International Lithosphere Program

Activity Report 2023 – Task Forces / Coordination Committees

Project Title: Formation, character, history, and behavior of Earth's oldest lithospheres (2023-2027）

Project No.: 2023-TF1

PI(s): Chair: T. Kusky, China and T. M. Harrison, USA;

1. Highlights of recent ILP Task Force work/results

In 2023, our ILP Task Force has made significant progress in multiple different research directions. Timothy Kusky, the chairman of the project, published over 26 papers in journals like *Nature Communications, Science Advances, National Science Review, and Earth-Science Reviews* in the past year. Of those, nine were written by Timothy Kusky as the first or corresponding author. Also, Tim and Mark were invited to give several keynote talks at international conferences, such as Goldschmidt Conference 2023. Many other Task Force members also gave talks, and interaction was lively. These achievements are closely related to the theme of this Task Force, which is to explore the timing and mechanism of the initiation of plate tectonics. A few highlights of the achievements funded by this project in 2023 are summarized as follows:

1) Ophiolitic mélange is a significant geological component in ancient convergent plate margins, potentially recording information on the style of early plate subduction and arc-continent collision. After years of geological mapping, the research group led by Timothy Kusky has identified two Neoarchean ophiolitic mélange belts, namely Zunhua and Shangying, in the Eastern Hebei Complex of the North China Craton. The Zunhua ophiolitic mélange is composed of a series of petrogenetically linked forearc affinity ultramafic-mafic blocks (peridotite, podiform-chromite bearing dunite, pyroxenite, metagabbro, metadiabase, metabasalt), which belongs to the suprasubduction zone (SSZ)-type ophiolitic mélange. In contrast, Shangying ophiolitic mélange to the east consists of layered and isotropic N-MORB affinity metagabbro, and garnet clinopyroxenite, formed by the MOR oceaic crust mixed with sediments within the subduction channel during the arc-continent collision. Documentation of the coexisting SSZ and MOR ophiolitic mélange in the Eastern Hebei Complex suggests that the large-scale subduction/accretionary zone was active in the late Neoarchean, and the geochronological data reveals that the geological process involving seafloor spreading, subduction initiation, forearc thrusting and exhumation of subduction materials occurred within < 80 Myr (million years), which is similar in duration to many Phanerozoic subduction-collision zones. These features indicate that the tectonic paradigm for the late Neoarchean has evolved to be similar to the modern Earth. This work was published in *Earth-Science Reviews* (Ning, W.B., Kusky, T.M.*, Wang, L., et al., 2023. Neoarchean SSZ and MOR ultra-/high-pressure ophiolitic mélanges of the Eastern Hebei Complex, North China Craton: Dynamics of an Archean paleo-subduction zone. *Earth-Science Reviews*, 240: 104403; https://doi.org/10.1016/j.earscirev.2023.104403).

2) The transition from the Neoarchean to the Paleoproterozoic was one of the most transformative and critical periods in the Earth's internal and epigenetic systems. The research group led by Timothy Kusky focuses on the early Paleoproterozoic Songshan Group foreland sedimentary sequence in the southern part of the North China Craton, and conducted detailed field mapping, structural, petrochronology, and big data analysis studies. It was found that the sequence was deposited in a foreland basin formed by Altaid-style arc-microcontinent collision at 2.50-2.47 Ga, and then converted to a fold-and-thrust belt at ca. 2.0–1.8 Ga due to Himalayan-style continent–continent collision. This work provides new sedimentary, chronological, and tectonic constraints for the two stages of orogeny in the North China Craton, and shows that the Archean was characterized by Altaid-style arc-continent accretion to "soft" collision, lack of high-pressure metamorphism, and formation of super-cratons, while the Paleoproterozoic was featured by widespread Himalayan-type continent-continent collison, cold subduction, and global supercontinent assembly. This study was published in *Nature Communications* (Huang, B., Liu, M., Kusky, T.M., Johnson, T.E., Wilde, S.A., Fu, D., Deng, H., Qian, Q., 2023. Changes in orogenic style and surface environment recorded in Paleoproterozoic foreland successions. *Nature Communications*, 14, 7997; https://doi.org/10.1038/s41467-023-43893-w).

