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Preface

Geochemical perspectives on mantle dynamics and plate interactions in Asia — A special issue in honor/memory of Dr. Shen-su Sun

This special issue was fermented as a result of "Advances in Chemical Geodynamics: A special session in memory of Dr. Shen-su Sun" that we convened at the Annual Symposium on Petrology and Geodynamics held at Peking University (Beijing, China) from October 30 to November 03, 2010. This special issue has been designed with emphasis on deciphering major geologic problems in Asia from a geochemical point of view. It presents seventeen research papers that report high-quality geochemical data concerning important geodynamic processes, such as ultrahigh pressure metamorphism (Dabie–Sulu belt), continental growth and mantle evolution (Central Asia), destruction of cratons and recycling by subduction (North China), mantle/crustal interaction along active margins (South China), and plate interaction and amalgamation (western China).

Dr. Shen-su Sun, who passed away in February 2005 owing to stomach cancer, was a world-renowned geochemist with academic achievements particularly on the Earth's composition and chemical geodynamics (see his resumé and representative publications attached below). He was an early leader in tying together isotope and trace element geochemistry with earth processes since his 1973 PhD thesis work at Columbia University in the United States. Those who had experiences of chatting with Shen-su should never forget how he quoted obscure elemental ratios in various types of rocks straight off the top of his head. As noted by Dr. Rod Page, Sun-su's long-term colleague and good friend at the BMR, Canberra, in his address during the memorial ceremony "who of us cannot remember Shen-su in the corridor?… His finger creating imaginary circles in the air or trace-element spider diagrams, as he did a calculation, usually to help someone else solve a problem. No matter who or what the problem, he always contributed with a positive suggestion, and it is this bountiful scientific largesse that abides in our memories." Shen-su was actually more like an international citizen given that he was born in Fujian, China, raised in Taipei, Taiwan, received his Ph.D. from Columbia University, and developed his major academic career in Australia. For many of his colleagues and students, he has been, and will continuously be, remembered not only for his outstanding contributions to the geochemistry of solid Earth, but also for his humanity and most unselfish personality. Shen-su devoted his entire life working tirelessly for everyone around him, whether it was on a scientific question, an experimental problem, career advice, or even a purely personal matter, and he never expected any personal return. He has done a lot in the education and mentoring of numerous young geochemists worldwide. In particular, he provided guidance with endless help to many Chinese scholars and students, some of whom are now leading researchers in their fields, even during his last years when suffering from the cancer treatment. As summed up by Dr. Warren Sun, a close friend of Shen-su's family and reader at Monash University, in his eulogy address: "Giving is what Shen-su was all about. To give his mind to science and truth; to give his heart to people and friends. If we wish to keep Shen-su's legacy alive, to keep his spirit soldiering on, we have to learn from him the willingness to give and the happiness to give."

The special issue starts with a review article by Yong-Fei Zheng, who synthesizes chemical geodynamics processes in the continental collision zones worldwide with emphasis on the geochemical reworking and recycling under high-pressure (HP) to ultrahigh-pressure (UHP) metamorphic conditions. This paper focuses on several key issues that have been repeatedly investigated in continental subduction zones, including the time span of UHP metamorphism, the origin and behavior of metamorphic fluid/melt, the mobility of elements and isotopes under HP to UHP conditions, the role of premetamorphic protoliths, and crust–mantle interaction in subduction channels. The author suggests that the nature of premetamorphic protoliths is a key to the type of collisional orogens and the size of UHP terranes, and source mixing in subduction channels is a fundamental mechanism responsible for the geochemical heterogeneities observed in continental and oceanic basaltic rocks. Therefore, the study of HP to UHP metamorphic rocks and their derivatives has greatly advanced our understanding of major geodynamic processes that drive the tectonic evolution from oceanic subduction to continental collision at convergent plate margins.

