2006 Philadelphia Annual Meeting (22–25 October 2006)

Paper No. 109-4

Presentation Time: 2:30 PM-2:50 PM

INSIGHTS INTO OROGENESIS USING THE HIMALAYAN SYNTAXES AS GEODYNAMIC LABORATORIES

ZEITLER, Peter K.[1], MELTZER, Anne S.[1], KIDD, William S. F.[2], KOONS, Peter O.[3], CHAMBERLAIN, C. Page[4], HALLET, Bernard[5], PARK, Stephen K.[6], SHRODER, John F. Jr[7], and BISHOP, Michael P.[7], (1) Department of Earth & Environmental Sciences, Lehigh University, Bethlehem, PA 18015, peter.zeitler@lehigh.edu, (2) Earth and Atmospheric Sciences, University at Albany, ES 351, Albany, NY 18015, (3) Department of Earth Sciences, University of Maine, 5790 Bryand Global Sciences, Orono, ME 04469, (4) Earth and Environmental Sciences, Stanford Univ, Building 320, Stanford, CA 94305, (5) Department of Earth and Space Sciences - Quaternary Research Center, Univ of Washington, Box 1310, Seattle, WA 98195, (6) Univ California - Riverside, 1432 Geology Bldg, Riverside, CA 92521-0423, (7) Geography and Geology, Univ of Nebraska at Omaha, Omaha, NE 68182

Both ends of the Himalaya terminate in broad structural and topographic syntaxes that reflect their proximity to a plate corner, where complex, variable, and active lithospheric deformation is underway. More locally, both ends of the Himalayan terminate in active metamorphic massifs marked by rapid rock uplift, pronounced relief, vigorous erosion, and active deformation. At both these scales, interactions between Earth-surface and solid-Earth processes have shaped lithospheric and topographic evolution.

We have conducted multidisciplinary studies on each syntaxis, using them as natural laboratories to study orogenic processes in the detail that the good exposure, young rocks and active geology of these regions make possible. The Nanga Parbat Continental Dynamics Project (~1994 to 1998) used the Nanga Parbat massif to study how metamorphic, surface, and other orogenic processes cause continental lithosphere to be “reworked,” that is, how ancient basement is structurally, petrologically, and chemically overprinted. The project “Geodynamics of Indentor Corners” (2001 to present) is a broader study of how deformation in both mantle and crustal lithosphere is partitioned near a plate corner, and to what extent surface processes play a driving role in orogeny. Both projects have involved contributions from many disciplines, including geochronology, geophysics, petrology, structural geology and tectonics, surface processes, and modeling.

We have found that tectonic and surface processes interact at many scales to produce characteristic landscapes. In the syntaxes, deformation provides the framework for surface morphology, but erosion is occurring at rates that lead to geodynamically significant mass removal, with large rivers playing an important part. Locally erosion can induce intense crustal overprinting through feedbacks involving thermally controlled rheological changes that couple with the large through-going fluvial networks cut into the syntaxes. The regional consequences of these processes can include the formation of elevated surfaces of surprising youth and patterns of erosion and deformation that are highly variable in space and time. We have also found that at least in SE Tibet, deformation in crust and mantle seems coherent, suggesting a considerable degree of mechanical coupling.

2006 Philadelphia Annual Meeting (22–25 October 2006)
General Information for this Meeting

Session No. 109
NSF Continental Dynamics Field Laboratories II: 20 Years On
Pennsylvania Convention Center: 108 B
1:30 PM-5:30 PM, Monday, 23 October 2006

Geological Society of America *Abstracts with Programs*, Vol. 38, No. 7, p. 272

108-10 **3:45 PM** Murdock, Beverly Lynne

GEOLGIC RESEARCH OPPORTUNITIES WITHIN THE NPS RESEACH LEARNING NETWORK

MURDOCK, Beverly Lynne, Department of the Interior, National Park Service, Geologic Resources Division, 4275 Deborah Court, Mt. Airy, MD 21771, lynne_murdock@nps.gov

This presentation will provide two case studies highlighting current climate research work going on in Glacier National Park and in Kenai Fjords National Park. Staff at both parks have used outcomes from this respeat photography work to train interpretive and concession staff and communicated a shared stewardship message. Second objective is to provide park research contacts and on-line research catalogouts with park research needs listed in prioritized order.

