

CatVolc: A new database of geochemical and geochronological data of volcanic-related materials from the Catalan Volcanic Zone (Spain)

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ABSTRACT

The Catalan Volcanic Zone (CVZ) (NE Spain) consists of an intraplate alkaline volcanic zone associated with the opening of the Western Mediterranean and the development of the European Rift System. Volcanic activity in the CVZ started in the L'Empordà area (ca. > 12–8 Ma), extended to La Selva (7.9–1.7 Ma), and finally migrated to the Garrotxa Volcanic Field (< 0.7–0.01 Ma). Despite the scientific interest in the CVZ since the early 19th century, certain aspects remain poorly constrained. These include a full understanding of the spatial and temporal evolution of the magma plumbing system(s) and ascent mechanisms, as well as the chronology of volcanism across the CVZ. Addressing these unresolved questions requires geochemical, petrological, and geochronological data, which, in the case of the CVZ, are scattered and have never been integrated or analysed within a unified framework. Here, we present the CatVolc (Catalan Volcanism) database, which compiles available geochemical and geochronological data of volcanic-related materials from the CVZ. The current version of the database contains geochemical analyses from 405 rock samples (296 juvenile magmatic rocks -including lavas and pyroclasts- and 109 xenoliths), and radiometric/thermoluminescence dating data from 57 rocks (55 volcanogenic and two dykes), 4 paleosols samples developed between volcanic deposits and 1 sample from sediments. For each sample, the CatVolc database lists general information about the sampling site, sample lithology, whole-rock analyses (including major and trace elements), isotopic ratios, mineral chemistry, and radiometric/thermoluminescence dating information, if available. A preliminary analysis of the information contained in the CatVolc database highlights the critical limitations of the current state of knowledge and allows suggesting potential future directions for volcanic-driven investigations in the CVZ. Additionally, the results obtained validate the CatVolc database as a key tool for comprehending the spatial and temporal evolution of the magmatic system(s) and volcanic activity in the CVZ, particularly in the Garrotxa Volcanic Field. This aspect is critical for advancing in the assessment of the volcanic hazards in the region and for gaining a comprehensive understanding of future volcanic activity.

1. Introduction

In recent decades, volcanic eruptions have become a major threat due to population growth and increased human settlements in volcanically active regions. Consequently, important efforts are being made to assess volcanic hazards and to develop appropriate hazard and risk maps

(e.g., Cioni et al., 1999; Lirer et al., 2001; Siebe and Macías, 2004; Martí et al., 2008, 2012). In this context, the analysis of past eruptive behaviour through the study of the geological record is key to better define possible forthcoming volcanic activity and estimating its potential impact. Traditionally, volcanic hazard assessments have focused on stratovolcanoes or compound volcanoes, and monogenetic volcanic

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fields have often been overlooked as potentially dangerous (Kereszturi et al., 2013, 2014). However, recent volcanic crises such as the 2021 Tajogaite (Cumbre Vieja) eruption in La Palma (Canary Islands, Spain) or the 2023 Sundhnúksgrár eruption (Iceland) have raised awareness of the significant potential destructive capacity of monogenetic volcanism. These latter events have emphasized the need to further advance the geological and geophysical knowledge of monogenetic fields to better understand their origin and evolution. Moreover, these crises have underscored the importance of accurate hazard assessments and effective monitoring strategies as essential mitigation measures to reduce the potential risk associated with volcanic events.

The Catalan Volcanic Zone (CVZ) (NE Spain) is one of the many manifestations of intraplate alkaline magmatism occurring in western and central Europe from the Miocene until the present (Fig. 1) (Wilson and Downes, 1991, 1992). Volcanic activity in the CVZ started in the L'Empordà area (>12–8 Ma), migrated south-westwards into La Selva (7.9–1.7 Ma) and then to the northwest, developing the Garrotxa Volcanic Field (GVF) (< 0.7 Ma) (Araña et al., 1983; Martí et al., 2011), which is officially considered to be volcanically active (Official Bulletin of the Spanish State (BOE-A-2013-1421) of 11 February 2013) (Fig. 2). Recently, Iriarte et al. (2023) analysed a 15 m long paleolake core in the GVF (Vall d'en Bas area, Fig. 2) covering the Late Pleistocene-Holocene transition. Thirty tephra layers detected in this core suggest an intense volcanic activity from 13.5 to 8.3 ka. Although these ages evidence early Holocene volcanic activity, at present, there is no direct correlation between these tephra layers and the volcanic deposits or eruptive vents in the GVF.

The GVF represents a good example of demographic expansion over a monogenetic field since the last known eruption occurred ~10.4–15.7 ka ago (Bolós et al., 2014a; Guerin et al., 1985; Puiguriquer et al., 2012). In particular, the southern part of this volcanic field, where the largest and most explosive volcanoes are located (e.g., Crosa de Sant Dalmat maar and Puig d'Adri), is near large population settlements (e.g., Girona ~102,000 inhabitants, 2022 population; Statistical Institute of Catalonia, <https://www.idescat.cat/>) and infrastructure (e.g., Girona-Costa

Brava International Airport, high tension line(s)) (Fig. 2) (Bolós et al., 2012; Pedrazzi et al., 2014, 2016, 2022).

Since the early 19th century, the CVZ has been a subject of scientific interest (e.g., Lyell, 1833). In recent decades, research has focused on determining the characteristics and evolution of all three volcanic areas (e.g., Cebriá et al., 2000; Cimarelli et al., 2013; Galán and Oliveras, 2014), as well as the temporal framework of magmatic and volcanic processes (e.g., Donville, 1976; Guerin et al., 1985). Special attention has been given to their relationship with the evolving geodynamic setting in the NE of the Iberian Peninsula, the Western Mediterranean and the European Rift (e.g., Araña et al., 1983; Martí et al., 1992; Martí and Bolós, 2019). Nonetheless, some important aspects related to the GVF magma feeding system that may help understand the evolution, dynamics, and eruptive recurrence of the volcanic field remain unsolved. Such open questions require geochemical, petrological, and geochronological data that, in the case of the GVF, are dispersed and have neither been merged nor analysed within a common framework.

Here, we present the CatVolc (Catalan Volcanism) database, which compiles available geochemical and geochronological data of volcanic-related materials (i.e., juvenile magmatic rocks and xenoliths found in diverse volcanic deposits) of the CVZ. By analysing the content of the CatVolc database, we can assess the quality and representativeness of existing information while identifying current information gaps. The CatVolc database also seeks to become a key tool for studying the magmatic origin and evolution of the GVF within the regional context of the CVZ and to provide support for future volcanic hazard assessment studies in the area.

The CatVolc database will be continuously updated through a collaborative effort involving the Faculty of Earth Sciences of the University of Barcelona, the Applied Volcanology Team at Geosciences Barcelona (Geo3BCN – CSIC), the Institut Cartogràfic i Geològic de Catalunya (ICGC, <https://www.icgc.cat>), and the Garrotxa Volcanic Zone Natural Park. The latest version of the database is freely accessible for download from the Zenodo open-access repository (Miranda-Muruzábal et al., 2023; <https://doi.org/10.5281/zenodo.8332518>), ensuring full accessibility to the scientific community and the general public.

2. Geological setting

Neogene-Quaternary alkaline volcanism in western-central Europe is related to the European Cenozoic Rift System (ECRS), which comprises a complex and continuous network of rifts extending from the North Sea to the Rhone depression in the western Mediterranean (Ziegler, 1992) (Fig. 1). Southwards, in the Iberian Peninsula, the ECRS continues along the Spanish Mediterranean coast to the Alboran Sea including the Valencia Trough, the eastern sector of the Betic Cordillera, and the Campo de Calatrava Volcanic Field (Martí et al., 1992; Martí and Bolós, 2019; Planagumà-Guàrdia et al., 2022). The prevailing hypothesis suggests that the central and northern segments of the ECRS are related to a passive rifting model associated with the main and late phases of the Alpine orogeny and the primary folding phase of the Pyrenees (e.g., Dèzes et al., 2004; Ziegler, 1992). Conversely, the southern propagation of the rift began during the Late Oligocene to Early Miocene and is associated with back-arc extension resulting from the rollback of the Tethys subducting slab beneath the continental lithosphere of Iberia and Europe (e.g., Roca, 2001; Séranne, 1999) and the opening of the western Mediterranean (e.g., Carminati et al., 2012; Lustrino, 2000; Lustrino and Wilson, 2007).

The Valencia Trough is a NE-SW oriented basin located between the Iberian Peninsula and the Balearic promontory (Banda and Santanach, 1992; Martí et al., 1992). The western side of this basin corresponds to the Catalan-Valencian domain, which includes the Catalan Coastal Ranges, the south-eastern part of the Iberian Range, and the northern and western sectors of the offshore basin (Martí et al., 1992) (Fig. 1). This domain is characterised by extensional tectonics, which have given

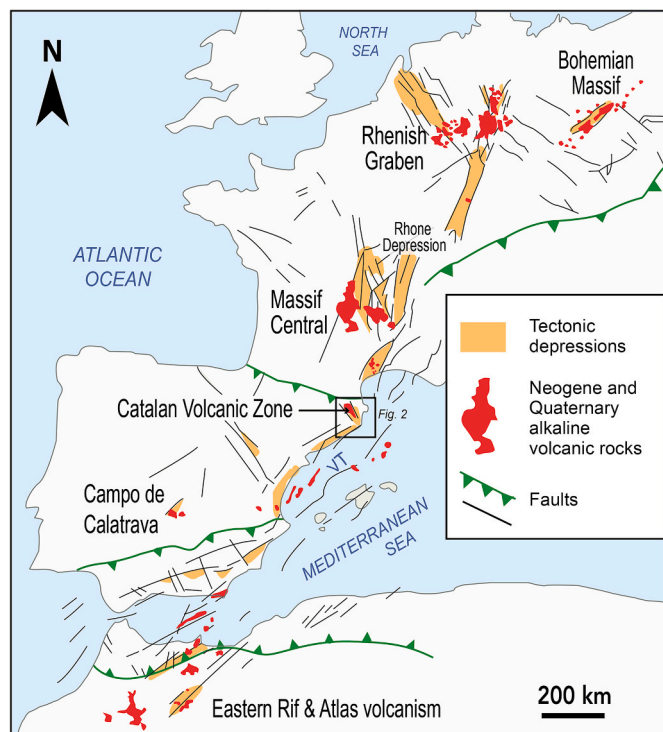


Fig. 1. European Cenozoic Rift System and its main alkaline volcanic provinces (modified from Martí and Bolós, 2019). VT: Valencia Trough.

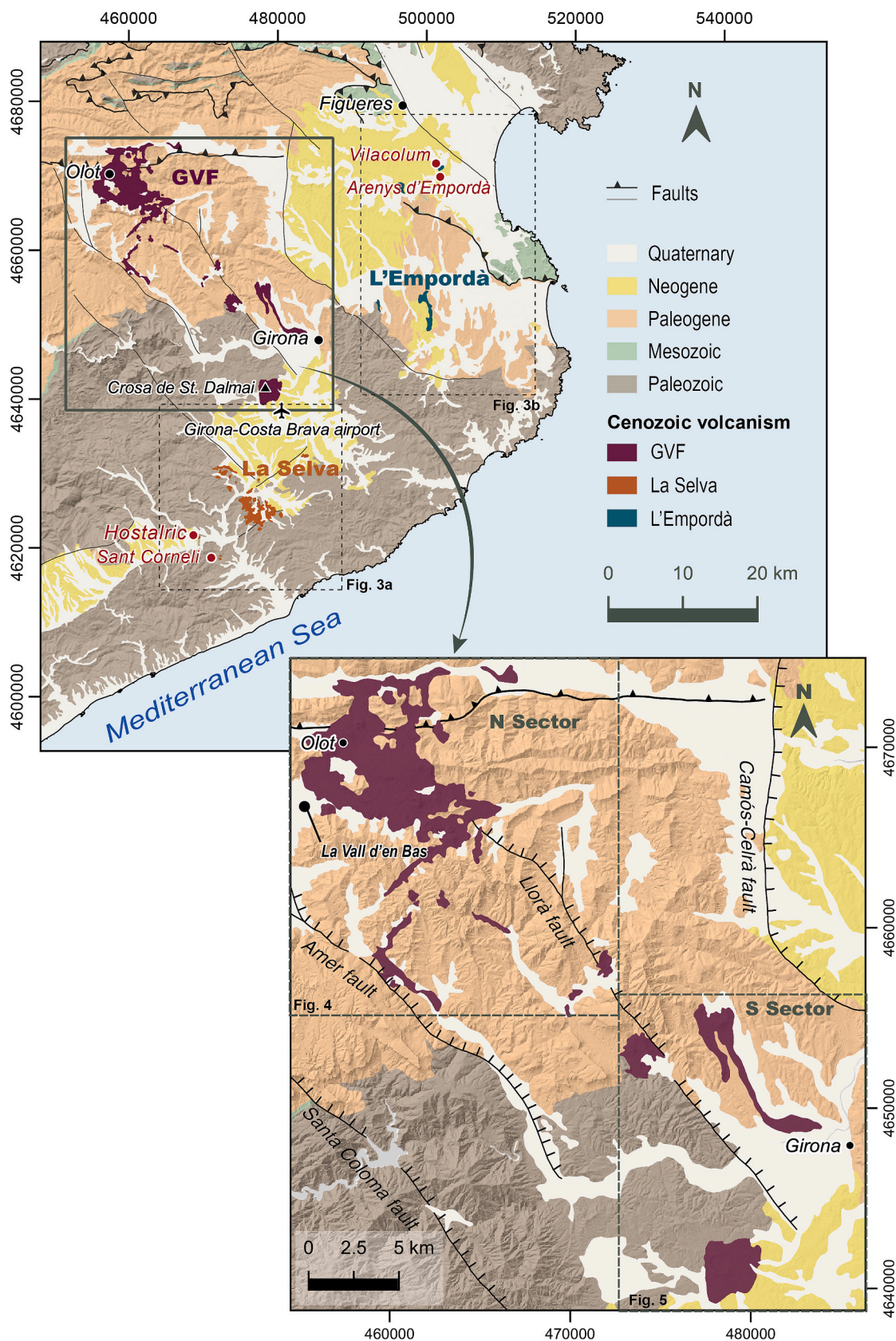


Fig. 2. Geological map of the CVZ (top) and the GVF (bottom). Based on the 1:250,000 geological map of Catalonia (ICGC, 2021).

rise to a widespread system of Neogene horsts and grabens bounded by ENE–WSW to N–S-oriented normal faults. Middle Miocene-to-recent alkaline volcanism associated with this domain is especially represented onshore, in the CVZ. This area is characterised by a set of NW-striking horst-graben structures that have controlled both volcanism and sedimentation (e.g., Bolós et al., 2015; Goula et al., 1999; Martí et al., 1992; Saula et al., 1994).

