Proposal for the establishment of a Task Force or Coordinating Committee of the

International Lithosphere Program (ILP) for 2021-2025

Bio-geodynamics of the lithosphere

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I. Introduction

Growing evidence suggest that geodynamic evolution of the mantle and lithosphere on Earth is intrinsically linked to the evolution of its atmosphere, oceans, landscape and life (e.g., DePaolo et al., 2008; Sobolev et al., 2011; Large et al., 2015; Stern, 2016; Pellissier et al., 2017; Zaffos et al., 2017; Lee et al., 2018; Dehant et al., 2019; Shields et al., 2019). Logically, this frontier research direction appears among the top ten research questions shaping 21st-century Earth Science (DePaolo et al., 2008): "**How has life shaped Earth - and how has Earth shaped life**?"

There is also growing understanding of multiple links between the establishment and evolution of the modern lithospheric dynamics style - plate tectonics - and the development of complex life on Earth (e.g., Stern, 2016; Sobolev and Brown, 2019; Gerya, 2019a; Dehant et al., 2019). One important characteristic of ***modern-style plate tectonics*** is the presence of the ***global continuously evolving mosaic of lithospheric plates*** (e.g., Bercovici and Ricard, 2014) that may have ***crucial implications for life evolution*** (e.g., Stern, 2016) (Fig. 1). Modern-style plate tectonics was likely established gradually through Earth history and an emerging holistic view of this global geodynamic evolution based on observations and numerical modeling (e.g., Gerya, 2014; Sobolev and Brown, 2019; Gerya, 2019b) is summarized in Fig. 2.

There is growing understanding that life evolution and variation in geographical distribution and diversity of species on Earth were strongly affected by changes in the global tectono-magmatic style of lithospheric and mantle evolution (e.g., Zerkle, 2018; Stern, 2016 and references therein). In this respect, modern-style plate tectonics is often viewed as a strong promoter of the biological evolution (e.g., Pellissier et al., 2017; Zerkle, 2018; Stern, 2016 and references therein). The influences of global tectono-magmatic style are at least twofold and regulate (A) supply and withdrawal of nutrients (via mantle degassing/ingassing, rock weathering and erosion, sedimentation and burial, subduction-related recycling etc.) and (B) space-time variations of environmental pressures (including evolution of landmass distribution, atmosphere, ocean and climate).

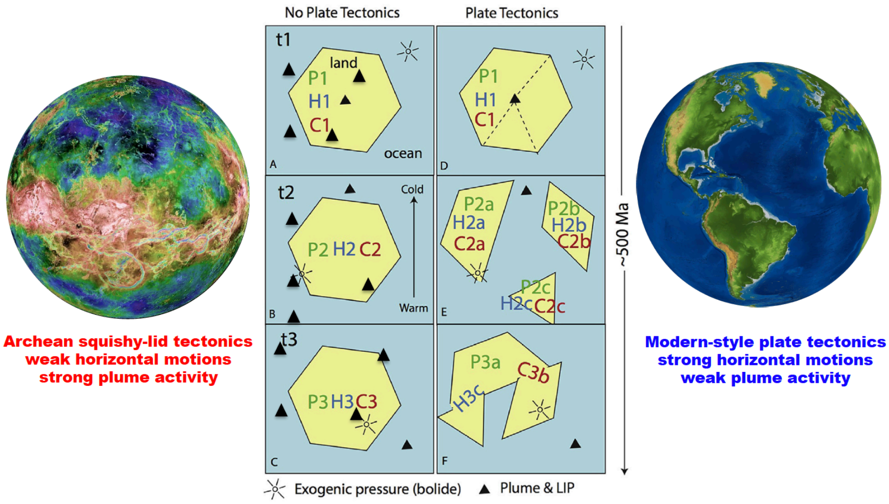

Figure 1. *Cartoon illustrating potential influence of global terrestrial tectonic styles on life evolution (modified after Stern, 2016). Two idealised Earth-like planets without (left, analogous to Hadean-Archean Earth) and with (right, analogous to modern Earth) plate tectonics are compared that possess continents (yellow) and oceans (blue) and three interdependent evolving life forms (plant "P", herbivore "H", and carnivore "C"). Three panels from top to bottom show three different times (1, 2, and 3) at ca. 100 million year intervals (characteristic timescales of the supercontinent cycle). It is assumed that exogenic evolutionary pressures (causing e.g. global mass extinction) depend on meteorite impacts and mantle plume activity including Large Igneous Provinces (LIPS). Plate tectonics causes breakup and movements of continents that provides many opportunities for isolation and diversification under different (geographic, climatic) conditions of natural selection, and evolution. On the other hand, when continents collide, different species comingle and compete and new ecological systems are established that further accelerate life evolution (Stern, 2016).*