108-11 **4:00 PM** Tomkiewicz, Warren C.

VISITORS' UNDERSTANDING OF GEOTHERMAL FEATURES AND ASSOCIATED THERMOPHILIC MICROORGANISMS AT MIDWAY GEYSER BASIN, YELLOWSTONE NATIONAL PARK

TOMKIEWICZ, Warren C., Earth Sciences, Plymouth State University, Boyd Science Center, 17 High Street, Plymouth, NH 03264, warrent@plymouth.edu

This study investigates people's understanding of a recent scientific theory concerning the evolution of life based on thermophilic bacteria and Archaea found below the surface of the Earth and the relevant correct concepts, missing concepts and misunderstandings that people hold in relation to this new theory. Yellowstone National Park contains more of the geothermal features which provide the environment for these organisms than all the rest of the world combined. YNP is the site where the first organisms were identified, isolated and then cultivated for technological and biological applications. Researchers interviewed 200 visitors at YNP's Midway Geyser Basin concerning these geological features, the associated organisms, biological diversity, and the value of these ancient life forms.

This research study is based on the following educational principles found in each of three major domains: (1) personal domain: existing relevant understanding is the most important factor affecting new learning, (2) social domain: learning is considered to be a social process in which groups of people negotiate new meaning and understanding and (3) physical domain: the learners' engagement with physical experiences.

The following research questions were posed:

- What conceptions and values do people possess which are relevant to thermophilic microorganisms and their environment?
- How are park visitors' understandings, values and beliefs affected by their visit to Midway Geyser Basin?

Two interview strategies were designed to assess understanding. The first interview was conducted before visiting the site (pre-tour) and the second after the visitors had toured the Midway Geyser Basin (post-tour). In the pre-tour interviews, general introductory questions were asked about the geology of the area, biology of the microorganisms, diversity of life in thermal pools and the value of the area and associated life. An interpretive approach was used to analyze the interview data to help answer the overall research questions. The extensive interviews provided an in-depth picture of visitors understanding and experience at the geyser basin. In reporting the results, we attempt to derive the important themes and key ideas while portraying enough detail to allow some sense of the complexity of the work. Results will be discussed.

SESSION NO. 109, 1:30 PM

Monday, 23 October 2006

T147. NSF Continental Dynamics Field Laboratories II: 20 Years On

Pennsylvania Convention Center, 108-B

109-1 **1:30 PM** Royden, L.H.

UPLIFT AND EVOLUTION OF THE EASTERN TIBETAN PLATEAU

ROYDEN, L.H.[1], BURCHFIEL, B.C.[2], VAN DER HILST, Rob[2], WHIPPLE, K.X.[2], HODGES, K.V.[2], KING, R.W.[3], and CHEN, Zhiliang[4], (1) Dept. of Earth, Atmospheric and Planetary Sciences, MIT, MIT 54-826, Cambridge, MA 02139, lhroyden@mit.edu, (2) EAPS, MIT, 54-1010 MIT, Cambridge, MA 02139, (3) EAPS, MIT, Cambridge, MA 02139, (4) Chengdu Institute of Geology and Mineral Resources, Chengdu, China

The Tibetan plateau is the highest region on earth, standing more than 5 km. Uplift of the plateau is the result of post-collisional convergence between India and Eurasia beginning at ~50 Ma. Within eastern Tibet uplift and associated crustal thickening have occurred without significant shortening of the upper crust. Instead, crustal material within deep crustal channels has flowed eastward for hundreds of kilometers from beneath the high plateau, doubling the thickness of the crust in eastern Tibet by lateral injection of middle to lower crustal material. Seismic data and the extremely low topographic gradient across the plateau also argue for a weak lower crust in this region. Eastward flow of deep crustal material is evidenced by the morphology of the eastern plateau margin, where flow is impeded by the strong lithosphere of the Sichuan basin. Here the plateau margin is steep and rimmed by an anomalously high-standing plateau edge, which reflects the elevated flow pressure within the crustal channel as material is diverted north and south around the Sichuan basin. The evolution and ongoing deformation of eastern Tibet attest to a lack of coupling between the upper crust and the underlying mantle lithosphere, with upper crustal, deep crustal and mantle rocks moving in different directions on length scales of hundreds to a thousand kilometers and displaying different orientations of seismic anisotropy. Thus in areas of widespread continental deformation, surface motions are not necessarily good indicators of the kinematics of the underlying mantle lithosphere or within the deeper asthenosphere.

