

行政院國家科學委員會專題研究計畫 成果報告

感應耦合電漿質譜術之建立與應用 (III): 青藏高原構造
演化

計畫類別：個別型計畫

計畫編號：NSC91-2116-M-002-024-

執行期間：91年08月01日至93年07月31日

執行單位：國立臺灣大學地質科學系暨研究所

計畫主持人：鍾孫霖

報告類型：精簡報告

報告附件：國外研究心得報告

出席國際會議研究心得報告及發表論文

處理方式：本計畫可公開查詢

中 華 民 國 93 年 8 月 10 日

感應耦合電漿質譜術之建立與應用(III): 青藏高原構造演化 – 期終報告

計畫編號：NSC 91- 2116 - M - 002 - 024

執行期限：91 年 8 月 1 日至 92 年 7 月 31 日 (延期至：93 年 7 月 31 日)

計畫主持人：台大地質科學系 鍾孫霖

計畫參與人員：溫大任、朱美妃、李皓揚 (博士生)

一、中文摘要

本研究計畫設計為一個三年期專題計畫，但將分年申請研究經費且應用研究不同的內容。前兩年已利用新購之 Agilent (原 HP) 7500s ICP-MS 設備，建立一種利用強酸密封溶解岩石樣品、以美國地調所標準岩樣作參考標準、另加若干質量監控溶液作為內標，分析岩石中大約四十種微量元素的方法。此一分析方法具有簡單、準確、同時測量多元素等優點，能夠快速有效地分析大多數常見的岩石樣品。第三年以來主要開發本儀器與雷射系統之連結，應用於微小標本之原位(in-situ)微量元素含量分析和鋯石 U-Pb 定年，並配合申購 MC-ICPMS，應用於青藏高原構造演化等研究。

關鍵詞：感應耦合電漿質譜術；微量元素分析；鋯石 U-Pb 定年；青藏高原

Abstract

This project is proposed as a three-year project to develop the quadrupole ICP-MS, i.e., a new Agilent (originally HP) 7500s, has been installed in this department for potential applications in geosciences and environmental sciences. In the first year, the analytical procedures which would enable the ICP-MS to precisely and simultaneously determine about 40 trace elements in rock samples has been established. The procedures includes: (1) digestion of rock samples using distilled HF+HNO₃ in screw-top teflon beakers in the clean room, (2) digestion of USGS and other rock standards through the same processes and then using them as calibration references, and (3) using certain internal standards during the measurements to monitor the sensitivity shift of the machine. Consequently, the ICP-MS method developed marks with: (1) simple sample preparation, (2) straightforward data reduction, and (3) high analytical precision, and thus can be applicable to trace element determinations of common rock samples. In the 3rd year of this project, the quadrupole ICP-MS has been successfully linked with a NW 213 laser ablation system, which can be used for in-situ trace element analyses as well as zircon U-Pb dating. These methods are currently applied to study certain outstanding geologic problems in Southeast Asia such as the tectonomagmatic evolution of the Himalayas and Tibetan platea.

Keywords: ICP-MS; Trace element determinations; zircon U-Pb dating, Tibet

本研究計畫執行期間，主持人和研究生於 92 年 8 月 20 日至 92 年 8 月 31 日赴北京離子質溥儀分析中心，進行鋯石定年實驗；於 93 年 4 月 26 日至 93 年 5 月 14 日赴澳洲 Macquarie 大學 GEMOC 研究中心，進行 LA-MC-ICPMS 分析實驗。主持人和博士班研究生三人於 92 年 4 月 4 日至 92 年 4 月 12 日赴法國尼斯，參加 EGS-AGU-EUG 聯合研討會，發表論文摘要如下：

Abstracts for the EGS-AGU-EUG Joint Meeting, Nice, France, April 6-11, 2003 (Tibetan Magmatic Evolution related Abstracts)

Adakites from continental collision zones: Melting of thickened lower crust in southern Tibet

S.-L. Chung (1), J.-Q. Ji (2), Dunyi Liu (3), M.-F. Chu (1), H.-Y. Lee (1), D.-J. Wen (1), C.-H. Lo (1), T.-Y. Lee (4), Q. Qian (5), Q. Zhang (5)

(1) Dept. Geosci., Nat'l Taiwan Univ., Taipei, Taiwan; E-mail: sunlin@ccms.ntu.edu.tw; (2) Dept Geol., Peking Univ., Beijing, China; (3) Inst. Geol., Chinese Acad. Geol. Sci., Beijing, China; (4) Dept. Earth Sci., Nat'l Taiwan Normal Univ., Taipei, Taiwan; (5) Inst. Geol. Geophys., Chinese Acad. Sci., Beijing, China

