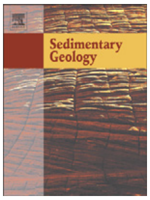
Sedimentary Geology 336 (2016) 68–80

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo



Sediment generation in humid Mediterranean setting: Grain-size and source-rock control on sediment geochemistry and mineralogy (Sila Massif, Calabria)

Hilmar von Eynatten [a,*], Raimon Tolosana-Delgado [b], Volker Karius [a], Kai Bachmann [b], Luca Caracciolo [c]

[a] *Geowissenschaftliches Zentrum der Georg-August-Universität Göttingen, Abteilung Sedimentologie/Umweltgeologie, Göttingen, Germany*
[b] *Helmholtz Institute Freiberg for Resource Technology, Freiberg, Germany*
[c] *Chemostrat Ltd., Welshpool, UK*

ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form 15 October 2015
Accepted 19 October 2015
Available online 30 October 2015

Keywords:
Geochemistry
Mineralogy
Chemical weathering
Comminution
Provenance
Compositional linear regression

ABSTRACT

Grain-size control on sediment composition is investigated in modern proximal sediment from the Sila Massif, where basic to felsic intrusive rocks are exposed in a Mediterranean humid–temperate upland climate. Samples were taken from small creeks and weathering profiles from three areas reflecting different bed rock compositions. Samples were separated into eleven grain size fractions from very coarse sand to clay and analyzed by (i) X-ray fluorescence for chemical composition and (ii) X-ray diffraction and Mineral Liberation Analysis for mineralogical composition. The chemical composition vs. grain size relations were modeled by compositional linear regression. Mineralogical composition of selected samples is used to substantiate the interpretations based on geochemistry. *Results:* reveal a high degree of chemical weathering with chemical index of alteration (CIA) up to 92. High CIA values are restricted to the fine-grained fractions, while sand-sized sediment average at low to moderate CIA values (~60). Although strongly weathered, the three sample suites reflecting basic to felsic plutonic bed rock can be effectively discriminated across all grain-size classes using trace elements such as V, Rb, and Sr. Linear trend modeling and mineralogical data reflect similar patterns for all sample suites implying similar processes independent of source rock composition. This includes overall decrease of quartz and K-feldspar over the full grain-size range from very coarse sand to clay, which is contrasted by overall increase of sheet silicates from coarse to fine. Among the latter, increase of clay minerals strongly outpaces the increase of micas in silt to clay fractions. A more complex behavior is shown by plagioclase, which is most abundant in intermediate grain-size fractions for all sample suites. This is likely caused by initial hydrolysis along cleavage and twinning planes and subsequent breakage of plagioclase crystals into smaller fragments. Towards finer grain size, intense hydrolysis has destroyed most feldspars.

1. Introduction

The chemical and mineralogical compositions of sediments and sedimentary rocks are strongly controlled by grain size (e.g. Blatt et al., 1972; Basu, 1976). Other factors include source rock composition, weathering, and physical as well as chemical processes that modify the sediment while being transported from source to sink (e.g. Johnsson, 1993). The effect of grain size is generally thought to exceed the impact of all other control factors on the variability of sediment composition (e.g. Garzanti et al., 2011; Bloemsma et al., 2012). Nevertheless, many studies inferring geologic or paleoclimatic conditions from sediment characteristics do not consider grain size influence adequately.

The high relevance of grain-size for analyzing sediment composition is contrasted by the fact that analyzing the entire grain-size spectrum is often impossible, due to limitations of the accessible rock record as well as specific methodological constraints (e.g., microscopic determination of framework grains or heavy minerals is restricted to certain grain-size ranges). Therefore, classic approaches to infer geological conditions from sediment composition typically rely on data obtained from a given narrow grain size range (e.g. Basu et al., 1975; Ingersoll et al., 1984; Morton and Hallsworth, 1994). The shortcomings of such approaches have been recently outlined by, for instance, Garzanti et al. (2009). Therefore, comparing data obtained from different grain size fractions or from sediment samples with contrasting grain size distributions inevitably requires an understanding of the compositional relations across grain size grades. If these relations are controlled by purely physical processes such as hydrodynamics or mechanical comminution, relatively simple empirical or numerical models can be used to correct for the grain-size dependent control on composition (e.g. Garzanti et al., 2009; von Eynatten et al., 2012). For complex interactions of chemical and physical processes, which must be considered the rule rather than the exception in natural systems, Bloemsma et al. (2012) developed a statistical method to separate the grain-size dependent part of compositional

