The Origin and Extent of Student's Understandings: The Effect of Various Kinds of Factors in Conceptual Understanding in Volcanism

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Abstract

This study investigated and compared 130 students' perceptions of volcanoes and volcanic activity from an inner city elementary school (Year 6), middle school (Year 9) and student teachers in the science education department. A qualitative and quantitative methodology was used for this investigation. The data collection was based on three research stages: collection of information by the association of ideas, a Q-Sort test and a questionnaire with open-ended questions. The findings indicated that the sample possessed an incomplete picture of volcanoes and volcanic activity including many alternative conceptions about it. Both the students and the student teachers had surprisingly similar alternative conceptions despite the fact that the latter received more instruction on this topic. Moreover, over the course of the curriculum, a closer relationship between alternative conceptions and accepted scientific knowledge was evident. Hence, it was possible to map out the categories of alternative conceptions of volcanism and to measure the influence of the curriculum by looking at the evolution of these alternative conceptions. Based on the results, some suggestions to help teachers and students avoid critical barriers to learning that may be difficult to overcome later in their education are presented.

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Introduction

At Key Stages 2 and 3 (7-14 years), the French National Science Education Standards require children to develop a scientific understanding of the Earth's materials and processes and, logically therefore, of the Earth's structure that provides the context for such an understanding (B.O.E.N, 2000a-b). In seeking to support children's understanding in this domain, constructivist theories of learning and teaching provide a model which highlights the importance of children's existing ideas as the focus for conceptual change.

What are the students' ideas in Earth Sciences? Is it possible to classify their ideas into categories, e.g. physics, biology or chemistry? Is it possible to analyze and explain their ideas which persist, the difficulties and barriers to learning?

During the last three decades, there has been an increasing awareness of the importance of the variation amongst the ways students conceptualize and think about the phenomena they encounter in either science classes or in daily life (Driver, Guesne & Tiberghien, 1985; Giordan & De Vecchi, 1987). Various science conceptions constructed in students' minds are called "misconceptions", "preconceptions" or "alternative frameworks" (Schnotz, Vosniadou & Carretero, 1999). If these terms are examined for similarities, they have almost the same meaning. In this article, the term *alternative conception* is used to describe any conceptual difficulties, which is different from or inconsistent with the accepted scientific definition.

In most cases, alternative conceptions are not necessarily spontaneous ideas. In fact, they arise from *knowledge at different levels* (Chevallard, 1991). These alternative conceptions may be a product of instruction or come from the analogies used by teachers or from textbooks. At the same time, they might arise from the discrepancy between daily language and scientific language as well as the students' social environments (Happs, 1985; Ford, 2005). Moreover, when the teachers do not fully understand the scientific content of and believe their conceptions are correct, they may cause the students to have alternative conceptions (Osborne & Freyberg, 1985).

If teachers have alternative conceptions, they will have difficulties identifying the students' alternative conceptions and correcting them. For this reason, an investigation of alternative conceptions amongst science student teachers who have had instruction on fundamental concepts of science and a comparison of the student teachers' alternative conceptions to those of students would both be worthwhile.

Researchers in many countries have tried to answer a number of important questions related to children's conceptions such as which alternative conceptions occur, what their sources may be, how extensive they are, why they are so resistant to instruction, and what teachers can do to facilitate conceptual change.

Most research in Earth Science alternative conceptions has focused on concepts in;

- The Earth's materials: minerals and rocks (Happs, 1982, 1985; Dove, 1998; Ford, 2005);
- The Earth's Structure (Lillo, 1994; Sharp, *et al.* 1995; Blake, 2005);
- The Earth's processes: mountains, volcanoes, earthquakes, weathering and erosion (Russell, *et al.* 1993; Bezzi & Happs 1994; Sharp, *et al.* 1995; Blake, 2005; Dal, 2005)
- Geological time (Ault, 1982; Trend, 1998).

Whilst there have been a number of informative studies on children's ideas about the Earth's materials such as rocks and minerals, there is very limited research on children's thinking about the Earth's processes and particularly about volcanoes. Findings take into consideration language students and teachers employed to describe and define volcanoes, the criteria used by novices to classify and identify the products from volcanic eruption, the nature of the materials constituting the volcanic structure, the make-up of this structure and its link to the Earth's make-up.

According to the criteria of researchers in the previous literature, the student's ideas appeared to represent three different alternative conceptions of descriptive and causal understanding for volcanoes and volcanic activity. Bezzi & Happs (1994), Sharp, *et al.* (1995) and Dal (2005) found that the student who failed to recognise volcanoes and volcanic activity as natural events (Level 1). The students who did recognise volcanoes and volcanic activity as natural events, but said that they did not occur in the past (Level 2) (Ault, 1982; Lillo, 1994; Trend, 1998; Blake, 2005), while the students who believed they had occurred in the past as well as the present (Level 3) (Ault, 1982; Sharp, *et al.*

1995; Trend, 1998). With regard to causation, Level 1 was assigned to children who did not know what caused volcanic eruptions ("it happened by itself") or offered some human cause, e.g., loud noises or people walking on the ground causing vibrations (Bezzi & Happs, 1994; Sharp, *et al.* 1995; Dal, 2005). Level 2 causes were naturalistic, but either eccentric (for example, the volcano gets too full of lava), or approached some degree of scientific understanding (for instance, internal heat from the core or magma being forced up by gas pressure beneath the Earth) (Ault, 1982; Bezzi & Happs, 1994; Lillo, 1994; Blake, 2005). Level 3 responses related volcanic activity to the action of crustal plates (Sharp, *et al.* 1995; Trend, 1998; Dal, 2005).

These studies confirm that children develop their own, mostly non-scientific, understanding of volcanoes concepts before instruction, and describe and interpret these in everyday terms that are familiar to them. In addition, they have shown not only how generally limited children's understanding of the volcanoes, the products from the volcanic eruption and the nature of the materials constituting the volcanic structure is, but how different their conceptions are from those of Earth scientists. Importantly, key "critical barriers" to children developing a scientific understanding in this domain have been identified (Ault, 1982; Bezzi & Happs, 1994; Trend, 1998):

- large scale patterns in the environment and the physical changes they represent;
- geological time.