The preexisting landscape of southeastern Tibet, which formed at low elevation prior to uplift, is still preserved over much of eastern Tibet and on the broad, 2000 km wide, southeastern margin of the plateau, where it forms a high-elevation mantle for the plateau. This older surface is currently being incised by headward erosion along the huge rivers that drain the eastern plateau where they cut gorges up to 3 km deep. Isotopic dating of the gorges indicates that rapid incision, and presumably plateau uplift, began at ~8-12 Ma, making uplift of the eastern plateau approximately coeval with onset of the southeast Asian monsoon and supporting the hypothesis that plateau uplift is genetically linked to the development of the monsoon.

109-2 **1:50 PM** Brown, Larry D.

PROJECT INDEPTH: PROBING THE BASEMENT ON THE ROOF OF THE WORLD

BROWN, Larry D., Institute for the Study of the Continents, Cornell University, 3120 Snee Hall, Ithaca, NY 14853, ldb7@cornell.edu and ZHAO, Wenjin, Chinese Academy of Geological Sciences, Baiwanzhuang Street 26, Beijing, 100037, China

Project INDEPTH is a multinational, multidisciplinary initiative that has now collected an extensive suite of geophysical data extending from the high Himalayas to the central portion of the Tibetan plateau. INDEPTH I detailed the geometry of the Main Himalayan detachment beneath which Indian continental crust is subducting beneath the deforming leading edge of Asia, providing an important new constraint on the amount of plate convergence that could be attributed to crustal shortening in the Himalaya. INDEPTH II seismic and magnetotelluric indications of partial melt in southern Tibet have lent support to tectonic models involving warm, weak crust and attendant material flow at depth. INDEPTH III results that are consistent with such flow beneath the central plateau include a highly conductive crust, restriction of local seismicity to the uppermost crust, reflective lamination in the lower crust, and coherent crustal anisotropy. Mantle tomography of INDEPTH III teleseismic recordings indicate a steeply dipping zone of anomalously fast (cold?) material in the mantle beneath central Tibet that likely marks subducted Indian lithosphere, an interpretation consistent with the gravity field over Tibet. Receiver functions computed beneath INDEPTH stations indicate a segmentation of the Moho that may reflect post-collisional reactivation of older accreted terranes. INDEPTH IV is now poised to complete its megatransect with new surveys across the northeast boundary of the Tibet Plateau as represented by the Kunlun Mountains and Qaidam Basins. INDEPTH IV will not only address outstanding crustal issues such as the role of Moho faults and extent of lower crustal flow, it will test tectonic models that postulate subduction of Asian lithosphere beneath the northern plateau.

109-3 **2:10 PM** Burbank, Doug

GEOMORPHIC-GEODYNAMIC COUPLING AT THE OROGEN SCALE: A HIMALAYAN TRANSECT IN CENTRAL NEPAL

BARROS, Ana, Department of Civil and Environmental Engineering, Duke University, Durham, NC 27708, ana.barros@duke.edu, BLYTHE, Ann, Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089, BURBANK, Doug, Department of Earth Sciences, University of California, Santa Barbara, CA 93106, burbank@crustal.ucsb.edu, EHLERS, Todd, Geological Sciences, University of Michigan, 2534 C.C. Little Building, 1100 North University, Ann Arbor, MI 48109-1005, HEIMSATH, Arjun, Department of Earth Sciences, Dartmouth College, Hanover, NH 03755, HODGES, Kip, Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, HUMPHREY, Neil, Department of Geology and Geophysics, University of Wyoming, Laramie, WY 82071, and PUTKONEN, Jaakko, Department of Earth and Space Sciences and Quaternary Research Center, Univ of Washington, MS 351310, Seattle, WA 98195

