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# Provenance control on chemical indices of weathering (Taiwan river sands)

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ABSTRACT

Geochemical parameters obtained from the analysis of sediments and sedimentary rocks are widely used to infer weathering and paleo-weathering conditions in source areas. Chemical indices of weathering, however, may not reflect weathering only, or even principally. The concentration of chemical elements in terrigenous sediments is constrained by the original mineralogy of source rocks, and is thus provenance-dependent. Moreover, the mineralogy and consequently the geochemistry of sediments may undergo substantial modifications by diverse physical processes during transport and deposition, including recycling and hydraulic sorting by size, density or shape, and/or by chemical dissolution and precipitation during diagenesis.

Around the island of Taiwan, temperature and rainfall are consistently high and relatively homogeneous, and no significant correlation is observed between geochemical and climatic parameters. Physical erosion, fostered by landslides induced by frequent earthquakes and typhoons, prevails because of high relief and extreme rates of tectonic uplift. In such a dynamic orogenic setting, all chemical indices of weathering are controlled principally by the geology of source terranes. Sedimentaclastic and metasedimentaclastic sands carried by western Taiwan rivers draining the pro-wedge display the strongest depletion in Na, Ca, Mg and Sr relative to average upper continental crust, and no depletion or even enrichment in K, Rb and Ba. Low WIP indices reflect erosion of phyllosilicate-dominated rocks in the Slate Belt and extensive recycling of clastic rocks exposed in the Western Foothills. Instead, metamorphiclastic sands carried by eastern Taiwan rivers draining the retro-wedge show no depletion or even enrichment in Mg and Ca, and low CIA and PIA, reflecting contributions from the Tailuko Belt and Coastal Range. Volcaniclastic sands have the same CIA values of their andesitic source rocks ($47 \pm 1$ versus $47 \pm 7$), indicating that weathering is subordinate both along the eastern side of the island and at its northern edge where annual rainfall is double.

Full caution is required when chemical weathering indices are used to extract climatic and paleoclimatic information from the sedimentary archive, especially in the case of diagenized sandstones where commonly massive precipitation of authigenic carbonate is very difficult to accurately correct for, especially in the absence of detailed petrographic and mineralogical data.



"The questions that we raise and our doubts depend on the fact that some propositions are exempt from doubt, are as it were like hinges on which those turn"
*Ludwig Wittgenstein, On Certainty, #341*

"I do not have the nagging doubt of ever wandering whether perhaps I am wrong"
*Hendrik Frensch Verwoerd, Architect of Apartheid*

## 1. Introduction

Since chemical indices of weathering were introduced in the pioneering article by Nesbitt and Young (1982), the degree of depletion in mobile alkali and alkaline-earth elements in rocks, soils and sediments, with complementary enrichment in dissolved loads (Kronberg et al., 1987), has been used extensively in paleogeographic reconstructions to evaluate climatic conditions and erosional regimes in source areas (e.g., Wronkiewicz and Condie, 1987; McLennan, 1993; Condie et al., 2001; Scheffler et al., 2006; Bahlburg and Dobrzinski, 2011; Perri et al., 2011). The standard application of chemical-weathering indices such as the CIA or the WIP, however, is to identify the degree of weathering in soil profiles developed on homogenous plutonic (Nesbitt and Markovics, 1997) or heterogeneous metamorphic rocks

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(Price and Velbel, 2003). Their application to sediments and especially sedimentary rocks suffers from a variety of problems, including the diversity of parent lithologies and grain-size control (von Eynatten et al., 2012), recycling and inheritance from previous sedimentary cycles (Borges et al., 2008; Li and Yang, 2010), hydraulic effects such as suspension sorting and selective entrainment (Garzanti et al., 2010; 2011), difficulties in separating CaO in carbonates or phosphates from CaO in silicates (Buggle et al., 2011), and various diagenetic processes including dissolution of unstable minerals, carbonate precipitation and post-depositional addition of $K_2O$ (Fedo et al., 1995; Morton and Hallsworth, 2007; Goldberg and Humayun, 2010).

The aim of this study on modern fluvial sands is to verify whether it is safe to assume that chemical indices are controlled fundamentally by alteration processes and can thus be used reliably as robust indicators of climate and paleoclimate. The island of Taiwan, characterized by extreme rates of tectonic uplift and sediment production largely through landslides triggered by earthquakes and typhoons is used here as a test case. Taiwan, an accretionary complex exposing a variety of tectonic units with different igneous, metamorphic and sedimentary lithologies (Fig. 1), has complex geology but it is small enough (~36,000 km$^2$) to let us assume relatively homogeneous climatic setting and geomorphological regime in mountain source areas. It thus represents an excellent natural sedimentological laboratory in which to investigate whether chemical indices of modern sands reflect alteration processes in present river catchments faithfully, or if and to what extent they are conditioned by the lithology of parent rocks and are consequently partly or even mainly provenance-controlled.

