# Volcanism and Submarine Sedimentation around Alps during Eo-Oligocene

Subjects: Geology

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Different magmatic systems developed during the Eo-Oligocene on and around the Alpine Belt, favouring the accumulation of thick volcanogenic submarine sedimentary sequences in the coveal foreland and foredeep basins.

periadriatic magmatism | northern alpine foreland basin | Northern Apennines | Taveyanne sandstones | Val d'Aveto–Petrignacola formation | SE France

## 1. Introduction

During the Eocene–Oligocene boundary, different magmatic systems developed in the Alpine belt, as testified by the large amounts of plutonic bodies and volcanic/volcanogenic sequences within and surrounding the main core of the belt (**Figure 1**). The deepest roots of such systems are included in the Periadriatic Magmatism (PM) plutons, whereas, on the surface, dykes crosscutting metamorphic and sedimentary units in the Southern Alps, and volcanic sequences of the Venetian Volcanic Province (VVP), the Biella Volcanic Suite (BVS), the Cerano–Mortara–Garlasco (CMG) volcanic centre and the Provence volcanoes (PV) represent the coeval surficial volcanic manifestations [1][2][3][4]. In addition, thick volcanogenic deposits in the foreland basins border the belt [5][6][7][8]. Within these latter sequences, some authors also include the volcanogenic turbidite system of the Val d'Aveto–Petrignacola Formation (APF) in the Northern Apennine Foredeep [9].

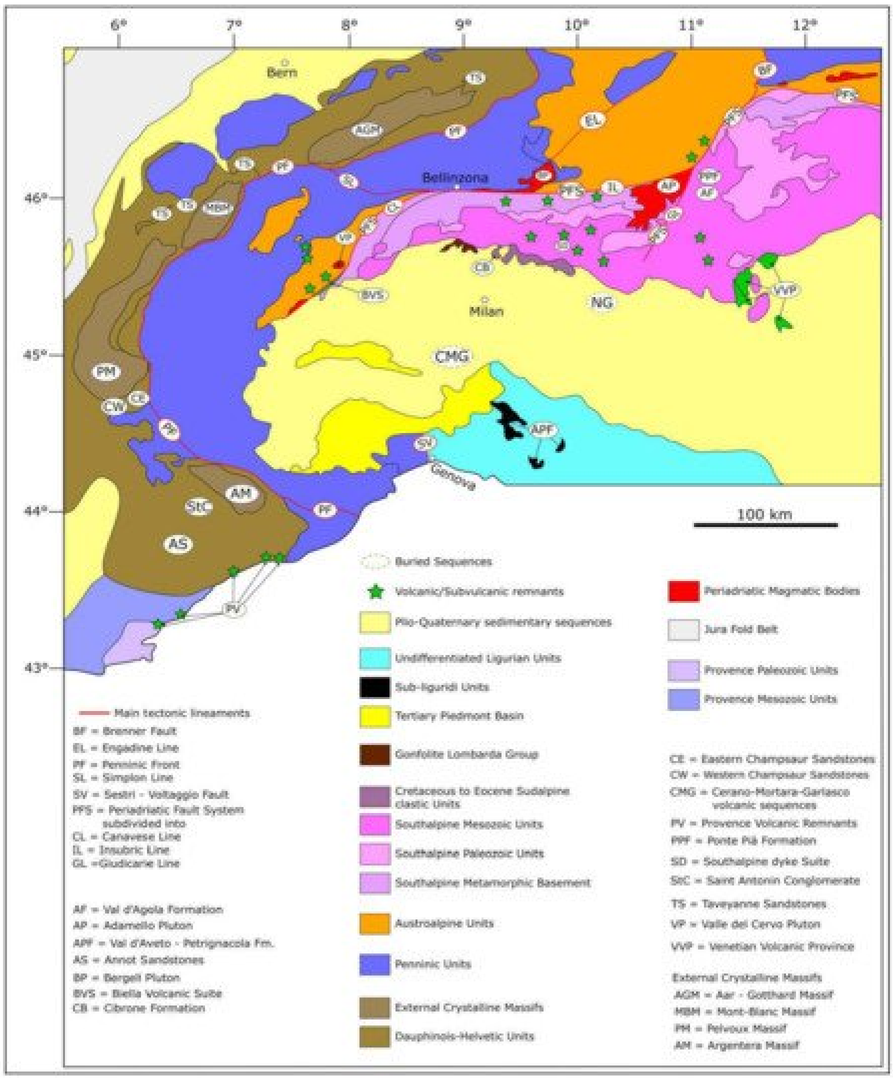


**Figure 1.** Geological map of the Alps, modified from [10][11][12].

# 2. The Source: Alpine Belt and Periadriatic Magmatism

## 2.1. The Alpine Belt

During the Eocene and the Lower Oligocene, only part of the modern Alpine belt was already exhumed and exposed to the surface. This part includes the central southern Alps, bordered to the west by the Canavese line (CL), to the north by the Insubric line (IL) and to the east by the Giudicarie line (GL) [4][13], the Sesia Lanzo block (NW of the CL (**Figure 1**)), although not rotated as currently [14][15], and the Austroalpine terrains in the Eastern part of Switzerland [12][16]. On the contrary, most of the Pennine nappes, including the Lepontine dome actually interposed between the Bergell pluton and the NAFB, were still involved in subduction [17]. In particular, it has been demonstrated that in the central part of the Alps, the Pennine nappes have been interposed between the Austroalpine domains and the Helvetic domain only at the end of the Late Oligocene–Early Miocene [16][17][18][19].

## 2.2. Plutonism

The most known expression of the Cenozoic magmatic activity in the Alps is represented by the large plutons aligned or near the PFS (**Figure 1** and **Figure 2**). Their emplacement was, in the beginning, considered as the crustal expression of a deep geodynamic mechanism known as slab break-off [20], and magmas ascended along the PFS [21]. In 2015, [22] postulated that the magmatic event was triggered by the retreat of the European slab and the progressive shift of the subduction partial melting zone from SE (Venetian area) to the orogeny before the slab break-off, on the base of geochemical and geochronological data on dykes of the Southern Alps. Currently, the work of [23] (and ref. therein), based on the tomographic images showing the unbroken European slab below the Adriatic plate, indicates that slab steepening, and not slab break-off, triggered the magma generation.