Volcanism in the CVZ spans the last ~12 Ma, with the most recent eruptions occurring during the early Holocene. Based on available ages (Donville, 1973a, 1973b, 1973c, 1973d; Donville, 1976; Araña et al., 1983; Guerin et al., 1985), this area has traditionally been divided into three subzones: (i) L'Empordà to the northeast (>12–8 Ma); (ii) La Selva (7.9–1.7 Ma) to the south; and (iii) the Garrotxa Volcanic Field (GVF) (<0.7 Ma) to the west (Fig. 2). The younger character of the volcanism in the GVF explains the presence of numerous well-preserved volcanic edifices. In contrast, pristine volcanic outcrops in the La Selva and L'Empordà subzones are limited to a few locations (e.g., the Hostalric, Sant Corneli outcrops belonging to La Selva, and Vilacolum outcrop at L'Empordà) (Figs. 2 and 3). The compositions of the CVZ alkaline rocks range from strongly silica-undersaturated to nearly silica-saturated (Araña et al., 1983; López Ruiz and Rodríguez Badiola, 1985) and include nepheline basanites, leucite basanites, olivine basalts, trachybasalts and minor trachytes (e.g., Araña et al., 1983; López Ruiz and

Rodríguez Badiola, 1985; Martí et al., 1992; Neumann et al., 1999; Cebrià et al., 2000). Whereas the erupting mafic magmas are believed to originate either directly from the source region at the upper mantle or from intermediate reservoirs at the base of the crust (e.g., Bianchini et al., 2007; Bolós et al., 2015; Cebrià et al., 2000; Martí et al., 1992; Neumann et al., 1999), the more evolved compositions (trachytes), only found in the L'Empordà sub-zone, correspond to the products of fractional crystallization of the alkali basalts (Martí et al., 1992).

The GVF, which covers an area of ca. 600 km², lies between the cities of Olot and Girona and hosts over 50 volcanic edifices (including scoria cones, spatter cones, tuff cones, tuff rings, and maars) and numerous lava flows that fill the valleys of the region. It is located within a NW-striking horst-graben structure controlled by two regional conjugated Neogene normal faults with a transtensional component: the Amer fault to the east and the Llorà fault to the west (Bolós et al., 2015) (Fig. 2). Based primarily on their location, volcanic edifices and associated lavas have been categorized into two main sectors (Fig. 2) (Martí et al., 2011). The northern sector is the largest (ca. 400 km², 49 volcanic edifices; Pedrazzi et al., 2023) and includes the Garrotxa Volcanic Zone Natural Park, which hosts some of the most well-known volcanoes (e.g., Croscat or Montsacopa scoria cones and Santa Margarida maar-crater) (Fig. 4). The southern sector (ca. 200 km²) contains fewer (8) but larger volcanic edifices, including the Crosa de Sant Dalmai, Puig d'Adri and Banya del

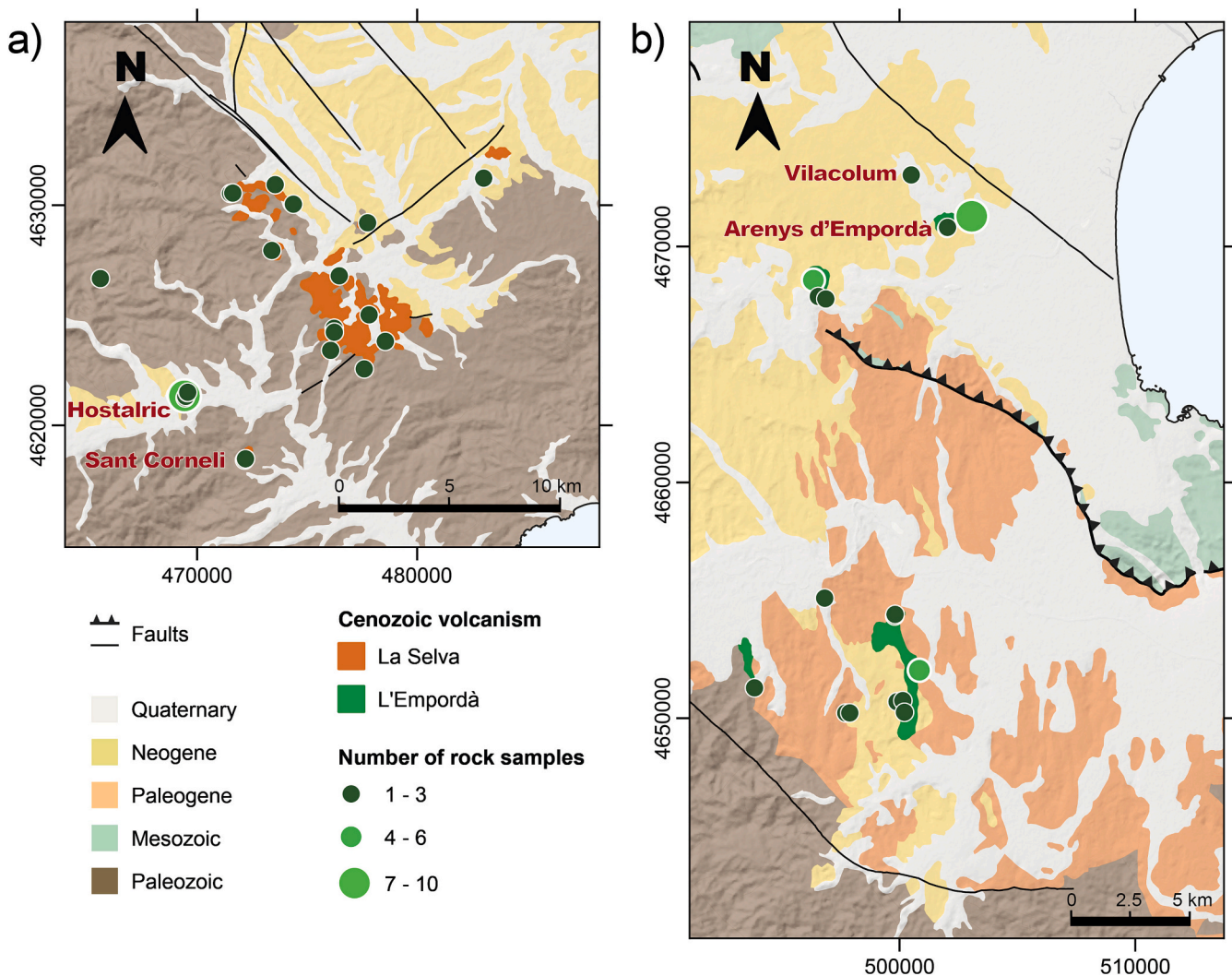


Fig. 3. Simplified geological maps of L'Empordà (a) and La Selva (b) zones based on ICGC (2021). Sampling sites of those samples listed in the CatVolc database are also indicated with green dots of variable size/colour based on the number of samples collected at each specific point. Map coordinates in meters: ETRS89 / UTM zone 31 N. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

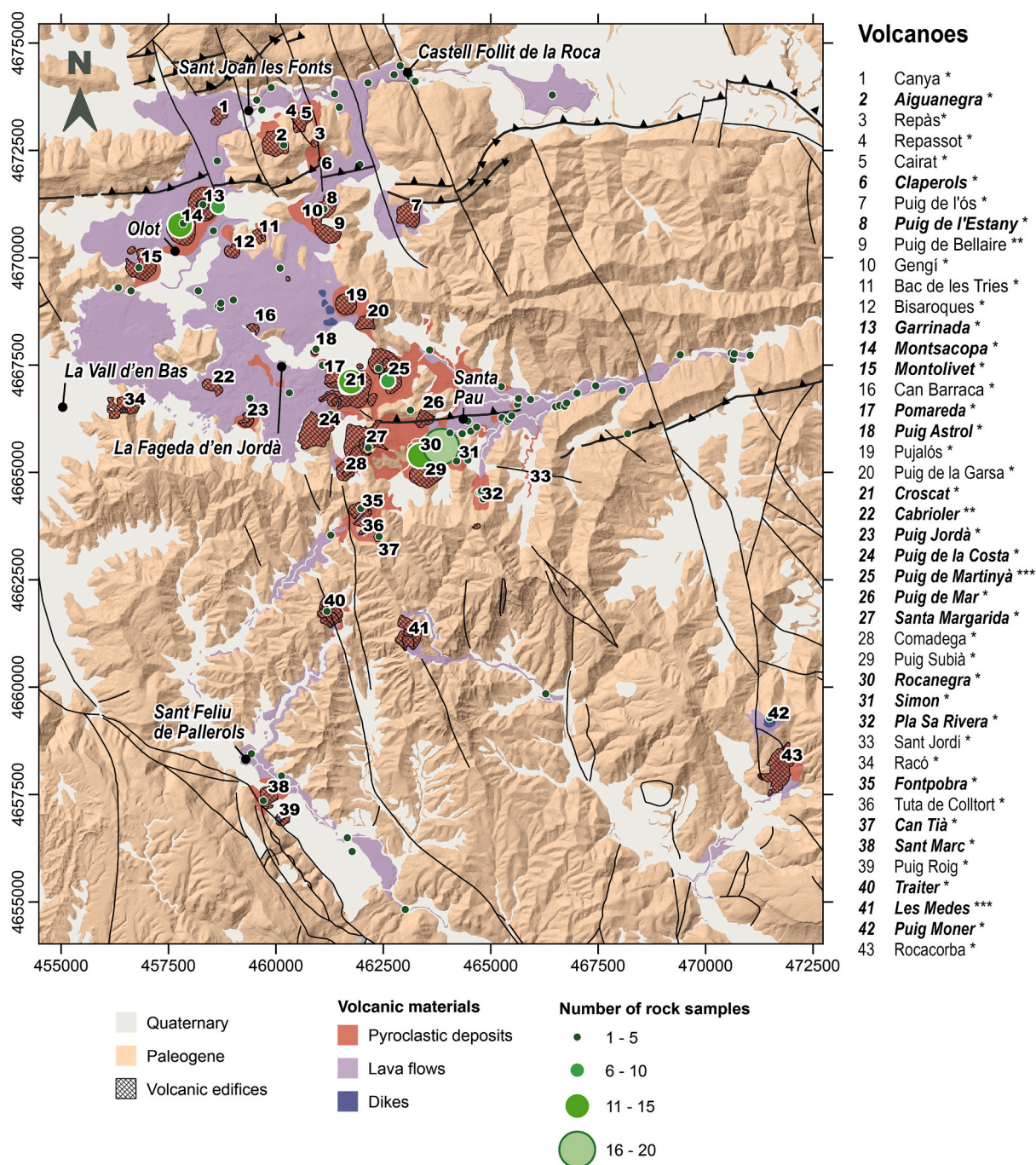


Fig. 4. Simplified geological map of the northern sector of the GVF based on the Carta vulcanològica de la Zona Volcànica de la Garrotxa (ICGC, 2007). Volcanoes are indicated with numbers. In the list, asterisks reflect the number of volcanic edifices per volcano according to Pedrazzi et al. (2023). Those volcanoes listed in bold and italics correspond to the ones with geochemical and/or geochronological information included in the CatVolc database. Sampling sites are also indicated with green dots of variable size/colour based on the number of samples collected at each specific point. Map coordinates in meters: ETRS89 / UTM zone 31 N. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Boc (Fig. 5) (Pedrazzi et al., 2023). In both sectors, volcanic edifices were formed through short-lived monogenetic eruptions with alternating volcanic activity, often transitioning between Strombolian and phreatomagmatic styles (di Traglia et al., 2009; Martí et al., 2011, 2017; Planagumà et al., 2023). In many cases, the final stages of volcanic activity also involved the eruption of lava flows that cascaded down the flanks of previously formed cones. The most spectacular and prominent lava outcrops in the GVF include, for example, Sant Joan les Fonts, Castellfolit de la Roca, and La Fageda d'en Jordà lava flows (Fig. 4). The volcanic products in the GVF encompass basanites, alkaline basalts, and

trachybasalts (Araña et al., 1983; Cebrià et al., 2000; Coy-Yll et al., 1974; Enrique and Toribio, 2009; López Ruiz and Rodríguez Badiola, 1985; Martí et al., 1992; Tournon, 1968, 1969).