The following two papers deal with the metamorphic and magmatic rocks from the Dabie–Sulu orogen, east-central China, characterized by the exposure of one of the most prominent UHPM terranes in the world as a result of the continental collision between the South China and North China blocks during the Triassic. Jian et al. present new SHRIMP U–Pb ages and REE data for zircon of two granulites, a garnet pyroxenite and a clinopyroxene amphibolite from the North Dabie complex. These zircon U–Pb ages provide important new constraints on the affinity of collided crustal blocks, the metamorphic history of HP–UHP granulites, and post-collisional crustal reworking in the region. Zhao et al. report a detailed analysis of zircon U–Pb and Lu–Hf isotopes, mineral O isotopes, and whole-rock elements and Sr–Nd isotopes for alkaline intrusive rocks (including gabbro, syenite and granite) in the Sulu complex. The data suggest that the alkaline rocks are syn-exhumation magmatic products from partial melting of the orogenic lithospheric mantle and the subducted continental crust.

The subsequent seven papers discuss the mantle composition and plate interactions particularly in the Central Asian Orogenic Belt (CAOB) and North China Craton (NCC). By performing a detailed analysis of Triassic high-Mg adakitic andesites (HMAs) from the Inner Mongolia–Daxing'anling orogenic belt, Liu et al. explore the fate of the Paleo-Asian Ocean plate and interaction between fossil slab-derived melts and the mantle peridotite. The authors argue that the HMAs were derived from

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partial melting of the subducted Paleo-Asian oceanic slab with additional sediments shed from the North China craton and hybridized by peridotite in the mantle. Such melting of fossil oceanic slabs could have played a crucial role in Phanerozoic crustal growth of this orogenic belt in particular and perhaps of the entire CAOB in general.

To better constrain the juvenile nature of the subcontinental lithospheric mantle beneath the eastern part of the CAOB, Zhang et al. conducted a detailed analysis, including mineral chemistry, clinopyroxene trace element and Sr–Nd–Hf isotope ratios, whole-rock major element, platinum group elemental and Re–Os isotope compositions of peridotite xenoliths in the Cenozoic alkali basalts from Abaga, Inner Mongolia. These results allow the authors to argue that the subcontinental lithospheric mantle in the region is mostly juvenile with minor relics of old depleted lithospheric mantle, which cooled from near-adiabatic to near-lithospheric temperatures and formed new lithospheric mantle during the formation of the eastern CAOB. In a comparative study, Sun et al. examined spinel harzburgite xenoliths from Hebi, located in middle of the NCC. Whole-rock Re–Os isotope data of the xenoliths confirm the notion that they represent Archean cratonic mantle relics beneath the NCC. In-situ trace element and Sr isotope measurements of clinopyroxenes within the xenoliths suggest that the clinopyroxenes have a metasomatic rather than residual origin and crystallized from carbonatitic melts that metasomatized the Hebi mantle xenoliths. In search for the primary compositions of mantle xenoliths, Huang et al. carried out leaching experiments on garnet and clinopyroxene separates from Roberts Victor eclogite xenoliths. The leaching process produces largest relative changes in Sr-isotope compositions, and less in Nd and Hf isotope compositions. After this leaching process, measurement of the primary isotopic compositions of Sr, Nd and Hf in the eclogitic garnets can be achieved. The leaching results also indicate that some Eu anomalies, commonly ascribed to shallow crustal processes, such as plagioclase fractionation, in eclogites were actually introduced by a secondary melt/fluid percolating in the lithospheric mantle.

Jin-Hui Yang et al. report a comparative study of silica-saturated and silica-undersaturated syenites in the northern NCC. The silica-saturated syenites, emplaced in the Permian–Triassic (254–246 Ma), show geochemical and Sr–Nd–Hf isotopic characteristics indicative of a magma origin from the lower crust followed with extensive pyroxene and plagioclase fractionation. The silica-undersaturated syenites, emplaced later in the Triassic (226–224 Ma), were the product of crustal assimilation and fractional crystallization of a mafic magma derived from an enriched lithospheric mantle source. Combined with information on the regional geology, the authors argue that the genesis of two types of syenites records the geodynamic transition from post-orogenic to intra-plate extension regime in the northern NCC.