It is important to note that these early studies have tended to focus more on the ideas about volcanoes and volcanic activity held by samples selected only from one course of the curriculum. Different from previous literature, this paper reports on a study that investigated the ideas about volcanoes and volcanic activity of samples selected from different types of curriculum. In addition, investigation and comparisons will be made of the understanding of the alternative conceptions of the student teachers and Year 6 and Year 9 students to determine if the student teachers' alternative conceptions can be the source of the students' alternative conceptions.

This paper begins with a discussion regarding the nature and the complexity of knowledge at different levels in the conceptually confined domain of volcanism. There then follows an investigation and a comparison of the levels of understanding of children from Year 6 (10-11 years), Year 9 (13-14 years) and student teachers in the first two years of their professional training about concepts of volcanism. Such discussions will reveal how, over the course of the curriculum, although some alternative conceptions persist, others appear at given times or evolve. Equally, the role classroom materials play in this evolution will be evaluated. This study is not centred on the description of barriers to learning, but it may constitute a preliminary study to aid their identification. Identifying barriers to learning, not only helps to develop teaching strategies but also provides a first step for future research, which should address the effects of developing guide materials and teaching strategies as well as organizing workshops for inservice and preservice teacher training. Finally, such implications of the findings of this study for further research and for classroom practice will be addressed.

Research Design: the knowledge concerned

The Importance of the Structure of Knowledge

The study on knowledge at different levels provided the epistemological framework of research: it has allowed an *ex ante* analysis to take place and to sketch out the methodology for both the collection of the data and for interpretation.

Let me to clarify what the definition of knowledge at different levels is and what kind of relationship amongst these different definitions of knowledge exists.

Students are presented with different ideas about the Earth's processes during their schooling at all levels (Happs, 1982, 1985). According to Giordan & De Vecchi (1987), these ideas originate from knowledge that has been gradually acquired by the scientific community during the development of science, and which shall be named *reference knowledge*. According to Chevallard (1991), the *reference knowledge* chosen is decontextualised knowledge. This *reference knowledge* is therefore the object of a *transposition* (recontextualisation, or even a redefinition) to be taught at a given level. This first transposition from *reference knowledge* to *knowledge to be taught*, is thus, in fact, followed by a second transposition, which, carried out by teachers (but also by Official Instructions and textbooks etc.) establishes a *school knowledge* with its own particularities. So, the *school knowledge* is a knowledge rebuilt specifically for teaching. Finally, the last stage of the student's work is to interpret the knowledge "the way he or she can" during various steps which will lead him/her to transform it into *acquired or assimilated knowledge* in a particular context.

In fact, it appears obvious that the teaching offered plays a role in the construction of the students' knowledge (Driver, *et al.* 1994), but what exactly is this role? How is the received information integrated? Is it the logic of knowledge which organises the student's mental models?

The research was carried out into the acquisition of this logic of knowledge by analysing its' structure at different levels: from *reference knowledge* to *school knowledge*. Thus it was possible to establish *ex ante* hypotheses about the way in which the pupils are most likely to approach volcanicity and the notional fields concerned. These two stages served as milestones in constructing the finally employed methods.

In addition, the history of Geology is informative about the various ways in which the problem of volcanoes has been tackled over time: these other approaches correspond to different contexts and times when the current techniques and theories did not exist: they were helpful in the interpretation of answers of pupils who did not yet have scientific theories at their disposition either.

Thus the two following questions addressed were: How does the knowledge concerning the case of volcanism come about**?** How has the geological phenomenon been interpreted since Antiquity?

How Does the Knowledge Concerning the Case of Volcanism come about?

The analysis of knowledge was based upon: with regards to *reference knowledge*, on possible sources of documentation of middle school Geology teachers, thus on works illustrating a first sphere of knowledge transfer from the field of research to that of university education (e.g. Francis, 1993; Scarth, 1999) or to that of a popularisation considered as satisfactory in the scientific world (e.g. Sigurdsson, *et al.* 2000; Frankel, 2005); with regards to the *knowledge to be taught*, on the curriculum and on Official Instructions (B.O.E.N, 1978a-b, 1979a-b and 1985a-b) for the levels considered as well as textbooks. According to Stern & Roseman (2004*)* and Ford (2006)*,* the textbook "proposes an order for learning", as much with regard to the general organisation of contents as to the organisation of teaching. Hence, it is related to the knowledge to be taught. However, it is also "a teaching aid for the students". It accompanies the teacher's action in the classroom and prolongs it outside the classroom. It represents an interpretation of Official texts. Thus, it already belongs to *school knowledge*.

These analyses mainly use the overall structure of the documents (in particular chapter division), indexes, glossaries and keywords. They make it possible to highlight the following points:

- For *reference knowledge*, as stated in the curriculum and textbooks (which are the means of knowledge transfer), it is possible to use a general definition of the object "volcano". To use the example offered by Sigurdsson, *et al.* (2000, p.42): "a volcano is an exit point where magma can get to the surface in an intermittent or continuous manner". However the *typical* volcano does not exist. Nevertheless, there are various shapes of volcanic structure which depend on the types of volcanic activities. These types of activity can be explained within the theoretical framework of plate tectonics, which allows us to form a model of Earth's internal dynamics (Vosniadou & Brewer, 1992).
- For the *knowledge to be taught*, similar to findings by Bezzi & Happs (1994), Lillo (1994), Sharp, *et al.* (1995) and Dal (2005), volcanism can be studied in various manners: three angles of approach were defined, corresponding to each of the particular notional fields; which are:
    - The human angle where all that corresponds to the relationship between man and volcanoes can be found: positive or negative consequences, with their catastrophic aspects, emotional or sensory; methods of study of the phenomenon and the vulcanologists' work; applied geology (Bezzi & Happs, 1994; Dal, 2005);
    - The descriptive angle in which all the geological objects related to volcanism are studied, for example, the products of the eruption (Sharp, *et al.* 1995);
    - The explanatory angle where the phenomenon is linked to the structure of the globe, the related mechanisms and matter transformations (Lillo, 1994).

In the textbooks used in French elementary and middle schools, these angles are weighted differently, according to the curriculum level and according to the publishers: for example, the Magnard Year 9 textbook seems to give more weight to the descriptive aspects than the Nathan textbook.