Adakites are geochemically distinct intermediate to felsic magmatic rocks that have been documented exclusively in subduction zones. Here we report Ar-Ar and SHRIMP U-Pb zircon age and geochemical data for the first case example of such magmas from southern Tibet in an active continental collision environment. The Tibetan adakites, had been termed dacitic or calc-alkaline rocks, formed between ~26 and 10 Ma. They occur either as dike swarms or as small-volume plugs that are widespread, >1500 km apart in the east-west dimension within the Lhasa terrane. They are coeval with but show remarkably different petrochemical compositions from the post-collisional ultrapotassic lavas also emplaced in the Lhasa terrane. The Tibetan adakites exhibit geochemical characteristics that suggest an origin by melting of eclogites and/or garnet amphibolites in the lower part (>50 km) of thickened Tibetan crust. This lower crustal melting requires a significantly elevated geotherm, which we attribute to convective removal of the tectonically thickened lithospheric mantle during the Oligocene-Miocene period. The identification of modern collision-type adakites from southern Tibet lends new insights into not only the geodynamic evolution of the Himalayan-Tibetan orogen but also the formation of early continental crust that consists dominantly of the tonalite-trondhjemite-granodiorite lithologies marked by adakitic geochemical affinities. Melting of hydrous basaltic material at the base of thickened crust following terrane accretion, therefore, may have played a more substantial role than commonly thought in the Archean crustal growth.

New SHRIMP U-Pb zircon data from the Gangdese batholith: implications for the Trans-Himalayan magmatic evolution

D.-J. Wen (1), S.-L. Chung (1), D.-Y. Liu (2), J. Ji (3), M.-F. Chu (1), B. Song (2), C.-H. Lo (1), T.-Y. Lee (4)

(1) Dept. Geosciences, National Taiwan University, Taipei, Taiwan; (2) Inst. Geol., Chinese Acad. Geol. Sci., Beijing, China; (3) Dept. Geol., Peking Univ., Beijing, China; (4) Dept. Earth Sci., Nat'l Taiwan Normal Univ., Taipei, Taiwan

The Gangdese batholith that crops out in the southern Lhasa terrane marks one of the main products of the Transhimalayan magmatism caused by northward subduction of the Neo-Tethyan slab before the India-Asia collision. Here we present new SHRIMP U-Pb zircon results for this batholith, which are combined with published age data to delineate a magmatic duration from ~104 to 40 Ma. Such a prolonged magmatic activity, however, appears to have clustered in two stages, in the Cretaceous (~104-78 Ma) and Paleogene (~60-40 Ma), respectively, with a gap during ~78-60 Ma. The age span of the former stage overlaps with that (~135-75 Ma) of the granitoids and associated volcanic rocks emplaced in the Nyainqentanglha belt in the northern part of the Lhasa terrane. In comparison with the Nyainqentanglha granitoids that are dominantly S-type and marked by significant involvement of the continental crust in magma generation, the Cretaceous Gangdese granitoids show geochemical affinities with adakites from modern subduction zones. The Gangdese adakites ($\text{SiO}_2 = 66-69\%$) are highly depleted in HREE and Y (<10 ppm), so coupled with elevated La/Yb and Sr/Y, and do not display Eu anomalies. Their overall geochemical and isotopic features are consistent

with an origin by melting of a garnet-bearing source that is most likely to be the subducting Neo-Tethyan slab. These observations point to a flat subduction that, as in the case of central Andes, can account for the heat required to melt the slab and the widespread nature of the Cretaceous phase of the Transhimalayan magmatism in the Lhasa terrane. In contrast, the younger phase of this arc magmatism was confined to the south, represented by the Paleogene stage of the Gangdese plutons and contemporaneous Linzizong volcanic successions. These magmas, ranging from mafic to felsic compositions typical of the calc-alkaline nature, have Sr-Nd isotope ratios [e.g., $\epsilon\text{Nd}(T) = +3$ to $+5$] suggesting a prevailing contribution by a juvenile mantle component that we infer to have been caused by an upwelling of the asthenospheric convection due to rollback of the Neo-Tethyan slab and its subsequent breakoff into the deep mantle.