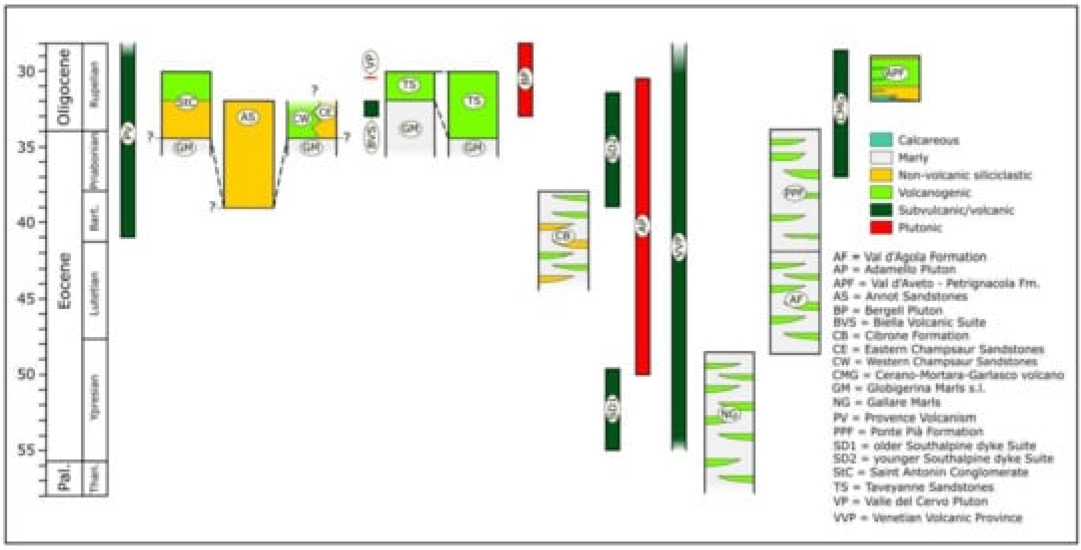


**Figure 2.** Magmatic manifestations and general stratigraphy of the sedimentary sequences included in the Northern Alpine Foreland Basin, Adriatic Foredeep and Northern Apennine Foredeep. Data from [1][2][5][9][11][24][25][26][27][28][29][30][31][32]. Shade sides mean that no temporal constraints are available.

## 2.3. Volcanoes and Volcanogenic Sequences

The surface expressions of the PM are scattered and/or badly exposed, and include dykes and subintrusive bodies, pyroclastic, hyaloclastite and volcanogenic deposits, as well as a volcanic edifice buried below the Plio–Holocene sediments of the Po Plain (the Mortara Volcano) (**Figure 1** and **Figure 2**). In general, dyke compositions strictly follow the geochemical compositions of the related plutons. Thus, they show a calc–alkaline to shoshonitic/ultrapotassic affinity, with a more heterogenous petrographic association in the Western Alps [33][34]. Only dykes magmatically related to the oldest suites of the Adamello show a tholeiitic to calc–alkaline association, which reaches high–k calc–alkaline affinity in the youngest dykes [22].

The Biella Volcanic Suite (BVS) includes volcanogenic deposits subaerially accumulated from 32.89 to 32.44 Ma on top of an Oligocene regolith, and [3][35][36] describe the suite as composed of dykes and remnants of explosive activity that accumulated thick volcanic breccia and tuff deposits. According to [14][15], after their emplacement, the BVS was tilted to SE with an angle of 60°.

Pluridecametric subintrusive bodies, feeding dykes and sills, crop out in the southernmost offshoots of the Alps (**Figure 1**). As described by [37] (and ref. therein), these bodies are characterized by porphyritic textures embedding plagioclase and hornblende as phenocrystals, and have a geochemical composition that ranges among andesite, trachyandesite and basalt.

# 3. The Sink: Alpine Peripheral Basins and Their Stratigraphy

## 3.1. The Northern Alpine Foreland Basin (NAFB)

In the NAFB, thick clastic sequences started to be accumulated at the end of the Eocene, closing the so-called Priabonian Trilogy on top of the (1) Nummulithic Limestones and the (2) Globigerina or Blue Marls [38][39][40]. Four clastic successions are grouped into four formations, named Annot Sandstones (Grés de Annot), Saint Antonin Conglomerate (Conglomérats de Saint Antonin), Champsaur Sandstones (Grés du Champsaur) and Taveyanne Sandstones (Grés de Taveyannaz) [5][6][7][39][41] (**Figure 2**).

The Annot Sandstones (Upper Eocene–Lower Oligocene) are exposed in the SE part of the French Alps and represent a nonvolcanic deep-water turbidite system, fed by detritus sourced from the Sardinia–Corsica margin and the Maures–Esterel Massifs [39].

The Saint Antonin Conglomerate (Upper Eocene to Lower Oligocene) crops out in the French Maritime Alps and consists of three coarsening-upward megasequences, formed of channelized conglomerates and massive sandstones with a total thickness of ca. 950 m ([5] and ref. therein). The lowermost megasequence has a genetic correlation with the Annot Sandstones and was accumulated in an open marine, outer shelf to the upper bathyal environment, whereas the other two members mark the progressive sea-level regression and the consequent infill of the basin [5].

The Champsaur Sandstones were accumulated in the homonymous basin developed SE of the Pelvoux Massif (Haute Alps Department), from the Uppermost Eocene to Lower Oligocene [7][42]. However, the large amounts of reworked fossils in the sediments make the lower boundary uncertain [25].

