



Norman Sleep

Professor of Geophysics, Emeritus

Bio

BIO

I apply heat and mass transfer to physical processes within the Earth. I maintain interest in geodynamics and its applications to the modern Earth and conditions for the origin of life on the young Earth and Mars. I am concentrating on the microphysics of friction and nonlinear seismology. I am currently applying the results to nonlinear attenuation and ground damage by strong seismic waves. I have developed a self-consistent rheology for faults that are dynamically weakened by heating of real contact asperities. I am developing flow-law alternatives to the traditional geotechnical approach with Masing Rules and testing it with real data. I am also examining the records from the Denali earthquake for interaction of high frequency S waves with the low-frequency near-field velocity pulse

ACADEMIC APPOINTMENTS

- Emeritus Faculty, Acad Council, Geophysics

ADMINISTRATIVE APPOINTMENTS

- Assistant Professor of Geophysics, Northwestern University, (1973-1979)
- Postdoctoral Research Associate, Massachusetts Institute of Technology, (1973-1973)
- Associate Professor of Geophysics and Geology, Stanford University, (1979-1984)
- Professor of Geophysics and Geology, Stanford University, (1984-1993)
- Professor of Geophysics, Stanford University, (1993- present)

HONORS AND AWARDS

- Fellow, American Geophysical Union (1980)
- James B. Macelwane Award, American Geophysical Union (1980)
- Fellow, Geological Society of America (1984)
- George P. Woollard Award, Geological Society of America (1991)
- Fellow, American Association for the Advancement of Science (1993)
- Wegener Medal, European Union of Geosciences (1997)
- Walter H. Bucher Medal, American Geophysical Union (1998)
- Member, National Academy of Sciences (1999)
- Wollaston Medal, Geological Society of London (2008)

BOARDS, ADVISORY COMMITTEES, PROFESSIONAL ORGANIZATIONS

- Panel member, National Science Foundation (2011 - 2011)
- Member, Committee on Earth Resources, National Research Council (2009 - present)
- Senior editor, *Astrobiology* (2004 - present)
- Chancellor's invited speaker, Louisiana State University (2000 - 2000)
- Chair of Reading Committees for Ph.D. orals in Engineering, Physics, Linguistics, Education, Geological and Environmental Sciences, and Geophysics, Stanford University (1992 - present)
- Outside Reviewer for Proposals from NSF, NASA, USGS, Petroleum Research Fund, and funding agencies in Israel, Australia, Czech Republic, France, Canada and the U.K., NSF, NASA, USGS, Petroleum Research Fund, and others (1992 - present)
- Associate editor, *Earth and Planetary Science Letters* (1989 - present)
- Member, Earth Sciences Library Committee, Stanford University (1984 - 2001)
- Associate Editor, *Tectonophysics* (1981 - present)

PROFESSIONAL EDUCATION

- Ph.D., Massachusetts Institute of Technology , Geophysics (1973)
- M.S., Massachusetts Institute of Technology , Geophysics (1969)
- B.S., Michigan State University , Geology and Mathematics (1967)

LINKS

- Geophysics: <http://geophysics.stanford.edu/sleep.html>
- Astrobiology web book for general reading and class use. Laboratory and field exercises.: <https://pangea.stanford.edu/courses/gp025/>
- GP150: old homework for general use: <https://pangea.stanford.edu/courses/gp150/>

Research & Scholarship

CURRENT RESEARCH AND SCHOLARLY INTERESTS

Research

I apply heat and mass transfer to physical processes within the Earth. I am currently studying convection at the base of the lithosphere and the interaction of the lithosphere with mantle plume material. Hot plume material locally thins the lithosphere and ponds within preexisting regions of thin lithosphere. I am also investigating the microphysics of friction. I am currently applying the results to nonlinear attenuation and ground damage by strong seismic waves. I am currently considering pre-photosynthetic sources of energy for life (like hydrogen from serpentine and methanogenesis) and the effects of photosynthetic ecology on surface and tectonic processes.

Teaching

I am now emeritus and not actively teaching.