3) Plate tectonics is one of the key characteristics that distinguishes Earth from other planets and and maintains a habitable surface. It is also an important indicator for searching for habitable planets. Hadean (> 4.0 Ga) rocks are hard to preserve due to their continuous reworking and recycling. While this considerably limits assessing the existence of early plate tectonics, >4 Ga detrital zircons contain geochemical signals that hint at tectonic affiliations and magma compositions. The research group developed high-dimensional machine learning approaches using zircon chemistry data (spanning 19 elements over 4.0 Ga) to characterize zircons that crystallized in some typical tectonic settings (e.g., arcs, plume-related hotspots, and rifts) and from either igneous (I-type) or sedimentary (S-type) magmas. Application of the trained ML models to Hadean zircons from Jack Hills, Australia, suggests that these zircons were mainly crystallized in continental arc–forming magmas (90%) with 45% belonging to S-type melts. This result provides clear evidence of sediment recycling associated with subduction activity in the Hadean. This work was published in *Geology* (Chen, G.X., Kusky, T.M., Luo, L., Li, Q.K., Cheng, Q.M*., 2023. Hadean Tectonics: Insights from Machine Learning. *Geology*. https://doi.org/10.1130/G51095.1).

4) The historical sciences cannot the undertake the sort of hypothesis testing avaiable to the experimental sciences but instead rely on internally consistent narrative explanations of Deep Time. This reliance, however, comes with a tendency for our community to be attracted to ruling theories. These give us the satisfaction of eliminating conceptual uncertainty, but can send us down blind alleys for decades (e.g., adoption of geosyncline theory, rejection of continental drift, etc.). But we only make advances by challenging conventional wisdom and acknowledging uncertainty. This vulnerability of our field has become salient as our discipline moves toward cementing the view that Earth transitioned from a stagnant to mobile lid tectonic regime at ca. 2.5 Ga as our paradigm. Harrison has begun a conversation within the tectonics community to examine the underlying assumptions of what makes us a science and to try and avoid the mistakes that litter our intellectual history (Harrison, T.M., 2023. On a scientific approach for deep time investigations. Perspec. Earth Space Sci. 4, 10.1029/2022CN000193).

2. Presence at international meetings/workshops (this year)

1) ***Kusky, T.M.,*** North China's Archean to Paleoproterozoic accretionary orogen, Symposium on "Orogenic architecture, crustal growth, metallogenesis, and global geodynamics, 2023 Annual meeting of the China National Committee for IGCP. Invited Keynote Talk.
2) ***Kusky, T.M.,*** Future Directions of Machine Learning-Big Data in the Geoscience, 2023 Annual meeting of the China National Committee for IGCP. Invited Keynote Talk.

3) ***Kusky, T.M.,*** and Wang, L., 2023, North China's Archean Central Orogenic Belt: An Ophiolitic Mélange-Bearing Witness to Late Archean Oceanic Crust Production and Destruction. ***Invited Keynote Talk*** for "Ophiolites: A witness of Earth's evolution, in Mantle-crust differentiation through time, Goldschmidt Conference 2023, July 9-14, Lyon, France. Accepted March 30, 2023.
4) ***Kusky, T.M.*** 2023. Musings over future direction of big data based analysis in geosciences. Invited Keynote Talk, First National Academic Seminar on Data driven Geosciences Development, Geological Society of China, Sun-Yat Sen University, April 14-17, 2023
5) ***Kusky, T.M.*** 2023. Musings over future direction of big data based analysis in geosciences with Special Application to Earth in Deep Time. Chinese Academy of Sciences, Guizhou. May 12, 2023.
6) ***Kusky, T.M.*** 2023. Geohazards and surface deformation from the February 6, 2023 earthquake sequence, eastern Türkiye. The 4th Badong International Geohazards Symposium. Sep. 1, 2023, ***Invited Keynote Talk***.
7) ***Kusky, T.M.,*** Wang, L., Ning, W.B., Huang, B., Wang, J.P., Deng, H., Zhong, Y.T., and Peng, Y.Y., 2023. Geological constraints on the crustal architecture of the Central Orogenic Belt, North China Craton, reveal Neoarchean Alpine-style tectonics, Annual Meeting of the Geological Society of America, Pittsburgh Pennsylvania. Oct. 2023.
8) ***Kusky, T.M.,*** Wang, L., Ning, W.B., 2023. New developments in understanding the Late Archean arc/continent collision of the Central Orogenic Belt, North China Craton, International Symposium on Continental Crust Evolution and Early Plate Tectonics, National Natural Science Foundation of China, Beijing, Oct. 10-15, 2023. ***Invited Keynote Talk.***
9) ***Kusky, T.M.,*** New developments in understanding the late Archean arc/continent collision of the Central Orogenic Belt, North China Craton. IGCP709 2023 Workshop and Field Excursion: Fiordland, New Zealand, Oct.29-Nov. 3, 2023. High pressure ultra-high pressure metamorphism and geochemical cycles in subduction zones. ***Invited Keynote Talk.***
10) ***Harrison, T.M***., The early mafic rust paradigm: Have we deluded ourselves again? , International Symposium on Continental Crust Evolution and Early Plate Tectonics, National Natural Science Foundation of China, Beijing, Oct. 10-15, 2023. ***Invited Keynote Talk.***