The Taveyanne Sandstones are widely exposed in the Alpine chain from SE France (Haute Savoie Department) to SE Switzerland (Canton of Graubünden) (**Figure 1**) [6][38]. They consist of volcaniclastic successions intercalated by thin marly beds, arranged in sedimentary architectures ascribed to different deep-water turbidite systems and related sub-environments accumulated from ~34 in SE Switzerland, ~32 in SE France to 29 Ma [26][43]. Volcanic pebbles were dated between 32.5 and 30.5 Ma with the $^{40}Ar/^{39}Ar$ method [26][44]. Detailed petrographic analyses of [6][8], as well as isotopes analyses of [7] on volcanic particles, reveal that the volcanic detritus was mixed with nonvolcanic detritus and both were sourced by syn-sedimentary volcanic edifices located along the PFS, together with the plutono–metamorphic terrains of the growing Alpine belt and the calcareous sequences of the Nummulite Limestones (**Figure 3**). These results have been later confirmed by U/Pb and geochemical analyses ($^{176}Hf/^{177}Hf(t)$ and Eu/Eu* ratios) on detrital zircons by [12][32][45]. In particular, the authors document that few are the magmatic zircons within the formation, characterized by two clustering ages around 41–29 Ma and 34–30 Ma in SE Switzerland and SE France, respectively. In SE Switzerland, the population is further subdivided into sandstone layers with zircon ages ranging from 41 to 32 Ma and a geochemical signature typical of the Adamello magmatic system, and sandstone layers with zircon ages ranging 33–29 Ma and a geochemical signature typical of the Bergell magmatic system. In SE France, magmatic zircons have a geochemical signature typical of the Biella magmatic system [12]. The interposed plutono–metamorphic basement sourced the nonvolcanic zircons [12][32][45]. According to [26], volcanogenic detritus is generally intermediate in composition, also comprising minor amounts of basic and acid terms (**Figure 4**). The positive relationship existing among bed thickness, bed grain size and content of volcanogenic particles (**Figure 5**) led to the identification of a volcanic control on the sedimentary system: During syn-eruptive periods, the rapid supply of volcanogenic detritus by the volcanic sources induced the accumulation of thick and coarse volcanogenic beds, whereas during noneruptive periods, the progressive decrease in sediment availability led to the drastic decrease in the accumulation of coarse-grained beds, favouring the accumulation of marly detritus [8].

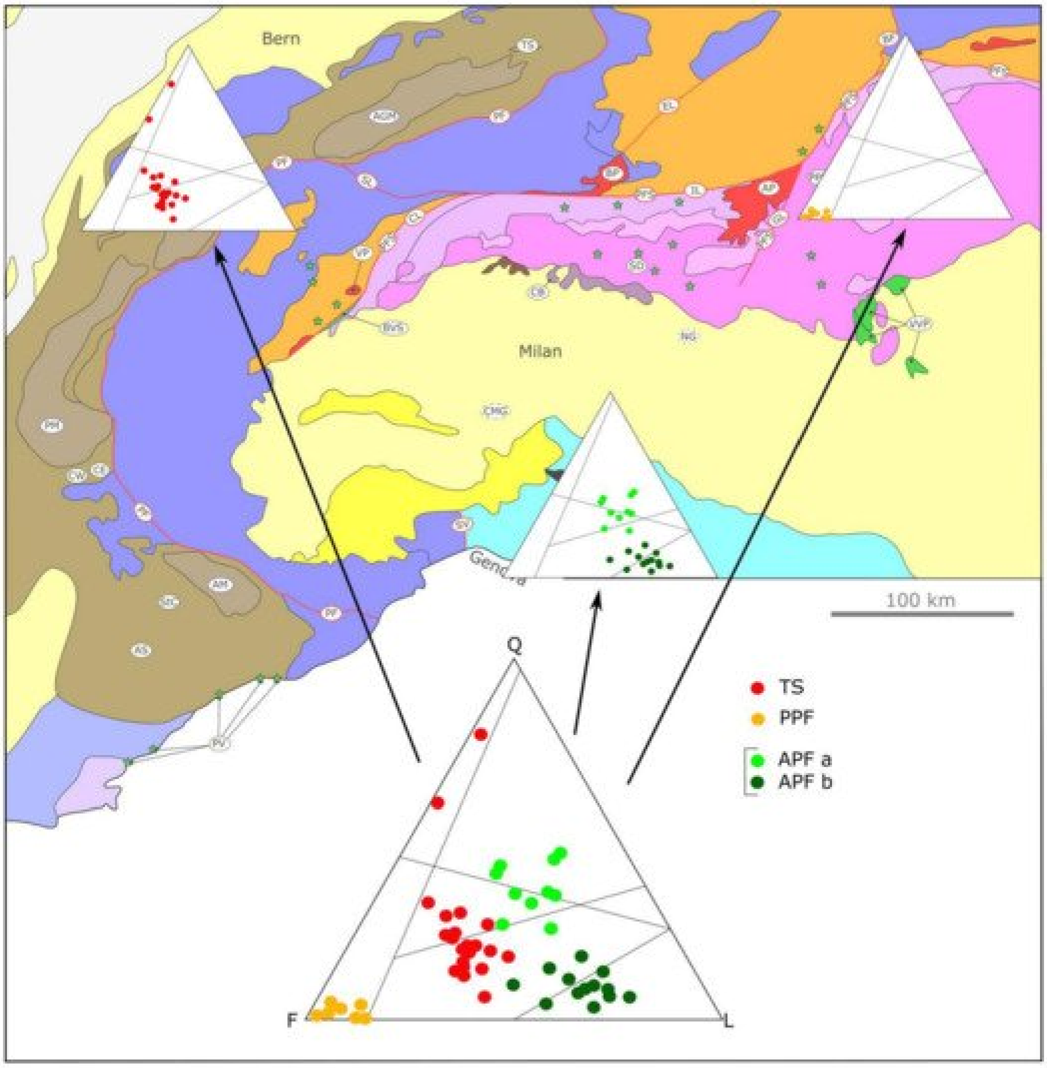


**Figure 3.** QFL$_{tot}$ diagrams. TS = Taveyanne Sandstones [26]; PPF = Ponte Pià Formation [27]; APF = Val d'Aveto–Petrignacola Formation nonvolcanic deposits (**a**) and volcanogenic deposits (**b**) [46].