Mantle peridotite xenoliths, as well as mafic and ultramafic cumulates in the CVZ, are particularly abundant in some volcanic deposits in the GVF (e.g., Banya del Boc, Puig d'Adri, or Rocanegra volcanoes) (Galán et al., 2008, 2011, 2016; Grachev, 2015; Llobera, 1983; Martí et al., 2011; Pedrazzi et al., 2016, 2022). These xenoliths suggest that the origin of the CVZ magmas can be attributed to an asthenospheric mantle enriched by two metasomatic events (Martí et al., 1992; Cebrià

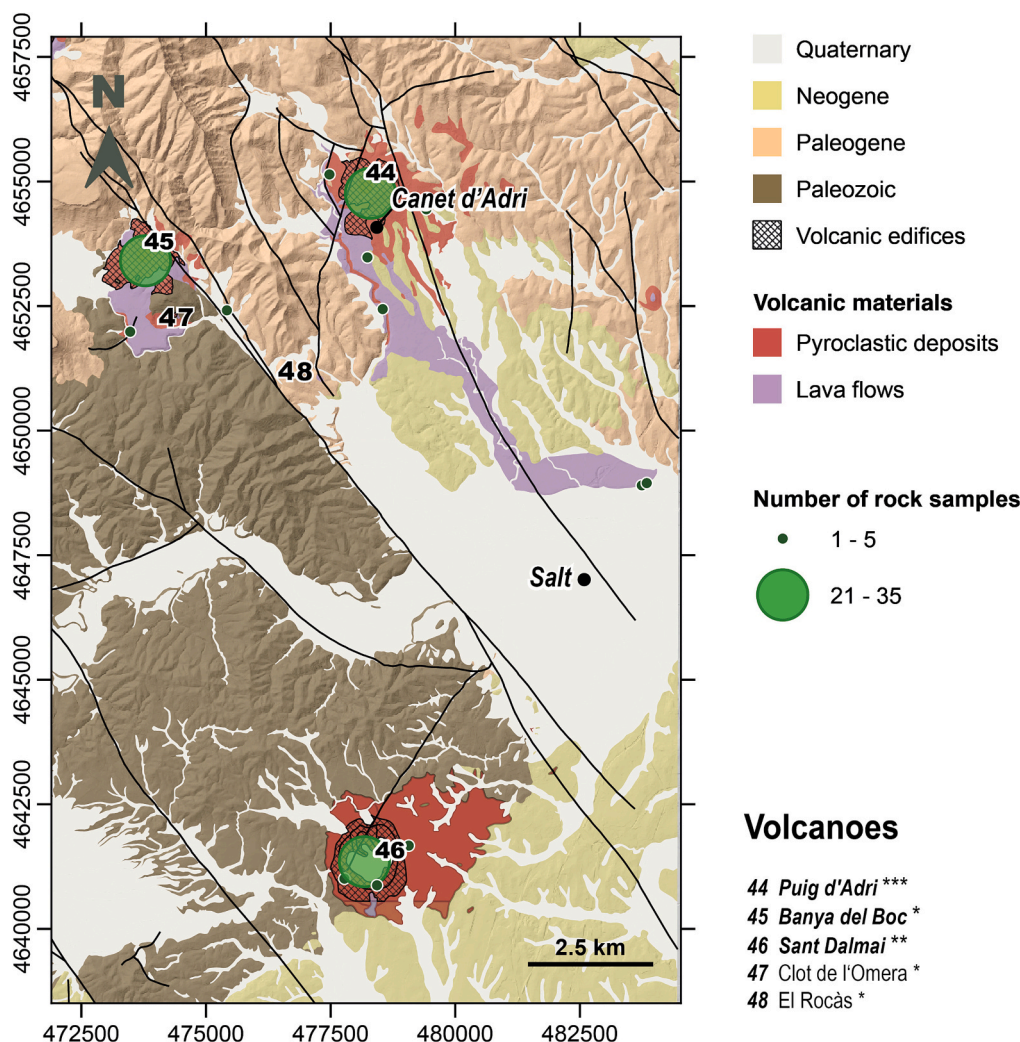


Fig. 5. Simplified geological map of the southern sector of the GVF based on the map sheets of Canet D'Adri (ICC, 1997), Salt (IGC, 2009) and Santa Coloma de Farners (IGC, 2006) of the 1:25,000 geological map series of Catalonia. Volcanoes are indicated with numbers. In the list, asterisks reflect the number of volcanic edifices per volcano according to Pedrazzi et al. (2023). Those volcanoes listed in bold and italics correspond to the ones with geochemical and/or geochronological information included in the CatVolc database. Sampling sites are also indicated with green dots of variable size/colour based on the number of samples collected at each specific point. Map coordinates in meters: ETRS89 / UTM zone 31 N. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2000; Bianchini et al., 2007). This enriched mantle undergoes partial melting through decompression caused by lithospheric and crustal thinning, resulting in the generation of primitive melts with a basaltic (or similar) composition. These primitive magmas can experience stagnation during their ascent to the surface, primarily at the boundary between the mantle and the crust (located approximately 30 km deep in the GVF) or within the lower crust (Gallart et al., 1991). During this process, the magmas undergo slight evolution, leading to the formation of cumulates such as pyroxenites, melanogabbros, and hornblendites (e.g., Bianchini et al., 2007; Neumann et al., 1999; Oliveras and Galán, 2007).

3. CatVolc database architecture

The construction of the CatVolc database involved a comprehensive review of 34 peer-reviewed scientific articles, three PhD theses, one Master thesis and one Bachelor thesis published between 1906 and 2016. From these works, we have extracted all available information regarding: (i) whole-rock analyses (including major and trace elements), isotopic ratios, and mineral chemistry of juvenile magmatic rocks and xenoliths; and (ii) radiometric/thermoluminescence dating information.

Moreover, the ICGC and the Garrotxa Volcanic Zone Natural Park both provided major and trace element data from 22 and 50 magmatic rock samples, respectively (see Supplementary Material 1). As a result, the current version of the CatVolc database contains geochemical analyses from 405 rock samples (296 juvenile magmatic rocks, including lavas and pyroclasts, and 109 xenoliths), and radiometric/thermoluminescence dating data from 57 rocks (55 volcanogenic and two dykes), 4 paleosols samples developed between volcanic deposits and 1 sample from sediments. The latest version of the database is included as Supplementary Materials (Supplementary Materials 1–3) and is also available for download from the Zenodo open-access repository (Miranda-Muruzábal et al., 2023; <https://doi.org/10.5281/zenodo.8332518>). Although included as Supplementary Material, we strongly recommend the readers to always download the latest version of the CatVolc database from the Zenodo repository before starting to analyse the content or to work with the database.

The current database version consists of three MS Excel files dedicated to geochemistry of juvenile magmatic rocks (*CatVolc_magmatic_rocks.xlsx*, Supplementary Material 1), xenoliths (*CatVolc_xenoliths.xlsx*, Supplementary Material 2) and radiometric/thermoluminescence dating information (*CatVolc_dating.xlsx*, Supplementary Material 3).

Each MS Excel file is structured around a main table (*Samples_general_info*) containing general information (e.g., location, age, sampling site) of the listed samples, and a certain number of secondary tables (*Fig. 6*). Secondary tables included in the MS Excel files for magmatic rocks and xenoliths report (*Fig. 6*): (i) whole-rock geochemistry (*Major elements* and *Trace elements*); (ii) isotopic ratios data (*Isotopic ratios*); and (iii) mineral and volcanic glass chemistry (*Amphibole*, *Feldspar*, *Feldspathoid*, *Glass*, *Mica*, *Olivine*, *Pyroxene*, *Oxides*, *Serpentines* and *Sulphides*). In addition to the *Samples_general_info* table, the *CatVolc_dating.xlsx* also includes radiometric/thermoluminescence dating information (*Dating*). Finally, in all three Excel files, we have incorporated a table with consulted references (*References*) and a glossary of the acronyms used for the parameters included in the main and secondary tables (*Codes*). The latter are further described in the following section. Parameters that are self-explanatory and do not require further description are omitted.

3.1. *Samples_general_info* table

Sample_name (column A): Indicates the name given to the sample by the collector(s).

Sample_id (column B): Alphanumeric code used to uniquely identify the samples included in the CatVolc database. *Sample_id* is used to link all tables in the database (*Fig. 6*) and is assigned based on the following

rule:

ZC_RefC_Sample_name

where ZC is a zone code that indicates where the sample was collected within the CVZ (E: L'Empordà; G: GVF; S: La Selva; U: Unknown), RefC is the code of the bibliographic reference (see *References* table), and *Sample_name* is the name of the sample (column A).

Zone (column C): Zone of the CVZ (L'Empordà, La Selva, or GVF) where the rock sample was collected.

Subzone (column D) (only applicable to GVF samples): Subzone—north or south according to the division proposed by Martí et al. (2011)—of the GVF where the sample was collected.

Origin (column E) (applicable only to GVF samples): Indicates the origin of the volcanic deposits where the rock sample was collected. It can refer either to: (i) the name of the volcano responsible for the eruptive event; or (ii) the name of a lava flow of unknown origin, but widely sampled and studied. Some examples include the lava flows of Batet (Batet flow), Castellfollit de la Roca (Castellfollit flow), or St. Joan les Fonts (St. Joan les fonts flow). In case the consulted reference does not specify the origin of the sample, this has been determined by comparing the location of the sample with the information compiled in the Carta Vulcanològica de la Zona Volcànica de la Garrotxa (ICGC, 2007); this process has been properly indicated in the *Comments* field.

X_UTM and *Y_UTM* (columns G and H): UTM coordinates, ETRS89 zone 31 N, WGS84.

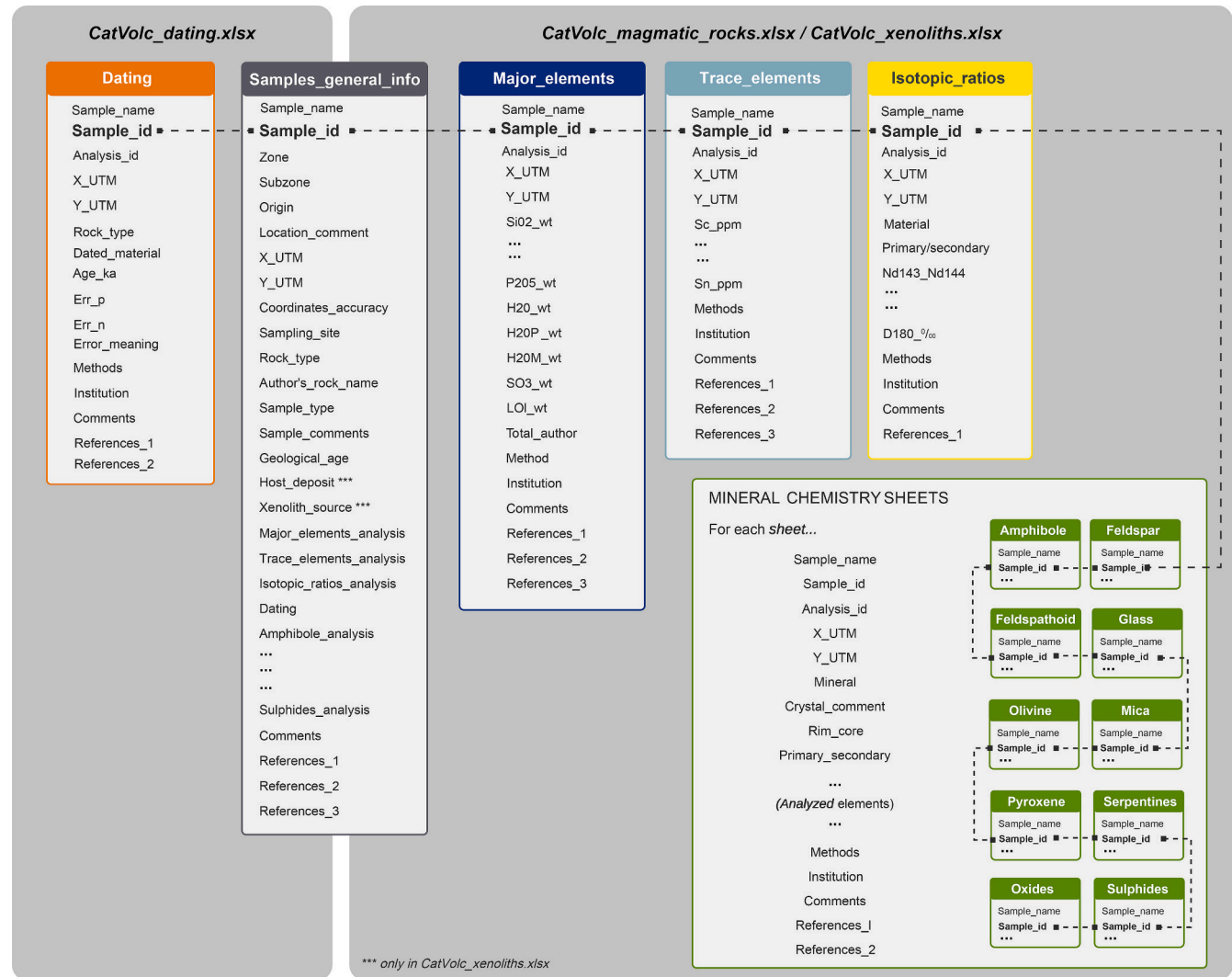


Fig. 6. Structure of the CatVolc database.

Coordinates_accuracy (column I): Indicates how the UTM coordinates (*X_UTM* and *Y_UTM*) have been determined. Options include: (i) with a GPS device (GPS); (ii) with Google Maps according to the description of the sampling location provided by the consulted reference(s) (Google_Maps); (iii) based on the centre of the volcanic edifice indicated in the source document (Google_maps_volc); or (iv) based on the city centre of the locality specified in the source document (Google_Maps_loc). Not_applicable is assigned if it has not been possible to determine the UTM coordinates following any of the above-mentioned methods.

Sampling_site (column J): Describes whether the sample has been collected: (i) at a conventional outcrop (Outcrop); (ii) at a short-lived outcrop, such as the foundation hole of a building construction (Ephemeral_outcrop); or (iii) from a sediment core.

Author's_rock_name (column N): Lithology name as given by the author(s) of the consulted reference.

Sample_type (only applicable to volcanogenic rocks, column M): Describes the type of volcanic material: (i) lava flow (Lava_flow); (ii) pyroclastic material (Pyroclast) (if available, particle size information is also provided); and (iii) volcanic conduit (Volcanic_conduit). If the type of material is not specified in the consulted references it is also indicated ("Unknown").

Geological_age (column N): Indicates the geological period according to the age ranges defined by Araña et al. (1983) and Martí et al. (2011) for the individual zones of the CVZ:

- GVF (< 0.7–0.01 Ma): Pleistocene-(Holocene)
- La Selva (7.9–1.7 Ma): Miocene-Pleistocene
- L'Empordà (>12 Ma – 8): Miocene

Host_deposit (only in *CatVolc_xenoliths.xlsx*, column O): Indicates the type of volcanic material hosting the xenolith: (i) lava flow (Lava_flow) and (ii) pyroclastic material (Pyroclastic_material). If the type of material is not specified in the original data source, it is indicated as "Unknown".