3. Important publications of ILP Task Force members (max. five) (not including those highlighted above)

The following papers was authored by our ILP Task Force members and acknowledge support by this project:

1) Wang, Z.S., Zhang, J.F., Zong, K.Q., Kusky, T.M., Wang, Y.X., 2023. Plate Tectonics: The Stabilizer of Earth's Habitability *Journal of Earth Science.* https://doi.org/10.1007/s12583-023-1864-9.
2) Zhang, Z.J., Kusky, T.M., Yang, X.K., Cheng, Q.M., 2023. A paradigm shift in Precambrian research driven by big data. *Precambrian Research*. 399: 107235. https://doi.org/10.1016/j.precamres.2023.107235.
3) Zhang, Zhen-Jie, Chen, Guo-Xiong, Kusky, T., Yang, J.M., and Cheng, Q.M., 2023, Lithospheric thickness records tectonic evolution by controlling crustal metamorphic and deformation conditions. *Science Advances,* v.9, Issue 50, DOI: 10.1126/sciadv.adi2134
4) Xiao, L., Huang, J., Kusky, T.*, Head, J.W., Wang, J., Wang, L., Shi, Y.T, Yu, W.C., Huang, Q., Marine sedimentary rocks in Utopia Planitia: In situ evidence for an Hesperian ocean on Mars, *National Science Review*, https://doi.org/10.1093/nsr/nwad137

5) Kuang, H., Morra, G., Yuen, D., Kusky, T., Jiang, S., Yao, H., and Qi, S., 2023, Metamorphism and the tectonic evolution of the Archean. *Precambrian Research* 397, Invited, 107195. https://doi.org/10.1016/j.precamres.2023.107195
6) M. Vogt, W.H, Schwarz, A.K. Schmitt, J. Schmitt, M. Trieloff, T.M. Harrison, and E.A. Bell (2023) Graphitic inclusions in zircon from Early Phanerozoic S-type granite: Implications for the preservation of Hadean biosignatures. Geochem. Cosmochim. Acta 349, 23-40. https://doi.org/10.1016/j.gca.2023.03.022

4. New contacts (this year)

Tim Chapman, Univ. New England (Aus), Geoffrey Clark, Univ. Sydney (Aus), Nathan Daczko (Macquarie Univ, Aus), Faouziya Haissen, Cassablanca, Morocco, Chunjing Wei (Peking Univ., China)

5. Usage of ILP funding (this year)

This year, our program funded the session and field trip "*Formation, character, history, and behavior of Earth's oldest lithospheres"* at the 2023 International Symposium on Continental Crustal Evolution and Early Plate Tectonics held in Beijing China, Oct. 10-12. More than 500 scientists from 13 countries and regions, including China, the United States, Germany, Australia, South Korea, Sri Lanka, Brazil, Iran, Canada, India, South Africa, Türkiye, and Hong Kong, attended the conference, covering more than 60 domestic geoscience research institutions and more than 20 foreign institutions. The conference had 148 oral presentations, of which 57 are invited keynote talks. The conference was followed by field trips, one (>150 participants) partly led by members of the ILP task force to visit some of the oldes crusts of the North China Craton in Eastern Hebei Province.

In addition, the task force leaders (T.M. Kusky, T.M. Harrison, Lu Wang) took a group of students and young professors for field work and sampling to assess the robustness of claims of a newly discovered Eoarchean terrane (Muzidian gneiss complex, Wang et al., 2023, EPSL) in the Dabie Shan of southern China. Samples were collected and are being processed for dating.

Our program has funded 7 articles, all of which have been published in top geological journals such as *Nature Communications, Science Advance, and Geology*, and all of which acknowledged this program. Remaining funds will be carried over to 2024.

6. Activities planned for 2024

We are planning a meeting a field conference in Australia, with a focus on the Pilbara, for 2024.