The Erquy Volcanic Series

A proterozoic volcanic series case study

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Introduction

There are numerous ancient volcanic series, or so-called «paleo-volcanics», in the Armorican Massif.

One of the most beautiful and classic examples is the Erquy volcanic series which is located on the eastern flank of the Bay of Saint-Brieuc. There, the series form 'pointe de la Heussaye' that protects the harbor of Erquy in the south (figure 1).

The Erquy volcanics are interesting for several reasons:

- the quality and accessibility of its outcrops;
- the variability of the rocks;
- the simplicity of the structure that allows for an easy understanding.

This region was geologically mapped by Barrois on a 1/80 000 scale (map of Saint-Brieuc, n° 59), who also published a first detailed description of the various facies in 1932. It was not until the [PhD] thesis of Bernard Auvray (1967) that the volcanics were studied from a modern perspective; he also mapped the volcanic series in detail. Numerous French and international scientists have kept studying the volcanic series of Erquy ever since.

Figure 1. «Pointe de la Heussaye» protruding in the sea, as seen from the east.

Tectonic context

General structure

The volcanic series of Erquy is faulted on the proterozoic basement (Coëtmieux–Fort-la-Latte diorite) towards the east (maps of Saint-Cast (n° 206) and Saint- Brieuc (n° 243)). Towards the north, at the port and cape of Erquy, we can find outcrops of red detrital rocks (Formation des grès [Sandstone Formation of] d'Erquy-Fréhel). The relationship with the Erquy volcanics is not visible in outcrop.

The volcanic rocks at 'pointe de la Heussaye', to the south of the roadstead of Erquy, follow each other in vertical to subvertical banks and alternate with sedimentary clay-, silt- and sandstones. The stratification is regular, in the E-W direction, dipping vertical to 80°S (figure 3). The polarity [polarité ~flow?] of the series can be established by using (i) the sorting of the sandstones [granoclassement dans les bancs gréseux] or (ii) in the submarine flows (polarity of the pillows). We can find the basis of the volcanic series in the south, and the top in the north (figure 2).

Deformation

The deformation of the volcanic series of Erquy is weak to moderate and is mainly characterized by tilting and a discrete schistosity (figure 3).

This subvertical schistosity has a 30-40°N direction and is only expressed in the pelites [metamorphised clay-rich sediments]. The schistosity is absent in the basaltic and acidic lavas as well as the more competent [high strength] sandstone levels. The regularity of the beds is interrupted by multiple faults with a 20-30°N orientation. Fieldwork suggests that both forms of deformation, the ductile (schistosity) and fragile (faults), do not find their origin at the same time of tectonic deformation.

The schistosity is probably Cadomien in age [~570 Ma] while the faults are reported to be Hercynian [~Variscian, ~ 300 Ma] in age.