Professional Activities

2008 Wollaston Medal, Geological Society of London; Election, National Academy of Sciences (1999); Walter H. Bucher Medal, American Geophysical Union (1998); Wegener Medal, European Union of Geosciences (1997); fellow, American Association for the Advancement of Science (1993); George P. Woollard Award, Geological Society of America (1991); fellow, Geological Society of America (1984); James B. Macelwane Award (1980); fellow, American Geophysical Union (1980)

Publications

PUBLICATIONS

- **Mars as a time machine to Precambrian Earth** *Journal of the Geological Society*
Lapotre, M., Bishop, J., Ielpi, A., Lowe, D., Siebach, K., Sleep, N., Tikoo, S.
2022
- **Evaluation of Seismic Hazard Models with Fragile Geologic Features** *SEISMOLOGICAL RESEARCH LETTERS*
Stirling, M. W., Oskin, M. E., Arrowsmith, J., Rood, A. H., Goulet, C. A., Ludwig, L., King, T. R., Kottke, A., Lozos, J. C., Madugo, C. M., McPhillips, D., Rood, D. H., Sleep, et al
2021; 92 (1): 314–24
- **Mild Displacements of Boulders during the 2019 Ridgecrest Earthquakes** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H., Hough, S. E.
2020; 110 (4): 1579–88
- **Are We Alone? An Interview with Dr. Norman Sleep.** *Astrobiology*
Lineweaver, C. H., Sleep, N. n.
2020; 20 (5): 563–71
- **Nonlinear Suppression of High-Frequency S Waves by the Near-Field Velocity Pulse With Reference to the 2002 Denali Earthquake** *JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH*
Sleep, N. H., Liu, T.
2020; 125 (1)
- **Nonlinear Rheology at Shallow Depths with Reference to the 2016 Kumamoto Earthquakes** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H., Nakata, N.
2019; 109 (6): 2674–90
- **Nonlinear Interaction of High-Frequency Seismic Waves With Sliding Fault Planes** *JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH*
Sleep, N. H.
2019
- **Friction in Cold Ice Within Outer Solar System Satellites With Reference to Thermal Weakening at High Sliding Velocities** *JOURNAL OF GEOPHYSICAL RESEARCH-PLANETS*
Sleep, N. H.
2019
- **Thermal Weakening of Asperity Tips on Fault Planes at High Sliding Velocities** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2019; 20 (2): 1164–88
- **Geological and Geochemical Constraints on the Origin and Evolution of Life.** *Astrobiology*
Sleep, N. H.
2018
- **Remote Faulting Triggered by Strong Seismic Waves from the Cretaceous-Paleogene Asteroid Impact** *SEISMOLOGICAL RESEARCH LETTERS*
Sleep, N. H., Olds, E.
2018; 89 (2): 570–76
- **Nonlinear body waves in the shallow subsurface, implications of flow-law rheologies. Proceedings of the 11th National Conference in Earthquake Engineering , Earthquake Engineering Research Institute, Los Angeles, CA.** *Proceedings of the 11th National Conference in Earthquake Engineering , Earthquake Engineering Research Institute,*
Sleep, N., Nakata, N.
2018
- **Cratonic basins with reference to the Michigan basin** *CRATONIC BASIN FORMATION: A CASE STUDY OF THE PARNAIBA BASIN OF BRAZIL*