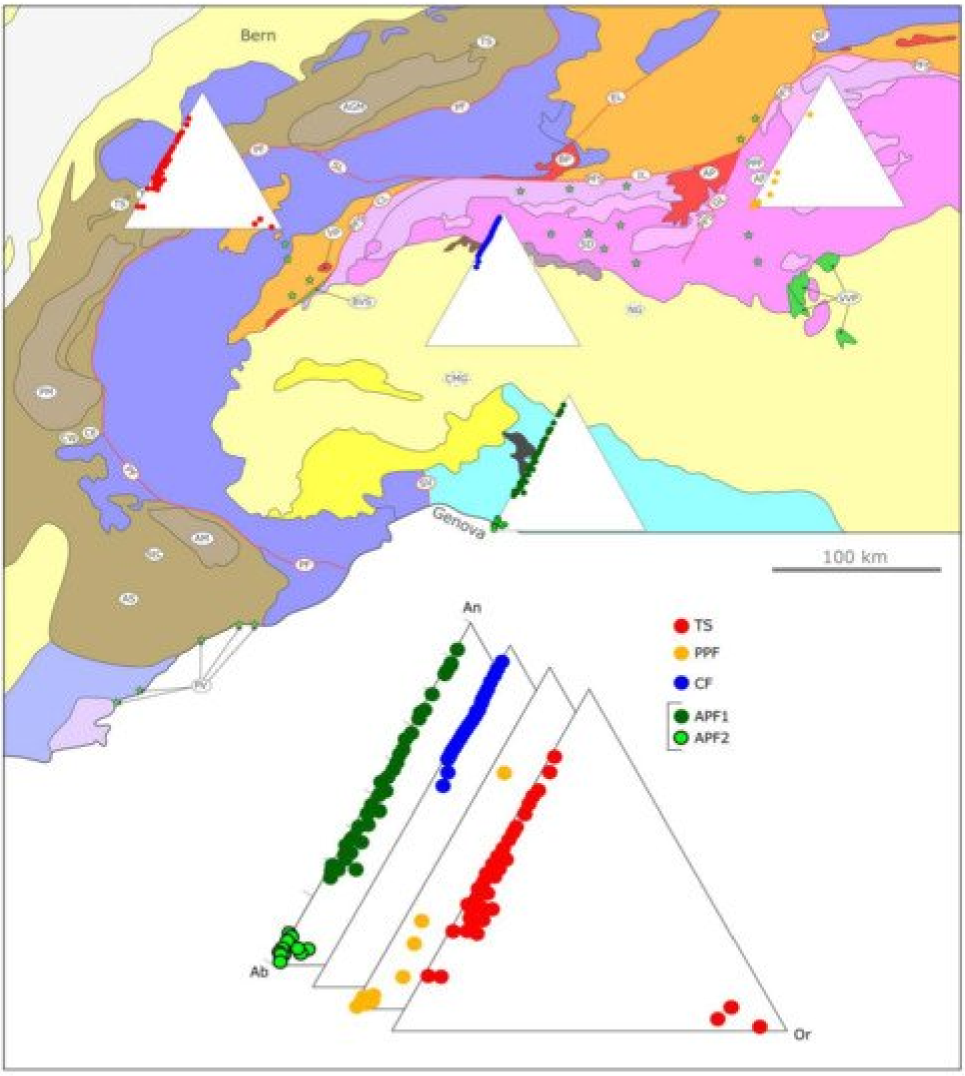


**Figure 4.** Compositions of feldspar crystals. TS = Taveyanne Sandstones [26]; PPF = Ponte Pià Formation [27]; CF = Cibrone Formation (this work); APF = Val d'Aveto–Petrignacola Formation (**1**) [31] and (**2**) (this work on pyroclastic density current deposit described by [47]).

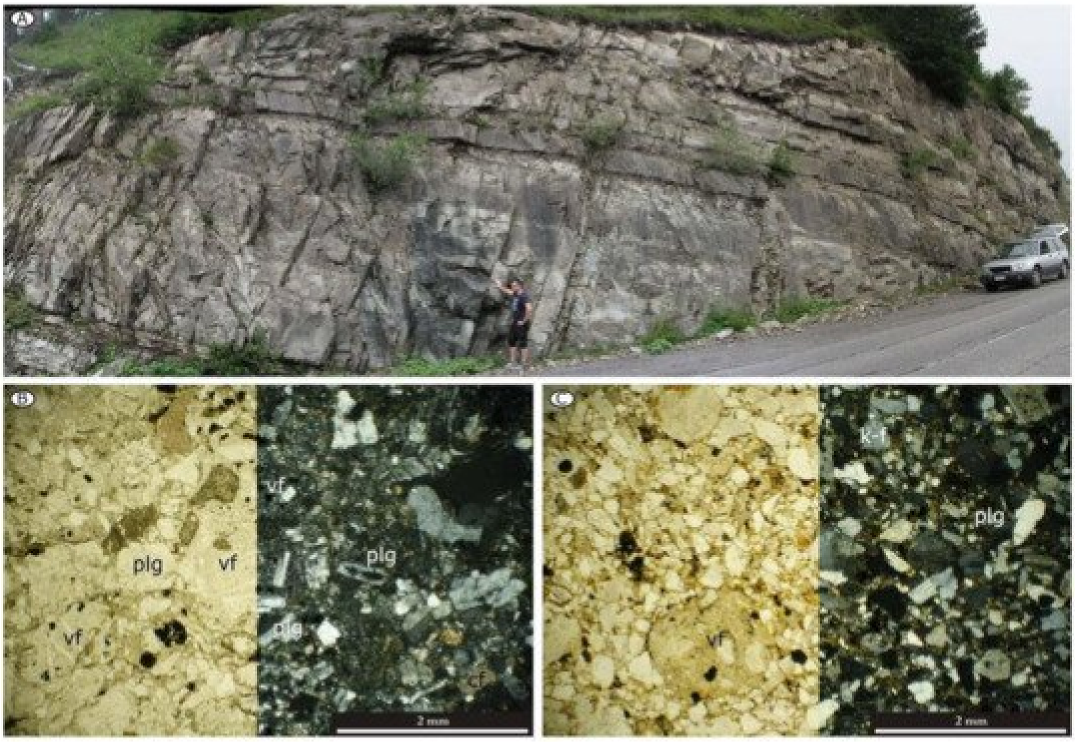


**Figure 5.** (**A**) A typical stratigraphic sequence of Taveyanne Sandstones in SE France, constituted of thick volcanogenic beds intercalated by thinner marly layers and nonvolcanic deposits. Dr. Crippa to scale. (**B**) Thin section of a syn-volcanic deposit, crossed nichols on the right. Large amounts of particles, plastically deformed, form a typical pseudomatrix and indicate a short time between the production of detritus and its accumulation underwater. (**C**) Thin section of a postvolcanic deposit, crossed nichols on the right. The presence of rounded particles indicates that detritus underwent to erosion and transport before the underwater accumulation. All the photos are modified from [8]. Plg = plagioclase; k-f = k-feldspar; vf = volcanic rock fragment; cf = calcareous rock fragment.