Age and geochemical constraints on the genesis of the Paleogene Linzizong volcanic successions in southern Tibet

Hao-Yang Lee¹, Sun-Lin Chung¹, Da-Jen Wen¹, Jianqing Ji², Qing Qian³, Ching-Hua Lo¹, Tung-Yi Lee⁴

¹ Department of Geosciences, National Taiwan University, Taipei, Taiwan

² Department of Geology, Peking University, Beijing, China

³ Institute of Geology and Geophysics Chinese Academy of Sciences, Beijing, China

⁴ Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan

The Himalayan-Tibetan orogen is formed by the collision between India and Asia starting early Cenozoic time. Preceding this collision, northward subduction of the Neo-Tethyan slab underneath Asia resulted in an Andean-type convergent margin associated with formation of voluminous arc magmas that are exposed as the Gangdese batholith and Linzizong volcanic successions emplaced in the southern Lhasa terrane, southern Tibet. To better understand the tempo-spatial distribution and petrogenesis of the Linzizong volcanic rocks, for which only very limited information is currently available, this study presents new ⁴⁰Ar-³⁹Ar dating and petrochemical data for volcanic rocks collected from several transverses in southern Tibet (~87-92°E) and explore their implications for the Himalayan-Tibetan orogenic evolution. Our ⁴⁰Ar-³⁹Ar dating results, along with published age data, appear to suggest two major episodes of volcanic eruptions, which are an older episode that occurred in the northern Lhasa terrane between ~110 and 80 Ma and a younger one in the southern Lhasa terrane between ~60 and 40 Ma. The so-called Linzizong volcanic successions comprise the younger episode and are generally flat-lying or only slightly tilted on top of sedimentary formations. They consist of basaltic to rhyolitic compositions characterized by the calc-alkaline differentiation trend. The overall geochemical features of the Linzizong volcanics are similar to those of arc lavas from the convergent margins worldwide, marked by various degrees of enrichment in LILE (Rb, Ba, Th, U, Sr), LREE and Pb, and depletions in HFSE (Nb, Ta and Ti). When compared with the older but geochemically similar volcanic rocks from the north, the Linzizong rocks appear to have relatively less enriched patterns in incompatible trace elements. Such a tempo-spatial variation is consistent with the notion that there was a slab rollback and increase in the Neo-Tethyan subduction angle during the late Cretaceous and early Cenozoic before the Linzizong volcanic eruption.

RARE EARTH ELEMENT CHEMISTRY OF APATITES FROM SOUTHEASTERN TIBETAN GRANITIC ROCKS

M.F. Chu (1), X.R. Liang (2), S.L. Chung (1), X.H. Li (2), Y.Q. Zhang (2)

(1) Department of Geosciences, National Taiwan University, Taipei, Taiwan, (2) Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, China

f88224109@ntu.edu.tw/Fax: +886-2-23636095

Accessory minerals such as zircon and apatite occur widely in various rocks because of their wide stability in geological processes, which allow these minerals to be used as an indicator for not only igneous petrogenesis but also potentially for sedimentary source provenance. In this study, we report trace element analyses of apatite separates from selected granitic rocks from southeastern Tibet using LA-ICP-MS, composed of a New Wave LUV-213 Nd:YAG laser and an Agilent 7500s ICP-MS at NTU. Samples that we analyzed include (1) undeformed I- and S-type granitoids from the Gangdese Batholith and Nyainqentanglha magmatic belt, emplaced in the southern and northern parts of the Lhasa terrane, respectively, (2) a granitic migmatite from Langxian, located in the southern margin of the Gangdese Batholith, and (3) a granitic gneiss from Tongmai, in the Jiali shear zone. These apatites show remarkable difference in their trace element compositions, best manifest by the contents of rare earth elements (REE). Apatites from I-type granitoids ($\text{SiO}_2 = 62\sim 70$ wt.%), the principal component of the Gangdese Batholith characterized by positive $\epsilon\text{Nd(T)}$ isotopic compositions, exhibit apparent enrichments in the light REE [LREE, e.g., $(\text{La}/\text{Yb})_N = 1.51\sim 26.8$; avg. $= 13.7 \pm 5.5$ (1σ , $n=33$)]. In contrast, apatites from S-type granitoids ($\text{SiO}_2 = 70\sim 74$ wt.%), which constitute the Nyainqentanglha belt and have negative $\epsilon\text{Nd(T)}$ values, show generally flat REE patterns [$(\text{La}/\text{Yb})_N = 0.56\sim 1.54$; avg. $= 0.99 \pm 0.73$ ($n=36$)]. Apatites from both types of the granitoids, further marked by significant negative Eu anomalies [$(\text{Eu}/\text{Eu}^*)_N = 0.04\sim 0.45$] in the REE patterns, can be distinguished from those from the metamorphosed rocks that show LREE-depleted patterns [$(\text{La}/\text{Yb})_N = 0.02\sim 1.30$; avg. $= 0.15 \pm 0.25$ ($n=29$)]. The latter shows mild Eu anomalies [$(\text{Eu}/\text{Eu}^*)_N = 0.13\sim 0.80$ and $0.21\sim 0.53$ for apatites of the Tongmai gneiss and Longxian migmatite, respectively]. This pilot study indicates that REE chemistry of the apatites (1) correlates with compositions of the host magmas and thus can be used as a probe into igneous petrogenesis, (2) varies between igneous and metamorphic conditions, and (3) has higher potential than zircon to be used as a provenance indicator in particular when combined with *in-situ* Sr isotope determinations of these apatites to be carried out.