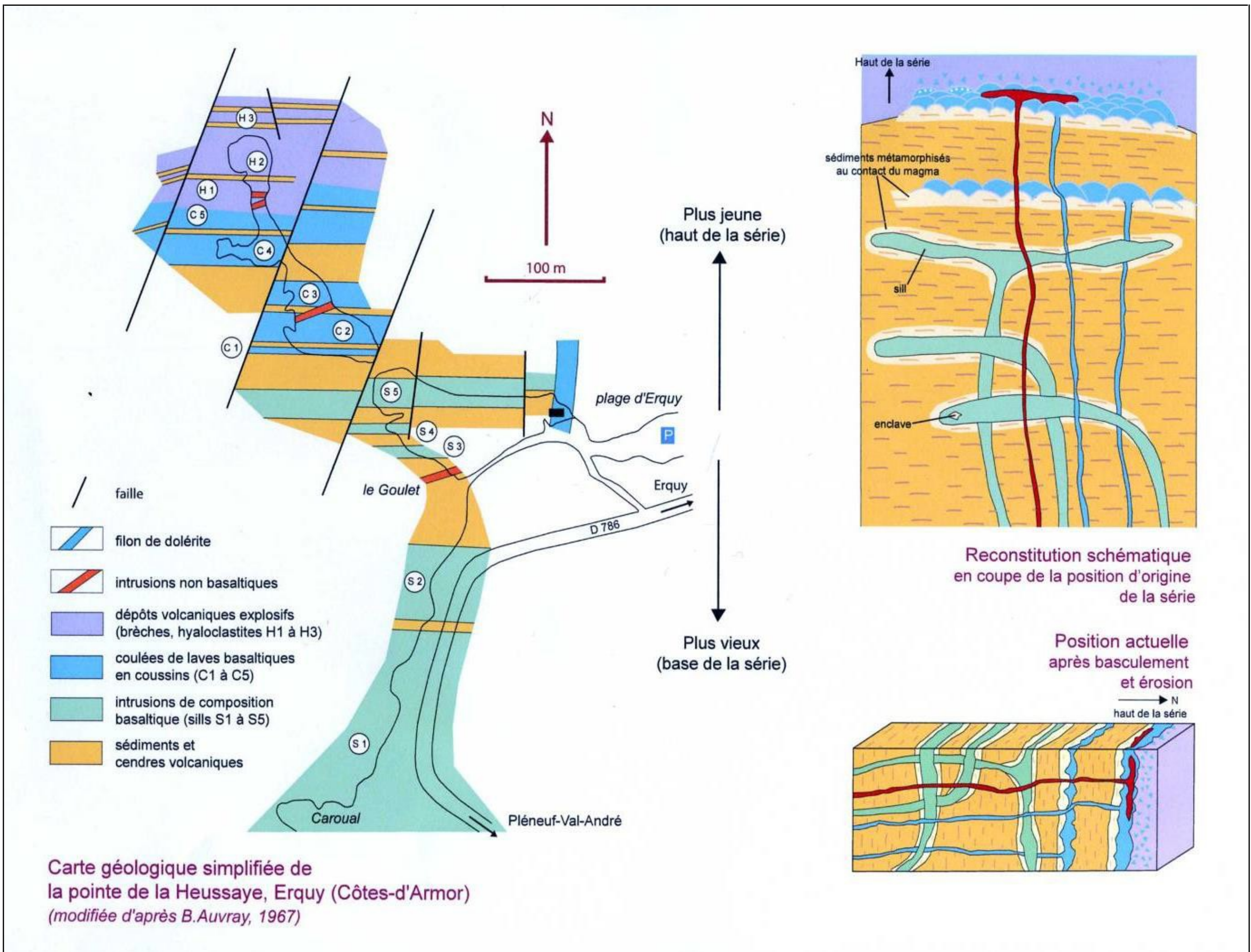

Figure 2. Geological map of 'pointe de la Heussaye',south of the roadstead of Erquy (after B. Auvray, 1967, modified by J. Plaine, 2014).

Figure 3. Stratification and schistosity in the sedimentary rocks of 'pointe de la Heussaye.

Diversity of the volcanics of the 'La Heussaye Series'

Within the volcanics of Erquy, we distinguish:
1) intrusions of basic rocks in layers parallel to the stratification (sills); 2) basic lava flows in the form of pillow lavas; 3) hyaloclastite breccias [poorly sorted, non-bedded, contact water]; 4) tuffs intercalated with the sedimentary rocks;
5) some rare dikes of acidic volcanic rocks.

The sills

At the base of the sequence, thick homogenous sheets [lames] of large volume outcrop within sediments with contact metamorphosis. This metamorphism (decimeter scale) transforms the sediments into hornfels, massive hard rocks that are resistant against erosion and appear in relief in the foreshore. These sills are hypovolcanics [subsurface?] (figure 4).

Figure 4. A basaltc vein injecting itself in the sedimentary rocks in the form of sill.

Lava flows with pillow lavas

The size of the pillows varies between 0.2 and 2.0 m (figures 5 and 6). Numerous pillows show an outer aureole of variolithic character [radiating fibres, chilled margin]. These 'varioles' are globulites [~spheres] of 1 to 5 mm in diametre and are made of plagioclase microcristals. These 'varioles' are interpreted as devitrification structures [development of crystals in a glassy rock].

Figure 5. Pillow lava of about a meter, seen in section, sowing a morphological dissymmetry.

Figure 6. Accumulation of pillow lavas within a basaltic flow.

The morphology of the pillow lavas (flat base, rounded upper edge [Figure 5] – tight [moulant?] base underlying the pillow lavas, peduncle [pédoncule] between two pillows) allows us to orient the volcanic series, that is now vertically exposed, with the top of the pile towards the north (figure 1). The matrix between the pillows is of a breccia or tuff nature. The presence of pillow lava flows is typical for submarine volcanism.

