# Miocene and Plio-Pleistocene volcanic rocks from two Neogene sub-basins of the Pannonian system (Styria and Carinthia): geochemical and Sr, Nd, Pb data, and geodynamic implications

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During the Neogene the Carpatho–Pannonian Region underwent major tectonic and magmatic events due to the combined effects of roll-back subduction of the European Plate under the Carpathians and the N–S shortening between the Adriatic and European Plates, to the west. The most evident results are the Carpathian thrust and fold belt, the Pannonian Basin and the associated volcanic activity. The volcanic activity can be divided into three phases: 1) widespread, but poorly studied acid volcanism began around 19 Ma ago in various sectors of the Pannonian Basin and was followed by 2) the formation of a calc-alkaline volcanic arc, active along the Western Carpathians and the northern part of the Eastern Carpathians from about 16 to 10 Ma ago; then the volcanism continued up to 0.2 Ma, shifting progressively southward along Eastern Carpathian arc; the origin of this continental margin arc is generally considered to be related to the Miocene subduction followed by detachment of the oceanic crust of the European Plate; 3) an "extension"—related Na-alkali basaltic volcanism phase which took place sporadically in the Pannonian Basin, from about 11–9 Ma up to the Pleistocene. The volcanism of the Styrian and Lavanttal Basins (Eastern Alps, Austria) occurred in Karpatian/Early Badenian–Middle Badenian (K/Ar ages: 16.3–14.0 Ma) and in Late Pliocene–Early Pleistocene (K/Ar ages: 3.8–1.7 Ma). According to the new petrographic, major (XRF), trace (XRF, INAA) element and Sr, Nd, Pb isotopic data carried out in this work on volcanics from most of the Miocene and Plio-Pleistocene centres, the petrogenetic affinity changed from orogenic-type in the Miocene (numerous2 outcrops and three boreholes from the Styrian Basin and one centre -Kollnitz- from the Lavanttal Basin) to anorogenic-type in the Plio-Pleistocene (numerous outcrops from the Styrian Basin).

The Miocene lavas have a variable serial affinity, ranging from high-K calc-alkaline (Kollnitz, Weitendorf, Mitterlabill) up to shoshonitic (Gleichenberg, Walkersdorf, Paldau). In the most voluminous Miocene volcano (Gleichenberg, 16.3–15.5 Ma) latites are the dominant lithotype; here trachytic and rhyolitic lavas occur locally. To the west, outcropping products are represented by relatively primitive (Mg# 66–70) high-K basaltic andesites/andesites (Kollnitz, 14.9 Ma) and high-K basaltic andesites (Weitendorf, 14.0 Ma). Boreholes samples are latites (Paldau and Walkersdorf) and high-K dacites (Mitterlabill). Incompatible trace element patterns of all the Miocene lavas, normalized to primitive mantle, show a moderate negative Nb-, Ta- and Ti-anomaly and high LILE/HFSE ratios, typical of "subduction-related" magmas. On geochemical basis, three groups of rocks can been distinguished: the first, Gleichenberg latites-trachytes and Walkersdorf latites, have negative Ba-anomaly with respect to Rb and Th; the second, Weitendorf high-K basaltic andesites, Paldau latites and Mitterlabill high-K dacites show a small negative Ba-anomaly. Otherwise they share similar incompatible trace element patterns, including a significant negative Eu-anomaly in chondrite-normalized REE diagrams. The rocks of these two groups,

all from the Styrian Basin, are geochemically distinguishable from the Lavanttal Basin volcanism, represented only by high-K basaltic andesites and a high-K andesite from Kollnitz. These latter have a marked positive Th-anomaly and a steep chondrite normalized REE pattern with a strong LREE enrichment without Eu-anomaly. The orogenic-type rocks of the Styrian and Lavanttal Basins (high-K calc–alkaline and shoshonitic series) are geochemically distinguishable from the orogenic-type volcanics (calc-alkaline and high-K calc–alkaline series) of the contemporaneous Western and Eastern Carpathian arcs, considered as the result of active oceanic subduction. The geochemical and petrological data so far obtained for the Miocene volcanics are compatible with a genesis by partial melting of a lithospheric mantle enriched by "subduction-related" components derived from the European lithosphere during the Paleogene N–S convergence which characterized the Eastern Alps/Westernmost Carpathian transect. Such a delayed melting of a recently enriched lithospheric mantle is considered to be related to Miocene extensional collapse of the Eastern Alpine chain leading to the formation of the Pannonian Basin. In the Styrian Basin, the occurrence of the orogenic-type volcanic activity during the climax of the rifting phase is in accordance with this hypothesis.

The studied Plio-Pleistocene volcanics are strongly silica-undersaturated and have a typical Na-alkaline affinity. They are mostly represented by lavas, except two vesiculated juvenile ejecta. Their compositional variation roughly range from nephelinites (Wilhelmsdorf and Steinberg), to basanites (Steinberg, Kloech, Kindsbergkogel, Riegersburg) and tephrites (Kalvarienberg). The overall incompatible element pattern of the Plio-Pleistocene lavas is within the range of OIB; they show an increasingly greater enrichment toward the most incompatible elements from P to Rb, which is in accordance with their strong silica-undersaturated character. In the Ba/Nb vs. K/Nb diagram these rocks plot in a narrow area, between the fields of Tristan da Cunha and St. Helena Islands. All these data are compatible with a derivation from low degrees of partial melting of an asthenospheric source. The isotopic data so far obtained are compatible with this conclusion.