Xenolith_source (only in *CatVolc_xenoliths.xlsx*, column P): Indicates potential origin for the xenoliths: mantle (mantle_xenolith), or crust (crustal_xenolith).

3.2. Major and trace elements and mineral chemistry tables

Analysis_id (column C): Alphanumeric code used to uniquely identify different analyses included in the database. The code was created as follows:

Sample_id_n1(n2)_suffix

where *Sample_id* is the sample unique identifier (*Sample_id*), *n1* refers to the number of analysis, and *suffix* indicates if the analysis corresponds to whole-rock major (*major*) or trace (*trace*) elements, amphibole (*amp*), feldspar (*feld*), oxides (*ox*), feldspathoid (*foid*), volcanic glass (*glass*), mica (*mica*), olivine (*ol*), pyroxene (*pyr*), serpentines (*serp*), and sulphides (*sul*). In the *Isotopic_ratios* and *Dating* tables, the *suffix* is *_iso* and *_dating*, respectively. In the case of mineral analyses, *n1* refers to the diverse crystals analysed in the same sample and *n2* identifies the different analyses performed in the same crystal.

Mineral (only for the mineral tables, column F): If specified, it provides further details on the mineral (e.g., plagioclase, clinopyroxene, orthopyroxene).

Crystal_comment (only for the mineral tables, column G): Provides additional information regarding the nature (e.g., phenocryst, micro-lite), size (e.g., large, small), colour (e.g., brown, green), and form (e.g., idiomorphic) of the analysed mineral crystal.

Rim_core (only for the mineral tables, column H): Indicates, if available, whether the analysis was performed in the core of the crystal (Core) or the rim (Rim).

Primary_secondary (only for the mineral tables, column I): If known, it indicates whether the analysed mineral is primary (magmatic origin) (PRIMARY) or secondary (formed by alteration processes)

(SECONDARY).

3.3. Isotopic ratios table

Material (column F): Indicates whether the isotopic ratio has been performed on whole-rock material (Whole_rock) or in a single mineral (e.g., Clinopyroxene).

3.4. Dating table

Age_ka (column H): Absolute age in ka.

Err_p and **Err_n** (columns I and J): Positive (Err_p) and negative (Err_n) errors of the Age_ka column.

Error_meaning (column K): Provides and explanation regarding what the errors provided in *Err_p* and *Err_n* represent or how they were calculated.

4. Overview of the CatVolc database content

4.1. Characteristics of the listed samples

The CatVolc database primarily contains information on volcanic rock samples, accounting for 75.1% ($n = 347$) of the dataset (Fig. 7a). Among these samples, the majority are lava flows (35.7%, $n = 124$) and pyroclastic materials (19.6%, $n = 68$) (Fig. 7b). A portion of the volcanic rock samples (43.5%, $n = 151$) is classified as unknown, while only a small percentage corresponds to volcanic conduits (~ 1.2%, $n = 4$). Additionally, 23.6% ($n = 109$) of the samples listed in the database are xenoliths (predominantly mantle xenoliths, 98.2%, $n = 107$) found in volcanic deposits of the CVZ (Fig. 7c). These xenoliths are either plutonic (mainly peridotites, pyroxenites, and gabbros) or metamorphic rocks (principally amphibolites). The CatVolc database also includes 4 paleosol samples (< 1%) that were used to date the Croscat volcano with the ^{14}C method (Fig. 7a).

Most samples in the CatVolc database (80.3%, $n = 371$) originate from the GVF. These were mainly collected from 23 different volcanoes located in the northern sector (70.1%, $n = 260$) (Figs. 4 and 5). Rock samples from the southern sector mainly correspond to the materials from the Banya del Boc, Puig d'Adri and Crosa de Sant Dalmai volcanic edifices. Volcanic materials from La Selva and L'Empordà are less represented, accounting for 11.5% ($n = 53$) and 7.8% ($n = 36$) of the total, respectively (Figs. 3 and 7d).

4.2. Geochemical information

The CatVolc database contains a wide variety of geochemical analyses, with whole-rock major and trace element analyses available for most of the rock samples (75.3% and 58.2%, respectively) (Fig. 8). However, mineral chemical information is included only for approximately one third of the samples (31.5%, $n = 143$), primarily focusing on pyroxenes, olivines, and feldspars (Fig. 8). Data on isotopic ratios (e.g., $^{143}\text{Nd}/^{144}\text{Nd}$, $^{87}\text{Sr}/^{86}\text{Sr}$) and volcanic glass geochemical composition are limited, reported for only 66 (14.3%) and 5 (1%) samples, respectively (Fig. 8). The analysed rock samples predominantly originate from the GVF, particularly from the northern sector (Fig. 9). Whole-rock major and trace elements analyses have been mostly conducted on volcanic rocks (82% and 77%, respectively), and isotopic ratios have been mainly obtained from plutonic xenoliths (62.1%) (Fig. 9).

4.3. Dating information

The CatVolc database includes dating information from 61 samples, which are evenly distributed among the three territories of the Catalan Volcanic Zone (CVZ): 34.4% ($n = 21$) in La Selva; 42.6% ($n = 26$) in the GVF; and 23% ($n = 14$) in L'Empordà (Fig. 10). Available data mainly consist of K-Ar, Ar-Ar and thermoluminescence analyses on 55 volcanic

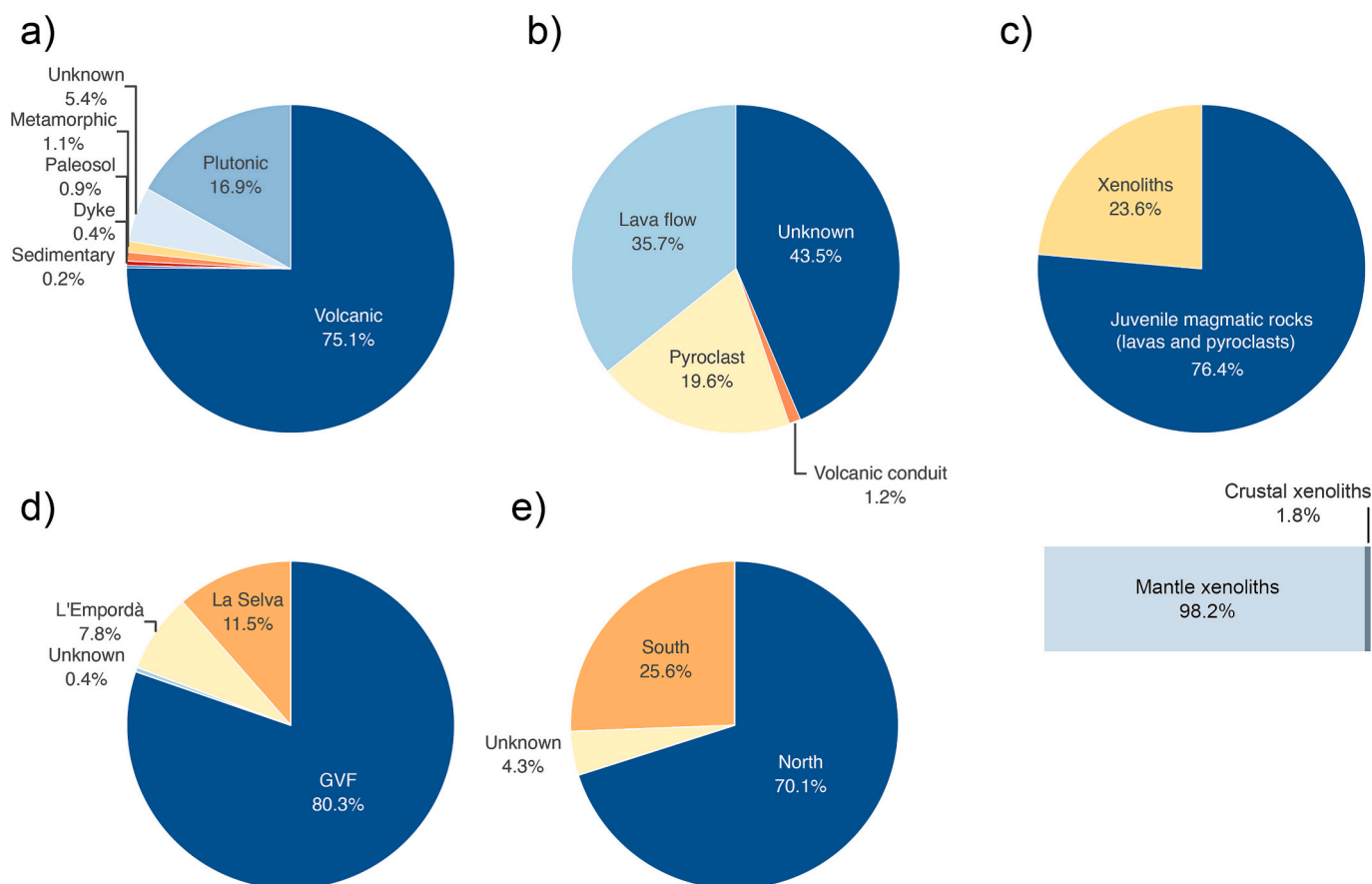


Fig. 7. Pie plots representing (a) the type of samples, (b) the different types of volcanic rocks, (c) the amount and origin of xenoliths, (d) the distribution of the samples among the zones of the CVZ, and (e) the location of the samples from the GVF according to the subdivision proposed by Martí et al. (2011). Percentage values have been rounded up to the closest first decimal. In the text, percentage values have been rounded to the closest integer for the sake of simplicity. An interactive version of these charts is included in the Supplementary Material 4.

rocks and 2 dykes (88.7% and 3.2%, respectively), and 4 (6.5%) ^{14}C data of paleosols from the Croscat volcano. Within the GVF, 15 volcanoes have been dated, 3 from the south sector (Banya del Boc, Puig d'Adri, Sant Dalmai) and 12 from the northern one (Aiguaneira, Cabrioler / Puig Jordà, Croscat, Fontpobra / Can Tia, Garrinada, Medes, Pomareda, Puig Mar, Puig de l'ós, Simón, Sant Marc and Traiter).

5. Geochemistry of the CVZ rocks

Although a comprehensive geochemical study of the CVZ magmas is beyond the scope of this paper, we provide here a brief overview of the geochemical information of the juvenile magmatic rock samples (including lavas and pyroclasts) included in the CatVolc database. For this, we have filtered the available whole-rock analyses based on total oxide content and Loss on Ignition (LOI) values and identified (and removed) the potential outliers in the remaining dataset.

Whole-rock analyses were filtered by removing all data with a total oxide content (including LOI if provided) below 98% ($n = 26$) or above 101% ($n = 2$). Additionally, using LOI values as an indicator of rock alteration, we have ruled out those analyses potentially corresponding to altered rocks (i.e., $\text{LOI} > 2.5 \text{ wt\%}$) (e.g., Le Bas et al., 1986). About 6.3% ($n = 22$) of the rock sample analyses included in the CatVolc database exhibit LOI values exceeding 2.5 wt%. These account for 21.9% ($n = 7$) and 39.1% ($n = 9$) of the whole-rock analyses available for La Selva and L'Empordà rock samples, respectively (see Supplementary Material 5). These findings are consistent with the well-documented occurrence of altered magmatic rocks in the La Selva and L'Empordà regions (e.g., Cebrià et al., 2000). By contrast, only 2% ($n = 6$) of the

GVF analysed rock samples are potentially altered.

After filtering the available data based on total oxide content and LOI value, an outlier detection analysis based on the estimation of Mahalanobis distance (e.g., Varmuza and Filzmoser, 2009) was conducted on the remaining whole-rock analyses ($n = 235$) (see Supplementary Material 5 for further details). The analysis did not identify any outliers in the whole-rock analyses from La Selva and L'Empordà. However, 11 outliers were detected among the GVF samples (see Supplementary Material 5 for further details). As a result, the overview of the geochemical information available in the CatVolc database is based on the remaining 224 whole-rock analyses.

5.1. Whole-rock compositions

The magmatic rocks included in the CatVolc database are strongly silica-undersaturated to nearly saturated alkaline magmas, ranging from basanites and alkali basalts to minor trachytes (Fig. 11a). The sample represented in the subalkaline field of the TAS diagram exhibiting anomalously low Na_2O and K_2O contents may be attributable to errors in the analytical procedure.