---

[*] Corresponding author.
E-mail address: hilmar.von.eynatten@geo.uni-goettingen.de (H. von Eynatten).

http://dx.doi.org/10.1016/j.sedgeo.2015.10.008
0037-0738/

variation from a residual part, which reflects other controlling factors such as provenance or diagenesis. Application of this tool revealed that trends of grain size vs. composition strongly depend on the specific geological setting, implying that more empirical studies and models are needed to better understand individual settings.

The aim of the paper is to describe and quantify the effects of grain size and source-rock lithology on geochemical and mineralogical compositions of sediments in a specific case study. The samples were taken from three areas of the humid–temperate Sila Massif, southern Italy, composed of contrasting basic to felsic plutonic source rocks. A broad grain size spectrum covering more than three orders of magnitude from very coarse sand to clay is considered. Previous studies have documented significant chemical weathering of soils and sediment in the Sila Massif (e.g. Scarciglia et al., 2007). In a first step, weathering and provenance effects on sediment composition, as well as their variations across the grain size grades from coarse to fine are evaluated. In a second step, the results are compared to a previous study (von Eynatten et al., 2012) from a highly contrasting climatic setting where chemical weathering is negligible and thus mechanical comminution controls sediment composition across grain-size grades.

The study is essentially based on geochemical data because they can be obtained easily and precisely for the full grain size spectrum from very coarse sand to clay, which covers >95% of the global clastic sediment budget given that conglomerates and breccias comprise only a few percent of the total clastic sediment record (e.g. Pettijohn, 1975). Mineralogical composition is obtained by X-ray diffraction for selected samples and grain-size fractions to verify interpretations based on geochemical data. Moreover, Mineral Liberation Analysis (MLA) has been tested on some samples because it potentially provides a tool to analyze mineral composition over a large grain size range.

2. Study area and sampling strategy

The study area is located in the uplands of the Sila Massif in northern Calabria (southern Italy) at altitudes between approx. 1150 and 1600 masl, characterized by a smooth topography with gentle hills and slightly incised streams in between. It has a typical Mediterranean humid–temperate upland climate, characterized by mean annual precipitation of 1400 to 1800 mm and mean annual temperature of 10–12 °C, with mean monthly temperatures ranging between -1 °C and 18 °C (cf. Scarciglia et al., 2012). The climatic and geomorphological conditions have caused deep and intense weathering of the respective bed rocks, which has been investigated in numerous weathering profiles (e.g. Le Pera and Sorriso-Valvo, 2000; Scarciglia et al., 2007), and is reflected in the sediments exported from the Sila Massif through the main drainage systems, i.e. the Crati and Neto River basins (e.g. Le Pera et al., 2001).

The Calabrian Massif constitutes an allochthonous crustal segment of the western Variscan belt in Europe, exposed in a structurally high position between the Alpine Mesozoic to Cenozoic sedimentary nappe piles of the Apennines to the North and the Maghrebides in Sicily to the Southwest (Ayuso et al., 1994; Graessner et al., 2000). The Sila Massif forms the northern part of the Calabrian Massif and is mainly composed of high-grade (granulite facies) metapelites in the West and Southwest, low to medium-grade metasedimentary rocks in the East, and the Sila Batholith comprising most of the central part of the Sila Massif (Fig. 1). Peak metamorphism is dated at around 300 Ma, roughly coeval to the Late Variscan intrusion ages of the batholith (Graessner et al., 2000). The Sila Batholith is a complex intrusive body composed of variable plutonic rocks that range from granites and granodiorites to tonalite, diorite, and even gabbroic rocks (Messina et al., 1991; Ayuso et al., 1994; Caggianelli et al., 1994). After intrusion the plutons cooled and were exhumed to mid-crustal levels in Permian to Triassic time (Ayuso et al., 1994; Graessner et al., 2000). Final exhumation of the Sila Massif is constrained by zircon and apatite fission-track analysis to Oligocene to Mid-Miocene time (35 to 15 Ma; Thomson, 1994). Late Pleistocene to Holocene catchment-averaged erosion rates for the flat uplands are low, scattering around 0.1 mm/a as inferred from cosmogenic nuclide data (Olivetti et al., 2012).