If we take a closer look at the contents of the curriculum, the study of the evolution of the contents of the curriculum was based on Year 9 and 10 levels in France (B.O.E.N, 1978a-b, 1979a-b and 1985a-b). Indeed, geology, as a taught discipline, was introduced into elementary school only with the Official Instructions of 1985 (B.O.E.N, 1985a) and the curriculum has not yet undergone any modifications at this level. This study highlights an evolution of the structure of the *knowledge to be taught*.

Before 1985, the starting points of Year 9 studies were regional; the teacher based initial activity on the observation and the analysis of a local landscape (B.O.E.N, 1978b, 1979b). The whole of the program was based on the study of objects or external phenomena. It was only in Year 10 that studies reached a planetary scale, where a *structural* model *of the Globe* was proposed. Global tectonics was approached with care, simply to specify and synthesise extra-curricular information**:** only "the existence of slow movements of the continents" was confirmed and that it was possible to see "the hypothetical cause of internal dynamics activities in these movements" (B.O.E.N, 1978b, 1979b).

After 1985, on the other hand, the study of landscape and local observations became little more than a teaching aid which "allows the study of global tectonics" and puts the explanatory value into perspective and which must be "invested in the explanation" of studied geological phenomena. The theory is not disputed: "the discussion of global tectonics does not concern the Year 9 class" and a certain bigotry appears here: use of affirmative forms without qualifications: it "shows that sedimentary accumulations have drifted... lithosphere functioning should be represented as a relevant system able to explain the genesis and setting of rocks" (B.O.E.N, 1978b, 1979b). The theory of global tectonics became a central point; it structures the unit of the *knowledge to be taught*. The explanatory aspect, (or interpretation), took the lead over the more descriptive aspects, which had been prominent before 1985.

How Has the Geological Phenomenon Been Interpreted Since Antiquity?

To analyse the way in which volcanism has been represented over the course of previous centuries, it is necessary to turn to works on the history of Geology (e.g. Gohau, *et al.* 1991; Simkin & Lee, 1994; Sigurdsson, 1999; Stanleys, 2005). A review of these brings to light descriptions of volcanism which are, on the whole, precise and correct. Through a study of the explanations attributed to the phenomena, conceptions emerge which are presumed to be present in different eras, revealing contemporary, social and religious influences, as well as scientific techniques of the time (e.g. volcanism was compared to the effects of gun powder until the 17th century). Similar to Bezzi & Happs, (1994), Sharp, *et al.* (1995), Blake (2005) and Dal's (2005) analysis in their articles, amongst the most common interpretations and those seen in the students' answers are the following.

- The existence of a central fire, fuelling the volcanic spouts (from Plato, fourth century B.C. to Hutton, 18th century, passing through Descartes' Principles of Philosophy, 17th century; "the Globe is fuelled by a central fire").
- Formation of volcanoes by the lifting up and bursting of the Earth's surface (from Albert the Great in the Middle Ages to the theory of Leopold von Buch in the 19th century)
- The likening of the volcanic structure to a "hollow mountain" (from Lucretius; "Etna is an entirely hollow mountain inside which an extremely violent wind circulates"; to Needham, 18th century)
- Volcanic emission of fire which originates from combustion, reasonably deep down, fuelled by mineral or organic materials and stirred up,

depending on the individual case, by winds, the Sun's rays or reactions with water…(from Antiquity until the 18th century; "volcanoes are caused by coal fires which melt neighbouring rocks into lava flows", Werner).

The Importance of the Epistemological Analysis For an Ex Ante Analysis

The analysis of knowledge helped to establish an *ex ante* hypothesis, clarifying which notional fields and which angles of approach the questioning had to deal with, as well as putting several research hypotheses forward. Indeed, it is possible to think that the influence of *school knowledge* on the student's ideas can be seen throughout the curriculum in the following ways:

- the progressive acquisition of scientific knowledge (Driver, *et al.* 1994);
- the importance of explanation compared with that of description (Vosniadou & Brewer, 1992);
- the development of objectivity in relation to that of subjectivity, with possible persistence of alternative conceptions distinct from *reference knowledge* (Schnotz, Vosniadou & Carretero, 1999).

In methodological terms, this can be interpreted as the need to observe the way the students approach the subject: for instance, do they think firstly about human consequences of volcanism? What vocabulary do they use? What are they referring to when explaining the formation of volcanoes, or their activity? These are the main objectives of this study.

Methods

Context

Teaching Earth sciences in France begins with a brief introduction of the Earth's processes (Volcanism, Mountain Building, Weathering and Erosion, and Digenesis) in Year 6 (10 to 11 years of age). Then, the introductory concepts such as the Earth's materials (rocks and minerals), the Earth's structure (the Land Surface, underground and inside the Earth) and Earth's processes are taught in middle school in Year 9 (13 to 14 years old). Formal earth sciences lessons start in Year 10 (14 to 15 years old).

Teacher training is a 2 year course offered to high school graduates who are selected from a nationwide examination. Student teachers take modules in Science and Social Science during their course. Students do their practice teaching in mainstream schools in their final year.

The Sample

All the schools in which the research was done are situated in the North of France. The study, which included a total of 130 people, took place in: two Year 6 classes from an inner city elementary school, containing 22 to 23 students (between the ages of 10 and 11); two Year 9 groups, from an inner city middle school, containing a total of 32 students (between the ages of 13 and 14) and 29 first year student teachers and 24 second year student teachers from an inner city university education department. These four groups are referred to in the study as ST1 (student teachers in their first year), ST2 (student teachers in their second year), YR6 (Year 6 students) and YR9 (Year 9 students).

Each student is represented in three sets of data, four even, for Year 9, in the form of questionnaires handed out, before the subject of volcanism had been tackled in class. It is considered that the alternative conceptions which appeared in Year 6 mainly refer to extra-curricular learning; in Year 9, these conceptions should refer back to what was learnt in Year 6; for student teachers, conceptions should consist of an inventory of fixed knowledge on volcanism at an adult level.

Instruments and the Data-Collection Procedure

The methodology of the study comprises three research stages: collection of information by the association of ideas, a Q-Sort test and a questionnaire with open-ended questions.

The association of ideas made it possible to determine the angles in which students approach the subject of volcanism and to compare it with the angles defined during the analysis of knowledge. It also revealed a first alternative conception of volcanism, which is global and consistently represented. The technique, partly based on *the autonomous method* of *construction of knowledge* of Di Lorenzo (1991), consists of making the subject draw up a list of link-words in relation to the word *volcano*, given as an inductive term. It should be pointed out that this technique was used twice for Year 9: the first time in the case of a geology lesson and the second, roughly six weeks later, in a French language lesson concerning a written poetry activity.

