HISTORY OF SCIENCE

Alexander von Humboldt and the General Physics of the Earth

In the early 19th century, Alexander von Humboldt laid the foundations for today's Earth system sciences.

Stephen T. Jackson

As scientists are celebrating the 200th anniversary of Charles Darwin's birth and the 150th anniversary of the publication of his *On the Origin of Species*, Darwin's ideas continue to shape and enrich the sciences (*1*). 6 May 2009 marks the 150th anniversary of the death of another 19th-century figure—Alexander von Humboldt—whose scientific legacy also flourishes in the 21st century. Humboldt helped create the intellectual world Darwin inhabited, and his writings inspired Darwin to embark on *H.M.S. Beagle.* More pertinent to our time, Humboldt established the foundation for the Earth system sciences: the integrated system of knowledge on which human society may depend in the face of global climate change.

Like Darwin, Humboldt undertook a major voyage that would shape his ideas and thinking. Humboldt spent 5 years (1799 to 1804) with botanist Aimé Bonpland exploring Venezuela, the northern Andes, and central Mexico, with visits to Tenerife, Cuba, and the United States. They collected botanical, zoological, geological, and ethnological specimens, made extensive atmospheric and geophysical measurements, and recorded the geographic location of their thousands of specimens and tens of thousands of measurements. Humboldt spent the next 22 years and most of his inherited fortune in Paris, preparing and publishing 45 volumes of a never-finished report on his travels.

Of these volumes, the first was a slim work entitled *Essay on the Geography of Plants* (*2*, *3*). The modest title belies the intellectual richness within. In the text and accompanying color plate (see the figure), Humboldt lays out a vision of a comprehensive "general physics of the Earth" aimed at nothing less than a synthesis of atmospheric, oceanic, geological, ecological, and cultural phenomena across the globe. Humboldt's obsession with geographically referenced measurements and collections was central to his vision. He recognized that spatial arrays of observations could be aggregated to reveal patterns that would in turn reveal underlying processes—such as the distribution of incident radiation, the transport of heat and materials in winds and ocean currents, the influence of temperature on plant form, and the effect of latitude and continentality on mountain snowline.

Intellectual riches. The central portion of Humboldt's *Physical Tableau of the Andes and Neighboring Countries*, published as part of (*2*, *3*), shows Chimborazo in profile, with vegetation zones, plant species, and snowline depicted at appropriate elevations. In the original, the profile is flanked on both sides by tables describing elevational patterns in temperature, humidity, light refraction and intensity, agriculture, fauna, and other physical, chemical, and biological features.

He expanded this vision in the succeeding years, establishing international cooperative networks of meteorological and geomagnetic measurement stations, inventing isotherms and other graphical devices to portray spatial patterns, and noting that plant form is often better predicted by local environment than by taxonomic affinity (a paradox resolved by Darwin). Humboldt's genius lay in his geographical vision, and in his intuition that Earth's land surface, oceans, atmosphere, and inhabitants form an integrated whole, with linkages among the various components (*4*, *5*). Humboldt's general physics of the Earth envisioned climate as a major control of Earth-surface phenomena, with vegetation serving as both an index of climate and a proximal control of microclimate, animal habitat, and cultural practices (*6*–*8*).

Humboldt's dream of systematic observational arrays across the globe took hold in the 19th century. Throughout the century, countless Humboldt-inspired explorations were launched, each involving systematic measurement and mapping of physical, biological, and often cultural features of landscapes and oceans (*8*–*10*). These surveys were relentlessly inductive, typically producing detailed descriptive reports with little integration within or among the component entities. However, for a few intellectually nimble participants—including Charles Darwin, T. H. Huxley, Matthew Maury, Asa Gray, C. Hart Merriam, and Peter Kropotkin—these explorations provided data and experience that spurred the development of biogeography, ecology, oceanography, and other environmental sciences (*11*).

Botany Department and Program in Ecology, University of Wyoming, Laramie, WY 82071, USA. E-mail: jackson@uwyo.edu

Unfortunately, the conceptual unification among the sciences of the Earth that Humboldt sought never developed in the century following his death. Disciplinary specialization played a large role in eclipsing Humboldt's integration, as did 20th-century trends toward reductionism, experimentalism, and fine-scale processes in many disciplines.

A new incarnation of Humboldt's general physics of the Earth began to emerge with the plate tectonics revolution in the 1960s. Drawing on Humboldtian spatial arrays of observations, this theory provided a unified explanatory framework for disparate geophysical, geological, paleontological, and biogeographic phenomena.

Today, a second, even broader manifestation of Humboldt's vision aspires to understand the interactions and feedbacks among the components of the Earth system, encompassing the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere as well as human societies and economies. This effort is often referred to as Earth system science, but it could just as well be designated "general physics of the Earth," using the early-19th century definition of physics as the study of the material world and its phenomena (which we now call science).

Global environmental change may be the greatest challenge faced by human societies since the advent of agriculture. Humboldt advocated for science that spoke to human needs and concerns (*5*). It is fitting that on the 150th anniversary of his death, we recognize his role in fostering the sciences that speak to the most profound human concerns—sustainability of human societies and the ecosystems on which they depend.