Xu et al. report a temporal geochemical variation trend in Eocene basalts from Shuangliao, NE China. These basalts have the highest Fe_2O_3 contents and lowest Sr isotope ratios among the Cenozoic basalts in eastern China. This is attributed to the differential melting of a heterogeneous source, i.e., subducted oceanic crust (SOC), which took place in association with lithospheric thinning. The authors propose that, during the basalt genesis, fusible upper oceanic crust would have melted earlier than lower oceanic crust and peridotites. They argue that the SOC components may have been derived from the seismically detected stagnant Pacific slab within the mantle transition zone. This hypothesis is supported by the same Indian MORB-like isotopic composition being found in the Shuangliao basalts and in the extinct Izanaghi–Pacific plate of NW Pacific. The latter has been subducting underneath the eastern Asian continent since the early Cretaceous.

Wei Yang et al. report Mg isotope data for some 125 to 6 Ma old continental basalts from the NCC to evaluate the effects of the western Pacific ocean subduction on the upper mantle evolution in the region. The Mg isotopic variation observed in the basalts is attributed to interaction of their mantle source with recycled carbonate melt, a component that is best explained as resulting from the subducted Pacific oceanic crust. Therefore, this work not only presents an example of tracing recycled carbonate into the mantle using Mg isotopes but also confirms the important role of the western Pacific oceanic subduction in the generation of continental basalts in the NCC.

The following four papers concern the magma genesis and tectonic evolution in the South China block since the Late Paleozoic related to the Pacific subduction. Xian-Hua Li et al., based on an integrated in-situ analysis of U–Pb, Lu–Hf and O isotopes of detrital zircons from the Middle to Late Permian sedimentary rocks, discuss the sedimentary source provenances, regional magmatic and crustal evolution in the Cathaysia block. The study identifies four major age peaks, among which the ubiquitous existence of ca. 280 Ma zircons in all studied samples suggests a widespread occurrence of Early Permian magmatic rocks in the southeastern China coastal region. These Early Permian zircons show coherent, negative correlations between $\varepsilon Hf(T)$ and $\delta^{18}O$ values, suggesting that the genesis of their host igneous rocks formed involved reworking of ancient supracrustal materials by mantle-derived magmas in an active continental margin related to the Paleo-Pacific subduction.

He and Xu study several Late Yanshanian (= Cretaceous) syenitic and gabbroic bodies from the coastal region of southeastern China that intruded in an early stage (141–118 Ma) and a late stage (98–86 Ma), respectively. It is suggested that the Late Yanshanian tectonic settings of southeastern China coastal region switched from compressional to extensional at ca. 110 Ma, resulting from transformation of the Paleo-Pacific subduction framework from forward to rollback mode. Wang et al. present a rare magmatic suite of adakitic granitoids and associated rocks that occurred in the late Early Cretaceous (~107 Ma) in the Hainan Island, Southeast China. The adakitic rocks are interpreted as products formed by partial melting of newly underplated basaltic lower crust with arc-like geochemical characteristics, and the driving mechanism was asthenospheric upwelling due to the rollback of the subducting Paleo-Pacific plate.

Wan et al. examine the micro-scale heterogeneity of orogenic andesites by analyzing melt inclusions and U–Pb and Hf–O isotopes of zircons from andesite of the Chilungshan volcano, northern Taiwan. SHRIMP dating of magmatic zircons yielded an emplacement age of 1.04 ± 0.06 Ma with $\varepsilon Hf(t)$ of 6.1 to 13.4 and $\delta^{18}O$ of 5.02 to 6.28‰. The zircons contain inherited cores and felsic to andesitic silicate-melt (glass) inclusions. This study supports the presence of micro-scale heterogeneity in the andesite as a result of mixing between mantle and continent derived materials. Contamination of continental crust occurs either within the magma chamber at a medium to deep crustal level and/or during dehydration and melting of a subducted oceanic slab and overlying sediments in an island–arc environment.