The open-ended questionnaire and the Q-Sort test made it possible to pinpoint the alternative conceptions in relation to the geological concepts concerned (see Appendix).

The questions were written based on assumptions about the notional fields of Earth Science (Francis, 1993; Sigurdsson, *et al.* 2000; Frankel, 2005), and indications provided by the History of Geology (Gohau, *et al.* 1991; Simkin & Lee, 1994; Sigurdsson, 1999; Stanley, 2005), and finally on the results of the previous data collections (quoted in the related literature e.g. Happs, 1982, 1985; Bezzi & Happs 1994; Lillo 1994; Sharp, *et al.* 1995; Blake, 2005; Dal, 2005). The corresponding notional fields relate to:

- the products from the volcanic eruption;
- the location, formation and transformation of the lava;
- the nature of the materials constituting the volcanic structure;
- the make-up of this structure and its link with the Earth's make-up;
- its formation.

Children enjoy drawing and are able to use drawings to communicate the identifiable features of objects they have been asked to draw (Haynes, *et al.* 1994), although caution is needed when using drawings to represent children's understanding as what is not drawn does not necessarily imply the absence of these mental structures (Newton & Newton, 1992). Data from the drawings were cross-referenced with information from other sources to provide a more complete "picture" of what a child understands.

To examine how students visualise these concepts, questions relating to the last two points asked for the answer in the form of a drawing. This kind of technique has been used by many researchers in the related literature (e.g., Lillo, 1994; Blake, 2005; Dal, 2005).

The cross-referencing of the data obtained using these two types of questionnaires made it possible to refine interpretations already made. In effect, they are two kinds of methods, one where the subjects are in a situation of production, the other more directive, the Q-Sort test, where they have to use operations of selection. For the Q-Sort test, it is a question of choosing the correct solution/s, or the best amongst a range of proposed solutions: the case could be that the correct solution appears in the cognitive field of the student whereas it was not there at the beginning; in addition the answer needs no structuring on the student's behalf. In the questions of production, the process is different: the student needs to recognise or to determine the correct response from the elements of his own cognitive field and to structure it correctly.

The open-ended questionnaire was therefore given first, then the Q-Sort questionnaire. The second questionnaire builds on the answers to the open-ended questionnaire in order to help understanding the sense of the first answers given by checking their coherence and thus allowing the validity of our interpretations. It therefore enabled pinpointing of the alternative conceptions concerned.

Data Analysis and Results

Association of Ideas (lists of words)

The elements taken into account are firstly, the average number of words suggested by the students at each level, and secondly, the vocabulary used. Similar to findings by Bezzi & Happs (1994), Lillo (1994), Sharp, *et al.* (1995), Blake (2005) and Dal (2005), the latter was classed into five categories.

- the "geological objects", i.e. elements characterising, for example the shape of the volcanic structures, the products of the eruption…(e.g. lava, fire, mountain…) and corresponding to the descriptive angle (Bezzi & Happs, 1994; Sharp, *et al.*1995);
- the "adjectives" often used at the same time as one of the preceding "objects" or in direct connection with this category (e.g. *hollow* mountain, *liquid* fire…) (Blake, 2005);
- the "phenomena" (e.g. eruption, fusion) corresponding to the explanatory angle (Lillo, 1994);
- words related to the "emotional and aesthetic fields", also comprising some isolated adjectives but, evoking feelings or impressions (e.g. danger, to destroy, fantastic) and connected to the human angle (Bezzi & Happs, 1994; Dal, 2005);
- some "variants" (e.g. dinosaur).

The percentage of answers in each category was quantified and translated into a graphical representation to facilitate comparisons. It should be noted that qualifying adjectives, which were not directly associated to an "object", were classified in the "emotional-aesthetics" category.

It can be seen (Table 1) that certain terms are found at all levels of the curriculum and can be interpreted as alternative conceptions of volcanism, like a *destructive eruption of red hot lava*; as for "fire" and "mountain" (the mountain that spits fire), they are consistently found in YR6, YR9 and ST1.

Table 1. **Elements of analysis in a list of words: The words most often seen are highlighted in bold.**

	YR6	YR9	ST1	ST2
Affective aesthetics	**Dead** **Killer** **Devastator** **Destructor** Red Hell Fear Noise	**Devastator** **Destruction** **Fear** **Death** **Red** Uncontrollable Flakes	**Destruction** **Catastrophe** **Red** Power/Strength Force Magic	(Very few responses) destruction Red
Objects	**Lava** **Fire** **Mountain** Ice cones	**Lava** **Mountain** **Fire** Rocks Flows Vent	**Lava** **Fire** **Rocks** **Stones** **Craters** Water Sparks Flames Clouds/Smoke/Steam	**Lava** **Rocks** **Craters** **Flows** **Magma** Lapillis Phenocrystal s Caldeira Rift Hotspot
Adjectives	**Hot Burning** Liquid	**Hot Burning** Viscous	(Very few) Hot	(Rare) Hot
Phenomena	**Eruption** **Earthquake**	**Eruption** **Earthquake** Melting Fissuring	**Eruption** Melting	**Eruption** **Melting** Rising terrestrial movements

It is possible to see on one hand, an increase of scientific knowledge from YR6 to ST2, in line with the level of the curriculum, and on the other hand, a correlative reduction of expression and subjectivity. The scientific angle of approach (objects, phenomena) is increasingly represented, especially the descriptive aspects (objects), whereas the explanatory angle is only well represented at the ST2 level (see Figure 1). Scientific teaching seems to have played its part in the acquisition of knowledge and a greater objectivity. The following results will make it possible to clarify this role.