This project was designed to assess the intriguing proposition that climatically modulated erosion strongly influences spatial variations in deformation within a collisional orogen. We focused on the central Nepalese Himalaya where precipitation in the High Himalaya during the summer monsoon exceeds that in almost any other Himalayan catchment. We installed a dense, high-altitude meteorological network across the Annapurna Range that revealed a 10-fold gradient in monsoonal rainfall. The highest rainfall (>4 m/yr) is localized where relief abruptly increases ~15 km south of the range crest. The band of high rainfall roughly parallels the trace of the Main Central Thrust (MCT) and lies near the toe of the Greater Himalaya. A stream-gauging network defined a north-to-south increase in the modern sediment flux, ranging from ~1 to >3 mm/yr. Cosmogenic nuclide concentrations in river sediment on the range's south flank also indicate average erosion of >3 mm/yr over the past 200 years. Fission-track and Ar-Ar dating of valley-bottom and vertical-relief transects indicate that, across the trace of the MCT, cooling ages abruptly become much younger. The juxtaposition of ages across the MCT require several km of slip in the past 2 Myr. Moreover, these data define a striking acceleration in erosion rates within the MCT hanging wall beginning ~2.5 Ma. Whereas rapid erosion rates at all time scales and Quaternary motion on the MCT are all consistent with predictions of focused deformation where rainfall is highest, the fission-track data indicate no significant change in erosion rates for ~50 km farther north, deep into the rain shadow. How then does erosion remain rapid despite 10-fold less rainfall? First, hillslopes steepen as rainfall lessens. Second, large storms that drive the most erosion penetrate farther into the range, such that the storm rainfall gradient is only ~4-fold. Third, whereas glaciers today are retracted and eroding slowly, large expansions of glaciers as recently as 8 and 12 ka promoted rapid erosion in the dry hinterland. Ultimately, climate reigns as the pacemaker of Himalayan erosion. At annual scales, it induces landslides; at millennial scales, it drives phases of impulsive aggradation and erosion; and at still longer scales, it flips the switch between the dominance of fluvial versus glacial erosion.

109-4 **2:30 PM** Zeitler, Peter K.

INSIGHTS INTO OROGENESIS USING THE HIMALAYAN SYNTAXES AS GEODYNAMIC LABORATORIES

ZEITLER, Peter K.[1], MELTZER, Anne S.[1], KIDD, William S. F.[2], KOONS, Peter O.[3], CHAMBERLAIN, C. Page[4], HALLET, Bernard[5], PARK, Stephen K.[6], SHRODER, John F. Jr[7], and BISHOP, Michael P.[7], (1) Department of Earth & Environmental Sciences, Lehigh University, Bethlehem, PA 18015, peter.zeitler@lehigh.edu, (2) Earth and Atmospheric Sciences, University at Albany, ES 351, Albany, NY 18015, (3) Earth Sciences, Univ of Maine, 5790 Bryand Global Sciences, Orono, ME 04469, (4) Earth and Environmental Sciences, Stanford Univ, Building 320, Stanford, CA 94305, (5) Department of Earth and Space Sciences - Quaternary Research Center, Univ of Washington, Box 1310, Seattle, WA 98195, (6) Univ California - Riverside, 1432 Geology Bldg, Riverside, CA 92521-0423, (7) Geography and Geology, Univ of Nebraska at Omaha, Omaha, NE 68182

Both ends of the Himalaya terminate in broad structural and topographic syntaxes that reflect their proximity to a plate corner, where complex, variable, and active lithospheric deformation is underway. More locally, both ends of the Himalayan terminate in active metamorphic massifs marked by rapid rock uplift, pronounced relief, vigorous erosion, and active deformation. At both these scales, interactions between Earth-surface and solid-Earth processes have shaped lithospheric and topographic evolution.

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109-5 **2:50 PM** Keller, G. Randy