The breccias, or hyaloclastites

These are abundant in the northern part of pointe de la Heussaye. These are remarkable rocks because of their color and structure: within a dark green matrix we find numerous angular black pieces that correspond with fragments of vitrified lava (figure 7). These breccias are the result of explosive eruptions made by the encounter, at shallow water depth, between very gas rich lava and seawater that is evaporated at the contact. These breccias are known as 'hyaloclastites'.

Figure 7. Volcanic breccia with numerous angular fragments of pillow lavas.

Tuffites (tuffs)

Between the flows we can see some clear grey or slightly greenish rocks, with a very fine millimetric or centimeter bedding. We cannot distinguish between volcanic or sedimentary rocks based on the very fine crystals. Most probably, these rocks are the result of a mixture (in very variable ratios) between pyroclastic elements and a sedimentary fraction during the volcanic explosions.

Later [younger] veins

These veins are clearly visible towards the top of the series. These are light-colored veins, a few meters thick, in relief from the surrounding rocks.

These rocks constituting the ultimate terms of volcanism, aphanitic, with a trachytic texture, are known as 'keratophyres' (figure 8).

Figure 8. Acidic vein injected in the volcanic formations, now in relief because of erosion.

To be complete, the geological map (figure 2) shows the existence, east of the Pointe de la Heussaye, of a dolerite vein, 10 to 20 m wide, micrograined, with rare plagioclase phenocrysts, intersecting the Erquy series in a 0-160°N angle.

This vein crosses the Erquy volcanics perpendicularly. On the foreshore, it is transformed into remarkable balls, with the outer parts looking like 'shells of a skin peeled onion'. A similar vein cuts across the Erquy-Fréhel Sandstone Formation, on the opposite shore of Erquy harbor, and probably represents the extension of this vein towards the north. This dolerite belongs to the vein procession which was emplaced in the north-east of Brittany at the end of the Paleozoic (~360 Ma) and does not belong to the history of the Heussaye volcanic series which is much older (610 Ma).

Texture and mineralogy of the different volcanic formations

Microscopic observations show that the textures (arrangement of minerals relative to each other) are very variable and result on the one hand from the cooling rate and, on the other hand, from the nature of the volcanic phenomenon (effusive or explosive phenomenon). The texture can thus be doleritic, arborescent, fluidal, hyaloclastic, etc.. Among the most characteristic aspects, the presence, in the pillow lavas, of very thin and long forked rods of plagioclase is characteristic of very rapidly cooling volcanic rocks, which is the case for these rocks covered by water.

All the volcanic rocks of this Heussaye series have very similar mineralogical compositions, only are the relative proportions of the minerals variable.

The most common minerals are plagioclase (albite), chlorite, epidote, calcite, opaque minerals and rarely quartz. Pyroxene is rare, only observed in the heart of the thickest sills. Unlike classic basalts, glass, or mesostasis, has disappeared.

These paleovolcanic rocks, most of the mineralogy of which are so-called low temperature minerals, are known as spilites. The late, clear, associated veins are known as keratophyres..

The table below summarizes the differences between a classic example of a volcanic association, the 'Chaîne des Puys'for example, where the recognized minerals are said to be of high temperature, and the components of the Erquy series, a so-called low temperature mineralogy.

Basaltic rock	**Acidic rock**	
Basalte	***Trachyte(domite)***	***Chaîne des puys***
Olivine (Silicate Fe, Mg) Pyroxène augite (silicate Fe, Mg, Ca) Feldspath plagioclase calcique Magnétite (Fe_3O_4) *Minéraux de haute température (1100 °C)*	Silice (tridymite) Feldspath sanidine (K - Na) Mica biotite (phyllosilicate OH, K, Fe, Mg)	Aerial lavas that are not altered by submarine hydrothermalisme
Spilite	***Kératophyre***	***Erquy - LaHeussaye***
Pyroxène magmatique relictuel Feldspath plagioclase sodique (albite) Chlorite Épidote Calcite Eau *Minéraux de basse température (300-400 °C)*	Feldspath plagioclase sodique (albite) Chlorite Épidote Silice (quartz) - peu -	Submarine lavas altered by hydrothermalisme

Figure 9. Comparative mineralogy between the volcanics of the chaîne des Puys and pointe de la Heussaye.