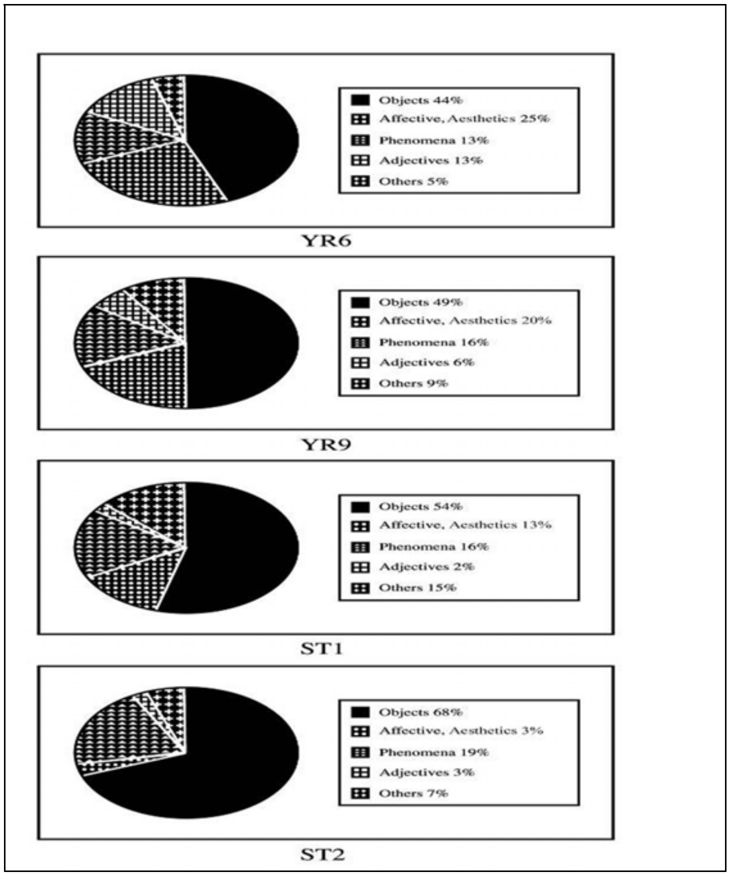

Figure 1. The angles of approach on different levels-The answers to the first questionnaire.

Open-Ended Questionnaire and the Q-Sort Test

Only the global result of the answers to the two types of questionnaires will be discussed here, taking into account the fact that the corresponding data was treated successively, the Q-Sort test having been conceived after the study of the answers to the first questionnaire. As for the data processing, the notional fields defined earlier constituted the reference grid. The analysis of the written answers was based on the description and the counting of "keywords" found in the students' conceptual levels (Bezzi & Happs, 1994; Sharp, *et al.* 1995; Blake, 2005; Dal, 2005).

The results obtained underlined the persistence of certain mental models: a volcano perceived like generally a cone-shaped relief, often hollow (Bezzi & Happs, 1994); a double origin of the volcanic structure: the up thrust mechanism given as important a role as (or even a more important role than) the accumulation of eruption products (Blake, 2005); the origin of the lava at the centre of the Earth (Lillo, 1994; Dal, 2005); short time scale in describing the products from volcanic eruption and the nature of materials constituting the volcanic structures (Ault, 1982).

The findings indicated that both student teachers and Year 6 and Year 9 students had some similar alternative conceptions (see Table 2). However, over the course of the curriculum, a closer relationship between alternative conceptions and accepted scientific knowledge was evident. Indeed, similar to Bezzi & Happs (1994), Lillo (1994), Sharp, *et* *al.* (1995), Blake's (2005) and Dal's (2005) analysis in their articles, seven categories (or types) of alternative conceptions were identified from idea generated answers (drawings and written responses). These categories were numbered from 1 to 7. Types 1 to 3 correspond to the more elementary conceptual levels, with a "leap" of knowledge in the third since it is at this level that the students began to allot a deep point of origin to lava; types 4 to 7 represent those with an increasingly elaborate knowledge or more scientific terminology. Examples of the students' drawings related to the various types are given in Figure 2.

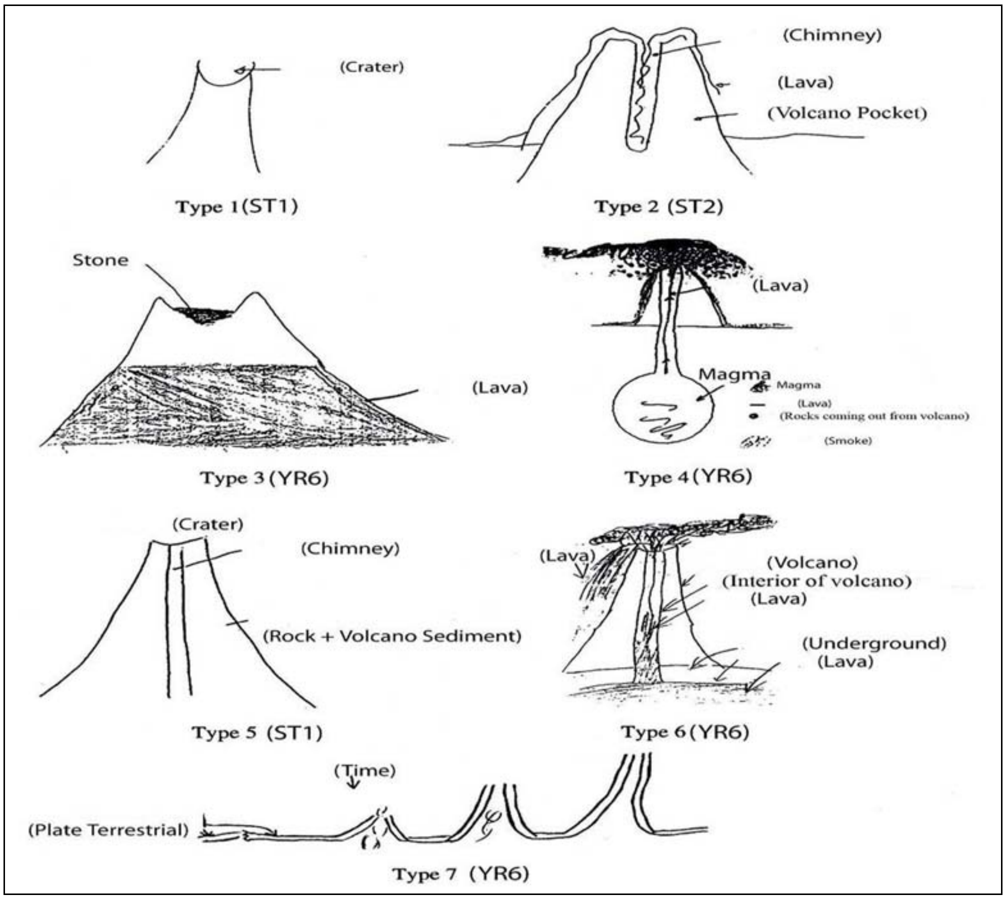

Figure 2. Some examples of the students' drawings.