下列為本計畫執行以來，已將發表的相關研究成果：

- (1) Lee, H.Y., S.L. Chung, J.J. Wang, D.J. Wen, Y.Q. Zhang, Y.W. Xie, C.H. Lo, T.F. Yang, T.Y. Lee, G.Y. Wu and J.Q. Ji (2003) Miocene Jiali faulting and its implications for Tibetan tectonic evolution. *Earth Planet. Sci. Lett.*, v.205, p.185-194.
- (2) Lan, C.Y., S.L. Chung, T.V. Long, C.H. Lo, T.Y. Lee and S.A. Mertzman (2003) Geochemical and Sr-Nd isotopic constraints from the Kontum Massif, central Vietnam for crustal evolution of the Indochina block. *Precambrian Res.*, v.122, p.7-27.
- (3) Chung, S.L., C.H. Lo and T.Y. Lee (2003) Petrologic case for Eocene slab breakoff during the Indo-Asian collision: Comment. *Geology*, v.31, p.e7-8.
- (4) †Qian, Q., S.L. Chung, T.Y. Lee and *D.J. Wen (2003) Mesozoic high Ba-Sr granitoids from North China: Geochemical characteristics and geodynamic implications. *Terra Nova*, v.15, p.272-278.
- (5) He, B., Y.G. Xu, S.L. Chung, L.X. Huang, Y. Wang (2003) Sedimentary evidence for a rapid, kilometer scale crustal doming prior to the eruption of the Emeishan flood basalts. *Earth Planet. Sci. Lett.*, v.213, p.391-405.
- (6) Xu, Y.G., H. Mei, J. Xu, X. Huang, Y. Wang and S.L. Chung (2003) Origin of two differentiation trends in the Emeishan flood basalts. *Chinese Science Bulletin*, v.48, p.390-394.
- (7) Wang, K.L., S.Y. O'Reilly, W.L. Griffin, S.L. Chung, N.J. Pearson (2003) Proterozoic mantle lithosphere beneath the extended margin of the South China Block: in-situ Re-Os evidence. *Geology*, v.31, p.709-712.
- (8) Qian, Q., *M.F. Chu, S.L. Chung, T.Y. Lee and X.M. Xiong (2003) Was Triassic continental subduction solely responsible for the generation of Mesozoic mafic magmas and mantle source enrichment in the Dabie-Sulu orogen? *International Geology Review*, v.45, p.659-670.
- (9) Chung, S.L., D.Y. Liu, J.Q. Ji, M.F. Chu, H.Y. Lee, D.J. Wen, C.H. Lo, T.Y. Lee, Q. Qian, Q. Zhang (2003) Adakites from continental collision zones: Melting of thickened lower crust beneath southern Tibet. *Geology*, v.31, p.1021-1024.
- (10) L. Xiao, Y.G. Xu, S.L. Chung, B. He and H.J. Mei (2003) Chem-stratigraphic correlation of late Permian lava successions from Jinping and Binchuan areas, Yunnan, China: Implications for the extent of the Emeishan large

igneous province. *International Geology Review*, v.45, p.753-766.