The L'Empordà samples show the widest range of compositions, encompassing alkali basalts to trachyandesites and trachytes. These intermediate to felsic compositions, which mainly correspond to volcanic rocks (lavas) from two specific localities, Arenys d'Empordà and Vilacolum (Figs. 2 and 3), display low FeO_t (2.5–6 wt%), CaO (0.5–4 wt%) and MgO (<1.3 wt%) contents, as well as the highest concentrations of alkalis (Na_2O 5.6–8.4 wt% and K_2O 3.6–5 wt%) (Fig. 12). The occurrence of felsic magmatism in the L'Empordà area has traditionally been

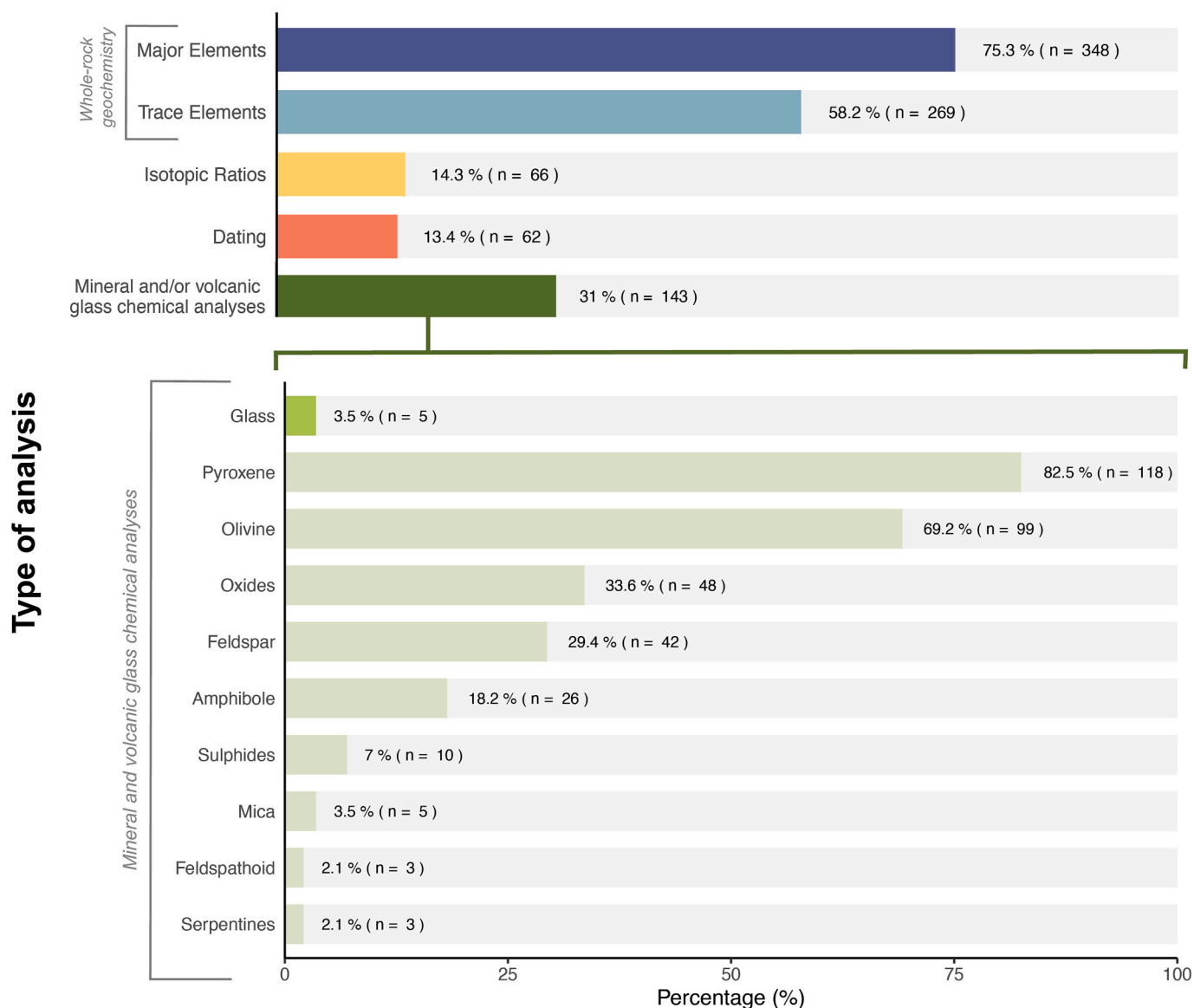


Fig. 8. Bar plots showing the percentage of each type of analysis in the database. In the top graph, percentages are estimated based on the total number of samples included in the CatVolc ($n = 455$). In the bottom bar plots, percentages are calculated considering only samples with mineral and/or volcanic glass analyses ($n = 143$). Percentage values have been rounded to the closest first decimal. In the text, percentage values have been rounded to the closest integer for the sake of simplicity. An interactive version of these charts is included in the Supplementary Material 4.

attributed to a process of differentiation through fractional crystallization of alkali basalts (e.g., Diaz et al., 1996; Gimeno, 1995; Martí et al., 1992).

La Selva magmas are compositionally constrained to mafic compositions, from basanites to alkali basalts and to trachybasalts, with SiO_2 contents ranging from ~42 to 50 wt% (Fig. 11a). In general, the samples from La Selva exhibit slightly lower TiO_2 (1.5–3.2 wt%) and FeO_t (8.3–12.5 wt%) contents compared to those from L'Empordà and the Garrotxa volcanic fields, but they have higher CaO (8.3–14 wt%) concentrations (Fig. 12).

The recent volcanic activity in the CVZ, represented by the volcanic products of the GVF, has been well documented in terms of geochemical data owing to the abundance and good preservation of outcrops (e.g., Gisbert et al., 2009; Martí et al., 2011; Pedrazzi et al., 2022). The magmatic samples from the northern sector predominantly fall within the range of ~43–50 wt% SiO_2 and 4–7 wt% $\text{Na}_2\text{O} + \text{K}_2\text{O}$. They are mainly classified as basanites, with some occurrences of alkali basalts and trachybasalts (Fig. 11b). The northern sector volcanics show reverse

compositional trends of TiO_2 , FeO_t , CaO, and MgO with SiO_2 , and normal correlations between Al_2O_3 and SiO_2 (Fig. 13). In contrast, the magmatic samples from the southern sector show more restricted compositions, primarily consisting of tephrites and basanites (i.e., ~44–47 wt% SiO_2) (Fig. 11b), and lower CaO content (8–9 wt%) (Fig. 13). However, it should be noted that the magmatic samples from the southern sector represent only about 24% of the total whole-rock analyses available for the GVF. Therefore, there may be biases in the observations and descriptions of the results due to this limited representation.

Trace elements are poorly represented in L'Empordà and La Selva geochemistry, whereas they are well-characterised in the GVF magmas. The trace element analyses represented in Fig. 14 display, in general, similar trends for most mafic CVZ (and especially, GVF) samples. For all analysed CVZ samples, the Rare Earth Elements (REE) are characterised by enrichment in light rare earth element (LREE) with relatively flat heavy rare earth element (HREE) pattern and no Eu anomaly (Fig. 14a). Values of $(\text{Eu}/\text{Eu}^*)_N$ have been calculated as $(\text{Eu})_{cn}/[(\text{Sm})_{cn} \times (\text{Gd})_{cn}]^{0.5}$.

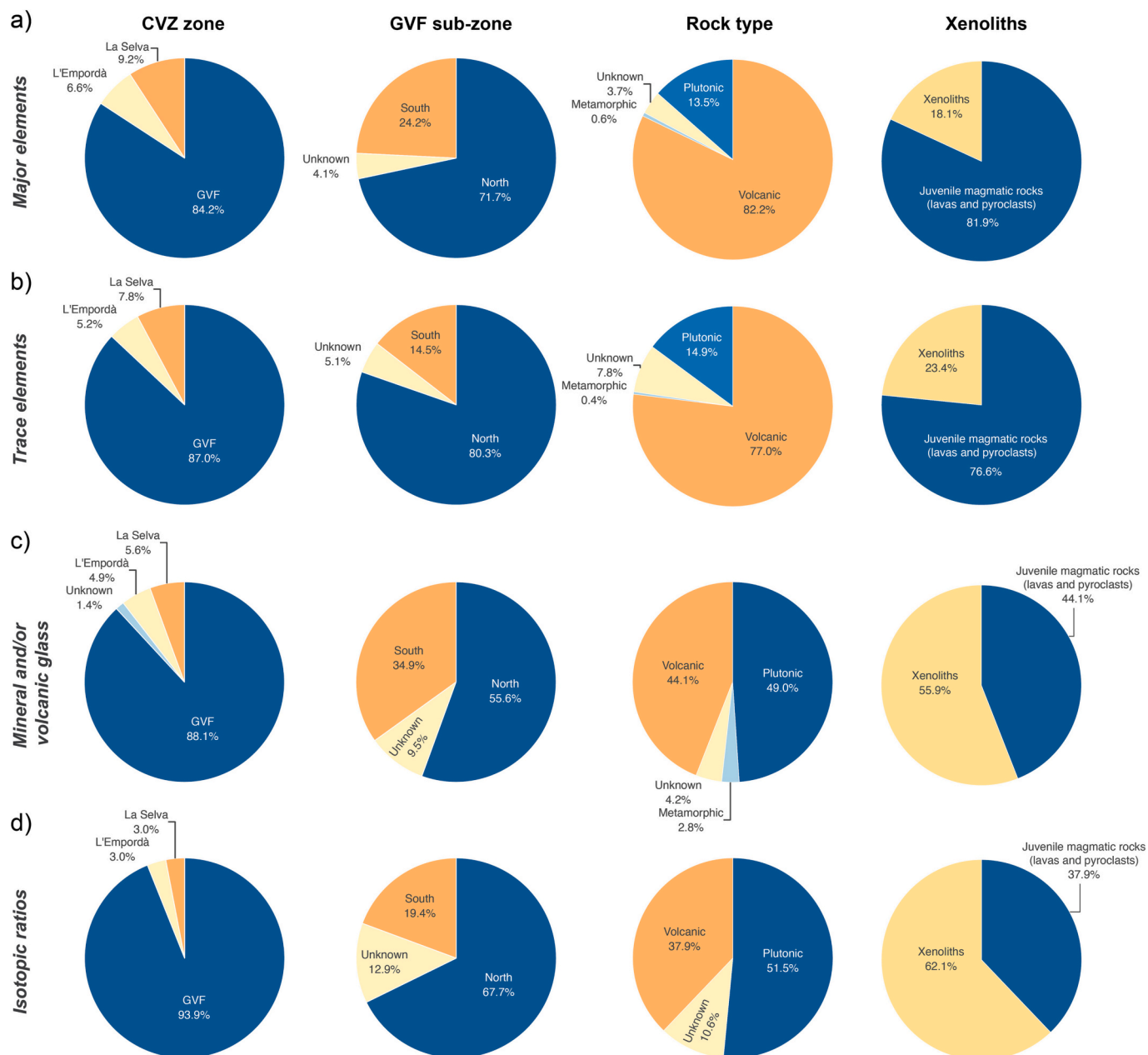


Fig. 9. Pie charts illustrating the type and location of rock samples with: whole-rock geochemistry of major elements (a) and trace elements (b), mineral and/or glass chemical analyses (c), and values of isotopic ratios (d). It is also indicated if the analysed rock sample is or not a xenolith. An interactive version of these charts is included in the Supplementary Material 4.

(subscript *cn* = chondrite-normalized) (McLennan, 1989). Results obtained (0.895–1.102) suggest that there is no significant plagioclase fractionation involved in the petrogenesis of the CVZ magmas. The significant LREE/HREE fractionation (enrichment in LREE) is evidenced by the $(La/Yb)_N$ ratio ranging from ~10 to ~25 and by $(La/Sm)_N \sim 2$ to 5 (see Supplementary Material 5). The REE patterns agree with the smooth convex-up incompatible trace element patterns, typical of alkali basalts (Fig. 14b).

Isotope analyses are the least represented geochemical data in the CVZ, with only a few $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios from GVF and L'Empordà rock samples (Fig. 15). The $^{87}Sr/^{86}Sr$ isotope ratios for the GVF range from 0.70360 to 0.70380, without significant variations between the north and south sector, while those from L'Empordà samples reach up to 0.70440. The $^{143}Nd/^{144}Nd$ isotope ratios, available only for the GVF, show a small range of variation, between 0.51272 and

0.51283 in both sectors. Despite the limited isotopic data available, differences with petrogenetic significance are observed, for instance, between the Empordà and GVF magmas. Hence, the importance of conducting a more extensive and detailed isotopic study to obtain a complete geochemical picture of the CVZ.

5.2. Mineral chemistry

The ternary diagrams in Fig. 16 show the distribution of pyroxene, feldspar, and olivine geochemical data available for the volcanic samples of the CVZ. Most of the analysed pyroxenes are clinopyroxenes, specifically diopsides, with a smaller presence of augites. A few orthopyroxenes xenocrysts have also been reported in the GVF samples. Plagioclases from the CVZ mafic magmas are mainly labradorite ranging between An_{70-58} , except for a few samples classified as andesine (An_{40}).

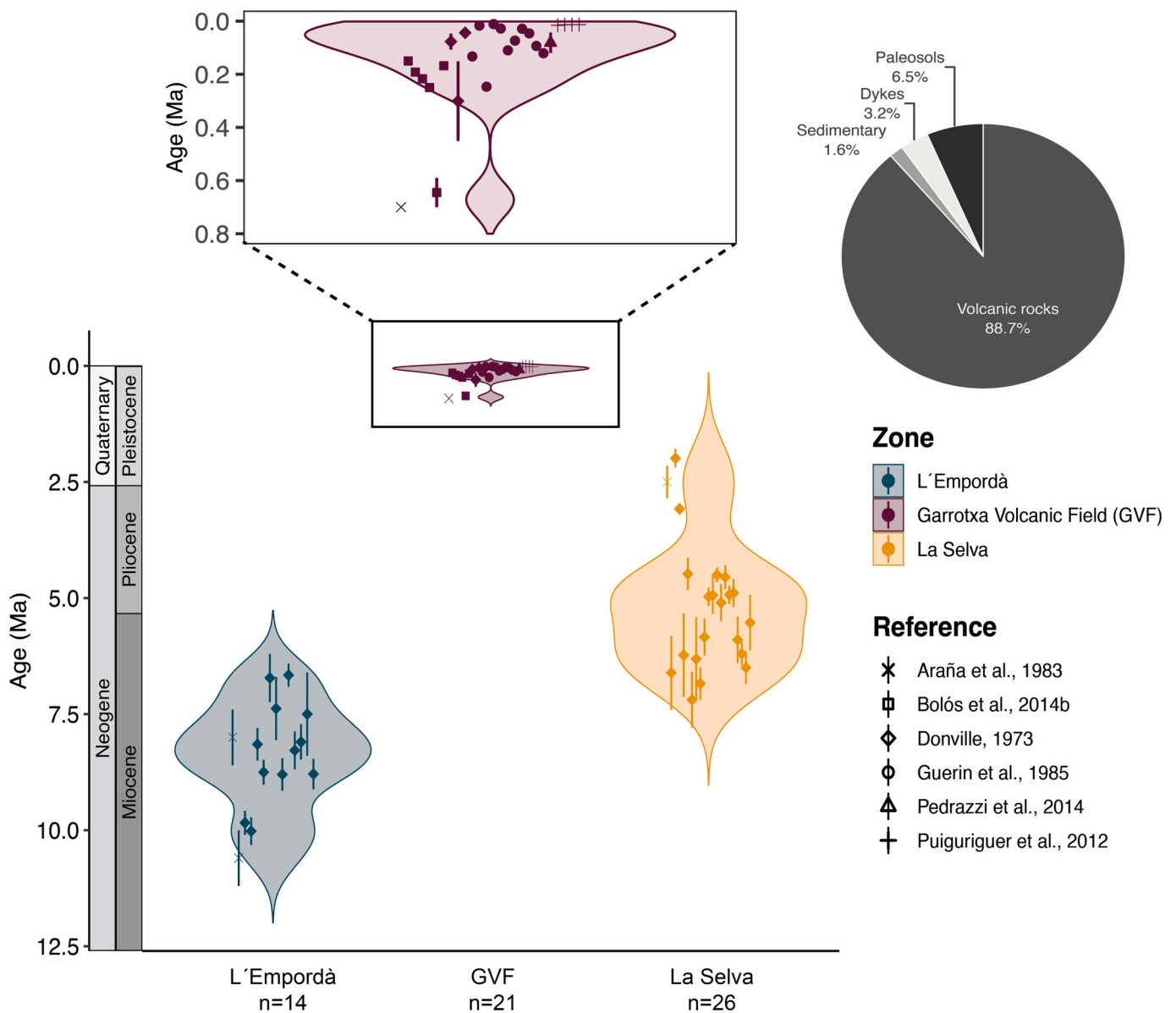


Fig. 10. Violin plots of available dating for the CVZ. Donville (1973a, 1973b, 1973c, 1973d, 1976) and Araña et al. (1983) ages are based on the K-Ar method, Guerin et al. (1985) ages are based on thermoluminescence, Puiguriquer et al. (2012) ages are based on the ^{14}C method, and Bolós et al. (2014b) ages are based on the Ar-Ar method. The varying positions of the data points along the x-axis are solely for graphical purposes and to prevent overlap between the points. The pie chart indicates the type of rocks dated. An interactive version of these charts is included in the Supplementary Material 4.

