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Using Raman Spectroscopy of Carbonaceous Materials to track exhumation of an active orogenic belt: An example from Eastern Taiwan

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ABSTRACT

The burial and exhumation history of an orogen can provide insights into the thermal history of rocks in the mountain belt. Asynchronous collision will exhume materials to the surface at different times and expose different metamorphic grades along the orogenic axis. By tracking the thermal signals of eroded materials, it is possible to compare spatial patterns of exhumation along the mountain belt. Previous studies such as bulk mineralogy of sandstones, crystallinity of clay minerals, and fission track thermochronology all suggest that the Pliocene to Pleistocene meta-sedimentary deposits within the preserved basins of the Coastal Range reflect the unroofing history of the Central Range in Eastern Taiwan. In this study, modern sediments from six drainages of the east Central Range (Liwu, Mugua, Laku- Laku, Luye, Jinlun, and Hsuhai Rivers) and three basin sections of meta-sedimentary deposits from the Coastal Range (Shuilien, Chimei, and Madagida sections) were sampled to reconstruct the thermal signals of each drainage along the modern orogenic axis and reconstruct temporal variations of thermal signals in preserved Plio-Pleistocene sedimentary rocks.

The temperature index (T.I.) of modern sediments determined by Raman spectroscopy of carbonaceous materials are medium to high (0.4–0.8). In conjunction with bio- and magneto-stratigraphy, our data suggest that the northern Shuilien area has been receiving detritus of medium metamorphic grade from the exhumed orogeny in the north from 3.4 Ma and higher grade since 2 Ma; meanwhile, the southern Madagida section has been mostly taking in juvenile detritus from the south part of the orogen until 1 Ma. The central Chimei section has started collecting mature detritus since 1.24 Ma. The data suggest that the Plio-Pleistocene basins contain a good record of orogen evolution.

1. Introduction

The thermal evolution of collisional orogens is dictated by rock burial and exhumation, which are controlled by feedbacks among tectonics, climate and earth surface processes. Asynchronous collision can cause exhumation to propagate in space and time, leading to systematic variations in cooling age and metamorphic grade along the axis of the orogen. Detrital sediments derived from an eroding orogen carry the thermal signals of exhumation down rivers to flanking basins where the signals are preserved in the stratigraphic record. Cooling and exhumation histories of orogenic belts are commonly investigated using methods of detrital thermochronology such as (U-Th)/He dating, fission-track, and U-Pb dating of detrital zircon and apatite (e.g., Garver et al., 1999; Bernet and Spiegel, 2004; Rahl et al., 2007).

Sedimentary basins linked to orogenic belts hold important information on mountain building processes, such as the timing of initiation of the orogeny, the rate of crustal deformation, the magnitude of exhumation, and the pathway of sediment transportation. Taiwan, one of the most active orogens in the world, is a classic example of mountain building processes showing oblique plate convergence and consequent erosion and sedimentation processes that impacted the basins around the uplifting mountain belt (Dadson et al., 2003; Willett et al, 2003). To the NE of Taiwan, the Philippine Sea plate is subducting beneath the Eurasian plate, resulting in the Ryukyu trench and arc system to the east of Taiwan, whereas the remnant South China Sea plate is subducting eastward beneath the Philippine Sea plate along the Manila trench, leading to the formation of the Luzon volcanic arc chain (Fig. 1). The Philippine Sea plate and Eurasian plate is converging at a rate of ~80 mm/yr in a NW direction (Seno et al., 1993, Yu et al., 1997).

As the arc-continent collision went on, proto Taiwan produced abundant detritus from the exhumed mountain belt into the adjacent