## 3.2. The Adriatic Foredeep

Differently from the NAFB, the Adriatic Foredeep received very few pulses of clastic sediments supplied by the Alpine Belt during the Eocene and the beginning of the Oligocene (Rupelian) starved stage of [19]. Sedimentation was mainly represented by marls and shales, locally interrupted by calcareous deposits fed by thrust-top carbonate platforms delimiting the interconnections between proximal and distal environments (e.g., Ternate-Travedona Formation in the Brianza area [48]; Pradelgiglio Formation in the Giudicarie Belt [49]). Occasionally, the marly sedimentation shows intercalations of coarse deposits whose siliciclastic detritus has an Alpine provenance fingerprint (cfr Montorfano Lariano Member of the Tabiago Formation in the Brianza area [50]; Val d'Agola Formation in the Giudicarie belt [51]). Volcanogenic sedimentation, preponderant in the NAFB, is here restricted to scattered and spatially limited deposits included into the Cibrone Formation (Brianza Area), the Val D'Agola and Ponte Pià Formations (Giudicarie Belt), and the Borgosatollo 01 and Chiari 01 wells (**Figure 1** and **Figure 2**) [1][2][27][30][51][52].

The Cibrone Formation, accumulated on top of the Tabiago Formation in the Brianza area (**Figure 1** and **Figure 2**) is a marly sequence in which frequent fine sandstone turbidite layers are intercalated [50][52] (**Figure 6**). Some of these turbidite layers are defined as plagioclase-arenite by [53][54], because they are mainly constituted of fresh and euhedral single minerals of plagioclase, with subordinate volcanic rock fragments and single minerals of amphibole, biotite and opaques [54]. Among opaques, spinel minerals have mantle origins and were transported to the surface by syn-sedimentary mafic to intermediate volcanic rocks [52]. WDS geochemical data presented in this work agrees and expands the previous data of [54], showing that plagioclase minerals have a composition ranging from bytownite to labradorite (**Figure 4**).

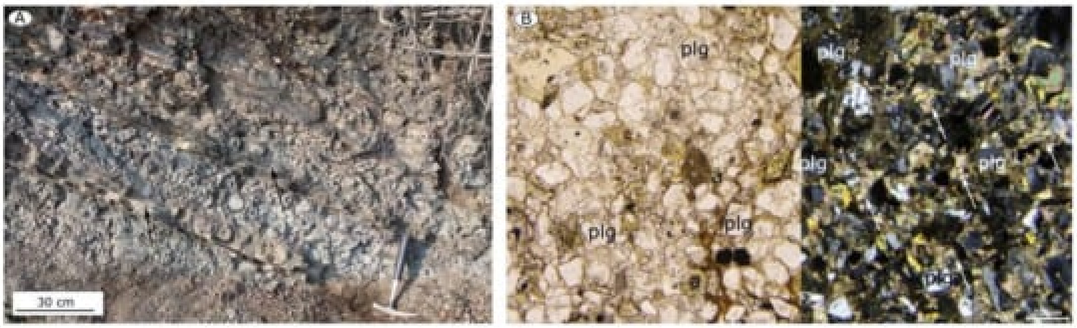


**Figure 6.** (**A**) Thin-layered volcanogenic sandstones (black arrows) in the marly sequence of the Cibrone Formation. (**B**) Thin section of a volcanogenic sandstone layer of the Cibrone Formation, crossed nichols to the right. Note the large amount of secondary calcite (white arrows) and zoned plagioclase minerals (plg). A = amphibole.

The Val d'Agola and Ponte Pià formations have a stratigraphic sequence similar to that of the Cibrone Formation, but the volcanogenic sandstone successions, comprised of the hemipelagic marly deposits, could reach 20 m in thickness [2][27] (**Figure 1** and **Figure 2**). Furthermore, the Val d'Agola Formation also includes conglomerates with andesite olistoliths and few volcanic layers defined as "lavas" by [2]. The volcanogenic deposits are turbidite and submarine mass-flow deposits, whose detritus is enriched in single minerals of plagioclase (up to 50%), minor volcanic rock fragments (some of them produced by subaqueous eruptions), heavy minerals often chloritized (biotite, amphibole, opaques), and rare accidental quartz [2][27] (**Figure 3**). U/Pb ages on detrital zircons of [32][45] indicate a syn-sedimentary volcanic source providing detritus to the foredeep sequences. Geochemical analyses (**Figure 4**) reveal that the volcanic detritus has affinities with the Re di Castello pluton (part of the Adamello batholith) and associated dykes, with minor contributions from the VVP for the older terms ([2][32][45].

## 3.3. The Northern Apennine Foredeep

As in the Adriatic Foredeep, the Eocene sedimentary record of the Northern Apennine Foredeep basin was characterized by the accumulation of muddy, marly and calcareous sediments with rare sandy intercalations (e.g., Argille e Calcari di Canetolo, Flysch di Vico [46]). According to [55] (and ref. therein), in fact, most of the terrigenous supply coming from the Ligurian Alps and Corsica was trapped into the piggyback basins interposed between the Ligurian–Penninic orogenic wedge and the foredeep basin. In these basins, also rare volcaniclastic intercalations occur during the Middle Eocene (Montepiano Marls) and the Early Oligocene (Ranzano Formation) [54]. These volcaniclastic layers are constituted of fresh and euhedral single minerals of plagioclase, variable amounts of ferromagnesian minerals (biotite, amphibole and opaques), rare volcanic rock fragments and volcanic quartz [54].

In the foredeep basin, instead, the first massive clastic inputs began the accumulation during the Oligocene (ca. 32 Ma, Rupelian), and led to the progradation of the nonvolcanic turbidite system of the lower part of the APF [29][31][46]. The APF has a complex stratigraphy, and its products are not limited to siliciclastic deposits [46][56]. At the bottom, a thick sequence of calcareous turbidites interfingering with fine drapes of varicoloured claystones opens the sedimentary sequence. Above it, thick packages of sandstones and conglomerates are arranged in channel and overbank deposits [56]. These sediments are mainly composed of metamorphic (quartzites, ortogneiss, paragneiss, amphibolite micaschists and rare metagabbros), non-coeval magmatic (granite, pegmatite, dacite, slightly metamorphosed rhyolite and andesite) and minor sedimentary detritus (**Figure 3**) [31][46][56]. As indicated by [56], Sardinia–Corsica block, SE France (Provence area) and Ligurian Alps are the most suitable areas from where the detritus came during the Oligocene. According detrital U/Pb zircon ages, [9] indicate that the Alps were the only source of the APF detritus. At around 31.09 ± 0.30 Ma (U/Pb on zircons [9]) until 29.2 Ma ($^{40}Ar/^{39}Ar$ age on a volcanic clast [57]), large volumes of volcanogenic detritus started to feed the turbidite system, overwhelming and/or mixing with the nonvolcanic supply [31][46]. Documented also by [47][56], for the first time, an almost 60 m-thick sequence of channelized pyroclastic density current deposits (from a metre to several metres thick) overlain by a debris avalanche deposit (**Figure 3**, **Figure 4** and **Figure 7**).