- Sleep, N. H.
edited by Daly, M. C., Fuck, R. A., Julia, J., MacDonald, D. I., Watts, A. B.
2018; 472: 17–35
- **Nonlinear Attenuation of S Waves by Frictional Failure at Shallow Depths** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H., Nakata, N.
2017; 107 (4): 1828–48
 - **Plate-tectonic evolution of the Earth: bottom-up and top-down mantle circulation1** *CANADIAN JOURNAL OF EARTH SCIENCES*
Ernst, W. G., Sleep, N. H., Tsujimori, T.
2016; 53 (11): 1103-1120
 - **Nonlinear Suppression of High-Frequency S Waves by Strong Rayleigh Waves** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H., Nakata, N.
2016; 106 (5): 2302-2312
 - **Anoxic oxidation of chromium** *GEOLOGY*
Oze, C., Sleep, N. H., Coleman, R. G., Fendorf, S.
2016; 44 (7): 543-546
 - **Asteroid bombardment and the core of Theia as possible sources for the Earth's late veneer component.** *Geochemistry, geophysics, geosystems : G(3)*
Sleep, N. H.
2016; 17 (7): 2623-2642
 - **Asteroid bombardment and the core of Theia as possible sources for the Earth's late veneer component** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2016; 17 (7): 2623-2642
 - **Heat flow, strong near-fault seismic waves, and near-fault tectonics on the central San Andreas Fault** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2016; 17 (5): 1778-1798
 - **The tethered Moon** *EARTH AND PLANETARY SCIENCE LETTERS*
Zahnle, K. J., Lupu, R., Dobrovolskis, A., Sleep, N. H.
2015; 427: 74-82
 - **Shallow S-Wave Well Logs as an Indicator of Past Strong Shaking from Earthquakes on the Newport-Inglewood Fault** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H.
2015; 105 (5): 2696-2703
 - **Nonlinear attenuation from the interaction between different types of seismic waves and interaction of seismic waves with shallow ambient tectonic stress** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Nakata, N.
2015; 16 (7): 2336-2363
 - **Long-term deformation driven by small ambient tectonic stresses and strong oscillating tidal within Enceladus with analogy to rock behavior near the San Andreas Fault** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2015; 16 (5): 1670-1686
 - **Terrestrial aftermath of the Moon-forming impact** *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*
Sleep, N. H., Zahnle, K. J., Lupu, R. E.
2014; 372 (2024)
 - **Terrestrial aftermath of the Moon-forming impact.** *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*
Sleep, N. H., Zahnle, K. J., Lupu, R. E.

2014; 372 (2024)