INTEGRATED STUDIES OF THE STRUCTURE AND EVOLUTION OF THE EAST AFRICAN RIFT SYSTEM

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The National Science Foundation's Continental Dynamics (CD) program supported a series (1985, 1990, 1994) of integrated investigations that were part of the Kenya Rift International Seismic Project (KRISP). The purposes of this effort were to investigate the structure and evolution of the East African rift (EAR) and to examine the implications of the results for understanding rifting processes on a global basis. The KRISP results clearly demonstrate that the Kenya rift is associated with sharply defined lithospheric thinning and very low upper mantle velocities down to depths of over 150 km. Major axial variations in crustal and uppermost structure were also discovered and correlate well with variations in the amount of extension, the physiographic width of the rift valley, the regional topography, and the regional gravity anomalies. Magmatic activity has certainly modified the crust but not to the extent previously suggested. This modification has taken the form of an underplated layer that constitutes the lowermost crust and local mafic intrusions beneath volcanic centers. More recently, the CD program supported the Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE) that was undertaken to provide a snapshot of lithospheric break-up above a mantle upwelling at the transition between continental and oceanic rifting. The focus of the project was the northern Main Ethiopian Rift (NMER) that cuts across the uplifted Ethiopian plateau, which is associated with the Eocene–Oligocene Afar flood basalt province. The initial results of the controlled source seismic portion of this effort are surprisingly similar to what was found in Kenya in many respects. For example, the velocity within the mid- and upper crust varies from ~6.1 km/s beneath the rift flanks to ~6.6 km/s locally beneath overlying linear Quaternary axial magmatic centers. In addition, the crustal thickness along the NMER axis varies from ~40 km in the SW to ~26 km in the NE beneath southern Afar. This variation is interpreted as reflecting the transition from rifted continental crust to the south to a crust in the north that could be almost entirely composed of mantle-derived mafic melt.

109-6 **3:10 PM** Trehu, Anne M.

PULLING THE RUG OUT FROM CALIFORNIA: SEISMIC IMAGES OF THE MENDOCINO TRIPLE JUNCTION REGION

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The Mendocino Triple Junction (MTJ), currently located near Cape Mendocino in northern California, has been migrating northward along the western margin of North America since the Oligocene, affecting the geologic evolution of California from Los Angeles to Oregon. A simple plate tectonic model of triple junction migration predicts abrupt thinning of the lithosphere and upwelling of aethenospheric mantle as the MTJ migrates to the north, bringing with it the Gorda plate and leaving the thin, wedge-shaped lithosphere of subduction zone forearc in its wake. The MTJ Seismic Experiment (MTJSE), which was the first of a series of NSF-funded Continental Dynamics projects to investigate the continental margins of North America using integrated onshore and offshore seismic techniques, was designed to test this model and evalute the impact of triple junction migration on crustal structure and seismic hazards.

Data for the MTJSE were collected during two field seasons in 1993 and 1994, resulting in a network of seismic reflection and refraction profiles covering the entire active plate boundary zone from 39-42oN and 121-126oW. Results from the seismic imaging include: 1) detailed constraints on the geometry of the subducting plate and its relationship to seismicity north of the triple junction; 2) indications that the strike-slip faults south of the triple junction penetrate through the entire crust, including a highly reflective lower crustal layer that is interpreted to result from aqueous fluids and/or magmatic underplating; and 3) correlation of intraplate deformation with plate age. While the first order plate tectonic model remains valid, the high resolution images of crust and upper mantle structure obtained from our seismic experiment have led to revisions of the simple plate tectonic model of triple junction migration to include generation of an ephemeral welt of thickened crust in the vicinity of the triple junction,evolution of thrust faults into strike-slip faults in advance of the triple junction, and the delayed impact of fluid processes in the subduction zone on later magmatism in the transform regime.

109-7 **3:45 PM** Zoback, Mark D.

GLOBAL CONTINENTAL SCIENTIFIC DRILLING AND THE CONTINENTAL DYNAMICS PROGRAM

ZOBACK, Mark D., Geophysics, Stanford University, Department of Geophysics, Stanford, CA 94305, zoback@pangea.stanford.edu

For almost two decades, continental scientific drilling projects have been going on at sites around world that have addressed a broad spectrum of scientific problems – from utilizing drilling to address key questions involving active faulting, volcanism and hydrothermal systems to using drilling for sampling Quaternary sediments for high resolution climate studies, Archean rocks that preserve evidence of early life and ancient impacts that record sometimes cataclysmic events in Earth history. The National Science Foundation's Continental Dynamics Program made much of this possible in four important ways. First, in collaboration with the U.S. Geological Survey and U.S. Department of Energy, it helped lead national continental scientific drilling efforts through the Interagency Coordinating Committee on Continental Drilling. These efforts marked an almost unparalleled era of interagency cooperation in multidisciplinary Earth science. Second, through it's sponsorship of DOSECC, a U.S. program to carry out multidisciplinary drilling projects, there exists now the capability to carry out projects as diverse as coring continuous samples of young muds in lake beds to coring lavas recording the history of the Hawaiian plume. Third, through it's participation in the highly successful International Continental Drilling Program, it is now possible for Earth scientists from many different countries to carry out a wide diversity of projects at sites of unique global importance. Fourth, through its support of individual U.S. scientists to allow them to participate in scientific drilling projects that, in many cases, have been led by other countries. In this talk, I will briefly review a number of the highlights of the accomplishments of some past continental scientific drilling projects as well as provide a few brief prospects of future activities.