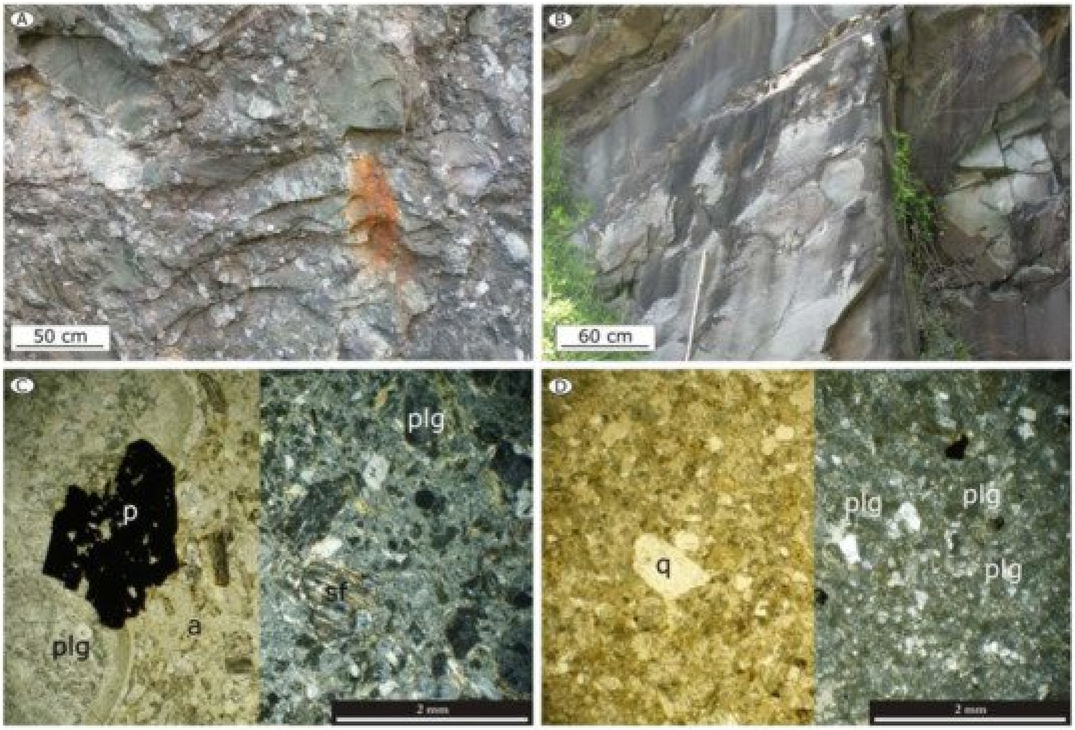


**Figure 7.** (**A**) Coarse-grained pyroclastic density current deposit of the Val d'Aveto Formation–Petrignacola Formation. (**B**) Thick volcanogenic sandstones of the Val d'Aveto–Petrignacola Formation. (**C**) Thin section of a pyroclastic density current deposit of the Val d'Aveto–Petrignacola Formation, crossed nichols on the left. (**D**) Thin

section of a volcanogenic sandstone of the Val d'Aveto–Petrignacola Formation, crossed nichols to the left. Large amounts of particles, plastically deformed, form a typical pseudomatrix and indicate short time between the production of detritus and its accumulation underwater. All the photos are modified from [56]. Plg = plagioclase; p = pyrite; q = quartz; a = amphibole; sf = phengite-bearing schist rock fragment.

# 4. Reassessing the Source-to-Sink System

*Most of the volcanic sources and their primary connections with depocenters have been, in fact, completely disarticulated or deleted by the post-Rupelian evolution of the belt. Close to the thick outcropping volcanogenic successions, almost no volcanic features have been recognized. On the contrary, where volcanogenic detritus is restricted to thin and scattered layers, volcanic features are represented by small volcanic bodies and effusive products accumulated on top of the Mesozoic sequences or the Hercynian basement. These differences, inherited from the different tectonic evolution between the Northern and the Southern Alps across the PFS, pushed Alpine geologists to identify in the large Periadriatic plutons the deep roots of ancient volcanic edifices unroofed during the Chattian, which would have been the only sources of volcanogenic detritus for the entire foreland basins around the Alps [58]. This hypothesis has consequently influenced the reconstruction of the pathways that supplied the volcanogenic detritus to the NAFB, the Adriatic and the Northern Apennine foredeeps (e.g., [6][9][59]).*

## 4.1. The Adriatic Foredeep

Although efficient to unravel the Alpine chain exhumation history, this oversimplification left along its path many clues fundamental in the reconstruction of volcanogenic aprons and their feeding systems. Combining stratigraphy with geochemical, petrographic and geochronological data, it is recognized that the first volcanogenic aprons and volcanic manifestations occurred in the Adriatic Foredeep. In the eastern part of the basin, volcanogenic aprons (Ponte Pià and Val d'Agola formations) were directly fed by the submarine eruptions of the VVP and eruptive centres related to the older suites of the Adamello [2][45] (**Figure 8**). To the west, the volcanogenic detritus of the Cibrone Formation was accumulated in the central part of the Adriatic Foredeep (accounting the biostratigraphic age of [35]). The abrupt incoming of volcanogenic detritus in the basin represents, for the Cibrone Formation, a proof that volcanism and sedimentation were contemporaneous [77]. Therefore, these volcanogenic layers could be considered as crystal-rich tuffs, according to [66], and consequently interpreted as the product of pyroclastic density currents accumulated underwater [78] or their rework [79]. Although source is still uncertain, the occurrence of Cr-bearing spinels in the volcanogenic sediments, typical of basaltic to andesitic magmas from harzburgites of a Supra–Subduction Zone [65], might suggest that the volcanogenic detritus was originated by small eruptive centres on top of the subintrusive bodies described by [42] in the Southern Alps. These hypothetical eruptive centres were subsequently eroded, as such kind of volcanic morphologies are generally highly prone to erosion [80,81]). In addition, all the Cretaceous to Paleocene sequences actually interposed between the potential source area and the Cibrone depocenter have been structured, together with the same Cibrone Formation, only starting from 34 Ma [13]. This would imply that the biostratigraphy ages of [35] correspond to the depositional age of the Cibrone Formation and give a temporal constraint to the volcanic source, which therefore was not the Bergell magmatic system, in disagreement with [68] (**Figure 8**). On the other hand, if the ages provided by [68] are the correct ones, the tectonic event involving the Cretaceous to Paleogene pile must be postdated, but provenance from the Bergell magmatic system remains difficult to explain according to the paleocurrent directions [64].