Chemical composition of the lavas of pointe de la Heussaye

The table of figure 10 shows the chemical composition of two examples of Erquy volcanic rocks: the center of a pillow lava and a dike intersecting the volcanics.

The chemistry of the pillow lava is overall the chemistry of a basaltic volcanic rock, but the mineralogy is of low temperature.

This type of rock is called 'spilite'.

The chemistry of the dike is enriched in SiO_2 and alkalines (Na_2O et K_2O): we call this 'keratophyre'. This association of paleovolcanics is known as a « spilite-keratophyre » association.

The origin of such an association has been the subject of controversy in the 1970-1980's with the publication of numerous books and scientific publications.

Interestingly, these debates are not 'in fashion' anymore.

There are three hypotheses regarding the origin of spilite:

- 1/ there exists a spilitic magma as such;
- 2/ we are dealing with an 'autometamorphized' basaltic magma, hydrothermalized in contact with sea water;
- 3/ these are old metamorphized basalts in a 'green schist' facies.

The second hypothesis, with the interaction of basalt and sea water, seems the most credible these days.

	Cœur de pillow	Kératophyre
SiO_2	54,78	71,12
Al_2O_3	13,7	13,5
Fe_2O_3	11,88	3,06
MgO	3,39	0,65
CaO	3,96	0,25
Na_2O	6,36	4,75
K_2O	0,38	3,06
TiO_2	2,13	0,22
MnO	0,19	0,08
H_2O	3,11	1,52
Total	**99,91**	**98,21**

Figure 10. Chemical composition of the center of the pillow lava (spilite) and dike/younger vein [filon tardif] (kératophyre)

Age of the Erquy volcanics

In 2001, A. Cocherie (BRGM Orléans) dated zircons using the U-Pb method on individual crystals from minerals extracted from a tuff horizon. The obtained age is 610 Ma and is being interpreted as the zircon crystalisation age within the protolithic magma, or the series of Erquy.

This age corresponds to the final Proterozoic, locally known as the « Briovérien », and internationally known as the Ediacarian.

Geodynamical context

The context of the emplacement of the Heussaye volcanics is still subject of debate. Regional geological data demonstrate the existence of an old continental crust, known as the Icartian socle (~2 Ga), and a magmatic continental arc, known as the 'Pentévrien'. The submarine flows of Erquy could have developed under a period of rifting, which would not affect the continental crust but the magmatic arc (the Pentévrien), that itself was possibly constructed on the Icartien. The subduction zone would have been active for a long period of time allowing for: 1) the construction of a continental arc, followed by 2) the rifting of this arc.

The Heussaye volcanism would have happened in the inter-arc basin. The Cadomien chain itself would be the result of the shortening of the basin a few tens of millions of years later, with the Erquy series being tiled and [schistoseé].

During the Paleozoic, the eroded Cadomien chain will be covered again, in discordance, by the sandstones of Erquy- Fréhel (Ordovician), and probably several other Paleozoic formations that have now been eroded.

Before these series were themselves slightly deformed during the Hercynian orogenesis, they were intruded, just like their Proterozoic basement, by doleritic dikes.

Author's note: this article was written in honor of Bernard Auvray (1938-1997), professor at the university of Rennes, whose work is fundamental for all studies related to this region.

Editor's note: Professor Sylvain Blais gave a presentation, during a meeting of the 'Commission de volcanisme de la SAGA', in April 2014, on the opening of the Atlantic Ocean and the paleovolcanics of Erquy, in the Côtes-du-Nord.

We are very thankful that he shared the text of his presentation so that it could be published [here] in *Saga Information*.

2015 Meeting between amateurs and professionals

Jean-Charles Campergue, président de la FFAMP.

The French federation of amateur mineralogy and paleontology (FFAMP) organizes, in collaboration with 'la Communauté d'agglomération Rouen-Elbeuf-Austre-berthe (CREA)', the first meetings between amateurs and professionals at 'Sciences la Terre'. These will take place on Thursday 12, Friday 13 and Saturday 14 March 2015 at Elbeuf, Seine-Maritime; these meetings are open to all, for an enrichment of opinions by exchange and debate.

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