109-8 **4:05 PM** DePaolo, Donald J.

HAWAII SCIENTIFIC DRILLING PROJECT: A UNIQUE VIEW OF MANTLE PLUME VOLCANISM

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The HSDP began with a workshop and proposal in 1986 and is nearing completion with a final phase of deep coring in late 2006. In 1993 a 1.04 km pilot hole was cored just east of Hilo, Hawaii, in lavas of the Mauna Loa and Mauna Kea volcanoes. In 1999 a 3.11 km hole was cored at a site 2 km south of the pilot hole; this hole was deepened to 3.35 km in 2005, and will be deepened further this year. The drilling, supported by NSF Continental Dynamics and ICDP, has produced a nearly continuous 3.1 km-thick (500 ky) record of the lava output of the Mauna Kea volcano as it drifted over the Hawaiian hotspot. The stratigraphy and volcanology of the core have been documented, and hundreds of samples have been measured for mineralogical, chemical, and isotopic composition. The results are reported in 48 publications involving 80 investigators and students from the U.S., Canada, and Europe. The Mauna Kea lavas were found to be twice as old as inferred from surface studies; the Hawaiian volcanoes grow more slowly and are active for a longer period of time than previously thought. The age-depth data can be accounted for with a relatively simple model of mantle plume magma supply which accords with geophysical data. Magma generation and transport parameters are constrained by trace and major element chemistry and are consistent with plume models. The isotopic geochemistry of Mauna Kea lavas changes systematically with age (depth), which corresponds to volcano position with respect to the hotspot. Large changes in He-3 and Pb-208 isotopes are accompanied by only slight changes in Nd, Sr, Pb-206, Pb-207, and Hf isotope ratios. The isotopic stratigraphy maps to structure at the base of the Earth's mantle where the plume originates. The He-3 isotope signal is apparently restricted to a layer, perhaps only 10 km thick, at the base of the mantle. The anomalous helium may be leaking into this layer from the Earth's core. The hydrology of Hawaii is more complex than had previously been recognized. At a depth of 1 km, the temperature in the hole is only about 12°C due to cold seawater circulating through the flanks of the volcano. The well intersected a number of pressurized aquifers - some fresh, and some salty -down to 3 km depth, which was unexpected and has implications for water resources. There are traces of microbiota in the rocks down to 2600 meters.

109-9 **4:25 PM** Olsen, Paul E.

CONTRIBUTION OF THE NEWARK BASIN CORING PROJECT TO ASTROCHRONOLOGY AND CELESTIAL MECHANICS

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The Newark Basin Coring Project (NBCP) was designed to core the entire Triassic age sedimentary record of the Newark continental rift basin of NY, NJ, and PA. Funded by the Continental Dynamics program of NSF, with AMOCO Production Company and Longyear as contractors, the project recovered 6770 m of continuous from seven sites in New Jersey from 1990-1993. An offset drilling method was used taking advantage of the deeply eroded half-graben structure of the basin. The nearly 25% overlap zones between each of the stratigraphically adjacent cores was used to test lateral correlations, scale the cores to one another, and combine them in a 4,660 m thick composite section. This composite shows that most of the sedimentary section consists of a hierarchy of sedimentary cycles of Milankovitch origin including all of the main precession-related periods. Evolutive Fourier and Wavelet analysis clearly shows that periodicities in thickness are remarkably stationary, spanning three orders of magnitude, with few changes in long-term accumulation rates.

With 24 m.y. of the Newark basin record calibrated by Milankovitch cyclicity, and with 47 major magnetic polarity zones, the NBCP composite record is the basis for an astronomically tuned geomagnetic time scale for the Late Triassic and earliest Jurassic. First proposed in 1995, the Newark basin AGPTS has been enhanced with data from the Taylorville and Hartford basins that modify the oldest and youngest parts of the record extending the time scale into the Sinemurian of the Early Jurassic, and in turn is correlated with polarity stratigraphies of Tethyian marine sequences permitting extension of marine stages, substages, and zones into continental sequences and vice versa globally.