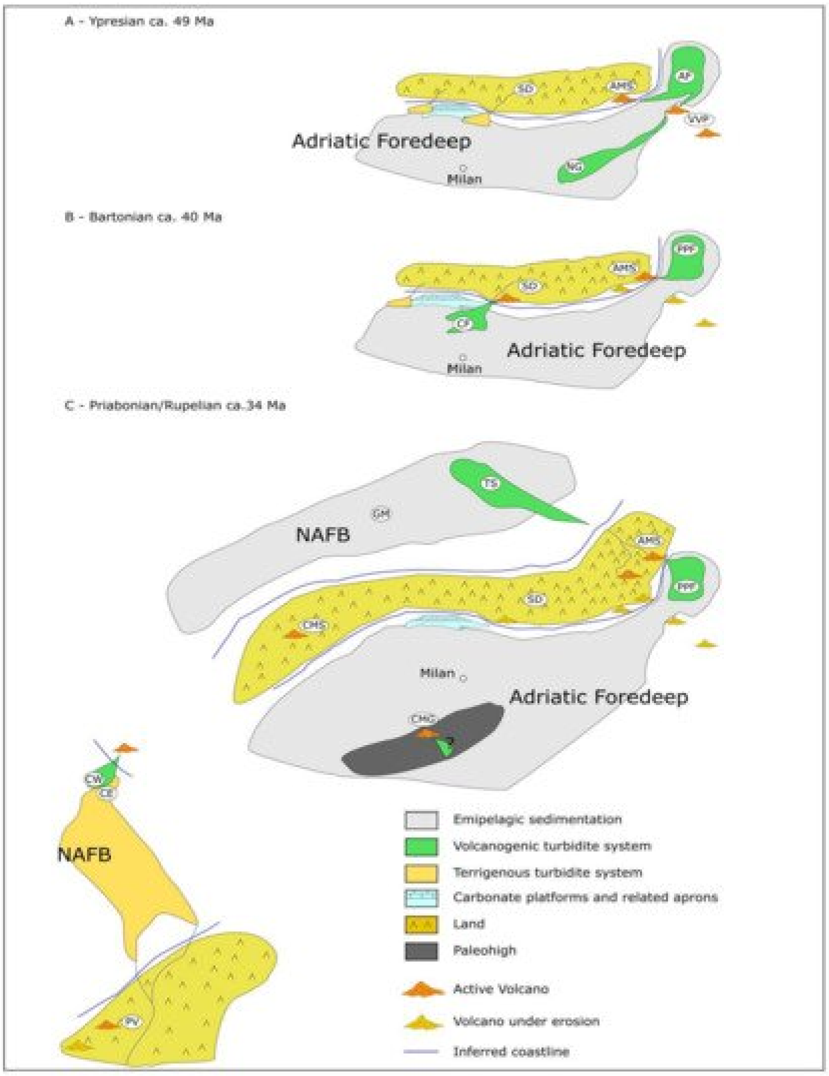


**Figure 8.** Paleogeographic reconstruction of the source-to-sink systems around the Alps during the Ypresian (ca. 49 Ma - SD = southalpine dykes; AMS = Adamello Magmatic System; AF = Val d'Agola Formation; VVP = Venetian Volcanic Province; NG = Gallare Marls), during the Bartonian (ca. 40 Ma, CF = Cibrone Formation; PPF = Ponte Pià Formation), and during the boundary between Priabonian and Rupelian (ca. 34 Ma, NAFB = Northern Alpine Foreland Basin; TS = Taveyanne Sandstones; GM = Globigerina Marls; CMS = Biella Magmatic System; CMG = Cerano-Mortara-Garlasco volcano; CW = Western Champsaur; CE = Eastern Champsaur; PV = Provence Volcanoes).

## 4.2. NAFB and the Source-to-Sink System

In the NAFB, volcanogenic sedimentation began later than in the Adriatic Foredeep, from ~34 Ma, according to the biostratigraphic constraints of [26][60][43] (**Figure 8**). Therefore, geochronological ages on the volcanogenic detritus reveal that only part of the detritus was coeval to sedimentation, whereas the other part derived from the accumulation after processes of weathering/erosion and transport of previous volcanic successions and related magmatic bodies. In the basin where the Taveyanne Sandstones (TS) (**Figure 8**) were accumulated, volcanic pebble ages support the hypothesis of a volcanic control on sedimentation. Magmatic zircon populations add spatial and temporal constraints on the volcanic source. All the zircon populations of [32] share the “34–32 Ma ages”. In SE Switzerland, the progradation of volcanogenic successions was controlled by the volcanic centres located in the Northern Adamello area, together with those in the Bergell area from 33 Ma. The net distinction among sandstones with Adamello geochemical signature and Bergell geochemical signature [32] clearly indicates that in the basin two distinct turbidite systems were accumulating. The turbidite system supplied by the Adamello magmatic system (AMS) (**Figure 8**) received a mix of syn-volcanic and post-volcanic detritus (sensu [61]), as shown by zircon ages with AMS geochemical signature (from 41 to 32 Ma [32]). Part of the volcanic detritus was generated and accumulated into the basin from active volcanic centres (syn-volcanic detritus), whilst part of the magmatic detritus was produced by the erosion of older volcanic centres and related intrusive bodies located in the southern part of the Adamello magmatic system (post-volcanic detritus). This latter hypothesis is supported by ages and geochemical signatures of the older (up to 41 Ma) magmatic zircons comparable to those of the magmatic zircons in the Val d’Agola Formation, according to [32][45].

### 4.3. The Northern Apennine Foredeep

The recognition of the magmatic system sourcing the volcanogenic sequences of the APF is a fascinating problem that attracted many authors in the past decades [9][31][57][56]. The counterclockwise rotation of the Apennine belt consequently to the opening of the Tyrrhenian sea [62] further complicates this recognition. In addition, the different geodynamic reconstructions provided through the years further complicate the efforts in the repositioning of the sedimentary units where they were accumulated ([63] and ref. therein). Nevertheless, some constraints could be found matching the large amount of data available in the literature, indicating the SE France volcanism as the best place from where volcaniclastic detritus came from (**Figure 9**).