References and Notes

1. P. J. Bowler, *Science* **323**, 223 (2009).
2. A. de Humboldt, *Essai sur la géographie des plantes* (Levrault, Schell & Co., Paris, 1807).
3. An English translation of (*2*) is currently in press at the University of Chicago Press, Chicago.
4. A. de Humboldt, *Personal Narrative of Travels to the Equinoctial Regions of the New Continent, During the Years 1799-1804, by Alexander de Humboldt and Aime Bonpland; with Maps, Plans, &c.* (Longman, Hurst, Rees, Orme, & Brown, London, 1814 to 1829), vols. 1 to 7.
5. A. von Humboldt, *Cosmos: A Sketch of the Physical Description of the Universe* (Johns Hopkins Univ. Press, Baltimore, 1997), vol. 1.
6. M. Nicolson, *Hist. Sci.* **25,** 167 (1987).
7. M. Nicolson, in *Romanticism and the Sciences*, A. Cunningham, N. Jardine, Eds. (Cambridge Univ. Press, Cambridge, 1990), p. 169.
8. M. Dettelbach, in *Cultures of Natural History*, N. Jardine *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1996), p. 287.
9. S. F. Cannon, *Science in Culture: The Early Victorian Period* (Dawson, New York, 1978).
10. W. H. Goetzmann, *New Lands, New Men: America and the Second Great Age of Discovery* (Viking, New York, 1986).
11. P. J. Bowler, *The Norton History of the Environmental Sciences* (Norton, New York, 1993).

10.1126/science.1171659

PLANETARY SCIENCE

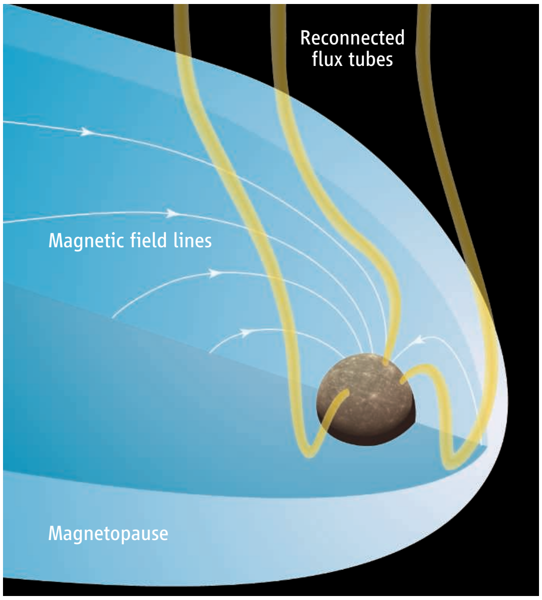
Magnetic Twisters on Mercury

Observations of Mercury during the recent MESSENGER spacecraft flybys reveal a complex magnetosphere.

Karl-Heinz Glassmeier

Mercury is an enigmatic planet. Located closest to the Sun and without an atmosphere, it has only a weak planetary magnetic field to help it withstand the solar wind. The recent flybys of the MESSENGER spacecraft confirm the existence of the Hermean magnetosphere (*1*, *2*), discovered 35 years ago by the Mariner 10 mission (*3*). This magnetosphere is rather small, with the magnetopause (the boundary between the interplanetary medium and the magnetospheric plasma) located as close as 1700 km above the planet surface. Not much is known about the structure and dynamics of the Hermean magnetosphere, and it is here where the observations by MESSENGER are shedding new light. Reports on the discovery of magnesium in the exosphere of Mercury by McClintock *et al.* on page 610 of this issue (*4*) and the detection of flux transfer events by Slavin *et al.* on page 606 (*2*) demonstrate that Mercury is directly exposed to the harsh conditions of the interplanetary medium.

Flux transfer events are regions of localized magnetic flux transfer due to transient magnetic reconnection at the magnetopause (*5*, *6*). Magnetic reconnection is the process that converts magnetic energy into kinetic energy and is one of the most fundamental processes in astrophysical plasmas. Reconnection occurs in regions of strong magnetic shear. Through pairs of magnetic flux tubes, a topological connection between the interplanetary and planetary magnetic field can be achieved. During MESSENGER's second flyby, the interplanetary magnetic field was pointing southward, antiparallel to the Hermean planetary magnetic field. The magnetopause is thus highly sheared—optimum conditions for reconnection. The magnetopause would usually separate the interplanetary magnetic field from the planetary field. Mass and energy flow across the boundary would thus be vastly reduced. During flux transfer events, however, the magnetopause is perforated at multiple points and the magnetosphere opens up, exposing the planet to the interplanetary medium (see the figure).



Magnetic twisters. As a result of dayside local magnetic reconnection, bundles of magnetic field lines penetrate the magnetopause, are convected tailward by the solar wind, plough through the magnetosphere, and interact with the planetary surface.

PHOTO CREDIT: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

It is such a perforated magnetopause that is described by Slavin *et al.* Of extreme interest is the large size of the observed flux transfer events. At around 900 km in diameter, they are comparable to the overall scale of the Hermean magnetosphere. These events also have a short lifetime, indicating a fast and efficient transformation of magnetic into kinetic energy. During magnetic reconnection events, interplanetary magnetic field lines are connected to

Institute of Geophysics and Extraterrestrial Physics, Technical University of Braunschweig, Braunschweig, and Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany. E-mail: kh.glassmeier@tu-bs.de