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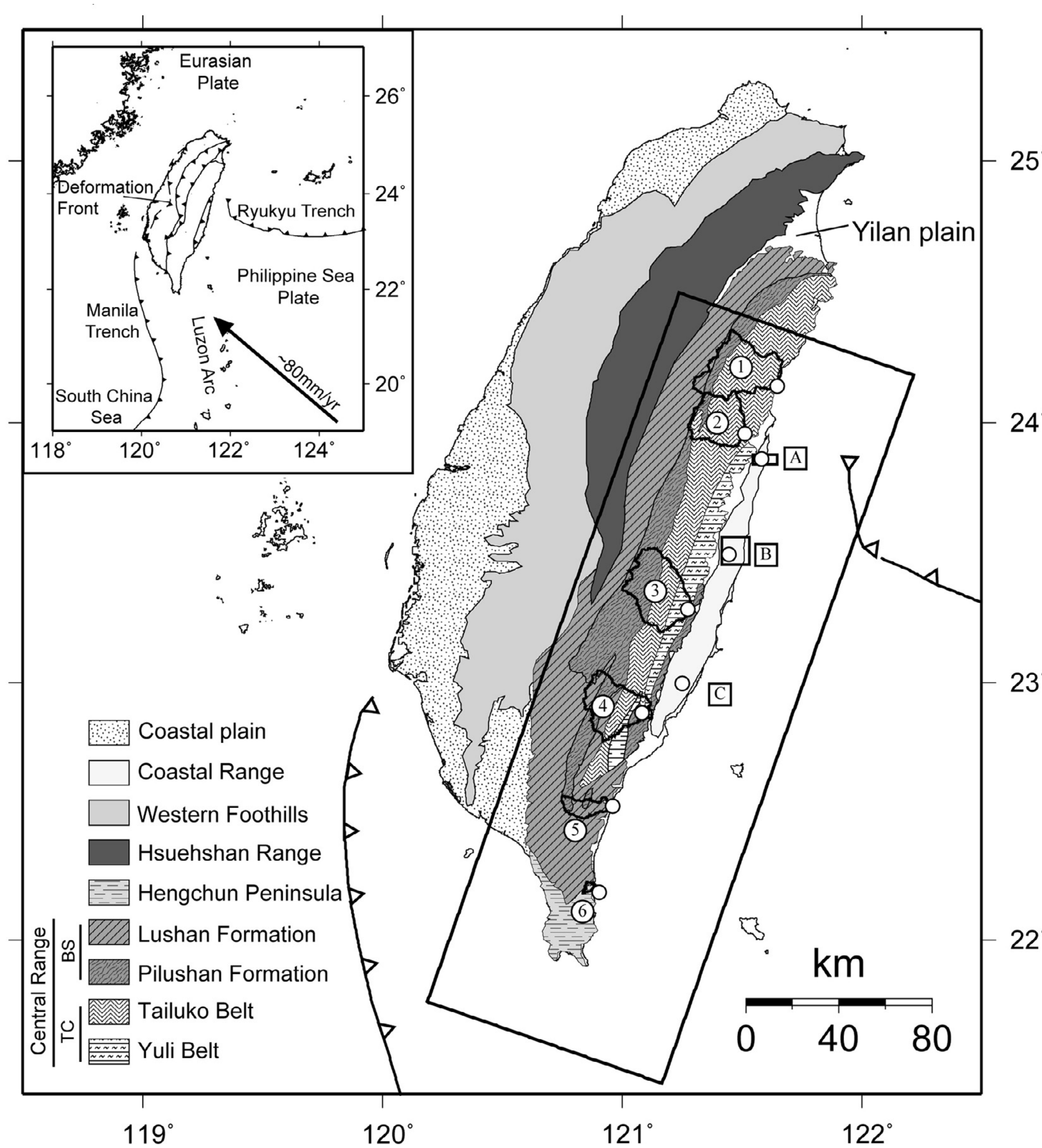

Fig. 1. The map of the study area, showing the framework of tectonic settings. The abbreviations are: TC-Tananao Complex and BS-Backbone Slates. The black arrow represents the convergence between Philippine Sea plate and Eurasian plate with a relative rate around 80 km/myr. The six studied catchments were numbered as 1. Liwu river, 2. Mugua river, 3. Laku- Laku river 4. Luye river, 5. Jinlun river, and 6. Hsuhai river, geographically from north to south. The three basin sections were named as A. Shuilien section, B. Chimei section, and C. Madagida section.

basins. The Coastal Range of east Taiwan therefore archived the transition of sedimentary records from Luzon-arc related volcanic sequences (Tuluanshan Formation) to arc-continent collision related detritus derived from low to high grade metamorphic rocks (Fanshuliao to Paliwan Formation) (Chen and Wang, 1988, 1995; Kirstein et al., 2009). These basin fills were later obducted and amalgamated to the island of Taiwan as the arc-continent collision proceeded (Buchovecky and Lundberg, 1988; Dorsey, 1988; Dorsey et al., 1988; Teng, 1979).

For several decades, researchers have investigated the Taiwan orogeny from diverse perspectives including the thermal characteristics of the exposed metamorphic belt (Beyssac et al., 2007; Burbank and Anderson, 2001; Fuller et al., 2006; Lee et al., 2006; Liu et al., 2000, 2001; Willett et al., 2003), the short-and long-term erosion rates of the Central Range (Dadson et al., 2003; Fuller et al., 2006; Lee et al., 2006; Li, 1976; Liu et al., 2000, 2001; Willett and Brandon, 2002; Willett et al., 2003), and petrography, thermochronology and composition of sediments preserved in the Coastal Range (Buchovecky and Lundberg, 1988; Chen and Wang, 1988, 1995; Dorsey, 1988; Dorsey et al., 1988; Horng et al., 2012; Kirstein et al., 2009, 2013; Teng, 1979; Ting, 2008).

Each of the aforementioned approaches has its own pros and cons when applied to the detritus from the Taiwan orogen. Traditionally petrography studies can help differentiate the metamorphic grade by recognizing the mineral assemblages and the deformation types of foliation. However, most of the slates and sandstones in the Taiwan orogenic belt contain mineralogical assemblages that are not favorable for conventional and quantitative petrologic studies and the existing publications regarding the physical conditions of metamorphism are mostly estimated from outdated petrogenetic grids. Low temperature thermochronology can reveal the near surface exhumation path of the rock particle yet provides little constraints on the peak metamorphic stages. Zircon fission track, for instance, can pin down the thermal condition only up to 240 °C and zircon U-Th/He to 180 °C (Reiners et al., 2004; Wagner and Van der Haute, 1992). In addition, analysis on clay minerals such as the illite crystallinity study in the Coastal Range mostly focused on the southern (Madagida) and middle (Chimei) sections with depositional ages around 3.4–1.07 Ma and 2.58–0.7 Ma,