### 1.1. Climate and geomorphology

The island of Taiwan, lying at tropical latitudes between N°21′54 and N°25′18, has mild climate throughout the year, with average annual temperatures ranging from 22° in the north to 24 °C in the south. Frost or snow may occur on the high mountains in winter, whereas

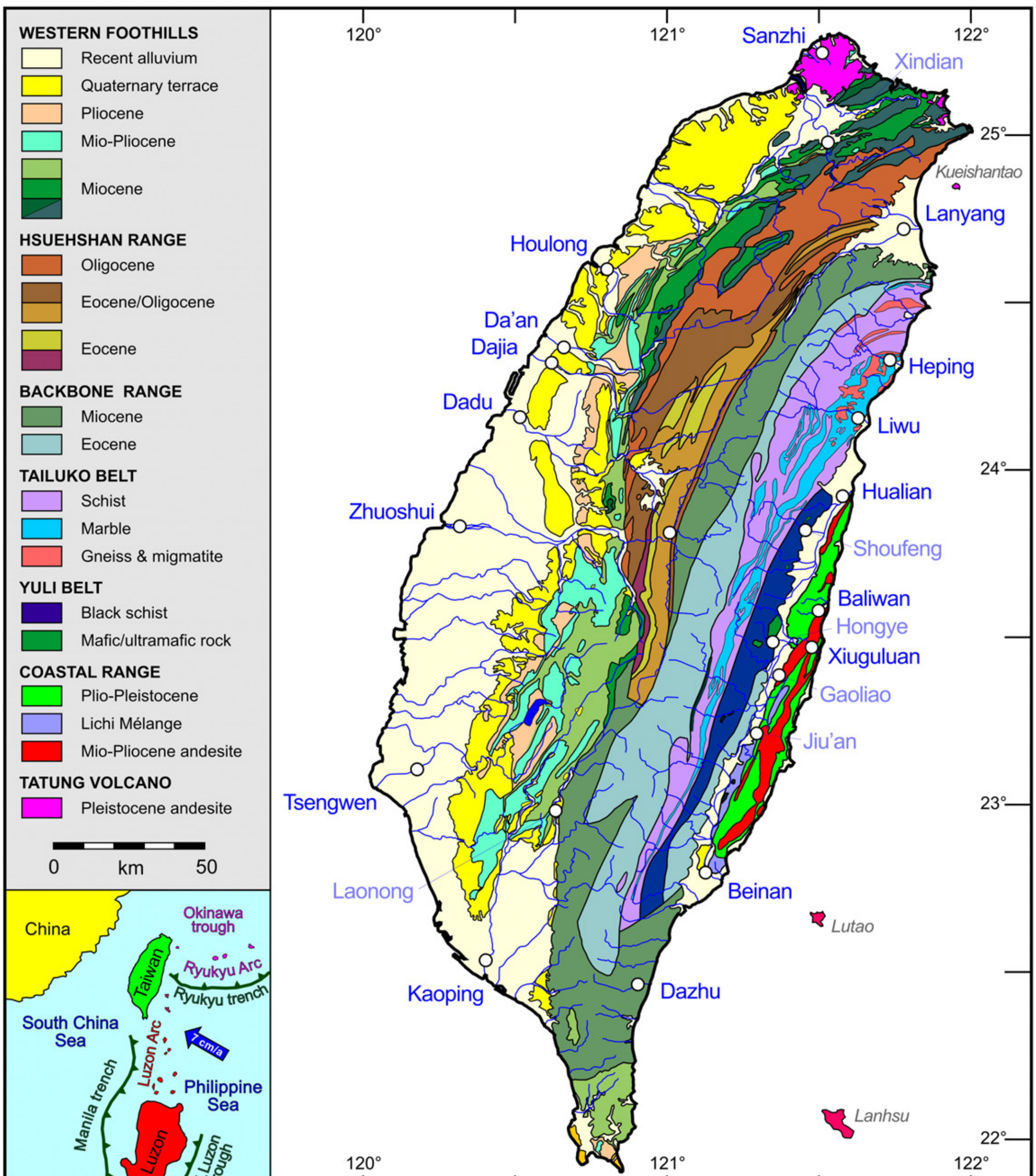


**Fig. 1.** Geological sketch map of the Taiwan orogen (after Chen, 2000), with location of river samples (full information on sample location is provided in Google Earth file Taiwan CHI Samples.kml and Appendix Table A1). The plate tectonic setting of Taiwan is shown in the lower left inset.