- (11) Wang, K.L., S.L. Chung, S.Y. O'Reilly, S.-s. Sun, R. Shinjo and C.H. Chen (2004) Geochemical and Pb-Sr-Nd isotopic constraints on the genesis of post-collisional magmatism around northern Taiwan. *Jour. of Petrology*, v.45, p.975-1011.
- (12) Yang, J.H., S.L. Chung, M. Zhai and X. Zhou (2004) Geochemical and Sr-Nd-Pb isotopic compositions of Cretaceous mafic dikes from the Jiaodong Peninsula, eastern China: Petrogenesis and mantle sources. *Lithos*, v.73, p.145-160.
- (13) Chung, S.L., M.F. Chu, Y.Q. Zhang, Y.W. Xie, T.Y. Lee, C.H. Lo, X.H. Li, C.Y. Lan, Q. Zhang and Y. Wang (2004) Tibetan tectonic evolution inferred from temporal and spatial variations in post-collisional magmatism. *Earth-Sci. Reviews*, in press.
- (14) Li, X.H., S.L. Chung, H. Zhou, C.H. Lo, Y. Liu and C.H. Chen (2004) Jurassic intraplate magmatism in southern Hunan, eastern Guangxi: ^{40}Ar - ^{39}Ar age, geochemistry, Sr-Nd isotopes and implications for tectonic evolution of SE China. *J. Geol. Soc. London*, in press.
- (15) Xu, Y.G., B. He, S.L. Chung, M.A. Menzies and F.A. Frey (2004) The geological, geochemical and geophysical consequences of plume involvement in the Emeishan flood-basalt province. *Geology*, in press.
- (16) Yang, J.H., F.Y. Wu, S.L. Chung, M.F. Chu, S.A. Wilde and W. Liu (2004) A three-component mixing model for the origin of granite: Geochemical and Nd- and Sr-isotopic evidence from Gudaoling granite and its mafic enclaves, NE China. *Geochim. Cosmochim. Acta*, in press.
- (17) Xu, Y.G., S.L. Chung, J.L. Ma and L.B. Shi (2004) Basalt chemistry suggests contrasting Cenozoic lithospheric evolution and architecture in western and eastern Sino-Korean Craton. *Earth Planet. Sci. Lett.*, in review.
- (18) Yang, J.H., S.L. Chung, S.A. Wilde, F.Y. Wu, M.F. Chu, C.H. Lo and H.R. Fan (2004) Geochronology, geochemistry and geodynamic implications of Late Triassic potassic to ultrapotassic rocks from the Jiazishan complex, eastern China. *Chem. Geology*, in review.
- (19) Yang, J.H., S.L. Chung, F.Y. Wu, C.H. Lo, S.A. Wilde, W. Liu, Y. Zhao, M.G. Zhai (2004) Thermo-chronology of the Liaonan metamorphic core complex in NE China: Implications for the Late Mesozoic tectonic evolution of the North China Craton. *Tectonophysics*, in review.
- (20) Yang, J.H., F.Y. Wu, S.L. Chung, S.A. Wilde and M.F. Chu (2004) A magma mixing model for the origin of A-type granites: Evidence from the Qianshan batholith in northeastern China. *Geology*, in review.
- (21) Xu, Y.G., J.L. Ma, X.L. Hunag, Y. Iizuka, S.L. Chung, Y.B. Wang, X.Y. Wu, J.F. Xu, Q. Wang (2004) Petrogenesis of Late Mesozoic gabbroic complex from Yanan, Shandong Province: Implications for mantle evolution beneath the North China Craton. *Chem. Geology*, in review.
- (22) Wen, D.J., Song, B., S.L. Chung, D.Y. Liu, J.Q. Ji, M.F. Chu, T.Y. Lee, C.H. Lo (2004) Discovery of Late Cretaceous intrusions of adakitic geochemical compositions from the eastern Gangdese belt, southern Tibet. (to be submitted: *Geology*).
- (23) Lee, H.Y., S.L. Chung, C.H. Lo, J. Ji, Q. Qian, T.Y. Lee, D.J. Wen and M.F. Chu (2004) Implications of Eocene magmatic flare-ups in southern Tibet for collision tectonics and environmental changes. (in prep.).
- (24) Liang, Y.H., S.L. Chung, M.F. Chu, D.Y. Liu, S.Y. O'Reilly, B. Song, N.J. Pearson (2004) Detrital zircon study along the Tsangpo River, southern Tibet. (in prep.).
- (25) Chu, M.F. S.-L. Chung, W.F. Griffin, S.Y. O'Reilly, N.J. Pearson, D.Y. Liu (2004) Magma generation in southern Tibet: Constraints from zircon separates by in-situ analyses of Hf isotopes. (in prep.).