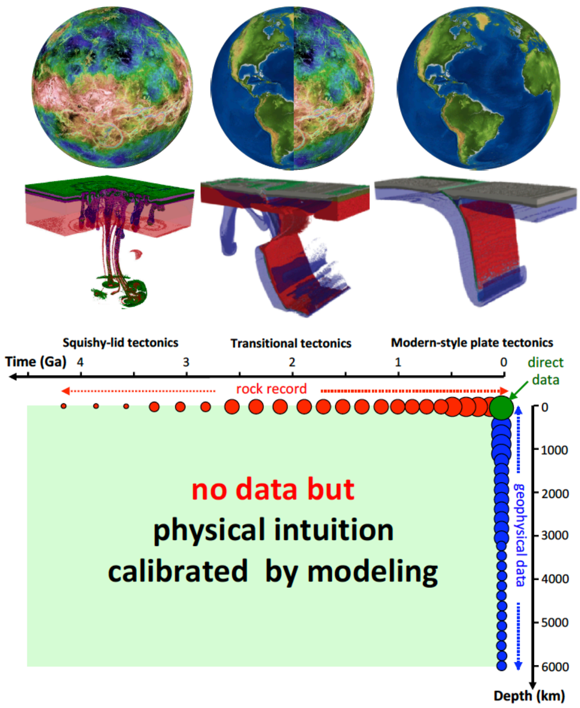

Figure 2. *Evolution of terrestrial tectonic styles (top), and time-depth diagram showing the availability of data for constraining geodynamic relationships for Earth (bottom) (Gerya, 2019b).*

Following Zerkle (2018), the nutrients-tectonics relations can be summarized as: ***Life is sustained by a critical set of elements contained within rock, ocean and atmosphere reservoirs and cycled between Earth's***

surface and interior via various tectonic, magmatic and surface processes. Over geologic time scales, tectono-magmatic processes play a critical role in recycling bioactive elements lost to the crust and mantle back to the ocean–biosphere system, via outgassing, volcanism, uplift and erosion. On the other hand, following Stern (2016), the environmental pressures-global tectonics relations can be formulated as: ***Tectonic processes such as the redistribution of continents, growth of mountain ranges, formation of land bridges, and opening and closing of oceans provide continuous but moderate environmental pressures that isolate and stimulate populations to adapt and evolve. In addition, mantle plumes and large bolide impacts provide episodic but potentially extreme environmental pressures capable of causing global mass extinctions.*** A planet with oceans, continents, and modern-style plate tectonics maximizes opportunities for speciation and natural selection, whereas a similar planet without plate tectonics provides fewer such opportunities (Fig. 1). ***Importantly, modern-style plate tectonics itself exerts continuous moderate environmental pressures that drive evolution and stimulates populations to adapt and evolve without being capable of extinguishing all life (Stern 2016).*** It is obvious that both nutrients and tectonics aspects are intimately related and have to be considered (and modeled) together for better understanding of life evolution and biodiversity.

For the purpose of our project, it is important to also point out that timescales of biological evolution estimated on the basis of the analysis of phylogenies and/or fossils are rather long and comparable to geodynamic timescales (e.g., Alroy, 2008; Marshall, 2017). In a constant rate birth-death model (Kendall, 1949), new species originate with speciation rate λ, and species become extinct with extinction rate μ, typically expressed as rates per lineage per million years ($L^{-1}Myr^{-1}$). Typically, estimates of speciation and extinction rates fall within the range 0 to 1 $L^{-1}Myr^{-1}$ (Marshall, 2017) and rarely exceed 1 $L^{-1}Myr^{-1}$, except within intervals of crisis (Alroy, 2008). ***We would like therefore to specifically stress that the relatively long timescales of biological evolution are similar to timescales of tectono-magmatic lithospheric and mantle processes. This timescale similarity creates a natural possibility for coupling of lithospheric and mantle processes with life evolution.***

This review, although incomplete, serves for the purposes of the Task Force proposal by suggesting the importance of a concerted cross-disciplinary community effort for better understanding couplings between lithospheric geodynamics, magmatism, mantle degassing/ingassing, evolution of atmosphere, ocean, climate, landscape and the diversification of life.

