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Anisotropy of magnetic susceptibility (AMS) and anisotropy of isothermal remanence (AIR) in red sedimentary rocks both typically show a bedding parallel foliation with minimum axes clustered perpendicular to the bedding plane. Our studies have observed this type of magnetic fabric in red bed units that have a range of ages and come from widespread localities. These units include the Mississippian Mauch Chunk Formation from the Appalachians, the Triassic Passaic Formation from the Newark basin in Pennsylvania, the Cretaceous Kapusaliang Formation from the Tarim basin in China, and the early Mesozoic Kayenta and Chinle Formations from the Colorado Plateau in southwestern North America. Bedding parallel foliations are also observed in magnetite-bearing rocks that carry a depositional remanence (DRM), suggesting the possibility of a DRM in red beds, even though the conventional wisdom is that they carry a post-depositional chemical remanent magnetization (CRM). Before the typical magnetic fabric of red beds can be used to indicate their type of remanence, we must determine what the magnetic fabric of a CRM looks like. For this reason, I conducted a series of hematite-growth experiments following the procedures outlined by Stokking and Tauxe (1987). I grew hematite in the laboratory on stacks of glass-fiber filter papers and in slurries of quartz and kaolinite. The hematite was grown from a ferric nitrate solution heated to 95°C for 8 hours. The samples were then dehydrated in a vacuum at room temperature for approximately 38 hours. It was possible to thermally demagnetize the eight filter paper samples to 350°C, but the six kaolinite-quartz samples were grown in plastic sample cubes and could only be thermally demagnetized to 150°C, enough to remove the thermoviscous magnetization acquired by the samples during the heating at 95°C. The mean CRM acquired by the red-brown magnetic phase grown in the experiments was within its alpha-95 of the steeply inclined (inclination=60°) ambient magnetic field. The kaolinite-quartz samples had a very scattered remanence, probably due to the physical disturbance of the samples upon the initial application of the vacuum. In both the filter paper and kaolinite-quartz experiments the AMS fabric of the CRM-carrying grains was foliated with the maximum and intermediate principal axes defining a great circle that passes through the mean CRM direction and is moderately inclined (approximately 45°) to the horizontal. The moderately inclined great circle defined by the maximum-intermediate principal axes is quite distinct from the horizontal maximum-intermediate axes observed in the natural red bed samples, despite red bed characteristic remanences that range from nearly horizontal (Passaic, Chinle, Kayenta) to as steep as 30° (Mauch Chunk, Kapusaliang). This observation suggests that red bed characteristic remanence is typically a DRM, rather than a CRM. This has implications for interpreting red bed remanence since DRMs in hematite-bearing red beds may have large inclination errors.

GP12B-08 1540h

Rheology and Magnetic Fabric

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Anisotropy of magnetic susceptibility (AMS) is a sensitive indicator of rock deformation, often developing before visible evidence. Apparently undeformed rocks may in fact be internally deformed. We have investigated the magnetic fabrics of apparently undeformed shales and limestones from 5 selected sites across the Appalachian fold belt where they crop out at the same locality. The AMS fabrics show different degrees of development in the shales and limestones. In the shales the AMS corresponds to a depositional fabric that shows the effects of vertical compaction but has been only lightly modified by later deformation. In the limestones the AMS minimum and intermediate axes are girdled about the maximum axes, which lie close to the regional strike of the fold axes. This kind of pattern has been observed in other studies during early stages of deformation when a horizontal shortening is superposed on a depositional fabric. Separation into paramagnetic and ferromagnetic components with a torsion magnetometer shows that the AMS is mainly of paramagnetic origin. The ferromagnetic fabric was not significant in this method. Acquisition of IRM and thermal demagnetization of a composite triaxial IRM show that the ferromagnetic mineral is mainly magnetite with minor amounts of hematite. Anisotropy of anhysteretic remanent magnetization (AARM) can thus be used to define the ferromagnetic fabric. The AARM pattern was more poorly defined than the AMS fabric, due to the low ferromagnetic mineral content, and in one limestone was not significant. The shape of the AMS ellipsoid was generally oblate in the shales and prolate in the limestones. The AARM results suggest that the ferromagnetic grains in each rock type responded more quickly to the tectonic forces than the phyllosilicates. Due to their higher phyllosilicate content the shales originally had more bedding compaction than the limestones. The layer-parallel shortening was less able to overprint the shale fabric than that of the limestone. The results suggest that tests of the suitability of a rock type for paleomagnetic studies should include magnetic fabric analysis.

GP12B-09 1555h

Petrofabric Interpretations Supported by Magnetic Anisotropy Observations for the Clavijo Intrusion, Colombian Andes

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Remanent magnetization studies on Late Tertiary shallow intrusions in allochthonous terranes of the Colombian Andes suggest two apparent modes of rotation, about vertical axes and about horizontal axes, as reported previously. The horizontal axes trend perpendicular to the regional structural trends, to judge by the dispersed remanence directions along vertical planes parallel to major strike-slip faults. Two distinct zones have been recognized, between Medellin and Manizales, and between Cali and Pasto (Risnes, 1995), extending approximately 600 km along the Andes. Research on the Clavijo body indicates the importance of combining studies of remanence with those of anisotropy of susceptibility (AMS) and of isothermal remanence (AIRM), and petrofabric studies, in interpreting the remanence directions in tectonically disturbed regions. In this body, hydrothermal alteration is associated with increased within-site scatter of AMS axes. Within-site remanence directions are however not dispersed by such alteration, while between-site remanence directions are affected. New results from electron-microprobe analyses of fresh and hydrothermally altered ferromagnetic (s.l.) and paramagnetic minerals are compared with the respective remanence and susceptibility anisotropies of altered and unaltered sites. A major objective is to determine if vertical flow directions in these shallow intrusions can be recognized, and thus utilized for tilt-corrections of remanence and improved tectonic interpretations. Risnes, K., 1995, Terre et Environnement, v. 2, 169 p., Dept. Mineralogy, Univ. Geneva.