The samples were collected in June 2010 (RT3) and September 2013 (RT4). They derive from three different areas of the Sila Massif, which were selected to represent the diverse range of the Sila Batholith from felsic to basic plutonic rocks. From north to south, the first area is located to the northeast of Lago Cecita and exposes felsic rocks of granodiorite to monzogranite composition (i.e. cordierite-bearing biotite–muscovite granodiorite to monzogranite according to Messina et al., 1991; peraluminous granite according to Graessner et al., 2000). These rocks range in SiO_2 content from 68 to 74 wt.% (Ayuso et al., 1994) and constitute the most felsic sample suite, termed F2 (Fig. 1). The second area is located around Carlo Magno and Silvana Mansio north of Lago Arvo. It belongs to the widely exposed hornblende and biotite-bearing tonalites to granodiorites, which range in SiO_2 content from 60 to 71 wt.% (Messina et al., 1991; Ayuso et al., 1994). The selected area constitutes the felsic to intermediate sample suite, termed F1 (Fig. 1). Some bedrock samples of this area indicate a dominant composition of F1 bedrocks in the less felsic part of the tonalites to granodiorites with SiO_2 content around 61 to 62%. The third area is located directly northeast of Lago Arvo around the village of Rovale and exposes basic to intermediate rocks of the so-called Rovale Zone or Complex. This small area (~15 km^2) consists of gabbroic rocks (norites, amphibole gabbros; 42–49 wt.% SiO_2, 18–26 wt.% Al_2O_3) in its western part close to Rovale, while in its eastern part plagioclase and amphibole-rich diorites and tonalites prevail (52–57 wt.% SiO_2, 17–18 wt.% Al_2O_3), with small local gabbroic bodies (Caggianelli et al., 1994). This area constitutes the basic to intermediate sampling area of the study, termed B (Fig. 1).

Two types of samples have been collected: modern sediment from small proximal creeks (Sed, $N = 10$) as well as material from weathering profiles or grus exposed in roadcuts (WP, $N = 6$). Small creek means channel width less than 2 m. Sampling was intended to cover a broad grain-size spectrum from very coarse sand to clay from each sampling site. Therefore, Sed-samples may represent a mixture of up to three subsamples taken from a small area of no more than approx. 20 m^2. Grus samples were taken from the debris cones developed along roadcuts through deeply disintegrated granitoid bed rock. While sample suites F1 and F2 comprise both Sed and WP samples (altogether seven samples for each suite), only two sediment samples are available from sampling suite B (Table 1).

3. Methods

Samples were separated in up to eleven grain-size fractions ranging from very coarse sand (1 to 2 mm, $-1 < \Phi < 0$) to clay (<2 μm, $\Phi > 9$), with Φ being the negative logarithm of the grain diameter d to the basis of 2 ($\Phi = -\log_2 d$). Grain size separation was achieved in one-Φ-unit steps by wet sieving of the sand-sized fractions ($-1 < \Phi < 4$), and by gravity settling for all finer fractions ($\Phi > 4$). Each separation step of the fine-grained fractions in Atterberg-cylinders was repeated 8 to 14 times until quantitative separation of the respective grain-size fraction was achieved. The remaining suspension was vacuum-filtered through 0.2 μm cellulose acetate filters. Therefore, the finest fraction actually represents the grain size fraction $9 < \Phi < 12$.

Each sediment grain-size fraction was powdered, fused using lithium metaborate, and subsequently analyzed by X-ray fluorescence (XRF) method using a PANalytical AXIOS Advanced sequential X-ray spectrometer at the Geoscience Center Göttingen. All samples and grain size fractions were analyzed for ten major element oxides (SiO_2, Al_2O_3, TiO_2, $Fe_2O_3^{tot}$ = total iron calculated as Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5), the loss on ignition (LOI), and 16 trace elements (Ba, Co, Cr, Cu, Ga, Nb, Nd, Ni, Pb, Rb, Sc, Sr, V, Y, Zn, Zr). The RT4 samples were additionally analyzed for Ce, Hf, La, Mo, Sm, Th, U, and Yb. The elemental concentrations of all samples and grain-size fractions are available in the Supplementary data file.