The last three papers discuss snapshots of Paleozoic geologic records in western China, a region that is known as a tectonic collage formed by sequential processes including subduction, accretion and terrane amalgamation. Xia et al. study a ~4.5-km-thick massif with lavas and intrusions in the middle part of the North Qilian suture zone. It comprises two distinct lithological units: the lower tholeiite unit and the upper boninite unit, dated at ca. 517–505 Ma and 505–487 Ma, respectively. The tholeiites are interpreted as products of the earliest infant arc magmatism, while the boninites resulted from arc splitting and subsequent back-arc basin development. Therefore, the long-lived tholeiite–boninite sequence presents a lithological record of early stages of supra-subduction zone magmatic activity that evolved from subduction initiation at ~517 Ma to back-arc extension at ~487 Ma in the region.

Yin-Qi Li et al. analyzed platinum group element (PGE) and other geochemical characteristics of Permian continental flood basalts in the Tarim basin, which represent a main component of the Tarim

Large Igneous Province (TLIP) in northwest China. Magma mixing in the magma chamber is evident by the PGEs and Sr–Nd isotope variations. This process might have also induced sulfur saturation and sulfide segregation in the later stage of magma differentiation. A comparison of chalcophile element characteristics of the Tarim basalts with coeval mafic–ultramafic rocks in the Eastern Tianshan and Beishan Rift areas indicates that the degree of partial melting plays an important role in the PGE fractionation and potential PGE-(Ni–Cu) ore formation in the TLIP.

Zhu et al. report zircon U–Pb ages and Hf isotopes along with whole-rock geochemistry of Cambrian (dated at ~492 Ma) volcanic rocks from the Lhasa terrane, southern Tibet. The results, together with relevant geologic information, suggest that the rocks were products of an early Paleozoic Andean-type magmatic arc. The authors further argue that eruptions of these volcanic rocks, and development of the Cambro-Ordovician angular unconformity in the central Lhasa subterrane, may have resulted from slab break-off of the subducted oceanic lithosphere following the collision/accretion of microcontinents or terranes outboard of the Australian proto-Tethyan active margin that was part of an early Paleozoic magmatic arc system facing the proto-Tethys Ocean.

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Brief curriculum vitae (Shen-su Sun)

Date and place of birth: October 27, 1943, Fukien, China.

Date and place of death: February 25, 2005, Canberra, Australia.

Marital status: Married (Ching-Oh), with two sons (Robert and Frank).

Education:

- 1966: B.Sc. Geology, National Taiwan University, Taipei, Taiwan, ROC.
- 1968–1971: Graduate Fellow, Lamont Geological Observatory of Columbia University, New York City, USA.
- 1971–1973: Graduate Fellow, Lunar Science Institute, Houston, Texas, USA.
- 1973: Ph.D. in Geochemistry, Columbia University, New York, USA.

Thesis title: Lead isotope studies of young volcanic rocks from ocean islands, island arcs and mid-ocean ridges. (Advisor: Paul Gast).

Professional appointments:

- 1973–1975: Post-doctoral Research Fellow, Department of Earth & Space Sciences, State University of New York at Stony Brook, USA.
- 1975–1978: Post-doctoral Fellow, Department of Geology & Mineralogy, University of Adelaide, South Australia.
- 1978–1983: Senior Research Scientist, CSIRO, North Ryde, New South Wales.
- 1983–1999: Principal Research Scientist, Division of Petrology and Geochemistry, Bureau of Mineral Resources, Geology & Geophysics (now Geoscience Australia), Canberra.

Main research fields:

- Chemical and isotope systematics in modem basalts from different tectonic environments and its implications for mantle dynamics, crustal recycling, subduction zone and other plate tectonic processes.
- Chemical and isotope systematics in early Precambrian mafic and ultramafic rocks and its implications for early history of the Earth, including accretion from planetesimals, core–mantle differentiation, and intra-mantle and mantle–crust fractionation.
- Integrated geochemical, geophysical and petrological approach to study the composition and evolution of the Earth, including a better understanding of element partitioning under high pressure and temperature among silicate, metal and sulfide, core–mantle interaction and the role played by mantle plume and D″ layer in a dynamic Earth.
- Integrated study to evaluate effects of major geological processes and different tectonic environments for the formation of various types of ore deposits.

Some benchmark publications:

- **Sun**, **S.-s.** and Hanson, G.N., 1975. Evolution of the mantle: Geochemieal evidence from alkali basalts. *Geology* 3, 297–302.
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