Olivines, which are only analysed in GVF samples, are classified as forsterites with Fo_{74-85} . The compositional variations are mainly associated with the analysed crystals (phenocrysts, microcrysts, and xenocrysts) as well as to the core-rim differences in zoned olivines (e.g., de Maisonneuve et al., 2016).

6. Geochronology of the CVZ rocks

The CatVolc database highlights how the majority of CVZ datings were published during the 1970s and 1980s (Donville, 1973a, 1973b, 1973c, 1973d; Donville, 1976; Araña et al., 1983; Guerin et al., 1985). These studies primarily aimed to determine the age of Neogene volcanism, specifically focusing on the volcanic activity within the L'Empordà and La Selva regions (Fig. 10). Although these findings have traditionally established age ranges for volcanic activity in each of the three zones of the CVZ, they are insufficient for establishing a proper chronological framework for events across the entire CVZ, particularly

within the GVF. In addition, it must be considered that the available datings were obtained using various methodologies (K-Ar, Ar-Ar, ^{14}C , and thermoluminescence), and different laboratories were employed for the most commonly used dating technique (i.e., K-Ar). Moreover, in some cases, the uncertainty associated with the obtained age is considerably high (e.g., Les planes d'Hostoles, D88, with an age of 40 ± 70 ka; Castellfollit de la Roca lava flow, D82, with an age of 77 ± 30 ka). All these factors, along with a lack of material type information for many dated samples, complicates the establishment of a detailed chronology of the volcanic activity in the CVZ.

In L'Empordà and La Selva zones, the volcanic outcrops are scattered and poorly preserved with some exceptions in the case of La Selva. This is due to the age of volcanism (ca. $> 12-8$ Ma and $7.9-1.7$ Ma, respectively), the apparently smaller volume of extruded magma compared to the GVF (e.g., Martí et al., 2011), and the fact that much of the volcanic material in this area is most probably covered by Pliocene continental deposits (e.g., Araña et al., 1983). In the case of L'Empordà, the main

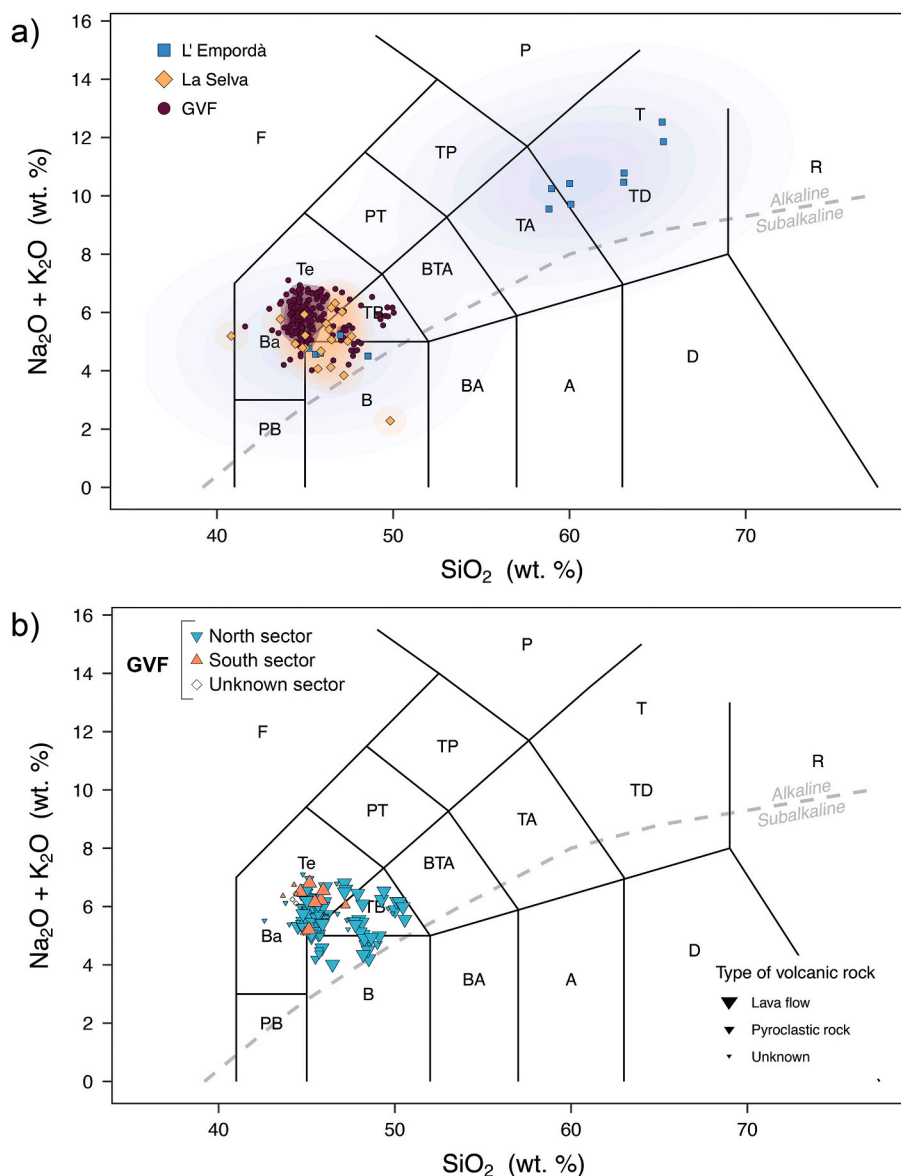


Fig. 11. Total Alkali vs. Silica diagram (TAS) for the whole-rock analyses of magmatic rock samples from all three zones of the CVZ (a) or only from the GVF (b). Major elements normalized to 100% (anhydrous) with Fe distributed between FeO and Fe₂O₃ following [Middlemost \(1989\)](#). Grey dashed line discriminates between the alkaline and subalkaline fields, according to [Irvine and Baragar \(1971\)](#). In (a) density clouds are also estimated for each CVZ zone. PB: Picro-basalt, B: Basalt, Ba: Basanite, Te: Tephrite, TB: Trachybasalt, BA: Basaltic andesite, BTA: Basaltic trachyandesite, PT: Phonotephrite, A: Andesite, TA: Trachyandesite, TP: Tephriphonolite, D: Dacite, TD: Trachydacite, T: Trachyte, R: Riolite, P: Phonolite, F: Foidite. This graph can also be found in the interactive geochemical report in Supplementary Material 5.

dated outcrops correspond to the trachytic lavas of Vilacolum (ca. 9 Ma, [Donville, 1973b](#)) (being the exception of the common mafic alkaline volcanic products), basalts from Arenys d'Empordà (ca. 7.5 Ma, [Donville, 1973b](#)) and basaltic outcrops north of La Bisbal d'Empordà (e.g., Rupia with ca. 8 Ma, [Donville, 1973c](#)). In La Selva region, the best-preserved outcrops correspond to the Hostalric volcanic neck with an age of ca. 2 Ma ([Donville, 1973d](#)) and the Sant Corneli quarry (2.5 Ma, [Donville, 1973a](#)).

Although the GVF is the youngest and best-preserved volcanic field with the highest volume of extruded magma of the CVZ ([Martí et al., 2011](#)), its age is also poorly constrained. The available radiometric and thermoluminescence dating (see Supplementary Material 3) indicate ages ranging from 700 ka for a lava flow at Sant Joan les Fonts to 11.5 ka for a pyroclastic deposit in La Pomareda, both in the northern sector ([Fig. 10](#)). Within this sector, the Batet flow (247 ka, [Guerin et al., 1985](#)), and the volcanic edifices of Garrinada (133 ka, [Guerin et al., 1985](#); [Bolós](#)

[et al., 2014b](#)), Puig de les Medes, Fontpobra and Traiter (93.18 ka, 73.5 ka, and 46.3 ka, respectively, [Guerin et al., 1985](#)) are some of the few with age constrains. In the southern sector, a particular case is the Crosa de Sant Dalmai maar, the largest volcanic edifice in the CVZ, with a crater diameter of 1200 m ([Bolós et al., 2012](#)). This maar is geographically located within La Selva volcanic field, but its extraordinary preservation has always pointed to more recent volcanism. The age of this volcanic edifice is not well established, but stratigraphic relations and existing U-Th and ¹⁴C ages of the upper lava flow and post-eruptive lacustrine sediments suggest an age range of 120 to 43 ka, belonging to the GVF activity ([Pedrazzi et al., 2014](#)). In this southern sector, other significant volcanic eruptions represented by Banya del Boc and Puig d'Adri volcanoes show ages of 121 ka and 168 ka, respectively ([Guerin et al., 1985](#); [Bolós et al., 2014a](#)).

[Puiguriguer et al. \(2012\)](#) provided ¹⁴C radiometric data to constrain the age of the most recent eruption, the Crosat volcano, obtaining ages

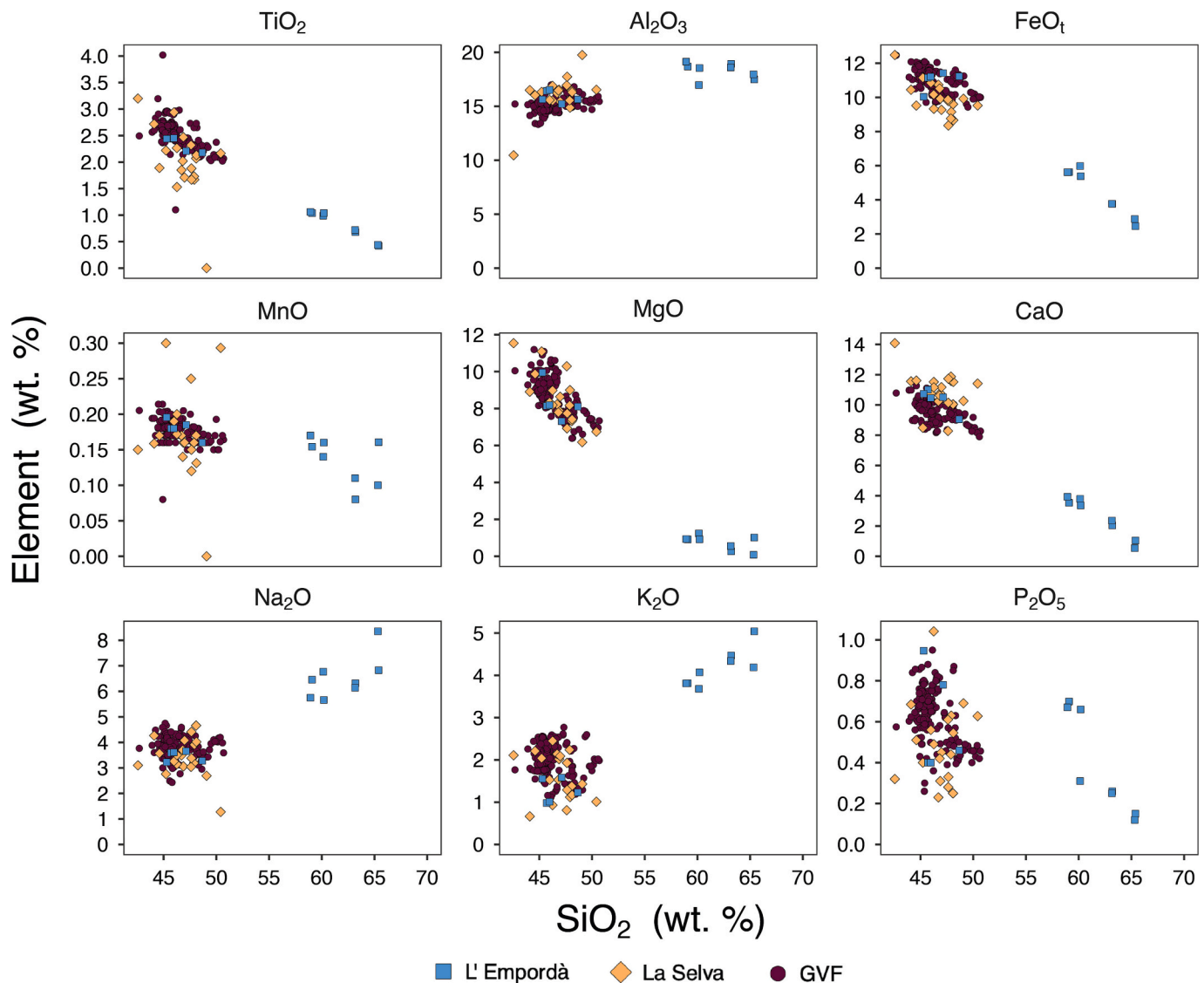


Fig. 12. Major element vs. SiO_2 content Harker diagrams for the whole-rock analyses of magmatic rock samples from all three zones of the CVZ. Major element compositions have been normalized to 100% in anhydrous base with Fe as FeO_t . This graph can also be found in the interactive report in Supplementary Material 5.

ranging between ~ 13.2 and 15.7 ka. Nonetheless, a recent study has detected 30 ash layers along a 15 m long paleolake sediment core extracted in La Vall d'en Bas area (~ 7 km from Croscat volcano) suggesting intense volcanic activity from 13.5 to 8.3 ka cal BP in the GVF, based on 15 radiocarbon dates obtained from bulk sediment and *Pinus* sp. macrofossils (Iriarte et al., 2023; Revelles et al., 2023). However, at present, no direct correlation exists between these tephra layers and the volcanic deposits or eruptive vents in this volcanic field. According to the authors, further geochemical evidence is needed to elucidate the autochthonous (i.e., GVF) or allochthonous origin of the tephra and lapilli layers (Revelles et al., 2023).