II. Objective

The main scientific focus of our ILP Task Force proposal can be formulated in form of a ***general scientific question***:

How did the evolution of lithospheric dynamics through the Earth's history affected evolution of life?

In order to answer this question a concerted cross-disciplinary effort is needed that combines natural observations with systematic numerical modeling (cf. reviews by Gerya, 2011, 2014; Stern and Gerya, 2018) to understand potential influences of different lithospheric and mantle processes for the evolution of the atmosphere, ocean, climate, landscape and biological diversity (e.g., Donnadieu et al. 2006, 2009; Sobolev et al., 2011; Large et al., 2015; Zaffos et al., 2017; Lee et al., 2018; Descombes et al., 2018; Shields et al., 2019). Requisites for this ***bio-geodynamical*** research activity (Zerkle, 2018) are development of cross-disciplinary, hybrid (i.e. observations+modeling) research approaches, which will allow to quantitatively analyze influences of geodynamic processes for the development of atmosphere, oceans, climate (e.g., Gillmann and Tackley, 2014; Donnadieu et al. 2006, 2009; Mills et al., 2019), landscape, (e.g., Ueda et al., 2015), and finally to species diversification and evolution (e.g., Gotelli et al., 2009; Stadler, 2012, 2013; Condamine et al., 2013; Descombes et al., 2018). In particular, coupled numerical bio-geodynamical computational models need to be developed that will likely become future key quantitative tools to isolate, investigate and understand various complex interactions among different processes involved in life evolution.

In this Task Force project we aim at ***building, stimulating and coordinating the international multi-disciplinary bio-geodynamical research community*** involving interested geodynamicists, geologists, (geo)biologists, ecologists, geochemistrists, paleontologists and climate evolution experts. ***We will focus on the two key aspects defining interactions between geodynamics and life evolution: delivery and removal of nutrients (e.g., Zerkle, 2018) and modification of geographical environment by tectonic processes (e.g., Stern, 2016; Descombes et al., 2018).*** Our activities will involve organization of special bio-geodynamical sessions at AGU, EGU and Goldschmidt conferences, bio-geodynamical workshops, publishing of special volumes in international peer-reviewed journals and preparation of a multi-disciplinary Initial Training Network (ITN) EU funded project on bio-geodynamics, sponsoring of meetings participation and open-access bio-geodynamical publications of prominent early career scientists.

The main focus of this Task Force project is largely fitting into the Geoscience of Global Change, but obviously involves aspects of three other themes of themes of ILP - Contemporary Dynamics and Deep Processes, Continental Lithosphere, Oceanic Lithosphere - that are related to broad varieties of geodynamic processes and lithospheric plates environments affecting life evolution directly or indirectly.

III. Cooperation

Summer 2021: Monte Veritas Workshop and summer school on Bio-geodynamics, Ascona, Switzerland

Spring 2022, 2024: Session on Bio-geodynamics at the EGU General Assembly, Vienna, Austria.

Summer 2023, 2025: Sessions on Bio-geodynamics at the Goldschmidt conference, tbd.

Fall 2023, 2025: Union Sessions on Bio-geodynamics at the AGU Fall meeting, USA

Summer 2021, 2023, 2025: Special discussion sessions on bio-geodynamical modelling at workshops on Mantle Convection and Lithospheric Dynamics, tbd.

2021-2022 – Preparation of an ITN EU project on bio-geodynamics (preliminary submission date in 2023)
2021-2022: Preparation of a special volume based on the Monte-Veritas workshop
2024-2025: Preparation of a special volume based on the AGU Fall 2023 session
2021-2025: Sponsoring of meetings participation and open-access bio-geodynamical publications of prominent early career scientists.