The defined categories are the following:

Type 1: a volcanic cone without structural detail, including diverse and unclear answers concerning the origin of lava, even the absence of answer; no mention of time scales (16 %) (Blake, 2005).

Type 2: a well demarcated cone, with an internal structure; the students producing this type of drawing give the lava a superficial origin related to the volcano ("interior of the volcano", "at the top of the volcano"); no mention of time scales and specific mention of short time scales (years or less) (36 %) (Sharp, *et al.* 1995; Dal, 2005).

Type 3: a cone filled with lava, associated to a major (but vague) origin including "the lava is under the ground and goes up to fill the volcano"; specific mention of short time scales (years or less) (Sharp, *et al.* 1995)
Type 4: the presence of a shaft linking the volcanic structure with a reservoir, deep point of origin of lava; specific mention of short time scales (years or less) and general terms of time used (36 %) (many years).
Type 5: a structure with an unfinished shaft; deep point of origin of lava; specific mention of short time scales and general terms of time used (many years) (Lillo, 1994).
Type 6: a shaft linking the volcano with a layer or lava cap; deep origin but often evoking "the Earth's crust", the "basement", and the "the Earth's internal layers"; general terms of time used (many years), specific mention of medium time scales (thousand) (9 %) and specific mention of long time scales (millions) (3 %) (Bezzi & Happs, 1994; Dal, 2005).
Type 7: volcanic structure comprised of two "terrestrial plates" which clash; deep origin of lava; specific mention of long time scales (millions) (Blake, 2005).
These alternatives conceptions are distributed as follows, according to curriculum level (see table 2).

Table 2. **Distribution of alternative conceptions.**

	YR9	YR6	ST1	ST2
Type 1	7	1	2	0
Type 2	7	3	1	1
Type 3	11	4	0	0
Type 4	8	10	7	9
Type 5	5	9	6	2
Type 6	3	6	4	16
Type 7	1	0	0	2
Total	42	33	20	30

The simplest types are more numerous at Year 6 level and decrease, and even disappear over the course of the curriculum, whereas, the most elaborate types characterize students at the most scientific level.

Thus it was possible to map out the categories of alternative conceptions of volcanism, in particular concerning the formation of the volcanic structure, the formation of lava and the understanding of geological time of the volcanic activities and to measure the influence of the curriculum through looking at the evolution of these alternative conceptions. It seems that, at the same time as the information they assimilate in their studies, similar to findings by Bezzi & Happs (1994), the students also acquire a specialised vocabulary (e.g. rock, magma) and that they all build a certain knowledge base, as the answers to the Q-Sort test confirm. They begin to link volcanism with the Earth's internal activity, understanding that: it is lava and not "fire" which comes out of a volcano during an eruption and this lava "transforms into rock" (see Figure 3). Descriptive approaches are, however, better represented than the explanatory approaches and appeared earlier in YR9, ST1 and ST2 as had been envisaged.

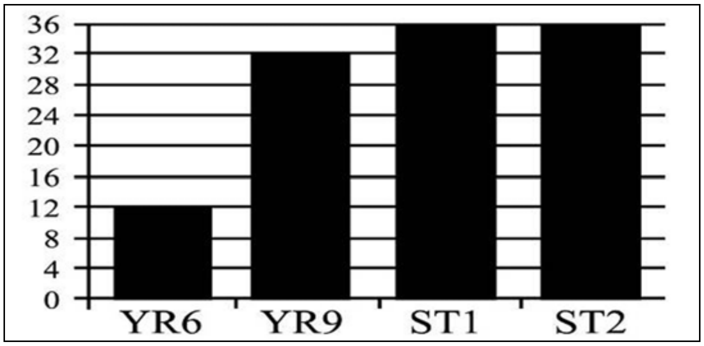

Figure 3. Example of the distribution of the answers to the Q-sort test: question 10: When lava comes out of a volcano, it cools down and transforms into rock?

The numbers express the "weight" of the given responses at each level for the same number of individuals, i.e. the score obtained by the addition of the points attributed to the questions and the total number of responses given; the possible choices went from -2 (completely disagree) to +2 (completely agree), (see questionnaire in the appendix).

Discussion: Do the Alternative Conceptions Listed Shed Light on Barriers to Learning?

Similar to findings by Driver, *et al.* (1994), it was noted that even though the alternative conceptions which are the most distinct from reference knowledge decrease as the amount of scientific teaching received, they do not disappear completely.

Therefore, taking only a few examples, the majority of students, including student teachers, consider that lava comes from the centre of the Earth, a place of mysterious and fantastic activity, an idea which dates back to Antiquity. For them, as at the time of Von Busch, a 19th century geologist, the volcanic structure is primarily formed by rising, under the influence of an internal push, "like a button" (Sigurdsson, 1999).

In addition, it is difficult to imagine the products from the volcanic eruption in another form (e.g. lava transforms into rock) (Sharp, *et al.* 1995; Blake, 2005). Furthermore, today we find them on the surface of the Earth, thus in thermodynamic conditions different from those within which they are formed. Moreover, the actual surface also creates phenomena that the students have not seen occur (Trend, 1998). Another reality that reinforces this complication is the fact that the transformations that they know happen over a short period of time, whereas they don't see the products from the volcanic eruption and the nature of the materials constituting the volcanic structure are the consequences of a slow processes (Ault, 1982; Happs, 1982; Blake, 2005).

Even if some children were not taught the relevant information, the conceptions of some adults, whatever they were taught, are sometimes inspired by *imagination, personal perceptions or analogical thought process* (Blake, 2005).

Similar to the relevant literature, the latter may be explained by certain characteristic difficulties of geology: particularly the difficulty of reproducing geological phenomena in experiments and of obtaining direct observations; or even the problem of understanding time and space (Trend, 1998).

Concerning the first point, available testimonies are generally fragmentary and are spread both over different historical periods and geographically: it is necessary to put the "puzzle" back together (Ault, 1982). In addition, especially in the classroom, the use of significant experiments and modelling which could be used as a substitute for reality and/or as conceptual aids, is difficult and generally only approximate.