The precession-related frequencies revealed in the NBCP cores generally follow predicted values, with the exception of the unpredictable longest period cycles related to Earth and Mars, the periods of which (1.75 and 3.5 m.a.) that differ significantly from the modern periods because of chaotic diffusion of the Solar System. This is the first calibration of the behavior of these cycles deviating from modern values and is a necessary first step in the future construction of an astronomically tuned time scale for the Phanerozoic.

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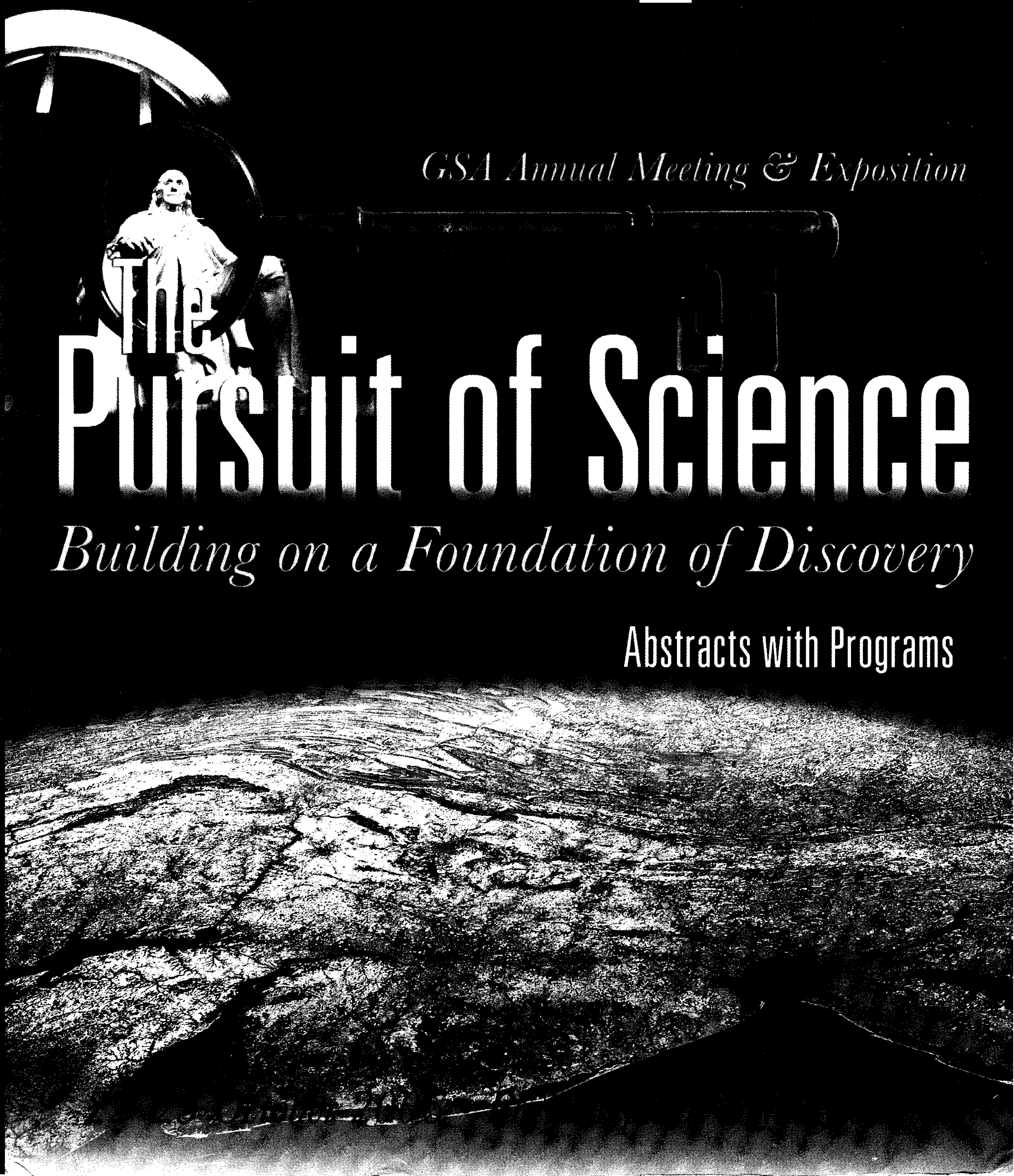

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