IV. Outreach

Development of a dedicated web page for the Task Force project

Publication of popular articles on bio-geodynamics

Public bio-geodynamical lectures on various occasions

V. Key partners within this planned task force

Anbar, Ariel, Arizona State University, anbar@asu.edu

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Zakharov, Vladimir, Moscow State University, Russia, vszakharov@yandex.ru

Zerkle, Aubrey, University of St Andrews, UK, az29@st-andrews.ac.uk

VI. References

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Lee, C.-T.A., Caves, J., Jiang, H., Cao, W., Lenardic, A., McKenzie, N.R., Shorttle, O., Yin, Q., Dyer, B. (2018) Deep mantle roots and continental emergence: implications for whole-Earth elemental cycling, long-term climate, and the Cambrian explosion, International Geology Review, 60:4, 431-448

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Stern, R.J. (2016) Is plate tectonics needed to evolve technological species on exoplanets? Geoscience Frontiers, 7, 573-580.

Stern, R.J., Gerya, T. (2018) Subduction initiation in nature and models: A review. Tectonophysics, 746, 173-198.

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Curriculum vitae chair and co-chair(s)

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Education & professional experience

Education

1984 MSc in Geology, Polytechnic University of Tomsk, Tomsk, USSR

1990 PhD in Petrology, Moscow State University, Moscow, USSR.

1999 Habilitation in Petrology, Moscow State University, Moscow, Russia.

2008 Habilitation in Geodynamics and analytical and numerical modelling of geological and planetary processes, ETH-Zurich

Positions

1984-1987: Junior Researcher, Institute of Geology and Geophysics USSR Academy of Sciences, Novosibirsk, USSR

1987-1999: PhD student, Research Associate, Senior Researcher, Head of the Laboratory of Metamorphism, Institute of Experimental Mineralogy Russian Academy of Sciences, Chernogolovka, Moscow dist., Russia

1990-1999: Associate Professor, Moscow State University, Moscow, Russia

2000-2004: Alexander von Humboldt Foundation Research Fellow, Guest Scientist, Geological Faculty, Ruhr-University of Bochum, Bochum, Germany

2004 -2005: Oberassitent (Senior research scientist, Lecturer) Geological Institute, ETH-Zurich, Zurich, Switzerland

2005 - 2008: Oberassitent (Senior research scientist, Lecturer, permanent Research Faculty since 2007) Geophysical Institute, ETH-Zurich, Zurich, Switzerland

2008 - 2010: Privatdozent, Institute of Geophysics, ETH-Zurich, Zurich, Switzerland

2010 - present: Professor, Institute of Geophysics, ETH-Zurich, Zurich, Switzerland

Honours

2007: Adjunct Professor of Geology Department of Moscow State University

2008: Listed in Top 50 Russian scientists abroad, Russian Newsweek Magazine

2008: Golden Owl Price from ETH-students for excellence in teaching

2008: Top Reviewer for Tectonophysics

2015: Best Reviewer for AGU-journals

2016: Best Reviewer for Nature-journals

2018: Elected to the Academy of Europe (Academia Europaea)

2019: Elected as American Geophysical Union Fellow (AGU Fellow)

Publications and other professional activities

Peer-reviewed journal or book articles>250 as author or co-author including 17 papers in high-impact journals (4 in Nature, 2 in Science, 5 in Nature Geoscience, 1 in Nature Astronomy Letters and 5 in Nature Communications)

Monograph: Introduction to Numerical Geodynamic Modelling, Cambridge University Press, >1600 copies sold, 334 citations on Google Scholar

Citations: ISI = 9716 citations (982/967/1585 per year in 2016/2017/2018), h-factor 57; Google Scholar = 12839 citations (1297/1223/1893 per year in 2016/2017/2018), h-factor 62, i10-factor 195

Responsibilities

Associate Editor of Solid Earth, Gondwana Research, Geology, Scientific Reports

Guest Editor of special volumes: International Journal of Earth Sciences, Lithos, Physics of the Earth and Planetary Interiors, Gondwana Research, Tectonophysics

Review Panel Member for DFG (Deutsche Forschungs Gemeinschaft) and RCN (The Research Council of Norway)

Reviewer for over 15 different journals including Nature and Science

Reviewer for 11 science foundations (NSF, SNF, NRC, RCN, NERC, DFG, AvH Foundation, ERC, GACR, ARC, FWF)

Faculty search boards: member of the boards in 2010, 2012 for the Department of Earth Sciences, ETH

Member of the Study Commission, Study Advisor for Geophysics, the Department of Earth Sciences, ETH (2013-2018).