Concerning the second point, the duration of geological phenomena is usually measured in millions of years and the notion of geological time is difficult to grasp, even for an adolescent or an adult. Ault (1982) and Trend (1998) have shown that, for students between the ages of 13 and 14, the most common barriers to learning concern the incapacity to evaluate the chronological succession, the duration of events and the concept of terrestrial dynamic. Sharp, *et al.* (1995) and Blake's (2005) works, already mentioned, also develop the discussion of difficulties of assimilation of the concept of geological time.

Thus, much attention is devoted to activities which illustrate the immensity of deep time. Moreover, the objects of geological knowledge vary dramatically in scale, from molecule (e.g. crystal lattice) to universe (e.g. planetology, astronomy), but it is often on a continental or planetary scale that they have to be represented (e.g. orogenesis is treated on a planetary scale. i.e. the birth of a chain of mountains, within the framework of the theory of plate tectonics).

Volcanism was partly chosen as it was thought that its difficulties could be tackled, volcanoes are, at least partially, accessible to observation, directly or thanks to the media, and their most visible activities can be studied on a human scale in time and space. Indeed, as Scarth (1999) says

> an Earth that has two speeds does not exist! The short duration activities are only transitory signs of a phenomenon of very long duration. This is where the difficulty of the study of earthquakes and volcanoes. It is necessary to find methods to connect completely disproportionate time scales. (p.115)

Thus, it seems that there are specific epistemological barriers to learning in many disciplines of Earth sciences.

However, the alternative conception analysis has shown that this is not the only type of barrier to learning that must be taken into account. Indeed, certain alternative conceptions, distinct from scientific knowledge seem to develop parallel to the teaching received: thus it is Year 9 students, who had studied volcanism in Year 6 and the ST2 who are the most common groups to consider that "lava passes between the plates of the Earth's crust", as the answers to the Q-Sort test confirm. Similar to findings by Sharp, *et al.* (1995) and Vosniadou & Brewer (1992), these students know about the existence of the lithospheric plates, but the mental model that they build gives rise to false interpretations of the observed phenomena.

The epistemological barriers to learning thus increase the didactic barriers to learning. These barriers to learning seem to be linked to the *didactic transposition* process, a concept that is attributed to Chevallard (1991). Several points of reflection can thus be considered in relation to elements likely to play a part in the persistence or the appearance of alternative conceptions distinct from the *reference knowledge*.

The first of these elements is the operation of the education system. Indeed, time devoted to each point of the curriculum is limited; this leads to a pace of teaching which takes into account neither the student's ideas nor the time required for learning. As Driver, *et al.* (1994, p.7) points out: "the education system tends to […] want to identify teaching time and learning time, and to treat in terms of educational failure or delay, any difference between these two rhythms". In addition, the choices which are made concerning the concepts to be taught, and the relations which organise them, lead to an important degree of abstraction, prioritising the mechanisms and interpretations even though students cannot yet conceive the relevant object of observation. This may explain the alternative conceptions which describe a concertinaing relationship between the dimensions of the plates and the magma hot spots (see drawing of type 7 of Figure 2).

A second element is the nature of the explanations that accompany diagrams in textbooks, and the way in which they are used by the teacher in the classroom. To quickly illustrate this point, it is necessary to compare examples of persistent alternative conceptions with the explanations used in textbook diagrams.

The first example is that of the existence of a layer of magma under the Earth's crust whereas the mantle is in fact in a solid state. In Year 6, Bordas Publishing's Sciences and Technology textbook explicitly confirms this interpretation by proposing it like an "explanatory model" of the structure of the Globe. The explanatory model, concerning what is under the lithosphere, suggests that:

> Rigid shell = The Lithosphere, Melting rocks = The Magma, Rigid materials = The Central Core, Zone of compression: Formation of a chain of mountains, Zone of separation: Formation of an ocean (Tavernier, 1987, p.12).

In Nathan Publishing's Year 9 Geology textbook, to help the students understand the convection currents in the mantle, a model is proposed, in the form of diagrams with accompanying notes, of water (thus a liquid) heated by an electric resistance. It is explained that:

> Reaction of water in a kettle: Water heated by resistance rises towards the surface. In contact with colder water, the hotter water is cooled, falls back to bottom and reheats… Such a phenomenon is called convection. It evacuates heat and creates zones at the surface of the container, some hotter than others (Périlleux & Thomas, 1988 p.53).

The solid state of the mantle in fact only indicated by two words, right at the bottom of a whole page of illustrations. It is written that:

> Convection on a global scale: The differences in temperature between the interior of the globe and the surface create movements, at the solid state, of rocks in the mantle. These movements allow the Globe's internal heat to escape (Périlleux & Thomas, 1988 p.53).

The second example is that of the formation of a volcanic cone by rising, without the products of the volcanic eruption playing any part. In Bordas Publishing's Year 6 textbook, an illustration likely to confuse children can be found. At the bottom of a whole page of illustrations concerning the formation of a volcanic cone, it states the following:

> The volcano Paricutin is found in Mexico. It appeared in 1943. Its growth was very fast. It stayed active for 9 years and it ejected 3.6 billions tons of material (Tavernier,1987, p.46).

Similarly, the following is found in the key for the "Forecast of Volcanic Eruptions" diagram in Magnard Publishing's Year 9 textbook. The diagram is accompanied by the following descriptions:

> "Period 1 the swelling of the volcano starts, Period 2 peak of swelling – the horizontal and vertical distances lengthen - the slope increases", Period 3 Eruption- Deflation – "the slope decreases" (Salviat & Desbeaux, 1988, p.55).

However no scale is given to indicate the relative value of this swelling and to situate the phenomenon in relation to the mouth of the volcano.

These explications, which go together with the diagrams, aim to facilitate the comprehension of relatively inaccessible phenomena thanks to simplifications or analogies; but in both cases, if the teacher is not careful, the alternative conceptions can be consolidated or generated by teaching. They may create barriers to learning of a didactic origin.

Conclusion

The analysis of the responses showed that the alternative conceptions defined in biology, physics, chemistry and more generally in science education, are also found in Earth Sciences. Thus, it is possible to establish categories of alternative conceptions, to identify barriers to learning, and to examine the role played by the didactic transposition.