7. Discussion

7.1. Data quality and representativity

Despite the relatively large number of juvenile magmatic rock samples and xenoliths included in the CatVolc database, their distribution among the three zones of the CVZ is not uniform. The higher interest in the most recent volcanism (i.e., GVF), coupled with the scarcity of well-preserved outcrops in La Selva and L'Empordà, has led to a bias in the dataset. Consequently, the volcanic materials from La Selva and

L'Empordà are significantly underrepresented in the database. Within the GVF, most studied magmatic rock samples were collected from 23 different volcanic edifices, mostly concentrated in the northern sector (Figs. 4 and 5). While certain volcanoes such as Rocanegra, Croscat, and Crosa de Sant Dalmai have been extensively characterised, there is a lack of geochemical data for others such as Puig Astrol, Puig de la Costa, and Can Tià (see Figs. 4 and 5). In addition, geochemistry of crustal xenoliths is hardly available compared to mantle-derived xenoliths (peridotites). Their geochemical characterization would enhance our understanding of the composition and structure of the CVZ crust and allow to further explore the contribution of crustal rocks to the composition of magmas in this area. Radiometric and thermoluminescence dating information is also incomplete, particularly at the GVF where less than one third of the volcanic edifices have been dated. All these limitations pose challenges to providing a comprehensive description and achieving a complete understanding of the evolution of the CVZ, and its magmatic plumbing system, particularly during the earliest phases. Additionally, available radiometric dating information is insufficient to properly estimate the eruptive recurrence in the GVF (Bolós et al., 2014b) and to carry out a temporal hazard assessment on the area (Bartolini et al., 2015). This highlights the need for more comprehensive and balanced sampling, analysis and dating of the different volcanic features within the CVZ.

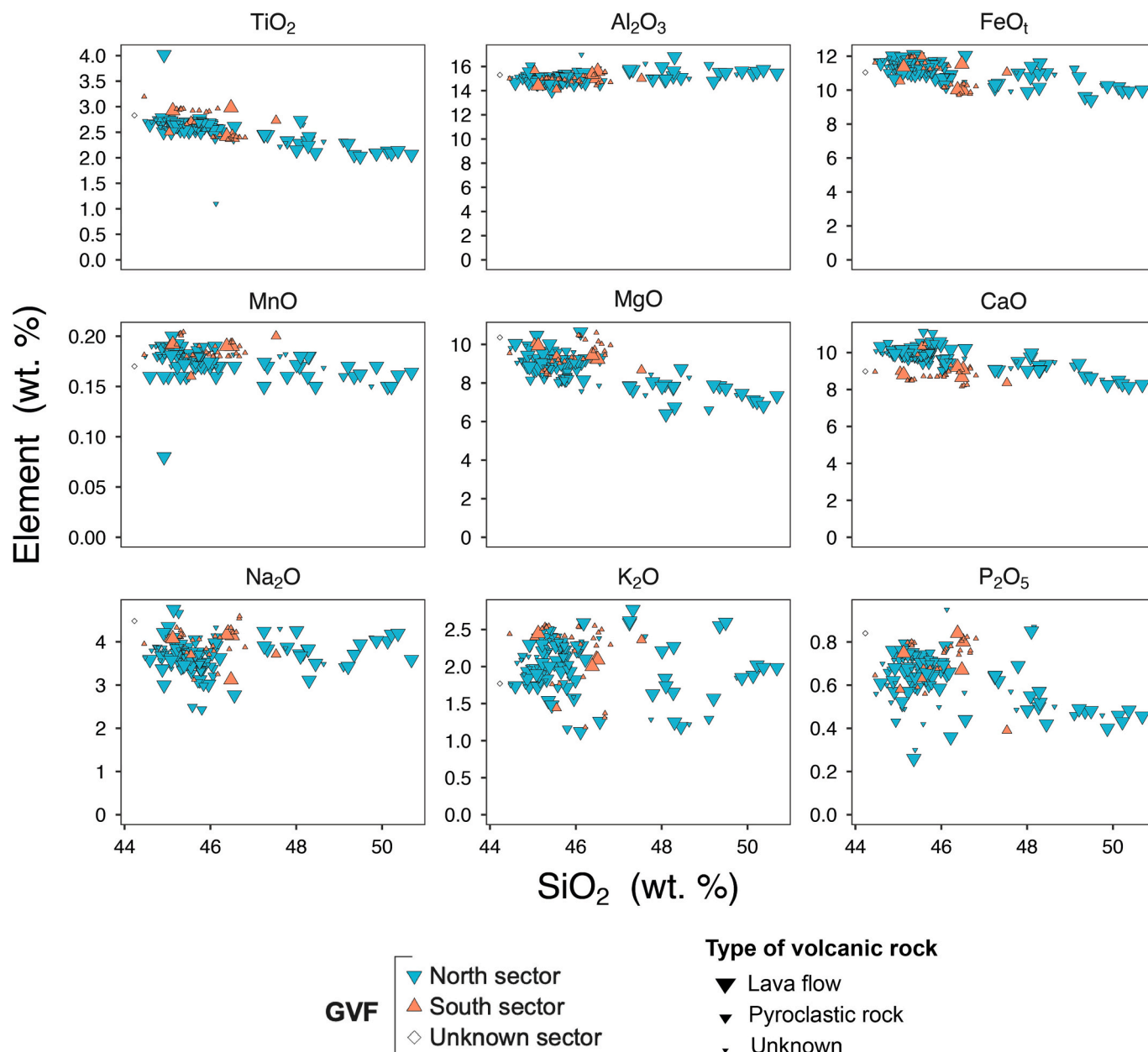


Fig. 13. Major element vs. SiO_2 content Harker diagrams for the whole-rock analyses of magmatic rock samples from the GVF. Major element compositions have been normalized to 100% in anhydrous base with Fe as FeO_t . This graph can also be found in the interactive report in Supplementary Material 5.

Regarding data quality, it is necessary to highlight the lack of accuracy concerning, for example, the location of the sampling sites. Indeed, only $\sim 10\%$ ($n = 46$) of the samples have been located using a GPS device. For most of them ($\sim 79\%$, $n = 360$), UTM coordinates have been manually assigned with Google Maps based on the description of the sampling location provided by the consulted reference(s). For the remaining 53 samples ($\sim 12\%$) their exact location is unknown and only the information regarding the CVZ zone (and occasionally subzone in the case of GVF samples) is available. Finally, it should be noted that some of the detected outliers in the dataset correspond to the analyses conducted by Calderón et al. (1906) and Washington (1907) (Fig. 17). It is important to consider that these analyses were performed during a time when analytical tools were in their early stages of development, and precision was significantly lower compared to modern standards. Therefore, it is possible that these outliers may be attributed to analytical errors or inaccuracies associated with the limitations of the analytical techniques available at that time.

Inevitably, potential errors may be present in the CatVolc database, stemming from typographical mistakes or other inaccuracies in the original publications or during the data compilation process. Additionally, discrepancies might arise due to the diverse and idiosyncratic formats in which experimental data are presented, spanning tables, table captions, online supplements, and sections detailing experimental methods and results. Furthermore, occasional corrections or revisions may be made in published errata or subsequent publications. Users encountering any discrepancies are encouraged to communicate with the corresponding author. Identified errors will be rectified, and an updated version of the CatVolc database will be made available on the Zenodo open-access repository (Miranda-Muruzábal et al., 2023; <https://doi.org/10.5281/zenodo.8332518>). For this reason, although included as Supplementary Material, we recommend the readers to always download the latest version of the CatVolc database from the Zenodo repository before beginning to analyse the content or start working with the database. In addition, the incorporation of data from a

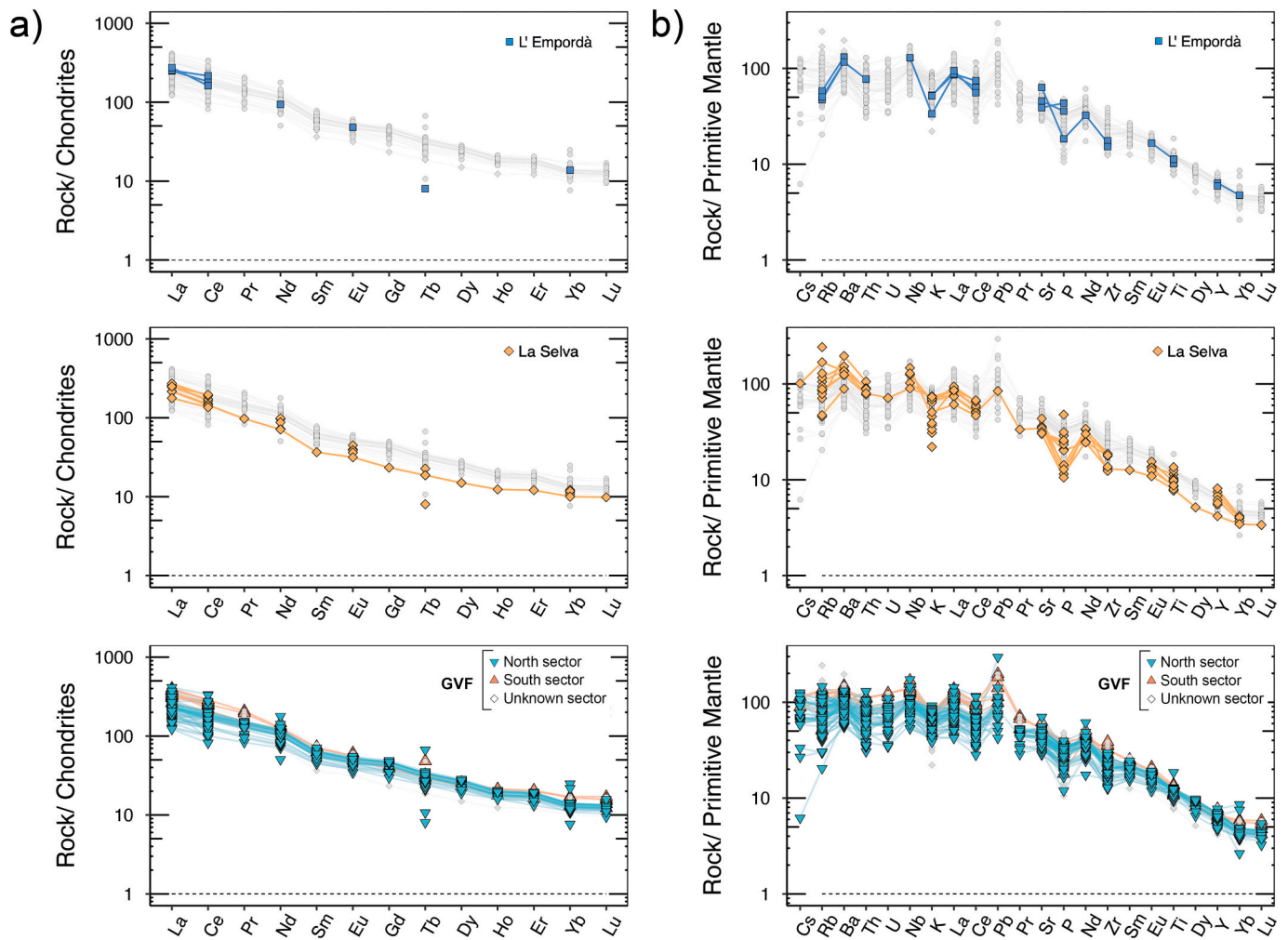


Fig. 14. a) Chondrite-normalized (Sun and McDonough, 1989) REE elements plots for L'Empordà, La Selva and GVF areas. b) Primitive mantle-normalized (Sun and McDonough, 1989) incompatible elements spider-diagrams for L'Empordà, La Selva and GVF samples. This graph can also be found in the interactive report in Supplementary Material 5.