GP12B-10 1610h

Thermoremanence and Stable Memory of Single Domain Hematites:Implications for Martian Magnetic Anomalies

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Single-domain (SD) hematites with grain sizes between 0.12 and 0.42 micrometer carry a strong and stable TRM. The thermoremanence is unaffected by 100 mT alternating field demagnetization and by 600 C thermal demagnetization. Most demagnetization occurs between 625 C and the Neel temperature of 680-690 C. The TRM memory recovered after low-temperature cycling is parallel to the original TRM and equally resistant to thermal demagnetization. TRM and TRM memory of SD hematites are mainly due to the hard spin-canted magnetism intrinsic to the crystal structure above the Morin transition (Tm), and not to the small and softer defect magnetism that survives below Tm. However, the defect magnetism may play a role in renucleating the spin-canted magnetism in a preferred direction during warming through Tm. TRM intensities are well predicted by Neel SD theory and increase in almost exact proportion to grain size. Although smaller than TRM intensities of multidomain hematites, SD TRMs are potent sources of remanent magnetic anomalies, particularly for larger grains (10-15 micrometer), and are likely to be more stable over geological time than multidomain (MD) hematite TRMs.

TRM memory after low-temperature cycling is relevant to Mars because surface temperatures in many parts of the planet cycle diurnally or seasonally through Tm in the essentially zero present-day Martian field. Where surface temperatures are lower than the Morin transition (240-260 K), SD and MD hematites will not contribute to Martian magnetic anomalies. Near the equator during Martian summer, the very stable magnetic memory of SD hematite, almost 40% of original TRM, could contribute partially to the Martian magnetic signal.

GP12C MCC: 130 Monday 1630h

Bullard Lecture

Presiding: **L Tauxe,** Scripps Institution of Oceanography

GP12C-01 1635h INVITED

Plumes and Earth's Dynamic History : from Core to Biosphere

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The last half century has been dominated by the general acceptance of plate tectonics. Although the plume concept emerged early in this story, its role has remained ambiguous. Because plumes are singularities, both in space and time, they tend to lie dangerously close to catastrophism, as opposed to the calm uniformitarian view of plate tectonics. Yet, it has become apparent that singular events and transient phenomena are of great importance, even if by definition they cover only a small fraction of geological time, in diverse observational and theoretical fields such as 1) magnetic reversals and the geodynamo, 2) tomography and mantle convection, 3) continental rifting and collision, and 4) evolution of the fluid envelopes (atmospheric and oceanic climate; evolution of species in the biosphere). I will emphasize recent work on different types of plumes and on the correlation between flood basalts and mass extinctions. The origin of mantle plumes remains a controversial topic. We suggest that three types of plumes exist, which originate at the three main discontinuities in the Earths mantle (base of lithosphere, transition zone and core-mantle boundary). Most of the hotspots are short lived (∼ 10Ma) and seem to come from the transition zone or above. Important concentrations occur above the Pacific and African superswells. Less than 10 hotspots have been long lived (∼ 100Ma) and may have a very deep origin. In the last 50 Ma, these deep-seated plumes in the Pacific and Indo-Atlantic hemispheres have moved slowly, but motion was much faster prior to that. This change correlates with major episodes of true polar wander. The deeper (primary) plumes are thought to trace global shifts in quadrupolar convection in the lower mantle. These are the plumes that were born as major flood basalts or oceanic plateaus (designated as large igneous provinces or LIPs). Most have an original volume on the order or in excess of 2.5 Mkm3. In most provinces, volcanism lasted on the order of 10 Ma or less, often resulting in continental breakup; the bulk of the volume actually erupted in 1 Ma or less. This makes LIPs the remnants of major geodynamic events, with fluxes possibly matching, over short time scales, the crustal production of mid-ocean ridges. The correlation between trap ages, extinctions and oceanic anoxia events proposed over a decade ago has improved steadily, to the point that trap ages may form much of the underlying structure of the geological time scale. The five largest mass extinctions in the last 260 Ma coincide with five traps, making a causal connection between the two unavoidable. The plume hypothesis provides a useful and exciting complement to the now conventional plate tectonics paradigm, and can provide a unified underlying mechanism to explain the few, key times when Earths dynamics behaved in a rather catastrophic way, of which our current world bears the memory. Plumes may express couplings between the Earths very different envelopes. They are a singular mode in which the Earths engine liberates its heat when normal plate tectonics do not suffice. They may modulate the intensity of many global phenomena, from reversal frequency generated in the liquid core to major continental breakup and finally to mass extinctions. The remarkably rich, diverse and exciting geophysical disciplines of geomagnetism and paleomagnetism, which are the lecturers main practical tools, have provided many of the key observations that have led to this view.