- **Ambient tectonic stress as fragile geological feature** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2014; 15 (9): 3628-3644
- **Effect of latent heat of freezing on crustal generation at low spreading rates** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Warren, J. M.
2014; 15 (8): 3161-3174
- **Physics of crustal fracturing and chert dike formation triggered by asteroid impact, similar to 3.26 Ga, Barberton greenstone belt, South Africa** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Lowe, D. R.
2014; 15 (4): 1054-1070
- **Nonlinear attenuation of S-waves and Love waves within ambient rock** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Erickson, B. A.
2014; 15 (4): 1419-1440
- **BIOLOGICAL EFFECTS ON THE SOURCE OF GEONEUTRINOS** *INTERNATIONAL JOURNAL OF MODERN PHYSICS A*
Sleep, N. H., Bird, D. K., Rosing, M. T.
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- **Self-organization of elastic moduli in the rock above blind faults** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2013; 14 (3): 733-750
- **Microscopic elasticity and rate and state friction evolution laws** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Life: Asteroid Target, Witness from the Early Earth, and Ubiquitous Effect on Global Geology** *ASTROBIOLOGY*
Sleep, N. H.
2012; 12 (12): 1163-1164
- **Maintenance of permeable habitable subsurface environments by earthquakes and tidal stresses** *INTERNATIONAL JOURNAL OF ASTROBIOLOGY*
Sleep, N. H.
2012; 11 (4): 257-268
- **Site Resonance from Strong Ground Motions at Lucerne, California, during the 1992 Landers Mainshock** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H.
2012; 102 (4): 1505-1513
- **Explosive eruption of coal and basalt and the end-Permian mass extinction** *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA*
Ogden, D. E., Sleep, N. H.
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- **Constraint on the recurrence of great outer-rise earthquakes from seafloor bathymetry** *EARTH PLANETS AND SPACE*
Sleep, N. H.
2012; 64 (12): 1245-1246
- **Paleontology of Earth's Mantle** *ANNUAL REVIEW OF EARTH AND PLANETARY SCIENCES, VOL 40*
Sleep, N. H., Bird, D. K., Pope, E.
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- **Seismically damaged regolith as self-organized fragile geological feature** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Deep-seated downslope slip during strong seismic shaking** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Serpentinite and the dawn of life** *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES*
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- **Seismically observable features of mature stagnant-lid convection at the base of the lithosphere: Some scaling relationships** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Habitable Zone Limits for Dry Planets** *ASTROBIOLOGY*
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- **Small-scale convection beneath oceans and continents** *CHINESE SCIENCE BULLETIN*
Sleep, N. H.
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- **Strong seismic shaking of randomly prestressed brittle rocks, rock damage, and nonlinear attenuation** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Sudden and gradual compaction of shallow brittle porous rocks** *JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH*
Sleep, N. H.
2010; 115
- **The Hadean-Archaeon Environment** *COLD SPRING HARBOR PERSPECTIVES IN BIOLOGY*
Sleep, N. H.
2010; 2 (6)
- **Application of rate and state friction formalism and flash melting to thin permanent slip zones of major faults** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Nonlinear Behavior of Strong Surface Waves Trapped in Sedimentary Basins** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H.
2010; 100 (2): 826-832
- **No climate paradox under the faint early Sun** *NATURE*
Rosing, M. T., Bird, D. K., Sleep, N. H., Bjerrum, C. J.
2010; 464 (7289): 744-U117
- **The Eons of Chaos and Hades** *SOLID EARTH*
Goldblatt, C., Zahnle, K. J., Sleep, N. H., Nisbet, E. G.
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- **Stagnant lid convection and the thermal subsidence of sedimentary basins with reference to Michigan** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Stagnant lid convection and carbonate metasomatism of the deep continental lithosphere** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Depth of Rock Damage from Strong Seismic Ground Motions near the 2004 Parkfield Mainshock** *BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA*
Sleep, N. H.
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- **The Bent Hawaiian-Emperor Hotspot Track: Inheriting the Mantle Wind** *SCIENCE*
Tarduno, J., Bunge, H., Sleep, N., Hansen, U.
2009; 324 (5923): 50-53
- **Anthropic Knots and the Rise of Life** *ASTROBIOLOGY*
Sleep, N. H.
2009; 9 (2): 251-252
- **Scaling relationships for chemical lid convection with applications to cratonal lithosphere** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Jellinek, A. M.
2008; 9
- **Nonlinear attenuation and rock damage during strong seismic ground motions** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Hagin, P.
2008; 9
- **Evolutionary ecology during the rise of dioxygen in the Earth's atmosphere** *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES*
Sleep, N. H., Bird, D. K.
2008; 363 (1504): 2651-2664
- **Channeling at the base of the lithosphere during the lateral flow of plume material beneath flow line hot spots** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Production of brief extreme ground acceleration pulses by nonlinear mechanisms in the shallow subsurface** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H., Ma, S.
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- **Edge-modulated stagnant-lid convection and volcanic passive margins** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2007; 8