The findings indicated that both student teachers and Year 6 and Year 9 students had some similar alternative conceptions. Based on the findings, we concluded that since student teachers had alternative conceptions similar to those held by the Year 6 and Year 9 students, any instruction that student teachers had received from Year 9 onward had little effect on their alternative conceptions. Furthermore, since the teachers are a prime source of instruction in the study context, their alternative conceptions can be easily transferred to their students. Therefore, if we take the alternative conceptions into account in planning future activities in teacher education and science curriculum development, students may have a better chance to scientifically develop the fundamental concepts of science. Since these concepts are building blocks for latter learning, their development will help students to meaningfully grasp the advance concepts of science.

In the science education literature, it is stated that alternative conceptions are resistant to change. Teachers affect their students mostly in instructional environments. If the instructional environment is not well designed, conceptual learning and conceptual change will be difficult to achieve. In addition, the classroom environment and teaching strategies should create enough dissatisfaction with existing knowledge so that students' alternative conceptions may change. Therefore, we should not expect student teachers to develop high quality materials that provide conceptual learning or conceptual change or completely intervene in the students' alternative conceptions.

Furthermore, science-textbook writers and teachers do not adequately take into account the students' previous learning, particularly their alternative conceptions. In other words, they expect that students already understand the underlying concepts that are prerequisite for further or advanced learning. When students had inadequate concepts, the study teachers generally blamed the teachers of earlier stages of schooling, and they claimed that the earlier teachers did not teach the concepts at an appropriate level. In fact, France has a centralized educational system, and all schools implement the same curricula. Different authors write the textbooks by taking into consideration the curriculum for each subject area. The science teachers in each school are free to choose one of the science textbooks for their teaching. As is the case in many other countries, teachers can prepare supportive teaching materials for their students. Therefore, this study can help current science teachers rethink their way of teaching as well.

Hence, science teacher educators should develop appropriate activities and strategies to introduce students' alternative conceptions to student teachers and also address the student teachers' own alternative conceptions. Thus, as science teacher educators, we can eliminate one of the most important sources of alternative conceptions. This approach can provide experiences in an actual classroom environment about how alternative conceptions are dealt with and remediated from a professional. Moreover, student teachers will become aware of the importance of prior knowledge and will be able to develop activities and build new knowledge during their teaching. Furthermore, current science teachers in schools should be provided with inservice training so that they can relinquish their alternative conceptions.

Schnotz, *et al.* (1999) noted that student conceptual understanding becomes clear when multiple-source data are interpreted from multiple theoretical perspectives. At that point, it may be concluded that we should take into account individual differences. That is, we should identify students' perspectives and then devise guide materials, which should be designed to facilitate conceptual learning. Moreover, inservice and preservice programs should be reorganized for better teacher preparation.

Given the aforementioned conclusion, although certain aspects are prevalent only in specific disciplines, such as problems linked to time and space and the problems of modelling, results of research in didactic, and particularly barriers to learning and their origin, should improve understanding of learning phenomena in this field. They can also aid adapting Earth Science teaching to knowledge transfer methods so that Earth Science concepts are accessible, whilst still remaining accurate, at all levels of the curriculum.

In the science education literature, learning as conceptualised in a constructivist framework is dependent on authentic experiences that help learners make these critical connections between scientifically rigorous concepts and their own sense-making (Vosniadou & Brewer, 1992). This is a particularly challenging task when thinking about geoscience education, however, as student and teachers alike generally have had fewer experiences with formal geoscience education. To what extent do children make connections between everyday encounters with geology and their formal classroom learning? In the country in which the research was done, there aren't any volcano sites visible to students. It is important to note that this study didn't try to search an answer to this question. This study explored the students' ideas of the volcanoes and volcanic activities as the focus for conceptual change. A further research that could be done in the Clermont Ferrand region in central France, where there are important volcanoes sites (*Puy-de-Dôme*) visible would report on the extent to which students make connections between their ideas about rocks learned in school and their experiences with volcanoes in their out-of-school lives.

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Official Instructions :

B.O.E.N - 1978a, Programmes du cours moyen.
B.O.E.N - 1979a, Programmes du cours moyen.
B.O.E.N - 1985a, Programmes des du cours moyen.
B.O.E.N - 1978b, Programmes des 4ème des collèges.
B.O.E.N - 1979b, Programmes des 4ème des collèges.
B.O.E.N - 1985b, Programmes des 4ème des collèges.
B.O.E.N – 2000a, Programmes du cours moyen.
B.O.E.N - 2000b, Programmes des 4ème des collèges.

Appendix

The Open-ended questionnaire and the Q-Sort Test were presented in the following manner:

The Open-ended questionnaire:
Dear student,
1. What comes out of a volcanic eruption?
2. In your opinion, where does lava come from?
3. How is lava formed?
4. What does lava become after a volcanic eruption?
5. In your opinion, are volcanoes still active?
6. What materials are volcanoes made of?
7. Please draw a diagram, with notes, of the longitudinal section of a volcano on the other side of this sheet of paper.
8. Are they several types of volcanoes?
9. Could you explain how you imagine different phases of the formation of a volcano (you may draw them)?

The Q-Sort Test:
Dear Student,
Please check the box that corresponds to your opinion (-2 completely disagree; -1: mostly disagree; +1 mostly agree; +2 (completely agree)

	- 2	-1	+1	+2	comments
1. Volcanoes have a cone shape?					--------------

2. A volcano is a mountain which opens to release lava?

3. Lava forms a continuous layer under the Earth's crust?
4. Volcanoes are very tall?
5. The visible part of a volcano is only formed with volcanic rocks?
6. It is fire that comes out of volcanoes?
7. Volcanoes are very tall because they were formed through uplift in the Earth's crust?
8. Lava comes from the fusion of rocks constituting a volcano?
9. Volcanoes are hollow?
10. When lava comes out of a volcano, it cools down and transforms into rock?
11. The visible part of a volcano is always formed with the same rocks as the rocks that form the Earth's crust?
12. Lava moves between plates in the Earth's crust?
13. There are volcanoes in France?
14. Lava comes from the Earth's centre?
15. It is solar energy that causes volcanic eruptions?
16. Volcanoes form a relief because they are formed through the accumulation of volcanic rocks.
17. The birth of a volcano is linked to (an earthquake)?
18. There are volcanoes under the sea?