Multi-stage carbonate veins at IODP Site U1504 document Early Cretaceous to early Cenozoic extensional events on the South China Sea margin

Liheng Sun[a, b], Zhen Sun[a, b, c, *], Yunying Zhang[a], Zhongxian Zhao[a, *], Jianxin Zhao[d], Cuimei Zhang[a], Zhe Zhang[a, b], Longtao Sun[a], Xiaoxi Zhu[a, b]

[a] *Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Key Laboratory of Ocean and Marginal Sea Geology, South China Sea Institute of Oceanology, Innovation Academy of South China Sea Ecology and Environmental Engineering, Chinese Academy of Sciences, Guangzhou 511458, China*

[b] *University of Chinese Academy of Sciences, Beijing 100049, China*

[c] *China-Pakistan Joint Research Center on Earth Sciences, CAS-HEC, Islamabad 45320, Pakistan*

[d] *Radiogenic Isotope Facility, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD 4072, Australia*

[*] *Corresponding Author:*

Z. Sun, Email address: zhensun@scsio.ac.cn**;** *Z. Zhao, Email address:* zxzhao@scsio.ac.cn

Abstract

Recognition of the pre-spreading tectonic characteristics of the South China Sea (SCS) continental margin is key to understanding how the SCS opened. However, information on this subject is extremely scarce because of the lack of direct chronological constraints on deformation events. The International Ocean Discovery Program sampled greenschist-facies mylonite from the basement of the Outer Margin High at site U1504 in the SCS, which could provide information on the pre-spreading history. The microstructure analysis revealed that two episodes of extension had affected the mylonites, namely early ductile and late brittle deformation. Pre-mylonite, syn-mylonite and post-mylonite carbonate veins were identified on the basis of the intersecting relationships with the mylonite foliation. The pre-mylonite carbonate veins yielded U–Pb ages of 210 ± 20 and 195 ± 32 Ma, which might represent the age of the protolith. The age of the syn-mylonite carbonate vein is 135 ± 12 Ma. No effective ages were obtained for the post-mylonite carbonate veins using U–Pb dating. The ^{13}C, ^{18}O and $^{87}Sr/^{86}Sr$ compositions of the post-mylonite carbonate veins suggest that they were formed by hydrothermal fluid precipitation dominated by seawater. Considering the extensively developed marine environment in the northern continental margin after the late Eocene, the post-mylonite carbonate veins at site U1504 likely formed in the Eocene or later. Combining the microstructure, geochemistry and seismic profile, we hypothesize that post-mylonite carbonate veins were formed during early Cenozoic rifting. In reference to the geological background, we conclude that the basement of the SCS margin experienced at

least two stages of extension before spreading: the first stage occurred during the Early Cretaceous and was caused by rollback of the Paleo-Pacific plate; the second occurred in the early Cenozoic because of passive rifting. These multiple extensional events of the active continental margin and of the passive margin collectively resulted in thinning the SCS continental margin.

Keywords: Continental margin of the South China Sea; Pre-spreading tectonics; International Ocean Discovery Program 368; Greenschist-facies mylonite; Carbonate U–Pb dating