- **Did earthquakes keep the early crust habitable?** *ASTROBIOLOGY*
Sleep, N. H., Zoback, M. D.
2007; 7 (6): 1023-1032
- **Weak thermal convection within tilted plume conduits** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2007; 8
- **Niches of the pre-photosynthetic biosphere and geologic preservation of Earth's earliest ecology** *GEOBIOLOGY*
Sleep, N. H., Bird, D. K.
2007; 5 (2): 101-117
- **Application of rate-and-state friction laws to creep compaction of unconsolidated sand under hydrostatic loading conditions** *JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH*
Hagin, P., Sleep, N. H., Zoback, M. D.
2007; 112 (B5)
- **Emergence of a habitable planet** *Workshop on Geology and Habitability of Terrestrial Planets*
Zahnle, K., Arndt, N., Cockell, C. S., Halliday, A., Nisbet, E., Selsis, F., Sleep, N. H.
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- **Reply to a comment by D. R. Lowe on "Weathering of quartz as an archean climatic indicator" by N. H. Sleep and A. M. Hessler** *EARTH AND PLANETARY SCIENCE LETTERS*
Hessler, A. M., Sleep, N. H.
2007; 253 (3-4): 534-535
- **Plate tectonics through time** *Treatise on Geophysics, Volume 9*
Sleep, N. H.
edited by Schubert, G.
Elsevier, Oxford.2007: 101-117
- **Emergence of a Habitable Planet** *Workshop on Geology and Habitability of Terrestrial Planets*
Zahnle, K., Arndt, N., Cockell, C., Halliday, A., Nisbet, E., Selsis, F., Sleep, N. H.
SPRINGER.2007: 35-78
- **TOPS: A small space telescope using phase induced-amplitude apodization (PIAA) to image rocky and giant exo-planets** *Conference on Techniques and Instrumentation for Detection of Exoplanets III*
Guyon, O., Angel, J. R., Bowers, C., Burge, J., Burrows, A., Codona, J., Greene, T., Iye, M., Kasting, J., Martin, H., McCarthy, D. W., Meadows, V., Meyer, et al
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- **Origins of the plume hypothesis and some of its implications** *Geological Society of America Special Paper*
Sleep, N.
edited by Foulger, G. R., Jurdy, D. M.
Geological Society of America.2007: 29-45
- **Strategy for applying neutrino geophysics to the earth sciences including planetary habitability** *Conference on Neutrino Geophysics*
Sleep, N. H.
SPRINGER.2006: 343-58
- **Frictional dilatancy** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
2006; 7
- **The astrobiology primer: An outline of general knowledge - Version 1, 2006** *ASTROBIOLOGY*
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2006; 6 (5): 735-813
- **Real contacts and evolution laws for rate and state friction** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Mantle plumes from top to bottom** *EARTH-SCIENCE REVIEWS*
Sleep, N. H.
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- **The rise of continents - An essay on the geologic consequences of photosynthesis** *PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY*
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- **Weathering of quartz as an Archean climatic indicator** *EARTH AND PLANETARY SCIENCE LETTERS*
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- **Impacts and the early evolution of life** *Comets and the Origin and Evolution of Life*
Zahnle, K. J., Sleep, N. H.
edited by Thomas, P. J., Hicks, R. D., Chyba, C. F., McKay, C. P.
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- **Telescope to Observe Planetary Systems (TOPS): a high throughput 1.2-m visible telescope with a small inner working angle** *Conference on Space Telescopes and Instrumentation I - Optical, Infrared and Millimeter*
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- **Physical basis of evolution laws for rate and state friction** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
Sleep, N. H.
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- **Cutting anthropic knots and the rise of O-2** *ASTROBIOLOGY*
Sleep, N. H.
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- **Evolution of the continental lithosphere** *ANNUAL REVIEW OF EARTH AND PLANETARY SCIENCES*
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- **Dioxygen over geological time** *BIOGEOCHEMICAL CYCLES OF ELEMENTS*
Sleep, N. H.
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- **Dioxygen over geological time** *Biogeochemical Cycles of Elements*
Sleep, N. H.
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- **Integrated laboratory compaction data with numerical fault models: a Bayesian framework** *Bayesian Inference and Maximum Entropy Methods in Science and Engineering*
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- **Models for noble gases in mantle geochemistry: Some observations and alternatives** *Plates, plumes, and paradigms*
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- **Long lasting epeirogenic uplift from mantle plumes and the origin of the Southern African Plateau** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Fate of mantle plume material trapped within a lithospheric catchment with reference to Brazil** *GEOCHEMISTRY GEOPHYSICS GEOSYSTEMS*
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- **Survival of Archean cratonic lithosphere** *JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH*
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- **Are high He-3/He-4 ratios in oceanic basalts an indicator of deep-mantle plume components?** *EARTH AND PLANETARY SCIENCE LETTERS*
Meibom, A., Anderson, D. L., Sleep, N. H., Frei, R., CHAMBERLAIN, C. P., Hren, M. T., Wooden, J. L.
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- **Mantle plumes?** *ASTRONOMY & GEOPHYSICS*
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- **Simple features of mantle-wide convection and the interpretation of lower-mantle tomograms** *COMPTES RENDUS GEOSCIENCE*
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- **The Physical Setting for Early Life** *Evolution on Planet Earth*
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