150°C. In northern Mexico the rocks cooled at a steady rate of ca.1.8°C/my through ca.300°C and are cut by plume-related mafic dykes. Extrapolating these cooling paths to the surface indicates that southern Mexico reached the surface between 710 and 760 Ma, whereas northern Mexico reached the surface by 550 Ma. This may be partly explained by different depths of exhumation: 30 versus 37 km for southern and northern Mexico, respectively. On the other hand, the oldest rocks resting on the ca.1 Ga basement are Tremadocian (ca.490-480 Ma) in southern Mexico and Middle Silurian (ca.430-425 Ma) in northern Mexico. Thus it would appear that Mexico records two breakup stages: (1) at ca.700 Ma possibly related to the breakup of Rodinia; (2) at ca.550 Ma possibly related to the transcurrent separation of Avalonia followed by thermal equilibration at ca.500 Ma leading to subsidence and development of a passive margin. These data suggest that the breakup of Rodinia occurred at ca.700 Ma and was followed at ca.550 Ma by separation of large terranes from the cratonic margins. If so, the Neoproterozoic supercontinent, Pannotia, may never have existed as a single coherent landmass.

GP23A-02 1345h

Preliminary Paleomagnetic Results From the Late Neoproterozoic of Eastern Greenland: A low-latitude Sturtian Glaciation?

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The coastal successions of Eastern Greenland present one of the most complete Late-Neoproterozoic to early Paleozoic sedimentary successions in the world. These successions contain abundant evidence for glacial deposition, with at least two major tillite horizons, the Upper and Lower Tillites, present. The Lower Tillite immediately overlies Late Riphean and Sturtian deposits of the Upper Eleonore Bay Group. We have carried out detailed paleomagnetic analyses of some 86 specimens, from 62 samples collected through the top of the Upper Eleonore Bay Group in Ella Ø, principally from Bedgroups 18 and 19. These comprise dark grey to black limestones, with occasional dolomitic shales. Progressive demagnetization uncovered a multi-component remanence structure, with AF demagnetization generally providing cleaner data than thermal techniques. The majority of samples carry a low-stability (generally $<$20mT, though occasionally persisting to 40mT) component of magnetization directed steeply down to the North, close to the present Earth's field. At higher demagnetizing fields a high-stability (generally removed by 60-90mT) component was uncovered in 28 samples, with a mean direction pointing down to the southeast in geographic coordinates (D=154°, I=61°). As these results come from one limb of a fold, tectonic correction for Ordovician-aged folding does not yield any constraints on the timing of magnetization. We note, however, that the mean declination and inclination in geographic coordinates do not resemble any younger direction. The mean direction in stratigraphic coordinates (D=148°, I=17°, k=19, a95=6°) yields a paleopole at 007°E, 6°S, and would indicate a paleolatitude of 9°. If this component of magnetization is primary it would indicate that eastern Greenland was in the tropics immediately prior to deposition of the Lower Tillite Group.

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Modelling a Neoproterozoic Snowball Earth

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Low-latitude sea level glacial deposits suggest the existence of snowball Earth' conditions in the Neoproterozoic. Previous modelling studies have offered conflicting support for the snowball hypothesis. We use a climate model of intermediate complexity, including an ocean GCM and a sophisticated thermodynamic/dynamic sea ice component, to conduct a suite of experiments with different orbital/paleogeographical configurations and atmospheric CO2 levels. We show that depending on the orbital configuration and paleogeography, snowball conditions prevail even with atmospheric CO2 levels up to 1800 ppmv. We demonstrate the importance of using an energy conserving thermodynamic sea ice component and suggest that the inability of some previous models to enter global glaciations may be largely a consequence of using a physically incomplete representation of sea ice. Overall our modelling paradigm is consistent with the original snowball hypothesis in which an ice covered ocean surrounds a largely snow and ice free barren land, with some coastal regions permitting the growth of thick glaciers.

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Geochemical Constraints on Paleoenvironments During the Neoproterozoic

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During the Neoproterozoic Era, sedimentological features such as glacigenic rocks overlain by cap carbonates indicate glaciation and cool climates were extensive, but also that there was the continued presence of organisms and equatorial ice-free open areas. Most paleoclimate inferences have relied on geochemical proxies such as carbon and sulfur isotopic compositions of carbonate rocks, but the degree to which these reliably reflect specific conditions is contentious. The Windermere Supergroup in NW Canada is a succession of shallow shelf to continental-slope deposits in which two major Neoproterozoic glaciations occurred, represented by the Rapitan and the Ice Brook glacial deposits, which correlate with the Australian Sturtian and Marinoan glacial deposits. Neoproterozoic carbonates from the Windermere have superb physical and sedimentological preservation that rival the best-preserved carbonates of this age anywhere. Despite this preservation, the cap and intervening carbonates, which were originally aragonite based on petrography and high Sr contents up to 3700 ppm, have undergone complete recrystallization to low-Mg calcite or dolomite, phases that typify carbonates in coeval sections around the world. Virtually all the geochemical markers have been variably disturbed or reset, depending on the relative level of concentrations in the carbonates and later diagenetic fluids. Most δ^{18}O values are near -10 permil, indicating resetting and other geochemical tracers such as Sr, Ba, Mn and Fe indicate resetting of primary values by later diagenesis. Carbon isotopic compositions, which can be shown to be near primary in many, but not all, samples, display large variations from slightly negative values in cap carbonates and carbonates deposited just prior to the younger glaciation to anomalously positive values in the intervening Keele Formation carbonates between the glaciations. These variations in δ^{13}C values result from sequestering of a major source of organic carbon in the deep ocean, implying that deep ocean venting had ceased prior to glaciation. Although Sr isotopic compositions have been altered more significantly than carbon isotopic compositions, initial isotopic compositions vary little throughout the section, implying that the relative flux of Sr from continents and ocean-ridge hydrothermal inputs before and after global glaciations must have been constant. Hence, models for Neoproterozoic paleoclimatic conditions must account for the sedimentology, C isotopic composition of carbonates and organic matter and constant Sr isotope ratios in carbonates as these are currently the only reliable proxies for the Neoproterozoic atmosphere-hydrosphere system.

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Neoproterozoic Glaciations and the Early Evolution of Animals

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