## 5. Concluding Remarks

The review presented here offers a first 4D model describing the evolution of the source-to-sink systems in relation to the evolution of the magmatic systems grown within the Alps across the Eo–Oligocene boundary. From the Eocene (**Figure 8**), the activation of the magmatic feeding systems in the Southern Alps, the southern Adamello and the VVP, favoured the accumulation of volcanogenic sequences in all the Adriatic Foredeep. Looking at the volcanic successions and volcanogenic deposits, it is possible to speculate that part of the volcanic activity was subaerial, supplied by littoral and/or island volcanoes, and part was submarine. In addition, it is possible to infer that volcanogenic successions now forming the Cibrone Formation were probably supplied from eruptive centres located in the central Southern Alps (east to the Cibrone Formation). Then, the progressive northward migration of the magmatic sources activated the accumulation of volcanogenic sequences in the Swiss NAFB. The acme of the volcanic activity occurred at 32 Ma, when a drainage pattern allowed the transport of the volcanogenic detritus of the Biella and Bergell plutons to the French NAFB, whereas the Provence volcanism, together with putative local sources near the Pelvoux Massif, fed the western part of the NAFB. During this period, volcanoes were on land, some near and some far away from the shoreline, as testified by the presence of pyroclastic density currents subaqueously emplaced [8]. At ~30 Ma (**Figure 9**), volcanogenic detritus also reached the Northern Apennine Foredeep. The palinspastic reconstructions proposed by [64][65] definitively exclude the Alps from the potential sources, demonstrating that no interconnections existed between the Adriatic Foredeep and the Northern Apennine Foredeep. The nonvolcanic detritus preserved in the APF points to a provenance from SW, supplied by the Ligurian–Penninic orogenic wedge. This would suggest that the SE France volcanism could be a good potential source for the volcanogenic material, but further work needs to confirm this hypothesis.

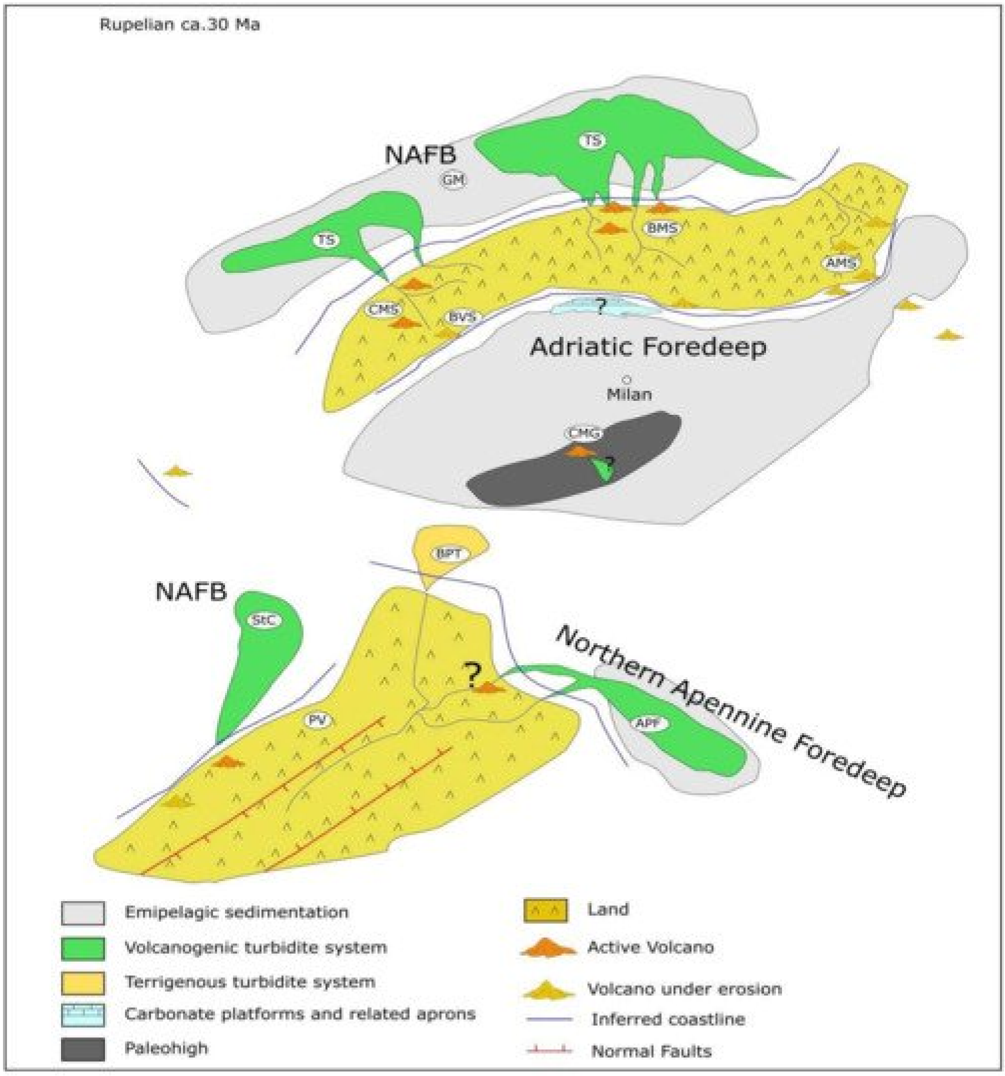


**Figure 9.** Paleogeographic reconstruction of the source-to-sink systems around the Alps during the Rupelian (ca. 30 Ma), NAFB = Northern Alpine Foreland Basin; AMS = Adamello Magmatic System; NG = Gallare Marls; TS = Taveyanne Sandstones; GM = Globigerina Marls; CMS = Biella Magmatic System; BVS = Biella Volcanic Suite; CMG = Cerano-Mortara-Garlasco volcano; CW = Western Champsaur; CE = Eastern Champsaur; StC = Saint Antonin Conglomerate; BPT = Tertiary Piedmont Basin; APF = Val d'Aveto–Petrignacola Formation; PV = Provence Volcanoes. Question mark indicates a putative volcano isolated according to [31], but genetically related to the Provencal volcanism [56], feeding the APF.

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