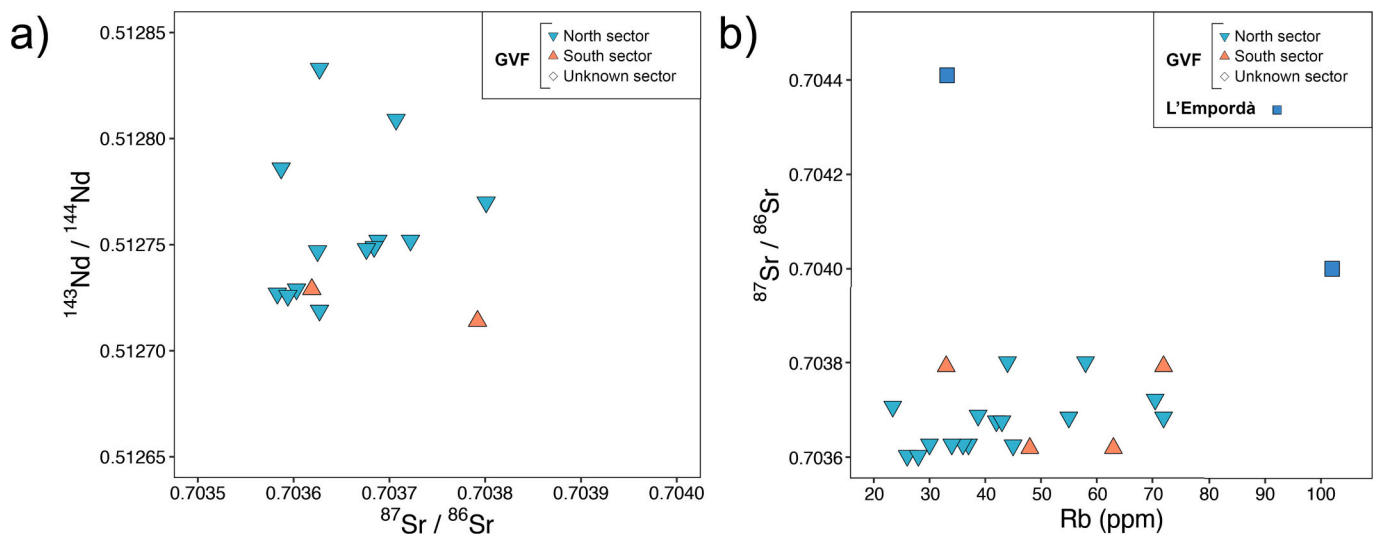


Fig. 15. $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $^{143}\text{Nd}/^{144}\text{Nd}$ (a) and Rb vs. $^{87}\text{Sr}/^{86}\text{Sr}$ (b) diagrams of the available isotopic data included in the CatVolc database. Note the higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the L'Empordà magmas. Further graphs can also be found in the interactive report in Supplementary Material 5.

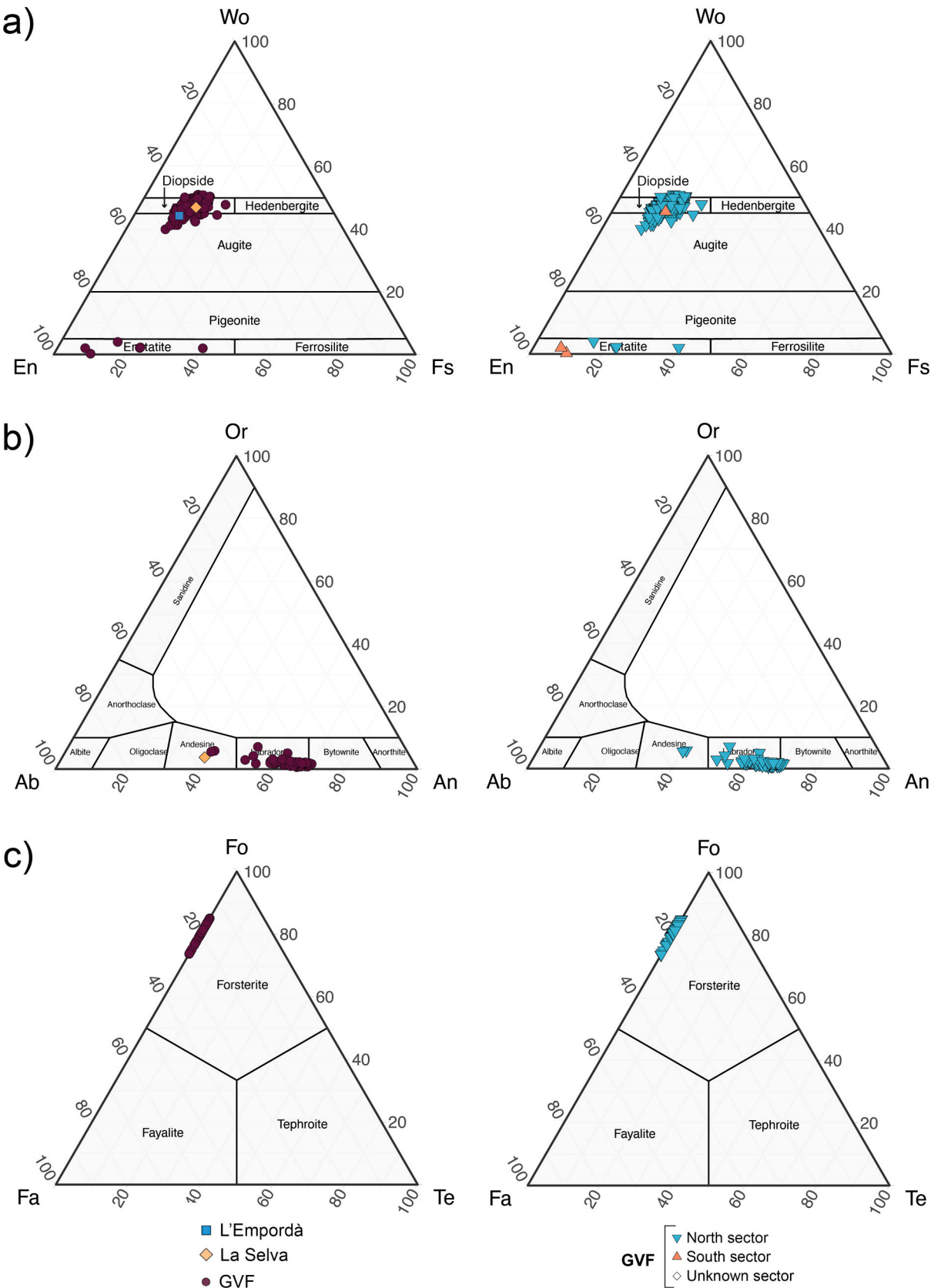


Fig. 16. Ternary diagrams for pyroxene (a), feldspars (b), and olivines (c). Ab: Albite; An: Anorthite; En: Enstatite; Fs: Ferrosilite; Or: Orthoclase Wo: Wollastonite. These graphs can also be found in the interactive report in Supplementary Material 5.

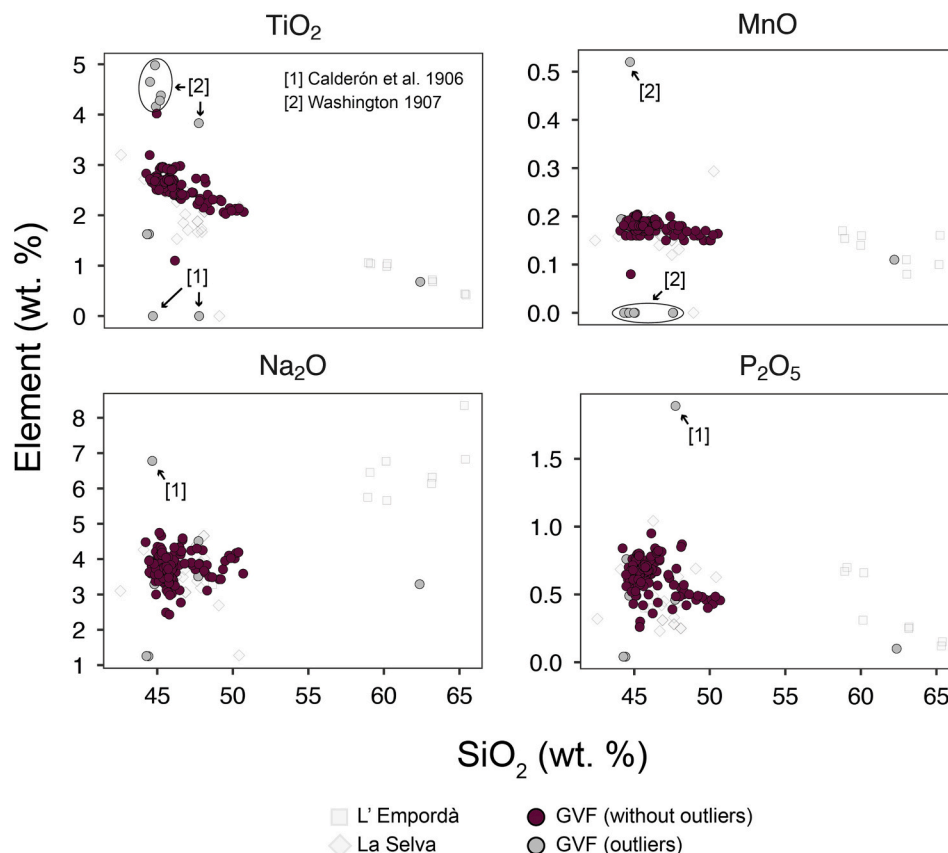


Fig. 17. Na_2O , TiO_2 , MnO and P_2O_5 vs SiO_2 content Harker diagrams for the whole-rock analyses of magmatic rock samples from all three zones of the CVZ. Major element compositions have been normalized to 100% in anhydrous base with Fe as FeO . GVF samples and their corresponding outliers have been highlighted. This graph can also be found in the interactive report in Supplementary Material 5.

specific paper into CatVolc does not imply any judgment from the authors of that paper regarding the quality of data/analyses. For this, CatVolc users are strongly encouraged to independently assess data by meticulous reviewing and independently evaluate the original published papers.

7.2. Future volcanic-driven studies at the CVZ

Based on the analysis of currently available data, we propose a series of future actions to fully understand the magmatic plumbing system and the dynamics of the magmatic processes occurring in the CVZ. First, there is an urgent need to increase the amount of geochronological data, particularly at the GVF. Such information is crucial for comprehending the temporal evolution of magmatic activity in the CVZ and establishing potential correlations between magmatic/volcanic processes and the geodynamic evolution of the region. Additionally, in the GVF, geochronological data would contribute to a better estimation of eruptive frequency in the area and enable more accurate assessment of temporal volcanic hazards.

Future research works should also prioritize expanding the available geochemical information across all three zones of the CVZ, with particular emphasis on the older areas such as L'Empordà and La Selva. This will provide a more comprehensive view of compositional variability in the region and enhance our understanding of the underlying magmatic processes. In this regard, numerous small outcrops of volcanic rocks related to the CVZ have recently come to light, such as those in Cadaqués, Port de la Selva, Llança, or Vilajuïga, in the easternmost sector of L'Empordà, in the Cap de Creus massif. The geochemical, petrological, and structural characterization of these scattered outcrops of volcanic rocks will contribute to advancing our comprehension of the

CVZ's context and evolution.

In the GVF, it is imperative to increase the number of studied volcanic edifices and provide detailed stratigraphic descriptions of the sampling locations. This will facilitate the examination of potential compositional changes among eruptive events and allow for the analysis of intra-eruptive variations if present. To further enhance our understanding, future studies should complement existing trace and major element data with thermodynamic modelling, geothermobarometry calculations, and new analyses focusing on isotopic and mineral chemistry. Additional investigations on specific mineral phases can include diffusion modelling and calculations of magma ascent rates, among other approaches. Finally, we encourage to further analyse the CatVolc database content with other multivariate techniques, such as principal component analysis or clustering, or applying geochemometrics, a geochemistry systematized branch resulting from the combination of geochemical principles with statistical, mathematical, and computational tools (e.g., [Aguirre Espinosa et al., 2022](#)). Such endeavours will contribute to a more comprehensive characterization of the magmatic system(s) and its dynamic processes.

8. Summary and conclusions

We present the CatVolc database, an up-to-date compilation of all published geochemical and geochronological data from the CVZ between 1906 and 2016 (34 peer-reviewed scientific articles, three PhD theses, one Master thesis and one Bachelor thesis). Moreover, both the ICGC and the Garrotxa Volcanic Zone Natural Park provided major and trace element data from 22 and 50 magmatic rock samples, respectively. The current version of the CatVolc database includes geochemical analyses from 405 rock samples (296 juvenile magmatic rocks -lavas and

pyroclasts- and 109 xenoliths), and radiometric/thermoluminescence dating data from 57 rocks (55 volcanogenic and two dykes), 4 paleosols samples developed between volcanic deposits and 1 sample from sediments. A preliminary analysis of the database content shows that the GVF is the most represented zone accounting for over 80% of the total samples. This observation reflects the interest of the scientific community for this volcanic field, mostly due to its larger areal extension and better conservation of the volcanic products compared to the older volcanic zones of L'Empordà and La Selva. Based on the analysis of information included in the CatVolc database, there is an urgent need to increase the number of geochronological data and expand the available geochemical information from all three CVZ zones. Such information is fundamental to fully comprehend the temporal evolution of the magmatic activity at the CVZ and to establish potential correlations between the magmatic/volcanic processes and the geodynamic evolution of the region. Additionally, in the GVF, geochronological data would contribute to estimate the eruptive frequency in the area and allow carrying out more accurate temporal volcanic hazard assessment. The latest version of the CatVolc database will be accessible for download from the Zenodo open-access repository (Miranda-Muruzábal et al., 2023; <https://doi.org/10.5281/zenodo.8332518>), ensuring full accessibility to the scientific community and the general public. We expect the CatVolc database to become with time a key tool for comprehending the spatial and temporal evolution of the magmatic system(s) and volcanic activity in the CVZ, particularly in the GVF. This aspect is critical for advancing in the assessment of the volcanic hazards in the region and for gaining a comprehensive understanding of future volcanic activity.

CRediT authorship contribution statement

Martín Miranda-Muruzábal: Conceptualization, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Formal analysis, Validation. **Adelina Geyer:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Meritxell Aulinas:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Helena Albert:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Miquel Vilà:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Fus Micheo:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Xavier Bolós:** Visualization, Writing – original draft, Writing – review & editing. **Dario Pedrazzi:** Writing – original draft, Writing – review & editing. **Guillem Gisbert:** Funding acquisition, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Llorenç Planagumà:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The latest version of the database is freely accessible for download from the Zenodo open-access repository (Miranda-Muruzábal et al., 2023; <https://doi.org/10.5281/zenodo.8332518>).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jvolgeores.2023.107998>.

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