Organisation of conferences: member of Scientific Organizing Committee for many international conferences and workshops, convenor or co-convenor of many sessions at international conferences (IGC-2008, EGU-2005-2019, AGU-2005,-2007,-2015, Goldschmidt-2007,-2014).

Outreach activities: press releases, ETH Study Week 2015 (responsible for the Department of Earth Sciences).

5 recent key publications by the proponent relating to the proposed TF/CC

Gerya T.V. (2019) Introduction to Numerical Geodynamic Modelling. Second Edition. Cambridge University Press, 472 pp.

Gerya, T. (2019) Geodynamics of the early Earth: Quest for the missing paradigm. Geology, 47, 1006-1007.

Gerya, T., Burov, E. (2018) Nucleation and evolution of ridge-ridge-ridge triple junctions: Thermomechanical model and geometrical theory. Tectonophysics, 746, 83-105.

Gerya, T.V., Stern, R.J., Baes, M., Sobolev, S., Whattam, S.A. (2015) Plate tectonics on the Earth triggered by plume-induced subduction initiation. Nature, 527, 221-225.

Gerya, T.V. (2014) Precambrian geodynamics: Concepts and models. Gondwana Research, 25, 442–463.

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Education & professional experience

Education

1968-1970: Studies in Political Science, University of California at Davis
1971-1974: Studies in Geology, University of California at Davis
June, 1974: B.S. in Geology (with honors)
1974-1979: Studies in Earth Science and Oceanography, Scripps Institution of Oceanography
Thesis title: "Late Precambrian Ensimatic Volcanism in the Central Eastern Desert of Egypt" Thesis adviser: A.E.J. Engel
December, 1979: Ph.D., Earth Science, University of California at San Diego.

Positions

1979-1981: Post-doctoral fellow, Department of Terrestrial Magnetism, Carnegie Institution of Washington.
January, 1982 - September, 1987: Assistant Professor, Programs in Geosciences, The University of Texas at Dallas.
September, 1987 - September 19, 1991: Associate Professor with Tenure, Programs in Geosciences, The University of Texas at Dallas.
September 19, 1991 - Present: Professor with Tenure, Programs in Geosciences, The University of Texas at Dallas.
Aug. 1997 – Aug. 2005 : Head of Geosciences Department, The University of Texas at Dallas
Sept. 2005 – Dec. 2005: Blaustein Fellow, Stanford University
Jan. 2006 – June 2006: Tectonics Observatory Fellow, California Institute of Technology
Sept. 2011-Feb. 2012: Blaustein Fellow, Stanford University
June-Aug. 2014: ETH Geophysical Fluid Dynamics Academic Guest
May 2015: Senior Tuve Fellow, Department of Terrestrial Magnetism, Carnegie Institution of Washington
June-Aug. 2015: ETH Geophysical Fluid Dynamics Academic Guest

Societies

American Geophysical Union (Fellow)
Geological Society of America (Fellow)
Geochemical Society
American Association of Petroleum Geologists

Awards

International Prize Geological Society of Japan 2019

Publications

275 papers in peer-reviewed journals through Nov. 2018
Statistics from Google Scholar June 2019:
23448 times cited (since 2014: 10718)
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i10 index: 246 (since 2013: 189)
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Responsibilities

Aug. 1997 – Aug. 2005 : Head of Geosciences Department, The University of Texas at Dallas

5 recent key publications by the proponent relating to the proposed TF/CC

Stern, R.J. (2016) Is plate tectonics needed to evolve technological species on exoplanets? Geoscience Frontiers, 7, 573-580.

Stern, R.J., Gerya, T. (2018) Subduction initiation in nature and models: A review. Tectonophysics, 746, 173-198.

Stern, R.J., Gerya, T.; Tackley, P.J. (2018) Stagnant lid tectonics: Perspectives from silicate planets, dwarf planets, large moons, and large asteroids. Geoscience Frontiers, 9, 103-119.

Stern R.J., and Miller N.R. 2018 Did the transition to plate tectonics cause Neoproterozoic Snowball Earth? Terra Nova 30, 87-94.

Stern, R. J., T. V. Gerya, and P. J. Tackley, 2017. Tackling unanswered questions on what shapes Earth, Eos, 98, https://doi.org/10.1029/2017EO065791. Published on 02 February 2017.